On energy and matter exchange between near-shore and out-of-shelf waters defining shelf ecosystems state

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Why important

- The main part of human-used oceanic biological production is extracted in shelf waters
- The main harmful anthropogenic effects on oceans are performed in and via shelves
- The most important geomorphologic processes are going in shelf areas
- The most intensive technical and production human activity is going on in near-shore regions

Dimensions and Processes – internal and on boundaries

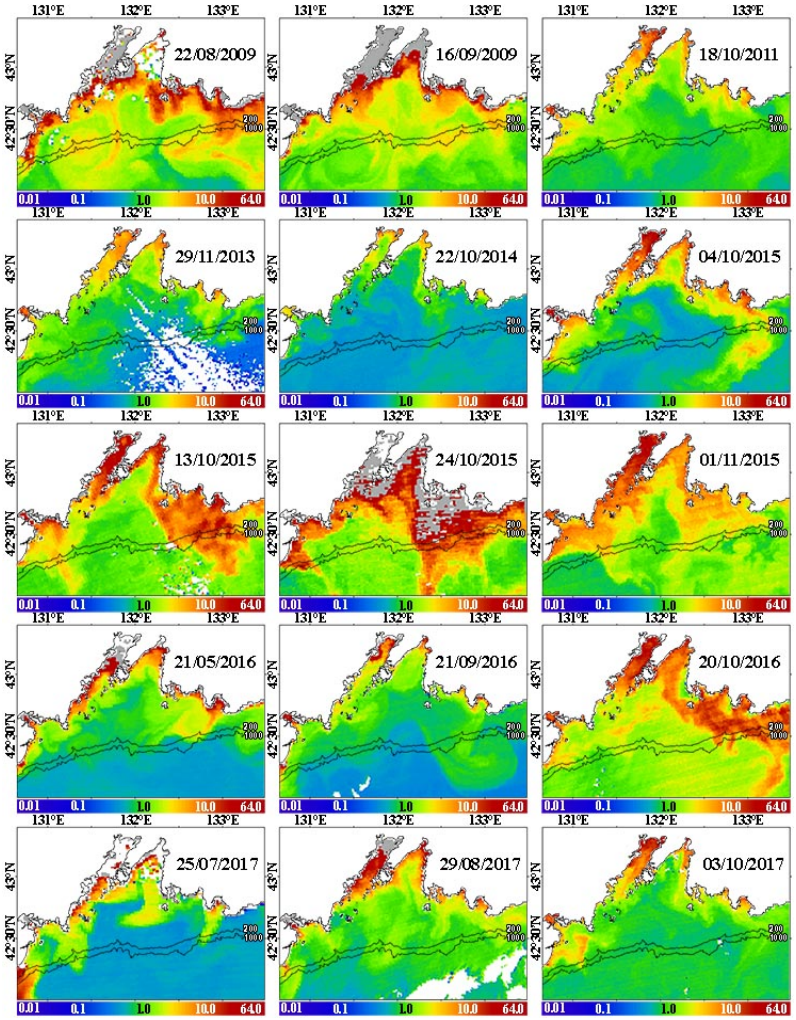
- Currents, tides, upwelling, and mesoscale eddies - main drivers in continental slope and adjacent to slope open-sea regions. Maximum of kinetic energy **is produced here or supplied** from the open sea.
- Sub-mesoscale eddies of local origin, internal waves (IW) and turbulence are the main players in the near-shore waters, where **dissipation of energy** of all motions and intensive **exchange of matter** between land and sea take place.

- Our goal is to analyze, basing on satellite observations and field experiments, the main mechanisms of physical and biological **interconnections** of the **wide-range-scaled processes running in the designated distant domains**

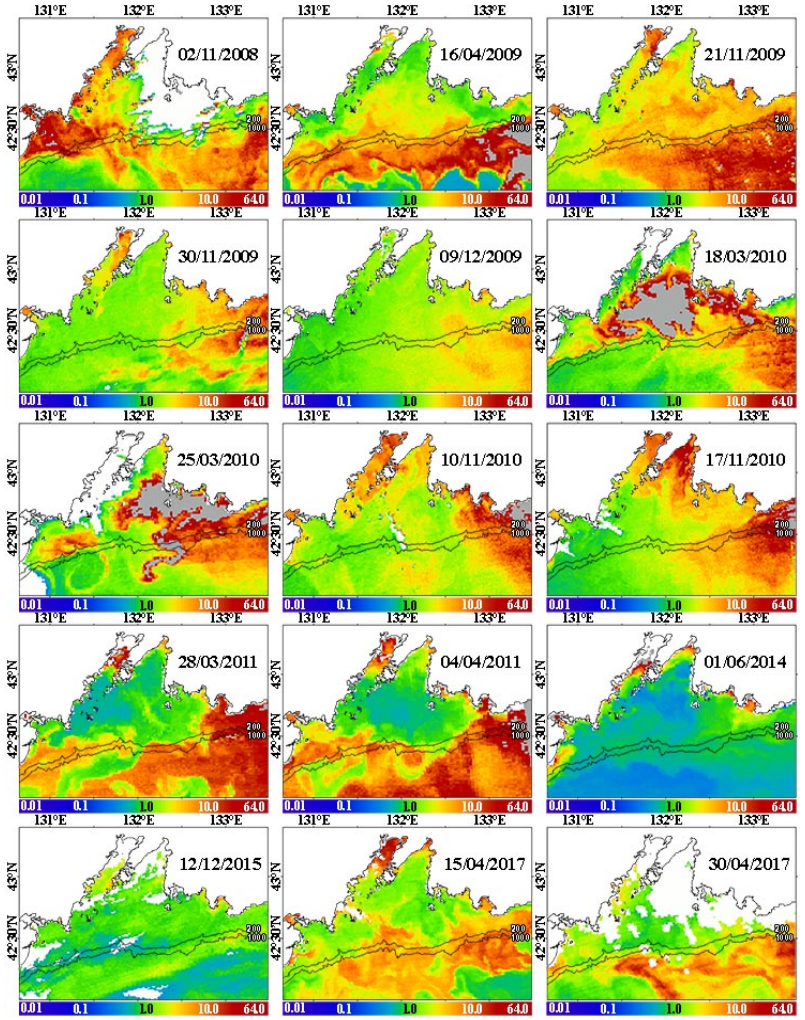
Satellite daily data of MODIS Aqua on chlorophyll-a concentration in the Peter the Great Bay of the Sea of Japan for the period **2008-2017** were analyzed [http://ocean.nowpap3.go.jp/TeraCatIII/seaCalNG.php]

Typical Chl-a distributions and dominant processes

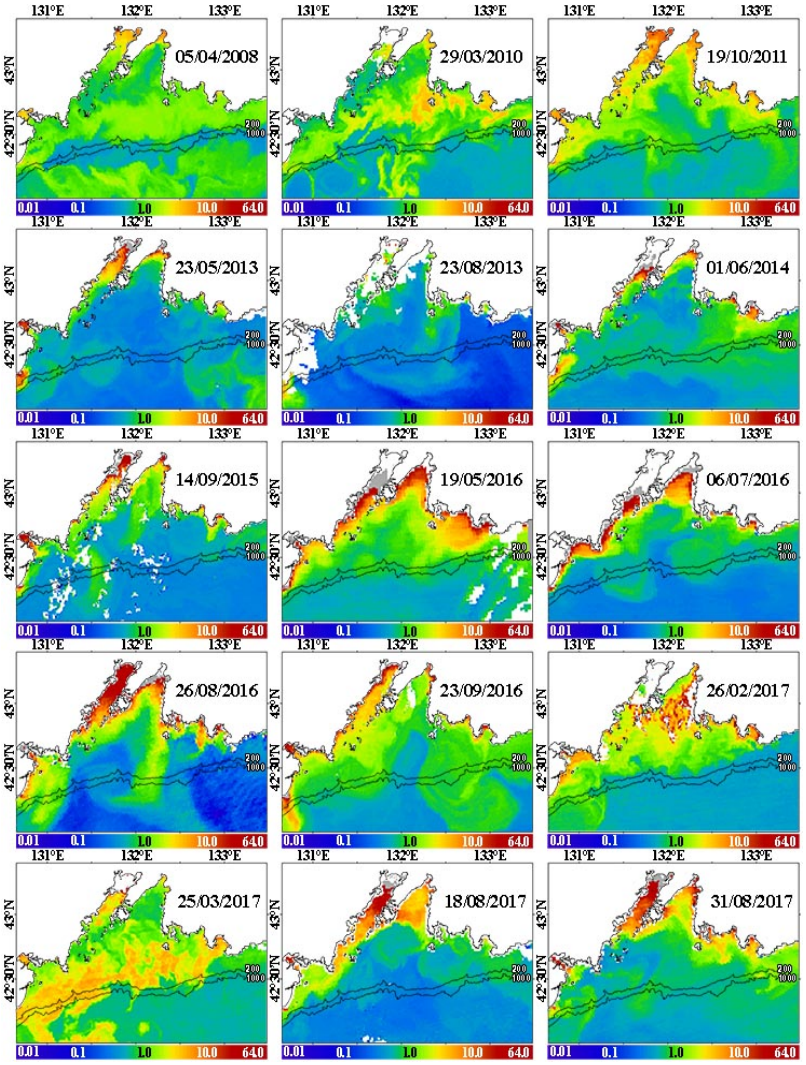
Shore (land) proximity



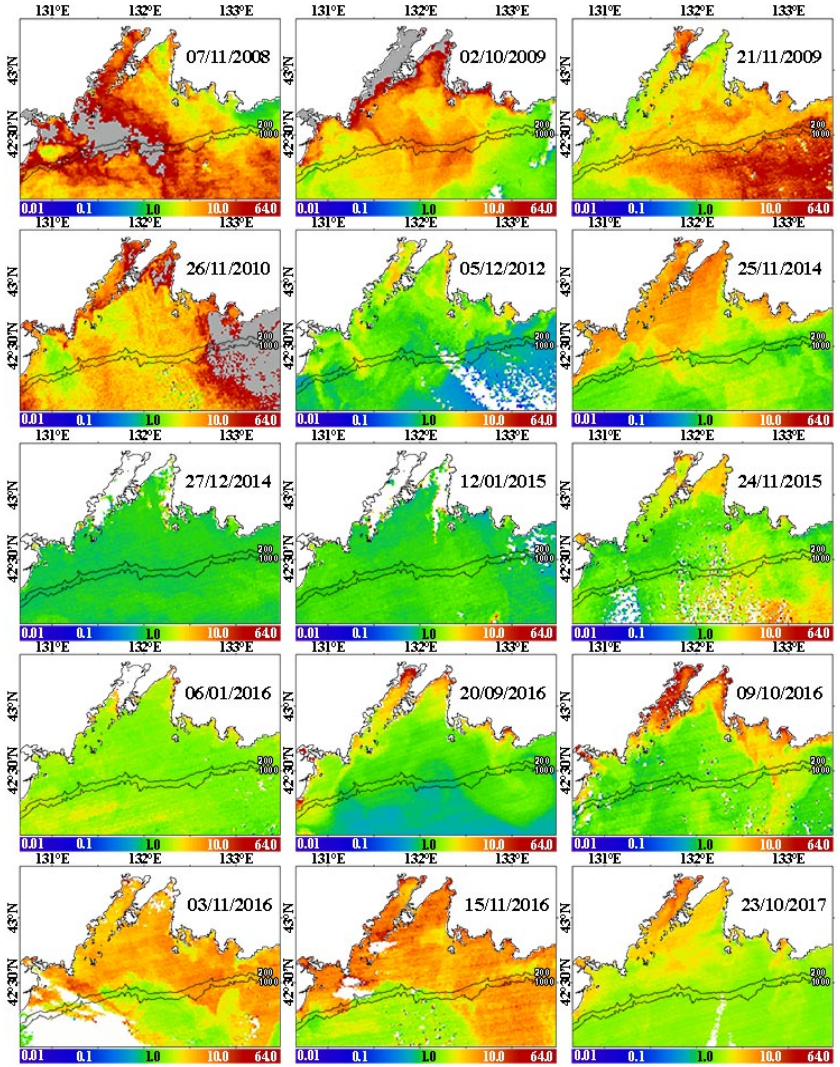
Advection (+Eddies+Upwelling)



Eddies (+Shore+Upwelling)



Convection

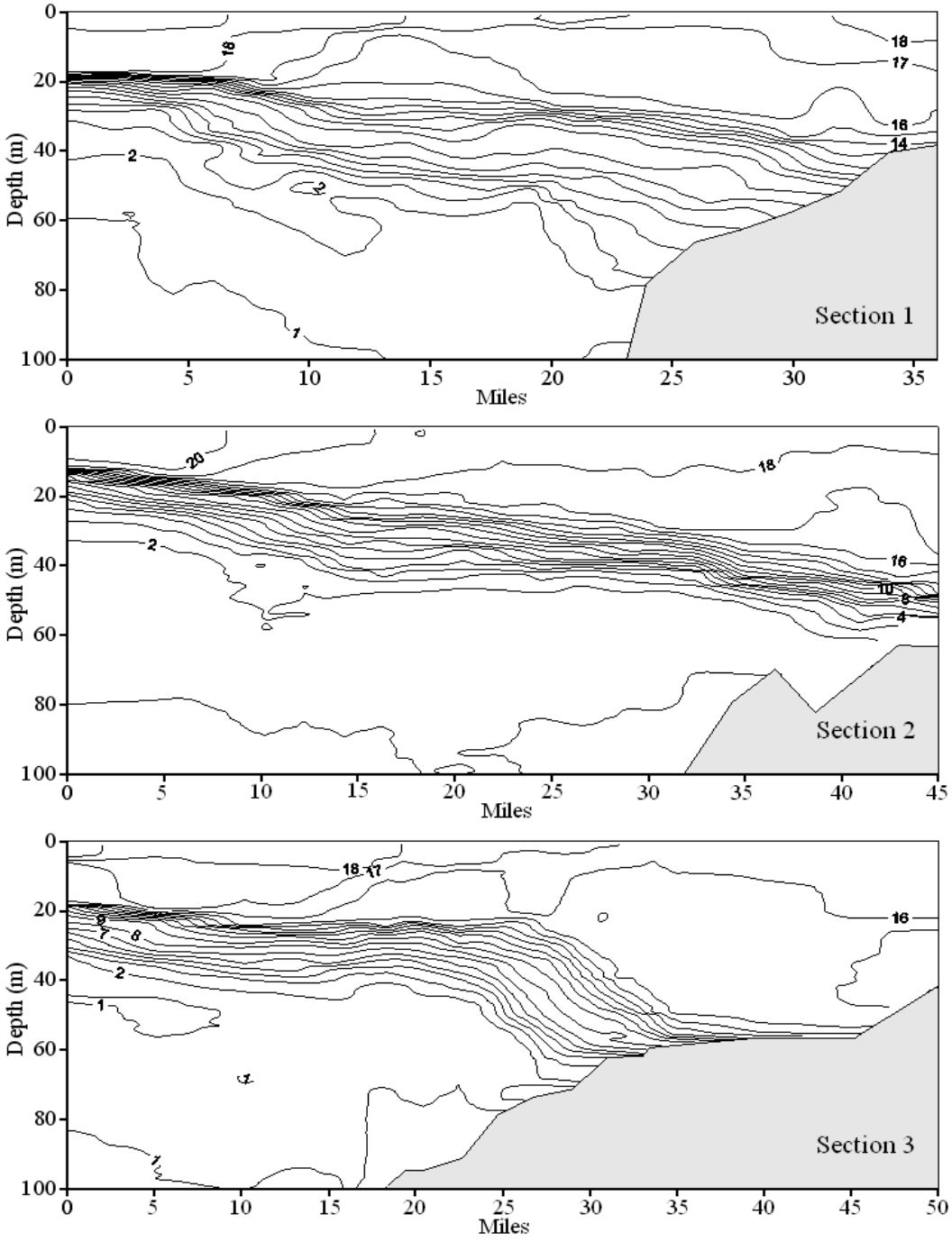


- There is tendency of **seasonal changes** in the Chl-a spatial distribution that can depend on seasonal **changes in physical processes**. The most apparent seasonally-dependent factor is **shore (land proximity)** in combination with eddies.
- Considerable part of nutrients falls out of biological cycle irretrievably by way of sedimentation. Supply of mineral and organic **material from land is necessary for quasi-stationary state of oceanic ecosystems** (rivers, other natural and anthropogenic fluxes, winds, shores distraction by surfing waves).
- The dissolved and particulate **terrigenous matter** concentrates **in near-bottom layers and in sediments**. It must be transferred to the open sea **through shelves** by means of vertical and horizontal mixing not only for feeding plankton, but also for sanitary ventilation of near-shore waters.

- Effective mixing is carried out by small-scale high-frequency quasi three-dimensional processes, but maximum energy in the ocean is in large-scale processes (currents, rings, mesoscale eddies), which are cut off from shores by the continental slope.

- The question is: **how and when** energy of large-scale processes is transported from off-shelf to near-shore regions and transferred into small-scale motions in the near-bottom layers?

The universal mechanism for long-distant energy transport – **internal waves (IW)**



The most frequently analyzed are gravitational IW

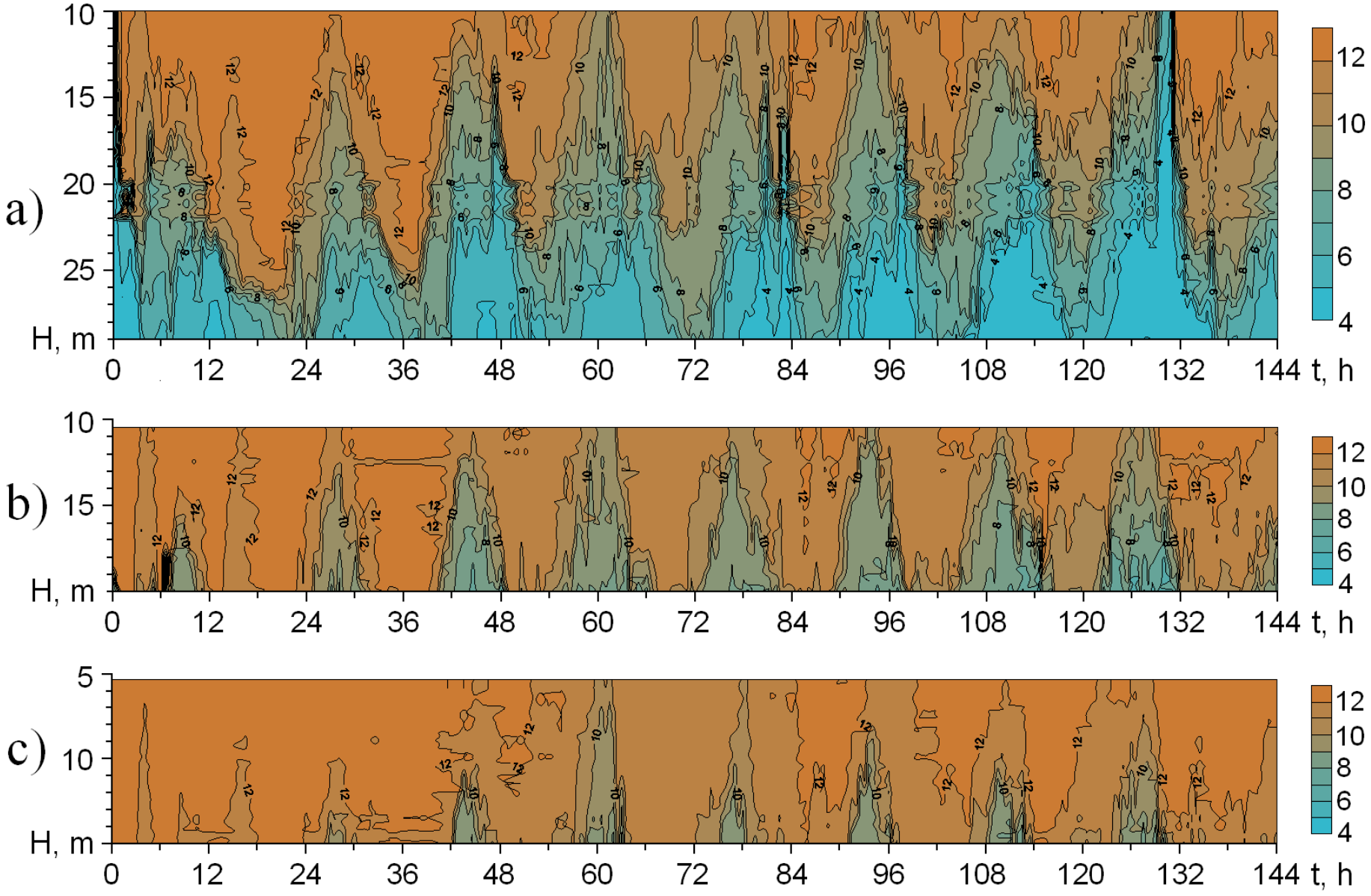
Seasonal thermocline at different sections across shelf boundary in the Peter the Great Bay, Sea of Japan.

Different slopes, different depths and different vertical gradients in points of IW-bottom contact.

IW generation, propagation, transformation

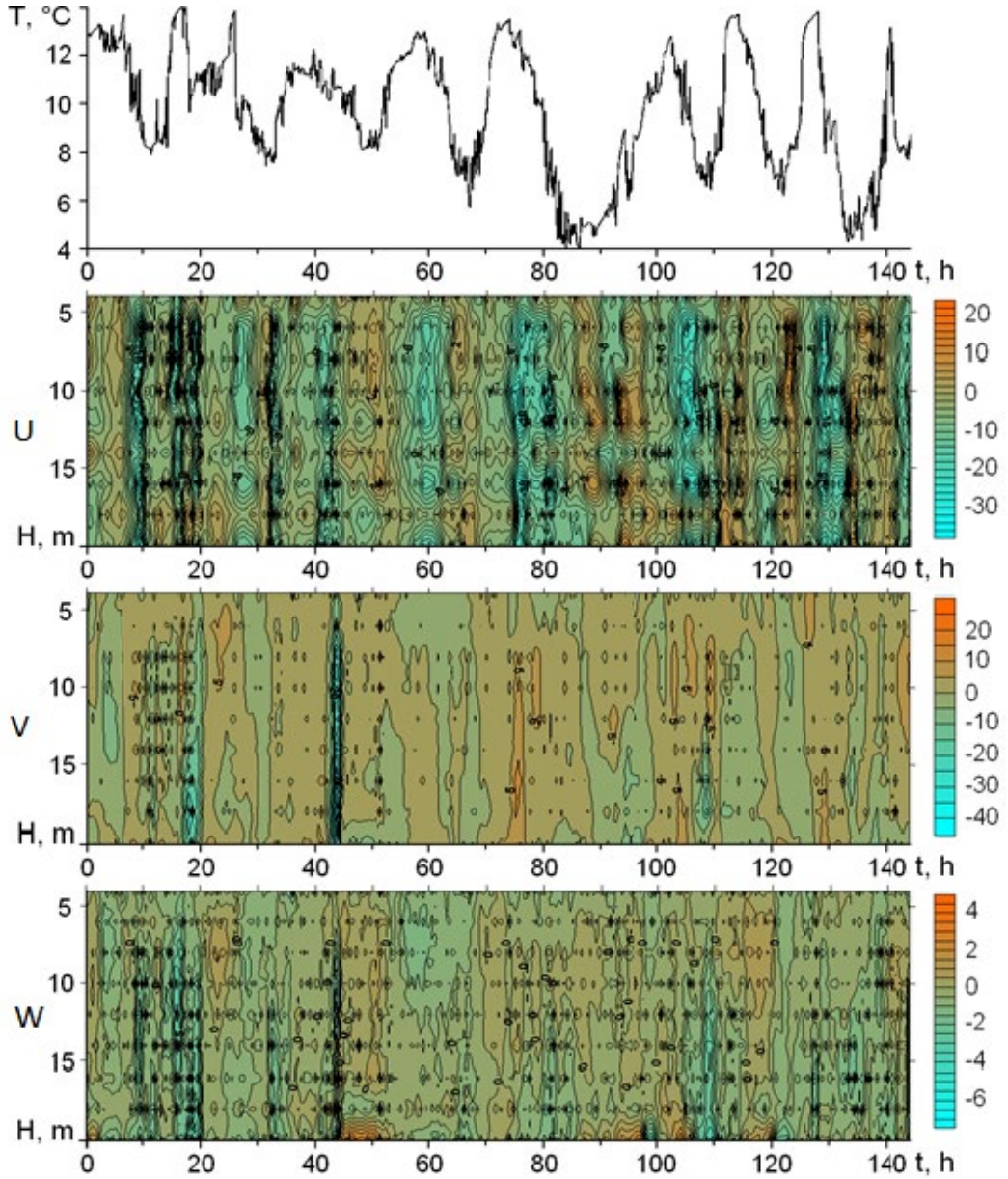
- **Tides:** Gravitational IW (internal tide). Max energy at 12 h. The 2-nd mode and rather wide spectrum can be formed depending on thermocline structure, slope steepness and tide intensity.
- **Eddies:** Interact with currents, slope, inertial oscillations. Eddies can generate inertial IW in general case, inertia-gravitational internal waves (IGW) in stratified layers over the slope (max energy close to local inertial frequency).
- **Boluses:** Exceptionally stable stratified formations moving in the quasi-homogeneous medium. Transport energy of primary IW further, than continuous picnocline can exist. **Mark beginning of an internal beach.** Can have internal fine strusture
- Mixing, turbulence, secondary IW, turb. dissipation.

Synchronous observations of internal waves and boluses at 3 stations with different bottom depths.



Main biological effects of IW

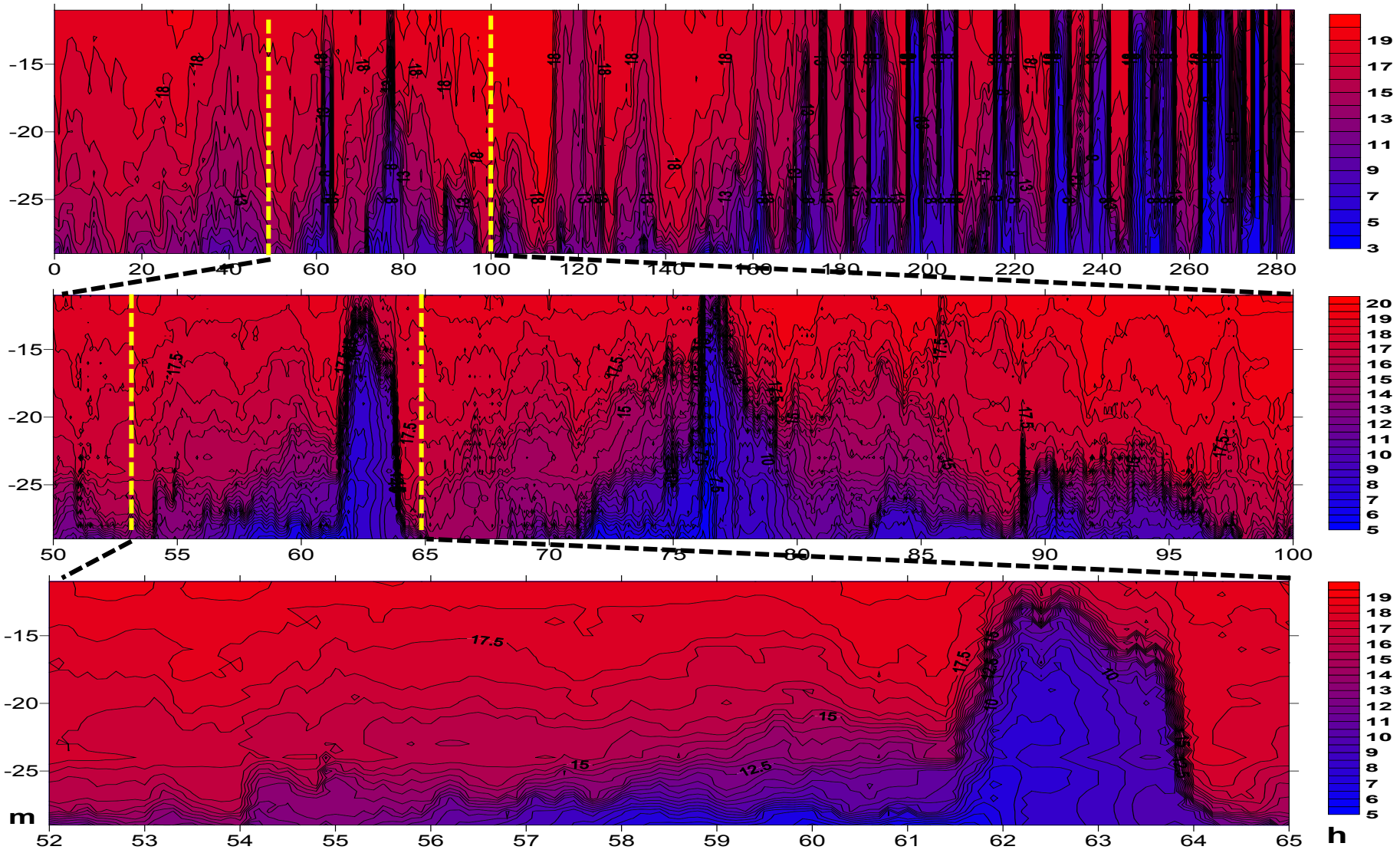
- Quick change of illumination intensity, extremely high vertical velocity-(vertical movements 10-15 m)
- Quick change of vertical and horizontal gradients of temperature, velocity, and heat and momentum fluxes
- Mixing and change in nutrients and contaminants concentration



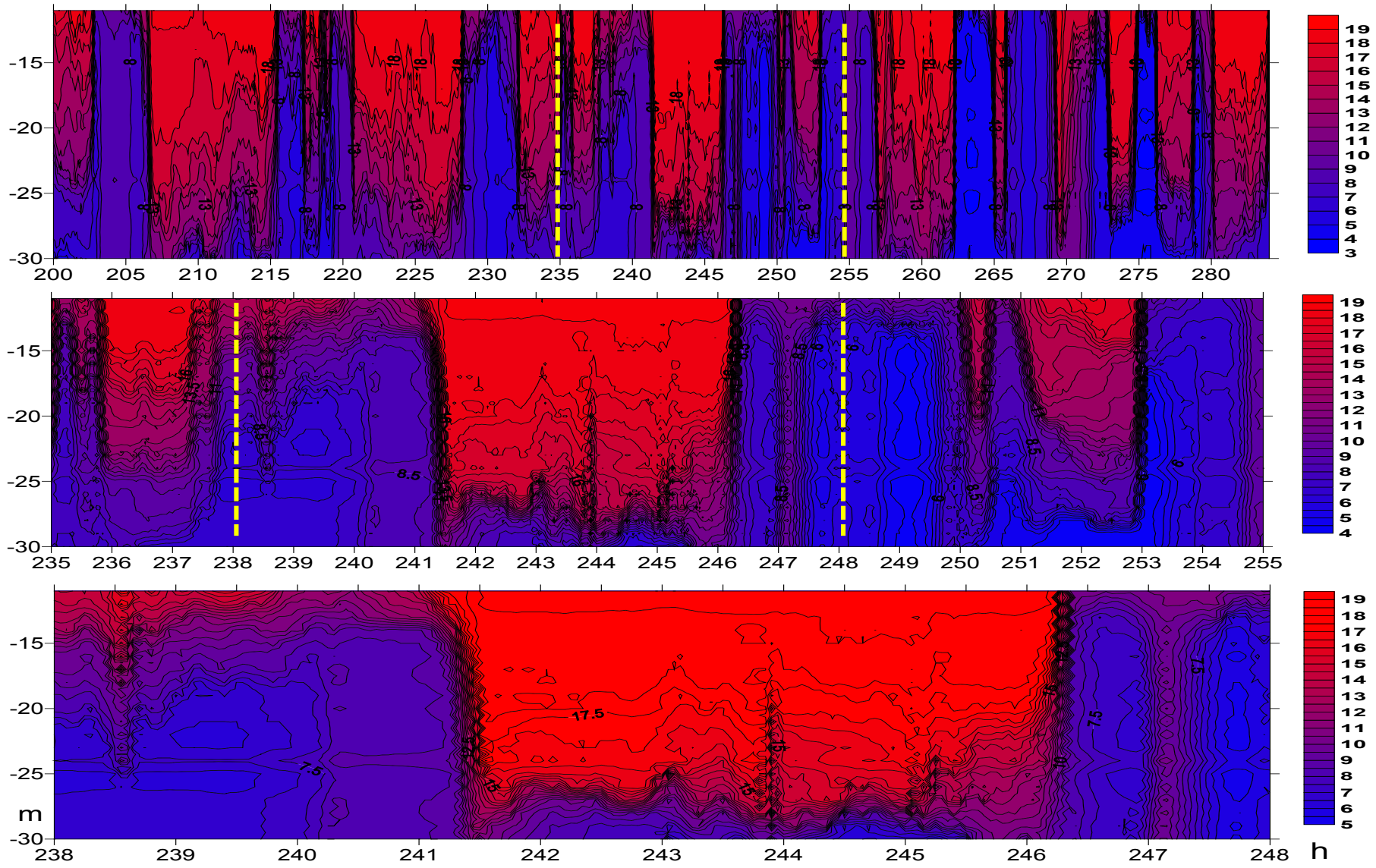
Near-bottom temperature fluctuations at the depth 21.5 m and current velocity components u,v,w measured in the layer 4-20 m with 1 m vertical spacing (October 13-19, 2016).

IW and boluses with high amplitudes **affect the major part of water column.**

Vertical and horizontal gradients of T
Peter the Great Bay, Vitiaz Bay, Sept, 2018

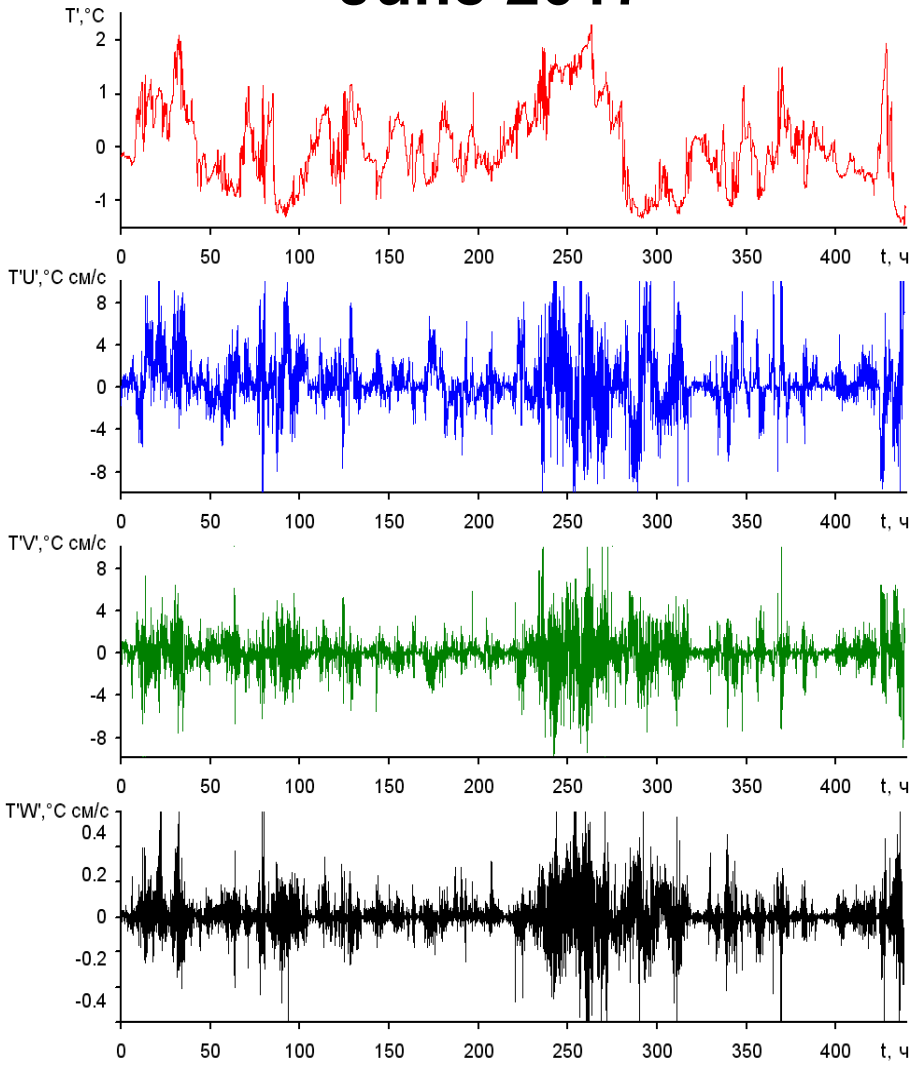


Sept. 2018, continuation

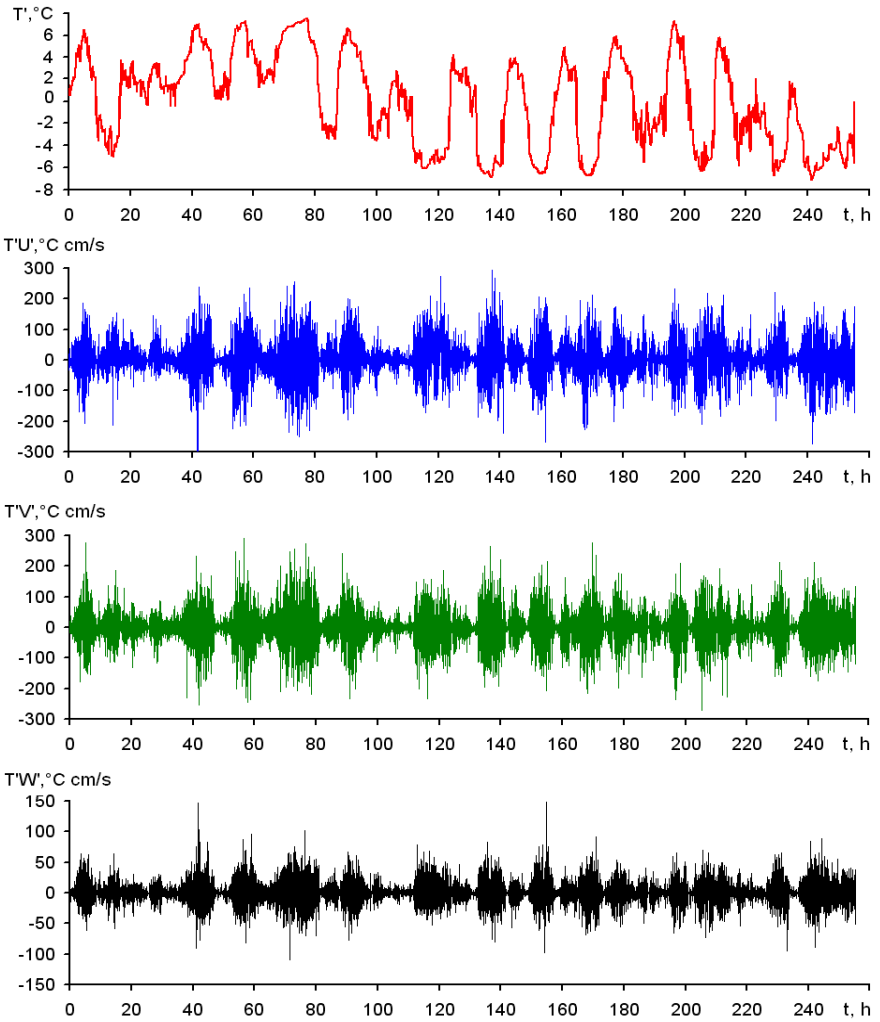


Fluctuations of temperature and heat fluxes (in degr*cm/s) at the level 23 m in in the near-bottom layer in the near-shore region of the Peter the Great Bay

June 2017



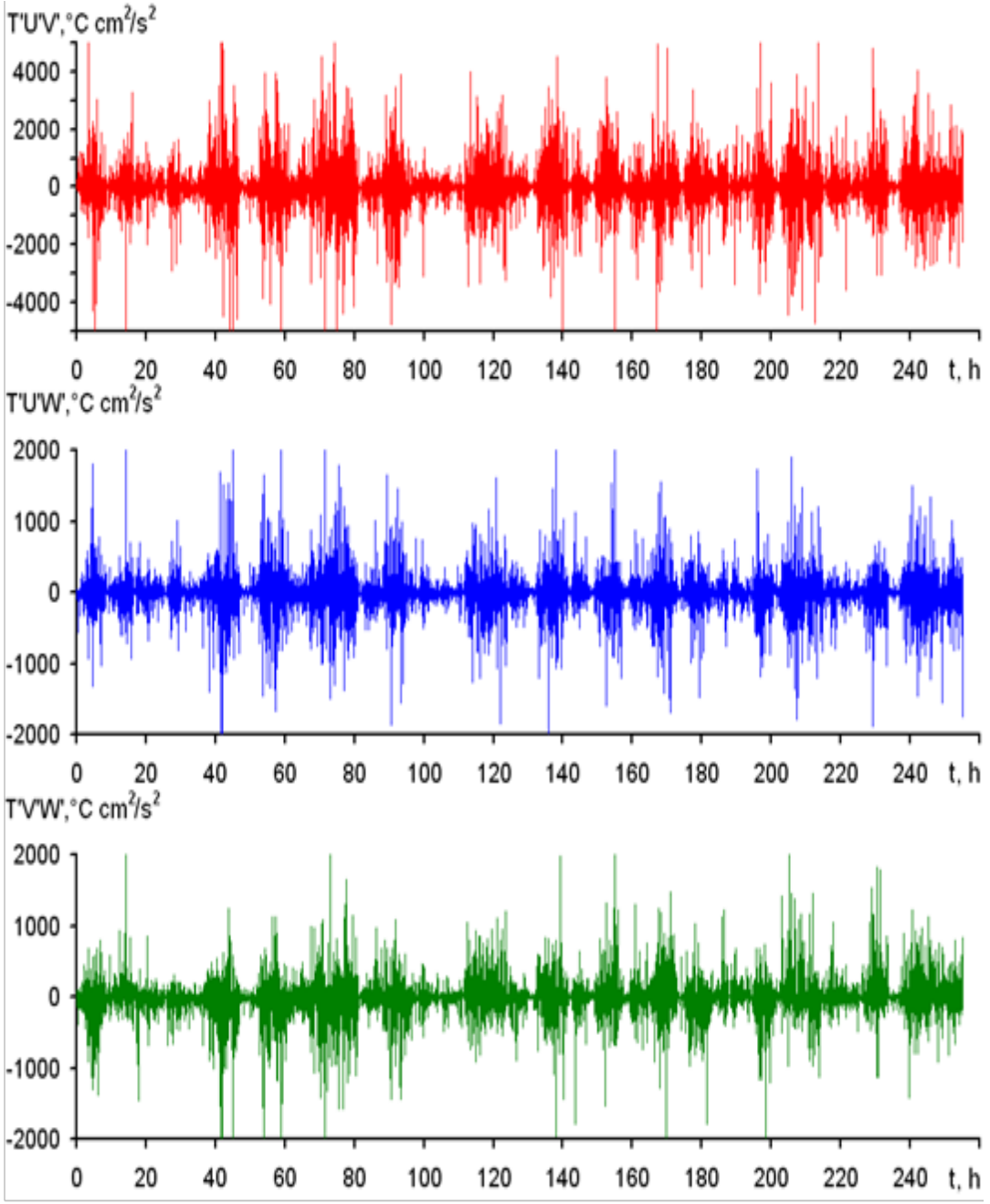
September 2017



Proxy for momentum fluxes in the near-bottom layer (PGB, September 2017)

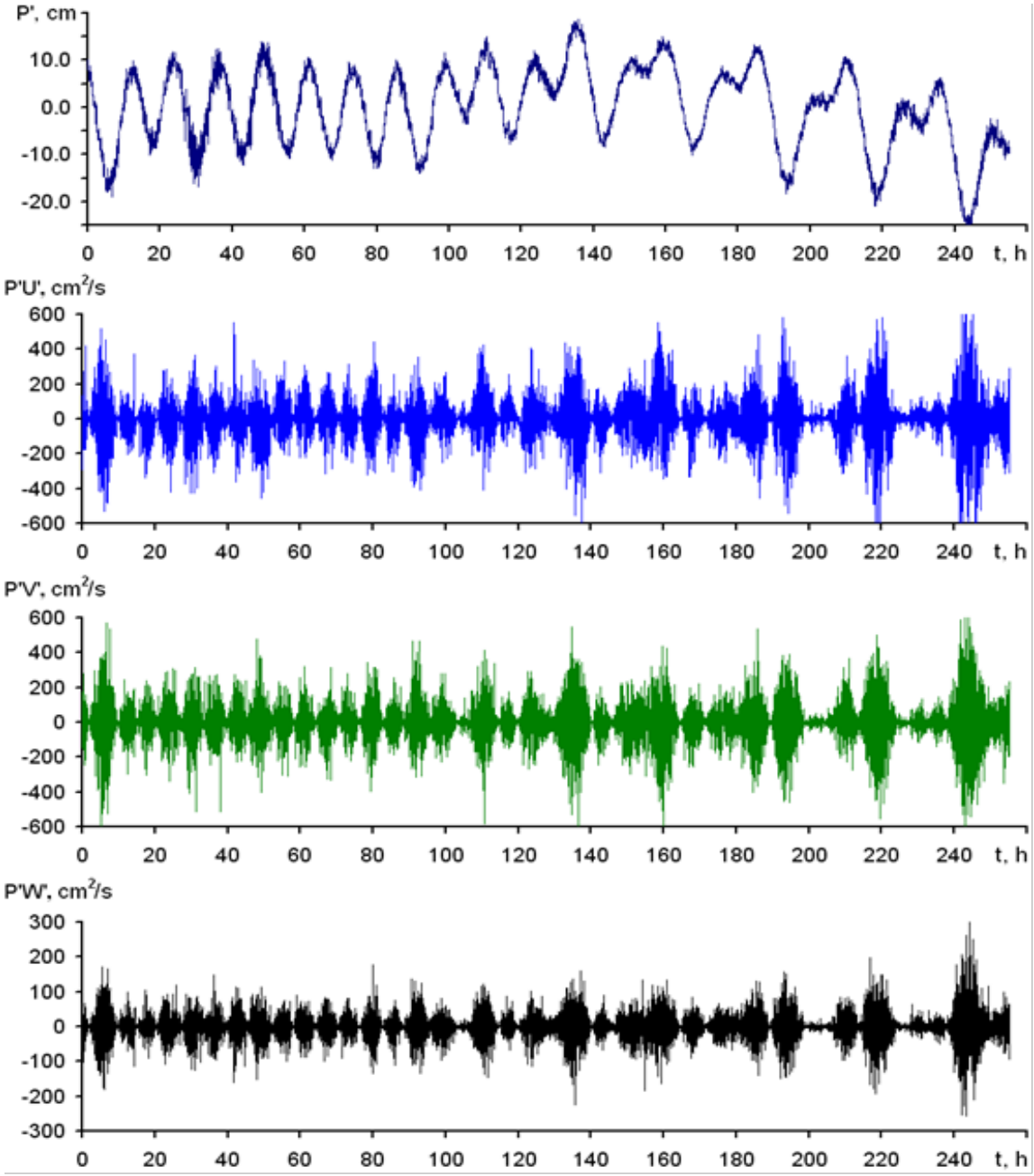
The wavy structure of temperature, velocity and pressure fluctuations leads to high intermittence of all fluxes and processes of mixing.

For relative comparisons we used temperature fluctuations as proxy for density fluctuations in analysis of momentum fluxes. Vertical and horizontal fluxes have about the same values.



Fluctuations of pressure and components of energy fluxes

The structure of energy fluxes is periodic, but generally with periods two times less, than in pressure fluctuations. That corresponds to 2 points of velocity maximum values in one cycle of pressure fluctuations.



Summary

- In shelf regions **Internal waves** are generated mainly over continental slope by tides, eddies, currents and their interactions at the expense of energy of large-scale processes. IW carry that energy to shallow waters.

- IW and IW-produced boluses render considerable effects on phytoplankton life conditions: a) quick change of illumination, b) extremely high vertical and horizontal gradT (up to 5^0/m vertically, 1^0/30-50m horizontally, 1^0/min in time, extra high particle vertical velocities, c) mixing driven high concentrations of nutrients and contaminants,

- **Internal waves** are **universal mechanism**, supporting productivity in shelf and offshore waters and ventilation of near-shore waters. It helps to **exchange ocean energy (going to shores) for terrigeneous matter (going to the ocean).**

- The relative role of IW and boluses in formation of Chl-a and phytoplankton spatial structures is **maximum in the warm months**, when strong **thermocline prevents upwelling of nutrients** over the continental slope, but IW and boluses have maximum heights, and their dynamic effects lead to enrichment of near-shore waters by terrigenous material.

- We considered local dynamic mechanisms of ocean-land interactions on ocean boundaries. On global scale, to obtain the matter from land, ocean uses mainly heat energy for evaporation and, with the help of atmosphere, washes out from land not only necessary elements, but also harmful products of human activity

- **Ocean and human health and malady are highly dependent on the processes in shelf waters !**

Thank you !