Numerical simulation of internal wave attractors in stratified or rotating fluids.

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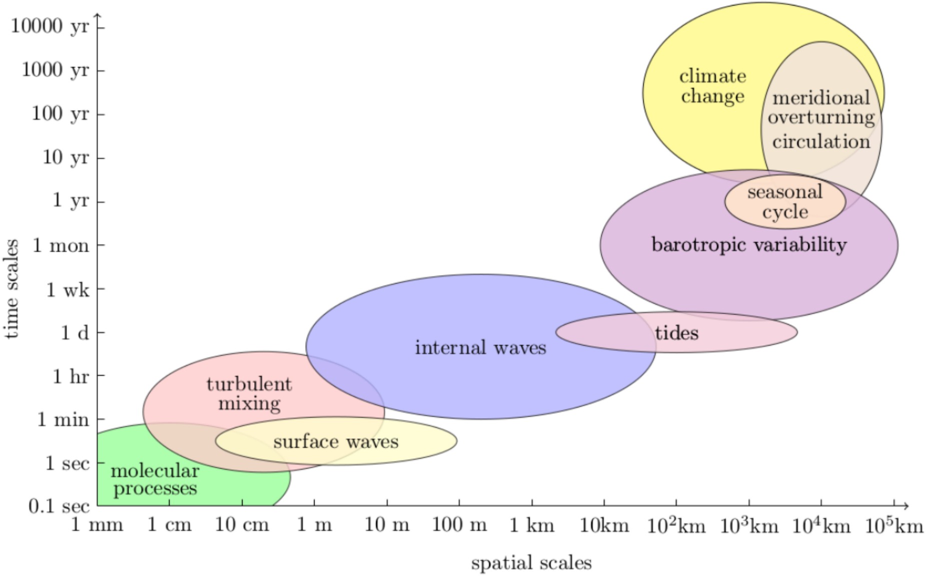
Leo Maas

ИО РАН

Ильяс Сибгатуллин

Сю Сюлинь

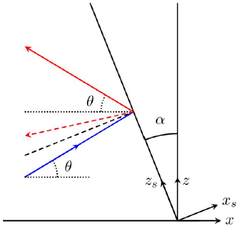
Time and space scales of ocean variability



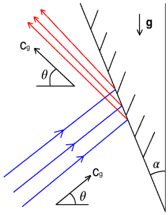
By F. Beckebanze

Attractors of inertial and internal waves

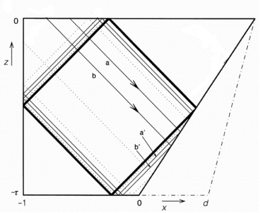
$$\frac{\omega}{N} = \pm \sin\theta$$



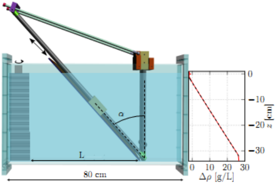
Reflection



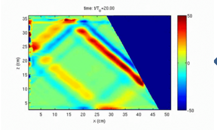
Focusing



Billiard of rays

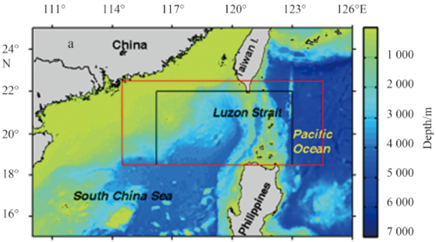


Experiments with ‘global’ forcing

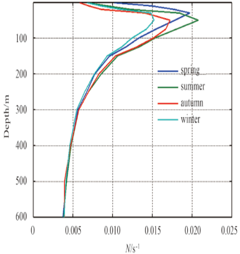


Waves

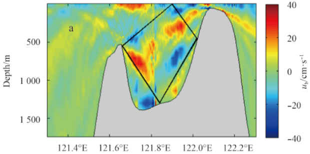
Possible explicit locations of attractors in the Ocean



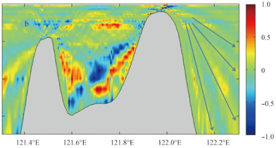
Аттрактор в Лусонском проливе



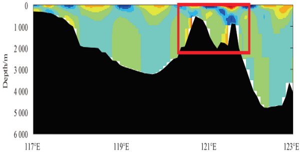
Buoyancy frequency
in winter and summer



Velocity field



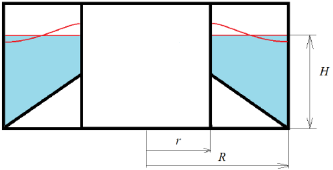
Perturbations of buoyancy

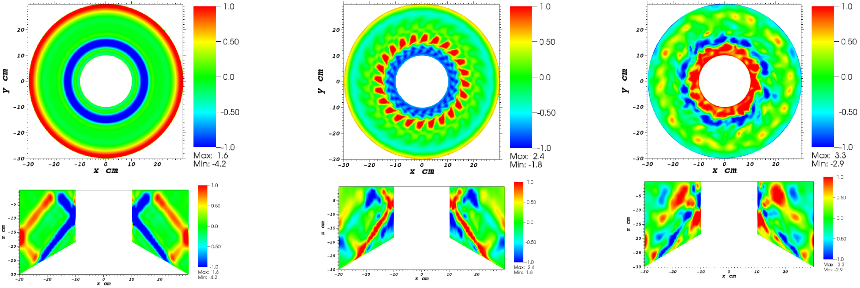


Bingtian et al.
(Acta. Oceanol. Sinica. 2015)

Wang G., Zheng Q., Lin M., Qiao F. Three dimensional simulation of internal wave attractors in the Luzon strait // Acta Oceanol. Sinica. 2015. V. 34, N 11. P. 14–21.

Inertial attractors. Axisymmetric forcing.

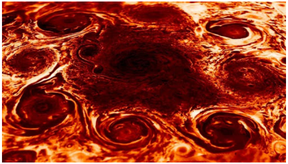


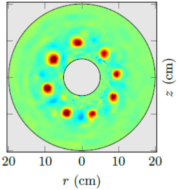


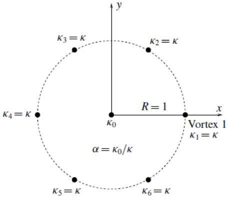
Instability developement

Sibgatullin I.N., Ermanyuk E.V., Xu X.L., Maas L., Dauxois T. Direct numerical simulation of three-dimansional inertial wave attractors // 2017 Ivannikov ISP RAS Open Conference, Nov 30 – Dec 1, 2017, Moscow, Russia. In: IEEE Xplore, DOI: 10.1109/ISPRAS.2017.00029, P. 137-143.

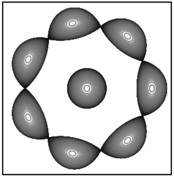
An open question: stability of vortex cluster

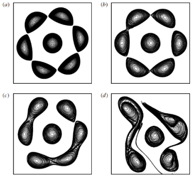






$(m + 1)$-vortex problem



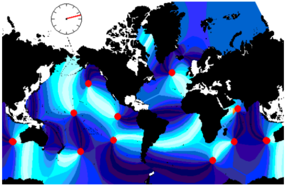


J. Fluid Mech. (2019), *vol.* 863, *pp.* 32–59.
doi:10.1017/jfm.2018.989

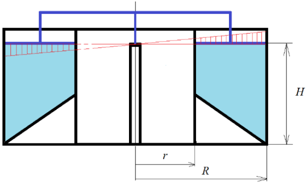
Three-dimensional quasi-geostrophic vortex equilibria with m-fold symmetry

Jean N. Reinaud†

Wave structure in rotating systems and mean flows



Surface tides in the Ocean



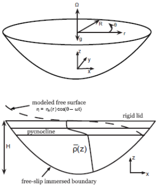


Fig. 1. Schematic of a parabolic basin with surface radius *R* and depth *H*. An initially quiescent fluid is set into motion by a body force **F**, which models forcing by a barotropic tide advancing cyclonically along the coastline with an amphidrome at the basin center. The stratification is characterized by a surface mixed layer, a strong pycnocline and a weak stratification at depth.

Winters K.B. Tidally-forced flow in a rotating, stratified, shoaling basin // Ocean modelling. 2015. V. 90. P. 71-82.

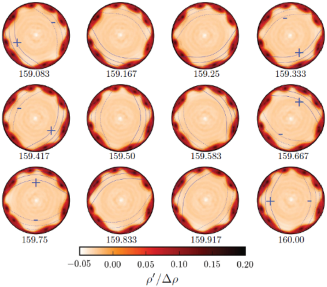
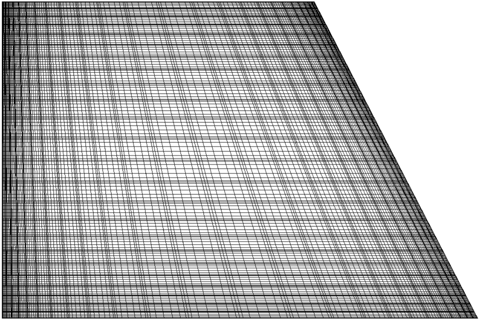
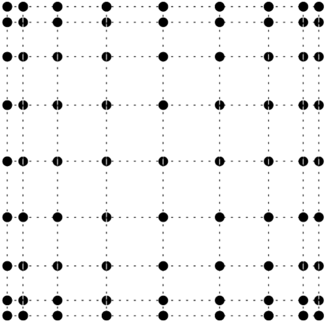


Fig. 7. Density at $z/H = 0.95$ during last simulated tidal period. Also shown are positive (solid, +) and negative (dashed, -) pressure contours. Time, scaled by the tidal period, increases moving to the right and down. The phase of the pressure field propagates cyclonically while the eddies remain approximately stationary on the fast, tidal time scale.

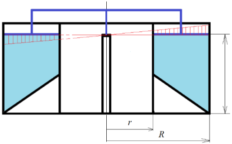
Coastal flow in numerical simulation

Spectral element approach.
Gauss-Lobatto-Legendre grid points in each element.





Wave attractors resulting from external nutation



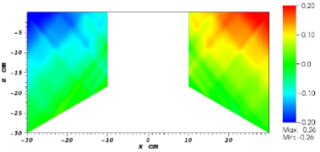


Figure 3. Vertical component of velocity in the slice $y = 0$, amplitude $a = 0.1$ cm, $\omega_0 = 2.4$ rad/s, $\Omega = 2$ rad/s for positive nutation.

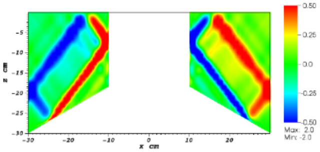
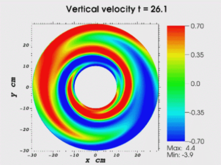
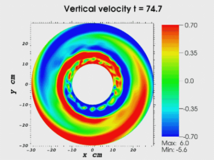
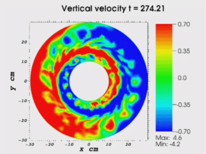


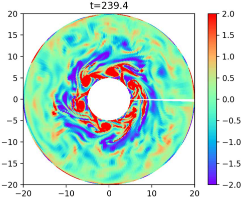
Figure 5. Vertical component of velocity in the slice $y = 0$, amplitude $a = 0.1$ cm, $\omega_0 = 2.4$ rad/s, $\Omega = 2$ rad/s for negative nutation.

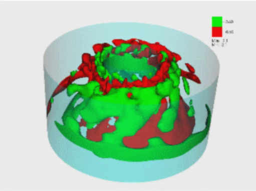
Attractors are formed only for retrograde nutation

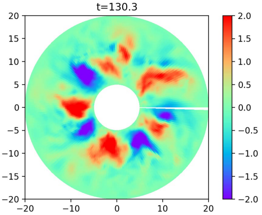


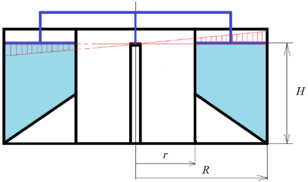


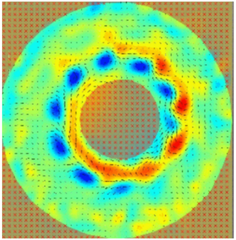




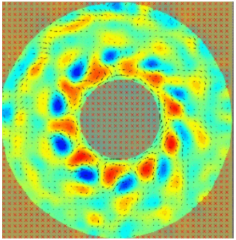






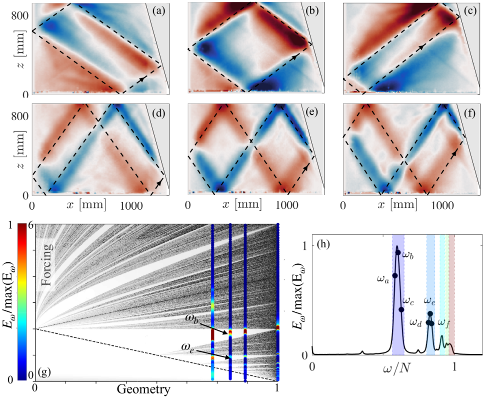


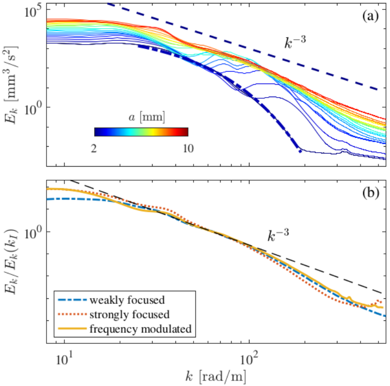
Instantaneous velocity



Averaged velocity

Experiments of Stanislav Subbotin





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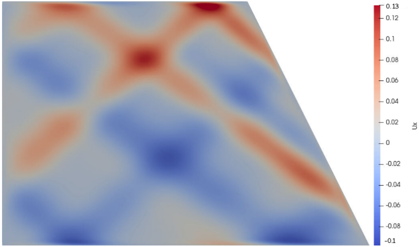
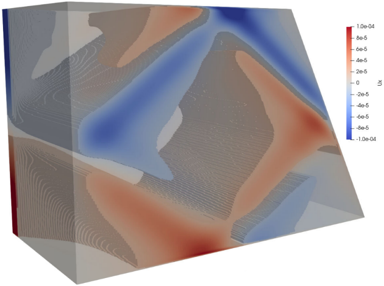
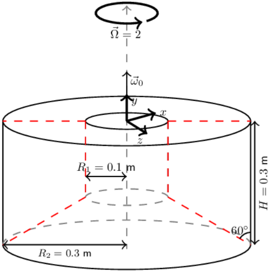
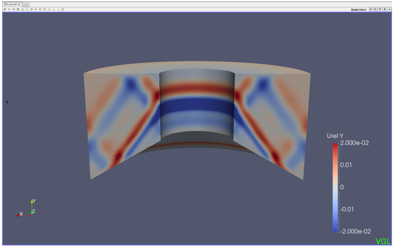
Implementation of Quasihydrodynamic System of Equations in OpenFOAM

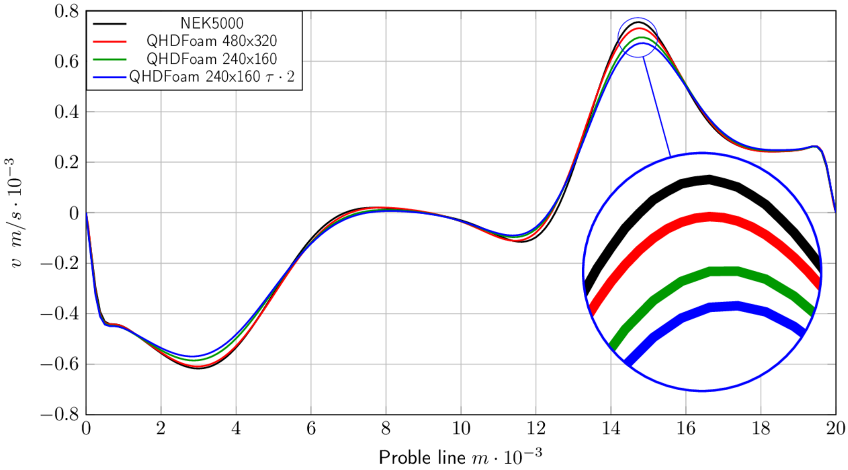








Quasihydrodynamic simulations



[0] Matvey Kraposhin, Daniil Ryazanov, Tatiana Elizarova, Ilias Sibgatullin, Michael Kalugin, Vasily Velikhov, and Eygene Ryabinkin. Openfoam high performance computing solver for simulation of internal wave attractors in stratified flows using regularized hydrodynamic equations. In Proceedings of the 2018 Ivannikov ISPRAS Open Conference, IEEE Xplore, United States, 2018.

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Matvey Kraposhin, Daniil Ryazanov, Tatiana Elizarova, Ilias Sibgatullin, Michael Kalugin, Vasily Velikhov, and Eygene Ryabinkin. Openfoam high performance computing solver for simulation of internal wave attractors in stratified flows using regularized hydrodynamic equations. In Proceedings of the 2018 Ivannikov ISPRAS Open Conference (ISPRAS, 22-23 Nov. 2018), IEEE Xplore Digital Library, United States, 2018. United States.

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