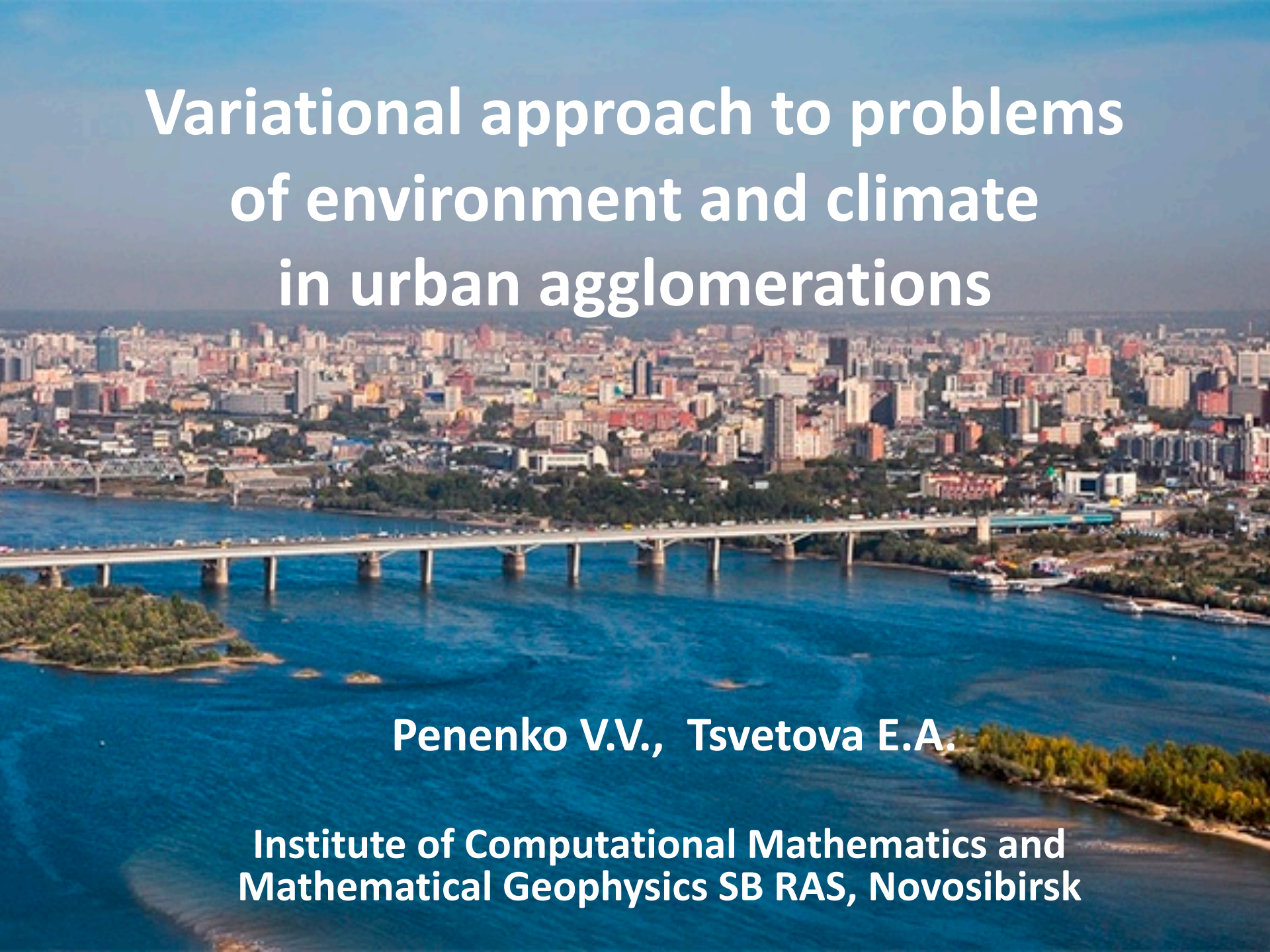
Variational approach to problems of environment and climate in urban agglomerations



Penenko V.V., Tsvetova E.A.

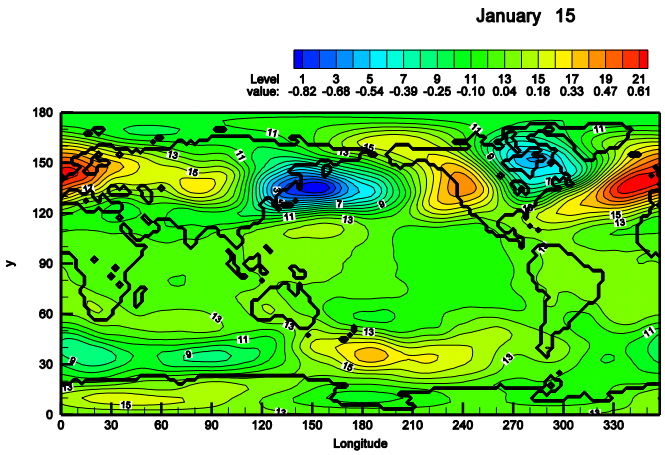
Institute of Computational Mathematics and Mathematical Geophysics SB RAS, Novosibirsk

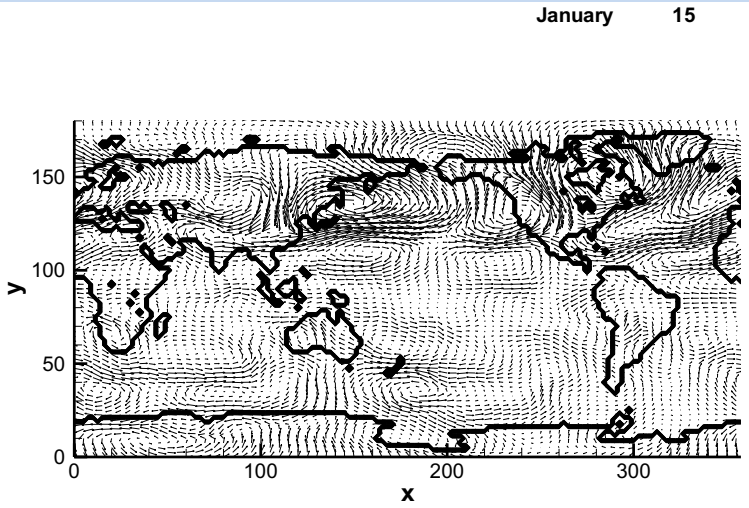
Evaluation of scale interactions in climate and ecological system

- Place of the object under study in the global system
- Decomposition of spatial and temporal scales
- Typical life times of objects and sources of impacts
- Meso - regional processes and typical mesoclimates on the background of global circulation
- Scenario approach

Methods of orthogonal decomposition. Subspaces of informative basis

Activity centers of the climatic system



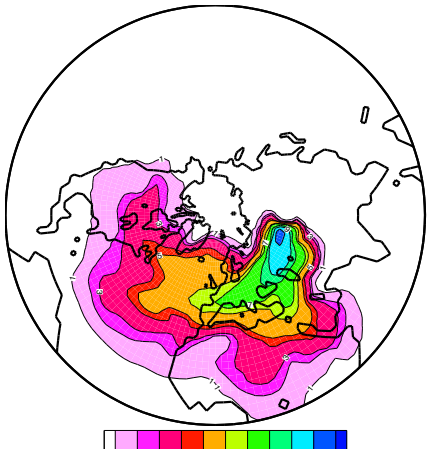


Penenko V., Tsvetova E. Orthogonal decomposition methods for inclusion of climatic data into environmental studies//Ecol. Model. V. 217. P. 279–291. 2008.

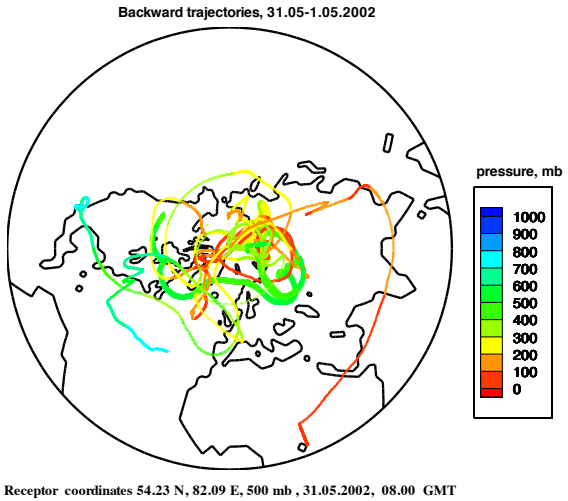
Inverse problems :Tracing long-range bioaerosol transport and evaluation of risk areas for the Novosibirsk region

(“adjoint Euler” and “adjoint Lagrange”)

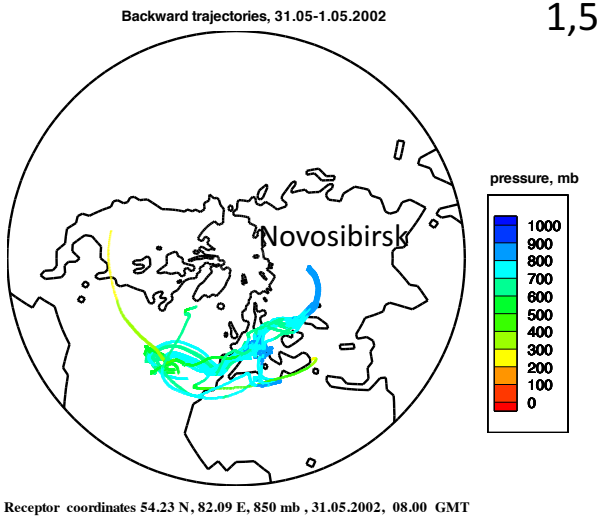
Risks from land-based sources



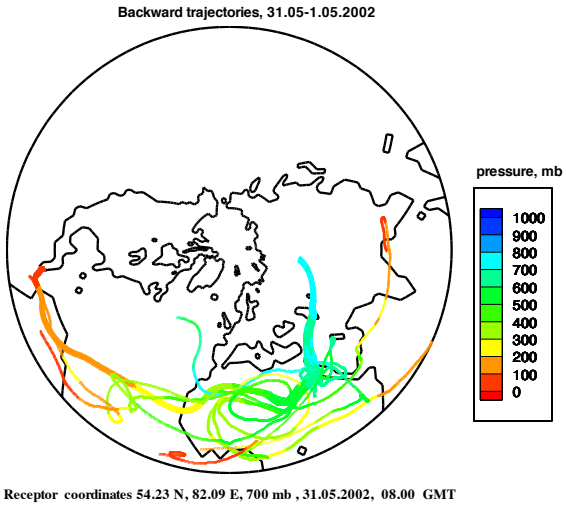
5,5 км



1,5 км



3 км



Typical conditions

- Terrain features
- The underlying surface
- Land use categories:
  - river, ponds
  - forest (coniferous, deciduous, mixed, shrubs)
  - urban areas (dense, sparse, tall, etc.)
  - the suburbs
  - farmland

THE PROBLEM OF PARAMETRIZATION

Experience in solving environmental problems for industrial regions and urban agglomerations

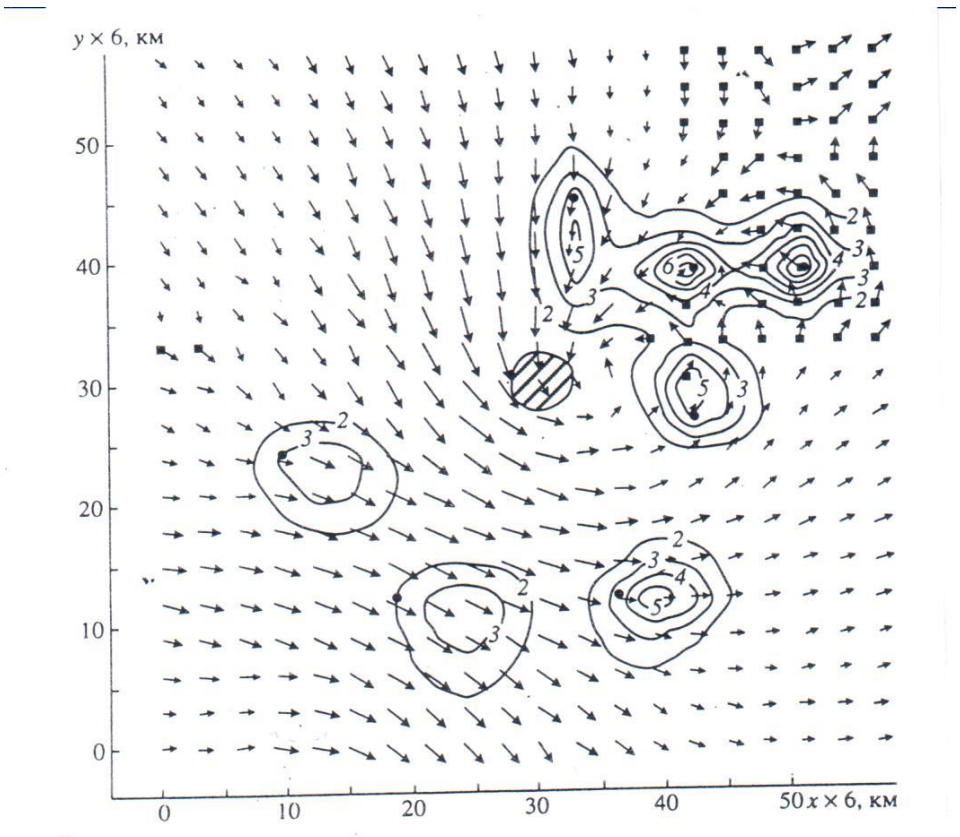
- **Almaty** (ventilating mechanisms and urban plans)
- **Novosibirsk** (assessment of risk areas from НЗХК, ТЭЦ 5, projects of highways, projects of placing incineration plant)
- **Krasnoyarsk** (evaluation of changes in mesoclimates after the construction of the HPP)
- **Ulan-Ude** (project of apatite plant, influence of the Baikal breeze on air quality)
- **Astrakhan** (the impact of emissions of a gas processing plant in the conditions of the Caspian sea, H2S)
- **Tomsk (** Seversk accident**)**
- **Industrial regions and cities of the Baikal region**

Опыт решения природоохранных задач

Москва (1985 г.)

- Формирование типичных мезоклиматов;
- влияние острова тепла.
- проект строительства кольца атомных станций в Центральном регионе России;

Пененко В.В., Алоян А.Е. ФАО, 1995



Фрагмент сценария, h=300м, 21 час;

Model of atmospheric dynamics

$$\frac{u}{t} + \mathrm{div}\quad u\mathbf{u}\quad M(u) + \frac{p}{x}\qquad (lv\quad kw)\quad (f_u + r_u) = 0$$

$$\frac{v}{t} + \mathrm{div}\quad v\mathbf{u}\quad M(v) + \frac{p}{y} + \quad lu\quad (f_v + r_v) = 0$$

$$\frac{w}{t} + \mathrm{div}\quad w\mathbf{u}\quad M(w) + \frac{p}{z} + g\qquad ku\quad (f_w + r_w) = 0$$

$$\frac{T}{t} + \mathrm{div}\quad T\mathbf{u} + A_T\quad T\,\mathrm{div}\,\mathbf{u}\qquad M(T)\qquad (f_T + r_T) = 0$$

$$\frac{p}{t} + \mathrm{div}\quad p\mathbf{u} + \qquad p\,\mathrm{div}\,\mathbf{u}\quad (\qquad 1)M(p)\quad (\qquad 1)(f_p + r_p) = 0$$

$$\frac{}{t} + \mathrm{div}\quad \mathbf{u} = 0$$

$$p = \quad R_d(1 + \quad)T, \qquad = (R_v / R_d\quad 1)q_v\quad q_l\quad q_f$$

$$M(\quad) = \mathrm{div}\qquad \mathrm{grad}(\qquad); \qquad A_T = \quad R_d(1 + \quad)/c_p; \qquad = c_p / c_v$$

Convection-diffusion-reaction system for humidity and gas - aerosol chemistry

$$\frac{\partial \varphi_i}{\partial t} + \operatorname{div}\left(\mathbf{u}\, M(\varphi_i)\right) + \left(S_i(\boldsymbol{\varphi}) - (f_i + r_i)\right) = 0 \qquad i = \overline{7,n};$$

Operators of transformation for chemical kinetics

destruction

$$S_i(\varphi) = P_i(\varphi)\,\varphi_i - L_i(\varphi)$$

production

$$P_i(\varphi) = \sum_{q=1}^{R_i} k(q) \prod_{j=1}^{U_q} s_j(q)^{\left(s_i(q^-) - s_i(q^+)\right)}$$

$$i = \overline{1,n_g}$$

! Important properties

$$P_i(\varphi) \geq 0; \qquad L_i(\varphi) \geq 0$$

Состав и механизмы трансформации аэрозолей

Состав	Основные механизмы
Фракции нелетучих материалов: почвенная пыль, морская соль, углеродные частицы	коагуляция , дробление
Частицы с конденсационным ростом: водяной пар, сульфатные аэрозоли	конденсация/испарение, гомогенная нуклеация , коагуляция
Смеси аэрозолей первых двух типов	конденсация, коагуляция, захват нелетучими частицами, гетерогенная нуклеация
Композитные аэрозоли: формирование радиоактивных частиц ; формирование кислотных субстанций; биологически активные аэрозоли	коагуляция и дробление , осаждение на аэрозоли;
	Трансформация типа газ-частица и нуклеация/ конденсация

Integral identity is a variational form of integrated system: hydrodynamics+ chemistry+ hydrology

$$I\left(\boldsymbol{\varphi}, \mathbf{Y}, \mathbf{r}, \xi, \boldsymbol{\varphi}^*\right) = \left(L\left(\boldsymbol{\varphi}, \mathbf{Y}, \mathbf{r}\right), \boldsymbol{\varphi}^*\right) =$$

$$\sum_{i=1}^{n} {}_i \left(\boldsymbol{\varphi}, \boldsymbol{\varphi}^* \right)_i + \int_{D_t} \left(S_i(\boldsymbol{\varphi}) \quad (f_{\ i} + r_{\ i}) \right) \quad {}_i^* dDdt \quad + \int_t p \mathbf{u}_\mathbf{n}^* d \quad dt +$$

$$\int_{D_t} \left\{ \quad l\left(uv^* \quad vu^*\right) + k\left(wu^* \quad w^* u\right) + gw^* \quad p \operatorname{div} \mathbf{u}^* \right\} dDdt = 0$$

$$\left(\quad \boldsymbol{\varphi}, \boldsymbol{\varphi}^* \right)_i = \int_{D_t} \frac{{}_i}{t} + \operatorname{div} \quad {}_i \mathbf{u} + \%_i \quad {}_i \operatorname{div} \mathbf{u} \quad \%_i M(\ {}_i) \quad {}_i^* \quad dDdt +$$

$$+ \int_D \left({}_i^0 \quad {}_{ai}^0 \quad {}_i \right) \quad {}_i^* \Big|_{t=0} dD + \int_t \left(R_{b_i \ i} \quad f_{b_i} \right) \quad {}_i^* d \quad dt, \quad i = \overline{1,n}.$$

$\mathrm{I}(\ \ , \mathbf{Y}, \square) = 0$ equation of the energy balance for the system

$\boldsymbol{\varphi} \quad Q(D_t)$ state vector; $\boldsymbol{\varphi}^* \quad Q^*(D_t)$ adjoint vector

Augmented functional for construction of optimal algorithms and uncertainty assessment

cost functional

misfit in observations

model's uncertainty

$$\%_k^h(\varphi,\varphi^*,\mathbf{Y},\mathbf{r},\xi) = {}_k^h(\varphi) + 0.5\Big\{ {}_1(\eta^T\mathbf{M}_1\eta)_{D_t^m} + {}_2(\mathbf{r}^T\mathbf{M}_2\mathbf{r})_{D_t^h}$$

$$+ {}_3(\xi^T\mathbf{M}_3\xi)_{D^h} + {}_4(\zeta^T\mathbf{M}_4\zeta)_{R^h(D_t^h)}\Big\}^h + \mathbf{I}^h(\varphi,\mathbf{Y},\varphi_k^*)_{D_t^h}$$

initial data unc.

parameters unc.

integral identity

$\mathbf{M}_i,(1=1,4)$, $_i$ 0 are weight matrices and coefficients for scaling,

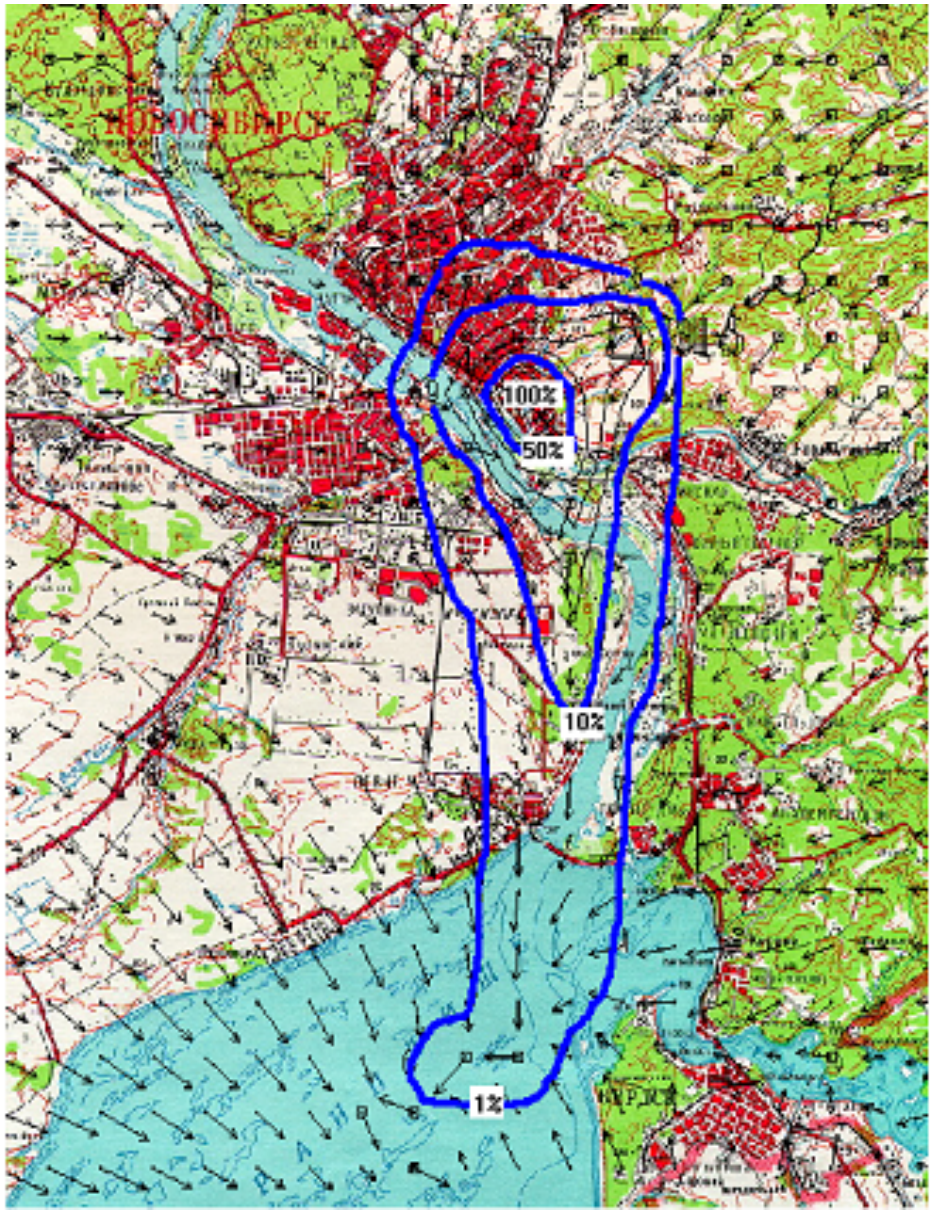
φ,φ_k^* are the solutions of the direct and adjoint problems generated by variational principle.

Symbol $()^h$ denotes discrete analogs. For approximation, finite volumes, decomposition and splitting methods are used.

D_t^h D_t is the grid domain

Penenko V. V. Variational methods of data assimilation and inverse problems for studying the atmosphere, ocean, and environment // Numerical Analysis and Applications, 2009 V 2 No 4, 341-351.

Novosibirsk
Satellite image,LandSat-5,2010-09-08



НОВОСИБИРСК

Сценарий распространения примесей от ТЭС-5 (проект)

при юго-западном
фоновом ветре
в ночных условиях
осенью

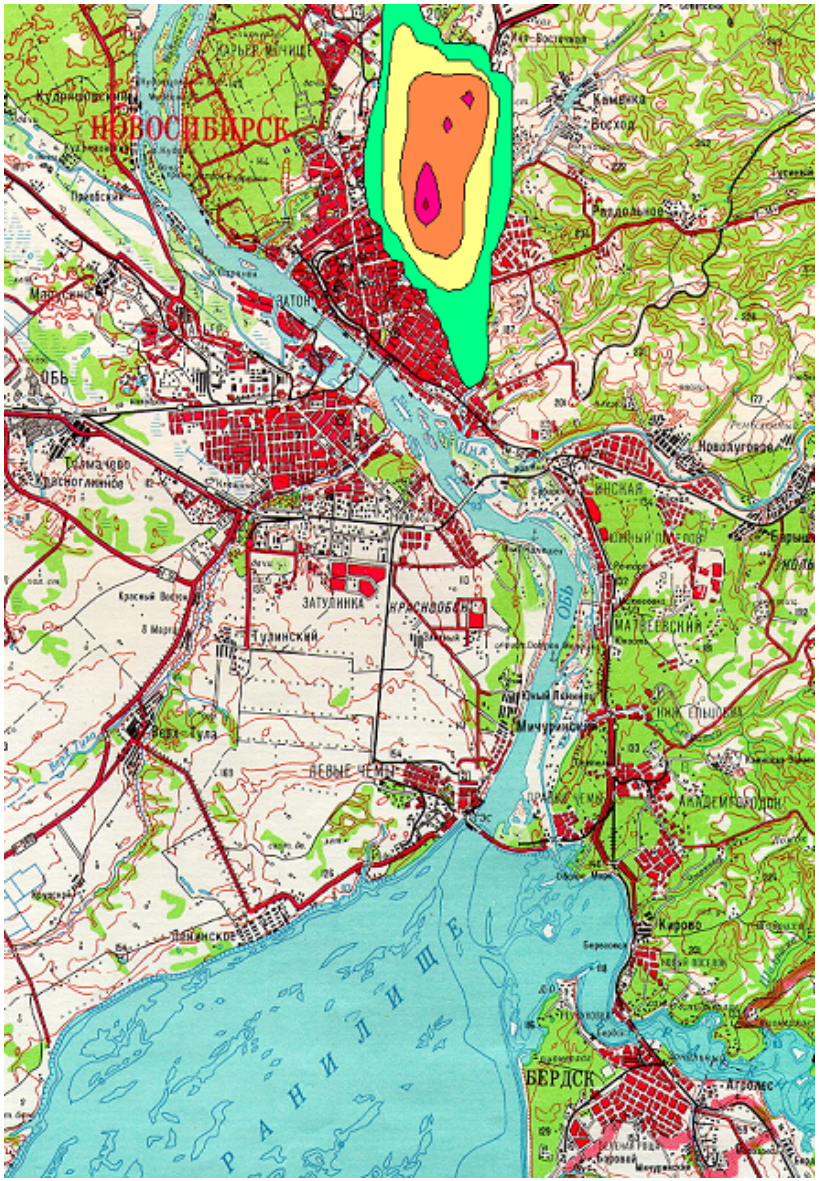
Горизонтальная структура поля ветра
и изолинии концентрации
(в % от максимальной)
на высоте 50 м от поверхности

ИВМиМГ

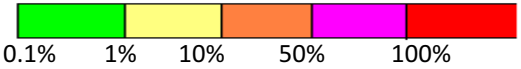
ИВМиМГ

Новосибирск

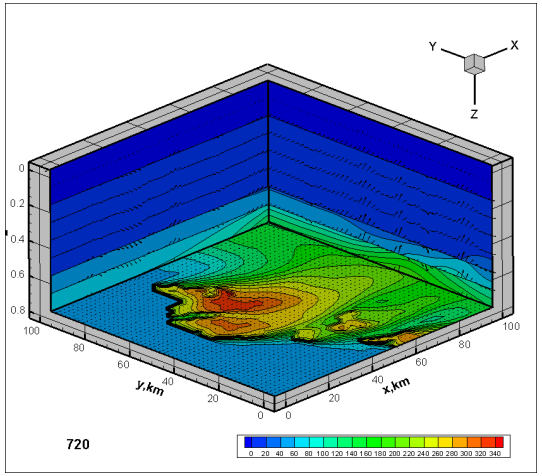
Сценарий распространения примеси от Новосибирского завода химконцентратов (НЗКХ) при юго-западном фоновом потоке

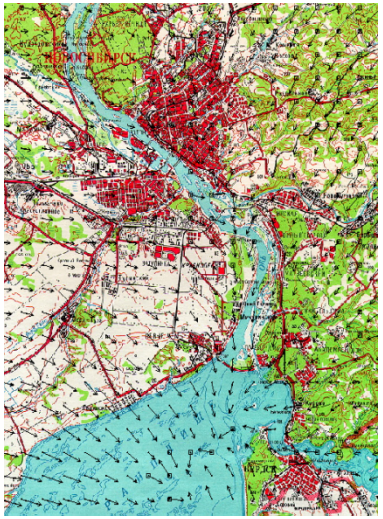


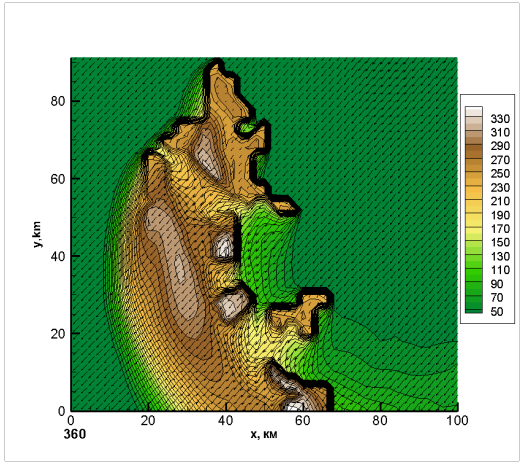
Изолинии поля концентрации
(в % от максимальной)
на высоте 50 м от поверхности

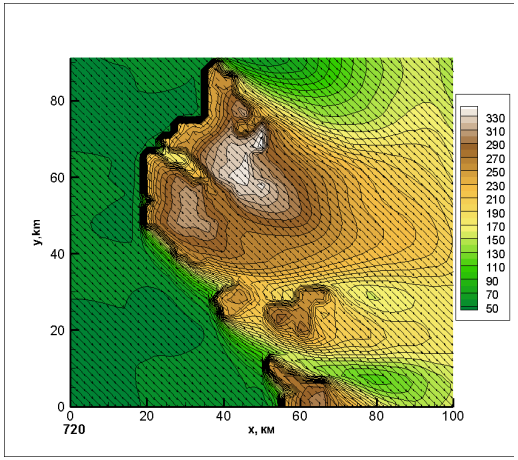


Wind field and concentration of impurities





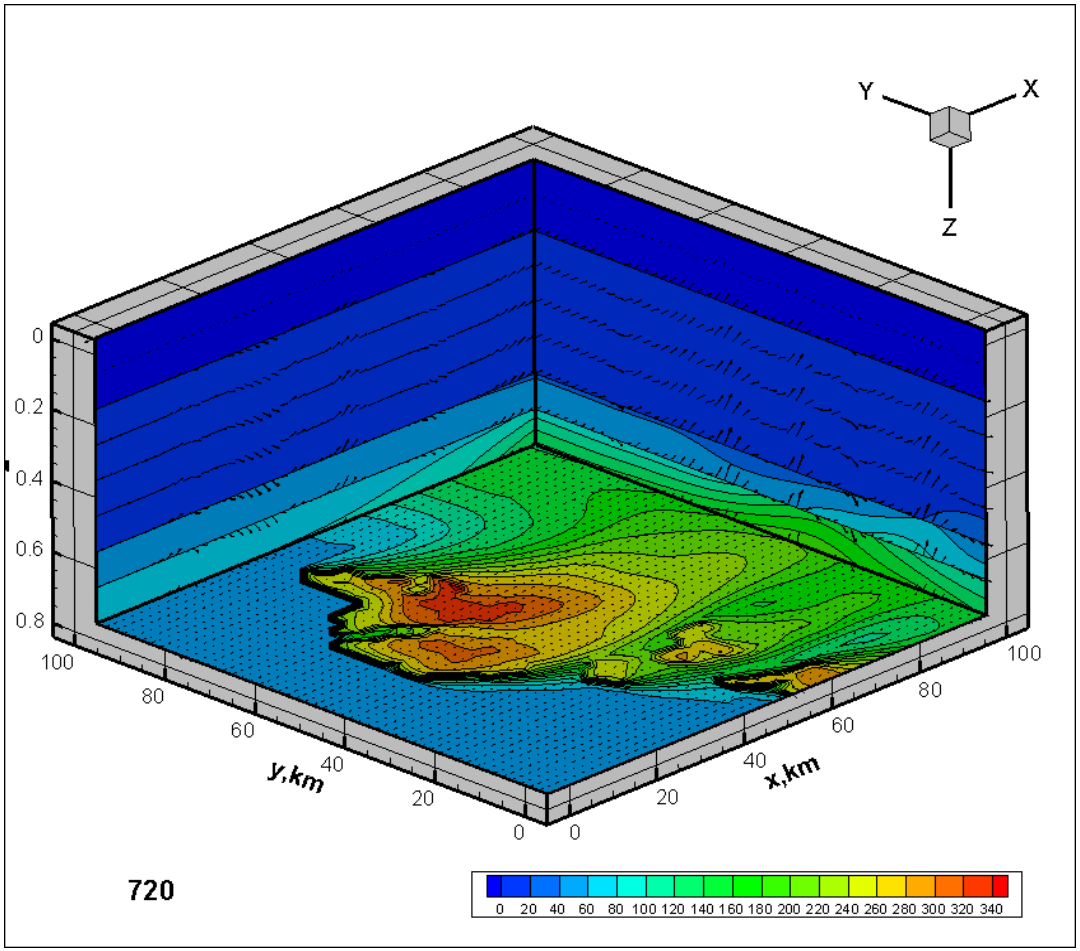




Распространение загрязнений от распределенных источников примеси расположенных в городской агломерации Новосибирска [лаб. ММГППС]

ИВМиМГ

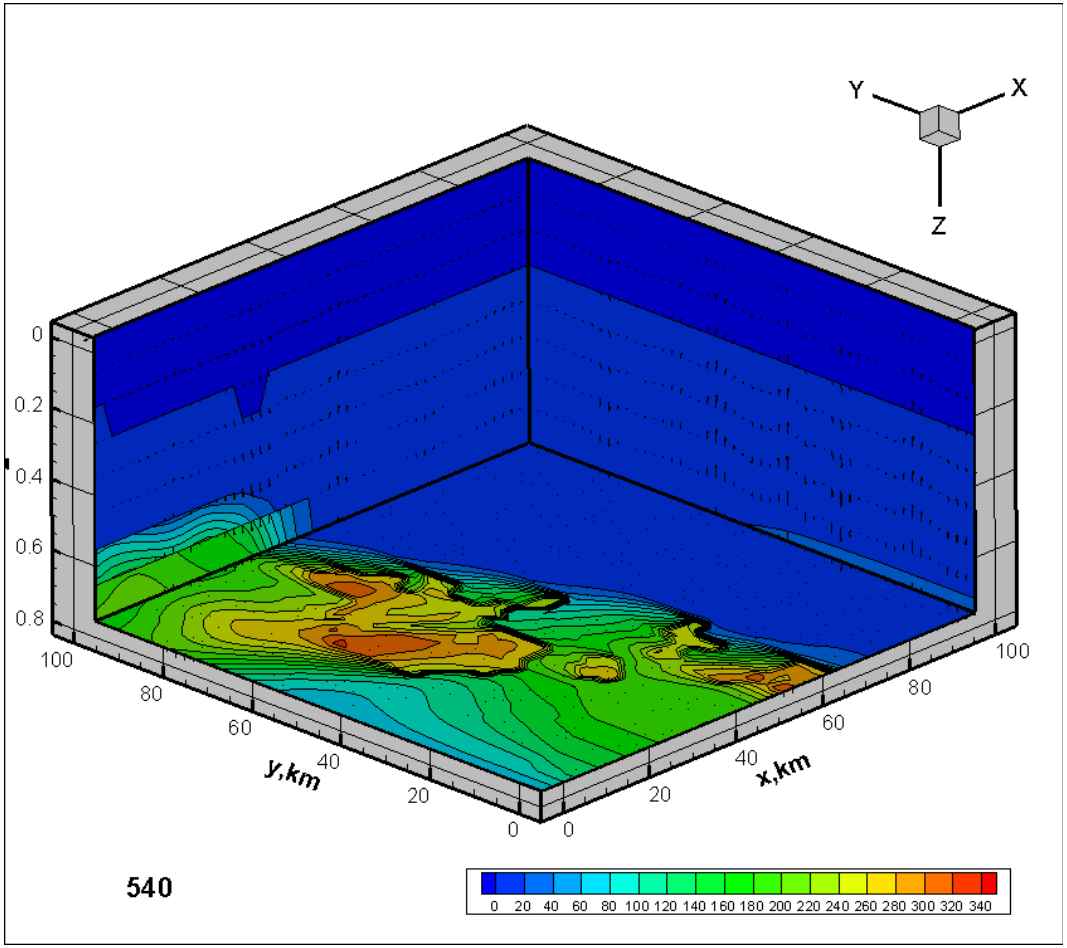
Wind field and concentration of impurities



14:00 час. местного времени

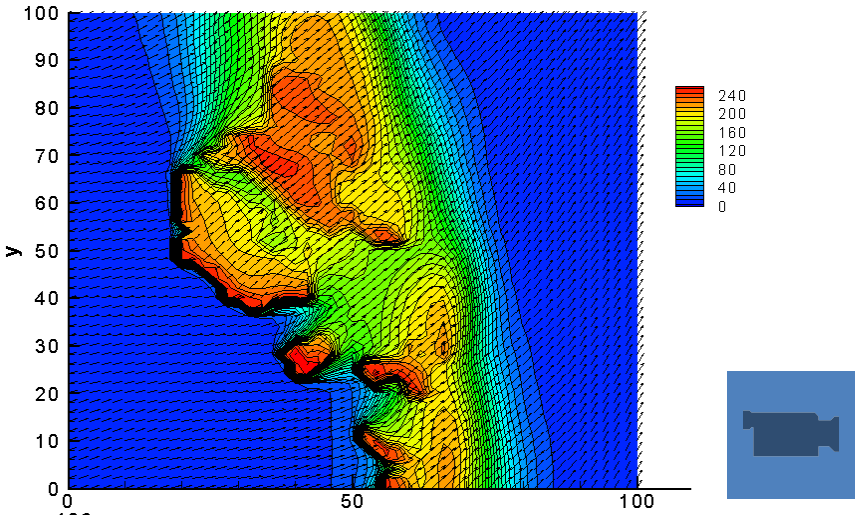
ИВМиМГ

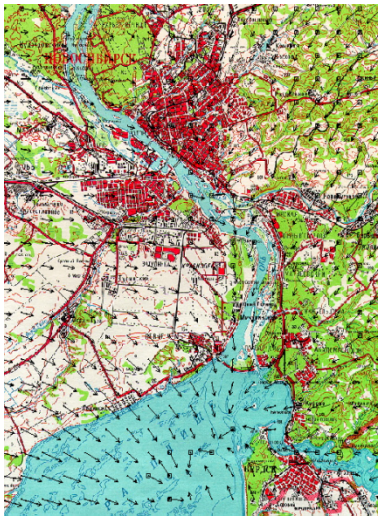
Wind field and concentration of impurities

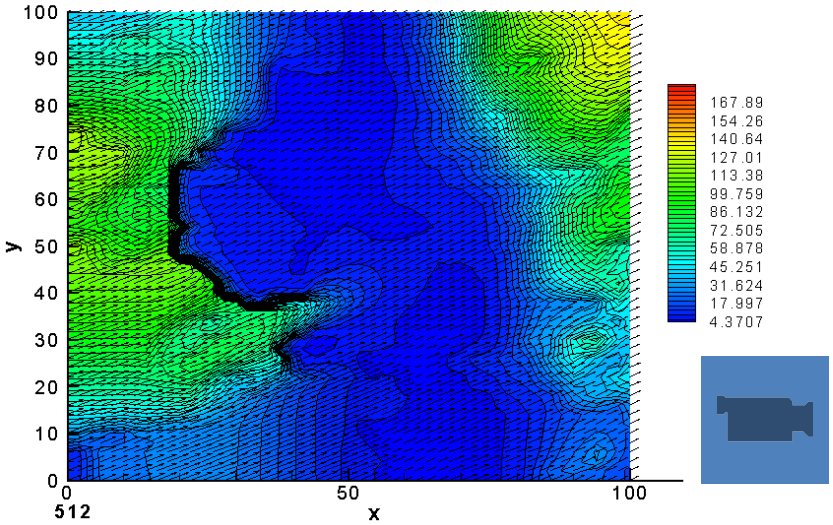


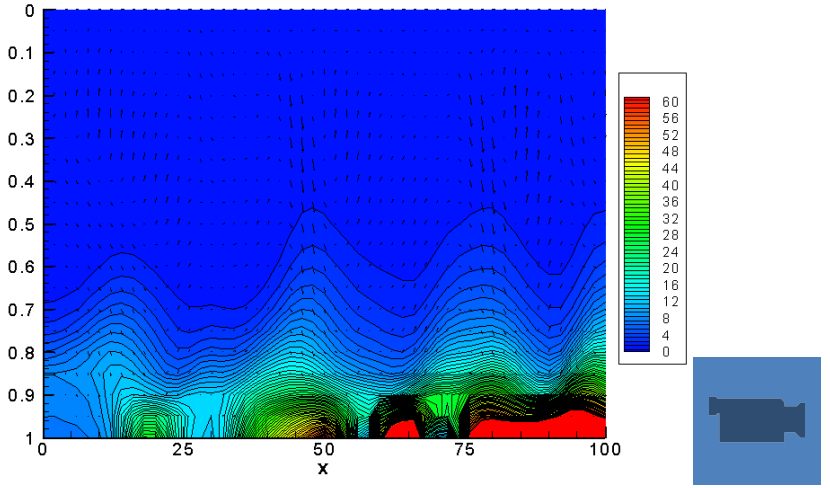
8:00 местного времени

Novosibirsk region









Problems of Krasnoyarsk

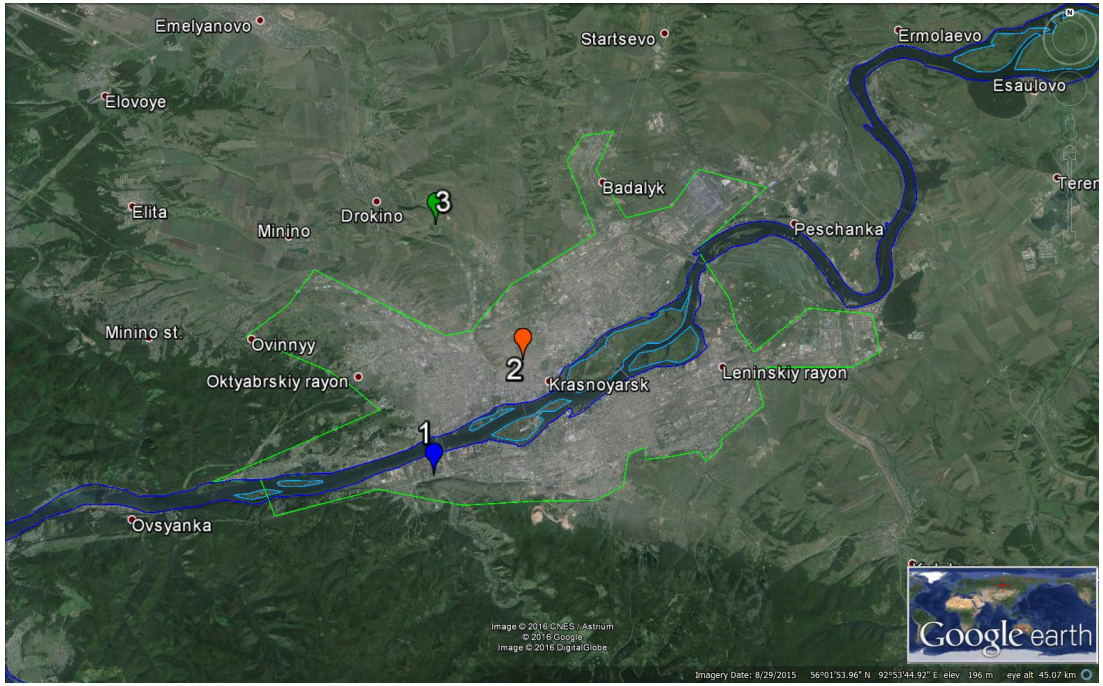
Complex terrain
Ice-free polynya
Severe pollution

150×140 km^2

301×281×35

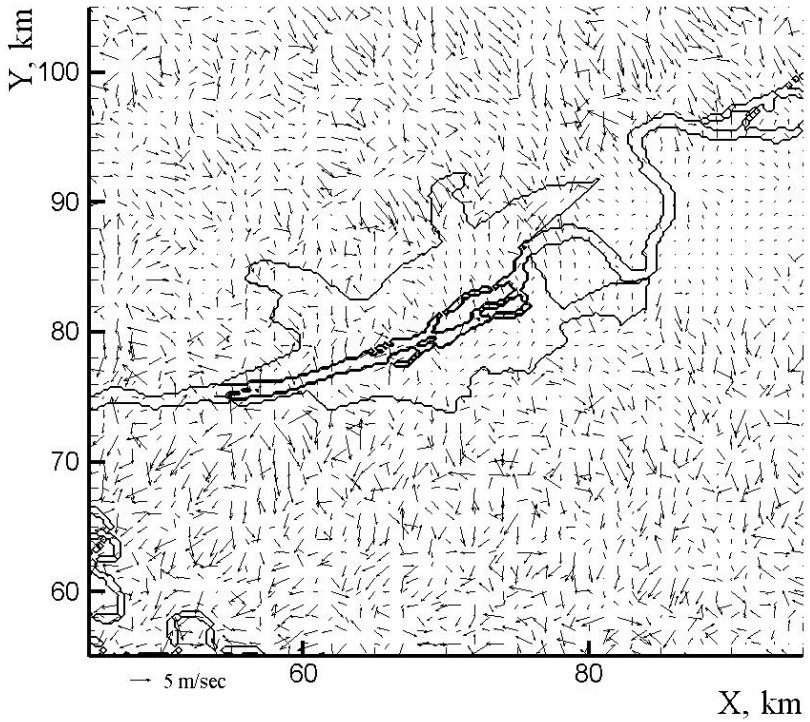
601×561×35

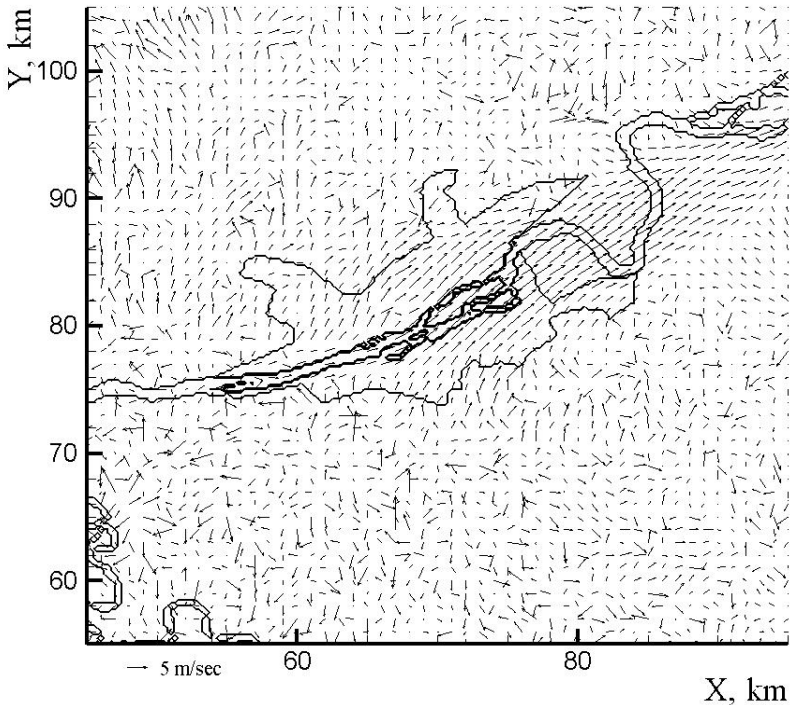
A part of the domain (city)



Scenario studies of local atmospheric circulations in the Krasnoyarsk region
E. A. Pyanova, V.V. Penenko, L.M. Faleychik (SPIE 2016)

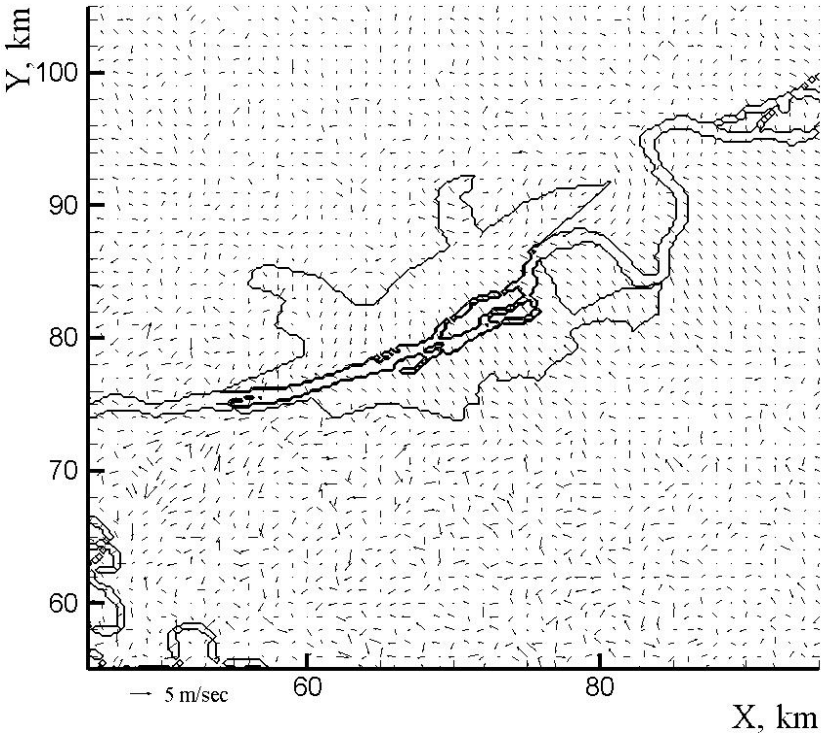
Summer scenario



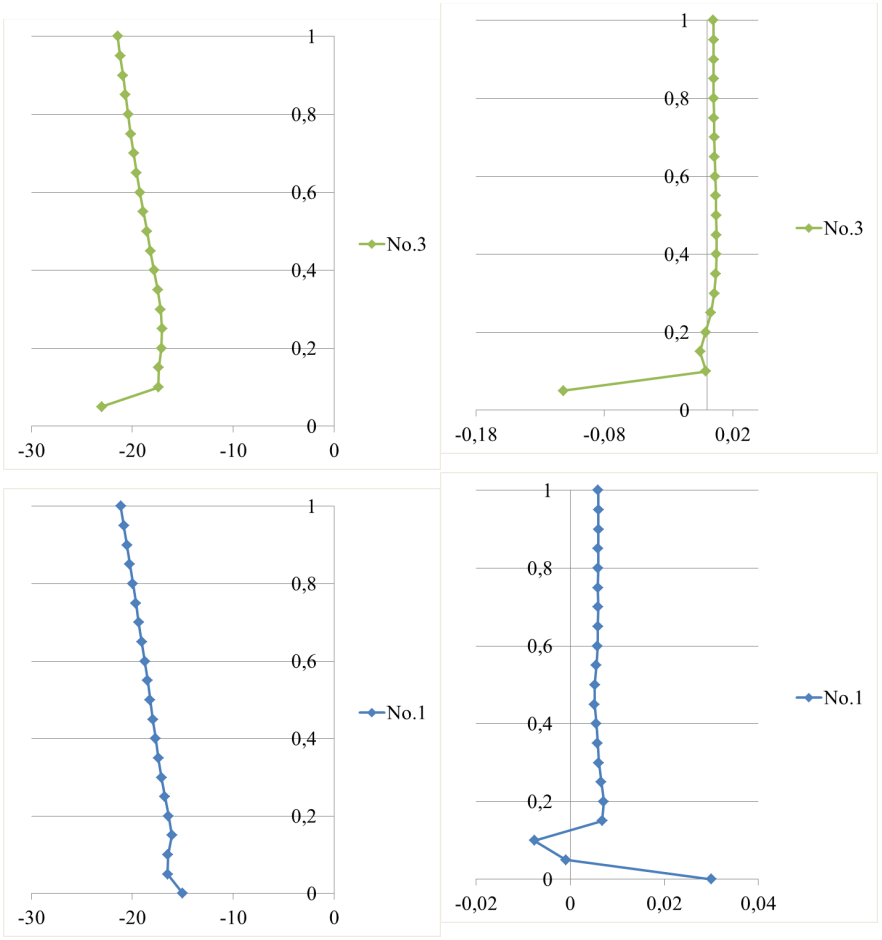


Fragments of the wind speed fields at a height of 50 m above the surface at 12:00 local time (on the left) and at 24:00 local time (on the right)

Winter scenario



A part of the wind field at a height of 50 m above the surface. The winter calm scenario at 12:00 local time



Vertical temperature profile (ºC) (right) and γ (ºC/m) (left) at 13:00 local time for points No3 (upper) and No1 (lower)

ИВМиМГ

Assessment and management of atmosphere quality in a “smart" city

- **Local, regional and global air pollution problems. Evaluation of cross-border transfers;**
- **"The chemical weather" - assessment of air quality (primary and secondary pollution, gas and aerosol composition of the atmosphere);**
- **Detection of unknown sources of emissions and evaluation of emission**
- **parameters;**
- **Development of risk management strategies;**
- **Environmental design in accordance with environmental safety criteria;**
- **Identify prerequisites and prediction of consequences of environmental disasters;**
- **Assessment of environmental risk and vulnerability;**
- **Targeted monitoring strategies;**
- **Data assimilation (including chemicals) in real time;**
- **Evaluation of uncertainty for the analysis of predictability**

Технопром-2016 Новосибирск

Концепция «умного» города

Города и промышленные регионы Сибири (Сибирское соглашение)

Оценка и прогнозирование изменений качества атмосферы в «умном» городе и его агломерации методами математического моделирования с использованием данных наблюдений (ИВМиМГ СО РАН, ИХКиГ СО РАН, ИОА СО РАН, СибНИГМИ)

Спасибо за внимание!