80th International Scientific Conference of the University of Latvia 2022

UNIVERSITY OF LATVIA

UNIVERSITY OF LATVIA
FACULTY OF PHYSICS, MATHEMATICS AND OPTOMETRY

80th International Scientific Conference

University of Latvia

MATHEMATICAL METHODS FOR RESEARCH EXCELLENCE

Book of Abstracts

Latvijas Universitātes

80. starptautiskās zinātniskās konference

Matemātiskās metodes pētījumu izcilībai

Tēžu krājums

2022

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Mathematical Methods for research excellence

Friday, 28th January **2022, 1.00 PM**, online

Programma/Programme

Vadītājs/Chair: Vadims Geža		
13.00–13.10	**Uldis Bethers** *Institute of Numerical modelling, University of Latvia*	**Atklāšana** **Opening**
13.10–13.50	**asoc. prof. Jānis Priede** *University of Latvia* *Conventry University, UK*	**Ar vienu garuma mērogu stohastiski ierosinātas divdimensionālas turbulences attīstība galīga izmēra sistēmā** **Development of two-dimensional turbulence in finite-size system driven by a mono-scale stochastic forcing**
13.50-14.10	**Jānis Bajārs[1], Juan F. R. Archilla[2]** *[1] University of Latvia* *[2] University of Seville, Spain*	**Solitona-elpotāju spektrālās īpašības 2D sešstūra kristāla režģī** **Spectral properties of soliton-breathers in a 2D hexagonal crystal lattice**
14.10-14.30	**Staņislavs Gendelis, Jevgēnijs Teličko, Mihaēls Doroņins** *University of Latvia*	**Dažādas orientācijas saules paneļu faktiskās efektivitātes mērījumi Rīgas klimatiskajos apstākļos** **Measurements of the actual efficiency of PV panels of different orientations in Riga climatic conditions**
14.30-14.50	**Leo Trukšāns, Andris Lapiņš, Elīna Kalniņa, Juris Vīksna** *University of Latvia*	**Kvantiskas atslēgu ģenerēšanas integrācija IPSec protokolā** **Integration of quantum key distribution in IPsec protocol**
14.50-15.20	**Coffee break, discussions**	

15.20–15.40	**Kirils Surovovs**[1], **Anatoly Kravtsov**[2], **Jānis Virbulis**[1] [1] *University of Latvia* [2] *SC «KEPP EU»*	**Heterogēna sildīšanas sistēma Si kristālu audzēšanai ar pjedestāla metodi** **Heterogeneous heating system for Si crystal growth with pedestal method**
15.40–16.00	**Rolands Aleksandrs Rudenko, Andrejs Timuhins, Uldis Bethers, Juris Seņņikovs, Vilnis Frišfelds, Daiga Cepīte-Frišfelde** *University of Latvia*	**Rīgas jūras līča klimatisks modelis** **Climatic model of the Gulf of Riga**
16.00-16:20	**Aleksandrs Jegorovs, Valters Dzelme** *University of Latvia*	**MHD skaitlisko aprēķinu eksperimentāla validācija** **Experimental validation of MHD numerical simulations**
16.20-16.40	**Maksims Pogumirskis, Tija Sīle** *University of Latvia*	**Sezonālo gaisa temperatūras prognožu kvalitātes avoti Latvijā** **Sources of seasonal air temperature forecast skill in Latvia**
16.40-17.00	**Dagis Daniels Vidulejs, Kirils Surovovs** *University of Latvia*	**Gaisa plūsmas un aerosola koncentrācijas modelēšana iekštelpās: skaitliskie aspekti** **Airflow and aerosol concentration modeling indoors: numerical aspects**
17.00	**Noslēgums, diskusijas** **Conclusions, discussions**	

SATURS

DEVELOPMENT OF TWO-DIMENSIONAL TURBULENCE IN FINITE-SIZE SYSTEM DRIVEN BY A MONO-SCALE STOCHASTIC FORCING

Jānis Priede
Department of Physics, University of Latvia, Riga, LV-1004, Latvia,
Fluid and Complex Systems Research Centre, Coventry University, Coventry, CV1 5FB, United Kingdom
E-mail: *J.Priede@lu.lv*

Distinctive feature of 2D turbulence is the existence of two inviscid quadratic invariants – one of velocity and the other of vorticity, which, respectively, represent the energy and enstrophy of the flow. It is well known that both these quantities cannot be conserved simultaneously as the bigger vortices disintegrate under the action of inertia into progressively smaller vortices. For both the energy and enstrophy to be conserved in the inertial flow regime, one quantity has to be transferred to the larger vortices while the other one is transferred to the smaller ones. In 2D turbulence, it is the energy which is transferred from small to large scales while the enstrophy is transferred in the opposite direction. Thus, in stark contrast to 3D turbulence, where the larger vortices progressively disintegrate into smaller vortices as the energy cascades down from the former to the latter, in 2D turbulence, small random vortices tend to produce large vortices. However, there is no still unanimity about the physical mechanism behind this self-organization which is often attributed to the clustering and merging of vortices with the same direction of rotation. It is also not clear whether 2D dimensional turbulence can reach a quasi-stationary saturated state without additional large-scale dissipation mechanism when there is a continuous flow of energy into large vortices of limited size. In the present study, recent results are presented of direct numerical simulation of 2D turbulence which is driven in a periodic rectangular domain by a stochastic forcing. The latter is applied at an intermediate length scale with a constant wave number k_f. The stochasticity of forcing, which is implemented using a pseudo-random number generator, ensures that energy and enstrophy are injected into the flow at a prescribed statistically constant rate. The use of single wave number, in turn, eliminates nonlinear interaction between the forced modes. The wave number k_f is chosen as a multiple of 25,which permits simultaneous forcing along 10 distinct directions of the wave vector $\overrightarrow{k_f} = (k_x, k_y)$ so increasing the isotropy of the flow. The intensity of forcing is characterized by the wave number kd at which the dissipation of enstrophy is expected to become significant.

Numerical results show that the flow consists of mono-sized vortices with the wave number k_f only up to $k_d \approx 1.4k_f$. At this critical point, the spatially monochromatic base flow becomes unstable with respect to vortices of other sizes which spontaneously emerge. This flow is weakly turbulent and looks like a white noise featuring a nearly uniform and isotropic modal energy distribution. As the forcing is increased further, the energy spectrum becomes broader until $k_d \approx 1.7k_f$. At this second critical point, the modal energy distribution abruptly changes from uniform to $E_k \sim k^{-2}$. This transition marks the emergence of large scale vortices, however the vorticity distribution still remains virtually featureless. With the further increase of forcing, the energy continues to pile-up at the largest available scale. This results in a pair of diagonally located vortices which move along a random-walk-like trajectory in the turbulent background flow. The diagonal arrangement of large vortices means that the associated flow consists of modes with the same parity of both wave vector components. We use this mode symmetry to separate the turbulent background flow from the coherent flow component. The latter still contains turbulent fluctuations which are removed by time-averaging in the co-moving frame of reference. In this way we find that the vorticity varies nearly logarithmically with the distance from the centres of the two large vortices except the core regions with the size comparable to that of the forced small-scale vortices. As logarithmic variation corresponds to a constant radial flux of vorticity, it means that the conversion of energy from the small to large scales occurs in the cores of the two large vortices. This results in a modal energy density spectrum of the coherent flow component which scales as $E_k \sim k^{-6}$. The background turbulent flow features an energy density spectrum with $E_k \sim k^{-4}$ which is characteristic for the direct enstrophy cascade at small scales. This classical spectrum clearly emerges at relatively moderate numerical resolutions with $256^2 - 512^2$ Fourier modes. Since obtaining a fully saturated turbulent flow regime often requires thousands of vortex turnarounds and, thus, long computational times, the spectral numerical code was implemented on the Graphics Processing Units.

SPECTRAL PROPERTIES OF SOLITON-BREATHERS IN A 2D HEXAGONAL CRYSTAL LATTICE

Jānis Bajārs, Juan F. R. Archilla
[1] *Faculty of Physics, Mathematics and Optometry, University of Latvia, Jelgavas Street 3, Riga, LV-1004, Latvia*
[2] *Group of Nonlinear Physics, Universidad de Sevilla, ETSII, Avda Reina Mercedes s/n, 41012-Sevilla, Spain*
E-mail: janis.bajars@lu.lv

In this work we study spectral properties of *intrinsic localized modes* (ILM), also known as *discrete breathers* (DBs), in a generic 2D hexagonal crystal lattice model of muscovite mica [1, 2]. For the first time the theory of exact traveling waves is extended to two dimensions and can also be easily extended to three dimensions [3]. Generically, these waves are *pterobreathers*, that is, traveling DBs with wings [4]. Exact time-periodic with spatial translation traveling waves in the $\omega - k$ representation are within resonant planes, each plane corresponding in the moving frame to a single frequency. These frequencies are integer multiples of a frequency called the fundamental frequency. A discrete breather is within a resonant plane called the breather plane and has a single frequency in the moving frame. The intersection of the resonant planes with the phonon surfaces produce co-traveling wings with a small set of frequencies. The $\omega - k$representation of a numerically obtained exact traveling wave is shown in Fig. 1, where the traveling wave consists of a breather and a soliton traveling together; thus, the name *soliton-breather*. Fig. 1 demonstrates the Fourier transform in two spatial variables and time (XYTFT) of the atomic displacements in the x-axis coordinate direction, that is, in the direction of travel, together with two branches of the phonon dispersion relation obtained from the linearized equations. To obtain such frequency-momentum representation is fundamental to be able to interpret possible signatures of localized nonlinear waves in physical spectra of real crystals.

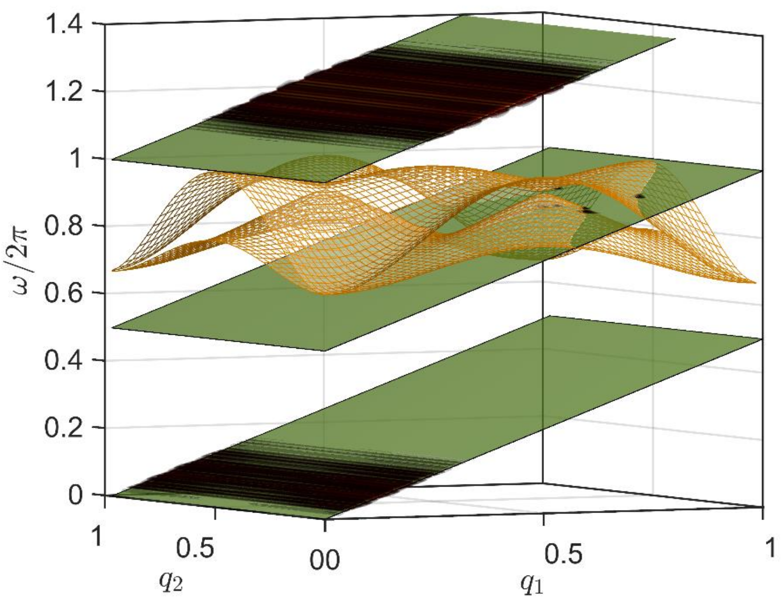

Fig. 1. Isosurface of the XYTFT of an exact soliton-breather, together with the resonant planes and the phonon surfaces

Acknowledgements:

J. Bajārs acknowledges support from PostDocLatvia grant No.1.1.1.2/VIAA/4/20/617. J.F.R. Archilla thanks projects PAIDI 2021/FQM-280 and MICINN PID2019-109175GBC22. He also acknowledges a travel grant from VIPPITUS-2020 and the University of Latvia for hospitality.

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MEASUREMENTS OF THE ACTUAL EFFICIENCY OF PV PANELS OF DIFFERENT ORIENTATIONS IN RIGA CLIMATIC CONDITIONS

Staņislavs Gendelis, Jevgēnijs Teličko, Mihaēls Doroņins
Institute of Numerical Modelling, Faculty of Physics, Mathematics and Optometry. University of Latvia, Jelgavas 3, Riga, Latvia
E-mail: stanislavs.gendelis@lu.lv

Polycrystalline photovoltaic (PV) panels of various orientations were installed in Riga, Latvia, for long-term monitoring and determination of the energy production and efficiency in real operation conditions. Measured data of the last 3 years of the monitoring (2019-2021) summarised in this work. Analysis of the available energy and environmental data allows for the quantitative estimation of actual energy productions and following efficiency calculation depending on spatial orientation with following comparison with manufacturer's values. The temperature dependence of the PV module's efficiency over the year is also analysed, showing a good agreement with theoretical temperature coefficient value.

Whereas the actual energy production depends significantly on cloudiness, which is highly variable in Baltic coastal climate, it influences solar irradiation over time, resulting in high variations in annual energy produced (see Fig.1). Energy production in the winter months accounts about 10% of the annual production for optimized orientation and less than 5% in the case with almost horizontal panels.

The choice of best orientation for PV panels for use in Latvia can be determined based on the following criteria:

- for the whole year – south 40°;
- for winter – south 90°;
- for summer – east/west 13° or south 40°.

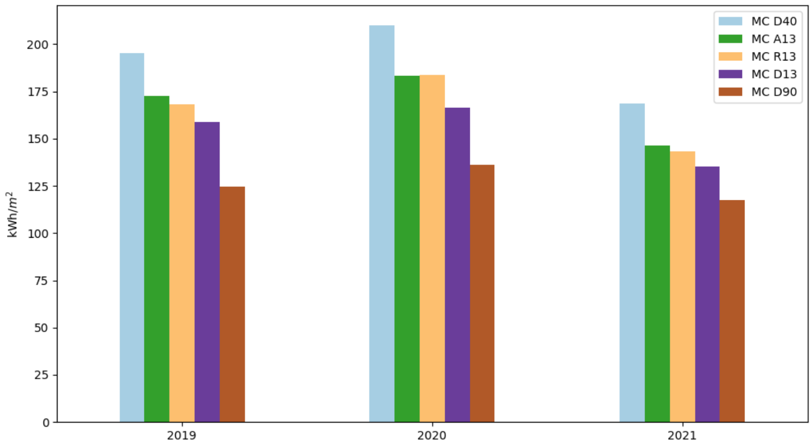

Fig. 1. Annual energy produced by different oriented PV panels in years 2019-2021

Acknowledgements:

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INTEGRATION OF QUANTUM KEY DISTRIBUTION IN IPSEC PROTOCOL

Leo Trukšāns, Andris Lapiņš, Elīna Kalniņa, Juris Vīksna
Institute of Mathematics and Computer Science, University of Latvia, Raiņa Bulvāris 29, Riga, Latvia
E-mail: leo.truksans@lumii.lv

Quantum Key Distribution (QKD) is a mechanism for agreeing on encryption keys that relies on the properties of quantum mechanics to ensure that keys have not been eavesdropped or modified by a third party. Whilst not yet widespread, commercial devices providing point-to-point QKD links have recently become available and can provide an additional layer of communication security.

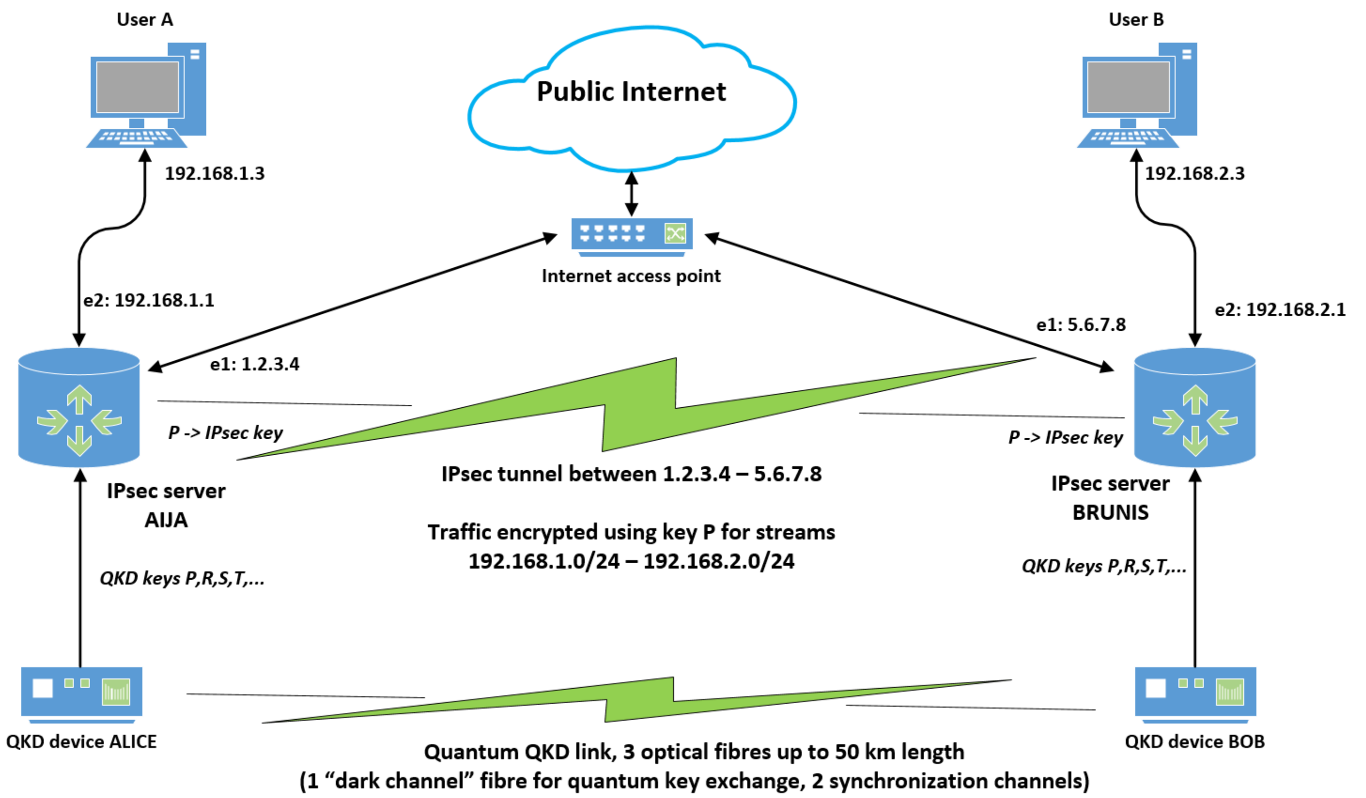

Fig.1. Scheme of the prototype integrating QKD in authentication and key exchange phases of IPsec protocol

With proper implementations the existing secure communication and encryption techniques are considered to be capable to provide security against all types of realistically implementable attacks. However, practically all widely used asymmetric encryption and digital signature algorithms (on which any cryptographic protocol essentially depends) are known to be insecure against attacks by quantum algorithms, which are known to solve factorization and discrete logarithm problems, on which these algorithms are based, in polynomial time. Although no sufficiently powerful quantum computers to implement such attacks have yet become available, the readiness for their appearance in the medium-term future is already regarded as an emergency that needs to be addressed.

QKD by itself does not give a satisfactory solution to this challenge, since it does not directly provide an authentication mechanism to communicating parties. Nevertheless, its complete security against eavesdropping attacks is a valuable asset, and use of QKD methods in combination with post-quantum encryption and digital signature algorithms (which are based on computational problems that remain hard also for quantum computers and currently are actively being developed) has a good potential to provide cryptographic solutions with an adequate level of security. Design of cryptographic protocols that incorporate either QKD or post-quantum encryption algorithms, or both, is currently very active research and development area. In this work we describe a modification of the IPsec protocol that uses QKD for the key exchange phase of the protocol (Fig. 1), thus providing additional security against eavesdropping attacks. There is a working prototype implementation that uses two Clavis 3 nodes for quantum key exchange and provides integration of QKD in IPsec protocol used by the Linux Ubuntu operating system.

HETEROGENEOUS HEATING SYSTEM FOR SI CRYSTAL GROWTH WITH PEDESTAL METHOD

Kirils Surovovs[1], Anatoly Kravtsov[2], Jānis Virbulis[1]
[1]*Institute of Numerical Modelling, University of Latvia, Jelgavas 3, Riga, Latvia*
[2] *AS «KEPP EU», Carnikavas iela 5, LV-1034, Riga, Latvia*
E-mail: kirils.surovovs@lu.lv

Some of the existing crystal growth methods require a crucible to hold the molten material. However, there are applications, for which quality requirements are so high and allowable impurity content is so low that crucible-free methods should be used. One of these methods is the pedestal method (PM) – a simpler alternative to float-zone method.

In the both methods, high-frequency electromagnetic (HFEM) heating is used. However, in the float-zone Si growth there are typically no other heat sources, which places very high requirements on HFEM generator and feed rod quality. On the other hand, in PM a heterogeneous – i.e., consisting of different heat sources – heating system can be used. The present work describes numerical modelling that helped to find the optimal power of different components of the heating system. For example, large part of induced power should come from the middle-frequency (MF) inductor, located near the pedestal side (see number 4 in Fig. 1., left).

The used HFEM inductor shape was optimized via gradient method [1] to increase melt depth for the cylindrical phase of large (diameter D_C = 100 mm) crystal growth from the pedestal with the diameter of 200 mm. However, the experiments demonstrate that at the beginning of crystal growth (seeding phase) even the addition of MF inductor is not enough to ensure that the free surface is completely molten, because of large heat losses from the central part of it. It can be compensated by additional free surface heating, e.g. with infrared lamps. The present work describes the calculations that were made to optimize free surface heating during the cone phase, simplistically described by cases with different crystal diameters, as shown in Fig. 1., right.

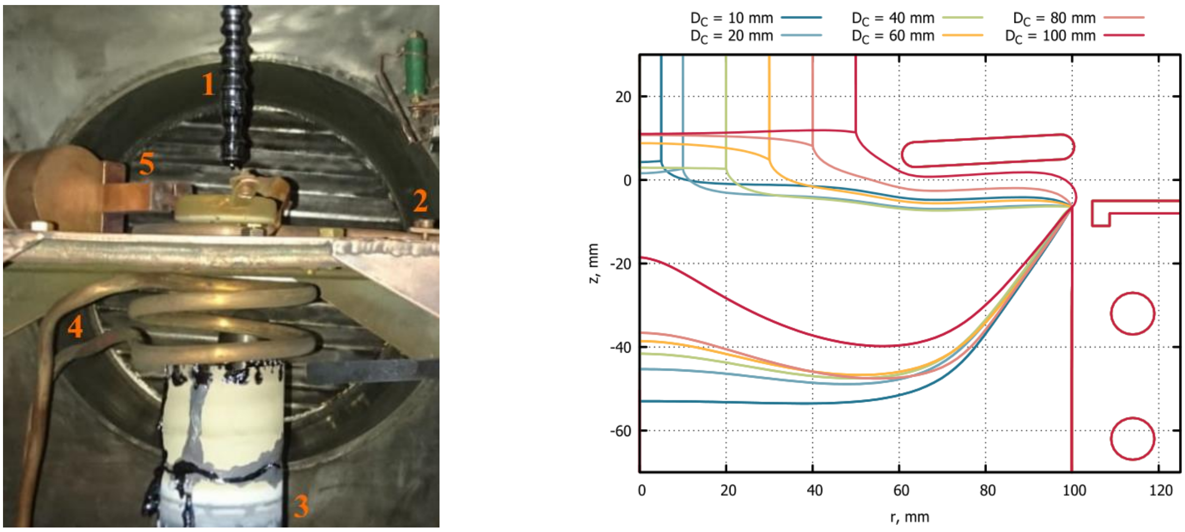

Fig. 1. Left – the overview of a growth chamber with the crystal seed (1), copper shield (2), pedestal (3), the MF and HF inductors (4, 5). Right – the simulated phase boundaries for different crystal diameters

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CLIMATIC MODEL OF THE GULF OF RIGA

Rolands Aleksandrs Rudenko, Andrejs Timuhins, Uldis Bethers, Juris Seņņikovs, Vilnis Frišfelds, Daiga Cepīte-Frišfelde
Institute of Numerical Modelling, University of Latvia, Jelgavas 3, Riga, Latvia
E-mail: rolands_aleksandrs.rudenko@lu.lv

The results acquired from the climatic model of the Gulf of Riga are discussed. The climatic model of the Gulf of Rigas is evolved from the operational oceanographic model of the University of Latvia based on HIROMB-BOOS. Spatial resolution of the climatic model is 0.5 nm. It provides daily output of physical state variables in 20 layers in period 1993-2020: velocity, water level, temperature, salinity, ice cover and thickness. Riverine input is simulated using E-Hype daily discharges [1], ERA-5 has been used for atmosphere data [2]. Oceanographic marine models having daily resolution can add much information about physical processes in the sea. Fig. 1 top row gives insight in seasonality of average water temperature and salinity of the Gulf of Riga according to the model.

The purpose of this work is to compare the results of the hindcast for the Gulf of Riga with the measurement data available in the calculation domain. Temperature and salinity were compared to evaluate the accuracy of the simulation results, Fig. 1 bottom row.

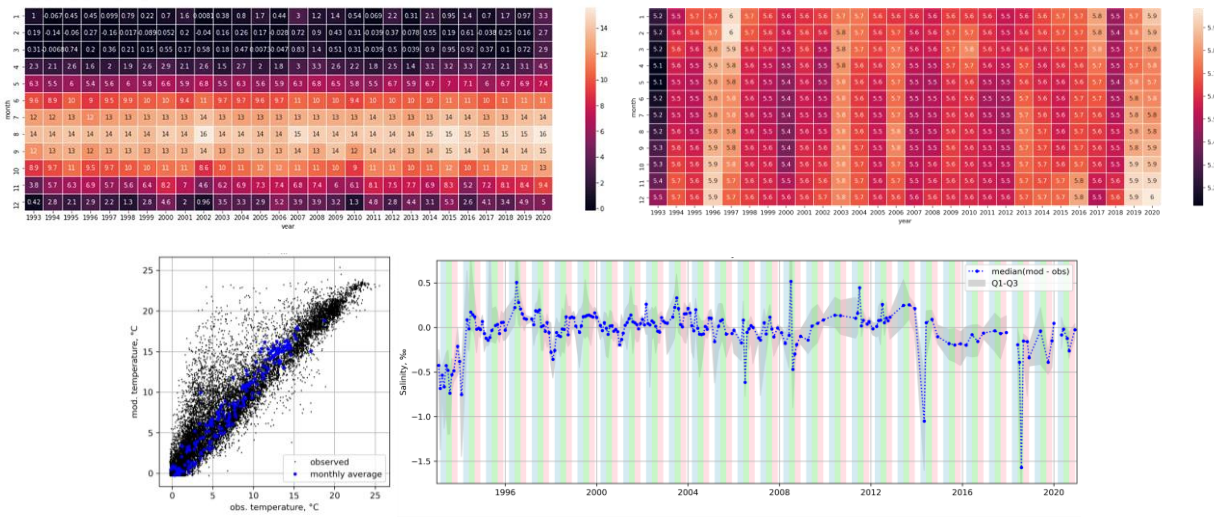

Fig. 1. Modeled seasonality of average temperature, °C and salinity, PSU in the Gulf of Riga (top row); Comparison of measurements and modeled temperatures and salinities (bottom row)

Acknowledgements:

Measurement data were provided by the Latvian Institute of Aquatic Ecology. The work has been carried out within the framework of the CE2COAST project funded by Ministry of Education and Science Republic of Latvia through the 2019 "Joint Transnational Call on Next Generation Climate Science in Europe for Oceans" initiated by JPI Climate and JPI Oceans. Contract No. 23-11.17e/20/246.

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[2] Copernicus Climate Change Service (C3S), 2017. ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate. Copernicus Climate Change Service Climate Data Store (CDS)

EXPERIMENTAL VALIDATION OF MHD NUMERICAL SIMULATIONS

Aleksandrs Jegorovs, Valters Dzelme
Institute of Numerical Modelling, University of Latvia, Jelgavas 3, Riga, Latvia
E-mail: Aleksandrs.Jegorovs@lu.lv

Current study is focused on magnetohydrodynamic experiment`s numerical validation using Elmer/OpenFOAM computational programs. Experimental setup includes vessel filled with liquid metal and nearby located rotating permanent magnet. Due to Lorentz force, which is proportional to magnet`s rotation frequency, flow pattern is developed, accompanied by characteristic free surface deformation. Validation is based on observing free surface projections, measuring time-mean surface shape, and other statistical data. Presentation will include such topics as:

Free surface image processing.

Use of parametric optimization of magnetostatics problem (Comsol Multiphysics) for determining permanent magnet parameters, based on magnetic field measurements.

Impact of turbulence model choice (RANS/LES) on free surface dynamics.

Acknowledgements:

This work was supported by the ERDF project No. 1.1.1.1/18/A/108 ”Development of numerical modelling approaches to study complex multiphysical interactions in electromagnetic liquid metal technologies”.

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SOURCES OF SEASONAL AIR TEMPERATURE FORECAST SKILL IN LATVIA

Maksims Pogumirskis, Tija Sīle
Institute of Numerical Modelling, University of Latvia, Jelgavas 3, Riga, Latvia
E-mail: Maksims.Pogumirskis@lu.lv

Weather forecasts for up to 7 days are known to be reliable. Meanwhile, reliability of seasonal forecasts for the next seven months is still a scientific question. Due to the chaotic nature of the atmosphere, seasonal forecasts are used for predicting deviations of the monthly mean from the climatic mean rather than predicting weather at the certain moment of time in the future.

In this work ECMWF seasonal air temperature forecasts [1] between 1993 and 2019 are verified against LEGMC observations in Latvia. Metrics such as anomaly correlation coefficient and area under ROC curve [2] are used for evaluating the skill of the forecasts. Possible sources of the forecast skill in the model are identified. Ways to improve the skill of seasonal forecasts in Latvia are suggested.

Overall, seasonal air temperature forecasts in Latvia show low skill. The seasonal forecasts are only slightly better than a random guess. Only for some “forecast month – forecasted month” pairs the correlation coefficient reaches 0.4. Significant part of the skill that exists can be explained by the fact that Latvia is located near the Baltic Sea which is a large reservoir of heat. However, the skill of the model forecasts is no better than statistically predicting mean air temperature of the following month from Baltic Sea surface temperature at the beginning of forecast.

Air temperature in Latvia between December and March is highly influenced by the North Atlantic Oscillation (NAO). Forecast systems are known to have high skill in predicting NAO. Such skill is caused by their ability to forecast sea surface temperature tripole [3] in the Atlantic Ocean which is highly related to NAO. ECMWF forecasts also show skill in predicting Atlantic Ocean sea surface temperature tripole. Meanwhile, in the model areas in Europe which are influenced by the NAO are spatially offset, which reduces the model skill in forecasting air temperature in Latvia.

Another large scale atmospheric that influences air temperature in Latvia between April and August is the Scandinavia pattern (SCAND). ECMWF forecast system is known to be able to skilfully predict [4] SCAND pressure pattern especially in the summer months. However, the model fails to predict the characteristic air temperature patterns that are related to the SCAND – higher temperatures in the Northern Europe and lower temperatures over the central part of Russia.

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AIRFLOW AND AEROSOL CONCENTRATION MODELING INDOORS: NUMERICAL ASPECTS

Dagis Daniels Vidulejs, Kirils Surovovs
Institute of Numerical Modelling, University of Latvia, Jelgavas 3, Riga, Latvia
E-mail: Kirils.Surovovs@lu.lv, Dagis_Daniels.Vidulejs@lu.lv

With advances in processing technology, it is often cheaper and faster to solve industrial and research problems using high-performance computing solutions. However, numerical modeling requires great user expertise, especially if open-source software is used. To reduce the difficulty of indoor airflow modeling we introduce a calculation program with the feature of user-definable room geometry. To ensure that a user can get accurate results with an arbitrary room geometry, we investigate the numerical stability and precision under variable mesh and numerical parameters and compare results to experiment [1].

The calculation program is based on the open-source software OpenFOAM and was created as part of the "EuroCC Latvia" high performance computing project. Specifically, the program provides calculation of a quasi-stationary airflow (Fig. 1a), air temperature distribution (Fig. 1b) and a transient aerosol concentration distribution in the room (Fig. 1c). A typical use case might be a designer looking to find out how well ventilated a room is or a researcher gauging the epidemiological safety of the room from virus aerosol concentration.

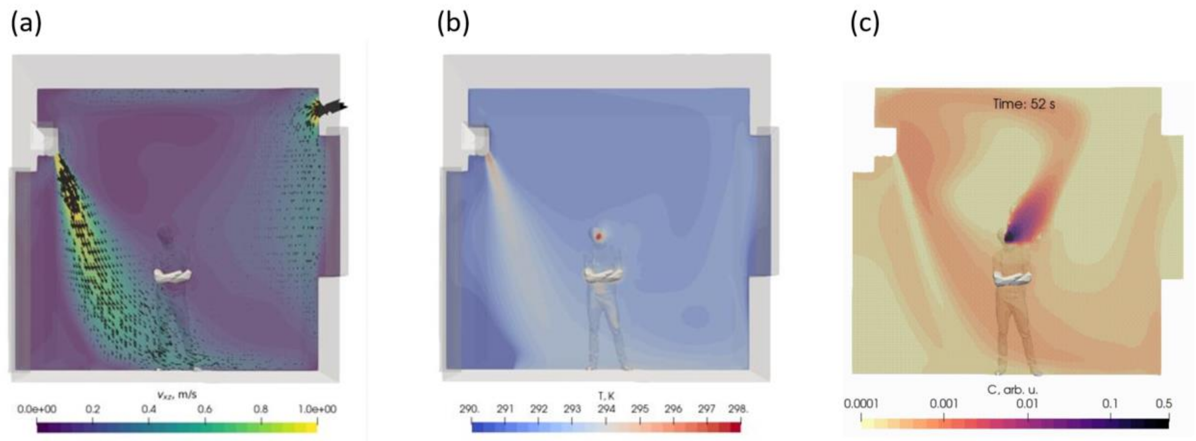

Fig. 1. Simulation results in a 3x3x3 meter room geometry with an air inlet from the air conditioner, an outlet, a door, a window and a person. (a) The air velocity field; (b) the air temperature distribution; (c) the aerosol concentration distribution after 52 seconds of the person breathing, arbitrary units for concentration were used (C=1 in the air that is breathed out).

Acknowledgements:

The work is supported by the project "National Competence Centres in the framework of EuroHPC – EuroCC", number 951732-EUROCC.

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