

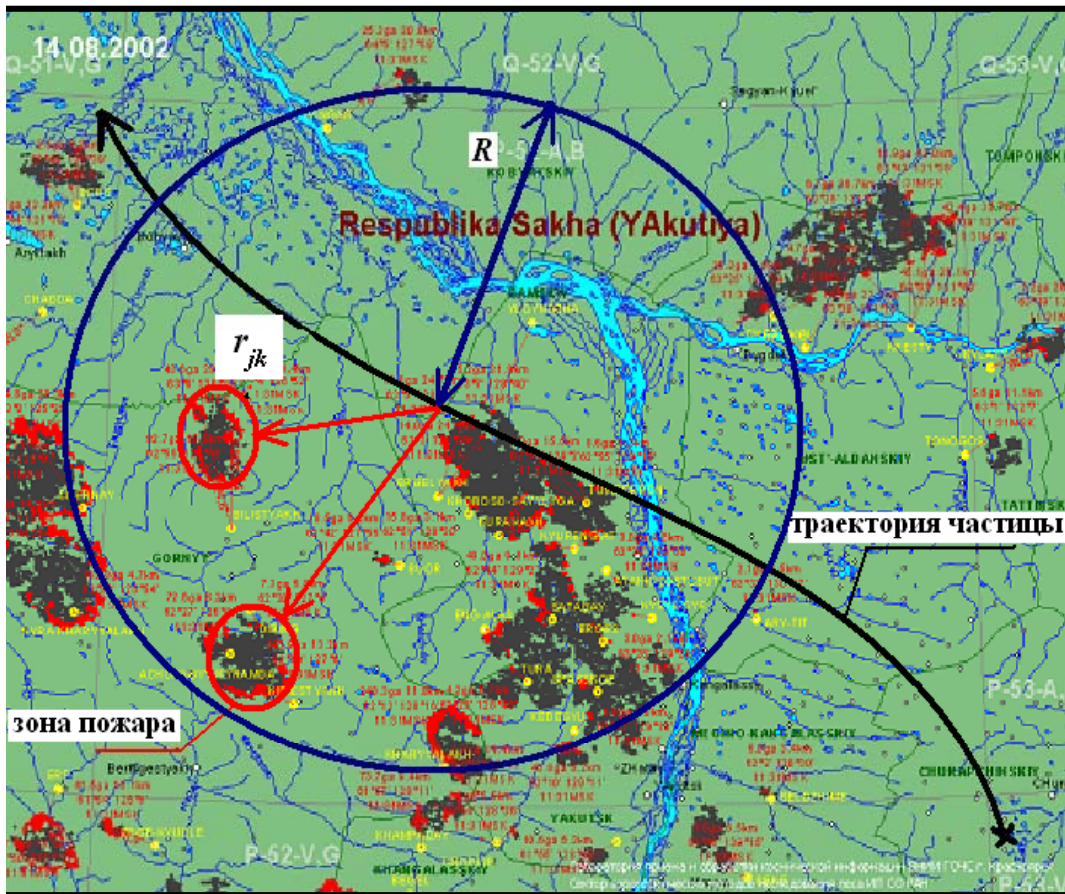
# Monitoring of environment above mass forest fires using the satellite data and meteorological information

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# Reconstruction of CO<sub>2</sub> concentration in a given region, according to biomass burnt data on the basis of backward trajectories



Trajectory equations:

$$\frac{d\lambda}{dt} = \frac{1}{a \cos \varphi} u(t, \lambda, \varphi, p)$$

$$\frac{d\varphi}{dt} = \frac{1}{a} v(t, \lambda, \varphi, p)$$

$$\frac{dp}{dt} = w(t, \lambda, \varphi, p)$$

$$w(t, \lambda, \varphi, p) = \frac{gp}{RT(\gamma_a - \gamma)} \left[ \frac{\partial T}{\partial t} + \frac{u}{a \cos \varphi} \frac{\partial T}{\partial \lambda} + \frac{v}{a} \frac{\partial T}{\partial \varphi} \right]$$

$$p^{n+1} = p^n + w(\lambda, \varphi, p, t)^n \Delta t$$

Along the trajectory produced data assimilation on the concentration

# Reconstruction concentration of CO<sub>2</sub> 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:

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

$K_1$  - 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

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

$\eta_k$  - value is determined by the biomass burnt down data.

For heights greater than 1.5 km, change of  $\Delta q_d^j$  in the vertical is calculated by the formula:

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

# Modeling of ensemble of backward trajectories

Since wind has random error, it needs to account these errors in the backward trajectories modeling.

For this purpose, an ensemble of wind fields was modeled:

$$\{U^{(i)}(\lambda, \theta, t), V^{(i)}(\lambda, \theta, t)\}, \quad i = 1, \dots, M$$

The ensemble of wind fields is modeled by adding random perturbations  $\xi_U, \xi_V$  :

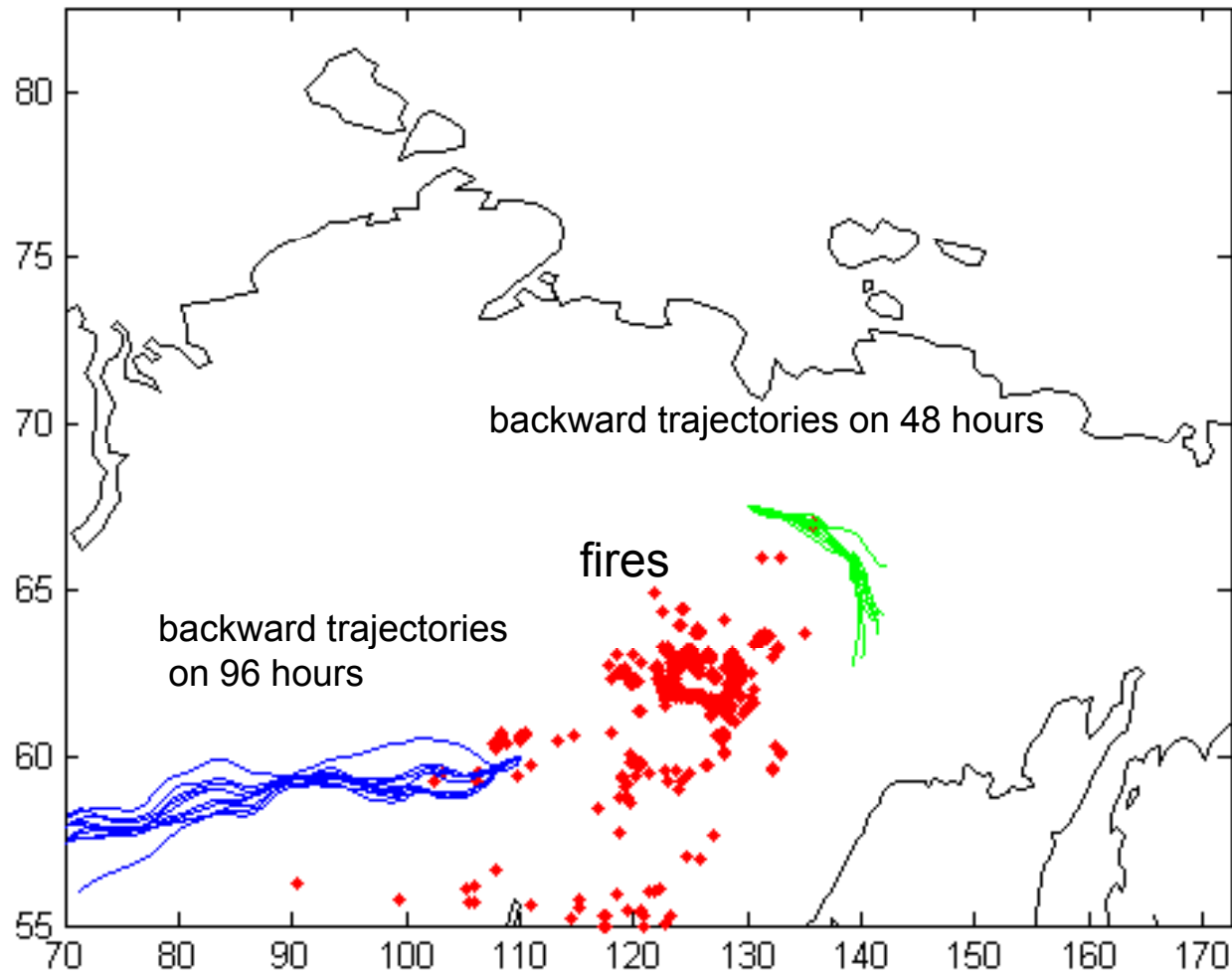
$$U^{(i)}(\lambda, \theta, t) = U(\lambda, \theta, t) + \xi_U^{(i)},$$

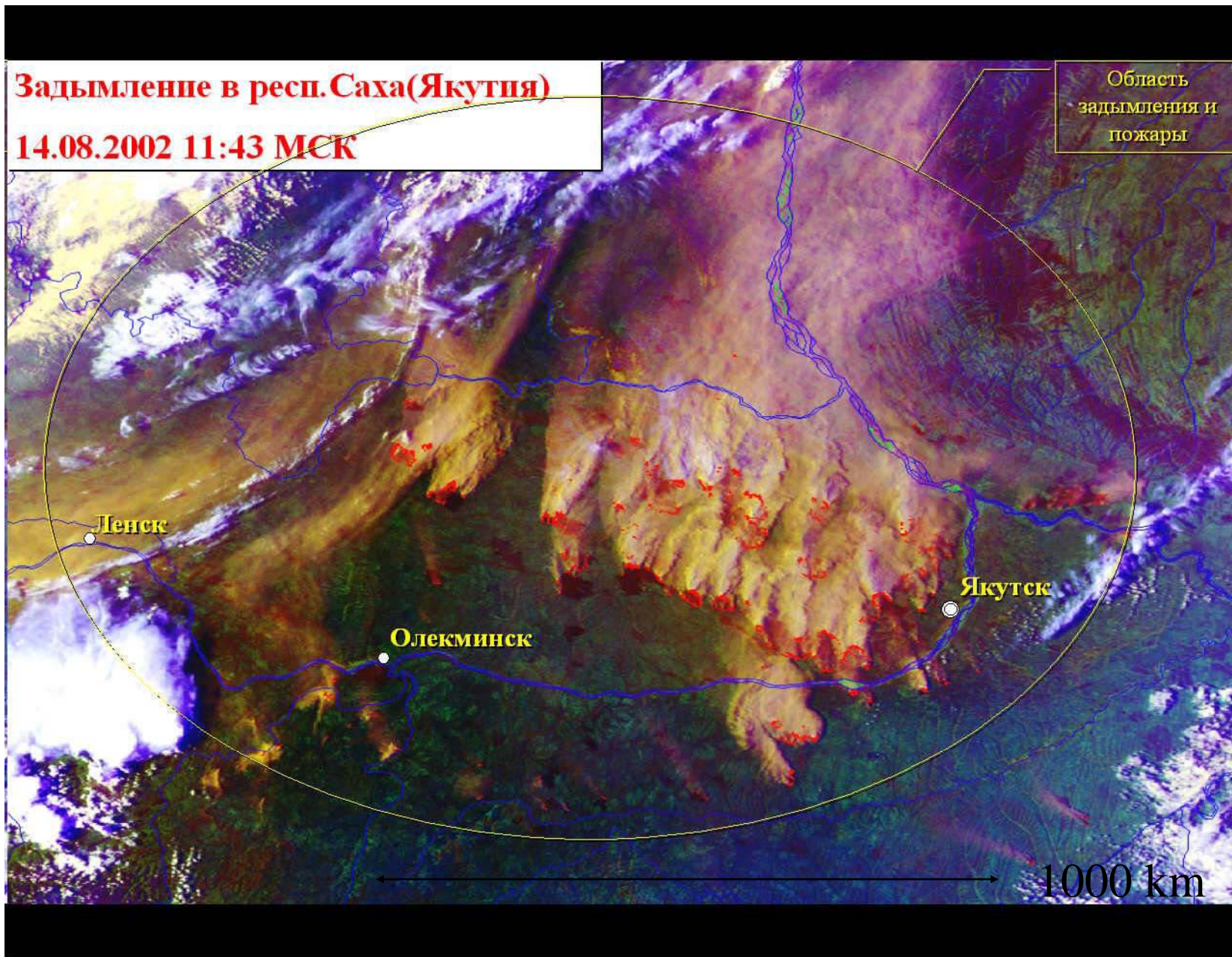
$$V^{(i)}(\lambda, \theta, t) = V(\lambda, \theta, t) + \xi_V^{(i)}$$

$$\xi_U \square N(0, \sigma_U^2), \quad \xi_V \square N(0, \sigma_V^2),$$

The concentrations of  $Q^{(i)}(\lambda, \theta, t_N)$  was estimated in a given region .

Trajectories ensemble reconstructed based on meteorological data for the points  $59^{\circ}$  N  $111^{\circ}$  E and  $67^{\circ}$  N  $129^{\circ}$  E (August, 14, 2002 )





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

## Reconstruction of concentrations based on ensemble backward trajectories

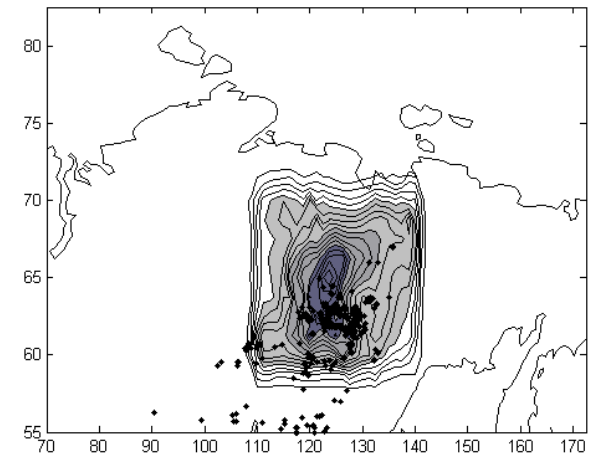
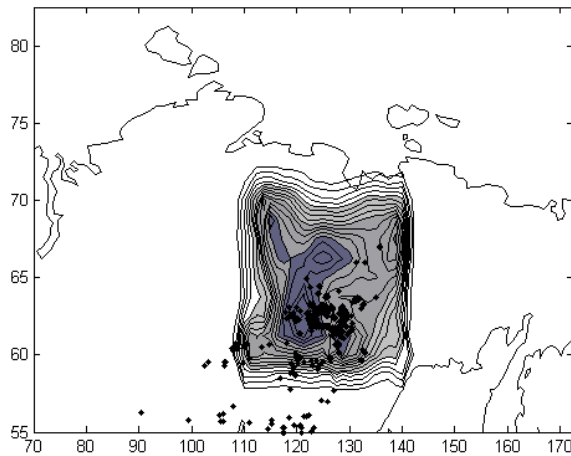
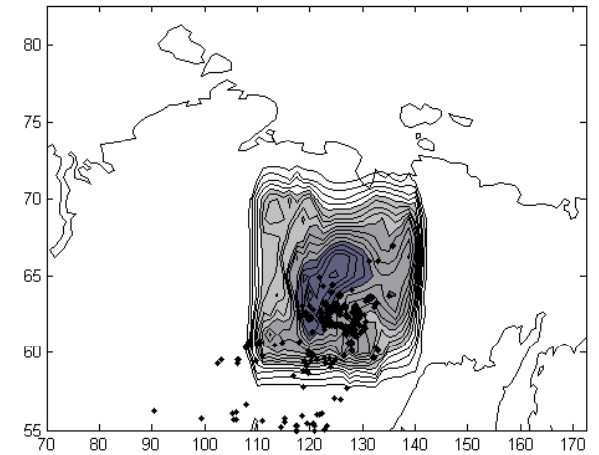
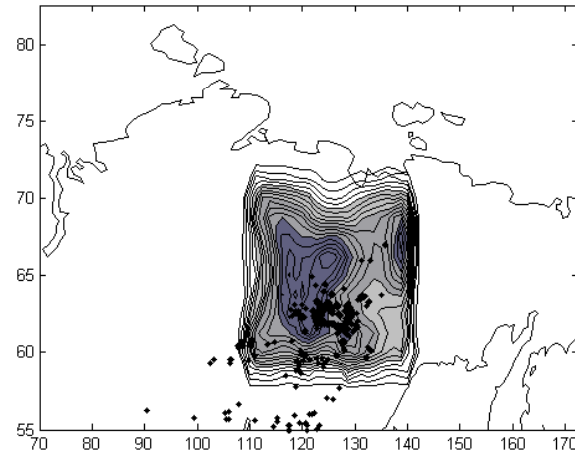
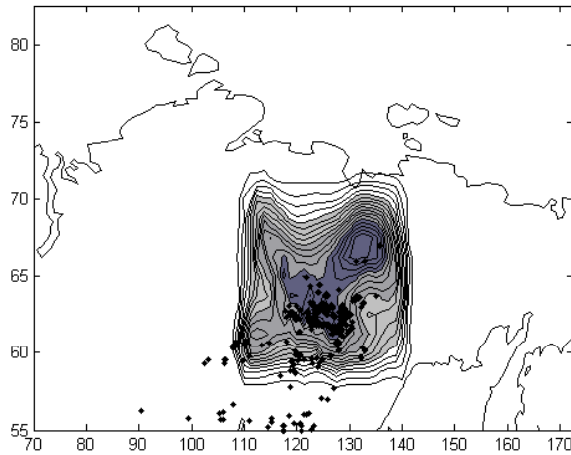
For the sample  $\{Q^{(i)}(\lambda, \theta, t_N)\}$  of concentration of CO<sub>2</sub> mean value and variance are calculated

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

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

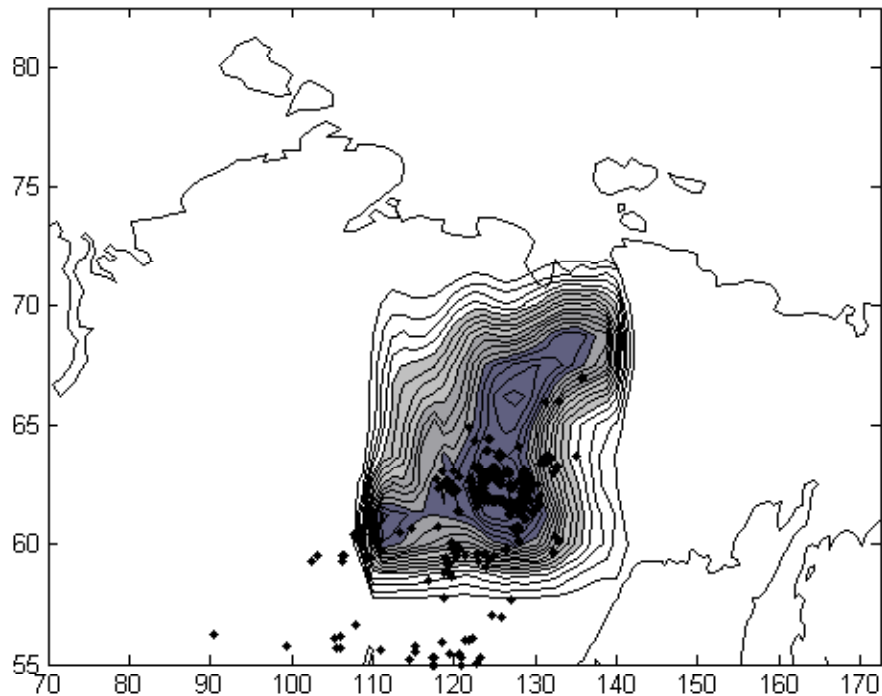
$\sigma_U^2, \sigma_V^2$  – root mean square values of wind forecast errors

# The ensemble of reconstructed concentration in a given region ( $57^{\circ}$ - $70^{\circ}$ N, $110^{\circ}$ - $140^{\circ}$ E)

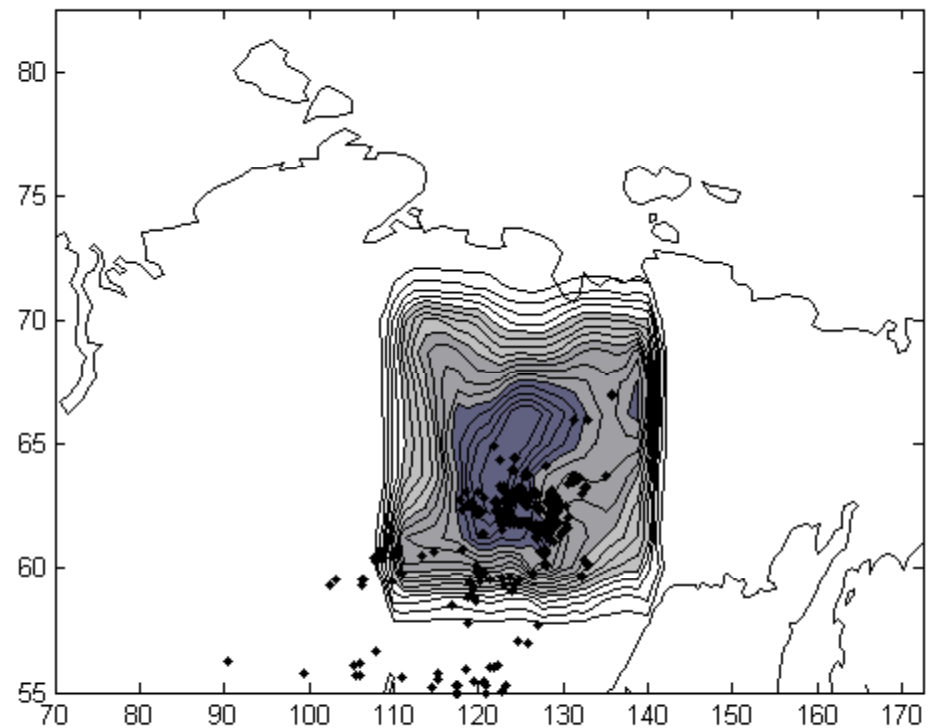


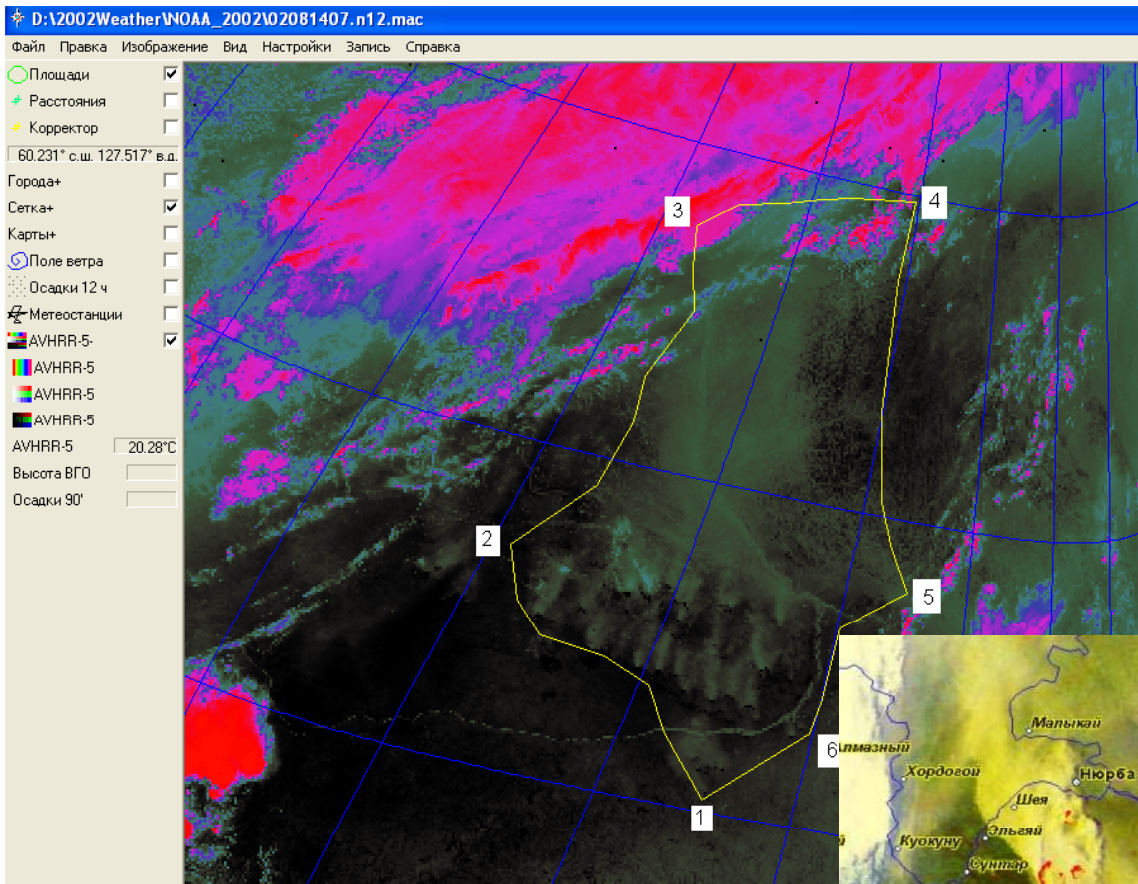
# The mean value calculated for the ensemble of 10 realizations of reconstructed concentration

backward trajectories were calculated on the 48 hours



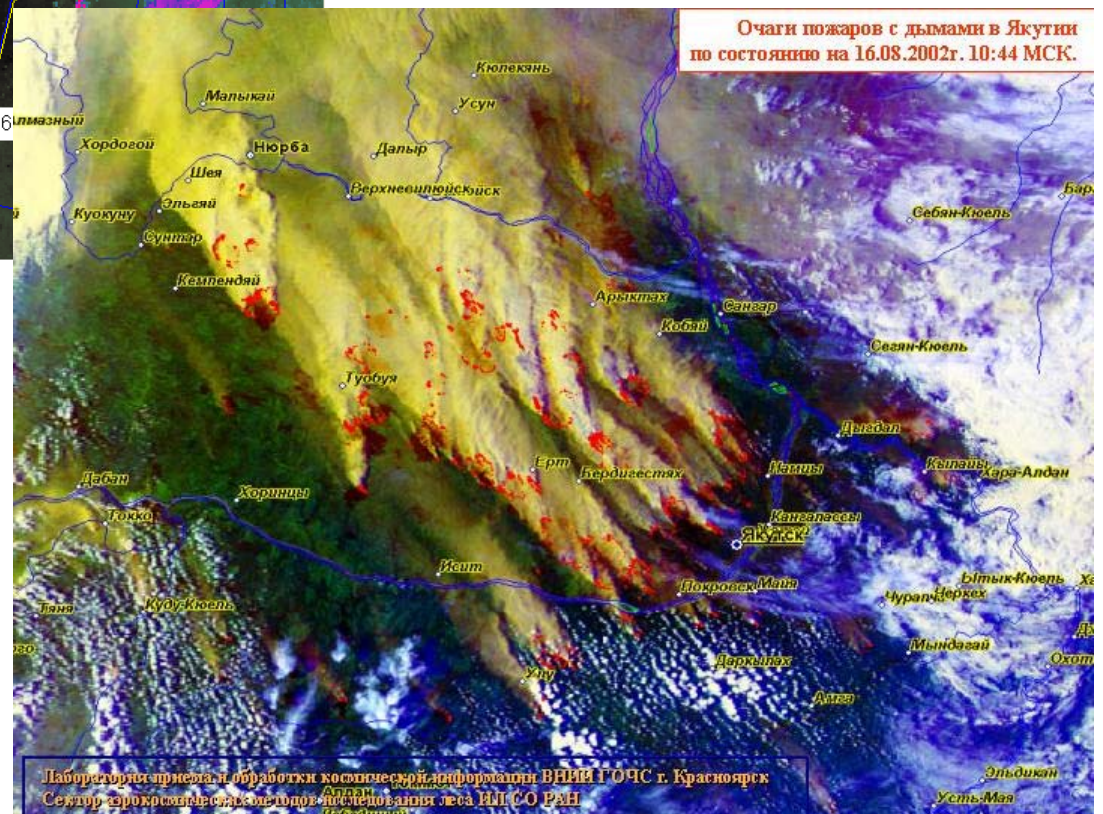
backward trajectories were calculated on the 120 hours





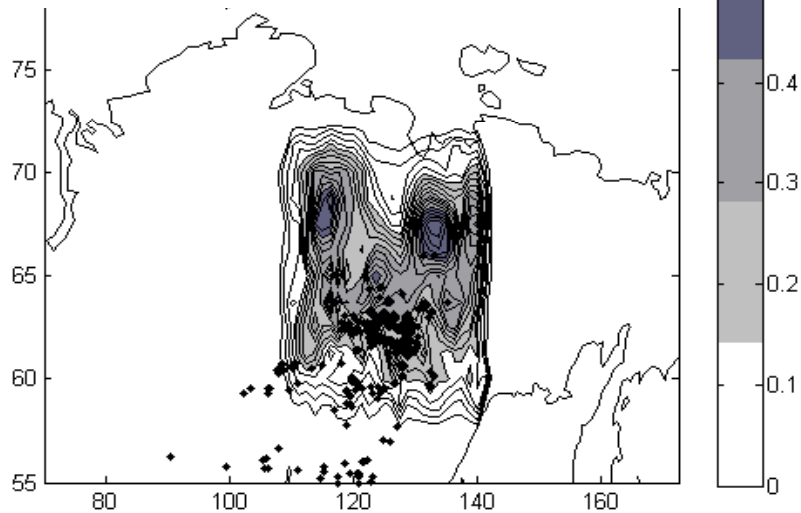
The structure of clouds and smoke plumes was analyzed by using of geoinformation system ARC-MAP9 and ERDAS IMAGIN 8.7

Satellite photograph of the fire with a smoke plumes

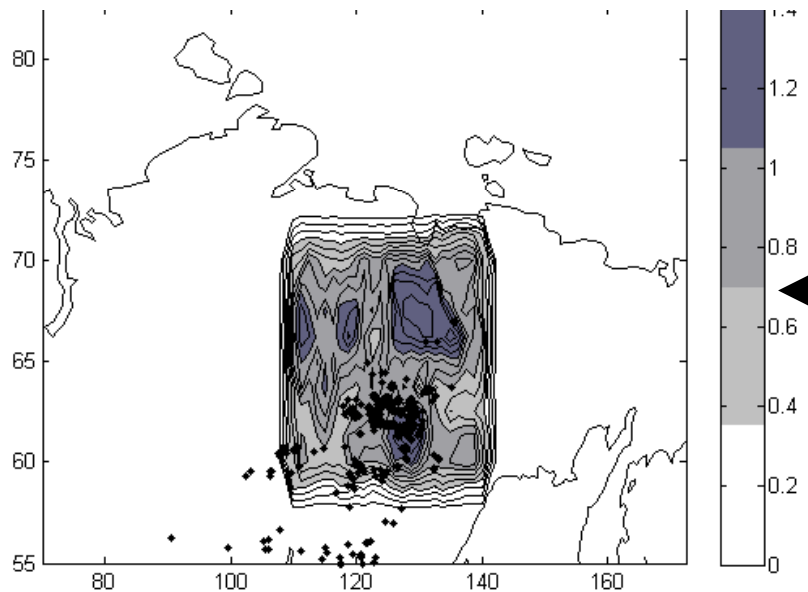
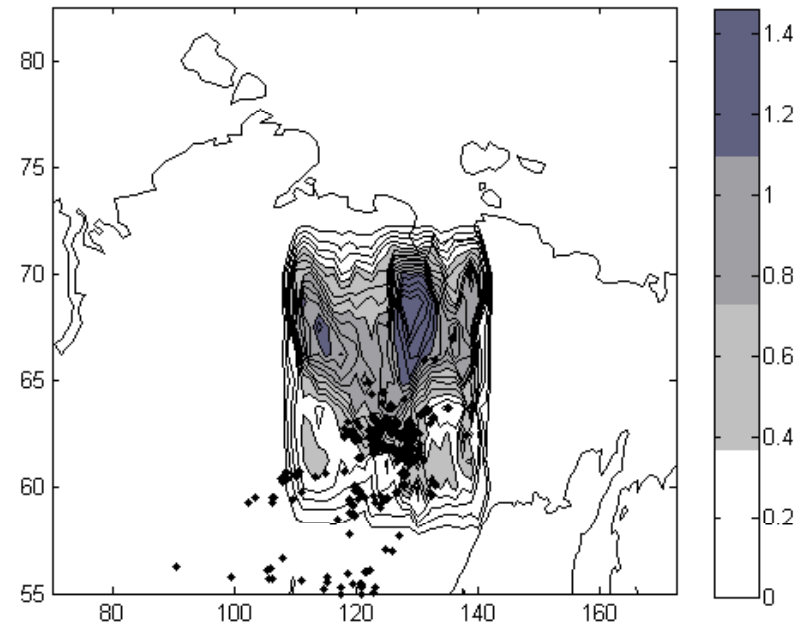


# Variance calculated on ensemble of 10 realizations of reconstructed concentration

backward trajectories were calculated on the 48 hours

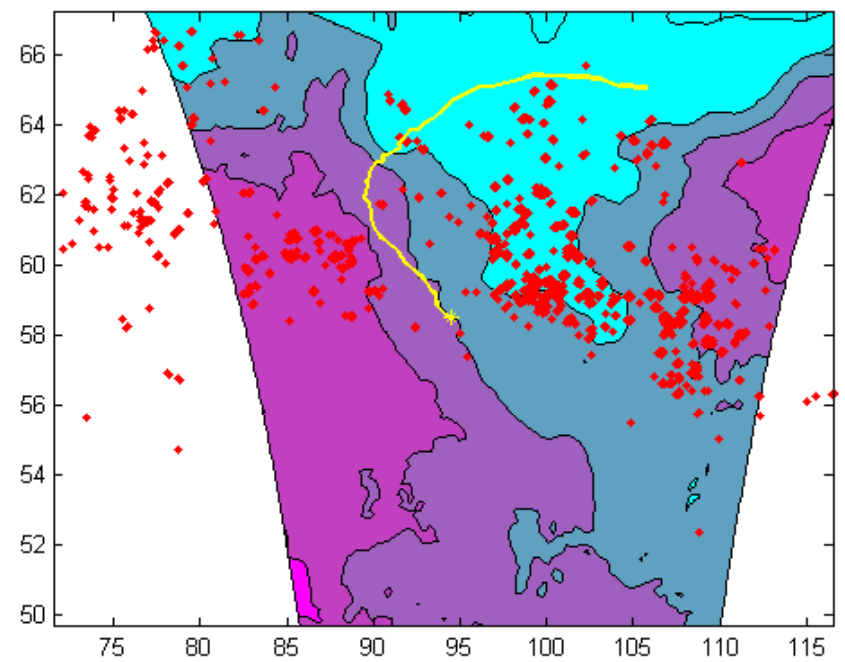
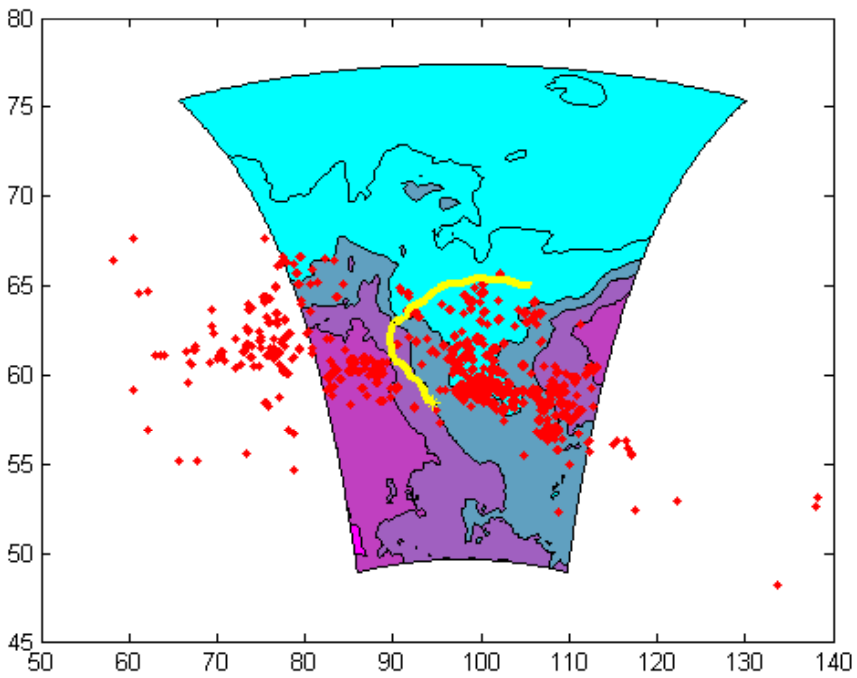


backward trajectories were calculated on the 120 hours



Variance calculated on ensemble of 50 realizations of reconstructed concentration (backward trajectories were calculated on the 120 hours)

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.



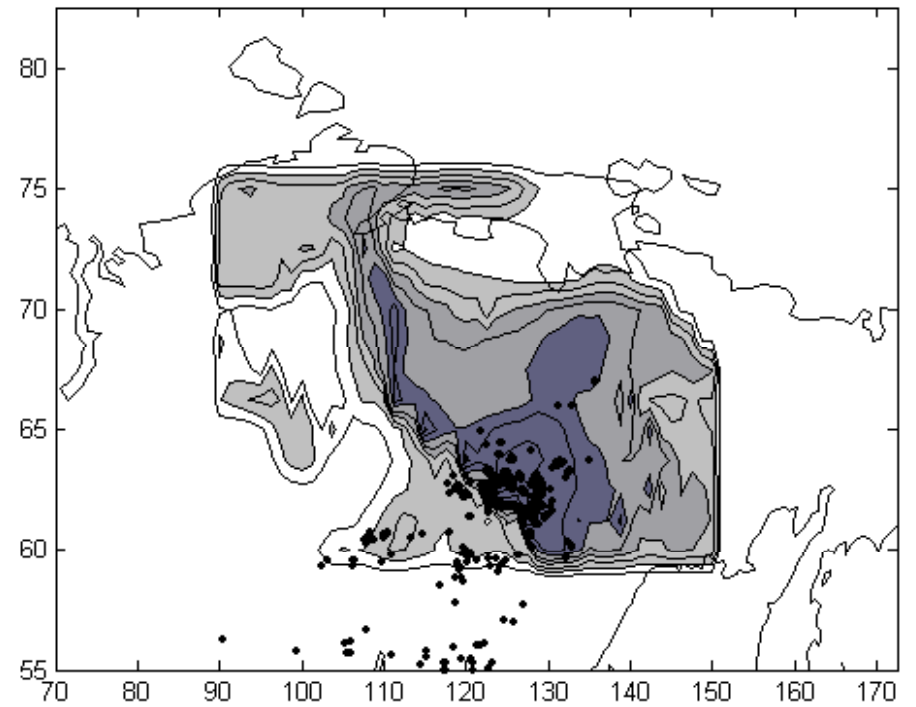
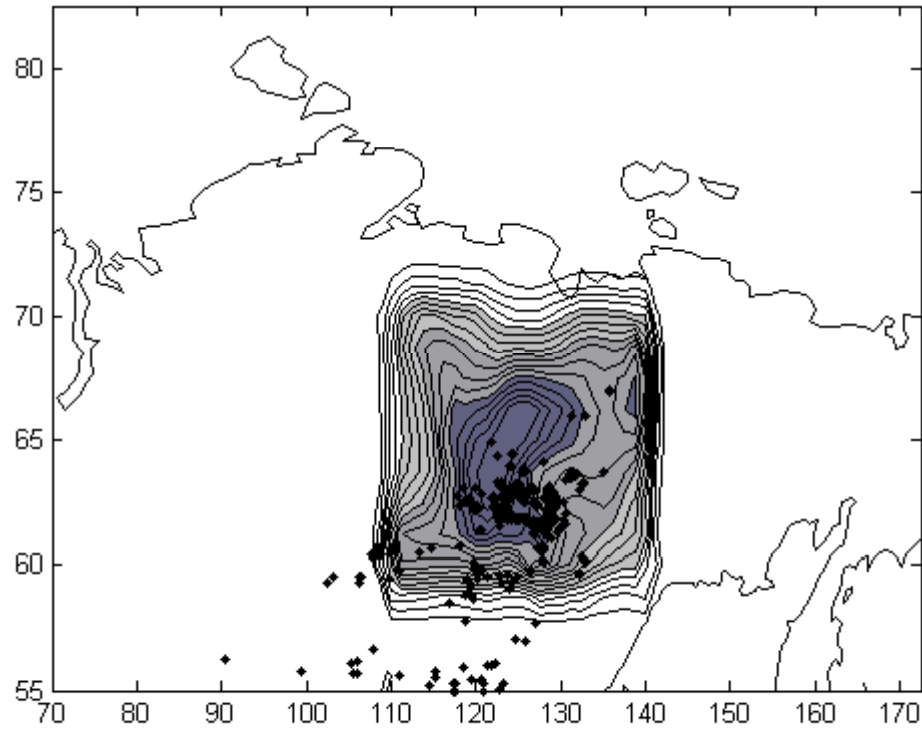
## Conclusion

❖ Ensemble approach is applied to calculate the distribution of gases from the massive forest fires for a given region with the use of meteorological data and satellite information on fires

## Future :

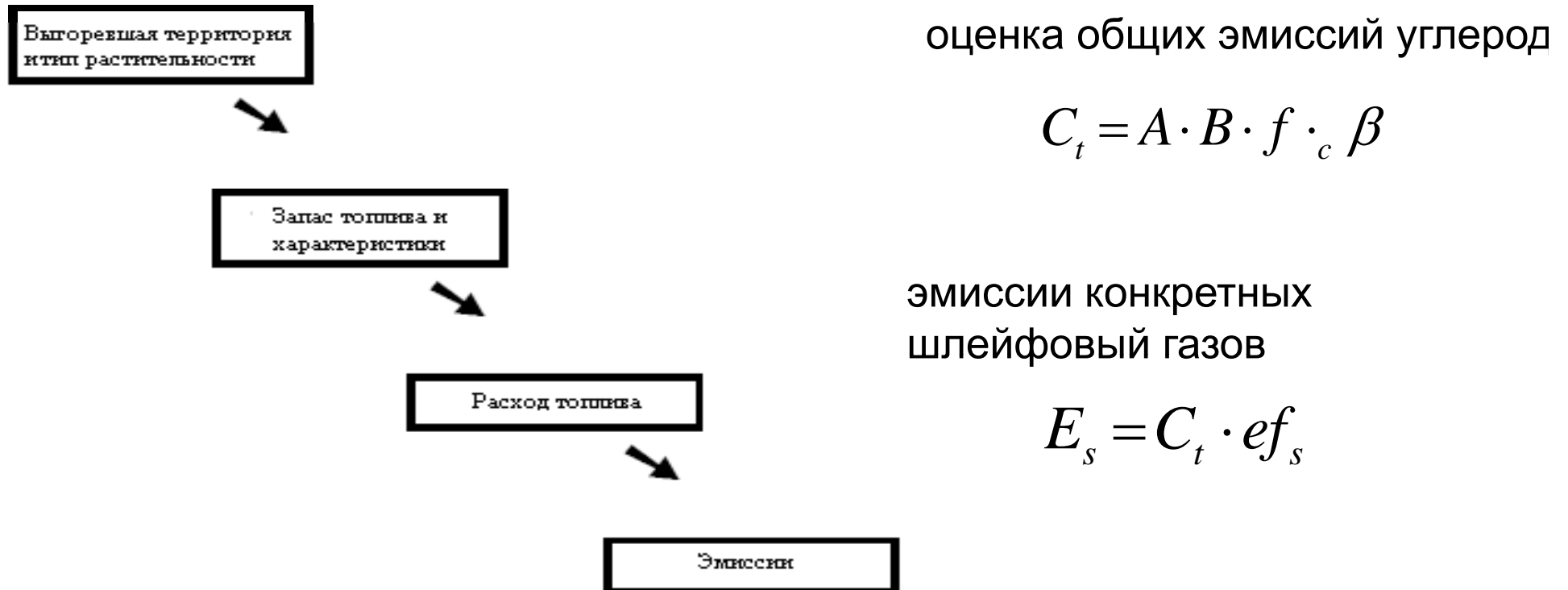
- ❖ Using forecasts of meteorological fields from WRF model.
- ❖ Development of data assimilation methods on fires data on the basis of ensemble Kalman filter.
- ❖ Quantitative estimate of technique quality by comparison of calculated and observed concentration.

## Comparison of results



# Оценка концентрации CO<sub>2</sub> по данным о сгоревшей

## биомассе



- где  $A$  это площадь пожарищ (га),  $B$  – средний запас биомассы (т/га),  $f_c$  – доля углерода в биомассе,  $\beta$  – масштабирующий коэффициент для доли биомассы, которая сгорела (связан с типом и интенсивностью пожара, а так же видом лесного горючего материала), и  $ef_s$  – коэффициент эмиссии для данного вида шлейфового газа  $s$  (обычно выражается как доля данного вещества по отношению к сухому топливу, сгоревшего во время пожара).

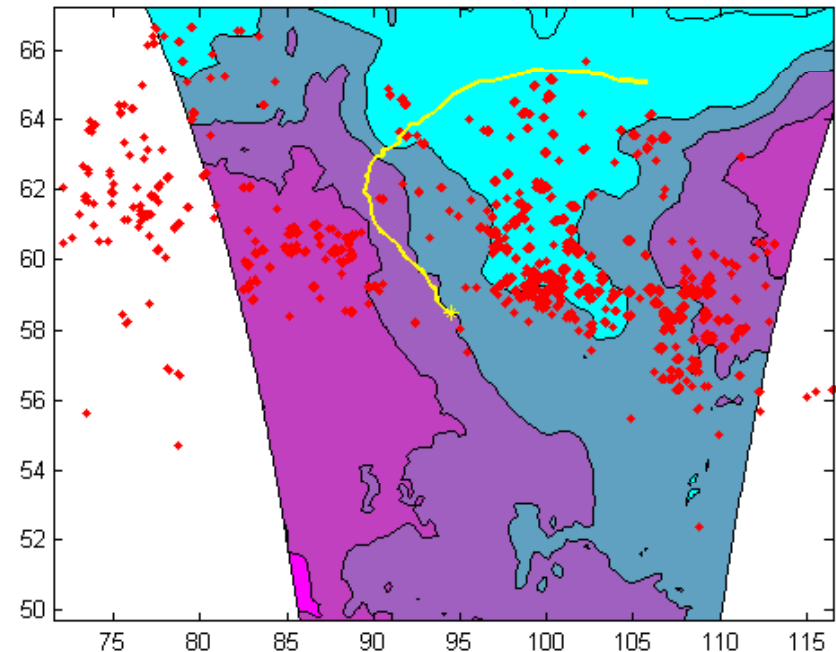
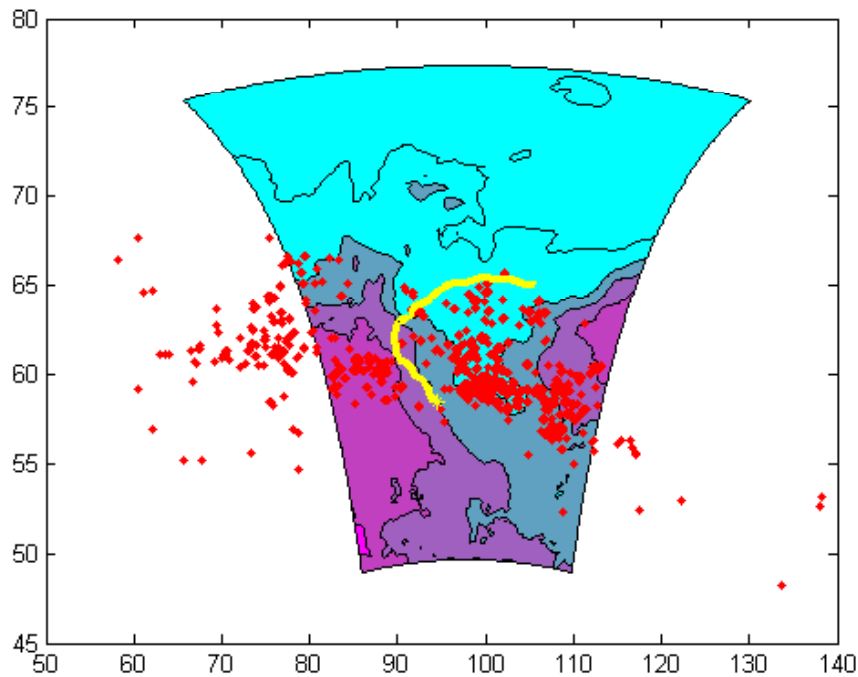
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Eric S. Kasiske, Edward J. Hyer, Paul C. Novelli, Lori P. Bruhwiler, Nancy H. F. French, Anatoly I. Sukhinin, Jennifer H. Hewson, and Brian J. Stocks. Influences of boreal fire emissions on Northern Hemisphere atmospheric carbon and carbon

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

