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WORKSHOP ON STRAITS: THEIR OCEANOGRAPHY AND INFLUENCE
ON ADJACENT SEAS HE. (U) LOUISIANA STATE UNIV BATON
ROUGE CENTER FOR WETLAND RESOURCES.

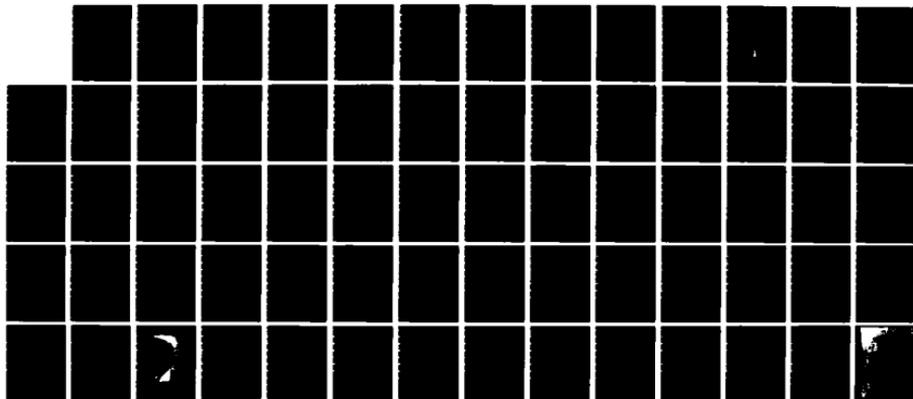
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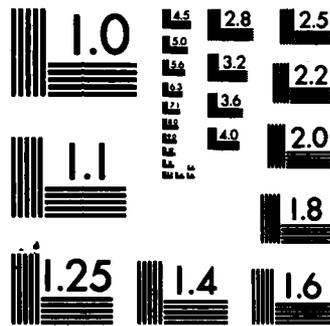
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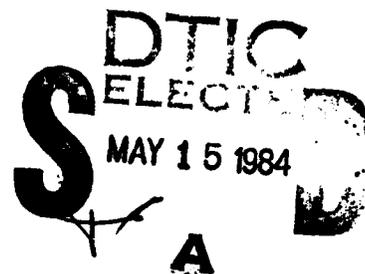
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Coastal Studies Institute
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SUMMARY REPORT

Workshop on Straits:
Their Oceanography and Influence on Adjacent Seas
Copenhagen 17 - 21 January 1983

Abstracts and Discussion Summaries



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KØBENHAVNS UNIVERSITET
INSTITUT FOR FYSISK OCEANOGRAFI

WORKSHOP ON STRAITS:
THEIR OCEANOGRAPHY AND INFLUENCE ON ADJACENT SEAS

Sponsored by the International Association for the Physical
Sciences of the Oceans, the Office of Naval Research, and
the Nordic Council for Physical Oceanography

Co-Conveners:

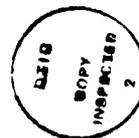
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and

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Held at the Institute for Physical Oceanography,
Copenhagen 17 - 21 January, 1983

ABSTRACTS AND DISCUSSION SUMMARIES



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REPORT No. 45

COPENHAGEN 1983

PREFACE

An important part of the work of an international organization like IAPSO is to stimulate scientific contacts, exchanges and discussions, for instance through functioning as an umbrella for international meetings. A very attractive form of such meetings is the workshop where a limited number of participants present and discuss their work on a well-defined problem area. Such meetings may not require much money and may not be hard to organize but they still require the moral support of one or more organizations.

Towards the end of 1981 IAPSO decided to sponsor a workshop on straits, their Oceanography and Influence on Adjacent Seas. The amount of money allocated to this was by relative measures quite considerable. After some discussions it was decided to have the workshop in Copenhagen early 1983. Further financial support was obtained from ONR and from NKFO which made it possible to invite an ideal number of participants from different parts of the world and covering a good range of subjects and area within the overall problem.

The Workshop was structured in seven sessions with presentations and discussions. In this report the abstracts are given together with summaries of the discussions, made by a rapporteur for each session.

The general aim of the Workshop was to produce a snapshot of the present understanding, in relation to straits of: the dynamics of various configurations; the control or influence on conditions in adjacent sea areas; the influence on circulation features and distribution of various properties; the state of the art as regards field investigations.

The discussions were generally lively and a lot of ideas were tossed around. Hopefully some of the positive and stimulating flavour from the Workshop may be transferred also to non-participants through this report. Copies can be obtained free at the Institute for Physical Oceanography (address see list of participants).

On behalf of the participants as well as the conveners I want to thank very much the sponsoring organizations for their generous support to the Workshop.

Copenhagen May. 1983

G. Kullenberg

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ABSTRACTS

(Addresses of the authors are on the list of participants)

Winter 1978 in The Straits of Tiran

by

A. Hecht and D.A. Anati, Israel

(Presented by D.A. Anati)

15 standard hydrostations, 9 Aanderaa stations, and 18 BT low-rings were taken by two research vessels in the Straits of Tiran and within 2 n.miles of the straits in March 1978. The results show a two-layer flow with a very steep slope (150 m dislevel in 1 km) of the interface between them. The thickness of the interface is about 1/5 of the sill depth. Indications are that the effective cross-sectional area of the straits is somewhat smaller than the actual cross-sectional area, and that the two openings of this strait cannot be considered as one joint opening for strait dynamics considerations. Internal waves of frequency about four times higher than the local stability N were detected in the pycnocline on several stations north of the Straits. A moored buoy near the saddle point, deployed slightly above the pycnocline shows that the barotropic (tidal) component of the current is of the same magnitude as the baroclinic (thermohaline) component, and that the measured speed of the current is that expected for critical interfacial Froude conditions.

Mixing Conditions Controlled by Straits

by

Gad Assaf, Israel

When a permanent pycnocline is found in a given basin one usually suspects that the stabilization is due to deep water formation which counteracts the wind mixing.

Fig. 1 illustrates the formation of permanent artificial halocline in the Great Salt Lake, due to construction a causeway across the lake. The causeway divided the lake into two parts, the northern and the southern arm. The southern arm received the fresh water inflow q₁ and the northern arm became an evaporation basin, where the brine concentrated.

Two calverts were constructed across the causeway and a two layer flow was established across the calverts with two parts, one is stratified permanently and the other is a source for deep water.

The upper flow q₁ consists of surface water from the southern arm and a lower flow q₂ of brine from the northern arm. The density differences between the two flows are more than 100 sigma units and a sharp halocline with density contrast of 100 sigma units over 1 m depth was established at 7 m depth.

We generalize a Monin-Obukhov mixing depth h_s for a basin

$$h_s = \frac{2\rho_a}{\rho} \left(\frac{au}{B_2} \right)^3 \frac{\sigma_2}{\sigma_1} \left(\frac{A_1}{A_2 \left(1 + \frac{A_1}{A_2} \right)} \right)$$

$$B_2 = \frac{g\sigma_2 E_2}{\rho} \quad \text{the buoyancy flux at basin 2}$$

where:

ρ_a - air density

ρ - water density

u - wind speed over stratified basin

σ_2 - the excess density of the deep water flow

σ_1 - the upper excess density in the mixed layer of the stratified basin

a - the wind mixing efficiency

A_1 - the area of the stratified part of the basin

A_3 - the area of the halocline

A_2 - the area of the basin that produces the deep water for the stratified portion.

E_2 - the rate of evaporation in basin No.2 (in m/sec)

g - the gravity

For stratified basins with light water flow q_i , such as the Black Sea, the extended mixing zone can be defined as:

$$h^* = \frac{a\rho_a}{\rho B} u^{\frac{2}{3}}$$

and

$$B = \frac{gq_i}{A\rho} (\sigma_{1d} - \sigma_{1i})$$

where:

q_i - the inflow rate of fresh water

A - the area of the basin

σ_{1d} - the density of the discharged water

σ_{1i} - the density of the inflowing light water

One should notice that when the depth h_s exceeds the depth of the straits the basin will be in a state of over mixing and $\frac{\sigma_2}{\sigma_1}$ or $\sigma_{1d} - \sigma_{1i}$ will be determined by the strait's dynamics (see e.g. Stommel and Farmer for short straits or Assaf and Hecht for long straits).

Table 1 summarizes the mixing condition of different basins. One can notice that in all the basins the wind mixing efficiency a , varied by a factor of 3 while the Richardson Number changes by three orders of magnitude.

$$R_i^* = \frac{g(\sigma_2 - \sigma_1)}{\rho u^{\frac{2}{3}}} \cdot h$$

We consider this simplicity as the most important claim of our paper.

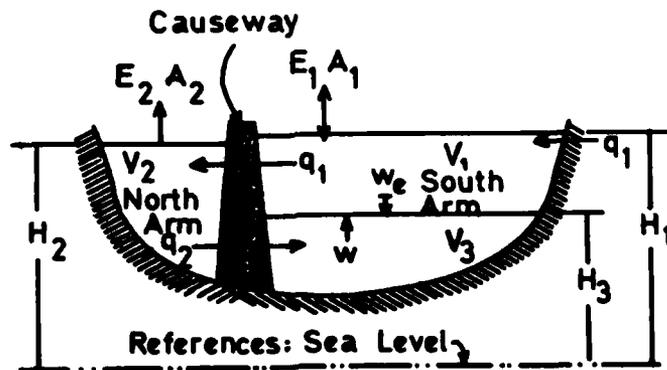
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Assaf, G. and A Hecht, 1974. Sea Straits: A Dynamical Model, Deep Sea Res., Vol 21, p. 947-958

Stommel H. and H.G. Farmer, 1952. Abrupt Changes in Width in Two-Layer Open Channel Flow. J. Marine Res., Vol. 12, p. 13-20.

Table 1 - The Mixing Conditions of Different Basins

	L (m)	$(u^3)^{1/3}$ (m/sec)	B ($10^{-8} m^2/sec^3$)	h (m)	$\Delta \rho$ kg/m ³	R_i^*	$a \times 10^6$
Great Salt Lake	10^5	5.1	- 5	8	100	2×10^5	1.3
Dead Sea	10^5	4.8	-10	30	2	200	3.3
Black Sea	10^6	7.7	- 0.25	10^3	10	10^6	4.0
Marmara	10^5	7.7	-10	25	10	4×10^4	4.0



CROSS-SECTION: GREAT SALT LAKE

Fig. 1. Formation of permanent artificial halocline in the Great Salt Lake.

Various Aspects of Flow through the Tsugaru Strait

by

D.M. Conlon, USA

The Tsugaru Strait is one of four straits which connect the Sea of Japan with the adjacent Pacific Ocean. The principal dynamic feature of the Sea of Japan is the Tsushima Current (a branch of the Kurushio), which enters the Sea of Japan from the South and exits primarily through the Tsugaru Strait. The large west-to-east transports through the strait (typically 1-2 Sv) serve to overwhelm the "normal" two-layer exchange found in most straits, flow in the strait does not normally reverse direction with depth nor with time, despite the presence of strong tidal currents.

In the immediate vicinity of the western entrance of the strait, the topography induces a curvature of flow ($r_c \sim 65$ km) which is reflected in sea level measurements on the northern and southern ends of the entrance and which is well modeled as a simple gradient current.

As the flow exits the strait into the Pacific, an anticyclonic gyre is always seen during warmer months of August - October and is always absent during January - March. The flow into this region displays a strong annual variation in its internal deformation radius, and it is suggested that the gyre is generated by an instability mechanism (seen in laboratory experiments of Whitehead and Miller) when the deformation radius increases beyond some critical value.

References:

Conlon, D.M. 1982. On the Outflow Modes of the Tsugaru Warm Current. *La Mer*, Vol 20, p. 60 - 64.

Whitehead, J.A. and A.R. Miller. 1979. Laboratory Simulation of the Gyre in the Alboran Sea. *J. Geophys. Res.* Vol. 84, No C7 p. 3733-3742.

Geostrophic Control for Barotropic Fluctuations

by

Chris Garrett and Bechara Toulany, Canada

Consider a strait of length L and width W connecting two larger bodies of water in which the surface elevations are $\text{Re} [\zeta_1 \exp(-i\omega t)]$ and $\text{Re} [\zeta_2 \exp(-i\omega t)]$. A simple model (Garrett and Toulany, 1982), in which the cross-strait slope is geostrophically balanced, and the along-strait slope is balanced by acceleration and friction, predicts an average surface current $\text{Re} [u \exp(-i\omega t)]$ where

$$u = gW^{-1} (\zeta_1 - \zeta_2) [(-i\omega + \lambda)(L/W) + f]^{-1}, \quad (1)$$

with a linearised bottom friction coefficient λ . For many straits, and low frequency motions, $|-i\omega + \lambda|(L/W) \ll f$, so that the flow is effectively limited by geostrophy; the sea level difference across the strait cannot be greater than $\zeta_1 - \zeta_2$.

The model is supported by analysis of the results of Buchwald

and Miles (1974) for Kelvin wave diffraction by a gap between two semi-infinite oceans. For a narrow gap (compared with the Rossby radius R) the transport through the strait is exactly as given by (1) with $\lambda = 0$ and L replaced by "end correction" $-2W\pi^{-1}\ln(0.22W/R)$. In practice this should be added to the actual length in (1).

The resulting formula, $Q = gHf^{-1}(\zeta_1 - \zeta_2)$, for the transport Q through a strait of depth H , in the limit of geostrophic control, is applied to a study of the response of the Mediterranean, and flows through the Straits of Gibraltar and Sicily, to fluctuating atmospheric pressure (Garrett, 1983).

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- Garrett, C.J.R., 1983. Variable sea level and strait flows in the Mediterranean. *Oceanologica Acta* (in press).

¿Donde Va? An Oceanographic Experiment Near the Strait of Gibraltar

by

Thomas H. Kinder, USA

In order to maintain water and salt mass balances, less saline Atlantic water flows eastward through the Strait of Gibraltar above a westward flowing more saline Mediterranean water. Surprisingly, the inflowing Atlantic current forms a permanent anti-cyclonic gyre in the western Alboran Sea, sometimes extending entirely across the sea from the coast of Spain to the coast of Morocco (Lanoix, 1974). Various explanations for the existence of this gyre and its fluctuations have been offered, (Nof, 1978; Whitehead and Miller, 1979; Preller and Hurlburt, 1982; Bryden and Stommel, 1982), but none has been accepted.

We designed a project to include numerical modeling, remote sensing, meteorology, and hydrographic and current measurements. The point of view of the project was that the Atlantic water flowing through the Strait of Gibraltar is the primary forcing for the gyre. The experiment was designed to measure important aspects of the inflow (speed, angle of the inflow, horizontal velocity shear) while monitoring the three dimensional gyre structure. Elucidation of the dynamics of the (steady and time-varying) gyre is the primary objective of the experiment.

Notable secondary goals include relating remotely sensed surface infrared and visible signatures to the current and hydrographic structure and to chemical and biological processes (optical measurements); relating atmospheric forcing to gyre fluctuations; tracing the paths of deep and intermediate waters; monitoring conditions in the Strait and Gulf of Cadiz (west of the Strait); and determining the effect of the internal tidal bore on other measurements.

The major experimental effort occurred during 4-18 October 1982, although some measurements extended over much longer periods. The

most intensive measurements were concentrated on a line SSE from Marbella, Spain, crossing the northern limb of the gyre. Measurements included: current meter moorings; shore-based HF radar surface currents; shipborne velocity profiles; air-dropped drifters; hydrography from CTD, XBT, and AXBT; aircraft infrared and visible (color) measurements; aircraft, shipborne and land-based meteorological measurements including airsondes and the establishment of three meteorological stations ashore; shipborne aerosol measurements; in situ transmissivity and irradiance measurements across the northern limb of the gyre; chlorophyll, nutrients, and dissolved solids across the northern limb of the gyre; AVHRR and CZCS satellite imagery; and a two-layer eddy-resolving numerical model. Four ships and four aircraft participated as well as shore stations. We plan to jointly use these extensive data sets to address experimental objectives (including some that are not listed here).

Investigators in the projects include: G. Parrilla and C. Garcia (Instituto Español de Oceanografía, Madrid); J. Fernandez (Instituto Hidrografico de la Marina, Cadiz); I. Tato (Instituto Nacional de Technica Aeroespacial, Madrid); M. Philipe (Centre de Meteorologie Spatiale, Lannion); H. van der Piepen (Deutsche Forschungs- und Versuchsanstalt für luft- and Raumfahrt e.v., Oberpfaffenhofen); M. Janopaul (Wave Propagation Laboratory/NOAA, Boulder); R. Fett (Navy Environmental Prediction Research Facility, Monterey); S. Hsu (Louisiana State University, Baton Rouge); E. Mack (Calspan Corp., Buffalo); and R. Arnone, H. Hurlburt, T. Kinder, P. La Violette, H. Perkins, R. Preller, and K. Saunders (NORDA).

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Aspects of Suspended Matter and Chlorophyll Fluorescence
Distribution in Areas Connected to Straits: Some Examples

by

G. Kullenberg, Denmark

The distribution of suspended matter has been investigated by means of in situ light scattering measurements. Scattering is caused by suspended matter, dissolved salts and by the molecular scattering of the water itself. Most of the variation of the scattering is caused by

the varying content of suspended matter. The amount of particles, their composition, shape and size distribution influence the scattering.

Observations are presented from the area east, west and north-west of Svalbard. The observations between Norway and Svalbard suggest that the inflow from the North Atlantic and the mixed water contained less particles than the water from the polar basin. The suspended matter distribution was very layered with intrusions from the surface and with internal rather thin layers of high particle content. Bottom boundary layers of high scattering were also found.

The observations in the Fram Strait suggested a clear connection between particle content (scattering) and salinity. The Atlantic Water mass was characterized by low scattering, and can be traced at intermediate levels. A deeper water mass, possible Greenland Deep Sea Water, was characterized by a slightly higher scattering. The fjords, connected to glaciers, and the drift ice are marked particle sources, as well as the biological production. (Submitted Journal du Conseil)

Chlorophyll *a* fluorescence observations were made with an in situ fluorometer of IFO design. The measurements in the Fram Strait area showed layers of very high chlorophyll content at 25 to 50 m depth in the slope region and further out. In the top 25 m the fluorescence was generally very low.

Fluorescence measurements were also carried out in the Georges Bank region of the Gulf of Maine. Strong influence of the topographic flow constrictions on the distributions of fluorescence were suggested, related to the supply of nutrients through the mixing induced by the combined action of tides and topography, and to the circulation induced by these factors. (ICES C.M. 1983/L:23; Biological Oceanography)

On the Hydrography of the Denmark Strait Overflow

by

Svend-Aage Malmberg, Reykjavik

The Denmark Strait is about 275 km wide and rather shallow, with a 40-50 km broad and 600 m deep channel between the East Greenland and Iceland shelf areas. The mode of water exchange between the Subarctic and the North Atlantic Oceans through the Strait has until recently been known in general (a.o. Dietrich 1957, Harvey 1961, Gade et al. 1965, Mann 1969, Stefánsson 1962, 1968, Malmberg et al. 1967, 1972, Stein 1974), but it was far from being thoroughly understood. With the Overflow '73 and MONA projects of ICES in the sixties (Anon. 1976, Ross 1977, Aagaard and Malmberg 1978) and the joint American-Icelandic so-called Iceland Sea Project in 1974-1975 (Swift et al. 1980, Swift and Aagaard 1981) much knowledge was gained about this exchange of water, its variability and complexity. The investigations were directed at the flow of cold water from the north through the Strait into deep and bottom layers of the Irminger Sea and the Labrador Basin. This flow of cold water was often referred to as a flow of Norwegian Sea Bottom Water (NSBW; $T < 0^{\circ}\text{C}$, $S > 34,90$ ‰). Other water masses in the area are a) the warm water (6°C) of the Irminger Current on the Eastern side of the Strait, b) Polar Water of the East Greenland current with temperature below 0°C and salinity less than $34,5$ ‰ in shallow waters on the west side of the Strait, and c) a mass of inter-

mediate water with temperature of $0-1^{\circ}\text{C}$ and salinity between $34.5-34.9$ ‰ on the western slope of the Strait, between the shallow and deep water masses. The last water mass consists of two different water masses, i.e. Arctic Intermediate Water (AIW) with salinity $34.7-34.9$ ‰ and temperature of $0-1^{\circ}\text{C}$, and Polar Intermediate Water (PIW) with salinity below 34.7 ‰, even as low as 34.5 ‰, and temperature below 0°C .

During annual and seasonal hydrographic investigations in 1970-1977 at the sill in the Denmark Strait, or even just south of it, NSBW was observed in 75 % of the cases in the bottom layer with a height as much as 100-200 m above the bottom (Malmberg 1978). Year long data from four recording instruments located near bottom at 1000-1500 m depth farther south on the East Greenland slope (MONA 5, 6; Aagaard and Malmberg 1978) showed negative temperatures in the overflowing water less than 1% of the time. Such negative temperatures are a necessary, but not sufficient indicator of NSBW because they can reflect cold PIW (Malmberg 1972). A concurrent record of salinity is required to determine the identity of the overflowing water. Such data were obtained by Ross (1978) during the Overflow '73 experiment. Both the total overflow ($T < 2^{\circ}\text{C}$) and the NSBW portion of this overflow ($T < 0^{\circ}\text{C}$, $S > 34.9$ ‰) has been estimated (Swift et al. 1980). The total value was 2.3 Sv. where only 10% was identifiable NSBW. Indeed very few samples of NSBW have been recorded south of Denmark Strait, except immediately just south of the sill as mentioned above.

It was concluded (Swift et al. 1980), that the component of the Denmark Strait Overflow of greatest significance is an intermediate water of arctic origin, at slightly under 34.9 ‰, but not NSBW. This is supported by relatively high tritium values of about 5 T.U. observed in the overflowing water compared with low tritium values in the NSBW of about 1.5 T.U. It is also unlikely that a dense overflow component with suitable properties can be produced from mixtures of the densest water masses available at the sill. The overflowing intermediate water is formed mainly in winter at the sea surface north of Iceland in the Iceland Sea (Swift et al. 1980).

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Transport Downstream from Straits

by

T.A. McClimans, Norway

Recent laboratory measurements of buoyant plumes in a rotating tank are interpreted in the context of outflow from deep-silled straits between vast quiescent ocean basins. In particular, entrainment to and from the outflow is considered.

For a wide strait of width B much greater than the deformation radius r_i , a buoyant flow may pass the strait as a coastal current subjected to modifications at the cape separating one sea from the other. Here, the transport may be estimated by the hydrographers equation based on geostrophic equilibrium.

For narrow straits ($B \ll r_i$) the buoyant outflow may be estimated from the condition of a critical Froude number for the accelerated flow through the topographical constriction. In the immediate vicinity of the outflow from a narrow strait, its jet-like nature will cause turbulent mixing and an entrainment to the spreading flow. Tests show that this energy can cause an increase in volume flux of 140% in the absence of wind. At a sufficient distance downstream (on the order of r_i) the

outflow will establish a coastal current of width $\sim 2 r_i$.

The exchange process along the coastal current is complicated and must be treated analytically as a multi-scale, non-uniform diffusion process to solve for lateral mass transports. Waves of wavelength $\lambda > 7r_i$ grow, and form whirls and rings which detach from the coast, producing a large mass flux to the vast ocean.

The spawning of a ring leads to a renewed frontal strength and the further development of waves on a current with a reduced transport. From the limited number of test results available, it appears that the flux is reduced to about 3/4 within a distance of $40 r_i$. In the absence of a buoyancy flux and wind along the coast, it is estimated that such a current may be well observed more than $200 r_i$ downstream of the strait. External energy sources could greatly reduce this number.

Hydrografi of the Faroese Channels ^{x)}

by

Jens Meincke, FRG

Hydrographic data and current measurements obtained during the international Overflow 73-Experiment were combined into a revised scheme of the circulation and the transports in the Faroe Channels. The inflow of North Atlantic water into the Norwegian Sea was found to be $2.0 \cdot 10^6 \text{ m}^3 \text{ s}^{-1}$, whereas the outflow of Norwegian Sea deep water amounted to $1.1 \cdot 10^6 \text{ m}^3 \text{ s}^{-1}$. The complexity of the circulation is caused by a Modified North Atlantic water and by Arctic Intermediate water which enter the Channels with a volume transport of 2.5 and $1.1 \cdot 10^6 \text{ m}^3 \text{ s}^{-1}$ respectively. Only part of this (1.2 and $0.3 \cdot 10^6 \text{ m}^3 \text{ s}^{-1}$) was observed to pass the Faroe - Bank Channel into the Atlantic, whereas the remainder recirculated into the Norwegian Sea. Baroclinic instability of the inflowing North Atlantic water above the Shetland slope area is suspected to cause the recirculation. Continuing observations of the water masses in the Faroe Channels show variations in the characteristics of the inflowing Atlantic water and the outflowing Arctic Intermediate waters, which are related to climatic fluctuations observed in the waters north of Iceland as well as in the open northeastern Atlantic.

^{x)} Summary of cooperative studies under ICES-auspices. (International Council for the Exploration of the Sea).

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Dynamics of Northern Red Sea Straits

by

Stephen P. Murray and Arthur Babcock, USA

Observation programs have been conducted in both the Jubal Strait, at the entrance of the Suez Gulf (1981), and the Tiran Strait, at the entrance to the Agaba Gulf (1982).

The Tiran Strait consists of two passages separated by a 5-km

ridge of active coral reef. The main Enterprise Passage is a steep-sided (-45°), V-notched groove with a sill about 1 km across and 5 km long. Sill depth is 250-270 m, but depths drop precipitously to thousands of meters at each end of the sill. The shallower Grafton Passage, rectangular in section, has about the same width but depths of only 80 m.

Twelve current meters were deployed on five moorings (see Fig. 1) in both passages, along with water level gauges and anemometers. STD transects (Fig. 2) were run repeatedly as ship opportunity allowed. Analyses of current data shows a strongly developed thermohaline circulation driven by the high evaporative flux (3-5 m/yr) in the Gulf, with upper-layer net inflow (30 cm/sec) and lower-layer net outflow (30-60 cm/sec). (Simple Knudsen balances apparently work reasonably well here!). Modulation of the thermohaline circulation by the fortnightly tidal cycle appears negligible at this point. Quite surprisingly strong wind stress of 3-5 dynes/cm² on a time scale of several days, directed southerly against the upper-layer inflow, appears not to affect the dynamics of the flow. Computation of the interfacial Froude number suggests that conditions are near critical much of the time, indicating that the discharge through the strait is often at its maximum and that excess pressure gradient force is available to balance out the wind stress.

Further detailed work involves investigation of the momentum balance in the strait. Effort is now focused on evaluating the role of lateral friction by studying the lateral Reynolds stress terms in both the supra tidal and the tidal bands. We are at the point of generating correlograms, which we hope will provide estimates of eddy strength and time scales of the supratidal fluctuations.

Analysis of data from much wider (20 km) Jubal Strait, only 50 km to the west, shows another thermohaline circulation, with lower-layer outflow of higher salinity water to the Red Sea. The internal Rossby radius, however, indicates that rotational effects should be important here. STD transects do show a marked lateral stratification, which does affect the lateral structure of the current. A simple model balancing frictional forces, barotropic and baroclinic pressure gradients, and wind stress makes reasonable prediction of observed current speed profiles under light to moderate winds. Observations show strong winds channel most current energy into the cross-channel component, i.e. the strait is blocked. A more sophisticated model will, it is hoped, explain this phenomenon.

(Figures on the following page)

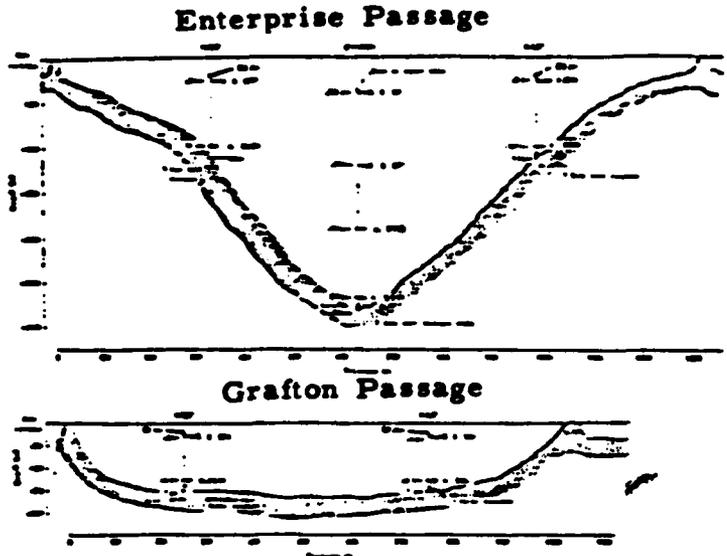


Figure 1

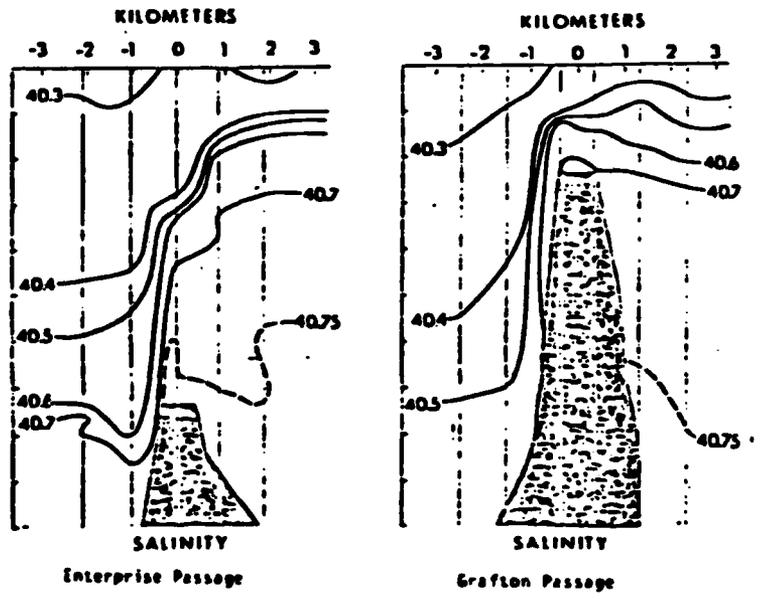


Figure 2

Remote Sensing of Straits-Generated Eddies

by

Jacques C.J. Nihoul, Belgium

Remote sensing photographs give evidence in several parts of the world of large scale solitary eddies generated at the passage of water streams through straits.

These eddies appear to propagate in adjacent seas independently of the eventual reversal of flow through the strait.

It is conjectured that such eddies are actually vortex pairs which originate in the free boundary layers in the wake of lands' pikes, on both sides of the straits, and are formed by successive amalgamations of smaller scales vortices.

The role of such eddies "puff" on transport and mixing through straits and in adjacent seas is discussed.

On the Flow through the Windward Passage

by

Doron Nof and Donald B. Olson, USA

(Presented by Doron Nof)

The flow through broad passages connecting oceans and marginal seas is examined by a simplified two-layer analytical model. Attention is focused on the flow resulting from the difference between the upper layer depth in the two basins which imposes a pressure gradient along the passage. The land masses separating the ocean from the adjacent marginal sea are represented by two portions of an infinitely long wall extending from the free surface to the bottom of the ocean. The passage, whose width is larger than the deformation radius, is represented by a gap separating the two portions of the wall.

The model is frictionless, hydrostatic and nondiffusive but the movements within the gap are not constrained to be quasi-geostrophic in the sense that the local Rossby number is not necessarily small and the interface displacements are of the same order as the upper layer depth. Steady solutions for the upstream and downstream fields are obtained analytically using the momentum equation in an integrated form, the Bernoulli integral and conservation of potential vorticity.

It is found that, surprisingly, the transport through the gap is independent on the gap's width. Upstream the oceanic water approaches the gap only from one direction; upon reaching the gap, the approaching current splits into two branches. One continues to flow in the oceanic basin and never enters the gap whereas the other passes through the gap and penetrates into the marginal sea. Downstream, the penetrating flow forms a boundary current which is confined between the wall on the right (looking downstream) and a free bounding streamline on the left.

A possible application of this theory to the flow from the Atlantic Ocean into the Caribbean Sea via the Windward Passage is discussed. The observed locations, positions and directions of both the upstream

and downstream flows agree with the model predictions. In addition, the predicted transport through the passage ($\sim 12 \times 10^6 \text{ m}^3 \text{ sec}^{-1}$) is approximately equal to the observed transport.

Numerical Modeling of the Alboran Sea

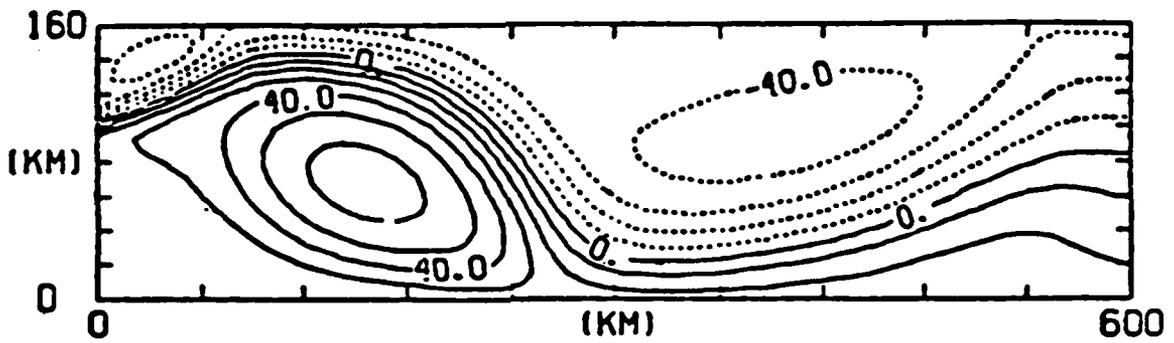
by

Ruth Preller, USA

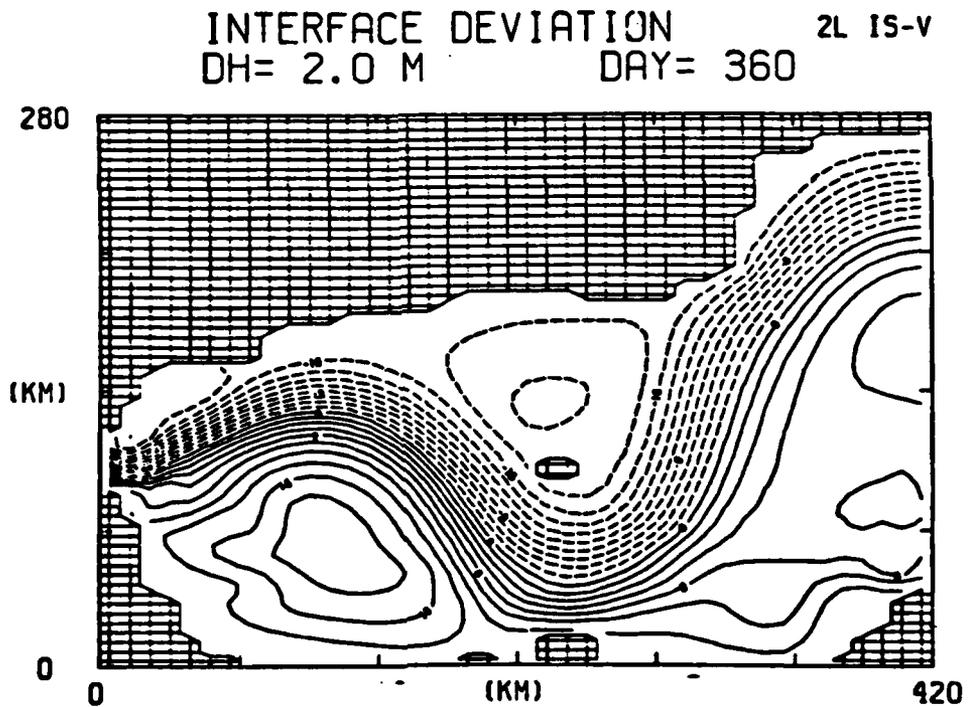
Two numerical models, the reduced gravity and two layer models of Hurlburt and Thompson (1980. *J. Phys. Oceanography*, 10, p. 1161 - 1651) have been adapted to study the semi-enclosed basin of the Alboran Sea. The reduced gravity model domain is a rectangle 600 km x 160 km with 10 km x 5 km grid resolution. The Strait of Gibraltar is modeled by a port in the western boundary and the eastern boundary is entirely open. When forced by an eastward or north eastward inflow, model solutions evolve to a steady state which exhibits a meandering current. The first meander forms the northern boundary of an anti-cyclonic gyre in the western portion of the basin. Horizontal dimensions of this gyre show a strong dependence on the angle of inflow. Shear applied at the inflow port altered the dimensions and location of the gyre. These solutions have been obtained without including bottom topography, coastline features or winds which have been suggested as important mechanisms in the formation of the gyre. These preliminary investigations (Preller and Hurlburt, 1982. *Hydrodynamics of Semi-enclosed Seas*, 34, p. 75 - 89) indicate the importance of the inflow angle, velocity and vorticity on the formation of the gyre.

The two layer model cases incorporate real geometry and topography. The 200 m deep upper layer retained the same boundary conditions as the reduced gravity case while the lower layer flow was prescribed as .2 cm/sec along the entire eastern boundary and moved westward. Flow exits the lower layer through the strait. Cape Tres Forcas appears as an important coastal effects in cases with due east inflow, deflecting upper layer flow mowing south, towards the east. Steady state results show that the slowly moving layer flow produces only minor effects on the gyre (Figs. 1a,b). The effects of topography are apparent in the lower layer, steering the flow toward the southern coastal shelf. When Alboran Isle is included in the topography, the magnitude of the velocity and therefor the transport, becomes important. When the incoming jet is of order 1.0 m/sec and angled north of east, the island deflects the jet to the north and inhibits the formation of the gyre. However, if the velocity is reduced to 30 cm/sec, the gyre reappears. Further tests changing the magnitude and direction of the inflow with time shows that the shape and location of the gyre are highly sensitive to these time variations.

(Figures on the following page)



PA (pycnocline anomaly) of the reduced gravity case at day 500. Inflow angle is 21° north of east. Solid contours are positive (downward) deviations. Dashed contours are negative (upward) deviations. Contour interval is 10 m.



PA of the two layer case with the Alboran Isle. Inflow angle is 21° and inflow magnitude is 30 cm/sec. Contours run from +20 to -20 meters with a contour interval of 2 m.

Figs. 1 a, b.

The influence of Bottom Topography
on Baroclinic Ocean Transports

by

Benoit Cushman-Roisin and James J. O'Brien, USA

(Presented by James J. O'Brien)

A new and reduced set of governing equations is proposed for the modelling of baroclinic motions in a two-layer system with variable bottom topography. The reduction of the equations, which eliminates all barotropic motions, is based on the assumption of almost vertically-compensated transports. The resulting equations differ somewhat from those obtained with a rigid-lid approximation. The limitations are topography variability only on horizontal scales greater than the wavelength and wavelengths shorter than the barotropic radius of deformation. These are not critical in many problems. Numerical solutions to the reduced equations are shown to be close to those obtained from the primitive equations, in one- and two-dimensional cases. In view of their relative simplicity, the new governing equations have also been applied to the analytical study of coastal upwelling in the presence of a canyon enhances coastal upwelling.

The success of the reduced equations proposed here resides in the fact that, if there are no externally forced barotropic motions, those formed by the interaction of baroclinic motions over variable topography are negligible. Because of the elimination of all barotropic motions, including barotropic planetary waves and barotropic shelf waves, it is concluded that the reduced equations will be best applied to coastal processes, fjords, small lakes and seas.

Tides, internal bars and internal solitary waves
on the Strait of Messina

by

E. Salusti, Italy

The Strait of Messina is a long, narrow channel connecting the Tyrrhenian and Ionian seas. (Fig. 1). Its width is $\sim 4+7$ km, the sill is 4 km large and ~ 100 m deep. The bottom topography deepens gently toward South and more abruptly toward North. At the two ends at the Strait the semidiurnal tides of the two main basins of the Mediterranean have comparable amplitude (~ 10 cm) but are in phase opposition (Vercelli, 1925). The resulting velocities can reach 2.5 m/s, (Defant 1940) Moreover in the hydrological structure of the adjacent basins (~ 15 m of "Atlantic" water over "Levantine" water) a baroclinic structure appears. The same can be seen in the time-average value of the velocity on the sill: an upper layer (~ 30 m deep) flows northward with velocity ~ 10 cm/s over an opposite flow of ~ 10 cm/s. It results that two steady opposite superimposed currents exist inside the Strait of Messina.

The result of these considerations have been obtained recently. Hopkins, Salusti and Settini have obtained theoretically that an internal wave of ~ 100 m of amplitude must be present inside the Strait. Abbate et al (1982) have indeed observed this wave by field measurements. A packet of internal solitary waves generated by these tidal phenomena has been studied by Alfars et al (1982) through images obtained by SEASAT - SAR.

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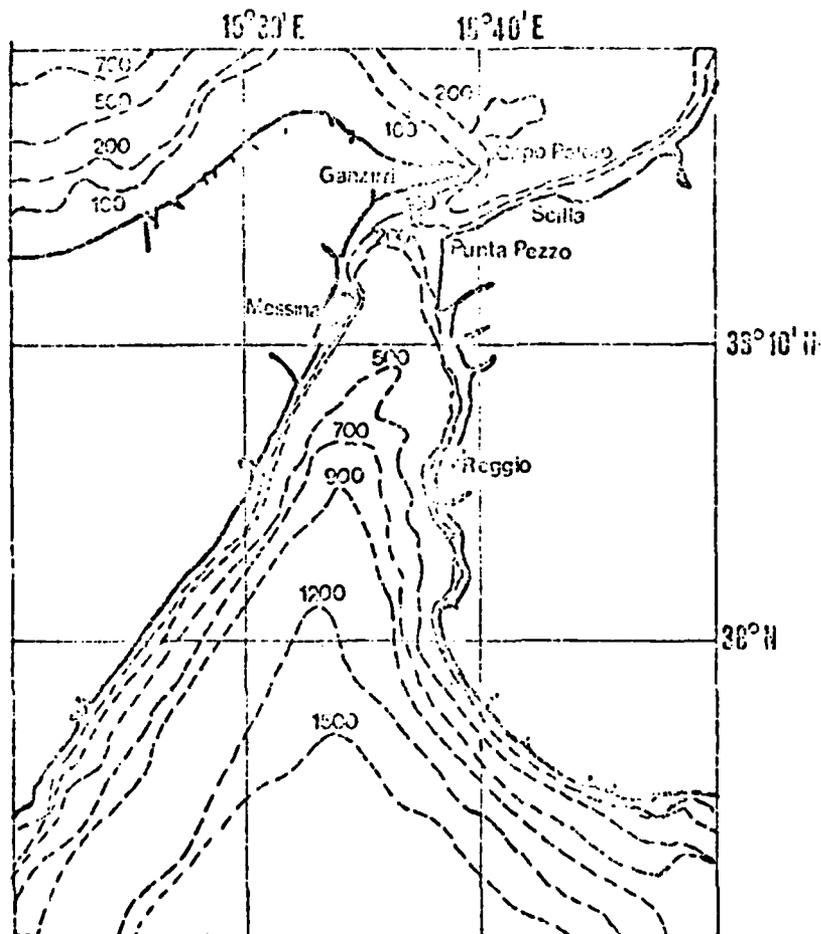


Fig. 1.

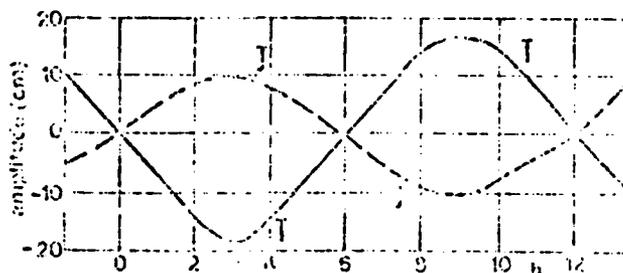


Fig. 2.

The Strait of Gibraltar Overflow investigated
by Geochemical Tracers

by

P. Schlosser, W. Roether and W. Weiss, W-Germany

We have available hydrographic-, tritium- and in part silica data from 6 stations taken in the Strait of Gibraltar area during cruises in 1974 to 1978. The tritium data allow a distinction between Levantine Intermediate Water (LIW) and Mediterranean Deep Water (MDW). They clearly show the presence of LIW at our sill stations in a layer up to 100 m thick. On the other hand the data exclude a substantial contribution of LIW at stations about 50 km west of the sill. We conclude that the outflow from the Mediterranean largely originates from depths between about 400 m and 700 m, in good agreement with previous tritium results (1). Our finding is consistent with hydraulic considerations (2) and with current measurements in the Alboran Sea (3).

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Transport through Unimak Pass, Alaska:
Forcing mechanisms and impact on the Bering Sea

by

James D. Schumacher, USA

Unimak Pass, the easternmost passage between the Gulf of Alaska and Bering Sea shelves, is about 19 km wide with minimum depths of about 55 m. Using current meter, bottom pressure, geostrophic (adjusted to the

surface) wind and CTD data, it has been shown (Schumacher, Pearson, and Overland, 1982) that: (1) current fluctuations between 3 to 10 days are highly ($K^2 \geq 0.7$) coherent with the along-pass bottom pressure difference, (2) this difference is strongly coherent with along-shore winds, suggesting that Ekman divergence is the mechanism responsible for such fluctuations, (3) there appears to be a seasonal trend in the long-term (order Months) flow (which varies from ~ 6 to 20 cm/s into the Bering Sea) and this is related to higher steric levels (0/50dbar) in the Gulf of Alaska and to the presence of the Kenai current (Schumacher and Reed, 1980; Royer, 1981, 1982) which flows along the Gulf of Alaska coast. Transport of about 0.1 to $0.3 \times 10^6 \text{ m}^3/\text{sec}$ of less saline water onto the Bering Sea shelf: (1) enhances the local manifestation of the middle front (Kinder and Schumacher, 1981) and may be an important source of nutrients (Hattori and Goering, 1981), (2) appears to be responsible to some extent for the cross-shelf density gradient along the Bering Sea side of the Alaska Peninsula which results in weak but statistically significant mean flow (Schumacher and Kinder, 1983), and (3) together with freshwater drainage may account for up to about one-third of the net northward transport through Bering Strait ($\sim 0.8 \times 10^6 \text{ m}^3/\text{sec}$, Coachman and Aagaard, 1981).

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The North Pacific: A Global Scale Estuary

by

Anders Stigebrandt, Sweden

The atmospheric net flow of water from the Atlantic to the Pacific Ocean is supposed to maintain the salinity difference between the two oceans. Assuming the existence of a subsurface level of no horizontal pressure gradient in the oceans the mean sea level in the Northern Pacific must be higher than in the Arctic Ocean. This mean sea level difference is supposed to drive the observed mean flow through the Bering Strait. This hypothesis, earlier put forward in the literature, is developed and tested here.

The Bering Strait is modelled by a rectangular channel and the barotropic pressure gradient is balanced by bottom friction. With a seemingly realistic channel geometry the estimated sea level difference (about 0.5 m) causes a volume flow through the Bering Strait which has the same magnitude as that estimated from the observed currents.

The estimated flow of fresh water through the Bering Strait is approximately equal to the estimated atmospheric net flow of water from the North Atlantic to the North Pacific. This justifies the formulation of a simple estuary model for the North Pacific in which the "brackish" water exits through the Bering Strait. From the simple model proposed in this paper a functional relationship between the salinity difference, the magnitude of the atmospheric net flow of water and the topography of the Bering Strait is derived. The estuary model gives residence times for water in the upper layer (about 1000 m thick) of about 1000 years and for the lower layer of about 4000 years. (subm. to J.P.O.)

A Model for the Exchange of Water and Salt Between the Kattegat and the Skagerrak

by

Anders Stigebrandt, Sweden

Because of strong inter-basin interactions in the Baltic entrance area the model has to include the Kattegat and the Belt Sea. These are modelled by horizontally two-layer sub-models. The most prominent dynamical properties of the submodels are wind-driven entrainment flows and rotational- baroclinic, hydraulic controls. The model is driven by a meteorologically forced barotropic transport, Q_b (calculated from the freshwater supply to the Baltic, Q_f , and the sea level fluctuations in the Kattegat), and turbulent entrainment flows coupled to the wind speed, W , and, in the Belt Sea, also to the barotropic transport. The most important bathymetric features of the basins are included.

The model equations are integrated numerically for a test period of one and a half year. The stratification in the Kattegat, as well as in the Belt Sea, is quite well predicted.

The effect of (short term) changes in the external parameters Q_b , Q_f , W and S_{2K} (the salinity of the Skagerrak water) upon the stratification in the Belt Sea and the Kattegat are also investigated. Finally the effects of long term changes in the external parameters upon the surface salinity of the Baltic are investigated. (to be publ. in J.P.O. 1983)

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Internal Gravity Waves in Sill Fjords: Vertical Modes,
Ray Theory and Comparison with Observations

by

Benoit Cushman-Roisin, USA, and Harald Svendsen, Norway

It is well known that marked topographic variations are an important feature by which surface gravity waves can generate internal gravity waves. Typical examples are the generation of internal tides on an abrupt continental shelf and in sill fjords. Two methods of description are available: vertical modes and ray tracing. Both have severe limitations. Decomposition into vertical modes is rigorously justified only if the bottom is horizontal, whereas ray tracing is asymptotically valid only if the wavelengths present are at most a small portion of the total depth. In view of these restrictions, neither method is strictly applicable to the study of internal waves in sill fjords. However, lacking any other applicable techniques, the methods have been applied to data from Skjomen, a sill fjord in Northern Norway.

Qualitative conclusions can be clearly stated: (i) interactions of the surface tide and the sill topography is certainly the mechanism responsible for the existence of internal waves away from the sill, (ii) surface or bottom reflection can account for changes in the direction of vertical phase propagation, (iii) waves tend to be a combination of the first few modes only, and (iv) there is no evidence of standing waves or waves coming from the head of the fjord.

Finally, currents caused by various wind conditions, both outside the fjord (up- or downwelling) or locally in the fjord, are likely to affect the horizontal propagation of the internal wave energy through the fjord. The influence of such currents on the direction and curvature of the rays is briefly discussed.

This is the first attempt to apply ray tracing to the study of internal gravity waves in fjords.

(Presented by Harald Svendsen)

**Water Exchange Through the Bosphorus and Its
Effects on the Black Sea Oceanography**

by

D. Tolmazin, USA

A 15-year program (1961-1976) to investigate the Mediterranean effluent in the Black Sea included field studies of thermohaline structure and current patterns in the pre-Bosphorus region, analysis of previous field measurements in the Bosphorus and adjacent seas (A. Merz, H. Pektas, et al.) and an analytical model for a baroclinic flow in the channel.

It is demonstrated that the Bosphorus is a major hindrance to water exchange in the Black Sea - Aegean Sea system. The currents in the strait are controlled by the difference in fresh water balance between the seas linked by the strait and the wind fields over the entire system. The near-field property distribution in the Black Sea displays a quite complicated track of the Mediterranean overflow above the northern sill and shelf zone in the Black Sea. The plume is contracted to the sea bed and it is usually well-defined by elevated salinity and temperature within a 15 - 25 km shelf area.

During stable northeasterlies the mixing rate in the strait sharply decreases, and high-salinity water overflows the sill in a form of a thin effluent. The opposite southwesterlies enhance mixing, and the effluent becomes abnormally strong. A part of salty water forms a plume which descends along the slope. A part of the Mediterranean water propagates in the intermediate layer of the sea in a form of well-defined lenses.

A baroclinic model in the strait is developed to investigate interaction between current and density fields. It is shown that the interface between water slopes down to the Black Sea steeper than the boundary between the upper and bottom currents. Therefore, the lower flow entrains a sizeable portion of the upper water back into the Black Sea. As a result the plume of the Mediterranean water takes form of a thin wedge while approaching the terminal point of the strait.

Transport Mechanisms in Eastern Long Island Sound

by

David Tolmazin, USA

Various circulatory mechanisms within the mesoscale range of tidal flows in Eastern Long Island Sound are investigated based on two 13-day time series of current measurements. The data were obtained from three moored current meters deployed in a form of triangle approximately 2 km apart. The depth of current meters was about 18 - 20 meter.

Statistical analyses provide evidence of residual circulation effects of topographic origin in the average flow field. The relative importance and periods of orderly residual patterns and turbulence motions are examined using kinetic energy spectra for the longitudinal and transverse components of the flow. These analyses reveal residual oscillations

having nearly the same time scales for all moorings and horizontal turbulent eddies which display a diversity of temporal scales ranging from 0.6 to 2.5 hours. Within the high-frequency band of temporal scales the computed spectral curves for longitudinal components generally follow Kolmogorov's "-5/3 law", while the spectra of transverse components have slope of approximately -1.

A computational technique was presented to calculate horizontal eddy coefficients in various directions using the mixing length hypothesis. The coefficients increase with averaging interval until they reach a certain 'saturation' value, in which the entire set of mesoscale turbulent eddies is accounted for. These computations show well-defined horizontal anisotropy in the strait.

The Strait of Belle Isle

by

Bechara Toulany, Brian Petrie and Chris Garrett, Canada

The Strait of Belle Isle, between Newfoundland and Labrador, is a shallow strait which connects the Gulf of St. Lawrence to the North Atlantic. The length over which the width of the strait doubles from its narrowest (17.5 km) is about 100 km; the average depth is about 75 m. The tidal streams, the low-frequency fluctuations and the mean flow are all of the order of $0.5 - 1.0 \text{ ms}^{-1}$.

Previous investigations by Garrett and Petrie (1981) and Garrett and Toulany (1981) have shown that (i) the sea level difference across the strait is a good measure of the surface flow (the cross strait geostrophic balance holds), (ii) the large scale atmospheric pressure difference across the strait provides a good representation of the forcing responsible for the flow through the strait.

Statistical analysis of long series of sea level and atmospheric pressure by Garrett and Toulany (1982) has shown that the flow is a frequency-dependent response to coastal set-up due to wind-driven long-shore currents on the Labrador shelf, and barotropic set-up of the North-east Gulf of St. Lawrence.

Current meters were deployed across the strait for 80 days from July to October, 1980. The purpose was to study the detailed structure of the flow fluctuations. Preliminary analysis shows very high coherence in the long strait current component throughout the whole cross-section, but with near-surface currents about 50% greater than currents 50 m below the surface.

A comparison has been carried out between (i) the sub-surface pressure difference (from sea level) across the strait and (ii) the difference between sub-surface pressure and bottom pressure at one side of the cross-section. The two series are coherent, with a gain and phase that are consistent with an extension of Garrett and Petrie's (1981) theory of frictionally induced baroclinic adjustment. The spin-down time is of the order of 12 hours.

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Some effects of topography and time dependence
on currents in Straits

by

J.A. Whitehead, England

The behavior of a barocline coastal current composed of low-salinity water in a saltier rotating fluid, the current being over a sloping bottom, is reported. The experiment is in a rotating tank. The current is produced by a source of light water which is impulsively turned on, so that a coastal current is started along the outside vertical wall of the tank upstream of the sloping bottom. This current which is like that studied by Stern, Whitehead and Lien Hua (1982), has a nose which detourains eddies as it propigates at a speed of order $\sqrt{g^*h}$ and is fed by a somewhat laminar current of width $0.4 \sqrt{g^*h}/f$ where h is depth of the current. When the current flows onto the sloping coastline, the following changes occur if the slope is small enough: 1. The current becomes wider. 2. The nose ceases the detrainment of eddies and becomes laminar. 3. A topographic shelf wave radiates ahead of the current and initiates a barotropic current in front of the nose. 4. The current propagates more slowly and constantly decelerates. The loss of current speed is probably linked to the drag of initiating the barotropic current. Data supporting the propagation of the wave ahead of the current and the decrease in current speed are presented.

Reference:

Stern, M.E. J.A. Whitehead and B. Lien Hua, 1982. The intrusion of a density current along the coast of a rotating fluid. *J. Fluid Mech.*

Straits as Amplifiers of Primary Production

by

C.S. Yentsch, USA

The thesis in this paper argues that accelerated current flow through large Straits augments primary production. To the degree to which we can ascribe the flow as geostrophic - the acceleration of the flow (due to constriction) changes the configuration of the density field which in turn changes the vertical distribution of nutrient concentration. A Strait in the northern hemisphere whose long (x) axis is east to west and whose flow parallels this axis, the nutrient boundary (y axis) slopes upward from the right to left side of the Strait, which is the inverse of the slope of the sea surface. This sloping boundary moves nutrients closer to the euphotic zone where mixing processes can easily serve to

supply that zone. Hence, photosynthetic production increases as a function of the nutrient boundary (N_B) and the height of sea surface (Δh); the conceptual strait model argues that,

$$\partial N_b / \partial y = \frac{\Delta h}{L} \cdot \frac{f}{g} \cdot \bar{\mu}$$

where L is the channel width $\frac{f}{g}$ the Coriolis parameter and $\bar{\mu}$, the mean flow through the Straits.

Measurements of chlorophyll concentration and nutrients and features of the density field throughout Western Boundary Current Straits in the Caribbean confirm the thesis by showing a close relationship between features at the density field sea level slope with productivity. Augmentation between Straits of varying width show that the increased velocities $\bar{\mu}$, in the Yuc Straits increase productivity about 10 times that observed in the unrestricted open ocean.

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Session 1, Hydrodynamics

D. Conlon, Rapporteur

Doron Nof: On the Flow through the Windward Passage

The discussion focused on the flow in the region west and north of the gap in Nof's model - Region 2 in Nof's notation.

Whitehead: How do you get a flow in Region 2 ?

Nof: The solution dictate a flow; if you allow a solution to exist. This flow must exist.

Garrett: I agree with Whitehead's misgiving; you can't get a signal in Region 2, so you must losing energy.

Nof: Why can't you get a signal in Region 2 ?

Whitehead: Because there is no wave; there is no Kelvin wave propagating along the coast.

Garrett: And in the two-layer case where $h_s \rightarrow h_n$, you get a linearized problem which accentuates Whitehead's objections - you just get an internal gravity wave arising.

Stern: It would help me if the same problem were reposed. Your argument is a little hard to buy, because your situation is not a controlled flow. If, rather, you postulate an incoming current on the eastern boundary, the problem would be well posed and the solution should be the same.

Nof: I have worked it out, and the solution is indeed very closely the same.

Nof: (later) If Kelvin waves were the only way to transfer energy from right to left, that is correct. That is, I have incorrectly implied that when I lift the gate, the disturbance goes to the left.

Now let us relax the condition of conservation of volume during adjustment and start with a current as Stern suggested. Then one finds that the current in Region 1 increases and the amount of increase goes into the Caribbean, while the current in Region 2 remains unchanged. The magnitude of the current into the Caribbean is the same in this formulation as in the previous case. This transport is still independent of the width of the gap.

Conlon: Would you (or others) care to comment on the extent to which hydraulic control is actually demonstrated by field observations ?

McClimans: In our fjord cases, there are many good cases of hydraulic control.

Assaf: Probably the relative amount of mixing is important. When buoyancy and flux are working in the same direction (as in certain straits like Tiran), critical conditions are achieved. Likewise the Black Sea is sufficiently large that flow in the Bosphorus is critical, but the Sea of Marmara is not large enough and so the flow in the Dardanelles is not critical.

O'Brien: The influence of Bottom Topography on Baroclinic Ocean Transports

Farmer: What similarity is there between this work and that of Hansen and Rattray in the 1960's ? They derived equations which bear a

striking resemblance.

O'Brien: Many authors have taken this sort of an approach for flat-bottom conditions, but I am not sure whether this response applies to the work you cited.

D. Farmer: Review of Flow over Sills in Narrow Fjords

Nof: Isn't there a problem with the hydrostatic approximation when the aspect ratio is large?

Farmer: The local slope here is reasonably small, of order 0.1 - 0.2.

Nof: But if the aspect ratio is of order one and the Froude number is of order one then the neglected terms are of order one.

Stern: You say that you are not getting hydraulic jumps, even though the model results indicate so.

Farmer: These flows are for $U < U_{critical}$.

Stern: But that criterion was originally formulated for a very simple case. For the situation you describe with greatly varying topography, wouldn't be more accurate to call this a hydraulic jump that results from special conditions?

Farmer: In fact, within our own laboratory we have been calling them hydraulic jumps. (Laughter).

O'Brien: Are you suggesting that there may be some interaction between modes - a transfer of energy from one to another?

Farmer: Not at this time, no.

J. A. Whitehead: Some Effect of Topography and Time Dependence

O'Brien: Am I correct in stating that your hypothesis is that the downstream vertical wall is not responsible for the downstream propagation of the waves in advance of the bore.

Whitehead: That is correct.

Conlon: The slope experiments you report on bear an interesting resemblance to conditions observed in the western Hokkaido coast near the Soya Strait.

Session 2, Large scale effects

F. Schott, Rapporteur

T. Kinder: ¿Donde Va? An oceanographic experiment
near the Strait of Gibraltar

D. Conlon: How is the experimental design and execution related to earlier developed concepts, e.g. Bryden and Stommel or others?

Answer: The experiment was mainly planned in cooperation with the numerical modeling effort by R. Preller, to be presented in one following.

M. Stern: Is the incoming current deflected to the left or right?

Answer: At first it is deflected to the left but after getting past the gyre it seems to turn back southward, i.e. to the right, at least there are eddy-like features along the N. African coast which seem to be associated with it.

M. Stern: Why does Denmark Strait overflow from bottom water while Gibraltar does not: the difference between wide and narrow sills

C. Garrett: Is the assumption made here, namely that there is more mixing in the Mediterranean outflow than in Denmark Straits overflow, really true?

Answer: There is only a small temperature difference between the out-flowing water and the original water mass arriving on the sill from the north.

C. Garrett: But the temperature change along the outflow axis depends on the temperature of the water it mixes with.

J. Meincke shows a graph of distribution of Norwegian sea water percentage in the overflow; it is still more than 50% 200 km downstream, suggesting, in fact, low mixing.

M. Stern: It certainly is much lower than the Mediterranean outflow where salinity decreases drastically on a short downstream scale from $> 38\text{‰}$ to 36.5‰ .

D. Nof: What is the dynamical difference in the calculation between the Mediterranean and the Denmark Strait cases?

Answer: It is given by the parameter $g'\mu/f^2$ where $\mu \approx M$ is the curvature w^2 ($w = \text{width}$, $\Delta M = \text{perturbation}$), hence μ is much larger in the Mediterranean than the Denmark Strait case. That means the flows goes down deeper before leaving the topography in the Mediterranean while banking on the right of the channel in the Denmark Strait.

A. Stigebrandt: There seems to be an f too much in the equation for Q . for a channel of rectangular cross section one should obtain

$$Q = \frac{1}{2} \frac{g' H^2}{f}$$

which is the same as obtained by degrading Margules' equation.

C. Garrett: How is the work related to earlier similar papers, e.g. Gill's.

Answer: The results will be the same as for chemical hydraulics but friction and thermodynamics can be added here.

A. Foldvik: Similar processes as discussed here are also seen at the Filchner depression, where the downflow seems to continue down to 3000 m.

C. Garrett: Geostrophic control for barotropic fluctuations

D. Nof: What happens if the solution is not periodic?

Answer: Solutions of different shapes can be synthesized. By Laplace transformation one can get a steady state solution.

M. Stern: What happens with that theory if a tidal wave comes up to the gap in shallow water?

Answer: In that case the nonlinear terms are large and the theory is not applicable. Nonlinear terms are small in the cases considered here.

D. Nof: How is the gap theory related to the channel problem?

Answer: So far the relation has been made by handwaving but it can be worked out.

R. Preller: Numerical modeling of the Alboran Sea

C. Garrett: What determines the size of the gyre?

Answer: It seems to be determined by the inflow angle because the current will hit the northern boundary at different locations accordingly and then get deflected to the south.

C. Garrett: Nevertheless the pictures seem to indicate that the curvature is always about the same, what determines that?

Answer: The curvature indeed seems to stay about constant for the oscillating inflow case; it changes if inflow angle is changed in the stationary runs.

Question: Is there not the possibility that the sequence is the other way round, i.e. that the gyre exists first and then deflects the incoming current?

Answer: Can be possible but nothing is known about cause and effect.

M. Stern: How does anticyclonic vorticity develop if it is not coming through the inflow port?

Answer: There is, in fact, anticyclonic vorticity at the inflow profile in the case where only the transport is specified.

C. Garrett: How important are the viscous terms for the gyre/current pattern?

Answer: This has not been studied carefully yet; but it seems that for horizontal eddy viscosity $\sim 2.5 \cdot 10^6 \text{ cm}^2/\text{s}$ the eddy is smooth and for smaller values we get instabilities.

A. Stigebrandt: Bering Strait effects on salinity difference between North Atlantic and North Pacific.

D. Nof: How is river discharge accounted for ?

Answer: Has not been included.

J. O'Brien: At the fall '82 AGU meeting in San Francisco, B. Warren (WHOI) presented a paper much related to this work; suggest correspondence with him.

Answer: That has already begun.

Session 3, Techniques

J. Schumacher, Rapporteur

P. Schlosser: The Strait of Gibraltar overflow investigated
by geochemical tracers

Question: Do the tritium concentration measurements indicate that the main discharge from the Strait is not Intermediate Mediterranean water but is from greater depths?

Answer: Yes.

J.J. Nihoul: The application of remote sensing
Straits-generated eddies

Question: The patch north of the formation region (strait) is cold, i.e. it can be seen in IR imagery, the eddies collect and drift away although the tide reverses, why?

Answer: This is an example of increasing scale cascade of energy - 2D turbulence, at least for the case (winter) when there is no vertical stratification.

Question: Is a possible alternative method for the formation of a cold path that water in the upper (warmer) layer removed by the reversal of the tide so that the result is a cold region?

Answer: The problem is barotropic, i.e., temperature is constant with depth so that there is no upper layer.

Question: What supports the cold core of these eddies?

Answer: The small eddies have upwelling of cold water.

Question: This throws a damper on 2D turbulence - at least until the eddies are larger and the Coriolis force is dominant?

Answer: 2D turbulence occurs when the eddies are \geq the depth.

Comment: Such features have been observed in tank studies.

Question: Is the colder water less saline than the warmer water?

Answer: There are horizontal but not vertical temperature gradients - salinity has not been considered yet.

D. Farmer: Acoustic Techniques

Question: Since you have acoustically measured horizontal and vertical velocities, have you calculated the stream function?

Answer: Yes, but approximations and assumptions must be made - the ship speed is not constant and velocities cannot be resolved directly over the sill since the depth is small and a finite time is required to apply this technique.

Question: What is the densimetric Froude number?

Answer: It is much greater than 1.

Question: From your measurements is the flow over the Knight Inlet sill asymmetric?

Answer: Yes.

F. Schott: Techniques and measurements in the Strait of Florida

Question: You have measured current speeds of 250 cm/sp, to what angle did the moorings lean under such conditions?

Answer: Up to about 35°.

Question: What bouyancy did you use on these moorings?

Answer: About 2000 lbs.

Question: Where is the level of no motion?

Answer: There is no "level of no motion" in the vertical, but there sometimes is one in the horizontal.

Question: Have you considered waves as being responsible for some of the observed fluctuations?

Answer: This is presently being done, there seems to be independent waves on either side of the Strait.

H. Svendsen: Internal gravity waves in sill fjords:
vertical modes, ray theory and comparisons with observations

Question: What does the Richardson's number look like - does it provide a clue to where the mixing occurs?

Answer: The calculations have not been done yet.

Question: How does the energy in the internal waves compare to the energy going into mixing?

Answer: It is probably small, but this has not yet been determined.

Question: Is this sill similar to Knight Inlet?

Answer: No, it is not nearly as steep and the tides are less energetic.

Question: Are there density inversions?

Answer: No, the density structure is smooth.

A. Foldvik: Stratified flow over large amplitude
sills-upstream influence

Question: What is overturning in linear theory?

Answer: This question was not answered per se.

Session 4, Arid zone straits

A. Stigebrandt, Rapporteur

D. Anati: Winter 1979 in the Straits of Tiran

Question: Is there any inconsistency if you treat the two main straits as independent (thus assuming a large separation between them) ?

Answer: I think so unless the depths of the interfaces are at the same depth in the straits.

G. Assaf: Mixing Conditions Controlled by Straits

Comments: Considering the vertical stratification the Monin-Obukhov length you calculate (1000 m) seems to be too large.

Comments: It appears to be dangerous to base a calculation of one single Monin-Obukhov length on several mixing processes occurring in different parts of a stratified fluid such as wind mixing and the mixing in dense bottom gravity current.

D. Tolmazin: Summary of investigations in Bosphorus:
turbulence, plume, effect on Black Sea conditions

Comments: You should be careful when using oxygen measurements from 1925.

Question: Can the flow in the Bosphorus be like that in an arrested salt wedge ?

Answer: Yes, for some time.

S.P. Murray: Dynamics of Northern Red Sea Straits

Comments: The large mixing coefficient used in the non-rotating solution may be an effect of stratified spin-up.

Session 5, Baltic Sea straits and others

J. Meincke, Rapporteur

D. Tolmazin: Summary of investigations in the Bosphorus:
turbulence, plume, effects on Black Sea conditions

Anati: What is the explanation for the different inclination of the velocity and the thermohaline interface ?

Answer: This difference is due to the entrainment, which has to be taken into account because of the near to critical Richardson numbers.

Stern, Schott: What is the basis for saying, that the Mediterranean water plume turns west, i.e. to the left when going down the Black Sea slope off the Bosphorus ?

Answer: This is based on direct observations, there is no explanation.

Yentsch: If you dam the freshwater inflow into the Black Sea and thus increase the Mediterranean water inflow, would H_2S decrease ?

Answer: Yes, the resultant decrease in the stability due to stratification could enhance the O_2 -flux into deeper layers.

A. Stigebrandt: A model for the exchange of water and salt between the Baltic and the North Sea

Schott, Whitehead: What is the character of the entrainment "constant" and what role does it play in driving the model ?

Answer: Entrainment is dependent in standard way on wind speed. It effects only salt, not momentum. The wind in this model is only used to drive salt exchange between inflow and outflow layers. When operating the model, the most important factor on salinity flux is the barotropic flow through the Belt. Wind effects on vertical mixing and salinity of deep Kattegat are of lesser importance.

Schott: Why is the Kattegat sea level height used as input for driving the barotropic flow rather than using the sea level difference across the Belt ?

Answer: Model results do not show any improvement in the prediction.

Garrett: How much does the eddy flux of salt contribute to the salinity fluctuation ?

Answer: 50%

Kullenberg: To what degree does a change of bottom friction determine the magnitude of salt flux between the Kattegat and the Baltic ?

Answer: Only to a small degree, i.e. the answers of this model to a possible negative effect of the proposed Belt-bridge are in favour of the bridge.

Jacobsen: Could verification of the model be achieved without light-vessel data ?

Answer: Badly.

Jacobsen: Does the Kattegat front affect the model results ?

Answer: Not yet known.

D. Tolmazin: Transport mechanisms in Eastern Long Island Sound

(No discussion)

A. Michelato: Current measurements in
the Straits of Messina and Sicily

Anati: Could the Strait of Sicily be considered a passage rather than a strait, i.e. is the bottom topography known well enough ?

Answer: All data are still restricted, the topographic charts will be released in a few months time.

Salusti: Is the observed outflow on the deepest instrument Lavantine intermediate water or is it Mediterranean deep water ?

Answer: Unfortunately the temperature sensor on the instrument failed, thus presently this question cannot be answered.

G. Kullenberg: Examples of suspended matter distribution in Straits

Framer: Are the observed high scattering values caused by organic or inorganic matters ?

Answer: For the Spitzbergen waters it is most likely inorganic particles originating from ice and meltwater run-off from Spitzbergen.

Meincke: Is there any obvious correlation between sea ice pattern and the observed structure of the near surface scattering layers ?

Answer: A correlation is possible, however it has not yet been evaluated.

Stern: Is the vertical resolution of the instruments good enough to resolve fine structure for information on turbulence above Georges Bank and in the channel next to it ?

Answer: The resolution is such that this information could be extracted.

Session 6 Pressure gradient and wind forcing

G Kullenberg, Rapporteur

J. Schumacher: Transport through Unimak Pass., Alaska:
forcing mechanisms and impact on the Bering Sea

Average depth 95 m. Winds drive fluctuations but not the net transport in Gulf. Questions concerned the wind influence and the wind history during the study. Wind generally towards NE in area, and in rest of Gulf towards W, SW.

On question how much of the coastal current that passes into Unimak Passage answer was that this is probably not known.

On question if satellite photos show any eddies or whirls answer was that some type of wave like features can be seen but not as much structure as has been seen, e.g. on European shelf.

Current measurements were carried out close to bottom in the passage, current on surface through ship drift was about 70 cm/s; Ekman divergence at coast.

B. Toulany: Strait of Belle Isle

Question concerning scatter in diagram showing geostrophic balance, and related resolution of current field, was answered by statement that the flow can be monitored by sea level measurements across the strait; currents are daily means based on 1/2 hourly observations. Salinity was observed with conductivity sensors on the Aanderaa meters, with inter-calibrated sensors.

The time scale of the linearized stratified model with strong frictional influence was days; after about 1-3 days the surface distortion becomes too large, moving isopycnals and may cause linearization to break down.

Rotational effects present? No.

D. Conlon: Various aspects of flow through the Tsugaro Strait

The sea level difference from gauges was about 10 cm, and currents south of straits about 30 cm, at the 400 m level; not all stations of observation were closing the shelf slope, but it was stated there was no leakage around the edge. The current was up to 4 knots towards the Pacific. The strait is 18 km wide with a strong curvature, seen in different current distributions depending upon current velocity, considering surface currents only. The flow was stated not to reverse vertically or in time; with 2 knots at surface, 1 knot close to bottom.

The structure of the jet when leaving the strait and the gyre, eddy or coastal mode current outside was much discussed; the spin, the transition, the existence or not of an eddy; this had not been observed; the relatively quick establishment of the coastal mode current; it was stated that we know very little of the dynamics of separation of these types of currents; it seems

that separation may or may not occur.

The question was asked if the Japanese considered using the current as an energy source. Not known.

Frictional effects along the strait were discussed and considered possibly important.

J. Meincke: Hydrography of the Faroe Channel

T/S diagrams were presented, question was asked what effects cause the scatter between and in these; this was considered to be related to the presence of frontal zones, use of individual observations and treatment of the individual data.

It was also pointed out that it is remarkable that the T/S diagrams give such a well defined relationship, and that this is the interesting point.

Session 7. Discussion

G. Assaf and B. Toulany, Rapporteurs

- G. Kullenberg: We have to agree on the following topics:
1. The definition of straits.
 2. Area for experimental work.
 3. Strategy for study.
- T. McClimans: Straits are commonly strategic areas with political restriction.
- J. Meincke: One should look on climate and large scale circulation and their interaction with straits. There is little information on the Canadian Arctic and Bering Straits.
- D. Farmer: From some measurements we made we know that these straits have practically no flow.
- B. Toulani: These straits are less accessible anyhow.
- D. Farmer: The question still remains: What are the relevant measurements and how to take them. I suggest the use of tide gages, bottom pressure measurements, and cables.
- S. Murray: One should classify the type of straits and the different mechanisms of the driving forces.
- D. Anati: The variability of the straits, such as the effect of multiple openings, calls for multi-national cooperative study.
- D. Tolmazin: Bosphorus and Dardanelles are important and we should approach the Turks to study them.
- G. Assaf: So far we can predict the behaviour of straits which control the mixing in the basins. Other straits are individual entities with different physics. One should concentrate on straits which control important basins and where there is public interest to pursue such studies, i.e., the straits of the Baltic Sea.
- D. Anati: We have not yet dealt with paleoclimate problems related to straits.
- C. Yentsch: Straits regulate the level of productivity in their region.
- M. Stern: We have the conflict between being too broad and generalized or too narrow and specialized.
- D. Conlon: Is Rasby radius of deformation a good indicator of the straits type (wide or narrow)?
When does bottom friction become important?
- M. Stern: We need laboratory model + theory + observation + interaction between them.

D. Conlon: What is your opinion on numerical models?

M. Stern: One has to recognize the essential physics before one may do any useful numerical study. For example, we do not know the nature of friction in stratified fluid without which the numerical models are handicapped and expensive.

MEASUREMENTS OF CURRENTS AND TRANSPORTS IN THE FLORIDA STRAITS BY VARIOUS METHODS

F. Schott

One of the main objectives of the subtropical Atlantic Climate Studies (STACS) program are long-range measurements of the mass and heat transport through the Florida Straits.

The Florida Straits work which began in April 1982, can be subdivided into two categories. The first one is a technical one, namely to determine the most reliable and costefficient method or combination of methods for long term monitoring of such variations. The second is the physical question to understand the nature of the observed variations in structure and transport of the Florida Current, i.e. their kinematics and dynamics.

In the following the status of these two objectives will be briefly reviewed.

1. The measurement program in the Florida Straits

Altogether, although not all are employed simultaneously, seven different techniques for current and transport measurements are being applied in the region between Jupiter Inlet on the Florida side and Grand Brhama Island (Fig. 1).

a) Moored Current Meter Measurements

The moored station work in the Florida Straits reported here is done jointly by the author and Dr. T. N. Lee, also from RSMAS/MPO.

Before launching the moored array, we did a test station for two weeks during November 1981 specifically to determine the drag reduction by fairings on the mooring wire. After that turned out satisfactorily, we deployed an array of five moorings for two months, from April - June, 1982 (Positions 146-150 in Fig. 1). The "W" shape of the array positions across the Straits was chosen to allow calculation of phase propagation of the low frequency fluctuation. This array is called STACS-I below.

The instrument depths and positions in that array are shown in Fig. 2 superimposed on the mean velocity profile along $27^{\circ}26'N$ by Richardson et al. (1969). In the high speed part of the current we use Niskin Wing Current Meters (NWCM's), in the other parts of the section Aanderaa instruments. Top instrument depths were 50m at the western station, 100 m at the two eastern stations and 200m below the core.

Retrieval of the array showed very strong wear on the western mooring and in subsequent arrays we kept the top instrument there at 100 m. In the core positions, 147, 148 we could increase mooring height to 150 m and still keep wire angles in the acceptable range. With these modifications, the next array was out from June to December, 1982 with good results.

First results of these measurements will be reviewed below.

A continuous hazard to the moored measurements is long line fishing in the Current. On several moorings we had marks on the mooring wire obviously from long lines hauled in and on a few moorings long lines were wrapped around - fortunately so far without losses of instruments or data quality.

b) PEGASUS Profiling

This instrument, drops at a known descent rate and measures its distance against bottom-mounted acoustic transponders. Eight transponder pairs are deployed across the Straits and various sections have been compiled (K. Leaman/RSMAS, and R. Molinari/NOAA) during two-week long cruises in April, June, September, and November 1982. The problem with these measurements is tidal aliasing; therefore tidal prediction was one of the first objectives of the moored current measurements.

c) Ametek-Straza Acoustic Ship Log

This instrument has been built into the R/V CAPE FLORIDA and a number of inter-comparisons have been carried out with moored currents and PEGASUS profiles.

Fig. 3 shows an intercomparison between LORAN ship speeds and those determined from the Ametek by bottom tracking. Each point corresponds to 15 mins. average of about 400 profiles. The standard deviation is ± 15 cm/s. A better agreement, within 5-10 cm/s, was obtained between individual PEGASUS profiles and Ametek profiles.

One short coming observed was that not enough back-scattered energy was received from depths greater than $\sim 150 - 200$ m (the nominal depth range is 400 m), maybe due to lack of scattering material or just too low energy level of the signal sent out.

In summary, it seems to be a useful instrument for monitoring the near-surface layer, especially the western shelf section where no moorings and PEGASUS stations are located (Fig. 1) and a number of surveys have been made on several cruises.

d) Tide Gauge Measurements

Continuous sea level measurements are carried out in Miami and Cat Cay on the Bahamas side (since 1981). For a better intercomparison with the actual measurements further north, pressure gauges have been deployed on both sides of the Straits near the moorings and PEGASUS positions. Initial intercomparisons (G. Maul/NOAA-AOML) show significant correlation between the sea level differences across and transports determined from PEGASUS sections. These correlations turn out much better than those between earlier drop sonde sections and sea level differences.

e) Cable Measurements

Cable voltages are recorded on both sides of the cable running from Jupiter to

Settlement Point (Fig.1). This cable is broken somewhere on the western shelf. As already Sanford (1982) has shown, a very good correspondence exists between the seasonal cycle of the cable voltage and the sealevel difference Miami-Bimini. First intercomparisons between cable data and transports calculated from moored data as well as PEGASUS sections (J. Larsen/NOAA-PMEL) show good correspondence also on shorter time scales suggesting that the cable measurements will be an important monitoring tool.

f) CODAR

Only few measurements with the Coastal Ocean Dynamics Applications Radar (CODAR) have been made so far but more complete intercomparisons are planned for July 1983 (R. Lyons, S. Frisch/NOAA-ERL)

g) Acoustic Tomography

Reciprocal transmission experiments between three stations near the moorings and PEGASUS sites are planned for July 1983 (H. DeFerrari, RSMAS).

2. Low-frequency Fluctuations of the Florida Current

a) Earlier Observational Evidence

Most of the present knowledge on the Florida Current is based on dropsonde sections taken in the 1960's (e.g. Schmitz and Richardson, 1968) and in one intensive survey period during 83 days in the summer of 1974 (Brooks and Niiler, 1977; Brooks, 1979).

These measurements showed the mean transport off Miami to be $29.5 \times 10^6 \text{ m}^3/\text{s}$ with indications of a seasonal maximum of about $34 \times 10^6 \text{ m}^3/\text{s}$ in June and a minimum of about $25 \times 10^6 \text{ m}^3/\text{s}$ in December (Niiler and Richardson, 1973). Besides the seasonal cycle, energetic fluctuations appeared in the 2-15 day period band with amplitudes of ± 3 to $4 \times 10^6 \text{ m}^3 \text{ s}^{-1}$, contributing 40 to 50% of the total variance; tidal fluctuations occurred with both diurnal and semi-diurnal periods, again with amplitudes of $\pm 3-4 \times 10^6 \text{ m}^3 \text{ s}^{-1}$ and accounted for 10-20% of the variance (Schmitz and Richardson, 1968; Brooks, 1979).

So far it is not clear what the driving mechanism of the low-frequency fluctuation. Their periods and wave-lengths seem to agree with analytical models of barotropic instability (Niiler and Mysak, 1971) but also with stable continental shelf waves (Brooks and Mooers 1976; Schott and Düing, 1976), for which local wind forcing might be the driving mechanism (Düing et al., 1977).

b) Detiding

Our major concern for the first part of the study is the kinematics and dynamics of the energetic fluctuation in the period range from several days to two weeks.

To use PEGASUS sections for studies of low-frequency variability the tidal aliasing must be removed as well as possible. This problem was recently addressed by Mayer et al. (1983) using STACS-I current meter data, PEGASUS sections and some historical data sets. Results indicate that at least 75% of the tidal energy is associated with the north component of velocity and at least 60% of this is attributed to the predictable (stationary) part of the tidal signal. Diurnal current fluctuations are the dominant component of the tidal energy and appear to result from a diurnal standing wave in the Florida Straits, in support of the hypothesis advanced by Zetler and Hansen (1970). Non-stationary (unpredictable) tidal motions occur in random bursts and appear to favor the western side of the Straits, suggestive of topographic generation of internal tidal motions. Indications are that tidal fluctuations account for at least 40% of the variance in total transport, which is considerably larger than that found by previous studies (Brooks, 1979).

c) Low-frequency Fluctuations

Time series of the band passed low-frequency current vectors (periods less than 40 hrs and larger than 14 days suppressed) from STACS-I are shown in Fig. 4a for station 147 on the cyclonic shear side of the stream and in Fig. 4b for station 149 on the anticyclonic side of the stream axis.

Current fluctuations with amplitudes of 10 to 30 cm s^{-1} occurred throughout the water column at both sites. Currents appear to be significantly correlated over vertical separations with little decrease in amplitudes with depth, indicating a considerable barotropic component for the fluctuations, whereas the mean flow was primarily baroclinic. This fact is expressed in the ratio of r.m.s. fluctuative amplitudes to mean current (Fig. 5) which increases downward and has maximum values at the western slope, indicative of dominantly barotropic wave nature there. (This explains the earlier emphasis on the several day period fluctuations in moored measurements which were taken close to the bottom due to technical reasons mostly on the western side, thus giving the impression of a much stronger fluctuative component relative to the mean flow than actually exists over the entire cross section.)

The several day period fluctuations at times indicate a mixed barotropic/baroclinic nature: in some events phases are fixed vertically throughout the water column, in others there is a phase reversal with depth. The current variations on the cyclonic shear side of the axis show mostly a cyclonic sense of rotation, whereas on the anticyclonic shear side the rotational sense is anticyclonic.

Many of the events indicate a positive correlation between downstream velocity and temperature at 147 and a negative correlation at 149. This is more clearly

visualized in the 40 HLP filtered data at the 300 m level (Fig. 6). Also the downstream velocity variations at 147 appear to be 180° out of phase with those at 149 during these events while temperature changes are mostly in phase.

The current and temperature fluctuations discussed above can be largely explained as meanders: The current structure consists of a northward baroclinic jet with a subsurface axis located approximately between moorings 147 and 149, in the vicinity of 148 (Fig. 2). The temperature structure supporting the baroclinic jet consists of a pattern of downward sloping isotherms toward the east, with the horizontal temperature gradient $\partial T / \partial x > 0$ at all depths. An offshore meander (axis shifts to the east) would cause a decrease in downstream velocity and temperature on the cyclonic side of the axis (147) and an increase in downstream velocity together with a decrease in temperature on the anticyclonic side (149). The opposite response would occur for an onshore meander (axis shifts to west): increasing downstream velocities and temperature on the cyclonic side and decreasing velocity together with increasing temperature on the anticyclonic side of the axis.

Besides this meandering mode there is obviously a significant amount of variance in that period range, which is not explained by this simple model, such that coherences between moorings are generally insignificant.

d) Energetics

Local wind forcing seems to be important: significant coherences between both the north component of the wind stress as well as the curl of the stress and downstream current and transport fluctuations are found in the period range of 10-20 days.

Barotropic and baroclinic energy conversion terms indicate zones of systematic energy conversion from the mean fields to the fluctuations and vice versa. Fig. 7 shows as an example the components of the important barotropic instability term $\overline{u'v'} \frac{\partial v'}{\partial x}$; if it is negative the fluctuation will grow. The figure indicates stabilizing effects on both sides of the current and destabilizing fluxes around the core. A very similar pattern is found from the much longer records of the STACS-II array (June-December, 1982).

The corresponding baroclinic instability term $\int_S \overline{u'T'} \frac{\partial T / \partial x}{|\partial T / \partial z|}$ indicates baroclinic instability across the whole section from the STACS-II measurements but stabilizing fluxes on the left side in the shorter STACS-I records.

These are only preliminary bits and pieces of results and work is underway to analyze the frequency contribution to these terms and integrate them across the section to determine net fluxes.

Also, wave-numbers of the fluctuations are calculated as function of frequency for different subsets of the array.

e) Several and Interannual Variability

The subjects of interest for climate related research in the STACS context are the much longer period fluctuations of the mass and heat transport and there the question is: to what degree is the Florida Current an indicator of the gyre scale circulation in the North Atlantic?

First lets look at the seasonal cycle. As mentioned above, the mean transport off Miami is $30 \times 10^6 \text{ m}^3/\text{s}$. As Leetmaa et al. (1977) have shown, about the same amount is carried southward by the Sverdrup transport in the interior of the subtropical Atlantic. On the seasonal time scale, however, there seems to be an out-of-phase relation between Florida Current and Sverdrup recirculation. The seasonal cycle of the Florida Current supposedly has a maximum in June and a minimum in December with an annual amplitude of $\pm 4 \times 10^6 \text{ m}^3/\text{s}$, but the anticyclonic wind stress curl, zonally averaged between the Bahamas and Africa, has a maximum in winter and a minimum in summer/fall (Leetmaa and Bunker, 1977). Converting the zonally integrated wind stress curl into Sverdrup transports would yield a transport of $48 \times 10^6 \text{ m}^3/\text{s}$ southward in winter and $21 \times 10^6 \text{ m}^3/\text{s}$ in summer/fall. Anderson in a numerical two-layer model circulation driven by monthly (Hellermann) wind stress fields has shown that in fact there would be a western boundary current of about $15 \times 10^6 \text{ m}^3/\text{s}$ seasonal amplitude without the Caribbean Island Arc and topography in the west. Introducing realistic topography produces the reduction in amplitude and out-of-phase relation observed in the Florida Current seasonal cycle. The much larger seasonal signal seems to occur further out in the interior, not close to the boundary in the Antilles region as we have also shown in a recent experiment and historical data analysis (Olson et al., 1983).

On the other hand the seasonal cycle of the Florida Current is in very good agreement with the integrated wind stress curl across the Caribbean (B. Elliott, pers. communication) and also with sealevel differences across the Caribbean.

What happens on time scales longer than seasonal? Unfortunately, time series of sea level difference Miami-Bimini or cable voltages Jupiter - Settlement Point (Fig. 1) long enough to study this question are not available. Sea level time series at various points in the subtropical North Atlantic (Fig. 8) indicate variability in the several year time period. While for the northern Atlantic across 45°N a significant correlation between Sverdrup transport and (eastern) sealevel variations was found in the several year period band (K. Thompson, pers. communication), no such relation can be found between the sea level at Miami and the integrated wind stress curl between the Bahamas and Africa.

In summary, the judgment is still open how good an indicator the Florida Straits transport really is for the North Atlantic Circulation. Numerical modeling using real-

istic seasonally and interannually varying wind fields has to be carried out with emphasis on the role of the Caribbean and the Antilles Arc.

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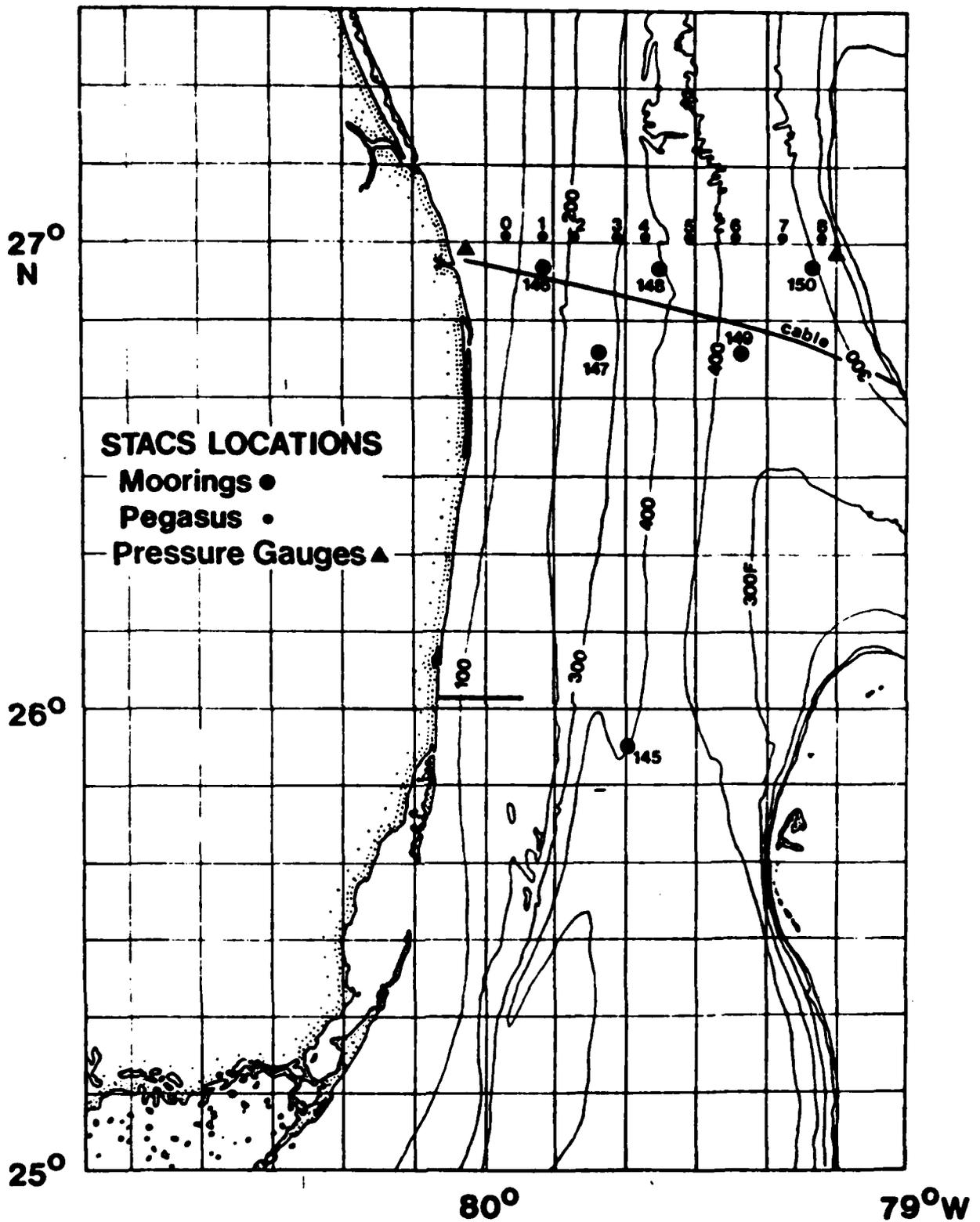


Fig. 1. Location of current meter moorings and PEGASUS stations. Mooring 145 was a 2-week test mooring.

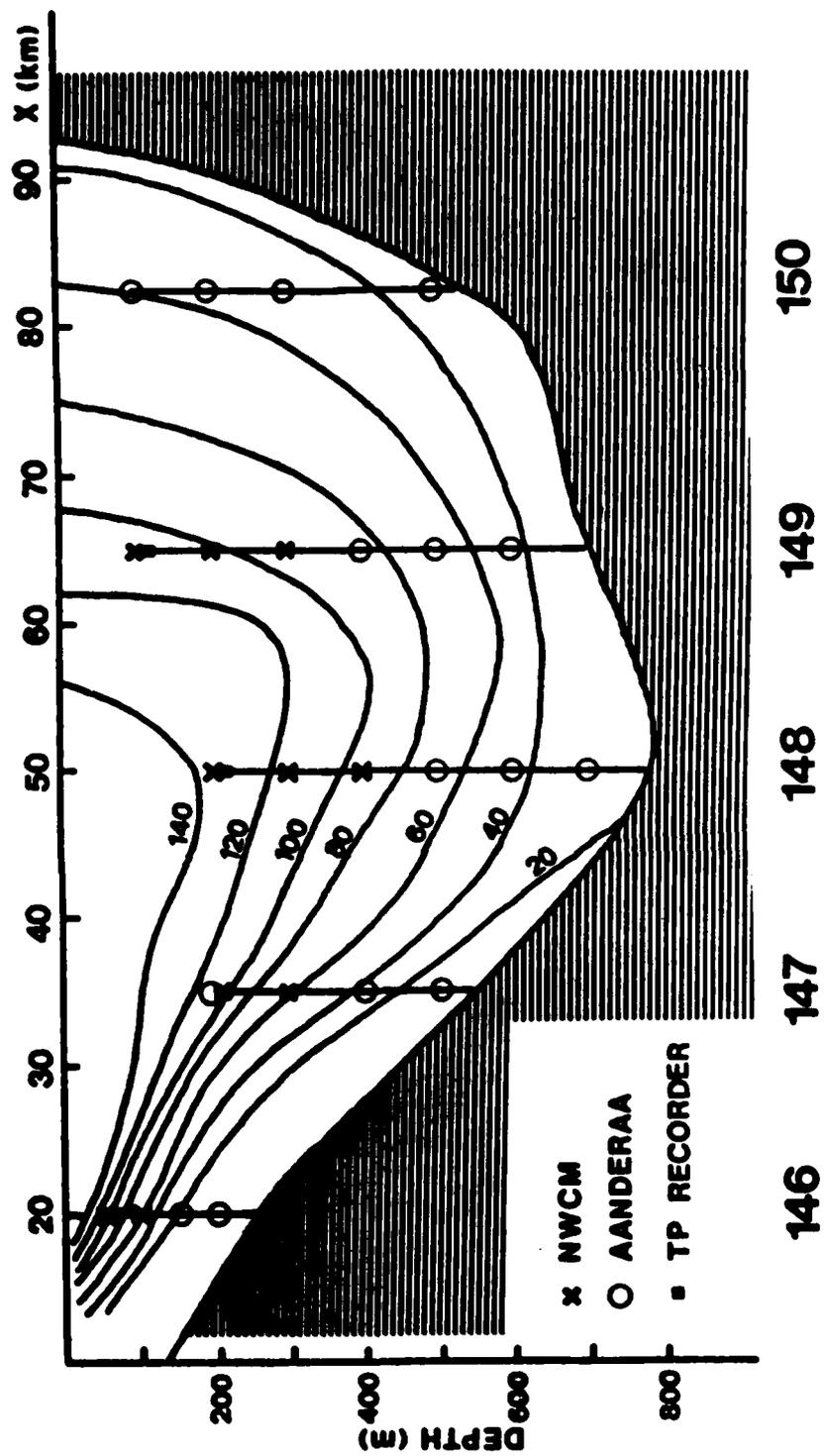


Fig. 2. Instrument position in moorings 146-150 see Fig.1, on mean velocity scheme at 27°26'N (from Richardson et al., 1969).

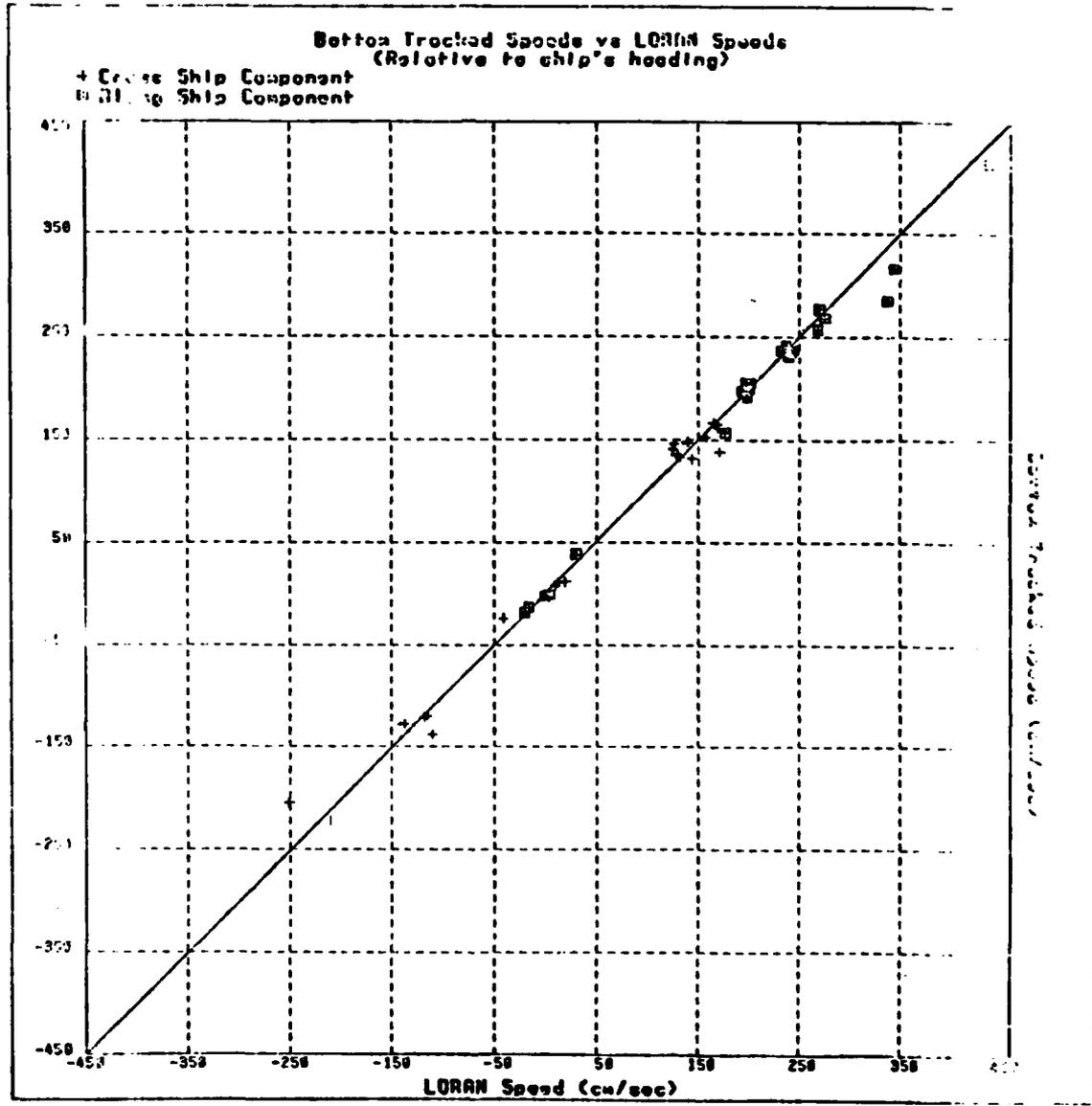


Fig. 3. Both components of bottom-tracked ship motion vector (by Ametek-Straza) versus LORAN determined components.

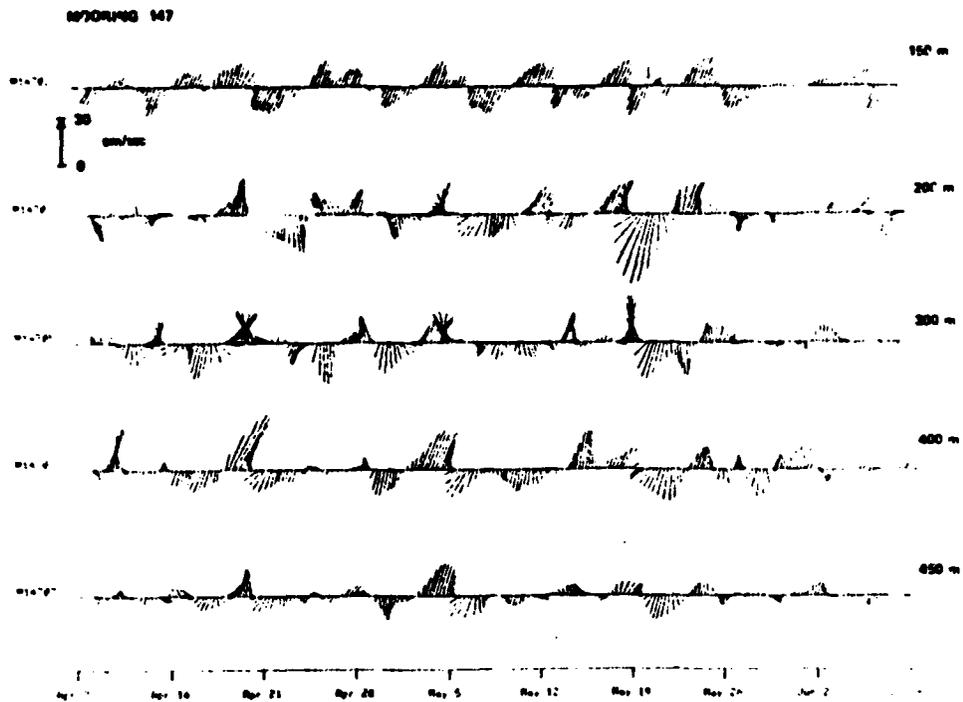


Fig. 4a. 6-hourly vectors of 40-hour to 14-day band pass filtered velocities at mooring 147 during STACS-I.

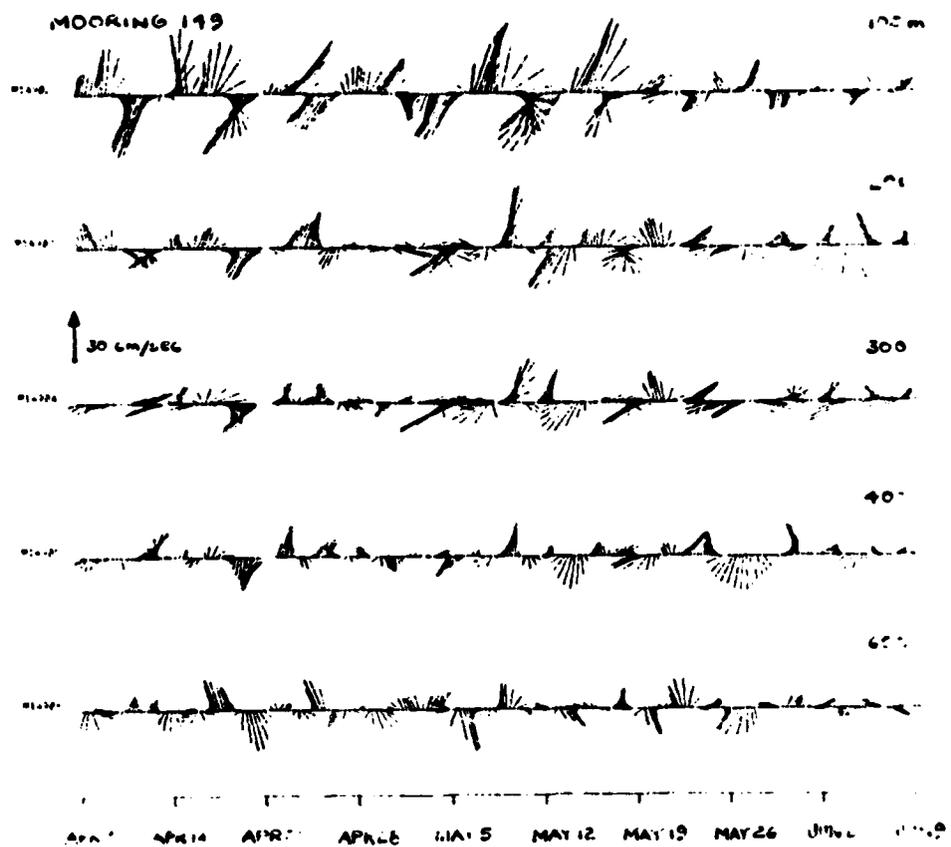


Fig. 4b. 6-hourly vectors of 40-hour to 14-day band pass filtered velocities at mooring 149 during STACS-I.

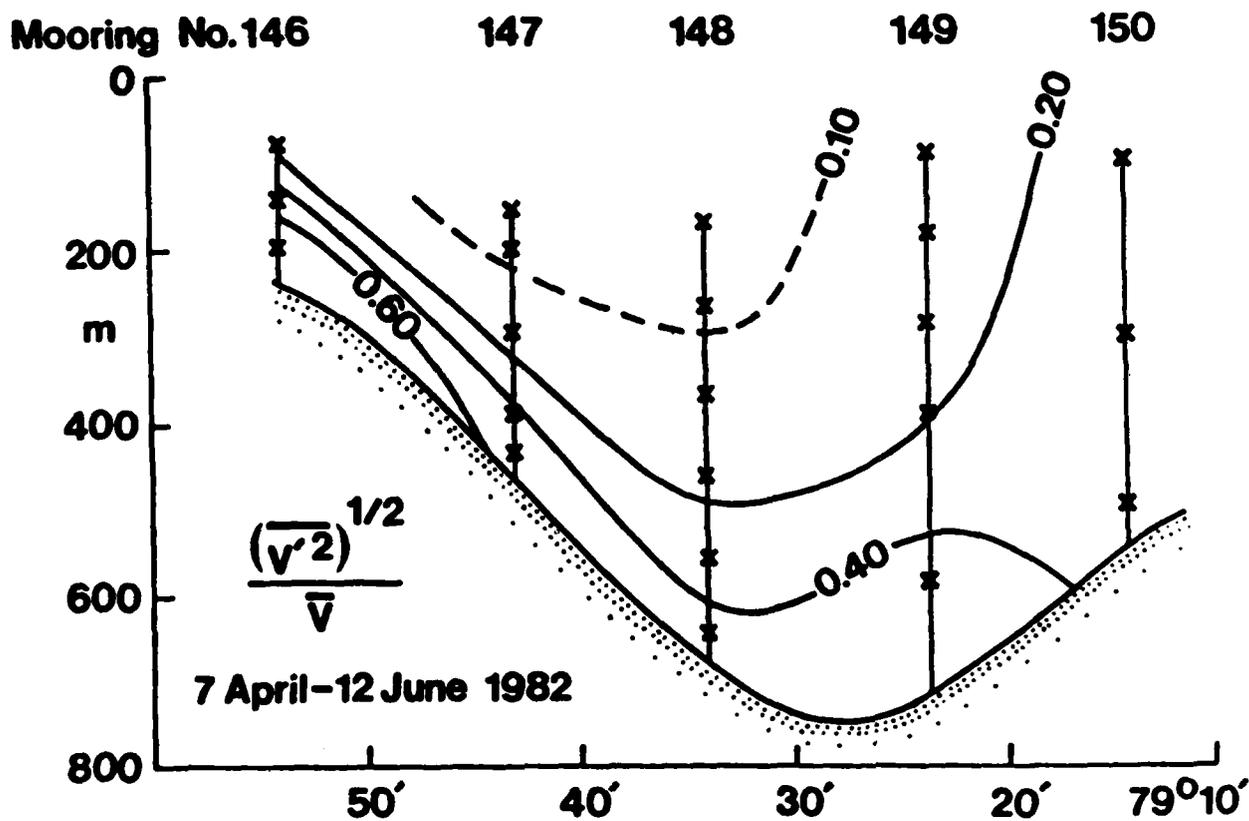


Fig. 5. Ratio of r.m.s. fluctuations to the mean flow for the north component of velocity during STACS-I.

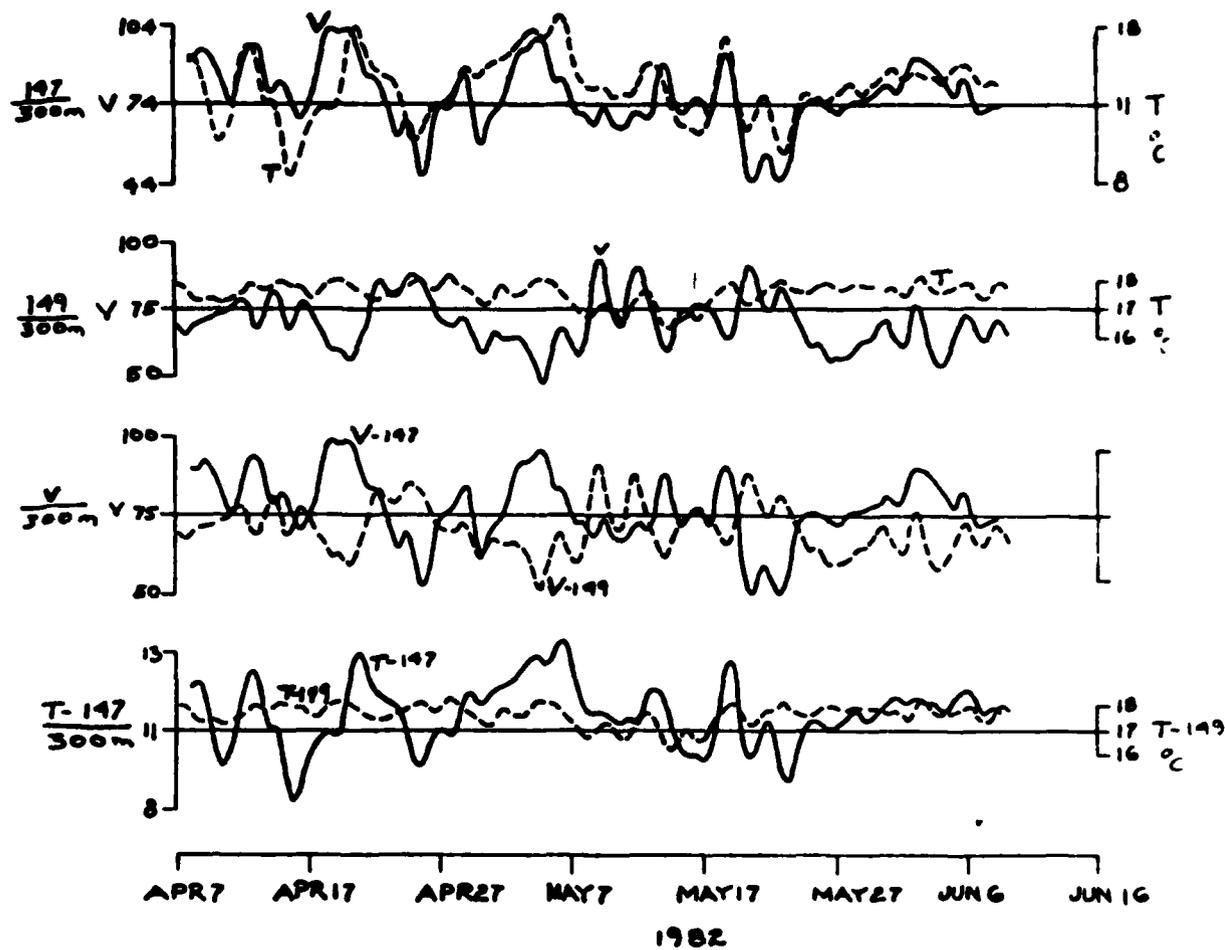


Fig. 6. 40-hour lowpass filtered east (u) and north (v) components of velocity and temperature (T) from moorings 147 and 149 during STACS-I.

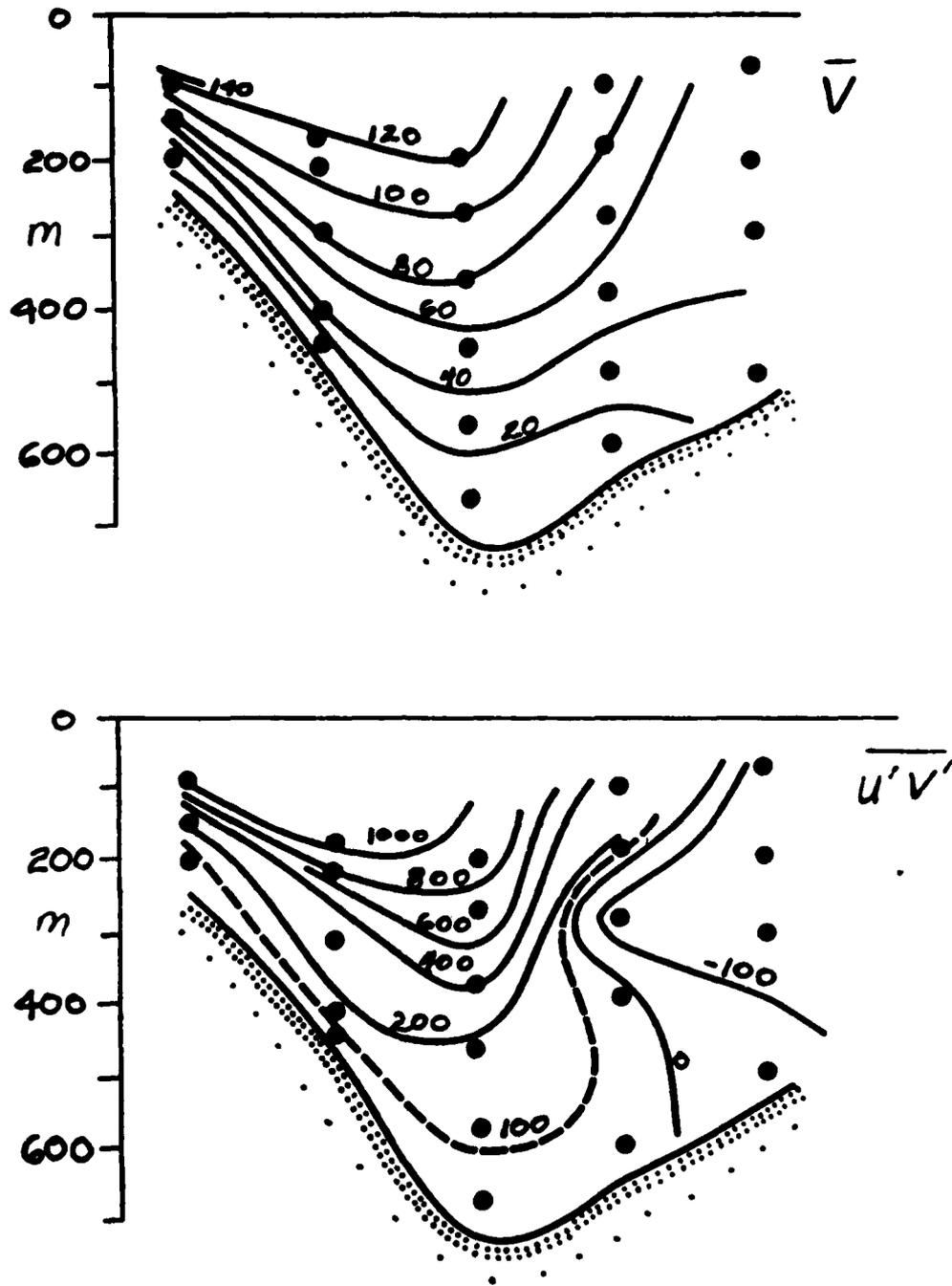


Fig. 7. Mean downstream velocity and cross-stream flux of northward momentum from 40-hour lowpass filtered data of STACS-I.

Stable	Unstable	Stable
$\overline{u'v'} > 0$	$\overline{u'v'} > 0$	$\overline{u'v'} < 0$
$\frac{\partial \bar{v}}{\partial x} > 0$	$\frac{\partial \bar{v}}{\partial x} < 0$	$\frac{\partial \bar{v}}{\partial x} < 0$

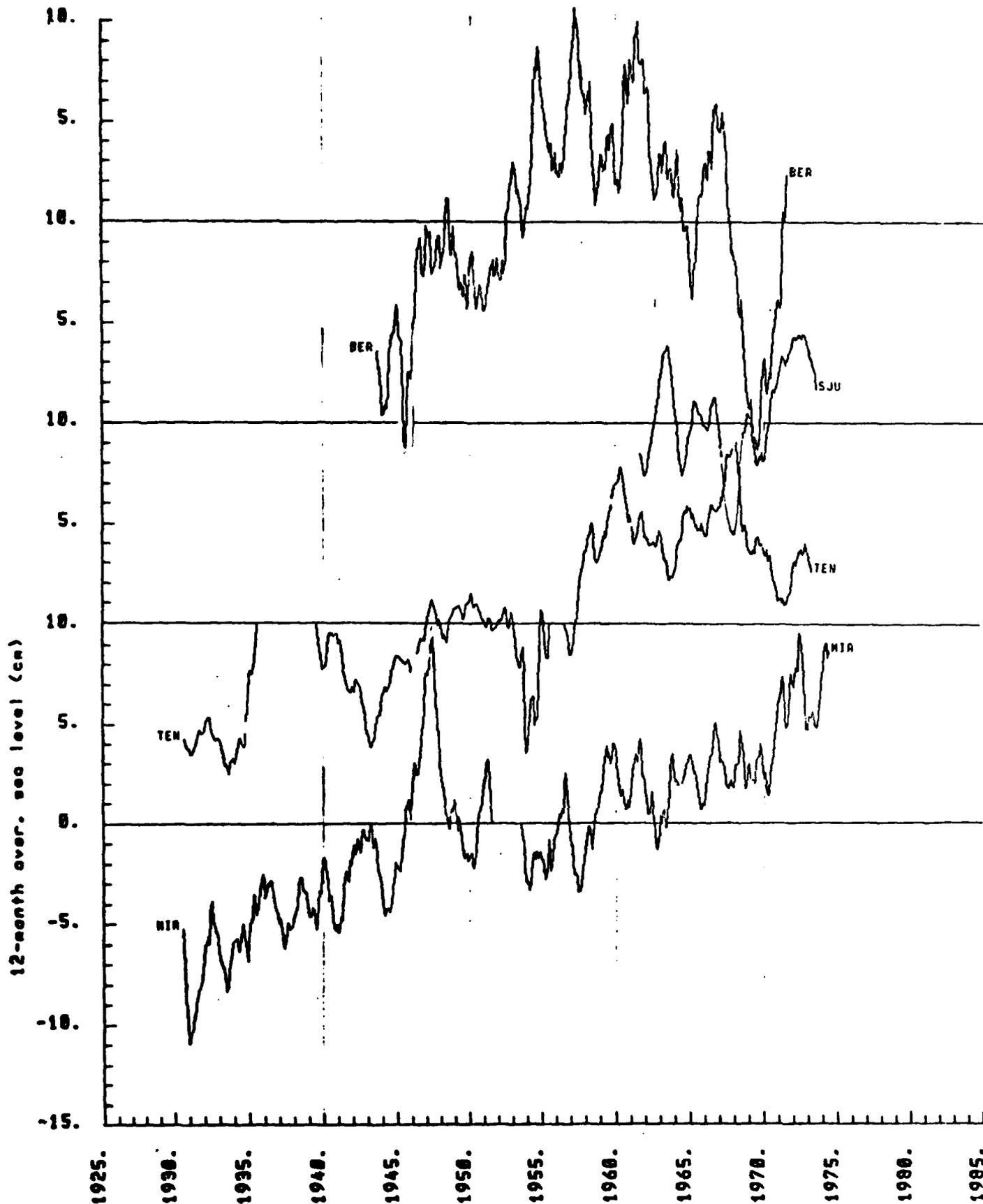


Fig. 8. Time series of monthly averages of sea level variations at Miami (MIA), San Juan (SJU), Bermuda (BER) and Tenerife (TEN); seasonal cycle removed by 12 months running means.

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13. ABSTRACT An important part of the work of an international organization like IAPSO is to stimulate scientific contacts, exchanges and discussions, for instance through functioning as an umbrella for international meetings. A very attractive form of such meetings is the workshop where a limited number of participants present and discuss their work on a well-defined problem area. Such meetings may not require much money and may not be hard to organize but they still require the moral support of one or more organizations.

Towards the end of 1981 IAPSO decided to sponsor a workshop on straits, their Oceanography and Influence on Adjacent Seas. The amount of money allocated to this was by relative measures quite considerable. After some discussions it was decided to have the workshop in Copenhagen early 1983. Further financial support was obtained from ONR and from NKFO which made it possible to invite an ideal number of participants from different parts of the world and covering a good range of subjects and area within the overall problem.

The workshop was structured in seven sessions with presentations and discussions. In this report the abstracts are given together with summaries of the discussions, made by a rapporteur for each session.

The general aim of the Workshop was to produce a snapshot of the present understanding, in relation to straits of: the dynamics of various configurations; the control or influence on conditions in adjacent sea areas; the influence on circulation features and distribution of various properties; the state of the art as regards field investigations.

The discussions were generally lively and a lot of ideas were tossed around. Hopefully some of the positive and stimulating flavour from the Workshop may be transferred also to non-participants through this report. Copies can be obtained free at the Institute of Physical Oceanography (address see list of participants). (U)

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