International conference
Theoretical and applied aspects of geophysical fluid dynamics
2025

Dedicated to Dr. GREGORY REZNIK
on the occasion of his 80th birthday
and 55th anniversary of scientific activity

ABSTRACTS

Shirshov Institute of Oceanology of Russian Academy of Sciences

International Conference

"THEORETICAL AND APPLIED ASPECTS OF GEOPHYSICAL FLUID DYNAMICS"

Dedicated to Dr. Gregory Reznik on the occasion of his 80th birthday and 55th anniversary of scientific activity

"REZNIK CONFERENCE"

Shirshov Institution of Oceanology of The Russian Academy of Sciences
Moscow, March 24–25, 2025

36, Nakhimovsky prosp., ground floor, small conference hall

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Conference language is English
The schedule is based on Moscow time (UTC +3)
Link to join: https://meet.ocean.ru/b/hvq-rw5-t9t-y4u

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Moscow 2025

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CONFERENCE PROGRAM

The conference will be held in hybrid mode: in person (P) and distance (D) presentations

MARCH 24, MORNING SESSION. Convener Sergey Gulev	
10:00 (P)	***Kravtsov, S. V.*** (Univ. of Wisconsin, Milwaukee, USA), ***Kizner, Z.*** (Depts. of Physics and Mathematics, Bar-Ilan University, Ramat-Gan, Israel), and ***Berloff, P. S.*** (Dept. of Mathematics, Imperial College London, UK). **Introduction. A jubilee view on G. M. Reznik's seminal contribution to GFD**
10:20 (P)	***Kuznetsov, E. A.*** (Lebedev Physical Institute; Landau Institute; Space Research Institute; and Skoltech; Moscow, Russia) and ***Mikhailov, E. A.*** (Lebedev Physical Institute; Physical Dept. MSU, Moscow, Russia). **Nonlinear dynamics of slipping flows**
10:40 (D)	***Prants, S. V.*** (Pacific Oceanological Institute, Vladivostok, Russia). **Lagrangian analysis of eddies in the ocean**
11:00 (D)	***Ermanyuk, E. V.*** (Lavrentyev Institute of Hydrodynamics, Novosibirsk, Russia). **Attrac-tors of internal and inertial waves: wave turbulence in closed domains**
11:20 (D)	***Ingel, L. Kh.*** (Research and Production Association “Typhoon”, Obninsk, Russia). **Some new problems in the theory of slope flows**
11:40 (P)	***Slunyaev, A. V.*** (Institute of Applied Physics, Nizhny Novgorod, Russia). **Simulations and measurements of rogue waves in the sea**
12:00–12:20 (tea/coffee break)	
12:20 (P)	***Osadchiev, A. A.*** (Shirshov Institute of Oceanology, Moscow, Russia). **Intense zonal freshwater transport in the Eurasian Arctic during ice covered season revealed by in situ measurements**
12:40 (P)	***Zavialov, P. O.*** (Shirshov Institute of Oceanology, Moscow, Russia). **Some aspects of river plume dynamics**
13:00 (P)	***Chashechkin, Y. D.*** and **Ochirov, A. A.** (Ishlinsky Institute for Problems in Mechanics, Moscow, Russia). **Classification of components of periodic flows in heterogeneous fluids**
13:20 (P)	***Ochirov, A. A.*** and ***Lapshina, K. Y.*** (Ishlinsky Institute for Problems in Mechnics, Moscow, Russia). **Geometry and energy of surface waves**
13:40 (P)	***Zatsepin, A. G., Gerasimov, V. V., Elkin, D. N*** (Shirshov Institute of Oceanology, Moscow, Russia). **Examples of coherent structure formation in a stratified and rotating fluid due to nonlinear effects (laboratory experiment)**
14:00–15:00 (Lunch)	
MARCH 24, AFTERNOON SESSION. Convener Mikhail Sokolovskiy	
15:00 (D)	***Koshel, K. V.*** (Pacific Oceanological Institute, Vladivostok, Russia). **Anomalous structures on the sea surface as an object of statistical topography. Numerical modeling**
15:20 (P)	***Berloff, P. S.*** (Dept. of Mathematics, Imperial College London, London, UK). **Clustering of floating tracers in the ocean**
15:40 (P)	***Stepanov, D. V.*** and ***Koshel, K. V.*** (Pacific Oceanological Institute, Vladivostok, Russia). **Clustering floating parcels driven by meso- and submesoscale dynamics on the Subpolar Front of the Japan Sea**
16:00–16:20 (tea/coffee break)	
16:20 (D)	***Dritschel, D. G.*** (Mathematical Institute, University of St Andrews, St Andrews, UK). **The onset of filamentation on vorticity interfaces**
16:40 (D)	***Sutyrin, G. G.*** (Graduate School of Oceanography, University of Rhode Island, Rhode Island, USA). **The importance of being asymmetric for geophysical vortices**
17:00 (P)	***Kurgansky, M. V.*** (Obukhov Institute of Atmospheric Physics, Moscow, Russia). **Theoretical model of a thin vertical conical baroclinic vortex**
17:20 (D)	***Benilov, E.*** (Dept. of Mathematics and Statistics, University of Limerick, Limerick, Ireland). **Unravelling the mystery of the stability of oceanic vortices**
17:40 (D)	***Kizner, Z.*** (Depts. of Physics and Mathematics, Bar-Ilan University, Ramat-Gan, Israel). **Cycloidal meandering of a mesoscale anticyclonic eddy**
18:00 (D)	***Bunimovich, L.*** (Southeast Applied Analysis Center, School of Mathematics, Georgia Institute of Technology, Atlanta, USA). **Finite time and the predictions for strongly chaotic systems**
MARCH 25, MORNING SESSION. Convener Vladimir Zhmur	
10:00 (D)	***Pelinovsky, E. N., Gurbatov, S. N.*** (Institute of Applied Physics, Nizhny Novgorod, Russia). **Distribution functions of the initiated KdV-like solitonic gas**
10:20 (D)	***Talipova, T. G.*** (Institute of Applied Physics, Russin Academy of Sciences Nizhny Novgorod, Russia). **Transformation of a soliton on a ledge**

10:40 (D)	***Chefranov, S. G.***, ***Chefranov A. S.*** (Obukhov Institute of Atmospheric Physics, Russian Academy of Science, Moscow, Russia). **Exact unsteady vortex solutions to the compressible Helmholtz equations**
11:00 (P)	***Vulfson, A. N.*** (Water Problems Institute; National Research University "Higher School of Economics", Moscow, Russia). **On the possibility of approximating vertical profiles of turbulent moments of a convective boundary layer based on the theory of local similarity**
11:20–11:40 (tea/coffee break)	
11:40 (P)	***Kurakin, L. G.*** (Water Problems Institute, Moscow; Institute for Mathematics, Mechanics and Computer Sciences, Southern Federal University, Rostov-on-Don, Russia), ***Lysenko, I. A., Ostrovskaya, I. V.*** (Institute for Mathematics, Mechanics and Computer Sciences, Southern Federal University, Rostov-on-Don, Russia) and ***Sokolovskiy, M. A.*** (Water Problems Institute, Shirshov Institute of Oceanology, Moscow, Russia). **On stability of the regular vortex polygon in the quasigeostrophic model of the point vortices in two-layer fluid**
12:00 (P)	***Kurakin, L. G.*** (Water Problems Institute, Moscow; Institute for Mathematics, Mechanics and Computer Sciences, Southern Federal University, Rostov-on-Don, Russia), ***Ostrovskaya, I. V.*** (Institute for Mathematics, Mechanics and Computer Sciences, Southern Federal University, Rostov-on-Don, Russia) and ***Sokolovskiy, M. A.*** (Water Problems Institute, Shirshov Institute of Oceanology, Moscow, Russia). **The stability of the configuration of N + 1 point vortices in two-layer fluid**
12:20 (D)	***Shrira, V. I.*** (School of Computing and Mathematics, Keele University, UK), ***Badulin, S. I.*** (Shirshov Institute of Oceanology, Moscow, Russia) and ***Almelah, R. B.*** (Dept. of Mathematics, Faculty of Science, Misurata University, Libya). **How does wave field evolution drive ocean currents?**
12:40–13:40 (Lunch)	
MARCH 25, AFTERNOON SESSION. Convener Mikhail Sokolovskiy	
13:40 (P)	***Diansky, N. A.*** (Faculty of Physics, Lomonosov Moscow State University, Moscow, Russia) and ***Gusev, A. V.*** (Marchuk Institute of Numerical Mathematics, Moscow, Russia). **Investigation of the Gulf Stream self-arrangement with using numerical and analytical techniques**
14:00 (P)	***Korotaev, G. K.*** (Marine Hydrophysical Institute, Sevastopol, Russia). **Long-term changes in the stratification of the Black Sea**
14:20 (P)	***Morozov, E. G.***, ***Pisarev, S. V., Frey, D. I.*** and ***Osadchiev, A. A.*** (Shirshov Institute of Oceanology, Moscow, Russia). **The Great Siberian polynya and mechanisms of its formation**
14:40 (D)	***Stepanyants, Yu. A.*** (School of Sciences, University of Southern Queensland, Toowoomba, Australia). **Radiation phenomena in geophysics**
15:00–15:20 (tea/coffee break)	
15:20 (P)	***Arakelyan, E. M.*** (Moscow Institute of Physics and Technology (National Research University, Dolgoprudny, Russia), ***Zhmur, V. V.*** (Shirshov Institute of Oceanology, Moscow, Russia; Moscow Institute of Physics and Technology, Dolgoprudny, Russia), and ***Chkhetiani, O. G.*** (Obukhov Institute of Atmospheric Physics, Moscow, Russia). **Composite structure of Jupiter's Great Red Spot**
15:40 (P)	***Gulev, S. K., Zyulyaeva, Yu. A.*** (Shirshov Institute of Oceanology, Moscow, Russia), and ***Sokolovskiy, M. A.*** (Water Problems Institute; Shirshov Institute of Oceanology, Moscow, Russia). **A three-layer model of polar stratospheric vortex**
16:00 (P)	***Riccardi, G.*** (Dept. of Mathematics and Physics, University of Campania "Luigi Vanvitelli", Rome, Italy). **On the time evolution of the Schwarz function of the boundary of a uniform planar vortex moving in an inviscid fluid**
16:20 (D)	***Kamenkovich, I.***, ***Lu, Y.*** (Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, USA), and ***Berloff, P.*** (Dept. of Mathematics, Imperial College London, London, UK). **Beyond the Flux-Gradient Relation in Parameterizing Lateral Eddy-Induced Transport**
16:40 (D)	***Flierl, G. R.*** and ***Morrison, P.*** (Dept. of Earth, Atmospheric, and Planetary Sciences MIT, Cambridge, USA). **Synthetic annealing and vortex structures**
17:00–17:20 (tea/coffee break)	
17:20 (D)	***Kravtsov, S. V.*** (University of Wisconsin, Milwaukee, School of Freshwater Sciences, Atmospheric Sciences group, Milwaukee, USA), ***Rudeva, I. A.*** (Bureau of Meteorology, Melbourne, Victoria, Australia), ***Gulev, S. K.*** (Shirshov Institute of Oceanology, Moscow, Russia). **Reconstructing spatiotemporal characteristics of sea-level pressure variability in reanalysis data set using a feature-tracking approach**
17:40 (D)	***Reinaud, J. N.*** (Mathematical Institute, University of St Andrews, St Andrews, UK). **Vortex interactions over bathymetry**
18:00 (D)	***McWilliams, J. C.*** (Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, USA). **Coherence in the ocean**
18:20 (P)	***Zavialov, P. O.*** (Shirshov Institute of Oceanology, Moscow, Russia). **Concluding remarks**
18:40 (D)	***Reznik, G. M.*** (Shirshov Institute of Oceanology, Moscow, Russia). **Close**
18:45–20:45 (Buffet reception)	

CONTENTS

УДК 551.50:551.

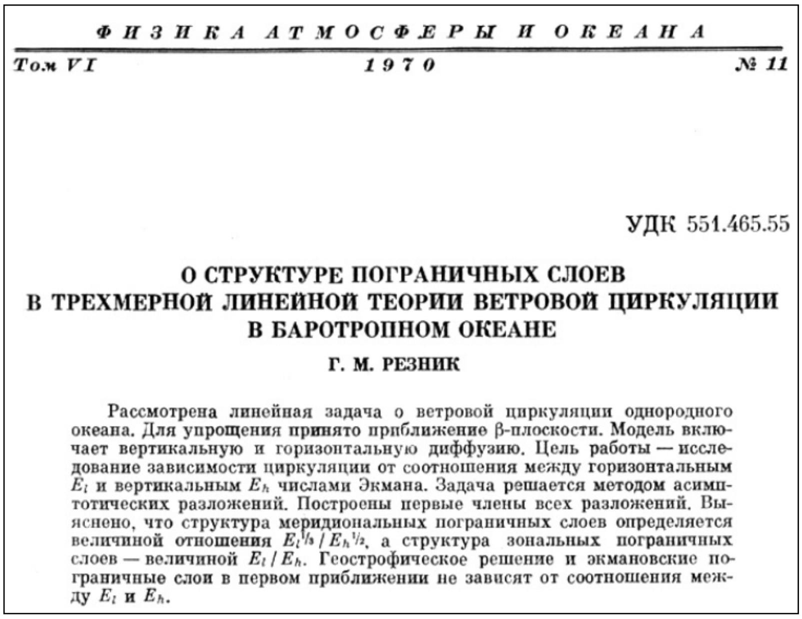
1.

INTRODUCTION. A JUBILEE VIEW ON G. M. REZNIK'S SEMINAL CONTRIBUTION TO GEOPHYSICAL FLUID DYNAMICS

Kravtsov, S. V. *(University of Wisconsin, Milwaukee, School of Freshwater Sciences, Atmospheric Sciences group, Milwaukee, USA),* **Kizner, Z.** *(Depts. of Physics and Mathematics, Bar-Ilan University, Ramat-Gan, Israel),* **Berloff, P. S.** *(Dept. of Mathematics, Imperial College London, UK)*

G. M. Reznik started his career in the late 60s as a graduate student of V. M. Kamenkovich. He made important contributions to the field of Geophysical Fluid Dynamics documented in well over 120 peer-reviewed articles and book chapters in high-ranked fluid-dynamical journals and monographs. We gather today to celebrate his illustrious career in science, honor his achievements, and wish G. M. Reznik many new and exciting discoveries in his continued research efforts.

55-year+ scientific career!



ФИЗИКА АТМОСФЕРЫ И ОКЕАНА

Том VI 1970 № 11

УДК 551.465.55

О СТРУКТУРЕ ПОГРАНИЧНЫХ СЛОЕВ В ТРЕХМЕРНОЙ ЛИНЕЙНОЙ ТЕОРИИ ВЕТРОВОЙ ЦИРКУЛЯЦИИ В БАРОТРОПНОМ ОКЕАНЕ

Г. М. РЕЗНИК

Рассмотрена линейная задача о ветровой циркуляции однородного океана. Для упрощения принято приближение β-плоскости. Модель включает вертикальную и горизонтальную диффузию. Цель работы — исследование зависимости циркуляции от соотношения между горизонтальным E_l и вертикальным E_h числами Экмана. Задача решается методом асимптотических разложений. Построены первые члены всех разложений. Выяснено, что структура меридиональных пограничных слоев определяется величиной отношения $E_l^{1/3} / E_h^{1/2}$, а структура зональных пограничных слоев — величиной E_l / E_h. Геострофическое решение и экмановские пограничные слои в первом приближении не зависят от соотношения между E_l и E_h.

Reznik, G. M., 1970: On the problem of three-dimensional circulation in a homogeneous ocean

Early achievements

- First joint works with V. M. Kamenkovich (1972a, b) on the separation of western boundary current, focusing on the importance of stratification and non- stationarity.
- Seminal contributions to the theory of oceanic general circulation as we know it now.
- A large body of work on Rossby waves using, in particular, the kinetic equation approach (Reznik and Soomere, 1983, 1984; Kozlov et al., 1987; Tobisch, Piterbarg, Reznik, 1990; Tobisch, Reznik, 1992; Reznik et al., 1993).

Доклады Академии наук СССР
1976. Том 231, № 5

УДК 551.466:532.59 **ГЕОФИЗИКА**

В. Д. ЛАРИЧЕВ, Г. М. РЕЗНИК

О ДВУМЕРНЫХ УЕДИНЕННЫХ ВОЛНАХ РОССБИ

(Представлено академиком Л. М. Бреховских 3 VIII 1976)

Цель настоящей заметки — показать, что совместное действие β-эффекта и нелинейности может приводить к существенной пространственной локализации возмущений или, иными словами, к образованию двумерных уединенных волн Россби.

На β-плоскости рассмотрим двумерные движения в слое однородной жидкости, заключенной между двумя горизонтальными плоскостями:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-fv=-\frac{1}{\rho}\frac{\partial p}{\partial x}, \quad (1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+fu=-\frac{1}{\rho}\frac{\partial p}{\partial y}, \quad (2)$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0; \quad (3)$$

Larichev, V. D., G. M. Reznik, 1976a: On two-dimensional solitary Rossby waves

Поскольку (см. ([1]))

$$\frac{J_1'(ka)}{J_1(ka)}=\frac{1}{ka}+2ka\sum(k^2a^2-\gamma_{1,n}^2)^{-1},$$

где $\gamma_{1,n}$ — возрастающая последовательность нулей функции $r^{-1}J_1(r)$, нетрудно видеть, что при любых фиксированных $a>0$, $p>0$ уравнение (10) имеет счетное множество положительных корней k, и, таким образом, условия (9) удовлетворяются.

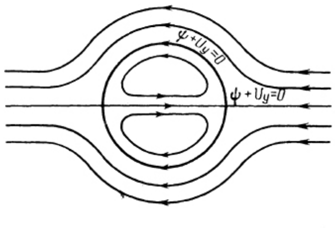


Рис. 1

Нетрудно теперь вычислить скорости u и v, а затем и давление p с помощью (1), (2). Так как функция тока ψ дважды непрерывно дифференцируема на всей плоскости x', y, то поля u, v, p непрерывно дифференцируемы, как этого и требуют уравнения (1)–(3), а поле вихря $\partial v/\partial x-\partial u/\partial y$ — непрерывно. В то же время поле скорости не является дважды непрерывно дифференцируемым, так как $\partial^3\psi/\partial r^3$ терпит разрыв при $r=a$. В силу конечности этого разрыва уравнение (4) удовлетворяется на всей плоскости. На рис. 1 схематически изображены линии тока, соответствующие наименьшему значению ka при фиксированных a и p.

Larichev and Reznik (1976)

- A breakthrough work [470 citations!] on what the authors called solitary Rossby waves, solitary eddies, or Rossby solitons, now best known as modons.
- Follow-up: Flierl, Larichev, McWilliams, Reznik (1980) [359 citations], McWilliams, Flierl, Larichev, Reznik (1981) [168 citations], topographic modons (Reznik & Sutyrin, 2001; Kizner, Berson, Reznik, Sutyrin, 2003), shallow-water modons (Kizner, Reznik et al., 2008), many others.
- Fundamental theory of singular vortices on the beta-plane which explains, among other things, self-induced drift of oceanic and atmospheric eddies via Rossby-wave radiation and near-field beta-gyres.

J. Fluid Mech. (1992), *vol.* 240, *pp.* 405–432 405
Printed in Great Britain

Dynamics of singular vortices on a beta-plane

By G. M. REZNIK
P. P. Shirshov Institute of Oceanology of the Academy of Sciences of Russia, Krasikova, 23, 117218, Moscow, Russia

(Received 28 February 1991 and in revised form 12 December 1991)

A new singular-vortex theory is presented for geostrophic, beta-plane dynamics. The stream function of each vortex is proportional to the modified Bessel function $K_0(pr)$, where p can be an arbitrary positive constant. If p^{-1} is equal to the Rossby deformation scale R_d, then the vortex is a point vortex; for $p^{-1} \neq R_d$ the relative vorticity of the vortex contains an additional logarithmic singularity. Owing to the β-effect, the redistribution of the background potential vorticity produced by the vortices generates a regular field in addition to the velocity field induced by the vortices themselves. Equations governing the joint evolution of singular vortices and the regular field are derived. A new invariant of the motion is found for this system. If the vortex amplitudes and coordinates are set in a particular way then the regular field is zero, and the vortices form a system moving along latitude circles at a constant speed lying outside the range of the phase velocity of linear Rossby waves. Each of the systems is a discrete two-dimensional Rossby soliton and, vice versa, any distributed Rossby soliton is a superposition of the singular vortices concentrated in the interior region of the soliton. An individual singular vortex is studied for times when Rossby wave radiation can be neglected. Such a vortex produces a complicated spiral-form regular flow which consists of two dipoles with mutually perpendicular axes. The dipoles push the vortex westward and along the meridian (cyclones move

Reznik (1992) – 94 citations

- An alternative to the classical point vortices, whose concept – as first shown here – is generally inapplicable in the environments with a gradient in the background potential vorticity, e.g., on the beta-plane.
- Later extensions to baroclinic environments with background flow (with Grimshaw and later with Z. Kizner), most recently augmented by numerical solutions (with S. Kravtsov).
- The theory represents a barebones conceptual model for the dynamics of localized vortices.
- Nonlinear theory of geostrophic adjustment two-part paper initiated a large suite of important works (2001–2018) on nonlinear wave interactions, in collaboration with V. Zeitlin and others.

J. Fluid Mech. (2001), *vol.* 445, *pp.* 93–120. © 2001 Cambridge University Press 93
DOI: 10.1017/S002211200100550X Printed in the United Kingdom

Nonlinear theory of geostrophic adjustment. Part 1. Rotating shallow-water model

By G. M. REZNIK[1], V. ZEITLIN[2]† and M. BEN JELLOUL[2]
[1]P. P. Shirshov Institute of Oceanology, Moscow, Russia
[2]LMD, Ecole Normale Supérieure, 24, rue Lhomond, 75005 Paris Cedex 05, France

(Received 3 April 2000 and in revised form 26 April 2001)

We develop a theory of nonlinear geostrophic adjustment of arbitrary localized (i.e. finite-energy) disturbances in the framework of the non-dissipative rotating shallow-water dynamics. The only assumptions made are the well-defined scale of disturbance and the smallness of the Rossby number Ro. By systematically using the multi-time-scale perturbation expansions in Rossby number it is shown that the resulting field is split in a unique way into slow and fast components evolving with characteristic time scales f_0^{-1} and $(f_0 Ro)^{-1}$ respectively, where f_0 is the Coriolis parameter. The slow component is not influenced by the fast one and remains close to the geostrophic balance. The algorithm of its initialization readily follows by construction.

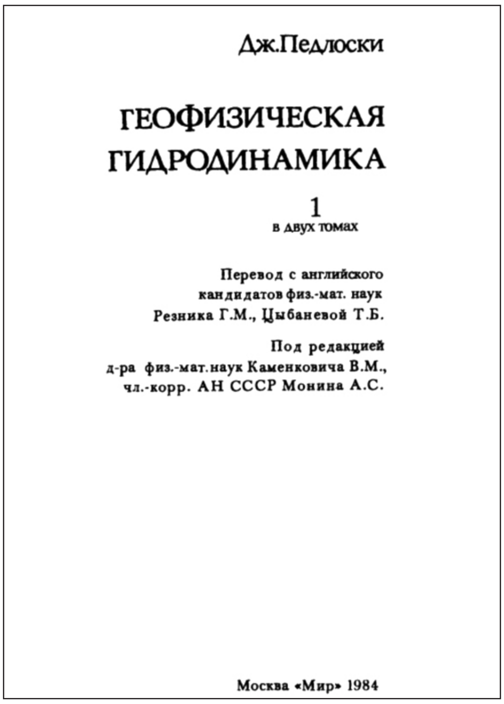
The scenario of adjustment depends on the characteristic scale and/or initial relative elevation of the free surface $\Delta H/H_0$, where ΔH and H_0 are typical values of the initial elevation and the mean depth, respectively. For small relative elevations ($\Delta H/H_0 = O(Ro)$) the evolution of the slow motion is governed by the well-known quasi-geostrophic potential vorticity equation for times $t \leqslant (f_0 Ro)^{-1}$. We find modifications to this equation for longer times $t \leqslant (f_0 Ro^2)^{-1}$. The fast component consists mainly of linear inertia–gravity waves rapidly propagating outward from the initial disturbance.

For large relative elevations ($\Delta H/H_0 \gg Ro$) the slow field is governed by the frontal geostrophic dynamics equation. The fast component in this case is a spatially localized packet of inertial oscillations coupled to the slow component of the flow.

Reznik, Zeitlin, Ben Jelloul (2001, 2003) [156 citations]

Teaching and mentoring

A superb translation (in collaboration with T. Tsybaneva) of Pedlosky's classical Geophysical Fluid Dynamics textbook into Russian is an example of GM's carefully measured, succinct teaching (and research) style, where physical clarity meets mathematical rigor, as noted by many of his students and colleagues.


Дж.Педлоски

ГЕОФИЗИЧЕСКАЯ
ГИДРОДИНАМИКА

1
в двух томах

Перевод с английского
кандидатов физ.-мат. наук
Резника Г.М., Цыбаневой Т.Б.

Под редакцией
д-ра физ.-мат.наук Каменковича В.М.,
чл.-корр. АН СССР Монина А.С.

Москва «Мир» 1984

In the 1990s, some of us (SVK & PSB) were fortunate to attend GM's GFD course for MIPT's Physical Oceanography students and witness these qualities firsthand.

Keywords: Reznik G. M., Geophysical Fluid Dynamics

2.

COMPOSITE STRUCTURE OF JUPITER'S GREAT RED SPOT

Arakelyan, E. M. (Moscow Institute of Physics and Technology *(National Research University), Dolgoprudny, Russia)*, **<u>Zhmur, V. V.</u>** *(Shirshov Institute of Oceanology, Moscow; Moscow Institute of Physics and Technology (National Research University), Dolgoprudny, Russia)* **and Chhetiani, O. G.** *(Obukhov Institute of Atmospheric Physics, Russian Academy of Science, Moscow, Russia)*

Looking at Jupiter's Great Red Spot (JGRS) as the core of the vortex, the authors propose a quasi-geostrophic model of this vortex formation, consisting of two vortices nested in each other. The vortex structure with an "attachment" is called a composite vortex. According to measurements obtained in interplanetary missions and on the Hubble Space Telescope (HST), the main outer part of the vortex is anticyclonic, while the inner region is in cyclonic rotation. It is natural to expect that the JGRS is a practically stationary baroclinic vortex, which is under the influence of a barotropic shear flow. The authors propose two variants of the model of such a vortex within the framework of the quasi-geostrophic approach in the approximation of the *f*-plane motion of the stratified atmosphere.

There are two possible cases for mutual combinations of the components of the composite vortex formation proposed by us as a model of the JGRS.

A stationary composite vortex composed of two ellipsoidal focal vortices in a horizontal zonal barotropic flow with constant shear. An exact solution of this nonlinear problem has been obtained within the framework of a rotating stratified atmosphere in the quasi-geostrophic *f*-plane approximation. The solution is based on the results of the study of the ellipsoidal vortex problem, described earlier in [1]. An important condition here is the stationary shape of both vortices. In such a campaign, with a given geometry of vortices and a shift in the background flow, the potential vortices of both vortices are uniquely determined. The main vortex has the same sign of potential vorticity as the background current. The nested vortex has the opposite vorticity. At the same time, the energy of a composite vortex exceeds the energy of a homogeneous stationary vortex without attachment.

A combination of a stationary external vortex and a non-stationary embedded vortex, provided that it has little effect on the behavior of the boundary of the main vortex. Both vortices here have an ellipsoidal core shape and are under the influence of the same external flow, a barotropic zonal flow with a shift, as in the first case. The potential vorticity of the main vortex is calculated precisely, and the vorticity of the nested vortex can be arbitrary. The inner vortex moves as a whole in elliptical orbits inside the main vortex. At the same time, the deformations of its core change periodically with a limited oscillation of the horizontal semi-axes. When the centers of the vortices coincide, the inner vortex, remaining in place, can rotate with limited deformation of its boundary. If the embedded vortex has a vorticity opposite to the main vortex, then the energy of the composite vortex turns out to be less than the energy of a homogeneous vortex without attachment. The latter property indicates the energy preference of the existence of composite vortices with a non-stationary embedding that weakly affects the boundary of the main vortex.

The proposed theory is compared with the results of observations of the JGRS [2] in the Voyager, Casino, Galileo and HST space missions. Both possible variants of the composite BCL model give qualitatively similar flow patterns, however, the model with an unsteady cyclonic investment requires less energy to maintain it, which speaks in favor of its more realistic applicability to the description of the properties of BCL, which includes, in particular, the unsteadiness of internal movements. The described mathematical method is also applicable to the description of stationary mesoscale ocean vortices in barotropic horizontal shear flows.

Keywords: Jupiter's Great Red Spot, baroclinic vortex, quasi-geostrophic approach, mesoscale ocean vortices

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3.

UNRAVELLING THE MYSTERY OF THE STABILITY OF OCEANIC VORTICES

Benilov, E. *(Department of Mathematics and Statistics, University of Limerick, Limerick, Ireland)*

Observations show that radii of oceanic eddies often exceed the Rossby radius of deformation, whereas theoretical studies suggest that such vortices should be unstable. The present paper resolves this paradox by presenting a wide class of large geostrophic vortices with a sign-definite gradient of potential vorticity (which makes them stable), in an ocean where the density gradient is mostly confined to a thin near-surface layer (which is indeed the case in the real ocean).

The condition of a thin “active” layer is what makes the present work different from the previous theoretical studies and is of utmost importance. It turns out that without it, the joint requirement that a vortex be large and have a sign-definite potential vorticity gradient trivializes the problem by eliminating all vortices except nearly barotropic ones.

Keywords: oceanic vortices, Rossby radius of deformation

4.

CLUSTERING OF FLOATING TRACERS IN THE OCEAN

Berloff, P. S. *(Department of Mathematics, Imperial College London, London, UK)*

Examples of floating tracers include marine pollution, marine biomass, brash ice, observational floats, etc. Floating and passive tracers have distinctly different characteristics, and the main feature of the former ones is their inherent tendency to get clustered, that is, to become organized in compact features with large density, surrounded by density voids. Despite many practical aspects, the dynamics of floating tracers and their clustering process remain poorly understood. In this talk we will discuss some early theoretical advances on the subject and provide perspectives on future research.

Keywords: floating tracers, density voids

5.

FINITE THE TIME AND PREDICTIONS FOR STRONGLY CHAOTIC SYSTEMS

Bunimovich, L.

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Georgia Institute of Technology, Atlanta, USA)

In statistical theory of dynamical systems, we are used to deal with asymptotic in time laws (various limit theorems where time lends to infinity). It seems to be the only natural approach because questions of a type how dynamics at time 17 differs from dynamics at time 25 indeed sound (not a little) crazy. For instance, in equilibrium statistical mechanics main questions essentially deal with phase transitions (a number of equilibrium states) rather than with evolution. It turned out that there are reasonable questions about at finite time transport in phase spaces of strongly chaotic systems, which could be answered.

Keywords: statistical theory of dynamical systems, strongly chaotic systems

6.
BAROCLINIC INSTABILITY IN THE COUPLED ATMOSPHERE OCEAN DYNAMICS

Carton, X., Vic, A., Gula, J. *(LOPS/IUEM/UBO, Brest, France)*

We study the linear instability of baroclinic parallel flows in two superimposed fluids. These flows are westerly jets in each fluid. They are thermally or mechanically coupled. The fluids are stably stratified, internally and mutually (the upper fluid is lighter than the lower fluid). For each fluid, we use the two-level surface quasi-geostrophic dynamics. Each jet is perturbed with normal modes.

Firstly, we check that, in the uncoupled case, the classical results of the Eady baroclinic instability are recovered. Then, in the case where the fluids are thermally and/or mechanically coupled, we investigate how the original instability is modified by this coupling. The four equations for linear instability are solved numerically via a matrix method.

With thermal coupling, and for meridionally uniform perturbations, a new mode of instability appears for long waves. This pair of unstable modes converges towards the modes of the uncoupled fluids at medium wavelengths. For perturbations with a non trivial meridional structure, the thermal coupling essentially damps the instability. For an upper flow with a larger deformation radius than in the lower flow, the growth rates of the perturbation are therefore more strongly altered in the former than in the latter. With mechanical coupling, the instability is essentially damped at large to medium scales, while the short-wave cut-off is extended towards smaller waves. When the fluids are both thermally and mechanically coupled, these effects add up.

The results found in the numerical model are confirmed by an idealized model of amplitudes and phases of perturbations for which simple solutions exist.

Keywords: baroclinic parallel flows, quasi-geostrophic dynamics, Eady baroclinic instability, matrix method

7.
CLASSIFICATION OF COMPONENTS OF PERIODIC FLOWS IN HETEROGENEOUS FLUIDS

Chashechkin, Y. D. and Ochirov, A. A.
(Ishlinsky Institute for Problems in Mechanics, Russian Academy of Sciences, Moscow, Russia)

In complete models of stratified fluids dynamics, the classification of periodic flows components is carried out, including gravitational surface and internal, inertial, capillary, acoustic, and hybrid flows. The complete solutions of the linearized fundamental system of fluid mechanics equations and state equations describe both waves and observed thin ligaments. An analytical method was developed to calculate the roots of dispersion relations using the theory of singular perturbations. Regular solutions correspond to wave components, while singular solutions correspond to ligament ones. The dependencies of flow component parameters on the properties of the fluid are presented. Changes in physical interpretation of solutions are traced by model simplifications. In limiting transitions, regular solutions agree with those known from wave theory. Results of calculations are illustrated with laboratory experimental data.

The study was supported by the Government program (contract #124012500442-3).

Keywords: periodic flows, heterogeneous fluids, theory of singular perturbations

8.

EXACT UNSTEADY VORTEX SOLUTIONS TO THE COMPRESSIBLE HELMHOLTZ EQUATIONS

Chefranov, S. G., Chefranov, A. S. *(Obukhov Institute of Atmospheric Physics, Russian Academy of Science, Moscow, Russia)*

Exact explicit analytical vortex solution to the three-dimensional Helmholtz equations in the Euler variables for an inertial movement of fluid particles in unbounded space is obtained [1] (see also [2], [3]). That solution is global regular for any large time and arbitrary smooth initial velocity field with finite integral of energy if an extremely small shear viscosity or some super threshold homogeneous linear friction is taken into account. An exact analytical explicit form for the well-known Riemann implicit solution is obtained [4]. The corresponding example of an exact solution in the main turbulence theory closure problem is stated on its basis [4]–[7]. Onsager's dissipative anomaly problem, which is also known as Kolmogorov's hypothesis about an independence of the turbulence energy dissipation rate on the Reynolds number, is resolved for the n-dimensional case, when only in the six-dimensional space Kolmogorov's mean field theory become exact [8], [9] in accordance with the previous estimations (for $n > 4$ in M. Nelkin [10] and for $n = 6$ in W. Liao [11]).

Keywords: compressible Helmholtz equations, Euler variables, Riemann implicit solution, turbulence theory, Onsager's dissipative anomaly, Kolmogorov's hypothesis

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9.

INVESTIGATION OF THE GULF STREAM SELF-ARRANGEMENT WITH USING NUMERICAL AND ANALYTICAL TECHNIQUES

Diansky, N. A. and Gusev, A. V.
(Faculty of Physics, Lomonosov Moscow State University, Moscow, Russia)

We solve the problem of theoretical justification and identification of physical mechanisms responsible for generation and self-arrangement of vortex oceanic structures, including the so-called fronts. With using the Russian model INMOM (Institute of Numerical Mathematics Ocean Model) and analytical approaches, we study a problem of transition of the circulation from its background mode to the vortex one. For this purpose, a new model version INMOM-NA (INMOM for North Atlantic) is implemented for the North Atlantic basin (covering a great part of the South Atlantic as well) with spatial resolution 1/16°×1/20° in longitude and latitude resolving vortex scales of ocean dynamics.

Open access datasets JRA55-do designed to drive the ocean in the scope of global climate simulations (https://climate.mrijma.go.jp/pub/ocean/JRA55-do/) are used to compute atmospheric forcing within the INMOM-NA. Initial data on the ocean thermohaline state are prepared based on, as well, the open access World Ocean Atlas 2018 (WOA2018, https://www.ncei.noaa.gov/access/world-ocean-atlas-2018/). Using the results of numerical experiments conducted by the method "Diagnosis – adjustment" proposed by Prof. A. S. Sarkisyan, and actual observations, we analyze self-arrangement of the Gulf Stream front, which is one of the most typical density fronts in the ocean.

By studying transitions of the available potential energy to the kinetic one, we solve a problem of accounting for the fact that the Gulf Stream width is about 100 km. By applying analytical techniques in the scope of the two-layer baroclinic ocean approach, we account for the Gulf Stream front self-arrangement reproduced in the numerical simulations.

The research was supported by the Russian Science Foundation grant No. 22-17-00267P.

Keywords: Gulf Stream, vortex oceanic structures, North Atlantic basin, global climate simulations

10.

THE ONSET OF FILAMENTATION ON VORTICITY INTERFACES

Dritschel, D. G. *(Mathematical Institute, University of St Andrews, St Andrews, UK)*

As far back as the late 1800s, Lord Kelvin, who was one of the greatest fluid dynamitist of all time, noted a curious property of the dispersion relation governing linear waves propagating on a vorticity interface. Such an interface divides two regions of uniform vorticity in a two- dimensional perfect (inviscid, incompressible) fluid. Remarkably, small-amplitude waves on both a linear interface (e.g. one lying on the y axis in equilibrium) and on the edge of a circular vortex patch oscillate at a frequency equal to half of the vorticity jump across the interface, $\Delta\omega/2$, when in a frame of reference moving with mean velocity at the interface. Notably, the frequency does not depend on the wavelength of the wave. As a result, in linear theory, any disturbance to a vorticity interface – which in general is made up of many wavelengths – oscillates at a fixed frequency, recovering its initial form after a time equal to $4\pi/\Delta\omega$. Kelvin had the insight to realize that, in the nonlinear equations, any finite-amplitude disturbance will experience a shear (induced by the equilibrium flow) which tends to slow down wave crests and troughs relative to points near the equilibrium interface position. He hypothesized that this shearing action would lead to progressive steepening of the disturbance, and, eventually, wave breaking.

It took over a century before there were numerical methods capable of accurately simulating the long-time behavior of disturbances to vorticity interfaces. The present author studied this problem with a novel numerical method based on 'contour dynamics', introduced a decade earlier by Norm Zabusky and colleagues. In [1], it was confirmed that waves do break and form thin filaments extruding from the interface, and moreover, they break repeatedly, once every period of the linear oscillation. This results in a huge growth in complexity of the interface, which becomes covered in many filaments. This eventuality has been termed 'Kelvin's hair'!

The present author was unaware of Kelvin's hypothesis until he met Alex Craik on a visit to the University of St Andrews in the early 1990s. Professor Craik pulled down an original volume in the collected works of Kelvin from his library at home, and found the passage in which Kelvin hypothesized this scenario. Kelvin's insight is all the more remarkable given that the wave steepening is quite unlike what is found say in Burger's equation. Instead, the wave 'performs a dance' every linear period, changing its form continuously: the wave crests at one instant of time later lie near the mean interface position then later still on the other side of the interface, etc. Crests and troughs do not remain in position (as they do in Burger's equation): the wave continuously distorts and then distorts back to its original form (or nearly). Hence, it is less obvious that shear will have the effect Kelvin hypothesized.

In [1], a weakly-nonlinear theory was developed to show that there is net steepening of the wave every period, but this occurs on a very long time scale inversely proportional to the square of the wave slope. (This puts severe demands on any numerical simulation of the process.) The present talk will discuss recent further developments concerning the mathematical structure and properties of the weakly nonlinear equation. In particular, we show that the equation possesses a self-similar form describing the last stages in the steeping of a disturbance – the onset of filamentation. Numerical evidence is provided which suggests that this equation is an attractor for almost all wave forms, implying that vorticity interfaces are generically prone to filamentation.

Keywords: filamentation, vorticity interfaces, 'contour dynamics', 'Kelvin's hair', weakly nonlinear equation

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11.

ATTRACTORS OF INTERNAL AND INERTIAL WAVES: WAVE TURBULENCE IN CLOSED DOMAINS

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Rotating and stratified fluids support inertial and internal waves, an essential ingredient of linear and nonlinear dynamics of geo- and astrophysical flows [1]. Inertial (internal) waves obey a specific dispersion law which relates the wave frequency and direction of wave propagation and does not contain any length scale. As consequence, inertial and internal waves exhibit a rich variety of wave motions (modes, beams), a specific reflection law (admitting wave focusing and formation of wave attractors in closed domains [2, 3]), and interesting non-linear dynamics (with development of triadic resonance instability [4, 5] and wave turbulence [6]). This report discusses wave turbulence in closed domains filled with stratified and/or rotating fluid, with emphasis on the non-linear regimes admitting wave attractors and formation of nontrivial azimuthal structures, Rossby waves and zonal currents [7–10].

This work was supported by the Russian Science Foundation (project No. 23-41-00090) and by project FWGG-2021-0011.

Keywords: wave turbulence, inertial waves, Rossby waves, zonal currents

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12.

SYNTHETIC ANNEALING AND VORTEX STRUCTURES

Flierl, G. R. and **Morrison, P.** *(MIT/CMPO; Cambridge, USA)*

If we phrase contour dynamics as a Hamiltonian system, we can define a procedure to find steadily rotating or translating states. First, the normal bracket, which conserves the Hamiltonian, H, and the areas, is extended to a Dirac bracket which conserves other additional properties such as symmetry. Then a synthetic annealing bracket is defined, this drives H to a maximum or minimum consistent with the constraints. We illustrate this with co-rotating vortex patch arrays and with a Red Spot model.

Keywords: synthetic annealing, vortex, Red Spot model

13.

A THREE-LAYER MODEL OF POLAR STRATOSPHERIC VORTEX

Gulev, S. K., Zyulyaeva, Yu. A. *(Shirshov Institute of Oceanology, Moscow, Russia),*
Sokolovskiy, M. A. *(Water Problems Institute; Shirshov Institute of Oceanology, Moscow, Rusia)*

A three-layer model of the polar stratospheric vortex is proposed. It is assumed that the upper layer contains the stratospheric part of the vortex (or upper troposphere), the middle layer corresponds to the tropopause, and the lower layer corresponds to the lower troposphere (atmosphere). In general, the vortex in an unperturbed state has a circular, axisymmetric, truncated cone shape, tapering from bottom to top. The horizontal piecewise constant distribution of potential vorticity in each layer approximates the structure of the average state of the vortex [1] using a set of annular vortex patches (by analogy, e.g., with [2–5]). We carried out (i) a numerical study of the stability of a three-layer vortex relative to small harmonic azimuthal perturbations in the shape of the external boundaries of vortex spots, (ii) studies of the possible impact of large-scale mountain systems on the vortex (the Himalayas in Northeast Asia and the Rocky Mountains in Northwest America).

Conclusions. Using a three-layer quasi-geostrophic model, numerical experiments were carried out on:

1. Study of the nonlinear stage of vortex instability with the characteristic features of the stratospheric polar vortex. It is shown that finite disturbances of circular vortex patches contribute to the formation of long filaments, as well as the entrainment of non-vortex air masses into the internal vortex domain.

2. Studying the influence of mountain systems (analogues of the Himalayas and Rocky Mountains) on the trajectory of the polar vortex. It is shown that the joint influence of these mountain systems has a stabilizing effect on the movements of the polar vortex.

We believe that these and other possible properties of polar vortex motion would be useful to investigate using modern methods for identifying coherent vortex structures, e.g. [6].

The work was carried out within the framework of State assignments FMWE-2023-0002 of the Shirshov Institute of Oceanology and FMWZ-2025-0001 of the Water Problems Institute.

Keywords: Polar Stratospheric Vortex, Three-layer Model, Stability

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14.

SOME NEW PROBLEMS IN THE THEORY OF SLOPE FLOWS

Ingel, L. Kh. *(Research and Production Association "Typhoon", Obninsk, Russia)*

Some new results related to the theory of slope flows common in the atmosphere are presented, in particular, generalizations of the classical Prandtl model.

1. A new mechanism for the occurrence of slope flows associated with spatial inhomogeneities of turbulent exchange coefficients is discussed. If the exchange coefficients depend on the distance to the inclined underlying surface (this is typical for turbulent exchange), then horizontal inhomogeneities of temperature and pressure and, consequently, slope flows arise in a stratified medium.

2. The Prandtl model is generalized to the case of volumetric heat release in air. A nontrivial possibility of intensifying slope flows with a decrease in the angle of inclination of the underlying surface is discovered.

3. The Prandtl model is generalized to the case of nonlinear (quadratic) resistance and heat exchange on the underlying surface. The stationary solution of the nonlinear problem of flow over a cooled inclined surface under such boundary conditions may not be unique – different stationary regimes are possible under the same external conditions.

4. The helicity of slope flows, which exists in the presence of a noticeable contribution of Coriolis accelerations, is analyzed. It is shown that the generation of helicity in slope flows, in principle, can be significant.

5. The Prandtl model is generalized to the case of a thermally inhomogeneous underlying surface.

Keywords: slope flows, Prandtl model, Coriolis accelerations

15.

BEYOND THE FLUX-GRADIENT RELATION IN PARAMETERIZING LATERAL EDDY-INDUCED TRANSPORT

Kamenkovich, I., Lu, Y. and Berloff, P. *(RSMAS, University of Miami, Miami, USA)*

Mesoscale currents ("eddies") play a crucial role in redistributing oceanic tracers, yet their effects remain unresolved in most ocean components of climate models and must be parameterized. Traditionally, lateral tracer transport by eddies is represented by the flux–gradient relation, which assumes that the eddy tracer flux is proportional to the large-scale tracer concentration gradient via an eddy transport coefficient tensor. However, recent studies highlight significant limitations and biases in this approach.

Using a high-resolution tracer model of the Gulf Stream region, we reassess the flux–gradient relation and propose an alternative framework that models local eddy forcing as a combination of diffusion and generalized eddy-induced advection. Our simulations demonstrate that this new approach better captures the stirring and dispersive effects of eddies. These findings suggest a pathway for improving traditional parameterizations of eddy-induced tracer transport.

Keywords: eddies, tracers, flux–gradient relation, Gulf Stream, eddy-induced advection

16.

CYCLOIDAL MEANDERING OF A MESOSCALE ANTICYCLONIC EDDY

Kizner, Z. *(Department of Physics, Bar-Ilan University, Ramat-Gan, Israel)*

By applying a theoretical approach, we propose an explanation for some features of the movement of a long-lived mesoscale anticyclone observed during a year in the Bay of Biscay [R. D. Pingree & B. Le Cann, Deep-Sea Res., Part A 39, 1147 (1992)]. In the remote-sensing infrared images, at the initial stage of observations, the anticyclone was accompanied by two cyclonic eddies, so the entire structure appeared as a tripole. However, at later stages, only the anticyclone was seen in the images, traveling generally west. Unusual for an individual eddy were the high speed of its motion (relative to the expected planetary beta-drift) and the presence of almost cycloidal meanders in its trajectory. Although surface satellites seem to have quickly disappeared, we hypothesize that subsurface satellites continued to exist, and the coherence of the three vortices persisted for a long time. A significant perturbation of the central symmetry in the mutual arrangement of three eddies constituting a tripole can make possible reasonably fast drift and cycloidal meandering of the anticyclone. This hypothesis is tested with two-layer contour-dynamics *f*-plane simulations and with finite-difference beta-plane simulations. In the latter case, the interplay of the planetary beta-effect and that due to the sloping bottom is considered. Close agreement is found between the observed and modelled anticyclone trajectories, both in shape and size and in the timing of passage through the various phases.

The talk is based on a publication by Z. Kizner, B. Shteinbuch-Fridman, V. Makarov, and M. Rabinovich (Phys. Fluids, 2017, 29, 086601).

Keywords: mesoscale anticyclone, cycloidal meandering, Bay of Biscay, tripole, topographic beta effect

17.

LONG-TERM CHANGES IN THE STRATIFICATION OF THE BLACK SEA

Korotaev, G. K.
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In the Black Sea area, in the last two decades, there has been a tendency towards a decrease in the intensity of the cold intermediate layer (CIL), the existence of which as an element of thermal stratification of the basin has been noted since the beginning of hydrological observations in the basin. Studies of changes in the state of the marine environment on interannual time scales in 2000–2020 based on available observation data and reanalysis results show that since the mid-2000s, the spatial continuity of the CIL, typical for all previous years, has been disrupted. The degradation of the CIL has accelerated significantly since 2012, and by 2020, the existence of the CIL with a water temperature in its core below 8°C has completely ceased. In addition to the increase in winter sea surface temperature associated with climate warming, the disappearance of the CIL is affected by a constant increase in water salinity within the main pycnocline. The salinization of the main pycnocline is apparently the cause of the warming of the sea waters at these horizons, limiting the depth distribution of the warmer Marmara waters entering the Black Sea with the Lower Bosphorus Current. In addition, the increase in salinity in the main pycnocline limits the depth of winter convection penetration.

In order to explain the observed increase in salinity in the main pycnocline, a simple model of the development of haline and density stratification in the Black Sea under the influence of buoyancy flows through the lateral boundaries is constructed. The proposed model shows that the haline stratification of the basin most likely has not yet reached a stationary regime after the opening of the Bosphorus Strait more than 7000 years ago. It also provides an estimate of the characteristic time of the reaction of the basin stratification to changes in external conditions and shows that the characteristic time of adaptation of the vertical cell of the Black Sea circulation, and, consequently, the vertical stratification of the basin, is determined by the inertia of the main thickness of the basin waters.

Keywords: stratification, Black Sea, cold intermediate layer, pycnocline, salinity, Lower Bosphorus Current

18.

ANOMALOUS STRUCTURES ON THE SEA SURFACE AS AN OBJECT OF STATISTICAL TOPOGRAPHY. NUMERICAL MODELING

Koshel, K. V. *(V. I. Il'ichev Pacific Oceanological Institute, Far Eastern Branch Russian Academy of Sciences, Vladivostok, Russia)*

Based on the ideas of statistical topography, the problems of the possibility of occurrence of stochastic structure formation in a quasilinear problem described by a first-order partial differential equation are analyzed. A feature of these problems is the occurrence of parametric excitation against the background of Gaussian pumping. Equations for the probability density of solutions of these equations are obtained, from which the possibility of stochastic structure formation with a probability of one follow, i.e., in almost every realization of random parameters of the medium. This report is devoted to the numerical modeling of such processes.

Keywords: stochastic structure formation, numerical modeling

19.

RECONSTRUCTING SPATIOTEMPORAL CHARACTERISTICS OF SEA-LEVEL PRESSURE VARIABILITY IN REANALYSIS DATA SET USING A FEATURE-TRACKING APPROACH

Kravtsov, S. V., Rudeva, I. A., Gulev, S. K. *(University of Wisconsin, Milwaukee, School of Freshwater Sciences, Atmospheric Sciences group, Great Lakes Research Facility, Milwaukee, USA)*

This study aimed to quantify the contribution of synoptic transients to the full spectrum of space–time variability of sea-level pressure (SLP) in middle latitudes. In previous work by the authors, it was shown that tracking cyclones and anticyclones in an idealized atmospheric model allows one to reconstruct a surprisingly large fraction of the model's variability, including not only synoptic, but also its large-scale low-frequency component. Motivated by this result, we performed tracking of cyclones and anticyclones and estimated cyclone/anticyclone size and geometry characteristics in the observed SLP field using 1948–2008 NCEP/NCAR reanalysis data set. Based on this tracking database, we produced what we called the reconstructed synoptic field by superimposing radially symmetrized eddies moving along their actual observed trajectories. We then quantified the fraction of the observed SLP variability due to reconstructed synoptic eddies and studied anatomy of this variability, as well as connections between these eddies and low-frequency variability (LFV) defined via more traditional spatiotemporal filtering. In particular, interannual changes in synoptically reconstructed variance obtained via our approach were found to be connected to the variability associated with major known teleconnection patterns.

Keywords: sea-level pressure, radially symmetrized eddies, low-frequency variability

20.

ON STABILITY OF THE REGULAR VORTEX POLYGON IN THE QUASIGEOSTROPHIC MODEL OF THE POINT VORTICES IN TWO-LAYER FLUID

Kurakin, L. G., Lysenko, I. A., Ostrovskaya, I. V. and Sokolovskiy, M. A.
(Water Problems Institute, Russian Academy of Sciences Moscow; Institute for Mathematics, Mechanics and Computer Sciences, Southern Federal University, Rostov-on-Don, Russia)

A two-layer quasigeostrophic model is considered. The stability analysis of the stationary rotation of a system of N identical point vortices lying uniformly on a circle of radius R in one of layers is presented. The vortices have identical intensity and length scale is $\gamma^{-1} > 0$. The problem has three parameters: N, γR and β, where β is the ratio of the fluid layers thicknesses. The stability of the stationary rotation is interpreted as orbital stability. The instability of the stationary rotation is instability of system reduced equilibrium. The quadratic part of the Hamiltonian and eigenvalues of the linearization matrix are studied.

The parameters space (N, γR, β) is divided into three parts: A is the domain of stability in an exact nonlinear setting, B is the linear stability domain, where the stability problem requires the nonlinear analysis, and C is the instability domain. The case A takes place for $N = 2, 3, 4$ for all possible values of parameters γR and β. In the case of $N = 5$ we have two domains: A and B. In the case $N = 6$ part B is curve, which divides the space of parameters γR, β into the domains: A and C. In the case of $N = 7$ there are all three domains: A, B, and C. The instability domain C takes place always if $N = 2n \geq 8$. In the case of $N = 2\ell + 1 \geq 9$ there are two domains: B and C.

The results of theoretical analysis are sustained by numerical calculations of vortex trajectories.

In conclusion, it can be noted that nonlinear stability analysis in the domain of B requires the use of resonance theory for Hamiltonian systems, just as this study was done for the case of an N-gon inside and outside a circular domain in the Kirchhoff model [3].

The main results are published in the papers [1, 2].

The work was carried out within the framework of the topics FMWZ-2025-0001 of the state assignment of the Water Problems Institute of the Russian Academy of Sciences and FMWE-2023-0002 of the state assignment of the Shirshov Institute of Oceanology of the Russian Academy of Sciences.

Keywords: regular vortex polygon, point vortices, two-layer quasigeostrophic model, linearization matrix, Hamiltonian systems, Kirchhoff model

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21.

THE STABILITY OF THE CONFIGURATION OF N + 1 POINT VORTICES IN TWO-LAYER FLUID

Kurakin, L. G., Ostrovskaya, I. V. and Sokolovskiy, M. A.

(Water Problems Institute, Russian Academy of Sciences Moscow; Institute for Mathematics, Mechanics and Computer Sciences, Southern Federal University, Rostov-on-Don, Russia)

A two-layer quasigeostrophic model is considered in the f-plane approximation. The stability of a discrete axisymmetric vortex structure is analyzed for the case when the structure consists of a central vortex of arbitrary effective intensity Γ and N (N = 2, …, 6) identical peripheral vortices. The identical vortices are uniformly distributed over a circle of radius R in the lower layer. The central vortex lies either in the same or in another layer. The problem has three parameters (R, Γ, α), where α is the difference between layer nondimensional thicknesses.

The instability is instability of the solution of the linearized perturbation equation. The two definitions of stability used in the study are orbital stability and G-stability. The theory of stability of steady-state motions of dynamic systems with a continuous symmetry group G is applied. The orbital stability is the stability of a one-parameter orbit of a steady-state rotation of a vortex structure, and the G-stability is the stability of a three-parameter invariant set OG, formed by the orbits of a continuous family of steady-state rotations of a two-layer vortex structure. The problem of orbital stability is reduced to the problem of stability of a family of equilibriums of a Hamiltonian system. The quadratic part of the Hamiltonian and the eigenvalues of the linearization matrix are studied analytically.

The parameter space (R, Γ, α) is divided on three parts: 1) the instability domain; 2) the domain of orbital stability in an exact nonlinear setting; and 3) the linear stability domain, where the stability problem requires the nonlinear analysis.

The results of theoretical analysis are sustained by numerical calculations of vortex trajectories.

In conclusion, it is noted that the nonlinear analysis in the linear stability domain requires the use of resonance theory for Hamiltonian systems, just as this study was done for the case of the configuration of 3 + 1 vortices in the Kirchhoff model [4].

The main results are published in the papers [1, 2, 3].

The work was carried out within the framework of the topics FMWZ-2025-0001 of the state assignment of the Water Problems Institute of the Russian Academy of Sciences and FMWE-2023-0002 of the state assignment of the Shirshov Institute of Oceanology of the Russian Academy of Sciences.

Keywords: point vortices, two-layer fluid, linearized perturbation equation, Hamiltonian system, Kirchhoff model

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22.

THEORETICAL MODEL OF A THIN VERTICAL CONICAL BAROCLINIC VORTEX

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Taking into account angular momentum diffusion, either positive or negative, which complements the conventional eddy viscosity in the angular momentum equation, a theory of thin vertical conical baroclinic vortices in an approximate state of cyclostrophic balance is developed. Taking angular momentum diffusion into account allows the existence of vortex solutions with an azimuthal velocity profile near the vortex axis that deviates from the linear profile and is described by a general power law. As a simpler methodological problem, the case of a strictly cylindrical vortex in a homogeneous fluid is considered. The classical Burgers – Rott vortex is reproduced in the absence of angular momentum diffusion and its generalizations are obtained for the case of taking angular momentum diffusion into account. In the case of vortices with conical symmetry, vortex solutions are obtained that are formally similar to the Burgers – Rott vortex and its generalizations for the case of taking angular momentum diffusion into account. It is shown that these vortices, while retaining their structure specified by the effects of eddy viscosity and angular momentum diffusion, become solutions to the fluid dynamical equations in the inviscid adiabatic limit.

Keywords: baroclinic vortex, cyclostrophic balance, cylindrical vortex, Burgers – Rott vortex

23.

NONLINEAR DYNAMICS OF SLIPPING FLOWS

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The process of breaking of inviscid incompressible flows along rigid body with slipping boundary conditions. Such slipping flows are compressible, which is the main reason for the formation singularities on the rigid boundary for the gradient of the parallel component velocity. Analytically, slipping flows are analyzed within the framework two- and three-dimensional inviscid Prandtl equations. Criteria gradient catastrophe in both cases are found. For 2D Prandtl equations breaking takes place both for parallel velocity along the boundary and for the vorticity gradient as well. For three-dimensional Prandtl flows, the breaking (formation of a folding in a finite time) arises for the symmetrical part of the velocity gradient tensor, as well as for the antisymmetric part – vorticity. The problem of the formation of the velocity gradients is numerically investigated for flows between two parallel plates within two-dimensional Euler equations. It is shown that the maximum velocity gradient grows exponentially in time at the rigid boundary while the growth of the vorticity gradient increases according to a doubly exponential law. Careful analysis showed that this process is nothing but fold formation, with a power-law relationship between the maximum velocity gradient and its width: max |ux|~l-2/3. The collapsing solution is found for 3D the inviscid Prandtl equations that describes the tornado type behavior.

The work was supported by the Russian Science Foundation grant No. 19-72-30028.

Keywords: slipping flows, nonlinear dynamics, Prandtl equations, vorticity, two-dimensional Euler equations, tornado

24.

COHERENCE IN THE OCEAN

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Written during the early phase of discovery for oceanic mesoscale eddies, Stern (1975) and Larichev and Reznik (1976) are seminal papers on the existence of nonlinear conservative steady-state eddy solutions in fluid dynamics, themselves growing out of parallel discovery phases in theoretical physics on solitons and nonlinear dynamics, whose opposites are coherence and chaos. In this talk I will broadly survey the history of developments in the theory of coherent vortices and their principal manifestations in oceanic measurements and simulations.

Keywords: coherence, mesoscale eddies, fluid dynamics

25.

THE GREAT SIBERIAN POLYNYA AND MECHANISMS OF ITS FORMATION

Morozov, E. G., Pisarev, S. V., Frey, D. I. and Osadchiev, A. A.

(Shirshov Institute of Oceanology, Russin Academy of Sciences, Moscow, Russia)

Existence of large-scale polynya in the Laptev Sea is analyzed. This polynya makes easier navigation in the Laptev Sea along the Northern Sea route. The permanent existence of this polynya along the 20–50 m isobaths is generally explained in literature as wind-forced ice-free surface of the sea. To our opinion wind conditions are almost the same over large regions of the Arctic Ocean; nothing special above the continental slope. Appearance of the polynya over isobaths 20–50 m only in the Laptev Sea is interpreted in our presentation as a phenomenon caused by tidal internal waves over the slope at critical latitudes for the M2 internal tide. In addition, the stream of modified warm and more saline Atlantic waters from the Fram Strait flows most closely to the slope in the Laptev Sea than in other seas of the northern Russian coast. The freezing temperature of water in this stream is lower than in the surrounding waters and internal waves provide mixing of waters transporting more saline waters from the bottom at 20–50 m closer to the surface.

Keywords: Great Siberian polynya, Laptev Sea, Arctic Ocean, M2 internal tide, Fram Strait

26.

GEOMETRY AND ENERGY OF SURFACE WAVES

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(Ishlinsky Institute for Problems in Mechanics, Russian Academy of Sciences, Moscow, Russia)

Changes in the free surface area of a disturbed fluid, the range and value of the available potential surface energy depending on the amplitude and frequency of the wave in various models of periodic surface waves are studied. The solutions obtained in linear, partially linearized approximations, as well as in complete nonlinear formulations are analyzed. Significant differences in the characteristics of free surface perturbation and available energy are noted in various mathematical descriptions.

The study was supported by the Government program (contract #124012500442-3).

Keywords: surface waves, potential surface energy

27.

INTENSE ZONAL FRESHWATER TRANSPORT IN THE EURASIAN ARCTIC DURING ICE-COVERED SEASON REVEALED BY IN SITU MEASUREMENTS

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The Kara Sea receives ~1/3 of total freshwater discharge to the Arctic Ocean (), mainly from the large Ob and Yenisei rivers. The Ob-Yenisei plume covers wide area in the central part of the Kara Sea during ice-free season (June–October) and accumulates ~1000 km^3 of freshwater volume. In late autumn, the Kara Sea becomes covered by ice, which hinders in situ measurements at this area. As a result, the fate of the Ob-Yenisei plume below sea ice during winter and spring remains unclear. In this study, we report multiple in situ measurements performed in the Kara Sea shortly before and during ice-covered season. We demonstrate that late autumn convection in the plume shortly before ice formation significantly reduces friction between the plume and the subjacent sea. The subsequent formation of solid sea ice coverage isolates the plume from wind forcing. These two factors precondition the Ob-Yenisei plume to form an intense buoyancy-driven coastal current below sea ice. As a result, the plume advects eastward to the Laptev Sea through the Vilkitsky Strait during several months in November–February. Eventually, by late winter this huge freshwater volume disappears from the Kara Sea and contributes to freshwater content of the Laptev Sea. The obtained result improves our understanding of freshwater balance of the Kara and Laptev seas, as well as providing an important insight into the large-scale freshwater transport in the Eurasian Arctic, which remain largely unknown during ice-covered season.

Keywords: the Ob-Yenisei plume, Kara Sea, situ measurements, freshwater discharge

28.

DISTRIBUTION FUNCTIONS OF THE INITIATED KDV-LIKE SOLITONIC GAS

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The statistical properties of a sequence of spaced solitons and compactions (soliton gas) with random amplitudes and phases are studied based on the example of solitary waves – solutions of the generalized Korteweg-de Vries equation with power nonlinearity (including fractional nonlinearity). Such sequences are used to specify initial conditions in problems of modeling soliton turbulence. It is shown in the paper that in the case of a unipolar soliton gas, there is a critical density, so that the soliton gas is sufficiently rarefied regardless of the nonlinearity type in the generalized Korteweg-de Vries equation, which is associated with the repulsion of the same polarity solitons. On the contrary, the density of the bipolar soliton gas can be any, since solitons of different polarities are attracted. The first statistical moments of the wave field are calculated. The probability density functions of the soliton and compaction sequence are calculated. A feature in these functions in the region of small field values due to the overlap of exponential soliton tails is noted. This feature is absent in the field of compactions occupying the finite space volume. The paper provides calculation examples of distribution functions for various approximations to the distribution function of the solitary wave amplitudes.

Keywords: Korteweg-de Vries equation, soliton turbulence, wave field

29.

LAGRANGIAN ANALYSIS OF EDDIES IN THE OCEAN

Prants, S. V. *(V. I. Il'ichev Pacific Oceanological Institute, Far Eastern Branch Russian Academy of Sciences, Vladivostok, Russia)*

Lagrangian approach is developed to study eddies in the ocean. It is based on calculation of relevant Lagrangian indicators which are functions of trajectories of virtual particles advected in the altimetry-based velocity field. The Lagrangian diagnostics seem to be more appropriate to study eddies and their evolution than the commonly used techniques because the Lagrangian maps are imprints of history of water masses involved in the vortical motion whereas vorticity, the Okubo-Weiss parameter and the similar metrics are 'instantaneous' snapshots. The Lagrangian approach allows us not only to identify and track real mesoscale eddies in any weather, but also to document 'biography' of each eddy anywhere in the ocean, both retrospectively and in the near-real time. In particular, we can estimate the fractions of water masses/ types the eddy's cores consist of. Using this approach and automatic eddy detection algorithm, a census of the mesoscale eddies in the northwestern Pacific have been done in the altimetry era.

Keywords: Lagrangian analysis, eddies, mesoscale eddies, altimetry era

30.

VORTEX INTERACTIONS OVER BATHYMETRY

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The presence of bathymetry affects the evolution of vortices, see e.g. [3]. For example, [1] showed that decaying turbulence leads to the formation of a large, persistent anticyclone over a basin. The authors indicate that this anticyclone is the result of mergers of smaller anticyclones. Other authors have found similar results. Recently, [2] have investigated the merger of two cyclonic vortices lying in the upper-layer of a two-layer quasi-geostrophic system. The authors showed that indeed cyclones merge faster when lying over a seamount due to a topographic 'β-drift'. The authors also confirmed that cyclones tend to be unstable and break into pieces over basins. By symmetry of the QG equations, the reverse is true for anticyclones. This leads to a preferential formation of strong and persistent cyclones over seamounts and anticyclones over basins.

In the present contribution, we consider the other main interaction which makes vortices grow in size: their vertical alignment. We consider two cyclonic vortices lying in different layers. We first consider a three-layer system where the two vortices occupy the upper and middle layers respectively. We recover similar trends: cyclones can align from further apart when lying over a seamount compared to a flat bottom. They tend to break into pieces when lying over a basin. Similar trends are also observed in a two-layer system where the lower vortex shares the same layer as the bathymetry.

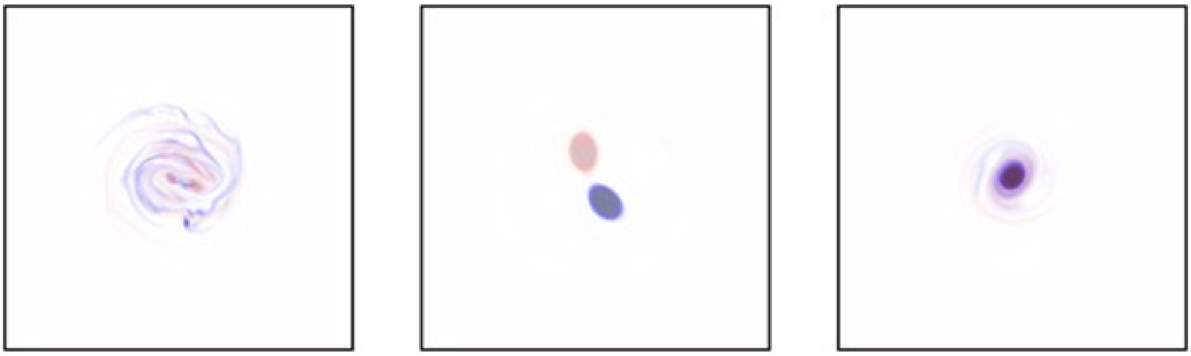

Figure 1: Top view over the upper and middle layers of a three-layer system at $t = 349$ for a basin (left), a flat bottom (middle) and a seamount (right). Vortices are initially distant by 3.5 times their radius. Their radius is 3 times the deformation length in each layer. The Gaussian seamount/basin has a characteristic radius 3 times the one of the vortices.

Keywords: vortex, bathymetry, turbulence, quasi-geostrophic system, cyclones, anticyclones

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31.

ON THE TIME EVOLUTION OF THE SCHWARZ FUNCTION OF THE BOUNDARY OF A UNIFORM PLANAR VORTEX MOVING IN AN INVISCID FLUID

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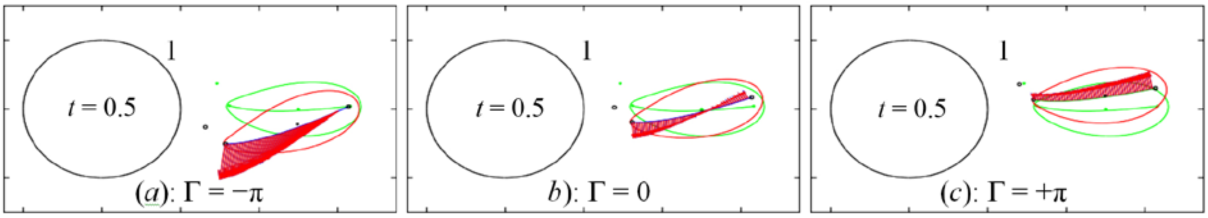
A uniform vortex P is defined by its boundary ∂P and vorticity level ω (constant in time). The internal singular set of the Schwarz function Φ generated by ∂P (i.e., the analytic continuation of the conjugate x of $x \in \partial P$) is a finite-length branch cut BC_i. Its endpoints (it is oriented from y_1 to y_2) are branch points of Φ. BC_i is called "mother body" because, by means of an appropriate form of the Biot-Savart law (see [1], p. 141) and equipped with the density of circulation $\gamma = -\omega\tau\,[\Phi]/(2i)$, where [Φ] is the jump of Φ across BC_i and τ the tangent unit vector, induces the same velocities of the vortex outside P. From the kinematic point of view, it behaves as a vortex sheet.

The Schwarz function is defined in a bounded (time dependent) domain D containing P, together with the analytic continuations of Cauchy integral and of its conjugate. By means of these functions, the continuations of the velocity (U) and of its conjugate (U) are defined. They are used for writing the initial value problem:

$$D t\Phi = \partial t\Phi + U\partial x\Phi = U \qquad x \in D(t)$$
$$\Phi(X; 0)\ \text{assigned} \qquad X \in D(0)$$

that gives Φ at times $t > 0$. By using the above differential equation, the velocities of the points of BC_i are deduced [2]. This approach is here extended to the motion of P in the presence of a circular cylinder. As sample cases, in the figures the numerical velocities (blue) at a small number of points $y \in$ BC_i are superimposed to the analytical ones (red) at the early stages of the motion. The numerical calculation of the branch cut velocities implies the Lagrangian tracking of the above points on BC_i, and for this reason, if BC_i is strongly elongated (as in a), the nodes move away from the branch point y_2. The vortex boundaries (green at $t = 0$, red at $t = 0.5$), the cut (green at $t = 0$, blue at $t = 0.5$), the centers of vorticity (filled dots, green at $t = 0$ and black at $t = 0.5$) and the branch points (empty dots, green and black) are also drawn. The vorticity level ω has been assumed unitary, and the circulation about the body Γ takes the three values indicated below.



Keywords: Schwarz function, vortex, Biot-Savart law, Cauchy integral

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32.

HOW DOES WAVE FIELD EVOLUTION DRIVE OCEAN CURRENTS?

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In most of the studies of wave-current interaction in the ocean, the focus was on the effect of current on the wind-wave field. The effect of waves on currents was mostly ignored, although, it was realized already by Hasselmann (1970) that in the rotating ocean wind waves exert substantial Reynolds shear stresses and, thus, can strongly affect surface currents. A mathematical framework for the dynamics of surface currents accounting for both the wind and wave stresses was formulated by Huang 1979: the corresponding equations are referred to as the Stokes-Ekman model, since the wave field affects currents via its Stokes drift. The classical Ekman model totally ignores waves. The most recent trend is to consider coupled numerical models of wave dynamics and ocean circulation (e.g. Couvelard at al., 2020). However, this approach is prohibitively expensive, and it is extremely difficult to untangle different effects occurring concurrently.

Here, we first examine analytically the surface current response to both wind and evolving wind-wave field within the Stokes-Ekman paradigm. The wave field evolution is presumed to be governed by self-similar large-time asymptotics of the Hasselmann equation. We focus on the common situations where the dynamics of surface currents is determined by the regimes of wave field evolution. By solving analytically, the Stokes-Ekman equation we find how the surface currents are driven by the evolving wave field. In particular, we establish how the vertical structure of the surface current evolves. Since the wave field and its contribution to surface current evolve, the induced surface current becomes horizontally nonuniform at the scales of the wave field. The non-uniformity of the surface current owing to the wave field evolutions creates the Ekman pumping/suction. We find the surface current curl and divergence analytically, which enables us to quantify how wind waves affect deep ocean currents via the Ekman pumping/suction and, thus, drive 3-D deep ocean circulation.

Keywords: ocean currents, Reynolds shear stresses, currents, Stokes-Ekman model, Hasselmann equation, wave field, surface current

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33.

SIMULATIONS AND MEASUREMENTS OF ROGUE WAVES IN THE SEA

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A brief overview of the research carried out by our laboratory at the Institute of Applied Physics will be given. It concerns revealing the physical mechanisms and key effects supporting generation of anomalously high waves, as well as the direct numerical simulation of irregular waves within the frameworks of approximate and primitive water wave equations, and in-situ measurements.

The research is supported by the RSF project No. 24-47-02007.

Keywords: rogue waves, irregular waves

34.

CLUSTERING FLOATING PARCELS DRIVEN BY MESO- AND SUBMESOSCALE DYNAMICS ON THE SUBPOLAR FRONT OF THE JAPAN SEA

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Based on high resolution model simulations, the clustering of the floating parcels is investigated on the Subpolar Front of the Sea of Japan from April to May 2009. The simulated circulation contains the basin-scale currents, mesoscale eddies and sub-mesoscale activity. The Lagrangian simulations show that the floating parcels are aggregated into clusters with very small spatial scale and the biggest parcel "density". The decomposition of the simulated velocity field on the geostrophic component including the basin-and mesoscale dynamics and ageostrophic component including the submesoscale dynamics allowed us to quantify the impact of both components on the floating parcel clustering. We confirmed a leading role of the submesoscale dynamics associated with the high divergence/convergence regions, where the floating parcels were clustered. However, the geostrophic component can enhance/suppress the floating parcel clustering. When adding the stochastic component to the geostrophic component, the floating parcel clustering can be suppressed.

Keywords: Subpolar Front, Japan Sea, clustering of the floating parcels, eddies, geostrophic component

35.

RADIATION PHENOMENA IN GEOPHYSICS

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Radiative forces acting on point sources when they move in a rotating or density stratified fluids are discussed. The forces are caused by radiation of Rossby waves (in a rotating fluid) or internal gravity waves (in stratified fluid) through the Cherenkov mechanism. Owing to the anisotropic nature of both types of waves, apart from the wave drag force directed opposite to the velocity of the source motion, there exists also a lateral force which is normal to the velocity of the source. On the basis of the results obtained, an interpretation of some properties of Larichev − Reznik vortices on the beta-plane are explained. It is shown that the westward motion of such vortices on a rotating Earth is unstable with respect to small variations of the angle at which their velocity is inclined, whereas the eastward motion is stable.

In the case of source motion in a stratified fluid, both vertical and horizontal motions are unstable; a stable direction is characterized by the angle of ~34° to the horizon. The free motion of a cylindrical body in a stratified fluid is studied in detail. Basic governing equations are derived, and their solutions are investigated theoretically and numerically. Typical trajectories of a cylindrical body moving in a stratified fluid are calculated.

Keywords: radiative forces, Rossby waves, Cherenkov mechanism, Larichev − Reznik vortices, stratified fluid

36.

THE IMPORTANCE OF BEING ASYMMETRIC FOR GEOPHYSICAL VORTICES

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Several types of spatial symmetry in vortex structures within rotating stratified fluids are examined by looking at self-propagating configurations in the quasigeostrophic model. The role of symmetry breaking in the dynamics of geophysical waves, vortices and instabilities is highlighted. In particular, the energy exchange of the large-scale vertical shear with monopolar and dipolar vortices is analyzed. Various coupled vortex-wave structures are described in terms of wavy and evanescent modes. The Rossby wave radiation is shown to induce a zonal asymmetry, which is needed for the energy support and self-amplification of vortices in large-scale flow. The consequences for the evolution of the most long-lived vortices in the subtropical westward flows are discussed.

Keywords: geophysical vortices, spatial symmetry, Rossby wave, zonal asymmetry

37.

TRANSFORMATION OF A SOLITON ON A LEDGE

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Analytically and numerically, the transformation of the soliton of the internal wave of the first and second modes on the bottom ledge under conditions of two and three-layer flows is considered within the framework of Euler's equations. The characteristics of secondary solitons behind the ledge are determined, the limits of applicability of the analytical weakly linear theory are more clearly defined, and the loss of soliton energy in the ledge area is shown depending on the height of the ledge and the amplitude of the soliton. The formation of a breather of internal waves of the first mode behind the ledge during the incursion of the second mode soliton is shown. The formation of a symmetrical soliton of the second mode, which occurs under the conditions of resonance of the breather of the first mode and the soliton of the second mode, is also shown.

Keywords: soliton, Euler's equations

38.

ON THE POSSIBILITY OF APPROXIMATING VERTICAL PROFILES OF TURBULENT MOMENTS OF A CONVECTIVE BOUNDARY LAYER BASED ON THE THEORY OF LOCAL SIMILARITY

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The report presents a version of the new theory of local similarity (NTLS) which uses the Prandtl "spectral" mixing path and the second moment of vertical velocity as basic parameters. This approach allows expressing the turbulent exchange coefficient, kinetic energy dissipation, and mixed moments of buoyancy and vertical velocity only through two independent "basic" parameters of local similarity. Comparison of local similarity approximations with experimental data convincingly confirms the correctness of the proposed relationships and demonstrates the high efficiency of NTLS.

The results of the new theory of local similarity are compared with the provisions of known semi-empirical theories of turbulence. It is shown that the new theory of local similarity significantly expands the scope of applications of classical semi-empirical theories. Therefore, NTLS is a powerful tool for studying turbulent convection.

The main results of the report are published in articles [1]–[3].

Keywords: theory of local similarity, Prandtl "spectral" mixing path, vertical velocity, turbulence

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39.

EXAMPLES OF COHERENT STRUCTURE FORMATION IN A STRATIFIED AND ROTATING FLUID DUE TO NONLINEAR EFFECTS (LABORATORY EXPERIMENT)

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Two laboratory examples of coherent structure formation in a stratified and rotating fluid under the influence of nonlinear hydrodynamic processes are presented.

The first example is a thin layering of an aquatic column with initially linear density (salinity) gradient under an impact of vertically uniform long-term turbulent stirring [1]. Stirring is produced by horizontally oscillating vertical rods producing nearly uniform turbulent effect throughout the entire thickness of the water layer. In each experimental run regular measurements of the conductivity (salinity) profiles were done and calculations of the vertical salt (mass) flux were performed. It turned out that in case of a sufficiently large density gradient, linear stratification gradually transforms into a stepwise form. In this case, the mass flux is a decreasing function of the density gradient, and this is the main condition for the formation of a stepwise fine structure, according to the Phillips [2] and Posmentier [3] mechanism. Thus, the results of the experiment confirmed the feasibility of this mechanism. The dependence of the vertical scale of the fine structure layers on the stratification parameters and turbulent effects is established.

The second example is a periodic vortex formation under an impact of a local constant mass flux a rotating fluid layer above an inclined bottom. In this laboratory experiment, conducted in a cylindrical tank on a rotating platform, the local constant rate source of water was located either at the inclined bottom or at the surface of a water layer of uniform density at a distance equal to half the radius of the tank from its center. The source was supplied with water of the same, or different density from the water density in the tank. During the action of the source an anticyclonic vortex column was formed above or below it. Having reached the critical diameter, the vortex column leaved the source and moved over the sloping bottom due to the topographic beta effect in the anticyclonic (“western”) direction, while a new column formed in its place, and so on. The periodic departure of eddies from the source was discovered and described in [4, 5, 6].

In the first example, the stepwise stratification of the initially linearly stratified water layer is formed due to the local suppression of turbulence in the areas of random stratification enhancement when the bulk Richardson number of the turbulent stratified media is higher than critical. As a result, a local decrease in vertical mass and further increase of density gradient is happening, while above and below the forming density interface the mass flux increases and the density gradient decreases. Estimates made for the oceanic pycnocline show that its fine structure can be produced by the analogous mechanism.

In the second example, self-oscillating process of formation of a chain of vortices from a local source of constant mass flux in rotating fluid upon an inclined bottom is caused because the velocity of the “western” drift of the vortex column produced by the source squarely increases with increasing of its diameter. Thus, the vortex column leaves the source periodically, giving place for the formation of a new column, and so on. The described mechanism may be related with the periodic formation of the intrathermocline vortex lenses in the ocean [7].

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Keywords: nonlinear effects, laboratory experiment, hydrodynamic processes, turbulent effect, vortex

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40.

SOME ASPECTS OF RIVER PLUME DYNAMICS

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Two problems related to the dynamics of river plumes in the coastal zone of the sea are considered. The first one is focused on the influence of river runoff-generated density stratification on the Ekman cross-shelf mass transport. A priori, even the sign of this influence is not obvious, since the two-layered structure created by the plume, on the one hand, increases the drift velocity in the surface layer, and on the other hand, reduces the thickness of the layer involved in the drift. To clarify this issue, a semi-analytical model of a river plume is proposed. It is shown that the presence of the two-layered stratification under certain conditions can significantly increase the intensity of cross-shelf transport. It is also shown that an intrinsic internal property of a river plume is periodic oscillations of the sea surface level with periods from several minutes to several hours. This is also confirmed by in-situ measurements. Analytical formulas are obtained that parameterize the values of the period and amplitude of these oscillations depending on the horizontal scale of the plume and the intensity of the river discharge.

Keywords: river plume dynamics, Ekman cross-shelf mass transport