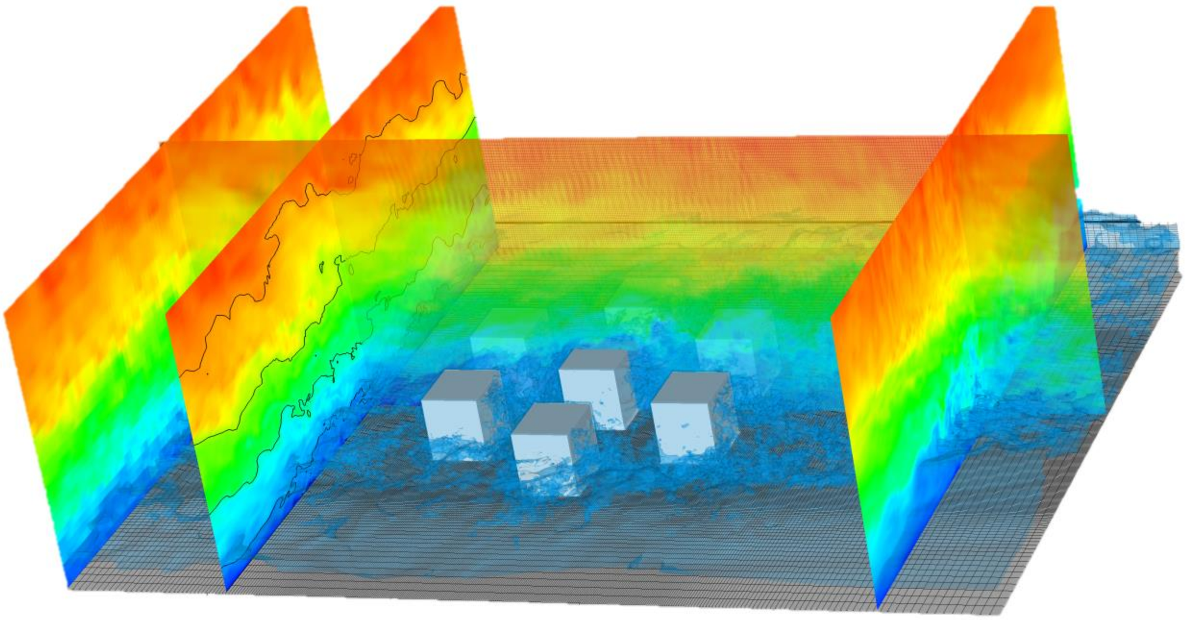
Novel approaches in observations and modeling of geophysical turbulence



6, 8 July 2019
Moscow, Russia

SCHEDULE

6 July, Saturday

Marchuk Institute of Numerical Mathematics,
Russian Academy of Sciences

12:00 – 13:00. A.V. Glazunov, E.V. Mortikov, K.V. Barskov, E.V. Kadantsev, S.S. Zilitinkevich, Yu.M. Nechepurenko, G.V. Zasko. *Large-scale structures in stably stratified turbulent shear flows*

13:00 – 13:30. G.V. Zasko, A.V. Glazunov, E.V. Mortikov, Yu.M. Nechepurenko. *Large-scale structures in stratified turbulent Couette flow and optimal disturbances*

13:30 – 14:00. V.B. Zametaev, A.R. Gorbushin. *Stationary secondary flow in a turbulent boundary layer and in free turbulent shear layers*

14:00 – 14:30. E.V. Kadantsev, E.V. Mortikov, A.V. Glazunov, S.S. Zilitinkevich. *On dissipation rates of turbulent second-order moments*

14:30 – 15:00. Coffee break

15:00 – 15:30. D.S. Gladskikh, V.M. Stepanenko, E.V. Mortikov. *On the simulation of inland waters in large-scale models: parameterization of mixing processes*

15:30 – 16:00. A.V. Debolskiy, E.V. Mortikov, A.V. Glazunov, E.V. Kadantsev, S.S. Zilitinkevich. *Evaluating single column parametrizations of turbulent vertical diffusion for use in GCMs*

16:00 – 16:30. K. Barskov, V.M. Stepanenko, I.A. Repina, A.Yu. Artamonov, A.V. Gavrikov. *The atmospheric boundary layer structure over the surface with large roughness elements*

16:30 – 17:00. A.D. Pashkin, I.A. Repina, V.M. Stepanenko, V.Yu. Bogomolov, S.V. Smirnov, A.E. Telminov. *Experimental study of the characteristics of atmospheric turbulence in the urban canyon*

17:00 – 17:30. E.V. Mortikov, A.V. Glazunov. *Supercomputer modelling of geophysical turbulence*

8 July, Monday

Research Computing Center,
Lomonosov Moscow State University

12:00 – 12:30. A.V. Debolskiy. *Dry and moist convection parameterization in atmospheric general circulation models*

12:30 – 13:30. S.S. Zilitinkevich, I.A. Repina. *Revision of conventional theory of unstably stratified turbulence*

13:30 – 14:30. Yu.I. Troitskaya. *On the coupled effect of sea-spray and foam to the aerodynamic resistance of the water surface at high winds*

14:30 – 15:00. Coffee break

15:00 – 15:30. M.I. Varentsov, P.I. Konstantinov, I.A. Repina, A.Yu. Artamonov, D.V. Blinov. *Urban heat islands and atmospheric boundary layer in the Arctic: experimental research and modeling*

15:30 – 16:00. P.A. Perezhogin, A.V. Glazunov. *Deterministic and stochastic parameterizations of subgrid eddies for ocean circulation models with intermediate resolution and their testing in NEMO ocean model*

16:00 – 16:30. D.S. Gladskikh, I.A. Soustova, Yu.I. Troitskaya. *A simple description of turbulent transport in a stratified shear flow taking into account the two-sided transformation of the kinetic and potential energies of turbulent pulsations*

16:30 – 17:00. G. Sahoo. *Transition from direct to inverse energy cascade in three-dimensional turbulence*

17:00 – 17:30. A.V. Chaplygin, N.A. Diansky, A.V. Gusev. *Load balancing method using Hilbert space-filling curves for INMOM (Institute of Numerical Mathematics Ocean Model)*

LARGE-SCALE STRUCTURES IN STABLY STRATIFIED TURBULENT SHEAR FLOWS

A.V. Glazunov[1,2], E.V. Mortikov[2,1], K.V. Barskov[3,2], E.V. Kadantsev[4], S.S. Zilitinkevich[4,5], Yu.M. Nechepurenko[1], G.V. Zasko[6]

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We analyzed the data of the numerical simulation of stably stratified turbulent flows with a velocity shift. It is shown that, along with chaotic turbulence, the flows contain large organized structures. In the temperature field, these structures appear as inclined layers with weakly stable stratification, separated by very thin layers with large temperature gradients. The existence of such layered structures in nature is indirectly confirmed by the analysis of field measurements. An increase of the turbulent Prandtl number with increasing gradient Richardson number was fixed in simulation data. The hypothesis is proposed that physical mechanism for maintaining of turbulence in supercritically stable stratification is connected with the revealed structures. It is proposed to use the theory of optimal perturbations to determine the spatial scale and the configuration of the identified organized structures.

LARGE-SCALE STRUCTURES IN STRATIFIED TURBULENT COUETTE FLOW AND OPTIMAL DISTURBANCES

G.V. Zasko[1], A.V. Glazunov[2,3], E.V. Mortikov[3,2], Yu.M. Nechepurenko[2]

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[2] Marchuk Institute of Numerical Mathematics, Russian Academy of Science
[3] Research Computing Center, Lomonosov Moscow State University

Direct numerical simulation data of a stratified turbulent Couette flow contains two types of organized structures: the rolls that arise at neutral and close to neutral stratifications, and the layered structures, which manifest themselves as the static stability increases. It is shown that both types of structures have spatial scales and forms that coincide with the scales and forms of the optimal disturbances of the simplified linear model of the Couette flow with the same Richardson numbers.

STATIONARY SECONDARY FLOW IN A TURBULENT BOUNDARY LAYER AND IN FREE TURBULENT SHEAR LAYERS

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A two-dimensional (2D) turbulent boundary layer (TBL) of a viscous incompressible fluid flowing past the surface of a flat plate [1], a 2D turbulent mixing layer of two fluid streams [2] and a 2D turbulent jet flowing into a submerged space [3] are considered. The characteristic Reynolds number of the flow, calculated from a given length, is assumed to be large, and the thickness of the turbulent layer is small. To analyze the complete Navier-Stokes equations, a multi-scale method was used, which allowed us to find and investigate the stationary secondary flow inside the turbulent layers, without using any additional hypotheses. The mechanism for the transfer of kinetic energy from the zone of maximum longitudinal velocity to the zone of turbulence production in the TBL near the streamlined surface, which is a self-induced entrainment of fluid from an external flow, is revealed. It is shown that the secondary stationary flow is viscous throughout the entire thickness of the turbulent layer, which suggests a large-scale viscosity and confirms the well-known physical concept of "turbulent viscosity", in contrast to the small viscous size in the zone of turbulence production. In a two-dimensional turbulent jet, a self-induced outflow of fluid transfers energy from the jet core to the periphery to the zone of turbulence production. Minimum pressure inside turbulent layers detected. Secondary stationary solutions were found analytically for the normal and longitudinal velocity components. The velocities found theoretically are compared with experimental averaged profiles in the TBL, in the mixing layer and in the jet.

1. Zametaev V.B., Gorbushin A.R. Stationary secondary flow in a turbulent boundary layer. *Int. Conf. on High-Speed Vehicle Science and Technology (HiSST*), 2018.
2. Zametaev V.B., Gorbushin A.R., Lipatov I.I. Steady secondary flow in a turbulent mixing layer. *Int. J. of Heat and Mass Transfer*, 2019. V. **132**. P. 655–661.
3. Gorbushin A.R., Zametaev V.B., Lipatov I.I. Stationary secondary flow in a plane turbulent free jet. *Fluid Dynamics*, 2019. V. **54**, N 2. P. 244-256.

ON DISSIPATION RATES OF TURBULENT SECOND-ORDER MOMENTS

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Most of the currently used turbulence closure theories employ the concept of downgradient turbulent transport, implying that vertical turbulent fluxes of momentum $\tau_{x,y}$, potential temperature F_z and other scalars are proportional to their mean gradients. The proportionality coefficients in such relations, called eddy viscosity K_M, eddy conductivity K_H and eddy diffusivity K_D, are just the unknowns to be determined. Recently Zilitinkevich et al. (2013) have developed a new energy- and flux-budget (EFB) turbulence closure based on the budget equations for the basic second moments. Then, the flux-budget equations are used instead of traditional postulation of turbulent exchange coefficients as proportional to the turbulent velocity scale multiplied by the mixing-length scale.

To comprehensively validate the EFB turbulence closure we performed direct numerical simulation (DNS) of stably stratified Couette flow. The results disclosed quite unexpected fact. According to the conventional vision of turbulence originated to Kolmogorov-1941, all turbulent time scales defined as the ratios of the second moment in question to its dissipation rate are assumed to be proportional to each other, so that their ratios are just universal constants. However, according to our DNS, this is the case only for the pair: total turbulent kinetic energy (TKE) and vertical turbulent flux of momentum. For any other pairs, the ratios of dissipation time scales depend on stratification and represent functions of a dimensionless stability parameter such as gradient Richardson number, Ri, or flux Richardson number, Ri_f.

Following Zilitinkevich et al. (2019) we propose new formulation of the dissipation rates of the major second moments and present the advanced version of EFB turbulence closure accounting for the just revealed stability dependencies of different dissipation time scales.

1. Zilitinkevich S., Elperin T., Kleeorin N., Rogachevskii I., Esau I. A Hierarchy of Energy- and Flux-Budget (EFB) Turbulence Closure Models for Stably-Stratified Geophysical Flows. *Boundary-Layer Meteorol*, 2013. V. **146**. P. 341-373.
2. Zilitinkevich S., Druzhinin O., Glazunov A., Kadantsev E., Mortikov E., Repina I., Troitskaya Y. Dissipation rate of turbulent kinetic energy in stably stratified sheared flows. *Atmos. Chem. Phys.*, 2019. V. **19**. P. 2489-2496, https://doi.org/10.5194/acp-19-2489-2019.

ON THE SIMULATION OF INLAND WATERS IN LARGE-SCALE MODELS: PARAMETERIZATION OF MIXING PROCESSES

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[3] Faculty of Geography, Lomonosov Moscow State University
[4] Marchuk Institute of Numerical Mathematics, Russian Academy of Science

The work is devoted to the study of thermohydrodynamic characteristics of inland waters associated with turbulent mixing and relevant to the problems of meteorology, climatology and hydrology. To describe such characteristics, numerical models of different detailization are used, having their own features and advantages. We consider the one-dimensional LAKE model [1, 2] with parameterization of the horizontal pressure gradient well-suited for implementation in large-scale models and climate models. We additionally use the three-dimensional hydrostatic model [3, 4] for verification of 1D model ability to correctly reproduce mixing processes by simulating turbulence in inland waters of various horizontal sizes and under different initial conditions. The effects of internal wave oscillations on the mixing dynamics are analyzed. In addition, the authors implemented the parameterization of the turbulent Prandtl number into the 3D model.

1. Stepanenko V., Mammarella I., Ojala A., Miettinen H., Lykosov V., Timo V. LAKE2.0: a model for temperature, methane, carbon dioxide and oxygen dynamics in lakes. *Geosci. Model Dev.*, 2016. V. **9**, N 5. P. 1977–2006.
2. Stepanenko V. M. Seiche parameterization for a one-dimensional lake model. *Trudy MIPT*, 2018. V. **10**, N 1. P. 97-111 (In Russian).
3. Mortikov E.V. Numerical simulation of the motion of an ice keel in stratified flow. *Izv. Atmos. Ocean. Phys.*, 2016. V. **52**. P. 108-115.
4. Mortikov E.V., Glazunov A.V., Lykosov V.N. Numerical study of plane Couette flow: turbulence statistics and the structure of pressure-strain correlations. *Rus. J. of Num. Analysis and Math. Modelling*. 2019. V. **34**, N 2. P. 119-132.

EVALUATING SINGLE COLUMN PARAMETRIZATIONS OF TURBULENT VERTICAL DIFFUSION FOR USE IN GCMS

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In preparation for a new version of INM CM (Institute of Numerical Mathematics Climate Model) we conduct an evaluation of several k - e (either with standard dissipation equation or relaxation one) based on extensive set of DNS (Direct Numerical Simulation), LES (Large-Eddy Simulation), and laboratory experiments datasets as well as previously introduced benchmarks such as GABLS1 and GABLS2. Evaluation was carried out within a uniform numerical formulation. The role of stability functions, extended dissipation equation and steady-state solutions on closure performance were also evaluated.

THE ATMOSPHERIC BOUNDARY LAYER STRUCTURE OVER THE SURFACE WITH LARGE ROUGHNESS ELEMENTS

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The report presents the results of an experimental study of the atmospheric boundary layer structure over the surface with large roughness elements and inhomogeneous horizontal aerodynamic and temperature roughness distribution. Specialized field experiments data on small lakes surrounded by forest were taken for analysis. These conditions cannot be considered homogeneous, thus using MOST to compute heat exchange in the surface layer may lead to significant errors. The momentum flux increases with height as an approximately linear dependence, and at the surface the momentum flux tends to 0, so that the main contribution to the momentum exchange is made not by the surface, but by the forest edge at the forest-lake border. Two heat-flux formation regimes in the surface layer were clearly distinguished. The contribution of warm air advection in the boundary layer, as well as large velocity shear at the tree height, are considered. It is assumed that there are lake-scale and canopy-scale secondary circulations emerging. One effect of the secondary circulations is the formation of persistent vertical up- and downdrafts near the forest-lake transitions that drive complex persistent patterns of the horizontal and vertical advection of scalars. It is also shown that the turbulent kinetic energy budget terms associated with horizontal inhomogenety can reach values comparable to the terms responsible for the main contribution to the transfer of turbulent kinetic energy over homogeneous surfaces. It is shown that the eddy-covariance sensible and latent heat fluxes correlate well with fluxes estimated from snow and ice heat balance even above inhomogeneous landscapes.

EXPERIMENTAL STUDY OF THE CHARACTERISTICS OF ATMOSPHERIC TURBULENCE IN THE URBAN CANYON

A.D. Pashkin[1,2], I.A. Repina[1,2], V.M. Stepanenko[2], V.Yu. Bogomolov[3,2], S.V. Smirnov[3], A.E. Telminov[3]

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Parametrizations which traditionally are used in atmospheric modeling, energy-balance and biogeochemical calculations are based on the Monin-Obukhov similarity theory (MOST). MOST assumes a uniform horizontal distribution of aerodynamic and temperature roughness of an underlying surface. These conditions are violated in heterogeneous landscapes, what requires special experiments to establish the limits of MOST applicability. Investigation of the atmospheric boundary layer (ABL) turbulent structure within urban area is an important task. The aim of our work is to establish links between statistical characteristics of turbulence in the urban landscape under different regimes of ABL. Measurements are made on the basis of the Geophysical observatory of the Institute of monitoring of climatic and ecological systems SB RAS, Tomsk. The measurement system includes five sonic anemometers located at different points and heights. Now the experiment works in a test mode and the report will present its first results.

SUPERCOMPUTER MODELLING OF GEOPHYSICAL TURBULENCE

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An overview of the numerical model, developed at Research Computing Center of Lomonosov Moscow State University and Marchuk Institute of Numerical Mathematics, for simulations of geophysical turbulence is given. The model uses three approaches for turbulence modelling: direct numerical simulation (DNS), large-eddy simulation (LES) and Reynolds averaged Navier-Stokes (RANS). Numerical aspects and implementation of the model for modern massively parallel supercomputers is discussed.

DRY AND MOIST CONVECTION PARAMETERIZATION IN ATMOSPHERIC GENERAL CIRCULATION MODELS

A.V. Debolskiy[1,2]

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Presented talk is a brief review of method and techniques contemporary used in climate and weather forecast models for parametrization of dry and moist shallow convection in atmosphere. A specific focus on how they are coupled with vertical turbulent diffusion scheme is made.

REVISION OF CONVENTIONAL THEORY OF UNSTABLY STRATIFIED TURBULENCE

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Current theory of turbulence in stratified sheared flows is based on the conventional paradigm postulating the only forward cascades of turbulent kinetic energy (TKE) and other properties of turbulence from larger to smaller scales, towards viscous dissipation. The paradigm is generally attributed to Kolmogorov (1941a,b, 1942), although his vision concerned the neutrally stratified flows. Moreover, it was extended to stratified flows just as self-evident, without proof.

This paper demonstrates that the conventional paradigm and all theories based on it are not applicable to unstably stratified turbulence. Instead, we reveal and confirm experimentally the following picture. The shear-generated 3-dimensional (mechanical) component of turbulence really consists of dynamically unstable *eddies* that break down to produce smaller eddies, thus performing the *forward cascade*: towards viscos dissipation of mechanical TKE. However, the buoyancy-generated (convective) turbulence consists of vertical plumes that merge to produce larger plumes, thus performing *inverse cascade*: from smaller to larger scales toward the conversion of convective TKE into kinetic energy of large-scale self-organised convective structures (cells or rolls in geophysical convective boundary layers).

As a result all conventional theories, in particular, the Monin-Obukhov Similarity Theory (MOST) of the surface-layer turbulence, yield erroneous formulations of *horizontal TKE, horizontal turbulent fluxes of heat and other scalars, and the dissipation rates of TKE and all other statistical moments of turbulence* (Zilitinkevich 1973, 2013; Zilitinkevich and Repina, 2019).

At the same time, conventional theories yield right formulations of the most practically important parameters: the TKE of vertical velocity fluctuations and the coefficients of vertical turbulent exchange. The paradox is explained by the fact that the *real rate of conversion* of vertical TKE is mathematically indistinguishable from the *imaginary rate of its viscous dissipation*. This lucky confusion is just the reason why these theories remained unquestioned so long.

1. Kolmogorov A.N. Local structure of turbulence in non-compressible fluid at very large Reynolds numbers. *Doklady AN SSSR*, 1941a. V. **30**, N 4. P. 299-303.
2. Kolmogorov A.N. Dispersion of energy in locally isotropic turbulence. *Doklady AN SSSR*, 1941b. V. **32**, N 1. P. 19-21.
3. Kolmogorov A.N. Equations of turbulent motion of non-compressible fluid. *Izvestiya AN SSSR*, Series Physics, 1942. V. **6**, N 1-2. P. 56-58.
4. Zilitinkevich S.S. Shear convection. *Boundary-Layer Meteorol.*, 1973. V. **3**. P. 416-423.
5. Zilitinkevich S.S. *Atmospheric Turbulence and Planetary Boundary Layers*. Fizmatlit, Moscow, 2013. 248 P.
6. Zilitinkevich S., Repina I. Paper in preparation (2019).

ON THE COUPLED EFFECT OF SEA-SPRAY AND FOAM TO THE AERODYNAMIC RESISTANCE OF THE WATER SURFACE AT HIGH WINDS

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Sea spray is a typical element of the marine atmospheric boundary layer (MABL) of large importance for marine meteorology, atmospheric chemistry and climate studies. They are considered as a crucial factor in the development of severe storms, since they can significantly enhance exchange of mass, heat and momentum between the ocean and the atmosphere. This exchange is directly provided by spumedroplets withthe sizes from 10 microns to a few millimeters mechanically torn off the crests of a breaking waves and fall down to the ocean due to gravity. However, the fluxes associated with the sprayare strongly uncertain, since even the mechanism of spume droplets' formation in extreme winds is unknown. Basing on high-speed video here we identify it as the bag-breakup mode of fragmentation of liquid in gaseous flows known in a different context. This regime is characterized by inflating and consequent bursting of the short-lived objects, bags, comprising sail-like water films surrounded by massive liquid rims then fragmented to giant droplets with sizes exceeding 500 micrometers. From first principles of statistical physics we develop statistical description of these phenomena and show that at extreme winds the bag-breakup is the dominant spray-production mechanism.

These findings provide a new basis for understanding and modeling of the air-sea exchange processes at extreme winds. Boosting the exchange processes by giant droplets can provide the pronounced increase in the air-sea thermal energy flux crucial for the observed fast intensification of hurricanes. We also discuss how the combined effect of spume droplets torn from the crest of waves by wind and foam on the water surface can explain the hitherto enigmatic reduction of the surface drag coefficient at extreme winds.

URBAN HEAT ISLANDS AND ATMOSPHERIC BOUNDARY LAYER IN THE ARCTIC: EXPERIMENTAL RESEARCH AND MODELING

M.I. Varentsov[1,2,3], P.I. Konstantinov[1], I.A. Repina[2,1], A.Yu. Artamonov[2], D.V. Blinov[3]

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[3] Hydrometeorological Research Center

The presented study is devoted to the urban heat island (UHU) research in the Russian Arctic cities in winter. The UHI effect is well studied for mid-latitudes, but until recently, it remained practically unexplored for the arctic and subarctic climate. At the same time, drivers and conditions of the urban microclimate formation in the Arctic are strongly different from temperate latitudes, especially in winter, in the conditions of the polar night and the predominance of stable stratification of the atmosphere. Short experimental campaigns conducted by the authors since 2013, and long-term observations based on the UHIARC network created by the authors (Konstantinov et al., 2018; Varentsov et al., 2018) revealed that in winter in arctic cities UHI is clearly expressed in conditions of clear, calm and frosty weather. Temperature differences between the city and the background can reach 6-7 ° C.

The recent experimental studies in the winter of 2018/19 were aimed to in-depth investigation of the relationship between the arctic UHIs and processes in the atmospheric boundary layer.

Intensive measurement campaign in the city of Nadym in December 2018 combined the monitoring of the surface temperature in the city and its surroundings using a network of thermal sensors and the monitoring of the thermal structure of the lower atmosphere using a microwave MTP-5 microwave profiler. A quadrocopter with thermal sensors was also used for observations. Results revealed that the near-surface UHI is most pronounced under conditions of strong temperature inversions in the lower 100 m. Since the simulation of highly stable stratification remains a problem of modern atmospheric models, the obtained series of observations open up wide possibilities for studying this problem in more detail. In our study, this problem is considered on the example of the mesoscale model COSMO.

1. Konstantinov P., Varentsov M., Esau I. A high density urban temperature network deployed in several cities of Eurasian Arctic. *Environ. Res. Lett.*, 2018. V. **13**, N 7. P. 75007.
2. Varentsov M., Konstantinov P., Baklanov A., Esau I., Miles V., Davy R. Anthropogenic and natural drivers of a strong winter urban heat island in a typical Arctic city. *Atmos. Chem. Phys*. 2018. V. **18**, N 23. P. 17573–17587.

DETERMINISTIC AND STOCHASTIC PARAMETERIZATIONS OF SUBGRID EDDIES FOR OCEAN CIRCULATION MODELS WITH INTERMEDIATE RESOLUTION AND THEIR TESTING IN NEMO OCEAN MODEL

P.A. Perezhogin[1,2], A.V. Glazunov[1,2]

[1] Marchuk Institute of Numerical Mathematics, Russian Academy of Science
[2] Research Computing Center, Lomonosov Moscow State University

In this work, we investigate applying of kinetic energy backscatter (KEB, [1], [2]) parameterizations to enhance mesoscale dynamics in NEMO ocean model, in Double Gyre configuration [3]. The model we tested has 1/4 degree resolution which corresponds to the “eddy-permitting” resolution, i.e. mesoscale eddies are badly resolved at the grid. KEB parameterizations simulate impact of unresolved (“subgrid”) eddies. We have tested KEB parameterizations of two types: stochastic and negative viscosity (which is deterministic). To assess quality of KEB impact in coarse-resolution model, we compare coarse models with respect to “eddy-resolving” one (1/9 degree resolution). KEBs allow to make eddy meridional heat flux, mean sea surface temperature (SST) and meridional overturning circulation (MOC) in coarse model close to the corresponding characteristics in high-resolution model (1/9 degree).

The work was partly funded by Russian Science Foundation (№ 17-17-01210, development of subgrid turbulence models) and Russian Foundation for Basic Research (№ 18-05-60184, calculations with idealized ocean model and results analysis).

1. Jansen M. F., Held I. M. Parameterizing subgrid-scale eddy effects using energetically consistent backscatter. *Ocean Modelling*, 2014. V. **80**. P. 36-48.
2. Jansen M. F., Held I. M., Adcroft A., Hallberg R. Energy budget-based backscatter in an eddy permitting primitive equation model. *Ocean Modelling*, 2015. V. **94**. P. 15-26.
3. Lévy M., Klein P., Tréguier A. M., Iovino D., Madec G., Masson S., Takahashi K. Modifications of gyre circulation by sub-mesoscale physics. *Ocean Modelling*, 2010. V. **34**, N 1-2. P. 1-15.

A SIMPLE DESCRIPTION OF TURBULENT TRANSPORT IN A STRATIFIED SHEAR FLOW TAKING INTO ACCOUNT THE TWO-SIDED TRANSFORMATION OF THE KINETIC AND POTENTIAL ENERGIES OF TURBULENT PULSATIONS

D.S. Gladskikh[1], I.A. Soustova[1], Yu.I. Troitskaya[1]

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On the basis of the kinetic approach, the expressions for turbulent fluxes of momentum, mass, energy, and other thermohydrodynamic quantities in a stratified medium [1], the form of which is determined by the assumption that the distribution function is close to Gaussian. The turbulence in a shear stratified flow is considered. The dependence of the turbulent Prandtl number on the gradient Richardson number is presented, which can be used in the k-ε turbulence model in order to take into account stratification when calculating the thermo-hydrodynamic regime of inland waters, the ocean and the atmosphere.

1. Ostrovsky L.A., Troitskaya Yu.I. The model of turbulent transport and the dynamics of turbulence in a stratified shear flow. *Izv. Atmos. Ocean. Phys.*, 1987. V. **3**. P. 1031-1040.

TRANSITION FROM DIRECT TO INVERSE ENERGY CASCADE IN THREE-DIMENSIONAL TURBULENCE

G. Sahoo[1]

[1] University of Helsinki

Three dimensional turbulent flows are different from two dimensional flows in a very fundamental manner; while energy transfers from large scales to small scales in 3D it switches the direction in 2D. However many flows in nature, like atmospheric and oceanic flows, could not be strictly categorized to either 3D or 2D. We show that the nonlinear dynamics of the Navier-Stokes equations could be controlled to observe a discontinuous transition in energy transfer in three-dimensional turbulence. Using a control parameter that could enhance or suppress some of the basic interactions among scales in turbulent flows, as it naturally occurs in flows under different boundary conditions or sustaining mechanism, we show that at a critical point energy transfer changes the directi on even though the dimensionality and symmetries of the system were not touched. Such a discontinuous transition in direction of energy transfer suggests turbulent flows as out-ofequilibrium systems very close to criticality.

LOAD BALANCING METHOD USING HILBERT SPACE-FILLING CURVES FOR INMOM (INSTITUTE OF NUMERICAL MATHEMATICS OCEAN MODEL)

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This paper presents a method of load balancing using Hilbert space-filling curves applied to a parallel sigma-coordinate ocean model INMOM (Institute of Numerical Mathematics Ocean Model). Due to land points in the computational grid, the load balancing is an especially urgent task. The method of load balancing using Hilbert space-filling curves is chosen as one of such methods. Computational domain is divided into small blocks and multiple blocks can be distributed to each node. This approach has several advantages: a more flexible decomposition into arbitrary rectangular domains, the most efficient work with cache memory. Also this approach allows implement the considered load balancing algorithm in such a complex program as the ocean model without any difficulty. The method of load balancing was tested for the Sea of Azov with a resolution of 250 meters. The method was tested for the three-dimensional sigma-coordinate ocean model INMOM and also for two-dimensional shallow water model. The paper demonstrates the greater efficiency of this method in comparison with the uniform partitioning without load balancing. It is shown that this method is a good alternative to the METIS standard library.