MODE HOT LINE NEWS

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In this issue:

Killworth, Anderson: Some thoughts on eddy generation
Mirabel, Vasilenko: Velocity spectra from 15 days to 2 hours at a hydrophysical Polygon in the tropical Atlantic

VELOCITY SPECTRA FROM 15 DAYS TO 2 HOURS AT A HYDROPHYSICAL POLYGON IN THE TROPICAL ATLANTIC

by A. P. Mirabel and V. M. Vasilenko

A large-scale hydrophysical experiment aimed at studying ocean current variability was conducted at a Polygon in the Tropical Atlantic (Brekhovskikh, et al, 1971). The Polygon data permit the calculation of spectra of velocity fluctuations over a wide frequency band.

The spectra were calculated from the five-month series of measurements by using the Fast Fourier Transform (FFT) technique for u and v components of the current vector. The currents were sampled at depths of 25 m, 100 m, 500 m, and 1500 m at the central point of the Polygon (16°30'N, 33°30'W).

The main features of these spectra are of interest (Figure 5). The total energy level drops off rapidly with depth in the meso-scale region of the spectra as well as in the synoptic region (this classification of oceanic processes is given by Monin et al, 1974). All the spectra show prominent and statistically significant peaks of energy at the inertial and semi-diurnal-tidal frequency bands (the inertial-current oscillations have the half-pendulum-day period for this latitude, i.e., 42 hrs.)

Between periods of 10 hrs. and 2 hrs., the spectrum attenuates toward higher frequencies at nearly -0.4 power slope at 25 m; the slope increases with depth to the value -1 power at 1500 m.

To the left of the inertial peak, at a period of about four days, there is a minimum

(continued page 2, left column)

SOME THOUGHTS ON EDDY GENERATION

by Peter Killworth and David Anderson

In this note we address ourselves to the question of what generates the propagating disturbances in the ocean ("eddies"), and in so doing, extend the concept of shmodes we introduced in Hot Line News No. 72 (referred to here as KA1). Three main suggestions have appeared as to the nature of eddies:

1. They are generated by some (traveling) atmospheric disturbances.

2. They are generated elsewhere; for example, by Gulf Stream eddies (Schmitz, Luyten, and Sturges, Hot Line News No. 61), or in some strong current system (Rossby, Hot Line News No. 70) by an instability process. They then advect into the region of observation as stable waves.

3. They are the result of open-ocean baroclinic instability in or near the region of observation; for example, they are unstable, wave-like oscillations (Gill, Green, and Simmons, 1974).

Here we examine the third possibility (in situ baroclinic instability) although some aspects of distant generation and propagation will also be explored.

Given a mean flow, what is the selection mechanism which produces eddies of a given size? For a steady mean flow, one would expect to see the most unstable shmode, providing that its growth rate is sufficiently large. Figure 1 shows growth rates. These depend quantitatively but not qualitatively on the form of the profile.

(continued page 2, right column)

VELOCITY SPECTRA FROM 15 DAYS TO 2 HOURS AT A HYDROPHYSICAL POLYGON (continued)

which becomes stronger with depth. A similar minimum at this period was found by Thompson (1971) and Gould et al (1974). This minimum seems to be a peculiar feature of large-scale processes in the ocean. The periods of the minimum may be used as the division between synoptic and meso-scale regions of the spectrum of kinetic energy of horizontal currents in the ocean.

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Brekhovskikh, L. M., K. N. Fedorov, L. M. Fomin, M. N. Koshlyakov, and A. D. Yampolsky (1971) Large-scale multi-buoy experiment in the Tropical Atlantic. Deep-Sea Res., *18*, 1189-1206.

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SOME THOUGHTS ON EDDY GENERATION (continued)

Positive values of U_{top} have smaller growth rates and are not shown. Note the angle of the lines of shmode change, and that the site of maximum growth rate moves to smaller wavenumber (k) for increasing $|U_{top}|$. The 2nd shmode has an absolute maximum growth rate of about $0.24 \times 10^{-7} sec^{-1}$ at $U_{top} = 2.5$ cm/sec, $k = 2 \times 10^{-7} cm^{-1}$. The 1st shmode has an absolute maximum growth rate for $k \sim 1.4 \times 10^{-7} cm^{-1}$, $U_{top} \sim -8$ cm/sec. There is no limit to the growth rate of the 0th shmode.

However, the problem of predicting the wavenumber for a given mean flow is not simply that of examining the fastest-growing shmode, since eddies and larger-scale effects will perturb the mean state. A slowly-growing eddy will probably mainly feel the long-term mean flow but is likely to be damped by other more energetic processes. However, more rapidly growing eddies will feel a shorter-term mean flow which may be different from the long-term mean; indeed, the largest shears are produced typically by the eddies themselves.

For the sake of simplicity, we examined two possibilities:

(a) an annual (seasonal) fluctuation on the mean velocity profile, and

(b) a rapid energetic oscillation imposed by the pre-existence of energetic eddies.

Without full integration of the non-linear equations, we cannot model the self-interaction terms explicitly, so we simulated (a) and (b) by

$$(a) \quad \bar{U} = (U_{top} + 1.5 \sin \omega_a t) e^{z/d}$$

$$(b) \quad \bar{U} = (U_{top} + 10 \sin \omega_b t) e^{z/d}$$

where $\omega_a = 2\pi/1$ year, $\omega_b = 2\pi/1$ month (perhaps a little high for a MODE eddy), and the velocities are in cm/sec.

We now integrate equation (2) of KAl with these two velocity profiles and calculate an effective growth rate. This will differ in general from that calculated for a steady shear of the mean value, because regions of larger and smaller growth rate (and sometimes different shmodes) are entered during the mean shear cycle.

This forced change of shmode means that the effective growth rate will not be well-represented by Figure 1, nor will the vertical profile be given by such a simple method. Figure 2, which shows the temporal behavior of an initially barotropic disturbance in a region of oscillating shear, illustrates the case in point. Although

(continued page 3)

there is an effective growth rate of about $0.5 \times 10^{-7}\text{sec}^{-1}$, the shape of the solution changes with time. This will present difficulty for the interpretation of such motions at a single mooring. A comparison of these profiles with Figure 6 of KA1 shows that in this case of slow, weak oscillatory shear, the baroclinic mode accounts for less variance than in the case of mean shear.

The effective growth rates for this case of oscillatory shear are shown in Figure 3a. Low growth rates in the non-oscillatory cases are enhanced by oscillations in shear, while high growth rates are usually reduced: the oscillations seem to act to smooth out the growth rate variation.

In Figure 3b is shown the effective growth rates when $\bar{U}$ is varied, as in (b). Where values are quoted, there is a recognizable growth rate with variations of order 10 percent. The important feature is the amplification of the growth rates for high wavenumber by factors of 5 or more. This means that a strong eddy field may itself help to produce more eddies, although the weighting to high wavenumbers implies a transfer of energy from larger to smaller eddies (a discrete form of the cascade process?). Alternatively, effective growth rates may be considerably larger in an eddy field.

To produce the relevant growth rates for a given region, it is necessary to know not only the mean shear but also its temporal variation. For example, McWilliams (Hot Line News No. 57) finds that for the long-term shear in the MODE-I region, the lst shmode is stable for wavenumbers corresponding to typical MODE eddy sizes. But these eddies are highly energetic and may be capable of producing significant growth at higher wavenumbers.

In our calculations, we have neglected horizontal variation of mean shear, whereas in the case of eddy forcing it must be relevant. There is also a feedback missing: our argument would suggest that continual cascades to smaller wavelength would lead to smaller wavelength eddies becoming most energetic. This does not seem to occur in the MODE-I region.

Since there is a high-wavenumber decay to the growth rate (Figure 1) for steady or oscillatory mean shear, a cascade would not continue indefinitely to smaller wavenumber; a range of wavenumbers would in general be selected. There is also the feedback from little eddies onto the mean flow and/or larger eddies which linearized perturbation theory cannot explore.

No periods of oscillation were given for the eddy-forcing results (Figure 3b), unlike the case of seasonal forcing. This is because no simple period could be identified by eye, although there were significant time variations in the growth rate. So the real and imaginary parts of the stream function ψ, namely ψ_r and ψ_i, together with $|\psi| = (\psi_r^2 + \psi_i^2)^{\frac{1}{2}}$ were Fourier analyzed in time and the periodograms for a typical case are given in Figure 5. ψ_r and ψ_i can be interpreted as the signals observed a quarter-wavelength apart; $|\psi|$ is not directly observable without more than one mooring.

Apart from the low-frequency domination (due to the exponential growth), the periods ψ_r and ψ_i are the shmodal period and beats between it and the forcing period. The forcing period itself is reflected only in $|\psi|$.

Resonance was found to occur between a shmode and the forcing if these have similar frequencies. For example, a forcing period of three months excites resonance at $k \sim 1.7 \times 10^{-7}\text{cm}^{-1}$ for $U_{top} = -5$ cm/sec; but the addition of a linear growth on top of the pre-existing exponential growth makes little difference. For forcing periods of one year, resonance occurs at $k \sim 5 \times 10^{-8}\text{cm}^{-1}$, but the effective growth rate is small; for forcing periods of one month, resonance occurs at $k \sim 6 \times 10^{-7}\text{cm}^{-1}$ with a strong growth rate, but these eddies are rather small (50 km diameter).

In summary, to decide if a given mean flow is capable of generating energetic eddies, it is necessary to decide what the mean flow really is.

Reference

Gill, A. E., J.S.A. Green, and A. J. Simmons (1974) Energy partition in the large-scale ocean circulation and the production of mid-ocean eddies. Deep-Sea Res., *21*, 499-528.

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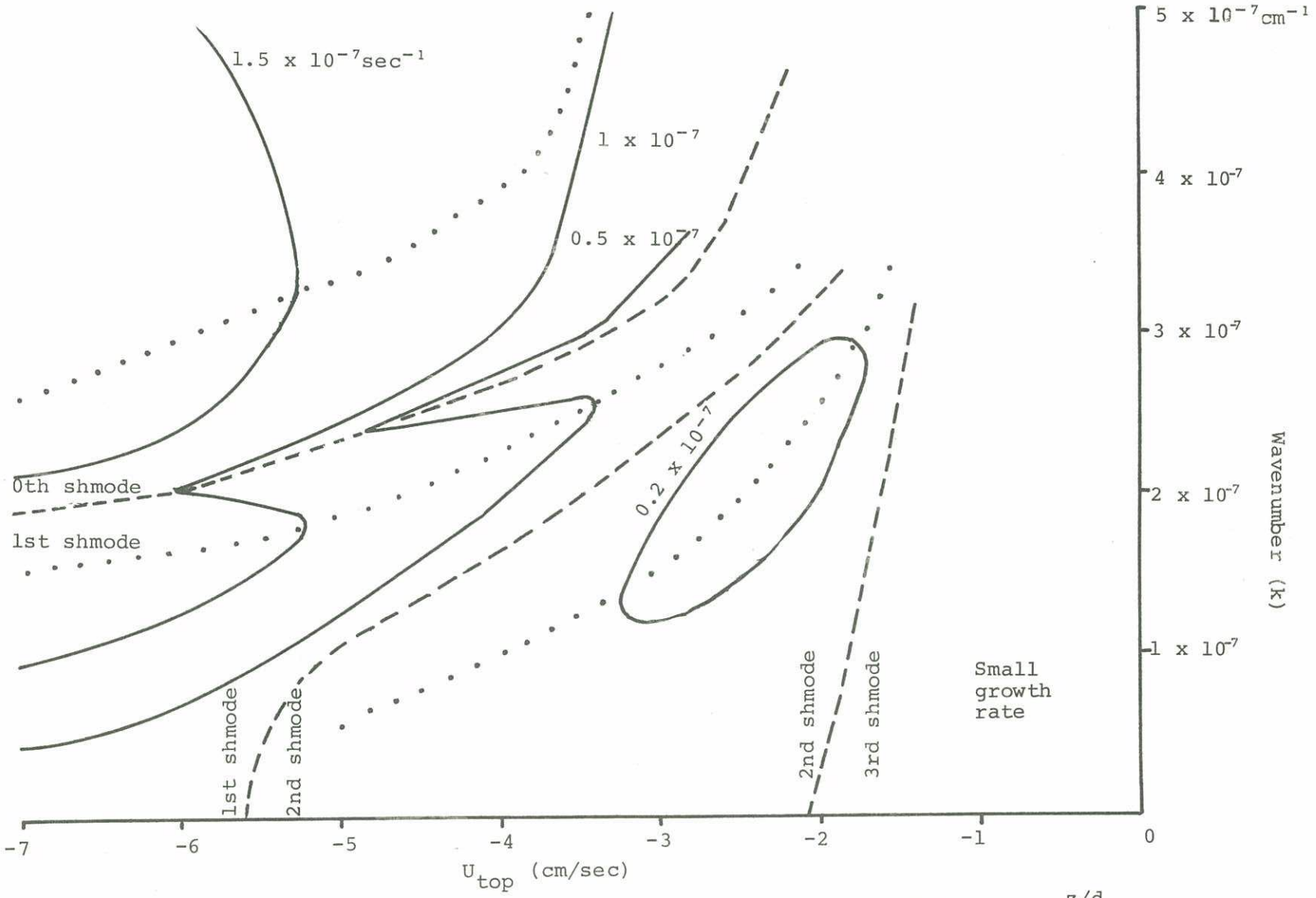
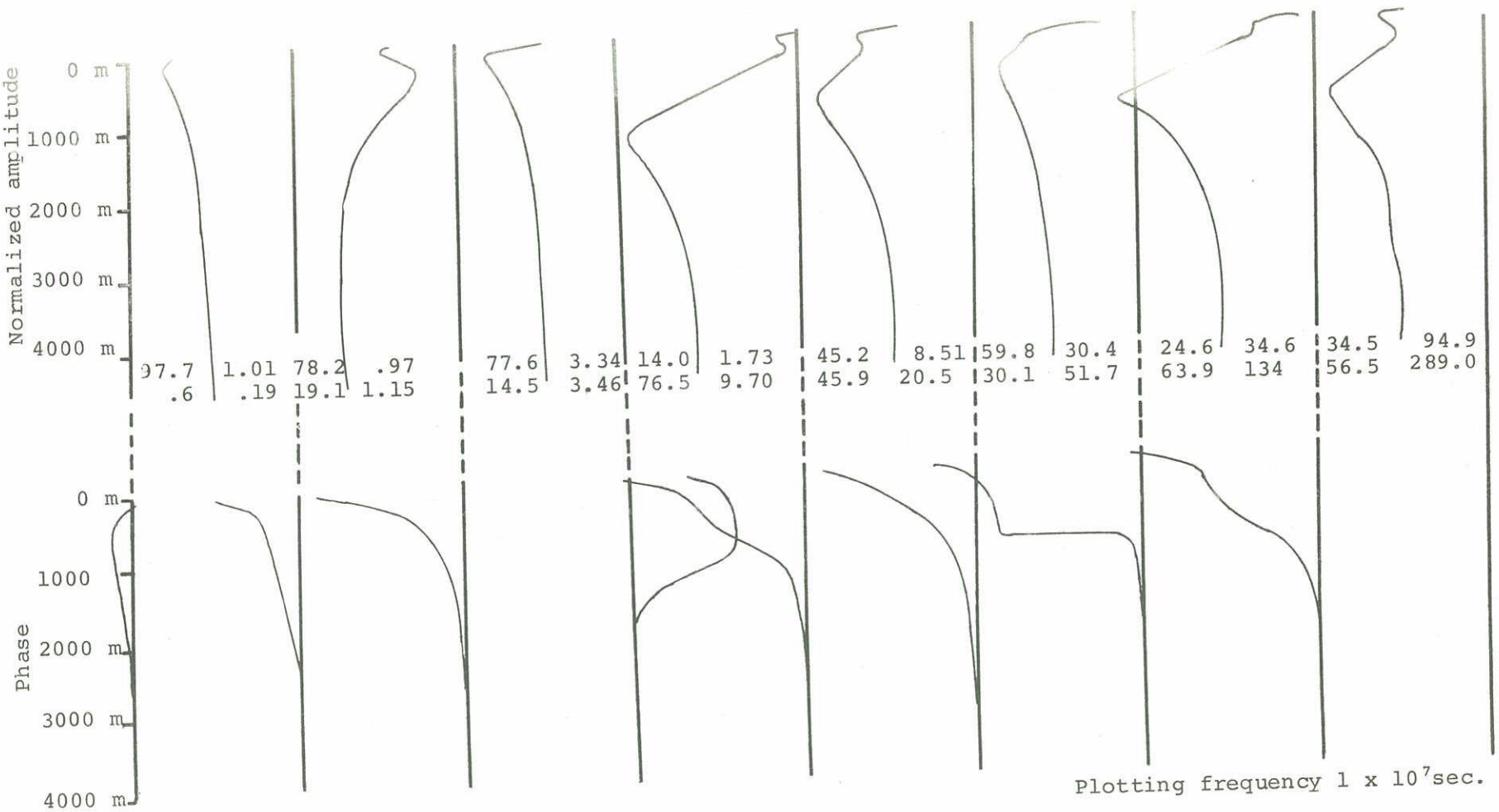


Contours of growth rate of unstable shmodes. The mean velocity $U(z) = U_{top} e^{z/d}$, where d = 900 m and ocean depth is 4500 m. Density of variations is $N^2/f^2 = 10^4 e^{z/d}$ and $\beta = 2 \times 10^{-13} cm^{-1} sec^{-1}$. Dashed lines show transitions; dotted lines show maxima.

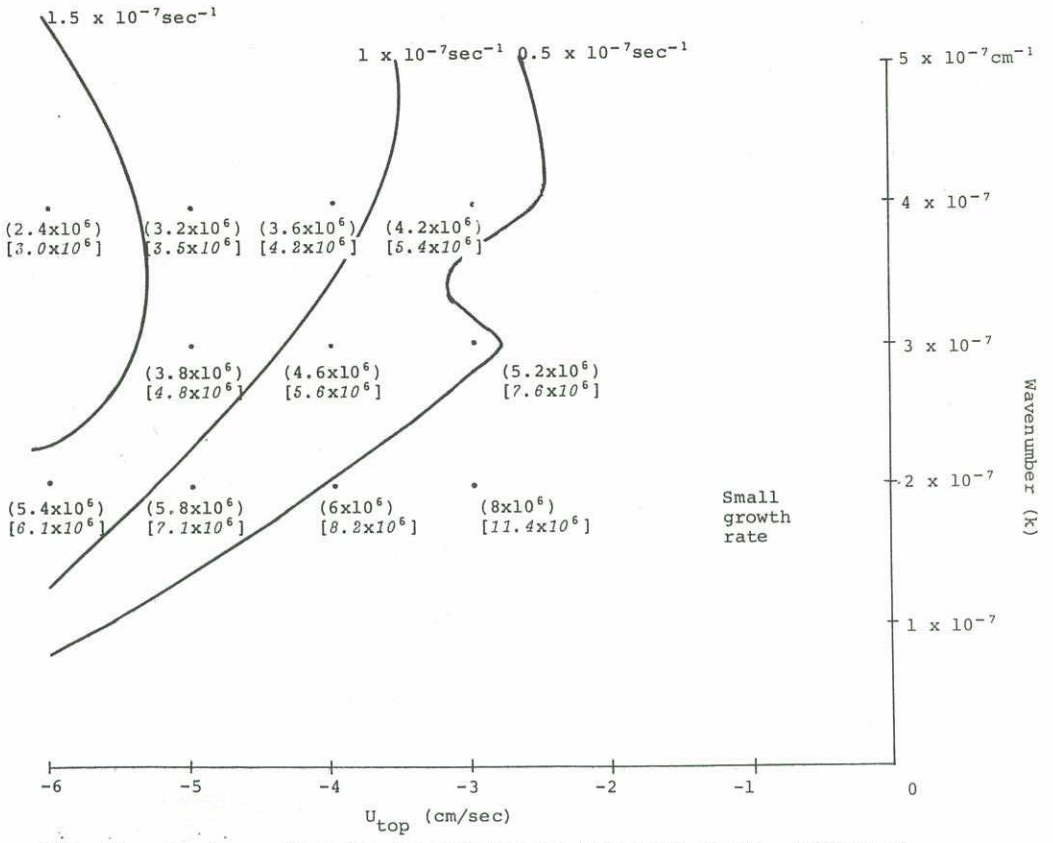
Figure 1 (Killworth and Anderson)



Temporal behavior of an initially barotropic disturbance in a region of oscillating shear. Below each profile are figures giving the percentage variance (on the left) accounted for by the barotropic and first baroclinic modes whose amplitudes are given (on the right).

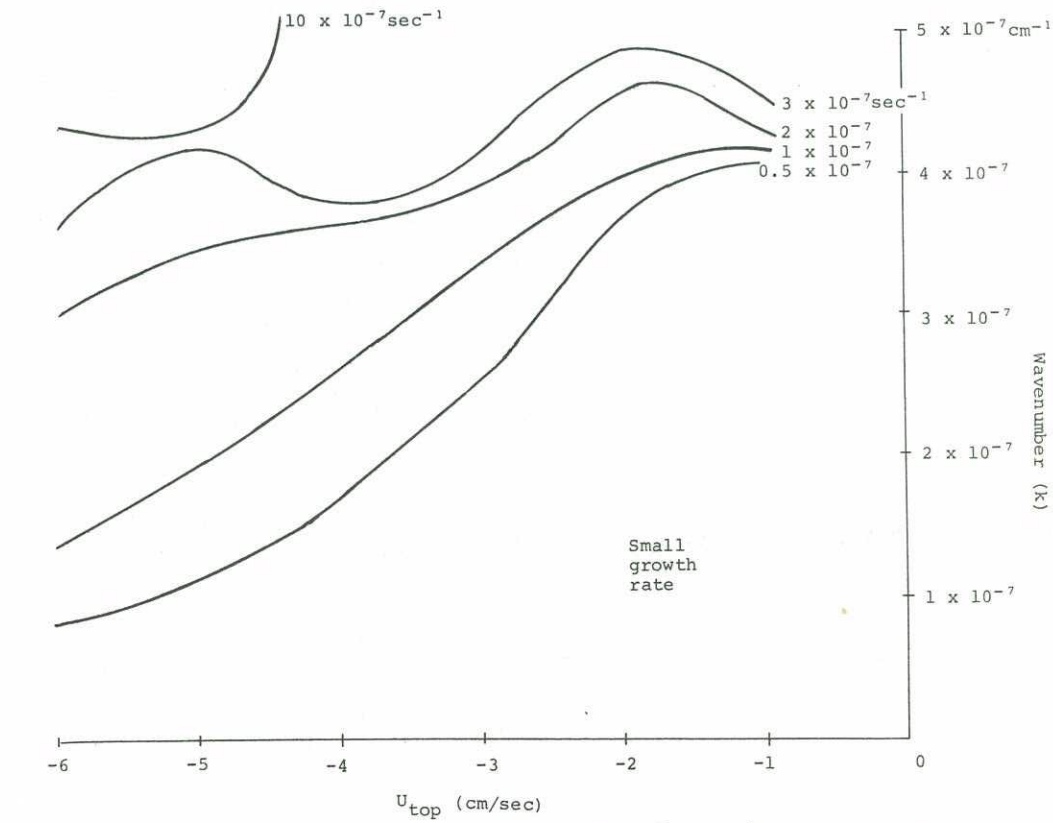
$k = 2 \times 10^{-7} cm^{-1}$. $U_{top} = -5 + 1.5 \sin(\frac{2\pi t}{1 \text{ year}})$.

Figure 2 (Killworth and Anderson)



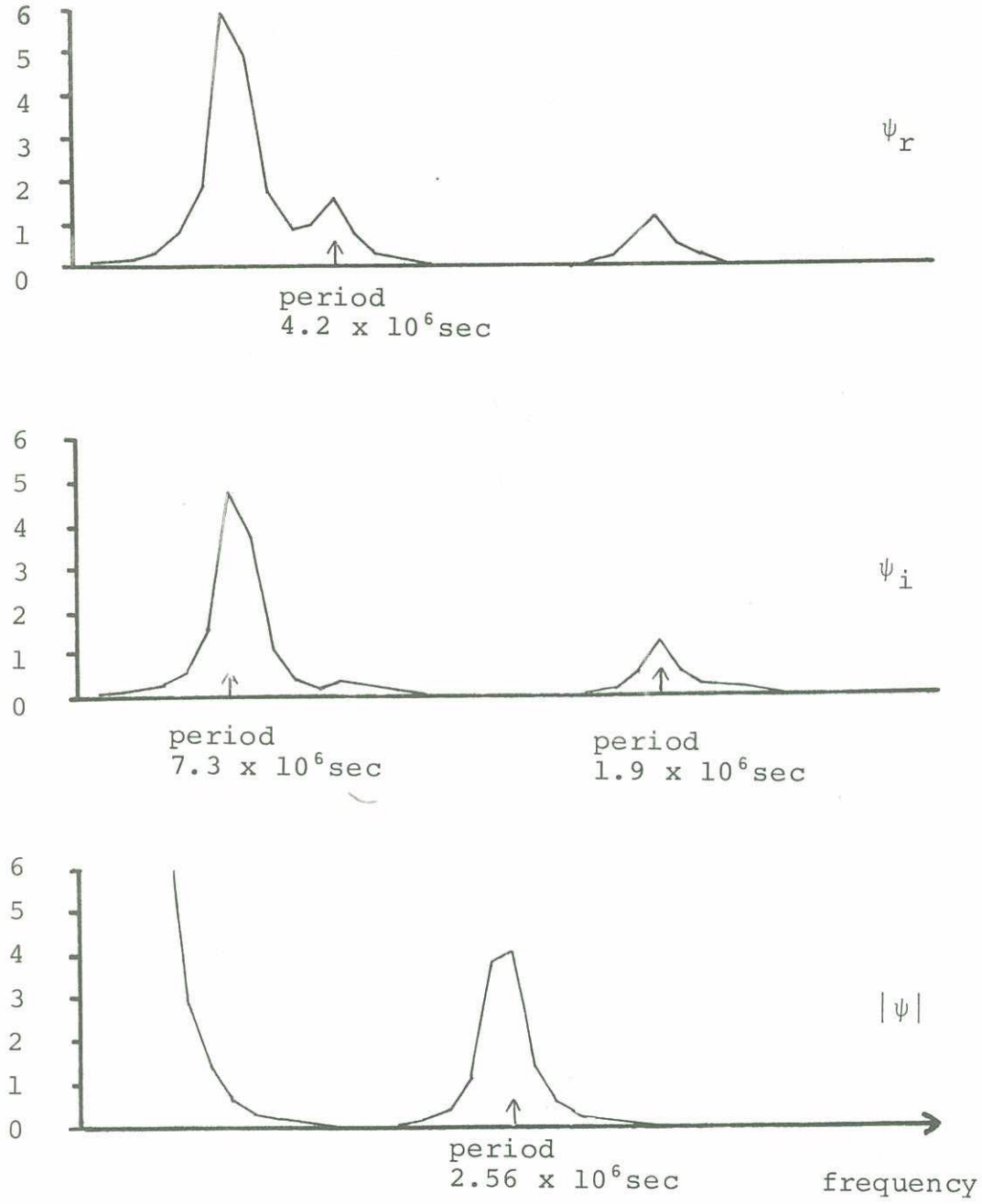
Effective shmode growth rates for oscillatory (seasonal) shear. Periods of the unstable shmodes in secs. are given for both non-oscillatory (brackets) and oscillatory (parentheses) cases. The periods in the oscillating case are not equal to the impressed period.

Figure 3a



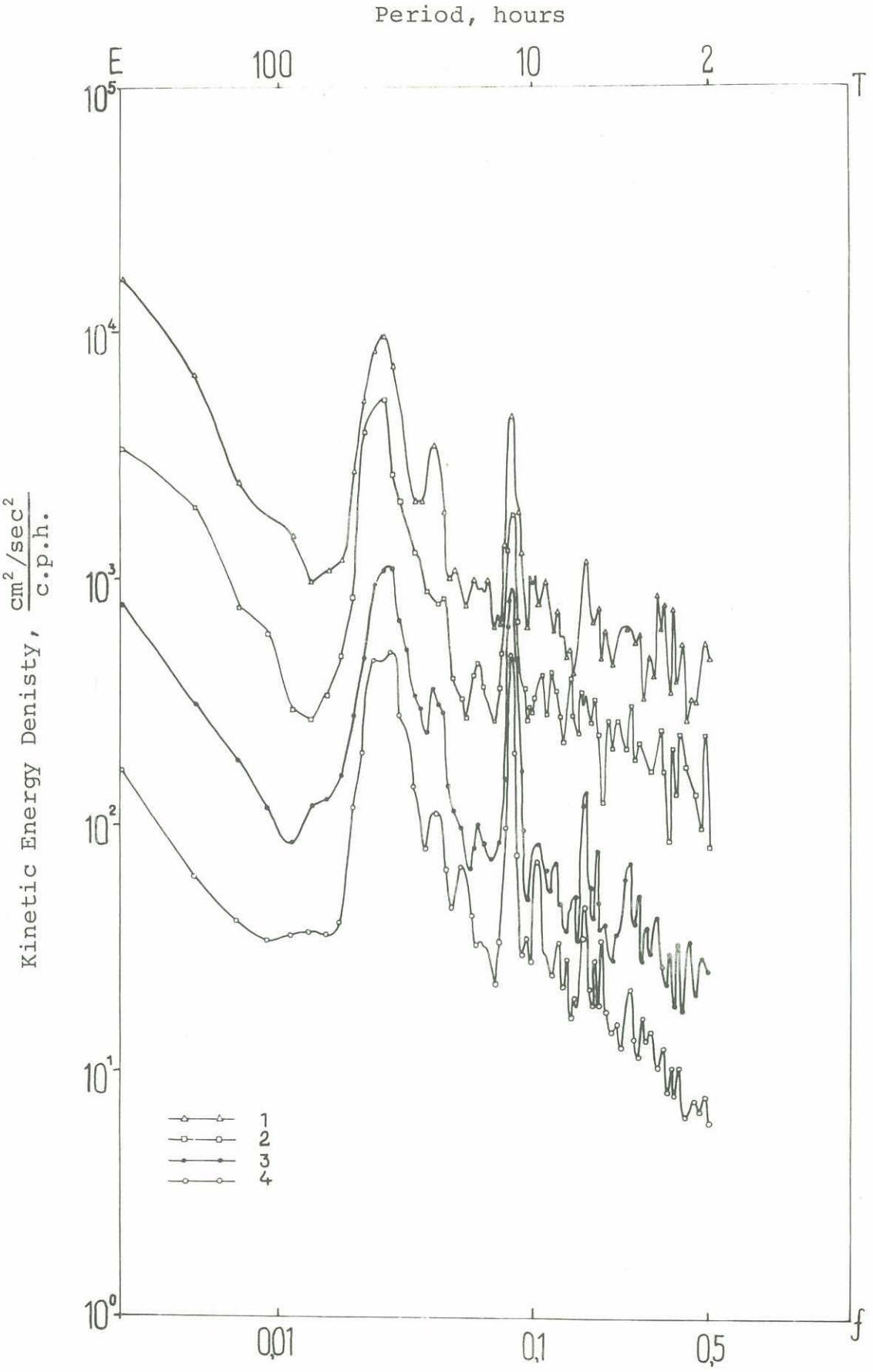
Effective shmode growth rates for $\overline{U} = \left(U_{top} + 10 \sin\left[\frac{2\pi t}{1 \text{ month}}\right]\right) e^{z/d}$ (eddy forcing).

Figure 3b
(Killworth and Anderson)



Periodograms for the stream function in the eddy-forcing case. Results for the stream function, $|\psi|$, as well as real, ψ_r, and imaginary, ψ_i, parts are given. $k = 2 \times 10^{-7} cm^{-1}$, $U_{top} = -5$ cm/sec, 1 month forcing.

Figure 4 (Killworth and Anderson)



Frequency, c.p.h.

Spectra of horizontal kinetic energy between 15 days and 2 hours (1-25 m, 2-100 m, 3-500 m, 4-1500 m).

Figure 5 (Mirabel and Vasilenko)

ATLANTIC HYDROPHYSICAL POLYGON-1970

Atlantic Hydrophysical Polygon-1970, edited by V. G. Kort and V. S. Samoĭlenko (in Russian), is being translated into English. The Table of Contents and short abstracts appear below.

Xerox copies of these articles are available in Russian from the U. S. POLYMODE Office, Room No. 54-1418, Massachusetts Institute of Technology, Cambridge MA 02139. Xerox copies of the English translation of them will be available in August, 1975.

The transliteration system used by the United Nations has been used for the Russian names.

CONTENTS

	Page
V. G. Kort, V. G. Neĭman: The 1970 Atlantic hydrophysical Polygon	3
L. V. Kool', Yu. A. Romanov, V. S. Samoĭlenko, Yu. A. Shishkov: Studies of the atmospheric circulation in the tropical latitudes of the northern Atlantic	20
V. G. Snopkov: Some meteorological and aerological characteristics of the trade-wind circulation at the Polygon site	46
L. V. Kool': The wind regime and atmospheric disturbances in the upper atmosphere over the tropical Atlantic in the summer of 1970	67
O. V. Reshetov: Air-sea interaction in the trade-wind zone of the Atlantic Ocean	76
K. V. Voĭtov, V. S. Samoĭlenko: Radiation studies in the Atlantic Polygon	83
Yu. A. Romanov, V. I. Byshev: The variability of meteorological elements in the Atlantic Polygon	95
N. A. Romanov: On the comparability of meteorological measurements from a vessel while drifting and under way	106
R. V. Abramov: A study of the diurnal variation from hourly meteorological observations at a quasi-fixed point in the tropical zone of the ocean	112
I. T. Ivatkin, L. V. Kool': The influence of extra-tropical processes on the atmospheric circulation in tropical latitudes of the Atlantic Ocean	123
L. M. Fomin: Vertical current structure from measurements at a Polygon in the tropical Atlantic	130
V. I. Byshev, K. A. Chekotillo: Features of large-scale water movements in the ocean	152
M. N. Koshlyakov, Yu. M. Grachev: Mesoscale currents at a hydrophysical Polygon in the tropical Atlantic	163
V. G. Kort, V. I. Byshev, V. M. Tarasenko: Synoptic variability of currents in the Atlantic Polygon	181
A. D. Yampol'skiĭ: On inertial oscillations in the current field	189
Yu. M. Grachev, M. N. Koshlyakov, V. G. Neĭman, V. M. Tarasenko: Mesoscale geostrophic currents at a Polygon in the tropical part of the North Atlantic	193
V. I. Byshev, Yu. A. Ivanov: Some results of an investigation into the reaction of the current field to atmospheric disturbances	198
Yu. A. Ivanov, A. G. Novitskiĭ: A theoretical model of the reaction of the ocean to atmospheric disturbances	208
V. I. Byshev, E. G. Morozov, E. A. Plakhin: On long-period temperature oscillations in the tropical Atlantic	221
Yu. A. Ivanov, E. G. Morozov: A study of temperature fluctuations at tidal and inertial periods	229
K. N. Federov, E. A. Plakhin, V. I. Prokhorov, V. G. Sedov: Features of the thermohaline stratification in the region of a Polygon in the tropical Atlantic	236
V. V. Navrotskiĭ: On the vertical structure of mesoscale temperature oscillations	283
V. I. Byshev: A program for the statistical analysis of observations carried out at the Atlantic hydrophysical Polygon	305

The 1970 Atlantic hydrophysical Polygon

V. G. Kort, V. V. Neĭman

Abstract:

Types of hydrophysical measurements at the Polygon are described. A map showing the arrangement of anchored buoy stations is presented. Information on the extent of investigations that were carried out is given.

Studies of the atmospheric circulation in the tropical latitudes of the northern Atlantic

L. V. Kool', Yu. A. Romanov, V. S. Samoĭlenko, Yu. A. Shishkov

Abstract:

Features of the atmospheric circulation of the trade-wind zone of the ocean in the spring and summer seasons of 1970 are examined using data obtained by meteorological observations during the six-month hydrophysical Polygon in the tropical latitudes of the North Atlantic, and synoptic charts. The seasonal variation of the meteorological elements is analyzed in detail, as are their short-period changes, especially of wind speed; cases of atmospheric disturbances in the tropics caused by the influence of extra-tropical cyclones are studied; conditions for the appearance of, and the paths of easterly waves, tropical depressions, and storms are examined.

Some meteorological and aerological characteristics of the trade-wind circulation at the Polygon site

V. G. Snopkov

Abstract:

Results of processing and analysis of atmospheric observations from February through September of 1970 in the tropical zone of the Atlantic Ocean at the hydrophysical Polygon are given. Characteristics obtained were the components of the heat balance at the ocean surface, the trade-wind circulation, a temperature inversion layer in the air, the moisture content of the atmosphere, and the correlation between vapor pressure at the ocean surface and the moisture content of the atmosphere.

The wind regime and atmospheric disturbances in the upper atmosphere over the tropical Atlantic in the summer of 1970

L. V. Kool'

Abstract:

This article is an addition to studies of the atmospheric circulation in the tropical latitudes of the Atlantic in the summer of 1970, since it significantly increases the spatial scales of these studies, embracing circulation processes in the upper troposphere relating the trade-wind and extra-tropical circulation.

Air-sea interaction in the trade-wind zone of the Atlantic Ocean

O. V. Reshetov

Abstract:

In this article, the results of computations of turbulent fluxes of heat, moisture, and momentum between the ocean and atmosphere are set forth and analyzed, and a series of general questions on the turbulent structure of the surface layer of air above the ocean are touched upon.

Radiation studies in the Atlantic Polygon

K. V. Voĭtov, V. S. Samoĭlenko

Abstract:

In this article the results of determinations of radiation elements of the heat balance of the ocean surface for seven months of work by research vessels in the Polygon are set forth and analyzed. In the article also are given characteristics of the integral transparency of the oceanic air mass, with a division into the transparency of water vapor and aerosol transparency of the atmosphere.

The variability of meteorological elements in the Atlantic Polygon

Yu. A. Romanov, V. I. Byshev

Abstract:

From data obtained by meteorological observations on the vessels Academic Kurchatov and Dmitri Mendeleev, periodically working on the hydrophysical Polygon in the Atlantic Ocean, continuous series of observations for six meteorological elements for the period from 22 February to 14 November, 1970, have been put together. With the help of spectral analysis of these series, spectral energy maxima at periods of synoptic, diurnal, and semidiurnal oscillations have been successfully revealed. For these periods, coherences and phases between various meteorological elements have been analyzed. It is found that the relations of various meteorological elements for oscillations with synoptic (3-4 days) and semidiurnal periods in the region of the Atlantic Polygon agree well with known theoretical arguments, and also with data of empirical studies for the near-equatorial regions of the ocean.

On the comparability of meteorological measurements from a vessel while drifting and under way

N. A. Romanov

Abstract:

A comparison of standard meteorological measurements, carried out from a vessel while drifting and under way, has been conducted. It is established that measurements of air and water temperature, absolute humidity and observations on cloudiness under varying work regimes of the vessel are equivalent within the error of the measurements. An estimate of wind speed measurements, with confidence near 1, showed that the discrepancy has a systematic character.

A study of diurnal variation from hourly meteorological observations at a quasi-fixed point in the tropical zone of the ocean

R. V. Abramov

Abstract:

The results of dispersion and spectral analysis of series of hourly measurements of atmospheric pressure, wind speed, cloud amount, water temperature, and air temperature and humidity, produced in the course of four months on a research ship in the tropical latitudes of the Atlantic Ocean are presented.

The influence of extra-tropical processes on the atmospheric circulation in tropical latitudes of the Atlantic Ocean

I. T. Ivatkin, L. V. Kool'

Abstract:

Analyzed and classified in this article are various synoptic processes of extra-tropical latitudes which can to a greater or lesser degree act as an influence on the trade-wind circulation in the tropical latitudes of the oceans.

Vertical current structure from measurements at a Polygon in the tropical Atlantic

L. M. Fomin

Abstract:

The vertical distribution of velocity under various forms of time-averaging is analyzed. A velocity component, disturbing the quasi-geostrophic velocity field, is isolated. This component changes direction with depth, and the regularity of the rotation of the vector with depth reveals a connection with the structure of the pycnocline. A theoretical model of the interaction of the mean current with inertial velocity oscillations in the ocean is proposed to explain this phenomenon.

Features of large-scale water movements in the ocean

V. I. Byshev, K. A. Chekotillo

Abstract:

The results of an analysis of large-scale variability of ocean water circulation are discussed, using Polygon data. Time scales (40-70 days) of characteristic disturbances of the current field are estimated. A qualitative and quantitative description of them is given. The question of the determination of stationary characteristics of the large-scale variability and of the average motion is considered.

Mesoscale currents at a hydrophysical Polygon in the tropical Atlantic

M. N. Koshlyakov, Yu. M. Grachev

Abstract:

The structure and dynamics of mesoscale currents, obtained after filtering out tidal and inertial oscillations in current data from moorings, is investigated, using Polygon data. In particular, an anti-cyclonic velocity disturbance with a baroclinic character, characterized by horizontal scales on the order of 100 km and a maximum rotational velocity of the water on the order of 25 cm/sec, distributed in depth to 1500 m and moving through the Polygon region to the west-southwest with an average speed of 5 cm/sec, has been detected. A kinematic model of this disturbance has been constructed. The results of a calculation of the mean velocities at various horizontal levels over the period of observations indicates that the movement of the disturbance is of a non-advective character. Comparison of the observed parameters of the disturbance with the results of a linear model of free planetary waves in a two-layer ocean allows the assumption that the dynamics of the disturbance were close to the dynamics of a baroclinic Rossby wave.

Synoptic variability of currents in the Atlantic Polygon

V. G. Kort, V. I. Byshev, V. M. Tarasenko

Abstract:

The variability of the current field in the range of time scales from 1-20 days is studied. An active cyclonic activity in the upper 300 m layer, which is related to cyclonic activity in the atmosphere, is revealed. The question of the nature of the observed disturbances is discussed, and some of their characteristics are estimated (speed and direction of propagation, spatial scales).

On inertial oscillations in the current fields

A. D. Yampol'skiĭ

Abstract:

In this article, features of inertial oscillations in the velocity field are examined using Polygon observations. Discussed are the intermittancy of these oscillations and the possibility of using a statistical approach to the study of inertial motions.

Mesoscale geostrophic currents at a Polygon in the tropical part of the North Atlantic

Yu. M. Grachev, M. N, Koshlyakov, V. G. Neĭman
V. M. Tarasenko

Abstract:

Dynamic charts, constructed from data obtained in two hydrologic surveys carried out at the concluding stage of work in Polygon, have been constructed. In the region of dynamic heights a smoothing of the density distribution on separate horizontal surfaces has been done. The geostrophic current vector, computed from the data of one of the surveys, agrees well in direction with current vectors, obtained by filtering out tidal and inertial oscillations from current meter data at moorings.

Some results of an investigation into the reaction of the current field to atmospheric disturbances

V. I. Byshev, Yu. A. Ivanov

Abstract:

A mutual statistical analysis between measurements of wind speed, atmospheric pressure and currents on different horizontal surfaces has been carried out. A significant connection is found for synoptic scales. The coherence is increased when integrated (in the vertical or horizontal) characteristics of the current are used.

A theoretical model of the reaction of the ocean to atmospheric disturbances

Yu. A. Ivanov, A. G. Novitskiĭ

Abstract:

A three-dimensional model of a continuously stratified ocean is considered. The reaction of the ocean to an atmospheric disturbance, bounded in time and space, is studied. It is shown that the ocean reacts barotropically to an atmospheric disturbance of synoptic scale. Greater time scales for the disturbance lead to the generation of baroclinic Rossby waves.

On long-period temperature oscillations in the tropical Atlantic

V. I. Byshev, E. G. Morozov, E. A. Plakhin

Abstract:

Long-duration realizations of temperature on several horizontal surfaces and simultaneous series of certain meteorological elements are examined. The statistical analysis that was carried out showed the dominant role in the temperature oscillations of processes with synoptic scales.

A study of temperature fluctuations at tidal and inertial periods

Yu. A. Ivanov, E. G. Morozov

Abstract:

Results are given for the mutual statistical analysis of temperature oscillations at various points in the Polygon. Phase diagrams have been constructed, from which the directions and lengths of internal tidal waves have been determined. It is shown that the wave parameters do not change in time.

Features of the thermohaline stratification in the region of a Polygon in the Tropical Atlantic

K. N. Federov, E. A. Plakhin, V. I. Prokhorov,
V. G. Sedov

Abstract:

The results of extensive measurements of a thin thermohaline structure of a layer 0-600 m in the region of the hydrophysical Polygon using the fast-response "AIST" probe are described in detail. Conditions for the formation of various types of structural features: temperature inversions, homogeneous layers and step structures, are analyzed. Significant gradients of temperature and salinity are detected, having the form of sharply localized frontal boundaries. The evolution of the upper, quasi-homogeneous layer and the time-variability of the temperature and salinity fields at a fixed point are studied.

On the vertical structure of mesoscale temperature oscillations

V. V. Navrotskiĭ

Abstract:

Temperature measurements, carried out in the Polygon region with the help of a towed chain of sensors, are described. The results of a statistical analysis of the spatial fluctuations of temperature are given.

A program for the statistical analysis of observations carried out at the Atlantic hydrophysical Polygon

V. I. Byshev

A complex of programs, designed for the processing of vector or scalar information of arbitrary duration is described. The desire to vary the calculation parameters in a wide range, on the one hand, and to maintain a flexible and versatile processing system, on the other hand, led to the necessity for creating a library of statistical computations. For the control of the calculation process it is proposed to use a control program and a logic scale.