Development of an eddy-resolving coupled ocean – ice model of the Arctic region

K. Ushakov

R. Ibrayev

V. Kalmykov

Hydrometeorological Center of Russia

1. The main goal of the work

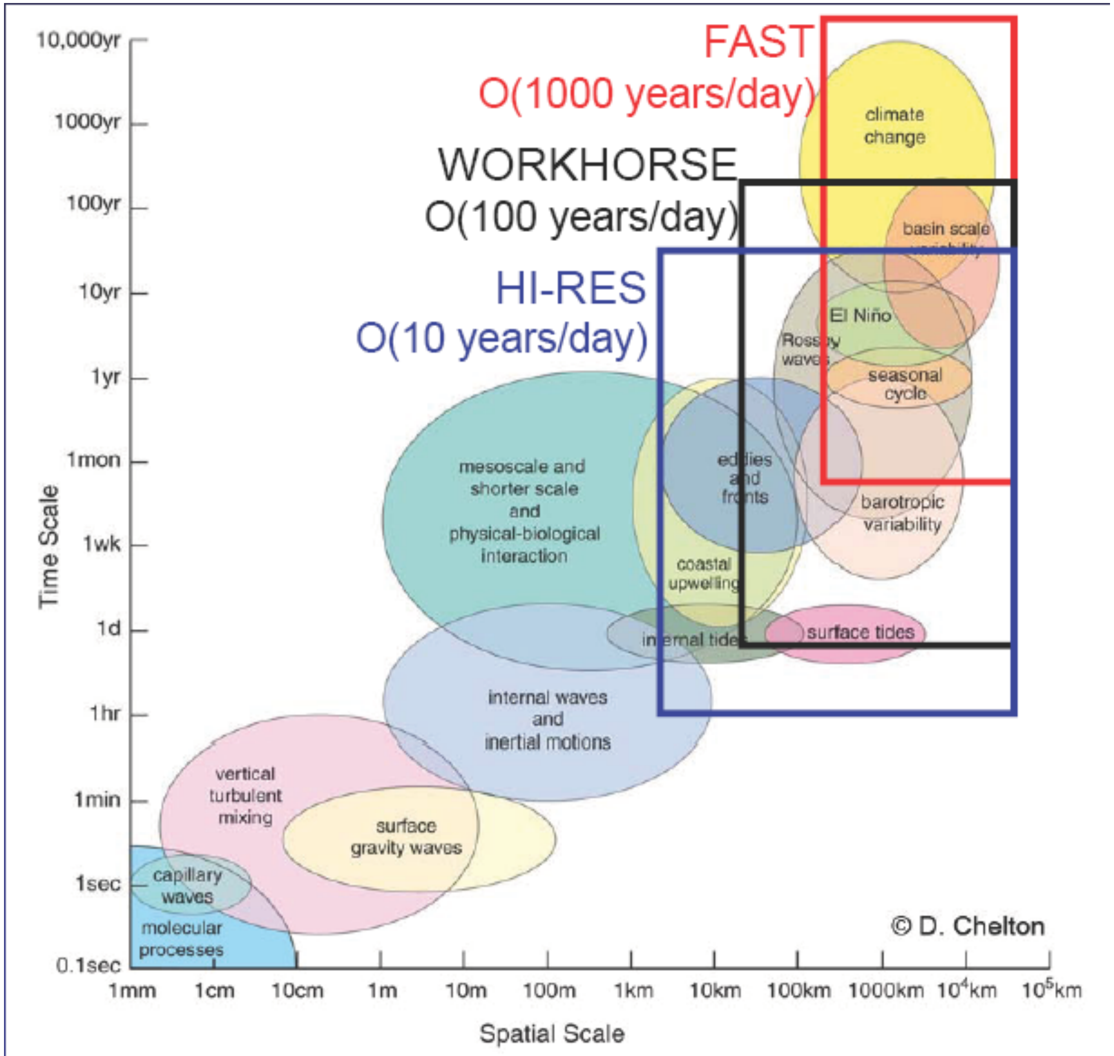
Development of a modern high-resolution coupled model of the polar ocean – ice – atmosphere – land system. The model will provide the operative forecast of physical processes in the hydrometeorological component of the Arctic climate system for the information support of governmental, social, and economical activities in the Russian sector of the Arctic.

2. Model physics requirements

1. Ocean upper layer
   - ocean – atmosphere interaction
   - ocean – ice interaction
   - Ekman layer
   - surface mixed layer
   - solar radiation
   - generation of turbulence
2. Horizontal processes
   - boundary currents
   - eddy dynamics
   - exchange through straits
3. Upwelling
4. Tides
5. Water budget
   - surface level change
   - wetting and drying
6. Tracer advection
7. Bottom currents

Horizontal scales, except for vertical mixing, are <u>L~ 10^3 -10^4 m, H~10[illegible] – 10[illegible] m, [illegible]~10^0 – 10^2 h</u>

3. Computational requirements

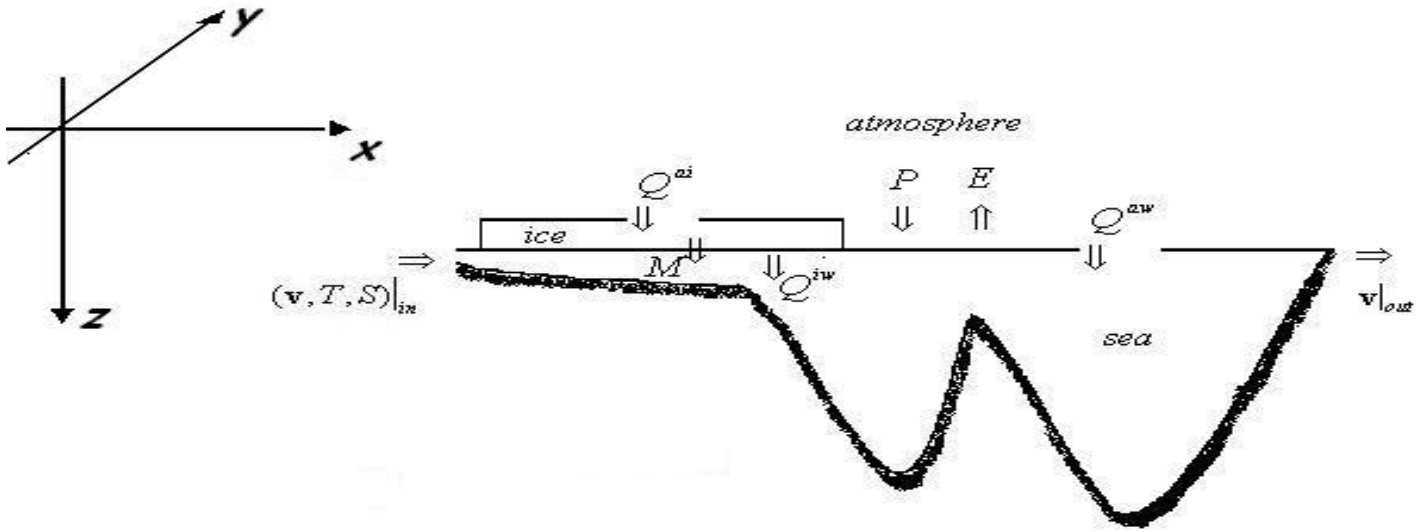


Horizontal resolution:
- 2-5 km for ocean
- 1-3 km for ice

Data volume:
- 5 Gb/day

Scalability:
- ≥ 500 processor cores

4. INM – IO ocean model: basic equations



$$u_t + (\vec{v}\cdot\nabla)u - fv = -\rho_o^{-1}p_x + (K_m u_z)_z + D_u$$

$$v_t + (\vec{v}\cdot\vec{\nabla})v + fu = -\rho_o^{-1}p_y + (K_m v_z)_z + D_u$$

$$p_z = \rho g$$

$$\vec{\nabla}\cdot\vec{v} = 0$$

$$\zeta_t + \vec{v}\cdot\vec{\nabla}(z+\zeta) = \rho_f^{-1}(P + M - E)$$

$$T_t + (\vec{v}\cdot\vec{\nabla})T = (K_h T_z)_z + D_T + (\rho_o c_p)^{-1} I_z \cdot (1 - A)$$

$$S_t + (\vec{v}\cdot\vec{\nabla})S = (K_h S_z)_z + D_S$$

$$\rho = \rho(T,S)$$

4. INM – IO ocean model: boundary conditions

Ocean – atmosphere interaction:
bulk formulae CCSM (CORE protocol) or (Launiainen, Vihma, 1990)
+ direct treatment of water, salt and radiation fluxes

Ocean – ice interaction: ice thermodynamics model(Scrum, Backhaus, 1999)

Solid boundaries: zero fluxes or zero velocities

Liquid boundaries: velocities and T,S of incoming flows

- + Framework for coupling models of other climate system components

Finite volume method

mutually consistent numerical schemes for water and tracer transport

Momentum advection: centered difference scheme

potentially unstable on highly distorted grid cells

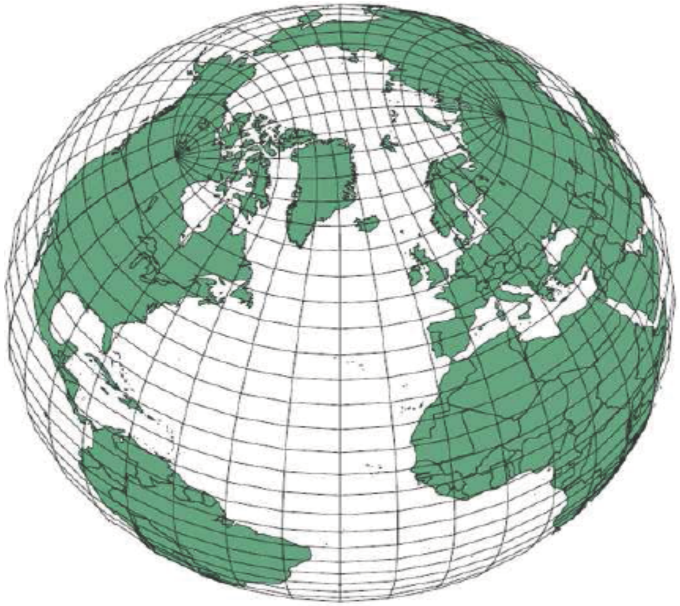
Tracer advection: Flux corrected transport (Zalesak, 1979), Second order moments (Prather, 1986)

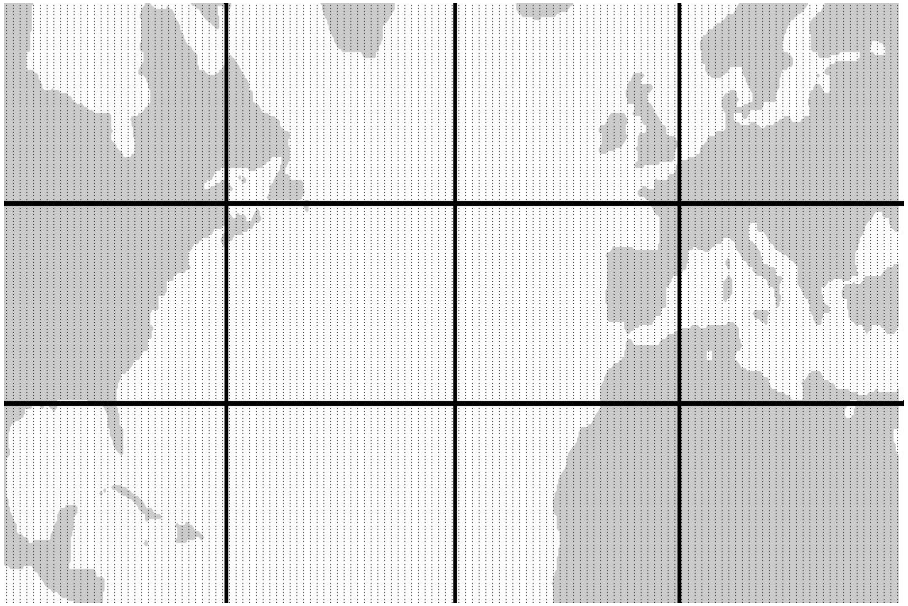
different schemes for different resolutions

Vertical mixing: Munk-Anderson (1958), Gent-McWilliams (Griffies, 1998), KPP (Durski, 2004)

Horizontal mixing: Smagorinsky viscosity, diffusivity, and biharmonical filter (Griffies, 2000)

Barotropic dynamics: predictor-corrector scheme for shallow water equations (MOM5)

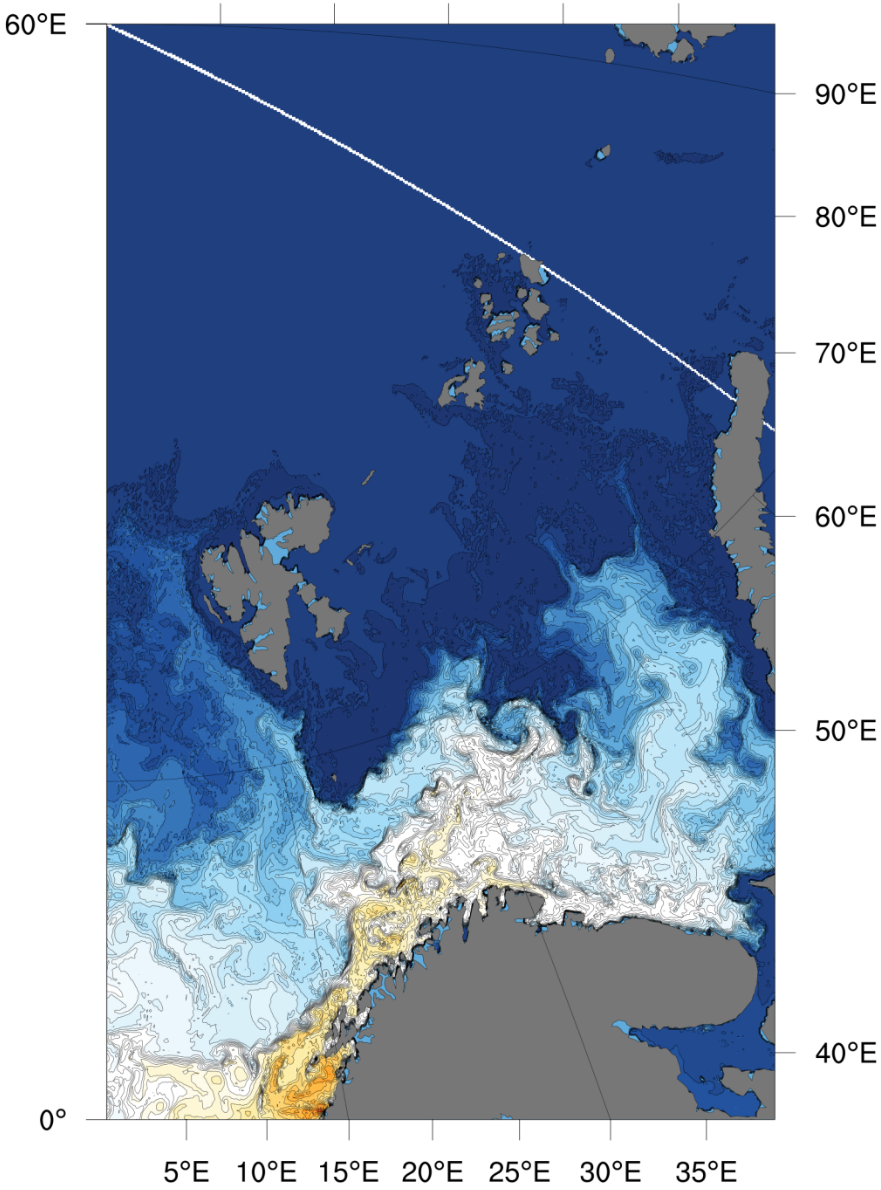




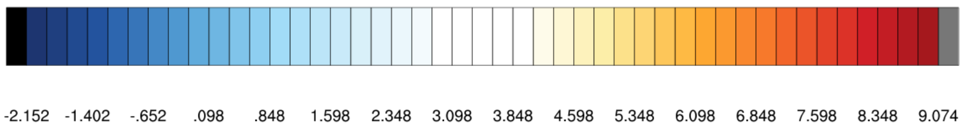
Global tripolar grid (Murray, 1996)

2D domain decomposition with fully local data and computation

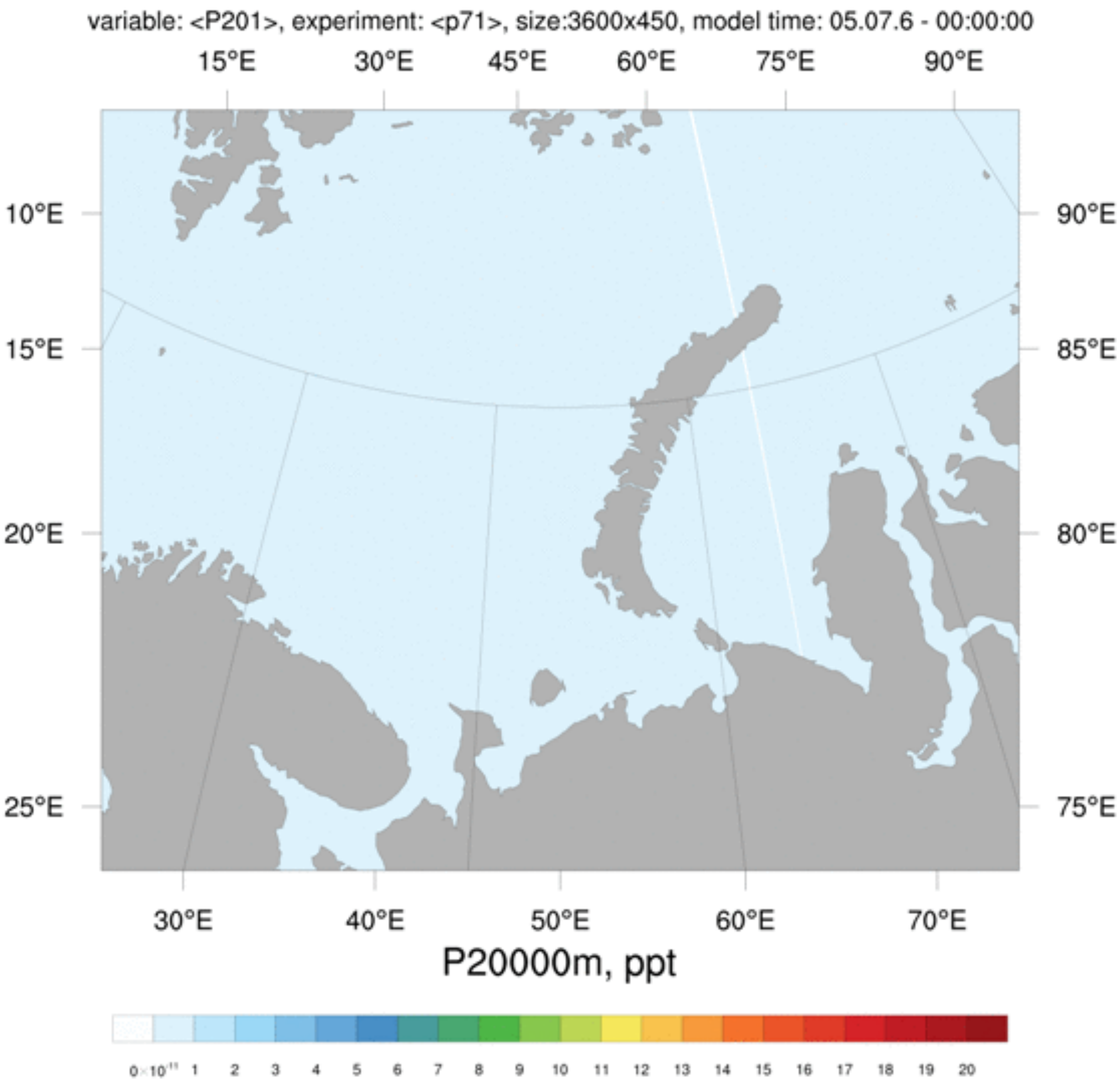
Linearly scalable up to 32 000 processor cores



Sea surface temperature on January 1 after 3 years of Arctic ocean model integration with 0.1^{o} resolution

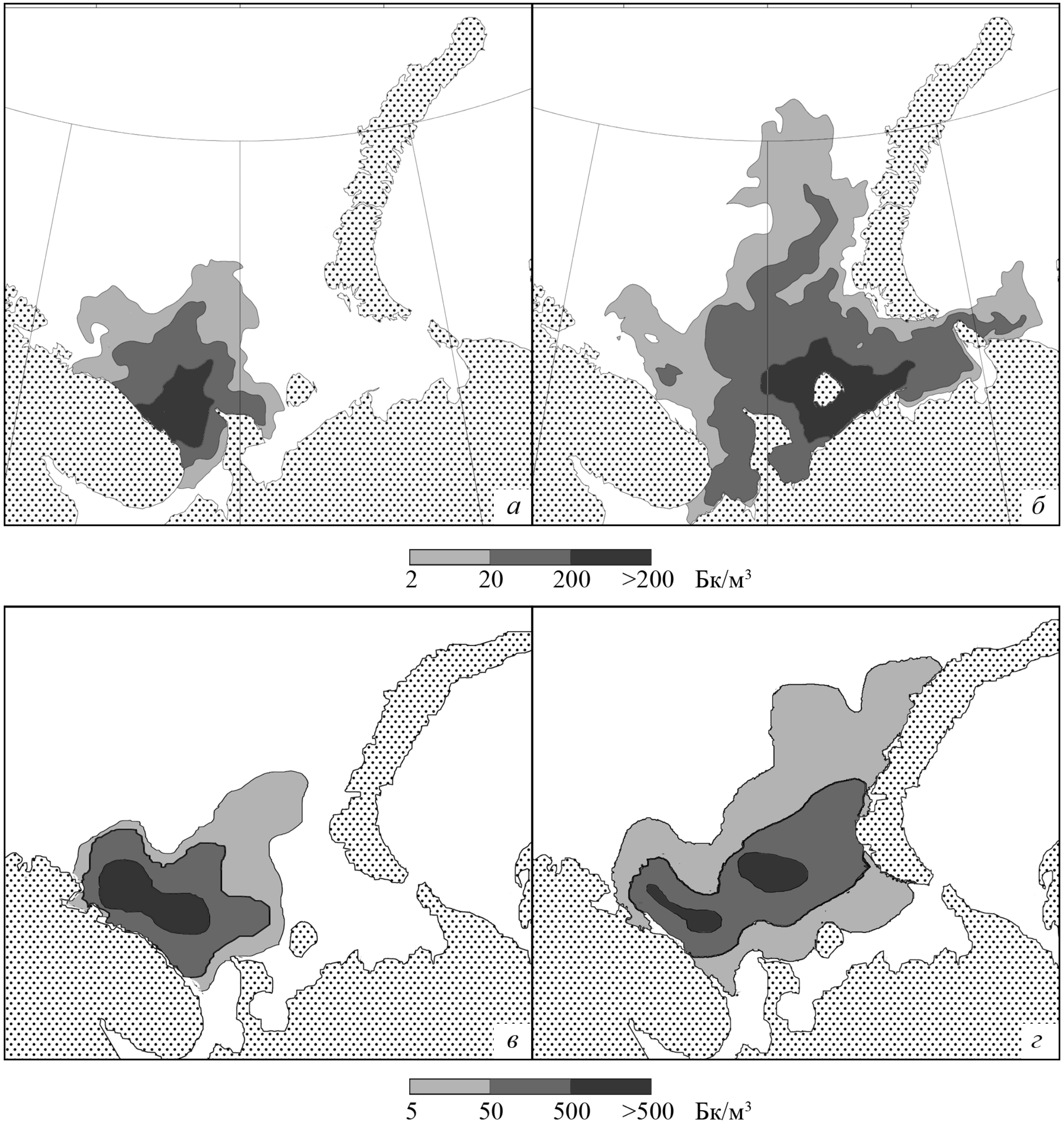


6. Numerical experiments: radioactive pollution transport



Instantaneous emission of ^{137}Cs with $5 \cdot 10^{13}$ Bk total activity

6. Numerical experiments: radioactive pollution transport



Forecats of ^{137}Cs spreading on the Barents Sea surface in INM-IO (top) and ROMS (*bottom*) models after 6(*left*) and 12(*right*) months after emission

(Heldal et al, 2013)

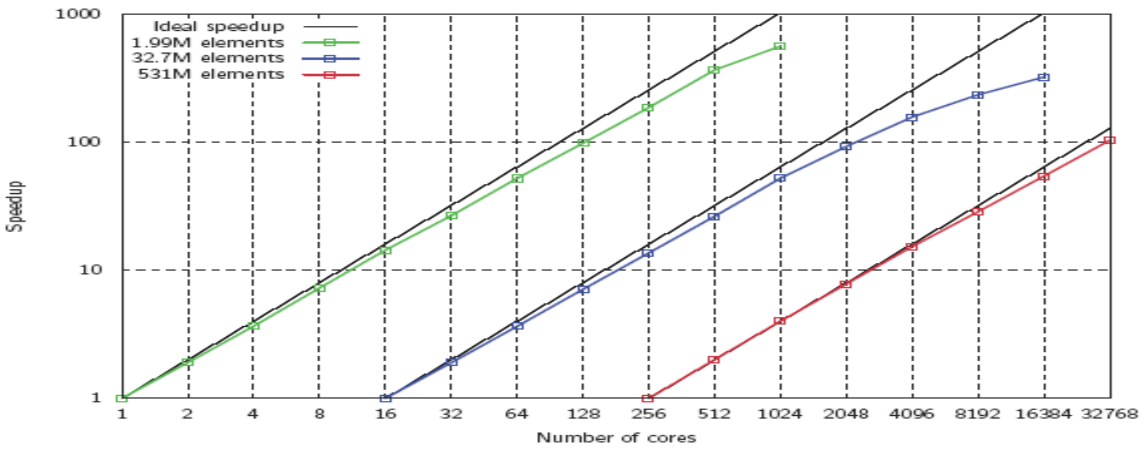
7. Now being implemented

- Coupling with the CICE-5 ice model
- Assimilation of AVISO Argo data
- Coupled model of ocean (INM - IO) – ice (CICE) – atmosphere (SLAV) in operation
- Nested grids for more detailed simulation of selected seas

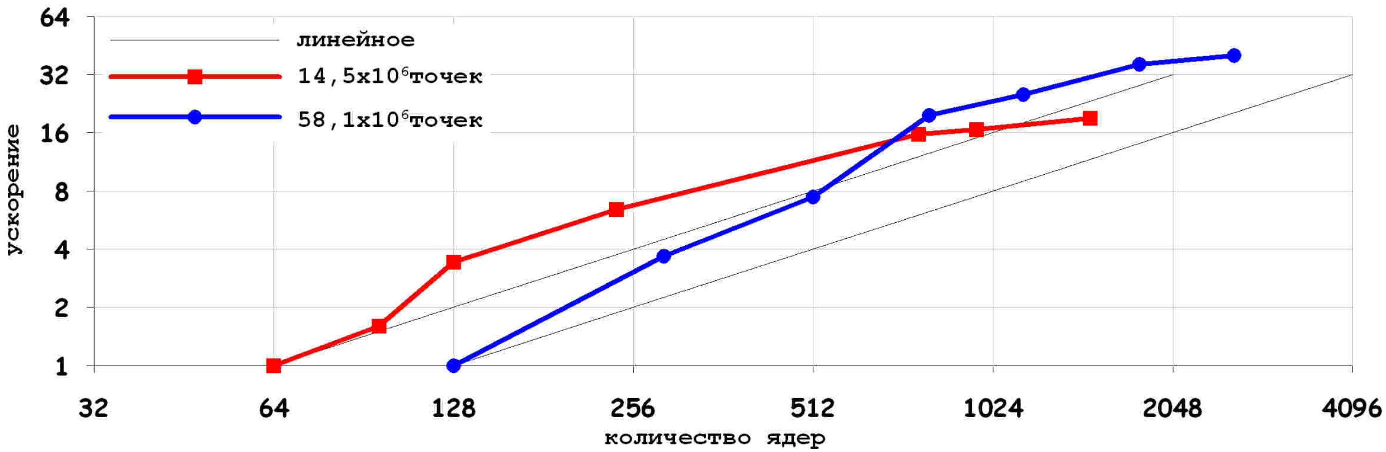

Thank you for
your attention!

2.4. Масштабируемость программного кода

<u>Определение</u>. *Масштабируемость программного обеспечения - способност программного обеспечения корректно работать на малых и на больших системах с производительностью, которая увеличивается пропорционально вычислительной мощности системы.*



Масштабируемость AMR для адвекции-диффузии.
(*Ghattas O., World Modelling Summit for Climate Prediction, Reading, UK, 2008*)



Масштабируемость модели Мирового океана, разработанной в ИВМ, ИО РАН для сеток с разрешением 15′ x 15′ 7,5′ x 7,5′ (*Ибраев, Калмыков, Ушаков, 2010*) неявная аппроксимация по времени

$$\left.\begin{aligned}
&\frac{\eta^{p+1}-\eta^{p}}{\tau}+\left(\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}\right)^{p+1}=\frac{1}{\rho_f}W^{l}\\
&\frac{U^{p+1}-U^{p}}{\tau}-fV^{p}=-gH\left(\frac{\partial \eta}{\partial x}\right)^{p+1}+R^{x}\\
&\frac{V^{p+1}-V^{p}}{\tau}+fU^{p}=-gH\left(\frac{\partial \eta}{\partial y}\right)^{p+1}+R^{y}
\end{aligned}\right\}\Rightarrow\ \frac{\eta^{p+1}}{\tau}-\tau gH\left(\frac{\partial^{2} U}{\partial x^{2}}+\frac{\partial^{2} V}{\partial y^{2}}\right)^{p+1}=R$$

явная аппроксимация по времени

$$\left.\begin{aligned}
&\frac{\eta^{p+1}-\eta^{p}}{\tau}+\left(\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}\right)^{p}=\frac{1}{\rho_f}W^{l}\\
&\frac{U^{p+1}-U^{p}}{\tau}-fV^{p}=-gH\left(\frac{\partial \eta}{\partial x}\right)^{p+1}+R^{x}\\
&\frac{V^{p+1}-V^{p}}{\tau}+fU^{p}=-gH\left(\frac{\partial \eta}{\partial y}\right)^{p+1}+R^{y}
\end{aligned}\right\}\Rightarrow\ \left\{\begin{aligned}
&\tau << \Delta t\\
&\left[t^{l};t^{l}+2\Delta t\right]\\
&2\cdot pl,\ pl=\Delta t/\tau
\end{aligned}\right\}\Rightarrow\ \left\{\begin{aligned}
&\hat{\eta}^{l+1}=\frac{1}{2\cdot pl+1}\sum_{p=0}^{2\cdot pl}\eta^{p}\\
&\hat{U}^{l+1}=\frac{1}{2\cdot pl+1}\sum_{p=0}^{2\cdot pl}U^{p}\\
&\hat{V}^{l+1}=\frac{1}{2\cdot pl+1}\sum_{p=0}^{2\cdot pl}V^{p}
\end{aligned}\right.$$