Simulation of gaseous fire pollutants transport using an ensemble of backward trajectories

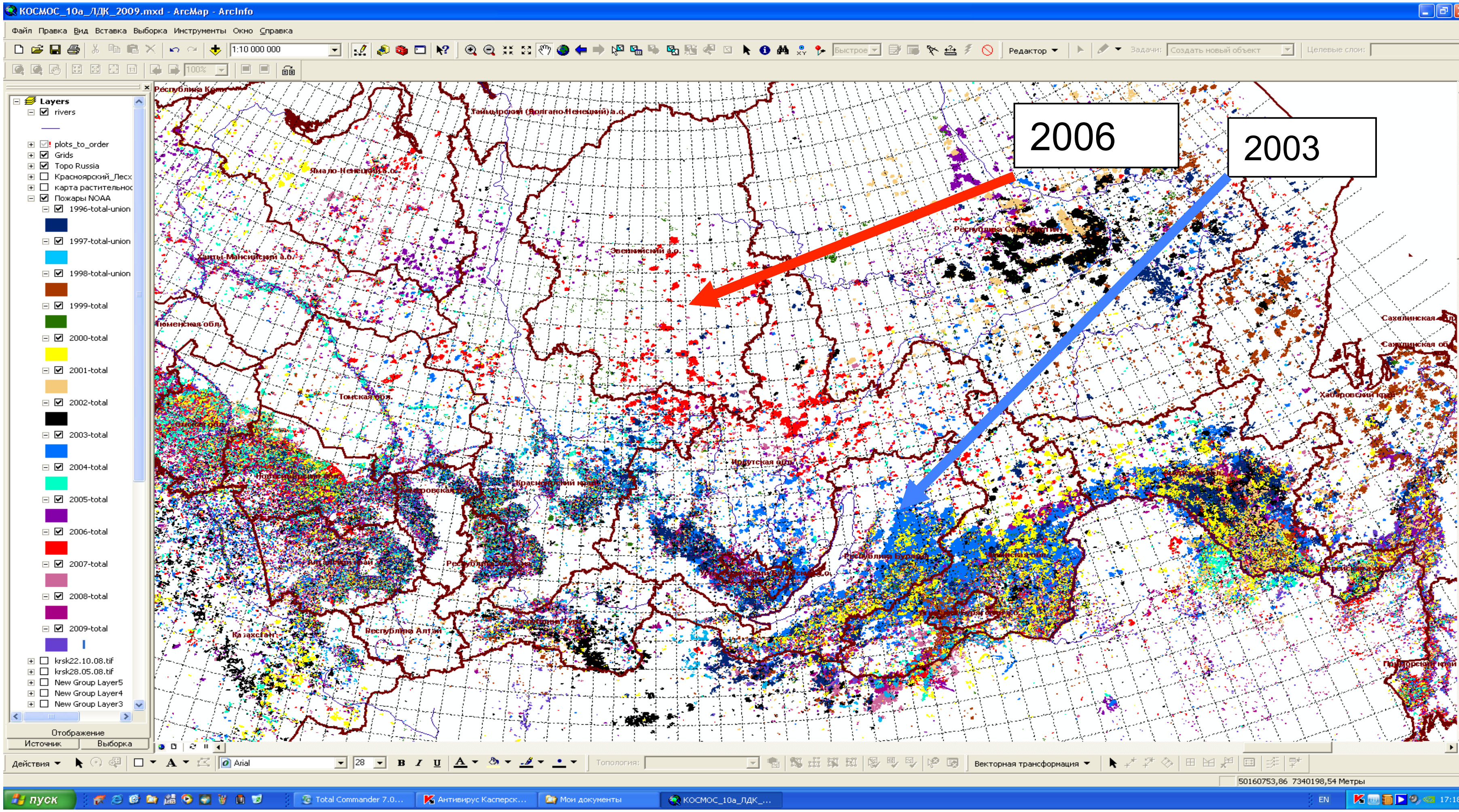
O. A. Dubrovskaya, E.G. Klimova, A.I. Sukhinin

Institute of Computational Technologies, Russian Academy of Sciences, Novosibirsk

V.N. Sukachev Institute of Forest, Russian Academy of Sciences, Krasnoyarsk

•e-mail: olga@ict.nsc.ru

Catastrophic fires during 1996-2009



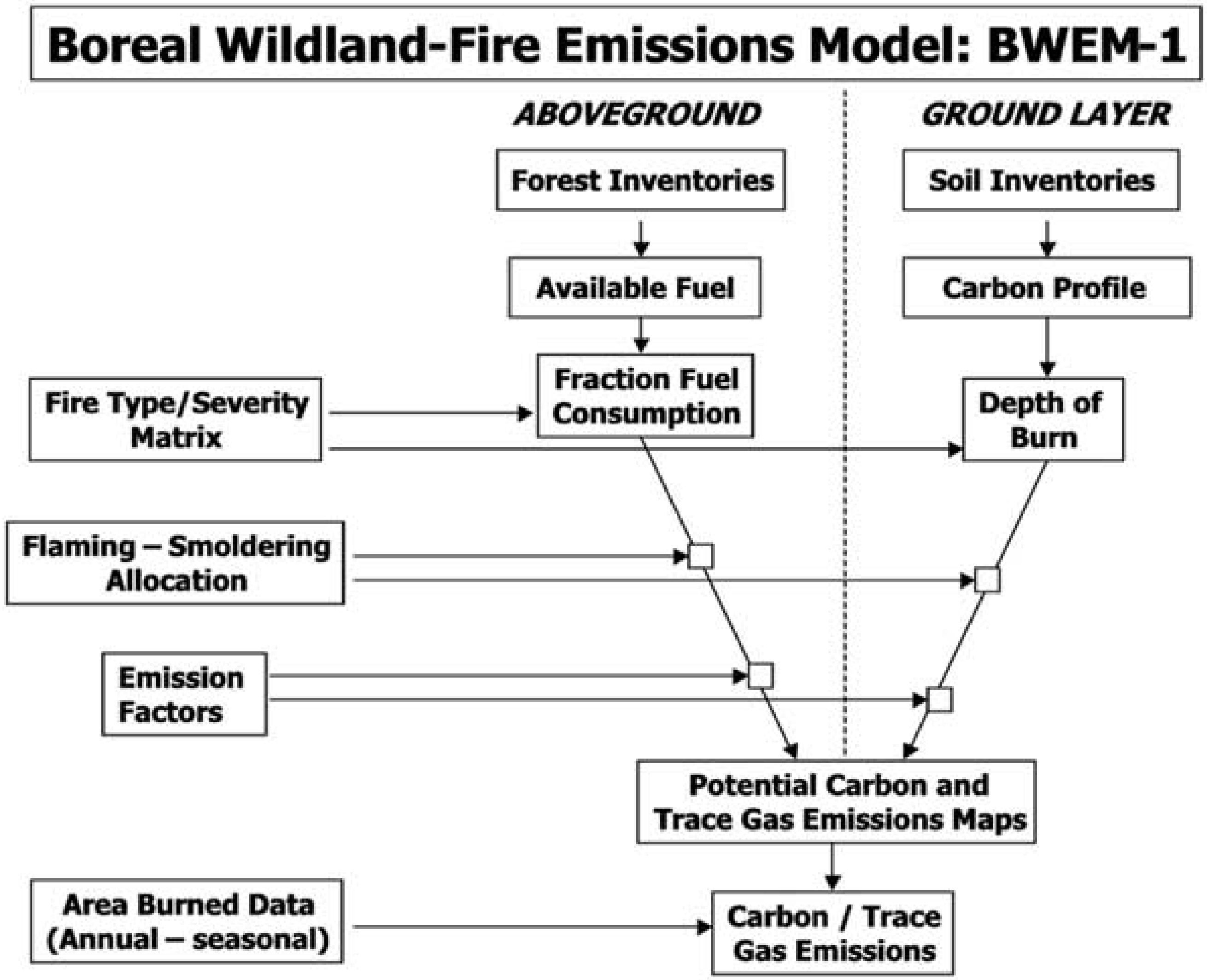
<u>General tendency</u>: northward expansion of the areal extent of catastrophic fires during the indicated period

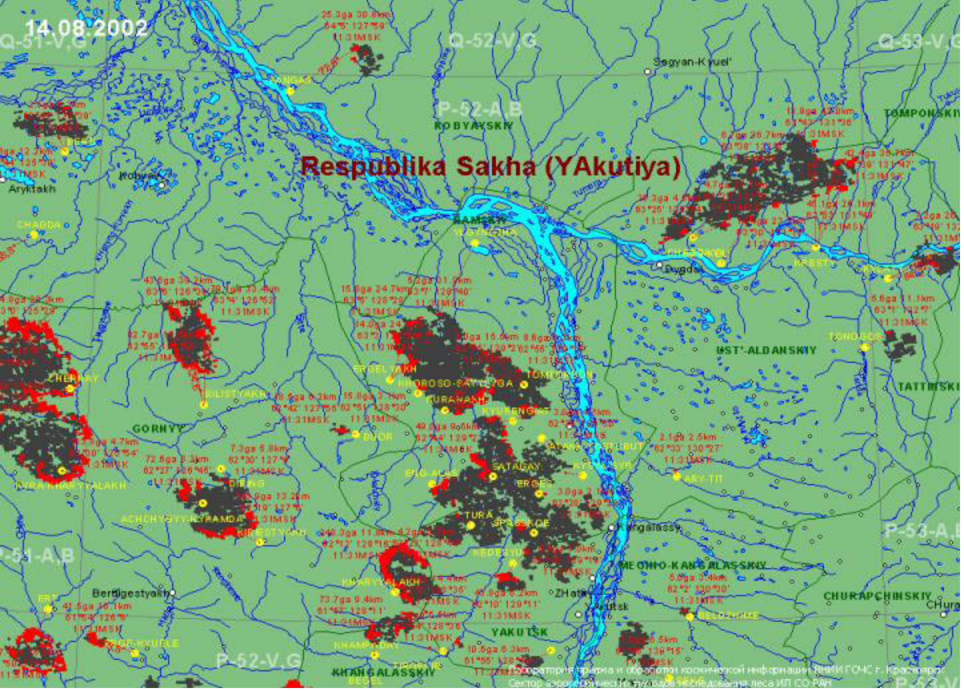
To estimate smoke emissions from wildfires in Siberia and to develop the methodology reconstruction of concentration of CO_2 based on observational data

We use:

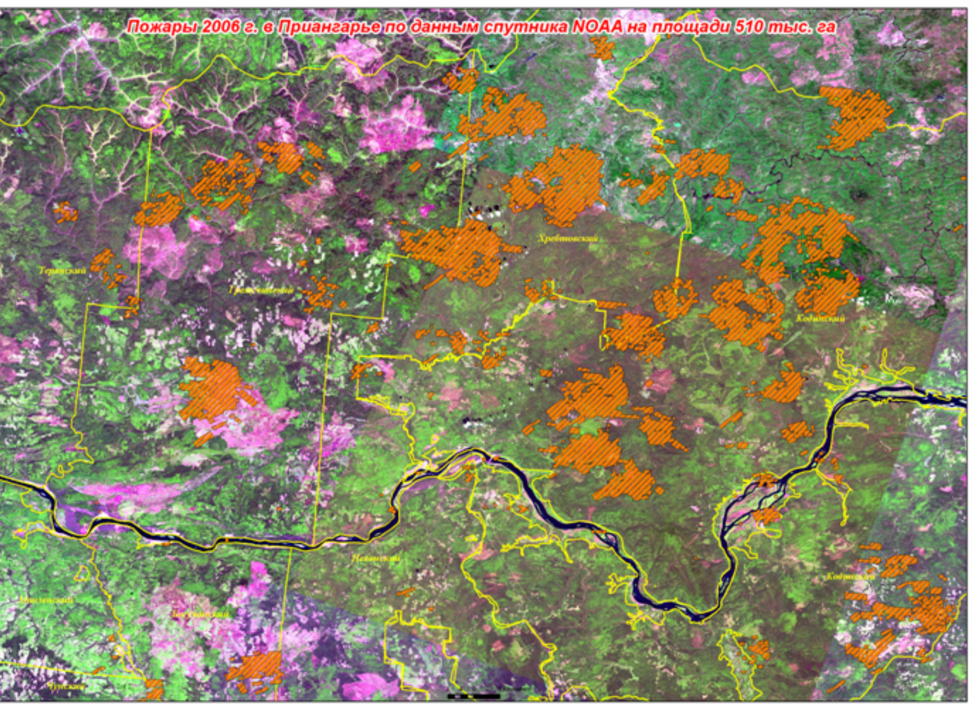
- **Boreal Wildland-Fire Emissions Model (BWEM-1);**
- **Methodology of trace gases concentration reconstruction in grid points for a given region using fire remote sensing and meteorological data;**
- **GLOBAL FIRE EMISSIONS DATABASE, VERSION 2.1 (http://daac.ornl.gov/VEGETATION/guides/global_fire_emissions_v2.1.html);**
- **Meteorological fields were calculated by using the WRF model.**

Structure of the Boreal Wildland-Fire Emissions Model (BWEM-1) [Soja et al., 2004; Kasischke et al., 2005]



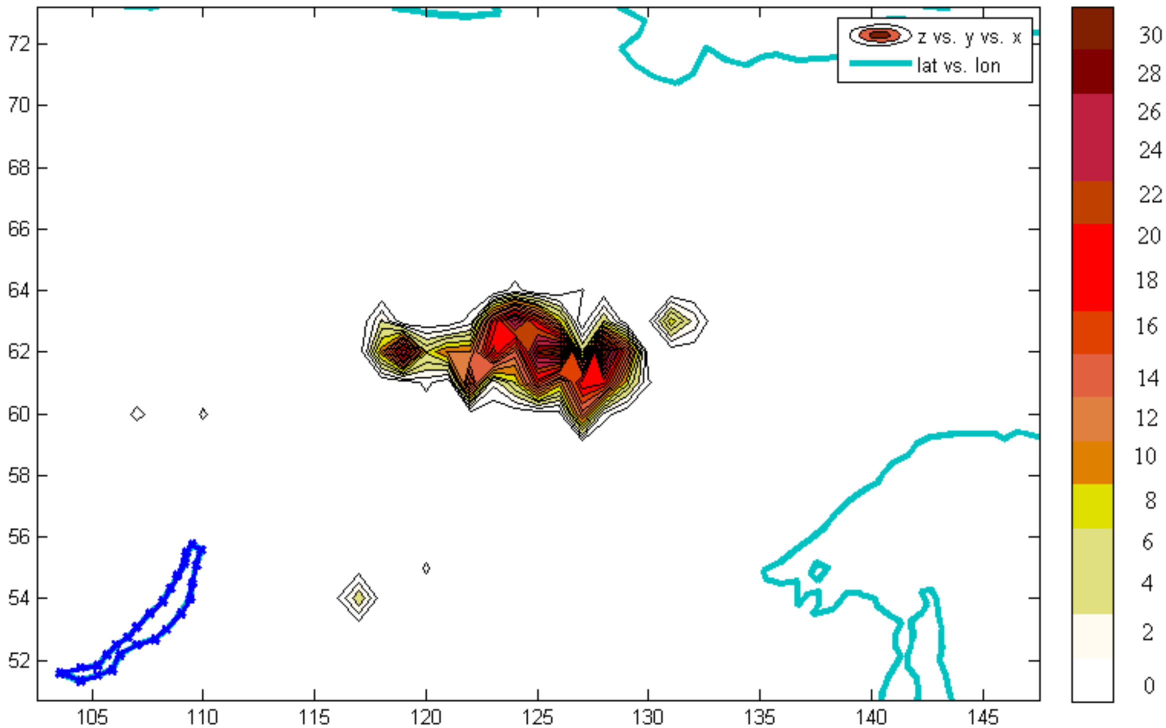


Example of daily NOAA-AVHRR-derived burn scar map (Yakutia, August, 14, 2002) produced by the Fire Laboratory of Sukachev Institute of Forest and displayed at the GFMC website.



Fires in Angara region in July 2006, burnt area is more than 450 thnd ha

Validation for August 2002

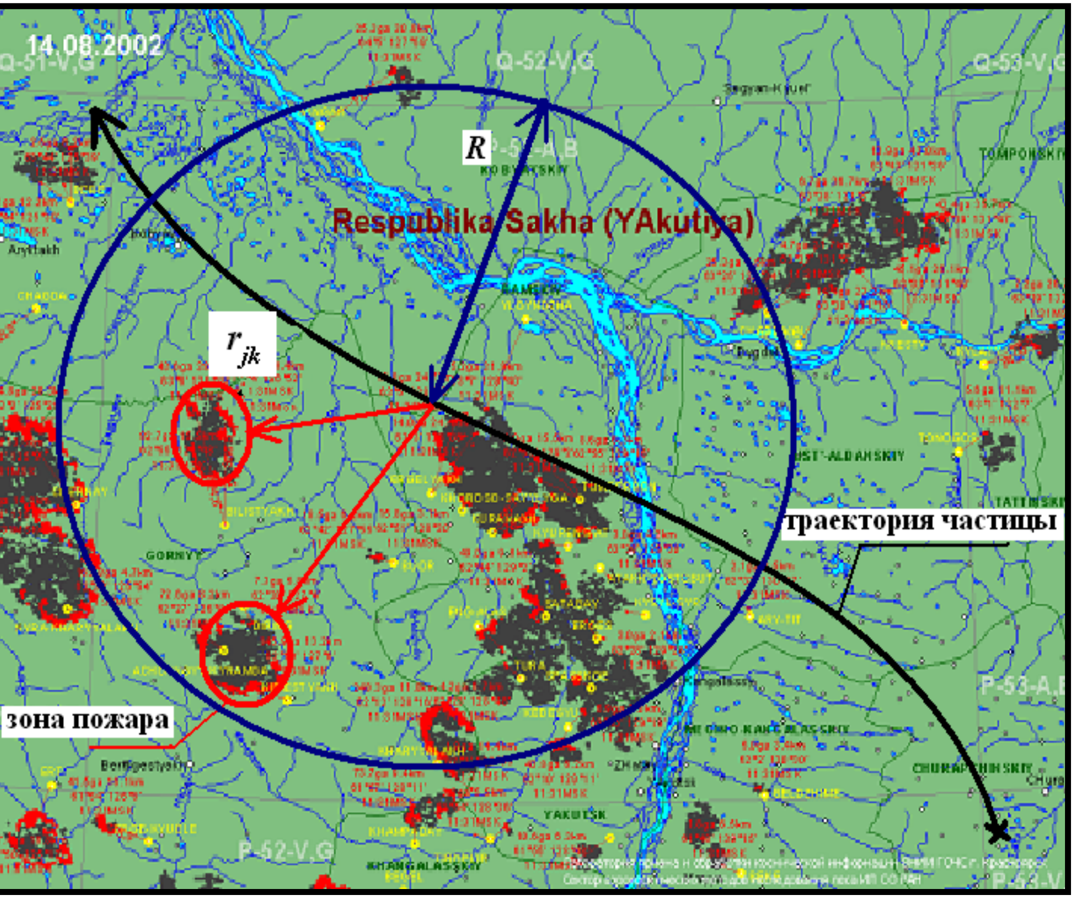


This data set consists of 1° x 1° gridded monthly burned area, fuel loads, combustion completeness, and fire emissions of carbon dioxide

Fire emissions of carbon dioxide (CO_2) (gCO_2/m^2/month)	
Simulated by using BWEM-1	17.65
Global fire emissions v2.1 data	20

http://daac.ornl.gov/VEGETATION/guides/global_fire_emissions_v2.1.html

Reconstruction of CO_2 concentration in a given region, according to biomass burnt data on the basis of backward trajectories



Trajectory equations:

1. 3D kinematic equations

2. Thermodynamic equation in adiabatic approximation

Along the trajectory produced data assimilation on the concentration

Reconstruction of concentration of CO_2 based on observational data

The "forecast" step on the trajectory for the one time step is calculated by the formula: $q_f^n = q_f^{n+1}$.

For the moment of time t^j when we have fire data, step "analysis" is performed using the exponential interpolation method:

$$q_a^j = q_f^j + \frac{\sum_{k=1}^{K_1} \alpha_{jk} \Delta q_d^j}{\sum_{k=1}^{K_1} \alpha_{jk}}, \qquad \alpha_{jk} = e^{-0.5\frac{r_{jk}^2}{(B^m)^2}},$$

K_1 - number of observation points, B^m - radius of correlation,

r_{jk} - the distance between the point on the trajectory $(\lambda(t^j), \varphi(t^j), p(t^j))$ and point of observation

$$\Delta q_d^j = \Delta t \cdot \eta_k,$$

η_k - value is determined by the biomass burnt down data.

For heights greater than 1.5 km, change of Δq_d^j in the vertical is calculated by using

$$\Delta q_d^j(p_1) = \Delta q_d^j(p_2) e^{-\frac{(h_1 - h_2)^2}{2L^2}}$$

Ensemble of backward trajectories

.

To account for random errors in wind field, an ensemble of wind fields was modelled by adding random perturbations ξ_U and ξ_V:

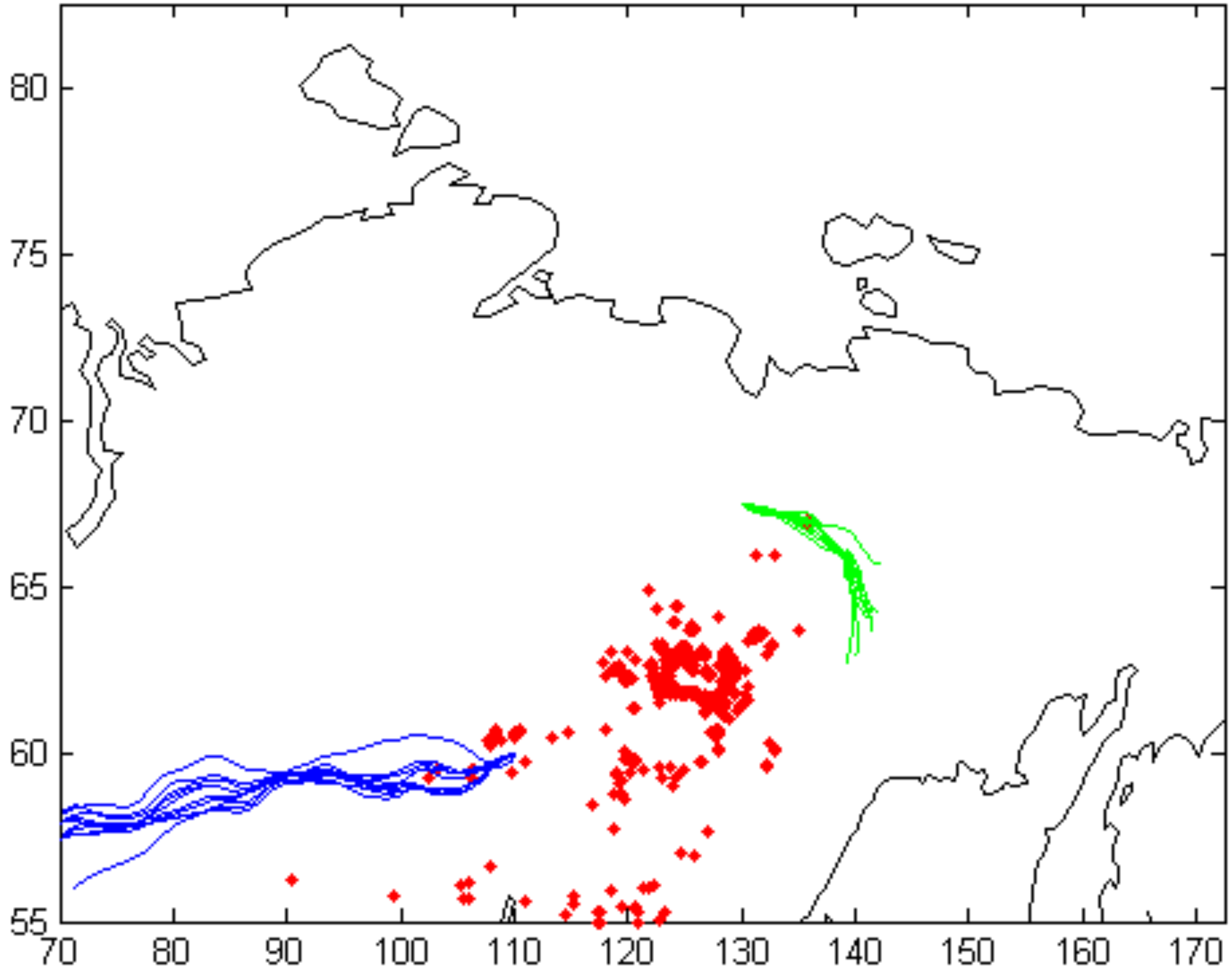
$$U^{(i)}(\lambda,\theta,t) = U(\lambda,\theta,t) + \xi_U^{(i)},$$

$$V^{(i)}(\lambda,\theta,t) = V(\lambda,\theta,t) + \xi_V^{(i)}, \qquad i=1,2,\dots,M.$$

Perturbations ξ_U and ξ_V were independently sampled from centered normal distributions with prescribed variances σ_U and σ_V.

An ensemble of concentrations $Q^{(i)}(\lambda,\theta,t)$ was sampled.

Ensemble trajectories reconstructed based on meteorological data for August, 14, 2002

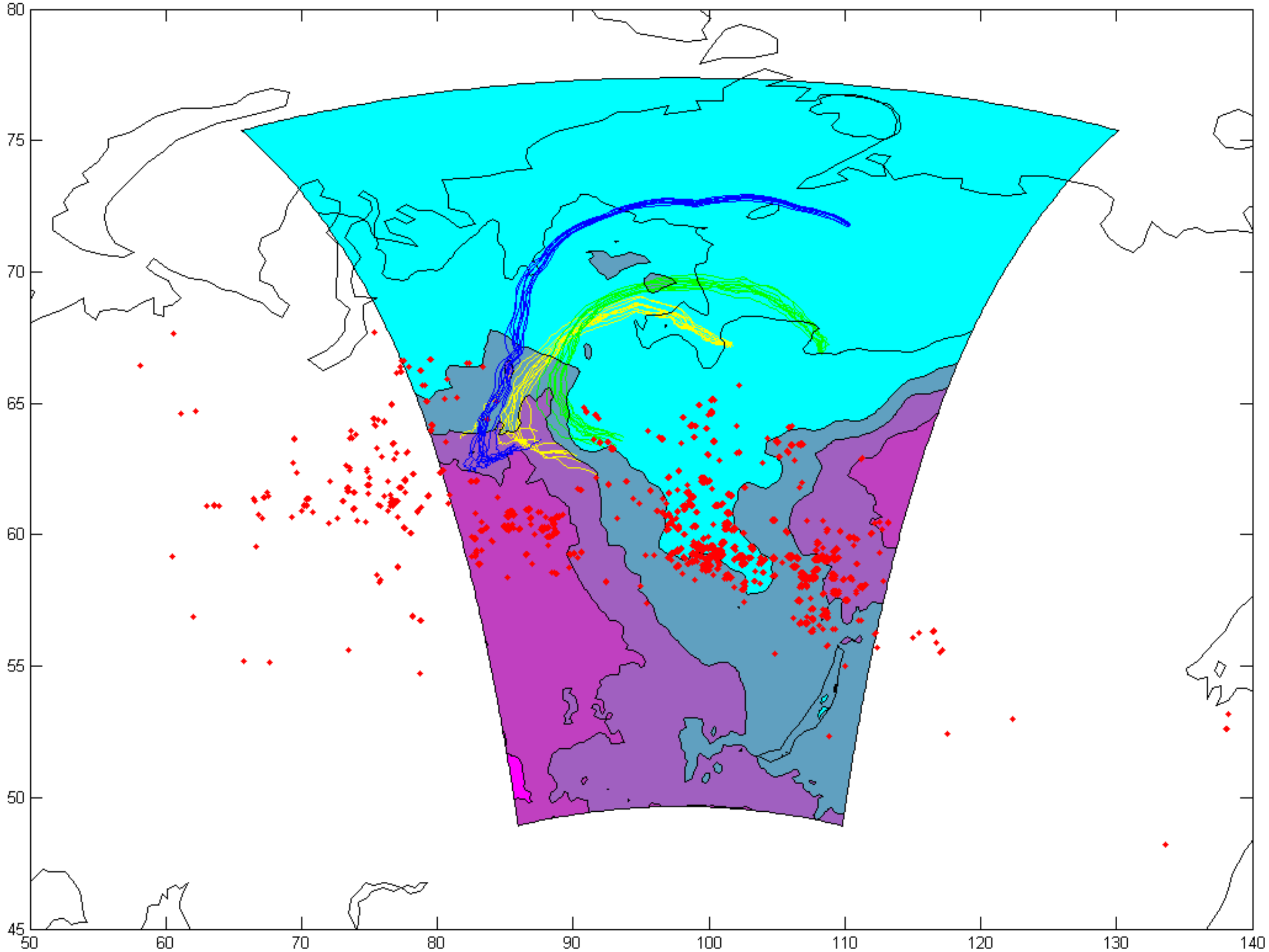


blue: 59^0 N 111^0E (for 48 h)

green:67^0 N 129^0 E (for 96 h)

red: fires

Ensemble trajectories reconstructed based on meteorological data for July, 21,2006 using WRF model



yellow:66^0N 106^0 E (for 96 h)

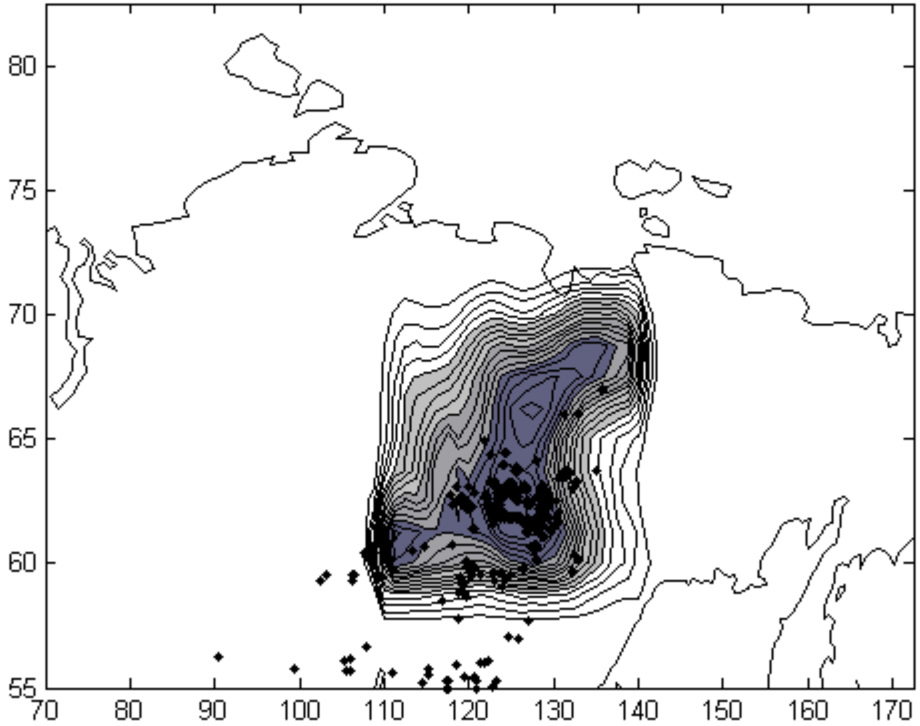
green:67^0N 110^0E (for 96 h)

blue: 73^0N 110^0E (for 96 h)

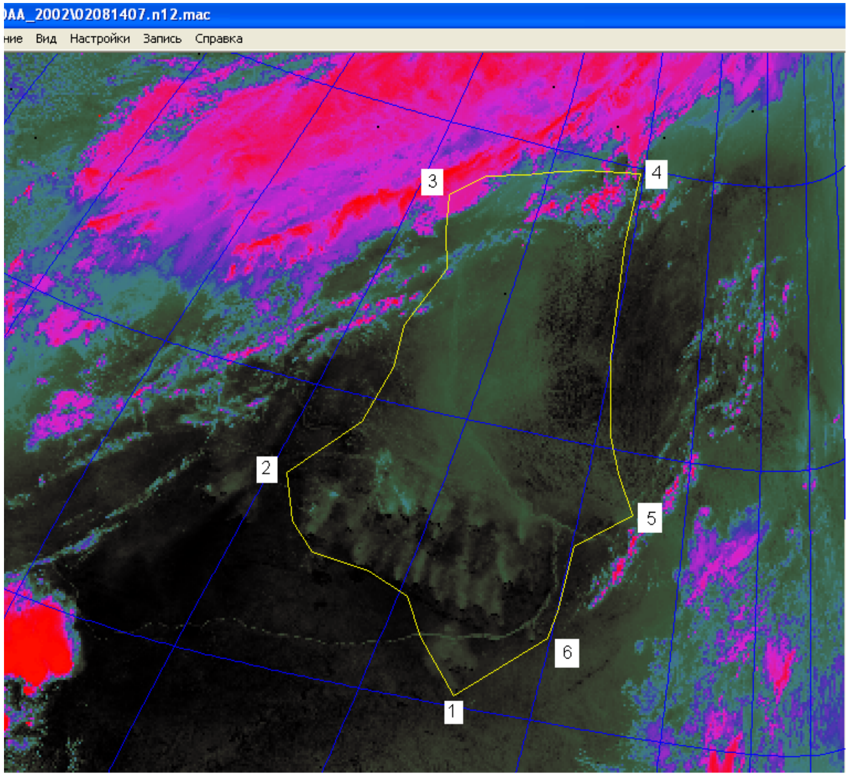
red: fires

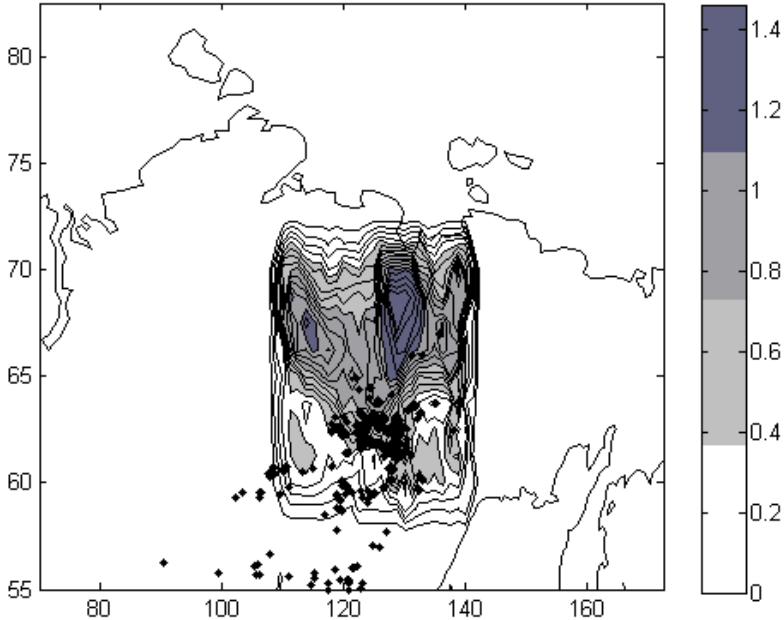
The mean value calculated for the 10-member ensemble of reconstructed concentration

backward trajectories calculated for 120 h

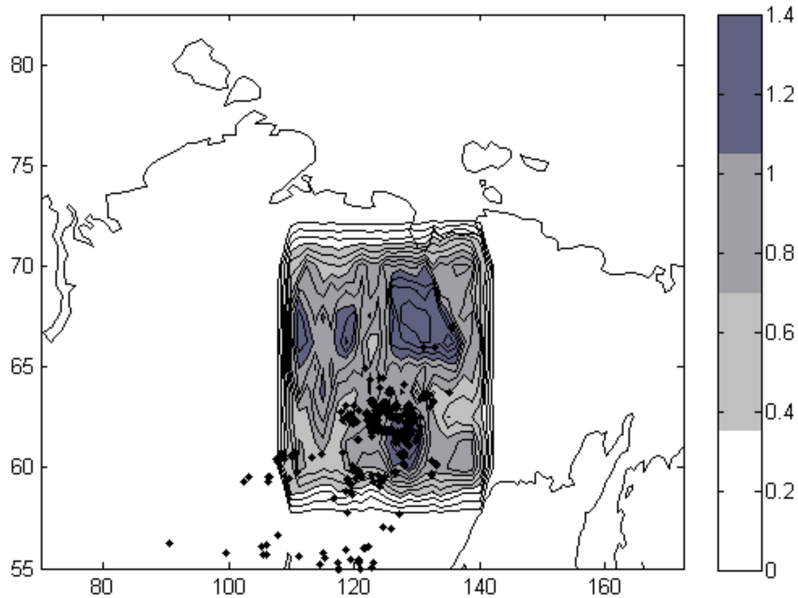


The structure of clouds and smoke plumes as analyzed by using the GIS ARC-MAP9 and ERDAS IMAGIN 8.7





Ensemble variance for CO_2 concentration calculated for the 10-member ensemble for 120 h



Ensemble variance for CO_2 concentration calculated for the 50-member ensemble for 120 h

Conclusions

❖ Ensemble approach is applied to calculate the distribution of gases from the catastrophic forest fires based on meteorological data and satellite imagery.

❖ The proposed technology reasonably reproduces the available observations for spatial resolution ~ 1 degree.

❖ For this spatial resolution, ensembles of moderate sizes (~10) are sufficient for accurate reconstruction of concentrations of gases tracers.

Approaches to estimate total carbon emissions (C_t) and emissions of a specific trace gas species (E_s) are based on the fundamental model introduced by Seiler and Crutzen [1980]

$$C_t = A \cdot B \cdot f_c \cdot \beta$$

$$E_s = C_t \cdot ef_s$$

- where A is the burned area (ha), B is the average density of the biomass (t ha1), fc is the carbon fraction of the biomass, b is a scaling factor for the fraction of the biomass that is consumed (related to the type or intensity of the fire and the biomass being burned), and efs is the emission factor for a specific trace gas species, s (typically expressed as grams of the species per kilogram of dry matter consumed during the fire)

$$C_t = \sum_{i=1}^{n} \sum_{J=1}^{N} B_j(x, y) A_{ij} \cdot a_{ij} \cdot b_{ij}$$

Eric S. Kasischke, Edward J. Hyer, Paul C. Novelli, Lori P. Bruhwiler, Nancy H. F. French, Anatoly I. Sukhinin, Jennifer H. Hewson, and Brian J. Stocks. Influences of boreal fire emissions on Northern Hemisphere atmospheric carbon and carbon

Reconstruction of concentrations based on ensemble backward trajectories

For the sample $\left\{Q^{(i)}(\lambda,\theta,t_N)\right\}$ of concentration of CO_2 mean value and variance are calculated

$$\bar{Q}(\lambda,\theta,t_N) = \frac{1}{M}\sum_{i=1}^{M} Q^{(i)}(\lambda,\theta,t_N)$$

$$\sigma^2(\lambda,\theta,t_N) = \frac{1}{M-1}\sum_{i=1}^{M}(Q^{(i)}(\lambda,\theta,t_N) - \bar{Q}^{(i)}(\lambda,\theta,t_N))^2$$

σ_U^2, σ_V^2 – root mean square values of wind forecast errors

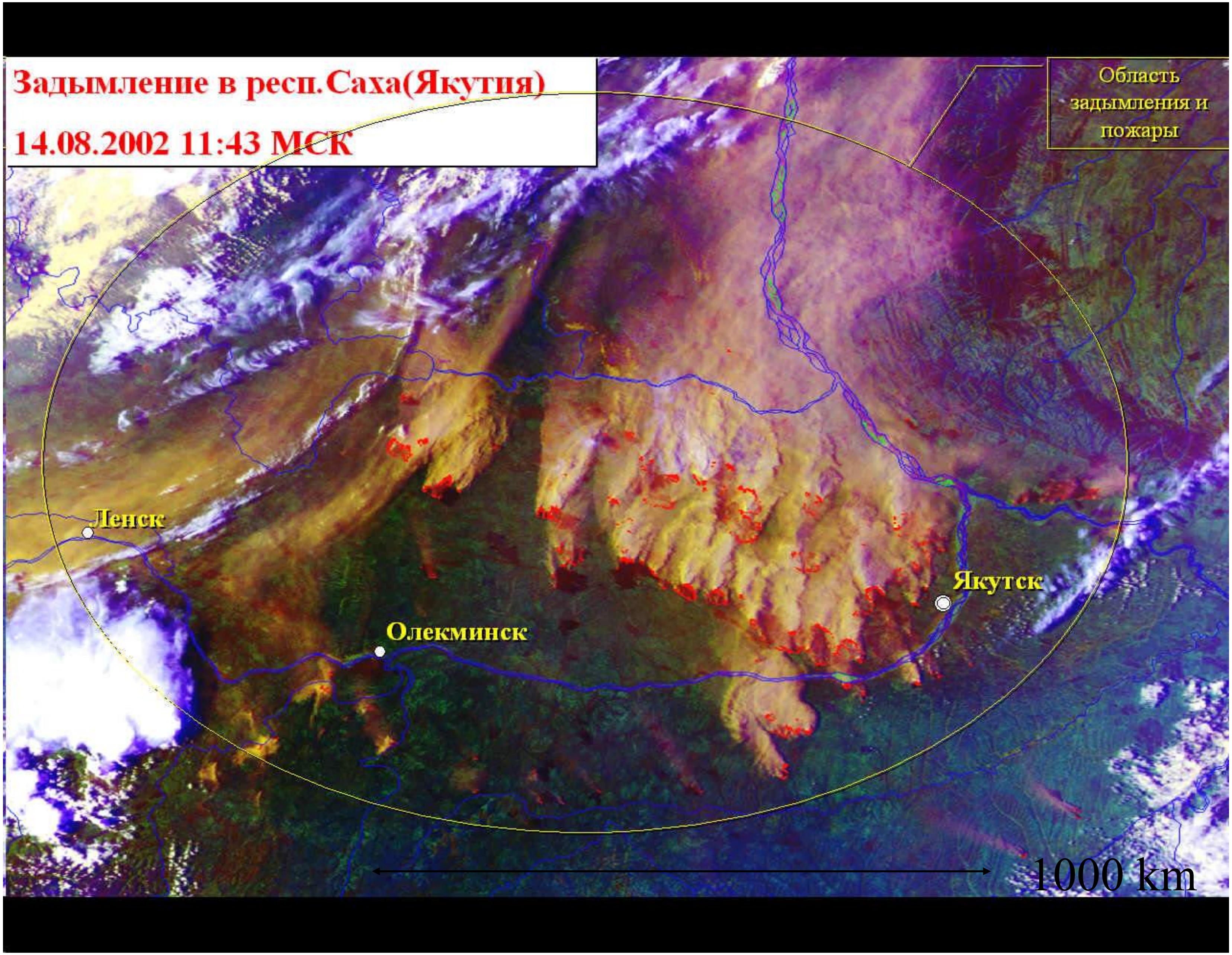
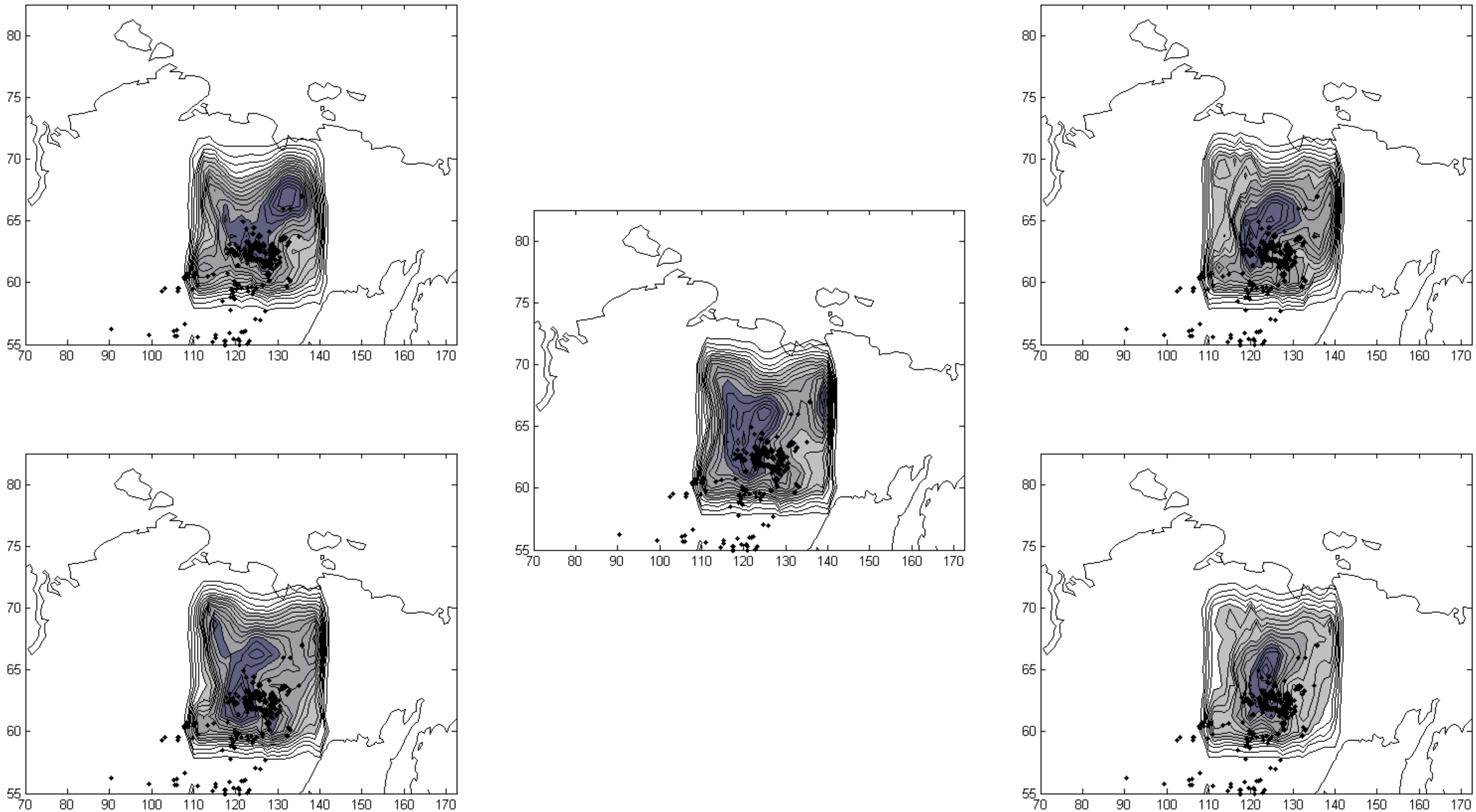
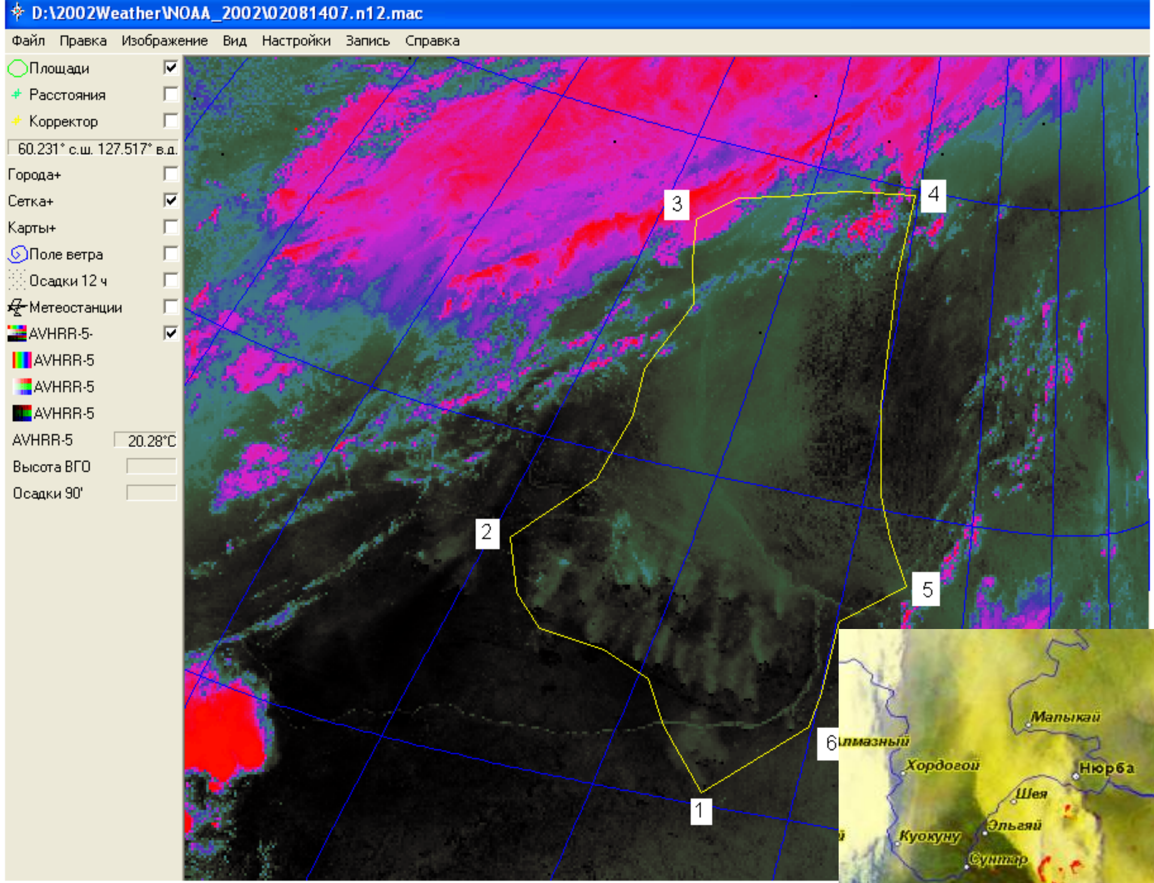


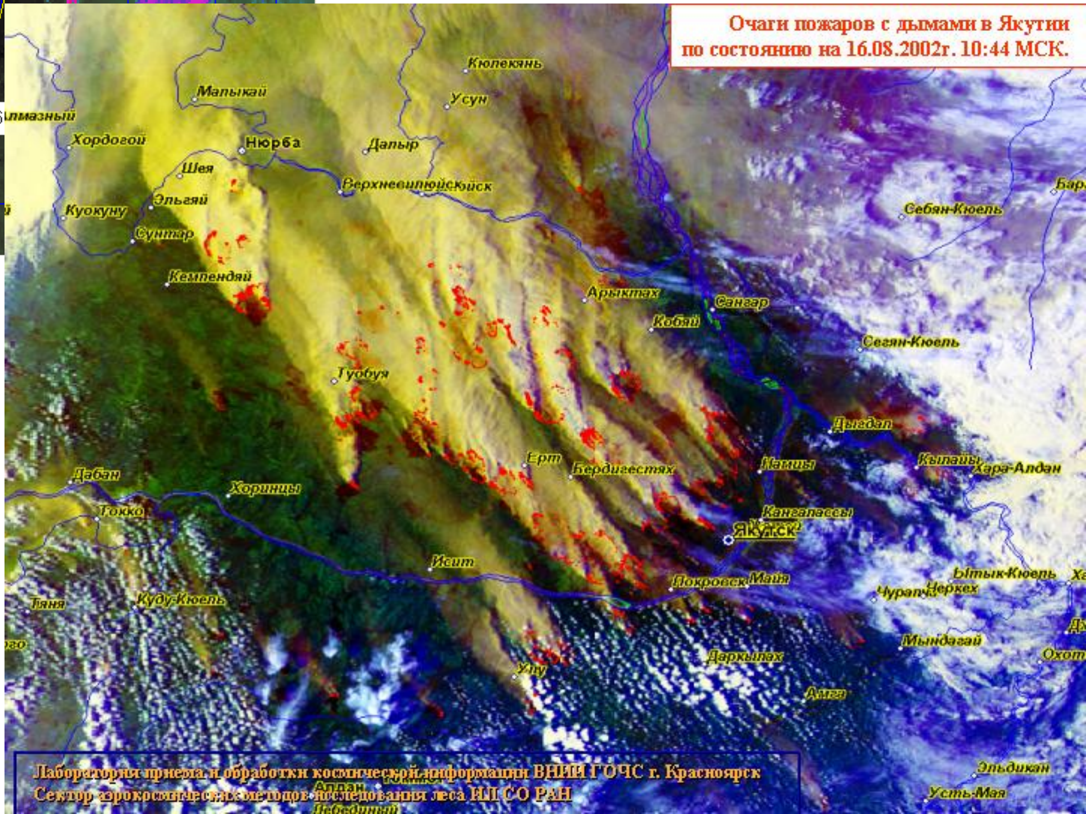
Figure 3. Fire activity peaking during the 2002 fire season in Yakutia depicted by NOAA AVHRR (14 August 2002)

The ensemble of reconstructed concentration in a given region (57^0 -70^0 N,110^0 – 140^0 E)



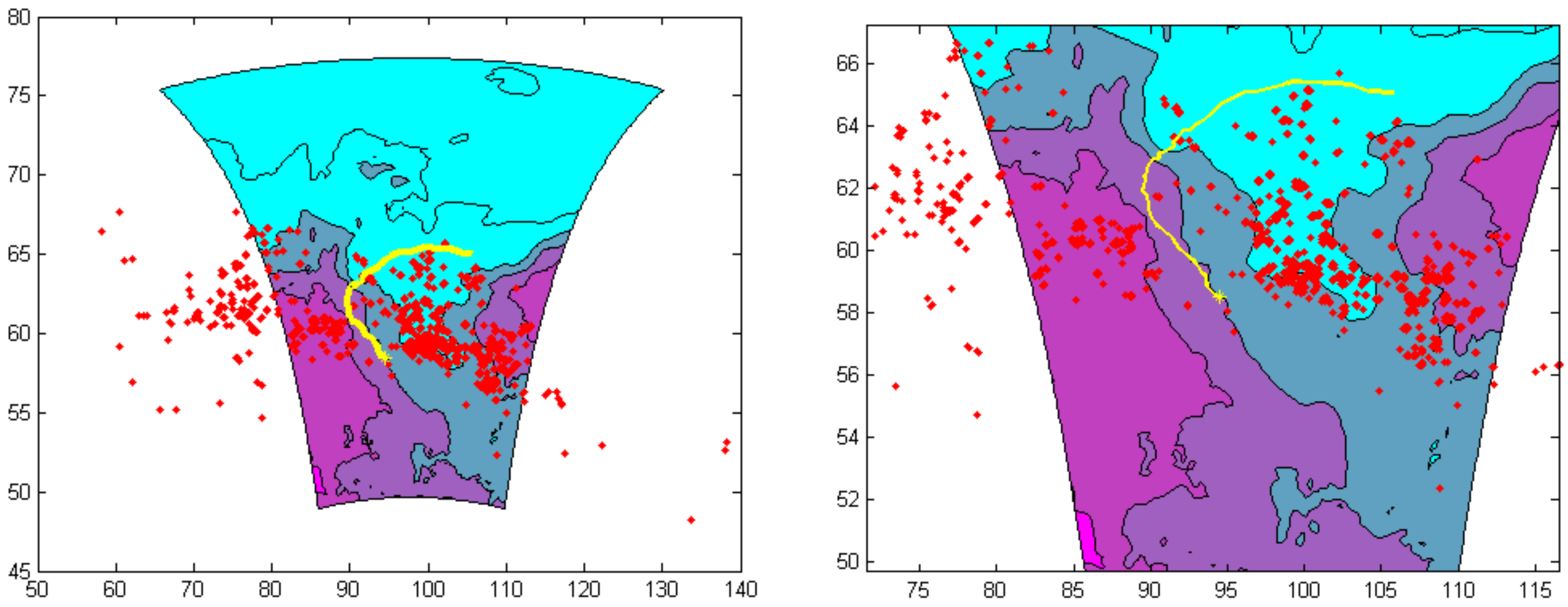


The structure of clouds and smoke plumes was analyzed by using of geoinformation system ARC-MAP9 and ERDAS IMAGIN 8.7

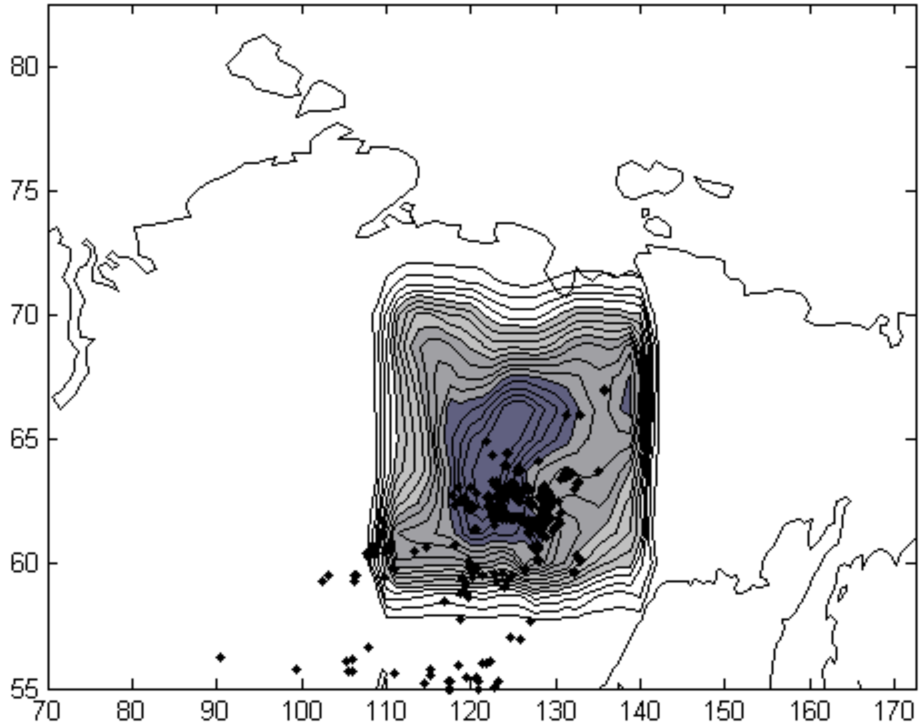


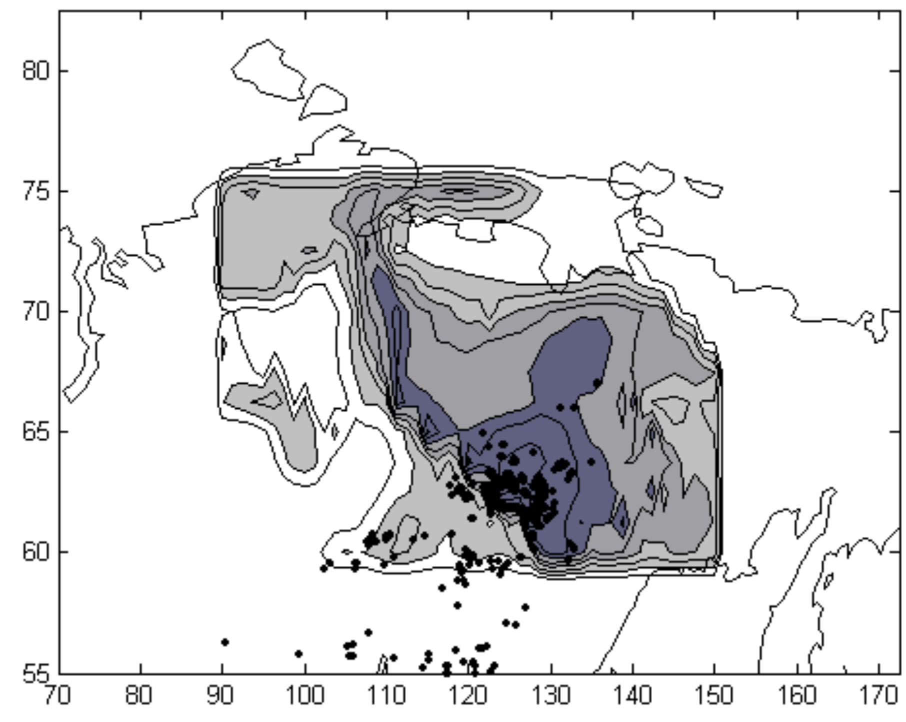
Satellite photograph of the fire with a smoke plumes

To recover a small-scale structure of the concentration and dynamics of mesoscale processes in the atmosphere within a given region, an attempt of implementation of this technique for the WRF model forecasts is planned.



Comparison of results





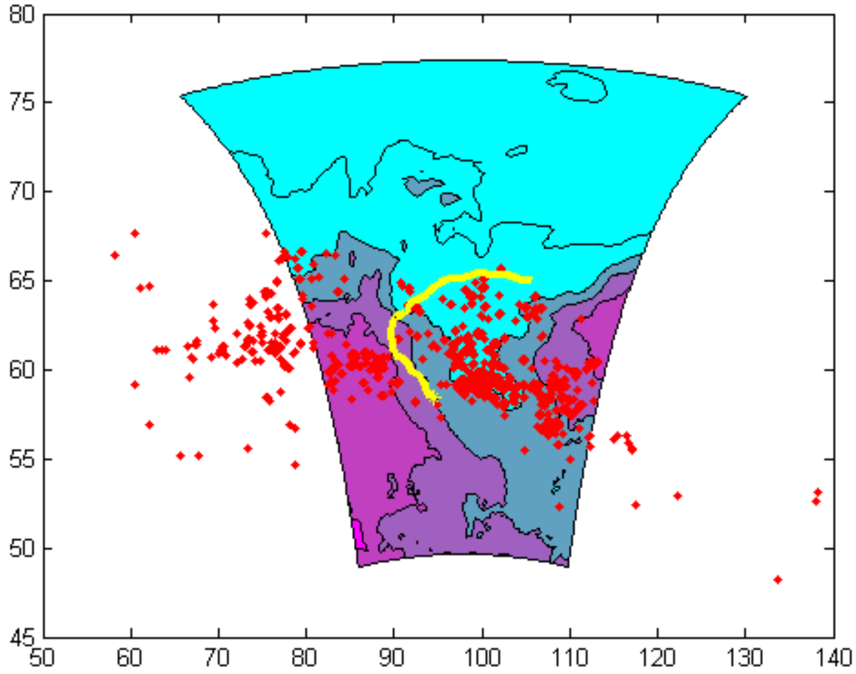
To recover a small-scale structure of the concentration and dynamics of mesoscale processes in the atmosphere within a given region, an attempt of implementation of this technique for the WRF model forecasts is planned.

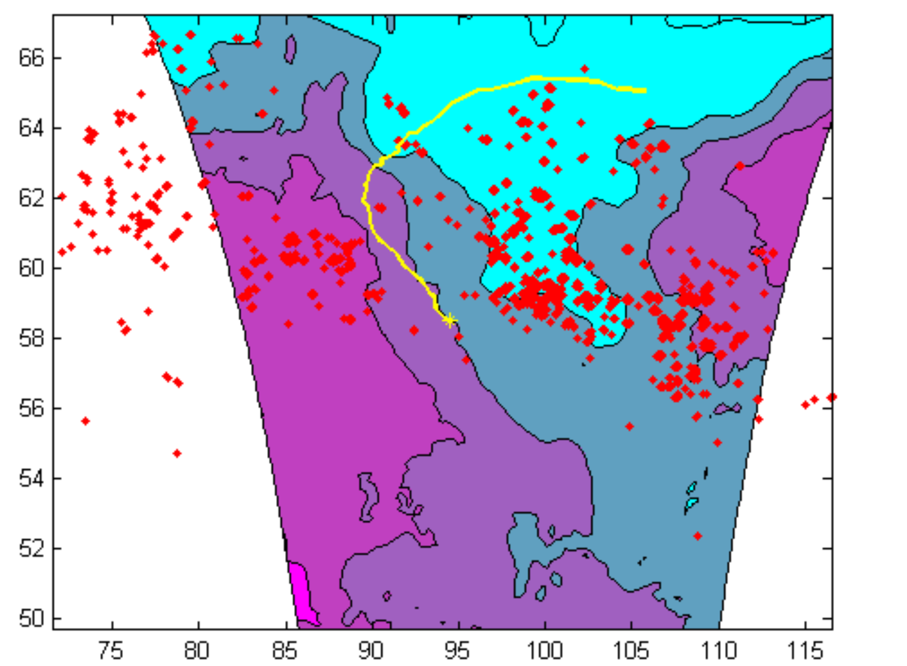
future trends:

1.Using forecasts of meteorological fields from WRF model.

2.Development of data assimilation methods on fires data on the basis of ensemble Kalman filter.

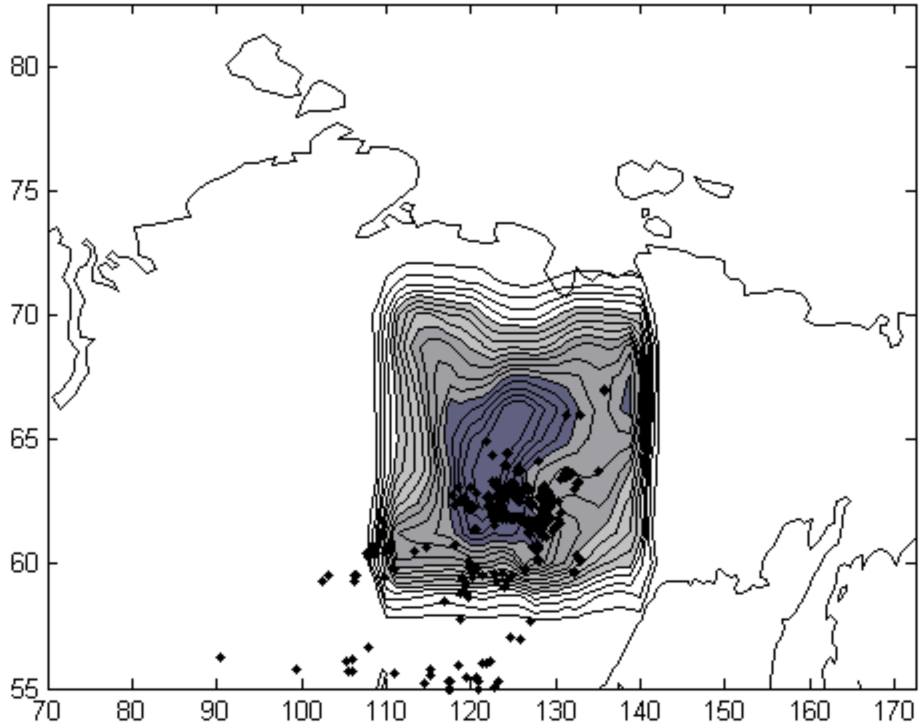
3.Quantitative estimate of technique quality by comparison of calculated and observed concentration.



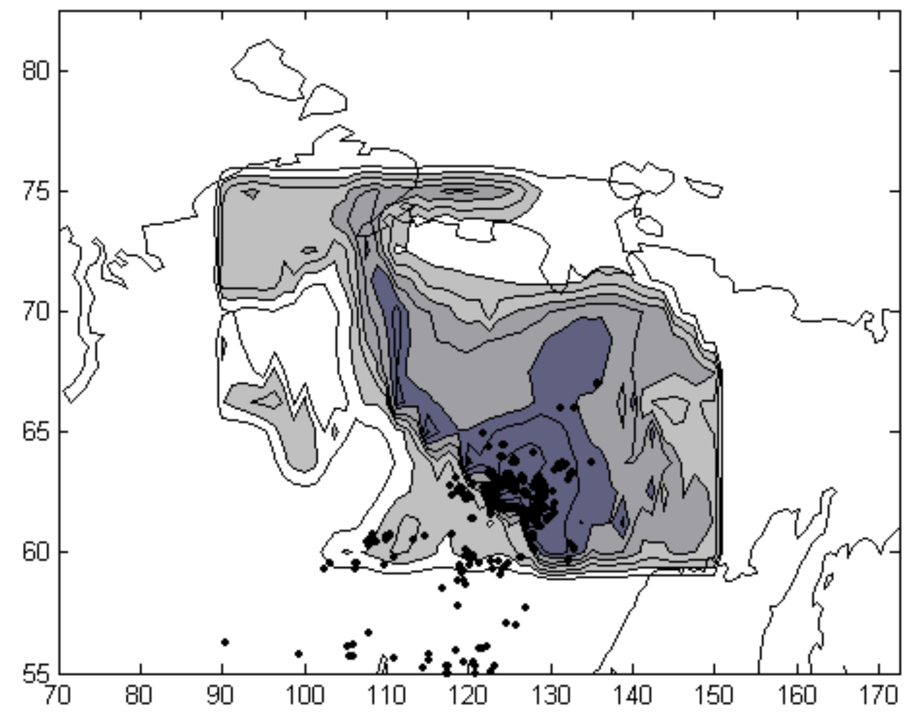


Satellite data NOAA/AHVRR/TOVS and Terra/MODIS

DATE	TIME_SEC	TIME	SATELLITE	LAT	LON	SQR_M	SQR_HA
22.03.2006	17680	04:54:40	NOAA-18	50,4408	105,4375	2841689	0,6506
22.03.2006	17680	04:54:40	NOAA-18	49,6394	111,7758	1678111	1,1258
22.03.2006	17680	04:54:40	NOAA-18	48,4601	121,9013	1793766	0,3730
22.03.2006	17680	04:54:40	NOAA-18	48,4411	121,9621	6283141	12,9243
22.03.2006	17680	04:54:40	NOAA-18	48,4239	122,1176	895654	0,1709
22.03.2006	17680	04:54:40	NOAA-18	48,6209	122,0368	9854847	0,1801
22.03.2006	17680	04:54:40	NOAA-18	48,6577	122,0488	895508	0,0278
22.03.2006	17680	04:54:40	NOAA-18	48,6603	122,1280	893882	0,4805
22.03.2006	17680	04:54:40	NOAA-18	48,7648	122,7235	892430	0,1098
22.03.2006	17680	04:54:40	NOAA-18	48,8977	123,8113	1805656	0,0100
22.03.2006	17680	04:54:40	NOAA-18	46,9787	126,2498	958066	0,0100
22.03.2006	17680	04:54:40	NOAA-18	47,1757	127,9472	2144510	0,0390
22.03.2006	17680	04:54:40	NOAA-18	48,0006	131,0395	1420200	0,2594
22.03.2006	17680	04:54:40	NOAA-18	47,9618	131,0495	1419740	0,4724
22.03.2006	17680	04:54:40	NOAA-18	47,9468	131,1063	1419650	0,0760
22.03.2006	17680	04:54:40	NOAA-18	47,9255	131,1458	7101014	0,6062
22.03.2006	17680	04:54:40	NOAA-18	48,0142	131,3216	13087918	1,7685
22.03.2006	17680	04:54:40	NOAA-18	50,4715	114,7191	2485822	0,0204



Comparison of results



- http://ekopro.spb.ru/index.php?option=com_content&view=article&id=418:ppm-tomgm3-converstion&catid=99:atmosphere&Itemid=599