Impact of wildfires in Central Siberia on the regional-scale near-surface carbon monoxide abundance as measured at the ZOTTO tall tower station

K.B. Moeseyenko[1], A.V. Vasiljeva[1], A.I. Skorokhod[1], J.-C. Mayer[2], N. Jürgens[2], A. Panov[3], M. Heimann[4], M.O. Andreae[2]

[1]Obukhov Institute for Atmospheric Physics, Moscow, Russia.
[2]Max Planck Institute for Chemistry, Mainz, Germany.
[3]Sukachev Institute of Forest, Kransoyarsk, Russia.
[4]Max Planck Institute for Biogeochemistry, Jena, Germany.

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Motivation

- Wildfires in North Eurasia are a climatologically important source of many pollutants affecting air composition at both regional and continental scale.
- The associated emissions provide up to 20% of global fire emissions of inorganic carbon (CO+CO2) and up to 9 % of soot and 20% of organic aerosols.
- Long atmospheric residence times of many fire emitted compounds lead to complex interplay with emissions from other anthropogenic and natural sources.
- Hence, correct assessment of wildfire emissions is needed for better understanding of key factors affecting atmospheric composition, radiative properties, and air quality.

The lack of systematic data on the near-surface air composition and emissions for Russian territory complicates studies for air quality, estimates of environmental burden and long-term trends in atmospheric composition on the whole Northern Eurasia.

The objective of this study is to partly fill this gap by conducting continuous observations of near-surface air composition at **Zotino Tall Tower observatory** (ZOTTO) **for background atmospheric monitoring in Central Siberia** launched in 2007.

Background character of the station provide an excellent opportunity to study regional as well as long-range impact of various climatically important sources of pollutants including regional industry and wildfires.

Basic results of the research

- **Seasonal dynamics of fire activity.** **The set of program modules has been developed for analysis and assimilation of satellite data on burnt areas (MODIS MCD45 Burned Area Level3 Product, 2000 – 2010);**

- **Climatology of the wildfire emissions.** **The program module has been developed for calculation of emissions (CO_2,CH_4,CO,NO_x) from biomass burning with high spatial end temporal resolution over the whole Northern Eurasia;**

- **Regional effects of wildfires in Central Siberia.** **Measurements data from ZOTTO station have been analyzed; contribution of regional transport to short-term and seasonal variations in air composition at the measurements cite was estimated.**

- **Assimilation in transport models.** **Regional impact of the wildfires in Northern Eurasia on near-surface CO were analyzed with use of RAMS/ HYPACT modeling system;**

Part I. Seasonal dynamics of fire activity.

Some known estimates for burned areas in Russia

Publication	Years	Territory	Source of data
Shvidenko и Goldammer (2001)	1950-1999	Fire-protected forest territories	Avialesookhrana
Conard и Ivanova (1997)	1991-1995	Transnoyarskii Krai	Avialesookhrana
Cahoon и др. (1994)	1987	SE Siberia and NE China	AVHRR
Cahoon и др. (1996)	1992	Russia	AVHRR
Conard и др. (2002)	1998	South of West Siberia and Far East	AVHRR and Avialesookhrana
Kajii и др (2002)	1998	Siberia, Far East, and North Mongolia	AVHRR
Sukhinin и др. (2004)	1996-2002	Siberia and Far East	AVHRR and Avialesookhrana
Gre´goire и др. (2003)	2000	Russia	GBA2000
Simon и др. (2004)	2000	Russia	GLOBSCAR
Hoelzemann и др. (2004)	2000	Siberia and Far East, Kazakhstan, and Mongolia	GLOBSCAR and ATSR-2
Ito и Penner (2004)	2000	Siberia and Far East north to 30°N	GBA2000 and ATSR
Zhang и др. (2003)	2001	Ruassia	SPOT-VGT
Soja и др. (2004)	1998-2002	Siberia and Far East	AVHRR
Kasischke и др. (2005)	1992, 1995-2003	Siberia and Far East	AVHRR
Bartalev и др. (2007)	2000-2004	Russia	SPOT-VGT and MODIS Active Fires

Scarcity and incompleteness of the data prevent its validation and generalization for the whole territory of Russia

Net mass of the species emitted is [to *Seiler*,*Crutzen* 1980]:

$$M = A \cdot B \cdot CC \cdot EF,$$

where

A [ha] – the area burned by fire, from MODIS MCD45 Burned Area Level3 product (500×500 m, ±8 days) scaled by MODIS fire active spots data;

B [kg/ha] – the density of dry biomass in A, land cover classification scheme by Wiedinmyer [2006];

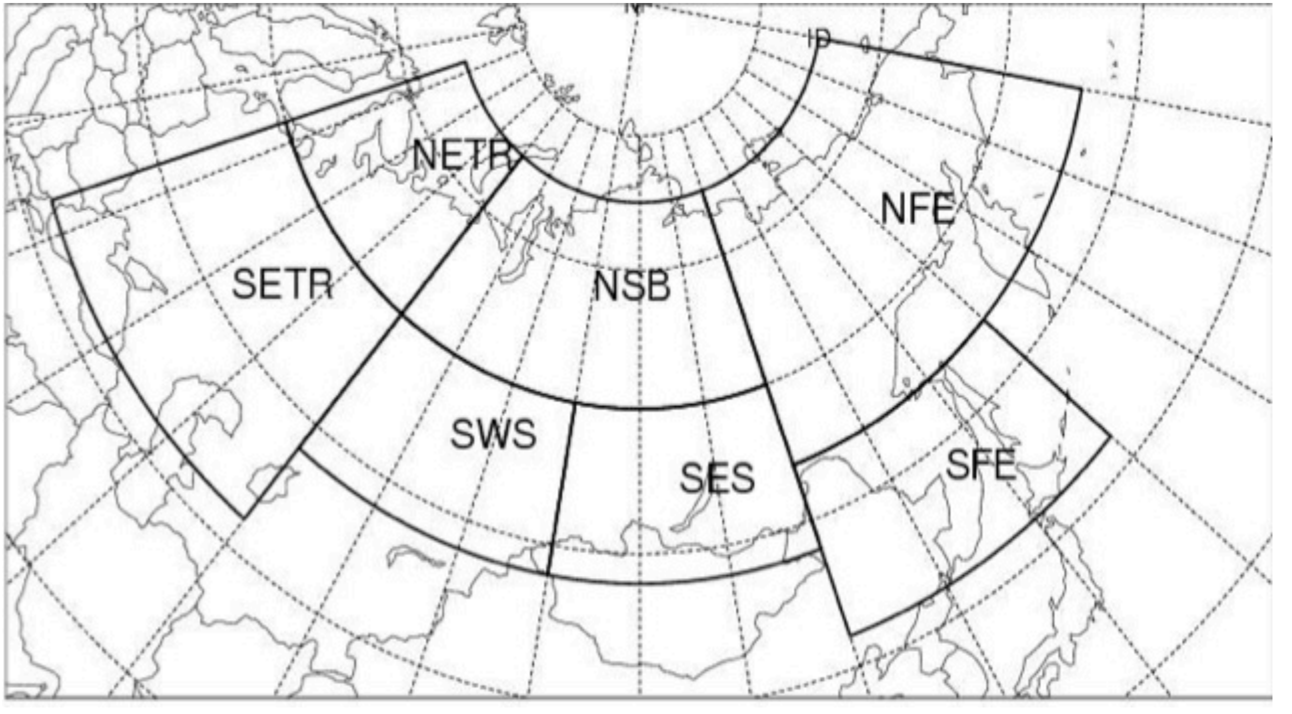
CC [%] – combustion completeness, empirical formulas from Wiedinmyer [2006];

EF [g/kg] – emission factor (the mass of the species per kg of the biomass burned)

Data processing and calculation procedure is following to the general methodology by *Vasiljeva et al* [2010,2011]

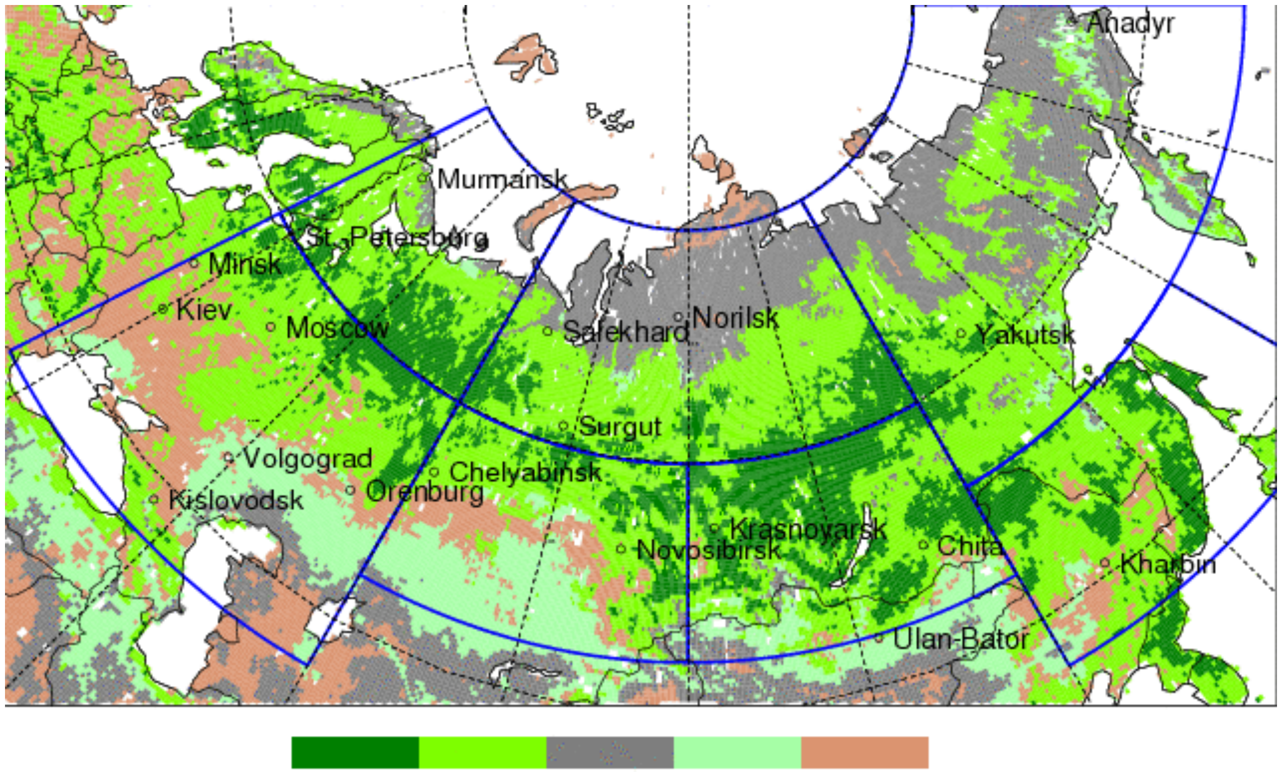
The developed module for analysis and assimilation of satellite data on burnt areas

(MODIS MCD45 Burned Area Level3 Product);



Geographical regions used for analysis of regional emissions and burnt areas

Bioclimatic zones by UMD-GLC classification and geographical regions



Bioclimatic zones:

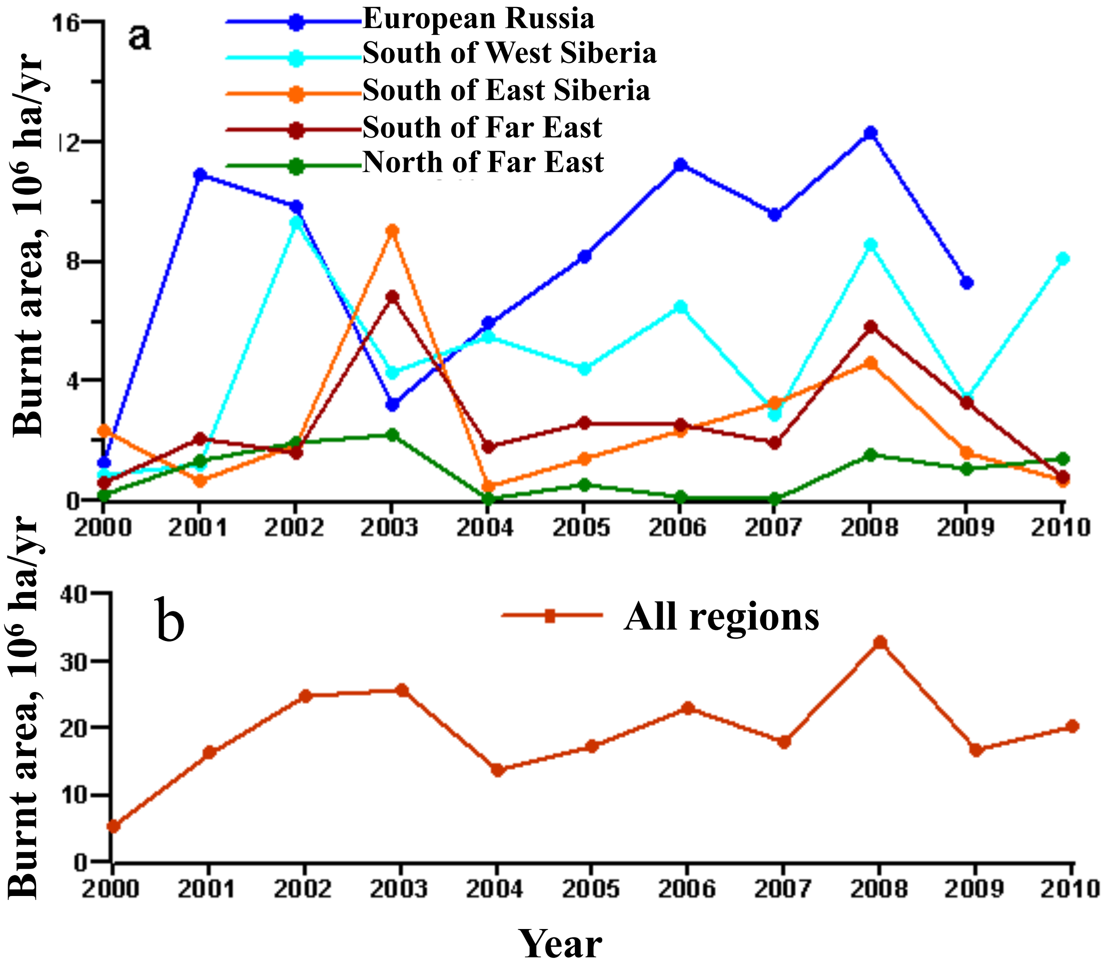
- **forests (TCC* >60%)**
- **woodlands (10%<TCC*<60%)**
- **shrublands**
- grasslands
- **croplands**

***TCC – Tree canopy cover**

Regions:

- **Center and South European Russia (CER)**
- **South West Siberia (SWS)**
- **South East Siberia (SES)**
- **South Far East (SFE)**
- **North European Russia (NER)**
- **North Siberia (NS)**
- **North Far East (NFE)**

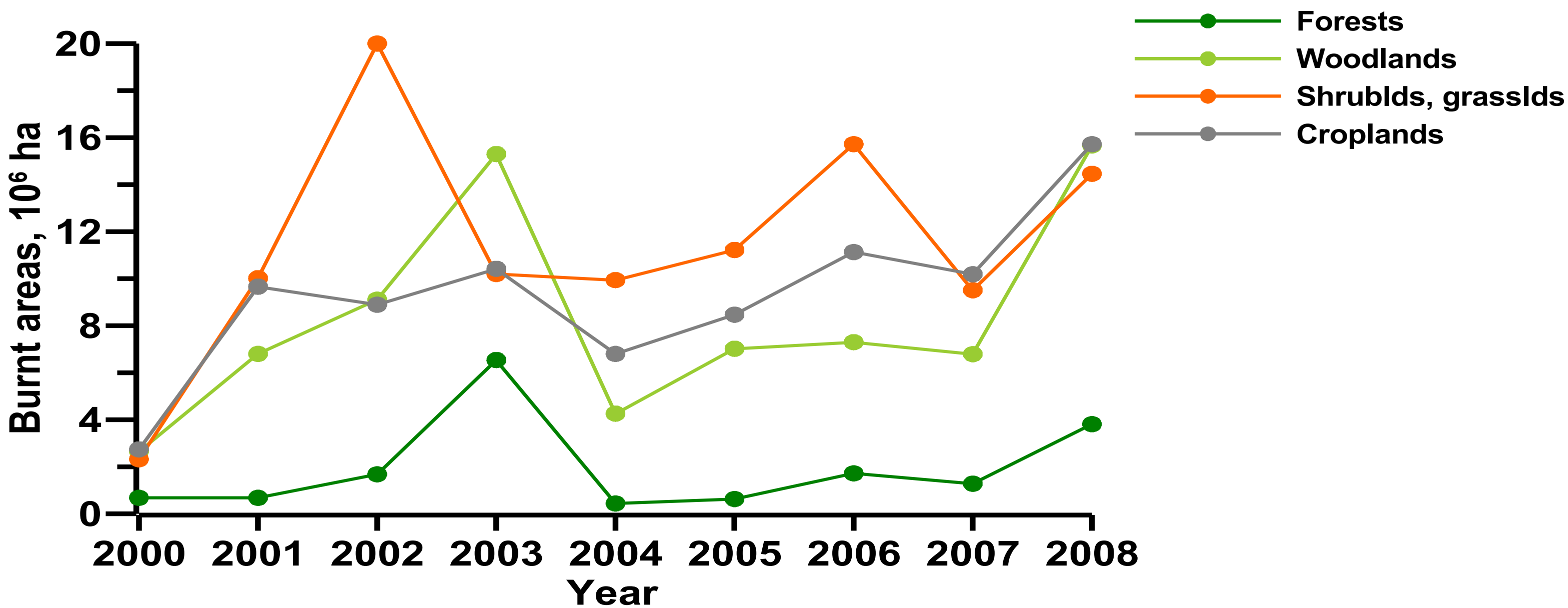
Inter-annual variability of burnt areas in different regions



Area:
42-75° N, 27-180° E

- **Two macro regions of similar fire activity patterns;**
- **Max fire activity – ETR and South Siberia (open territories + croplands);**
- **Strong inter-annual variability driven by meteorological conditions (5.4 -33.0 Mha).**

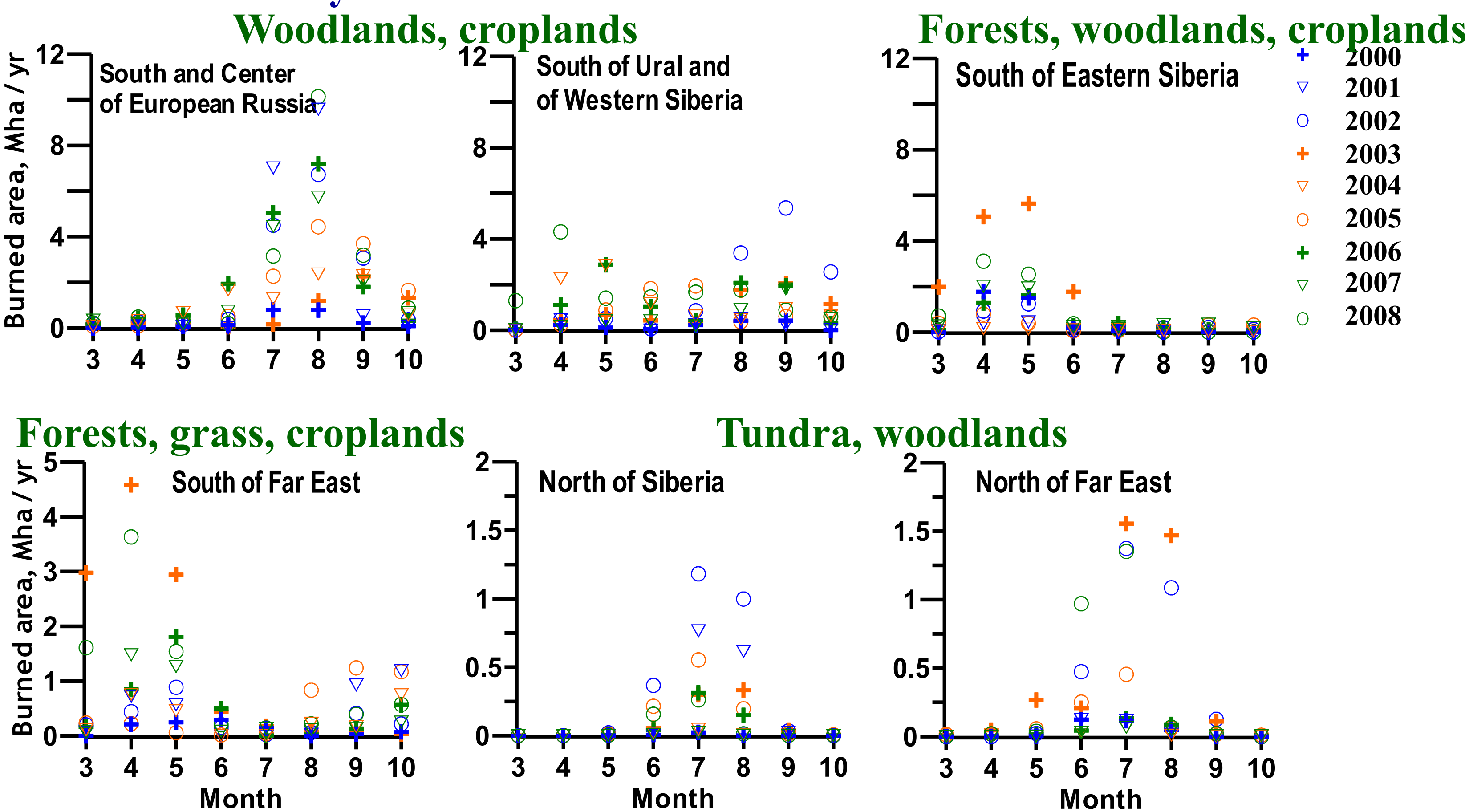
Inter-annual variability of burnt areas in different ecosystems



Forest fires < 1 Mha except for 2003 (4.1 Mha) and 2008 (2.5 Mha),

Total area = 11.6 Mha, 50% - South of East Siberia, 40% - South of Far East, 5% - European Russia.

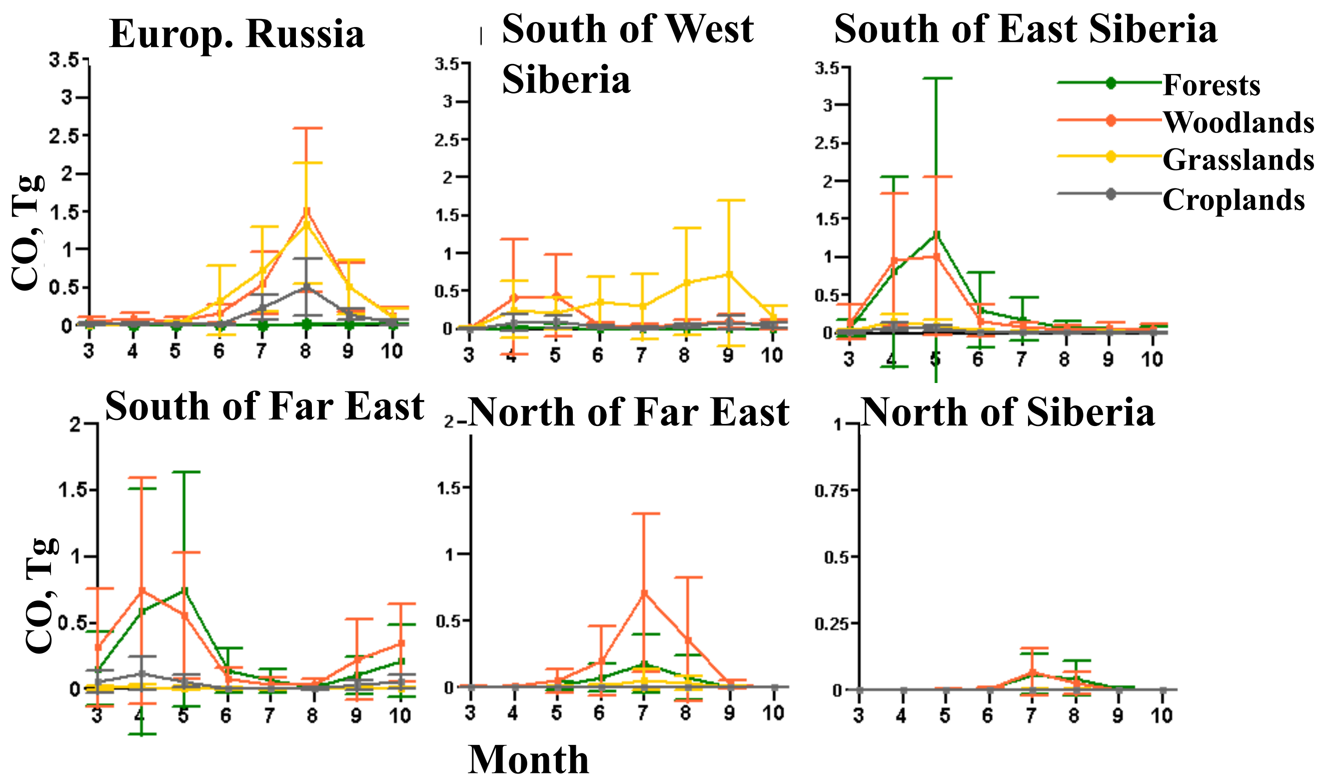
Seasonal variations in total monthly burnt areas by MODIS MCD45 data over 2000-2008



Different seasonal patterns of wildfire activity: single-modal (Europe, East Siberia, North regions) and bimodal (South of Ural and West Siberia, and Far East)

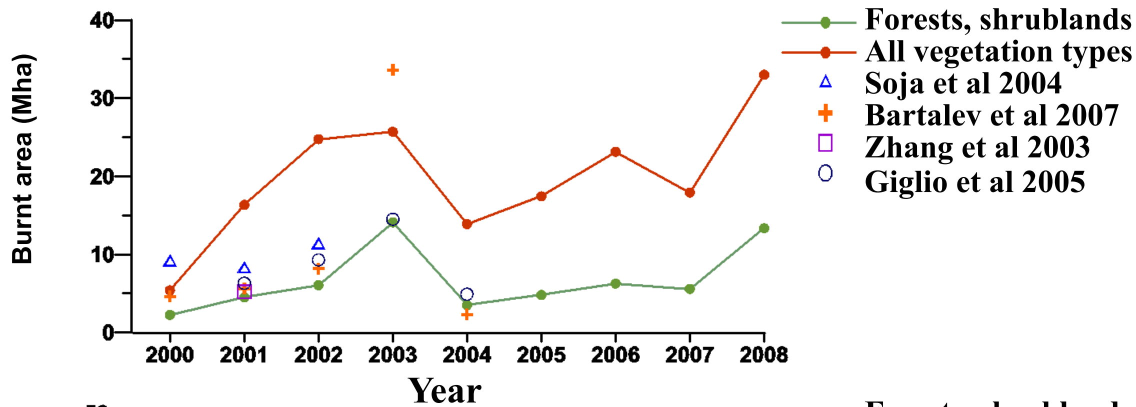
Part II. Climatology of carbon monoxide emissions from wildfires in Russia

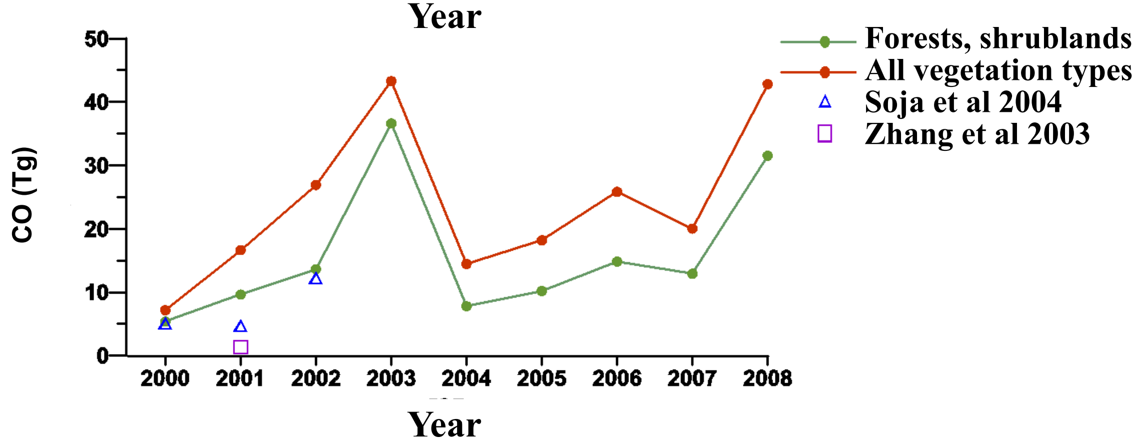
Seasonal variations (±σ) of wildfire CO emissions for different regions and ecosystems



Seasonal variations in CO emissions are quite different over the regions and vegetation types.
Total CO emissions from wildfires are from 7–43 Tg/year which is about 20–120% of anthropogenic CO emissions
Fires in forests and woodlands are from 5–35 Tg/year and consist 15–80% of all wildfire emissions.

Comparison with previous results





The differences are due to:

Geographical areas used for analyses

Initial data (type, temporal and spatial coverage, completeness)

Fire detection algorithms

Vegetation classes

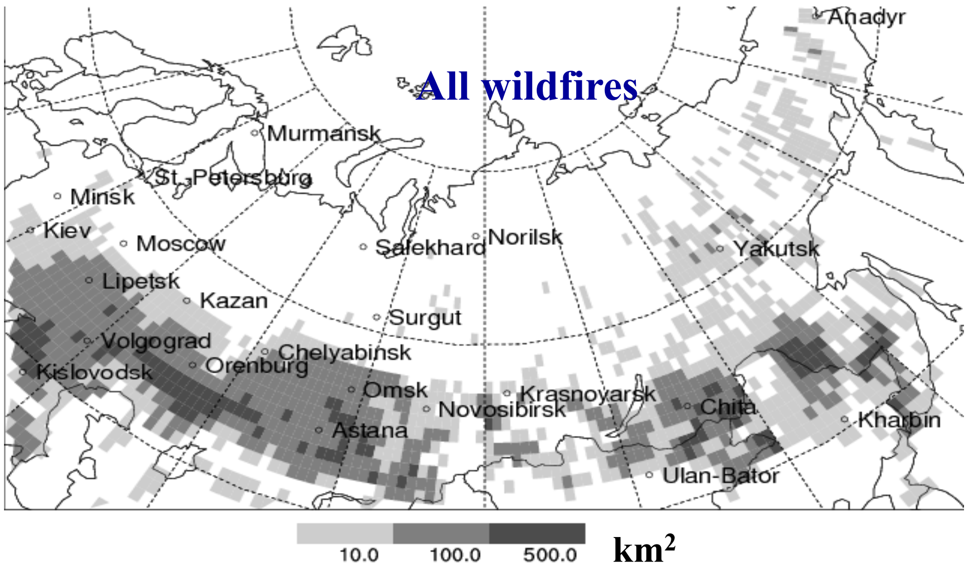
Soil model

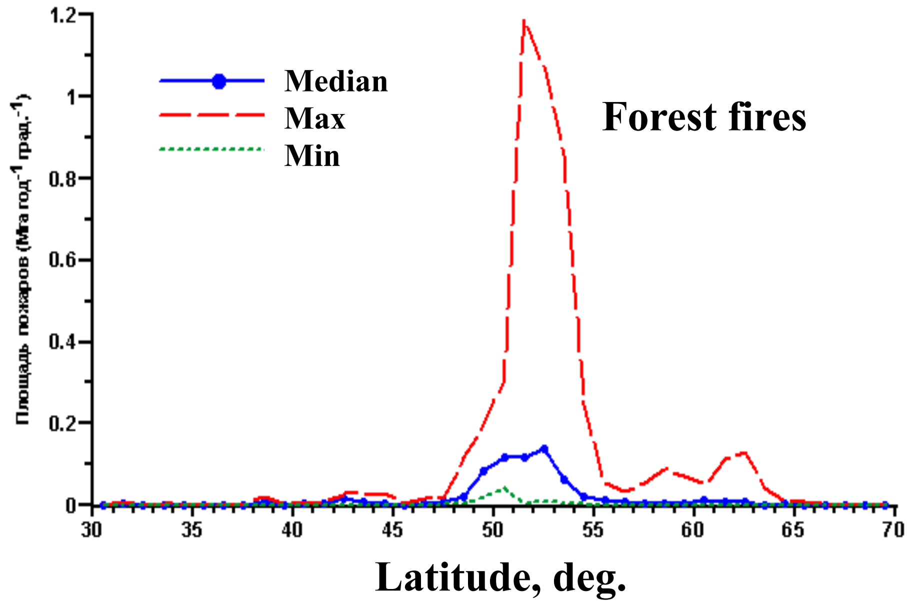
Annual CO emissions from anthropogenic sources (EDGAR-2000) and wildfires for the period 2000-2010.

Regions	CO emissions Mt / yr			
	EDGAR anthrop.	FIRES max.	FIRES median	FIRES min.
European Russia	24.3	11.4	8.0	0.9
South of West Siberia	2.7	8.1	3.8	0.6
South of East Siberia	0.8	20.7	3.5	0.6
South of Far East	6.7	11.9	3.2	1.2
North of Far East	0.1	4.2	1.6	0.1
North of Europ.	1.0	0.01	<0.01	<0.01
North of Siberia	0.3	0.7	0.1	0.03

For the years of severe wildfire activity the associated CO emissions consist:
up to 30% for European part of Russia;
65 – 95% for Siberia and Far East;
≈ 100% for north regions;

Annual burnt areas from *MODIS MCD45* for 2000-2010.





The most regions of severe wildfires are located in midlatitudes where

- **Climatically important anthropogenic sources are persist as well;**
- **Increase in fire activity is predicted by climatic models.**

What is the combined effect of the both sources on background CO ?

Part III. Regional effects of wildfires in Central Siberia as seen from ZOTTO data

ZOTTO Tall Tower monitoring station (60°26′N, 89°24′E):

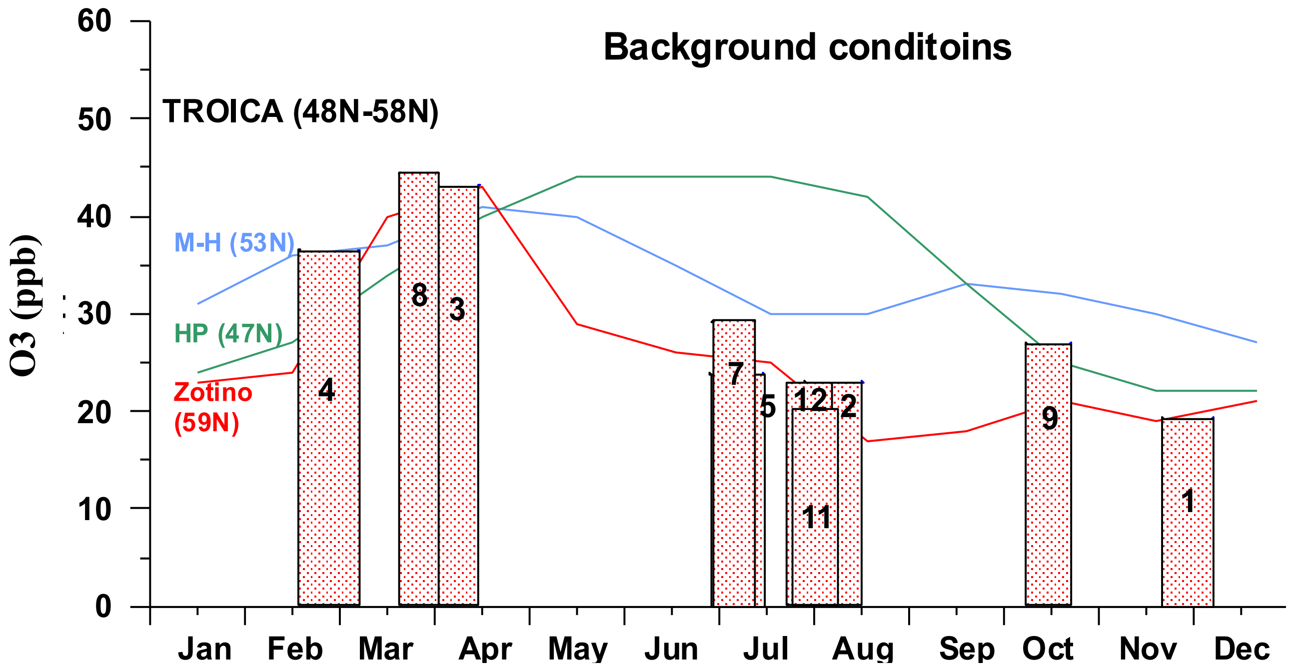
Studies of regional and trans-boundary effects of atmospheric transport and associated phenomena

- **Contiuous CO_2 and CH_4 Gas Measurements at 301, 227, 158, 92, 52, and 4 m height with Cavity Ring Down Spectroscopy (CRDS) by Picarro, Inc.**
- **Contiuous Aerosol Measurements at 301, and 52 m height with self made instrument**
- **Contiuous CO Measurements at 301, and 52 m height with Aero-Laser**
- **Contiuous Ozone, and NOx Measurements at 30 m height**
- **Contiuous Meteorology Measurements at 301, 227, 158, 92, 52, and 4 m height, and on the ground (Temperature, Wind, Humidity)**
- **Biweekly Flask Sampling at 301 m height**
- **Various irregular ecosystem measurements**

ZOTINO project participants

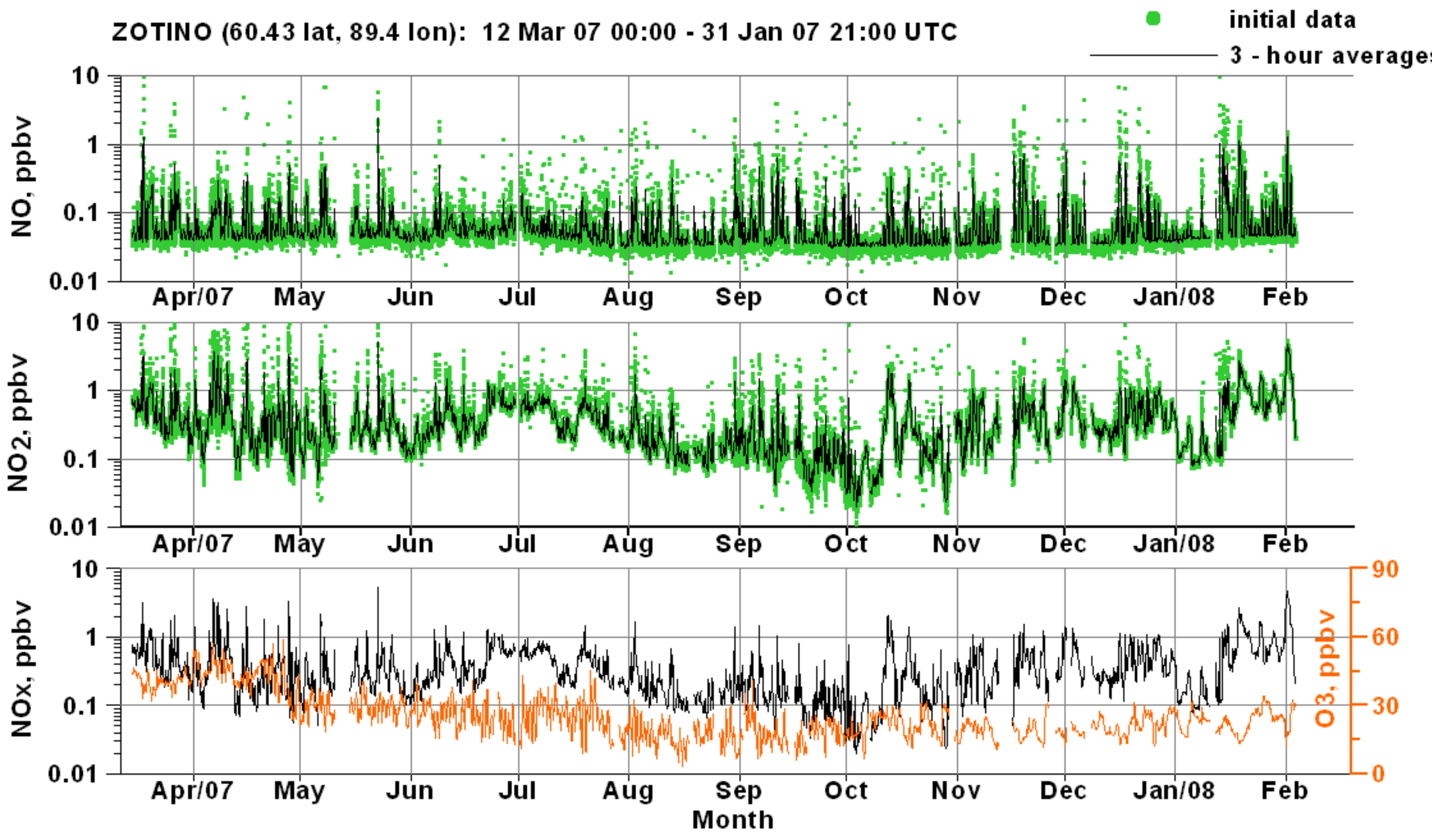
E. Vaganov, S. Verkhovetz	V.N. Sukachev Institute of Forest, RAS	Krasnoyarsk, Russia
A. Skorokhod, I. Belikov, R. Shumsky	A.M.Obukhov Institute of Atmospheric Physics, RAS	Moscow, Russia
M. Heimann, J. Winderlich, E.D. Schultze	Max-Plank Institute for Biogeochemistry	Jena, Germany
M.O. Andreae, N. Jurgens	Max-Plank Institute for Chemistry	Mainz, Germany
W. Birmili, J. Heintzenberg	Leibnitz Institute for Tropospheric Research	Leipzig, Germany
M. Gloor	University of Leeds	Leeds, UK
A. Manning, E. Kozlova	University of East Anglia	Norwich, UK

Averaged over the continent background ozone concentrations (TROICA expeditions) versus stationary observations on Hohenpeissenberg (HP), Mace Head (MH) and ZOTTO.



- Atmospheric photochemical system is rather uniform over continental areas of North Eurasia.
- The ZOTTO measurement data are representative at regional scale if considered at seasonal scale (›› synoptic times).

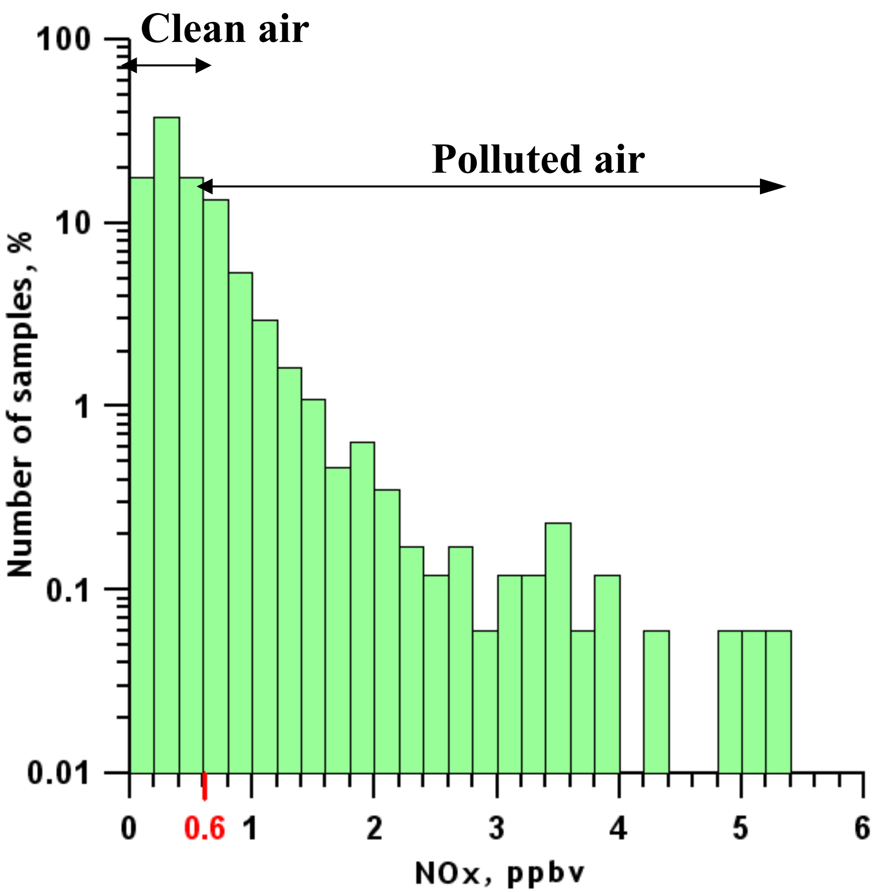
Surface NO, NO2, NO_X and O3 measured at ZOTINO during 2007.03 – 2008.01



Measured NOx (as NO + NO2):

- **low background concentrations (<1 ppbv)**
- **short-term fluctuations from 0.1 to 10 ppbv**

Histogram of ZOTTO 4 m a.g.l. NO_X concentrations



- Top quartile of NOx concentrations experience seasonal variations within 0.6-0.8 ppbv.
- NOx from top quartile serve as indicators of polluted air which could have been transported from distant emission sources.

TRAJECTORY STATISTICAL MODEL FOR RESIDENCE TIME ANALYSES

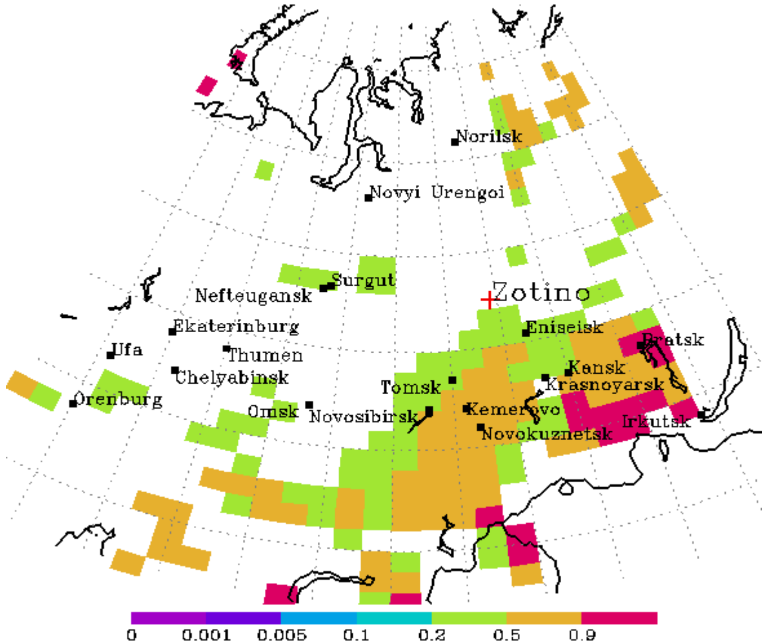
The ensembles of backward Lagrangian air parcel trajectories were calculated with the specially developed trajectory model driven by the NCEP FNL meteorological input data.

The model supports calculations for three types of trajectories:

- **2D isobaric (at constant pressure levels)**
- **3D with vertical wind velocity in p-coordinate system**
- **2D mean transport vector (with wind speed averaged within the boundary layer)**

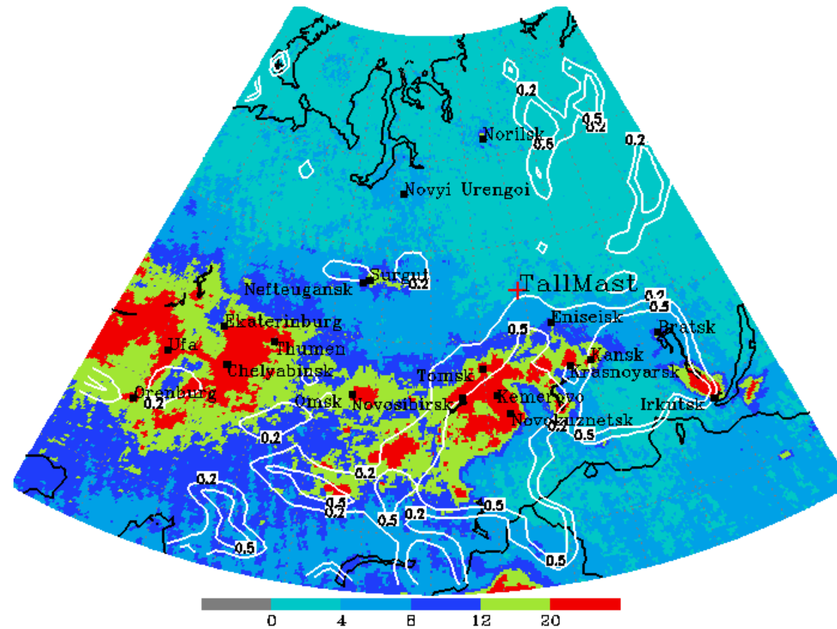
The meteorological input is taken from the NCAR/NCEP reanalysis data at regular 1°x1° lat-lon grid with 12h time increment. The data include horizontal wind speed and vertical wind velocity at 21 pressure levels from 1000 to 100 mbar.

Yearly mean conditional frequencies (CF) of air with high NOx



Normalized frequency

NOx Potential source contribution function

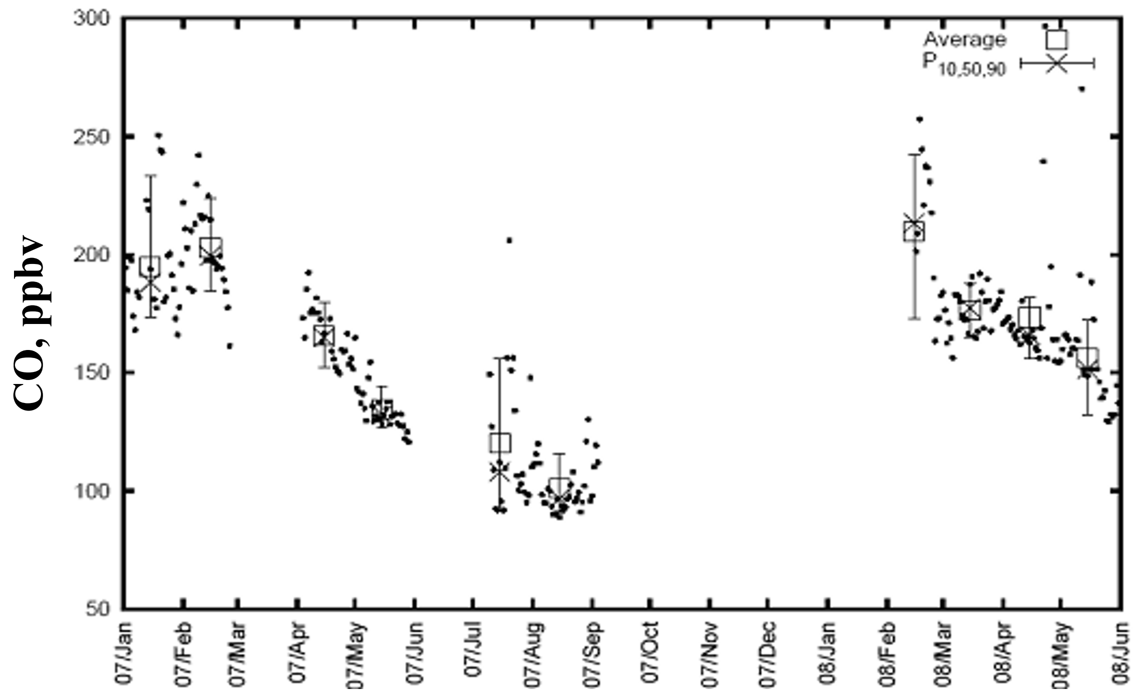


NO_2 <10^{15} molec / cm^2>

CF against yearly tropospheric NO_2 from OMI

The climatologically important sources of NOx are primary associated with industrial areas in the South Siberia.
Impact of Southern Ural was not revealed probably because of larger distances to ZOTTO.

ZOTTO CO near-surface obs. (Jan 2007 – Jun 2008)

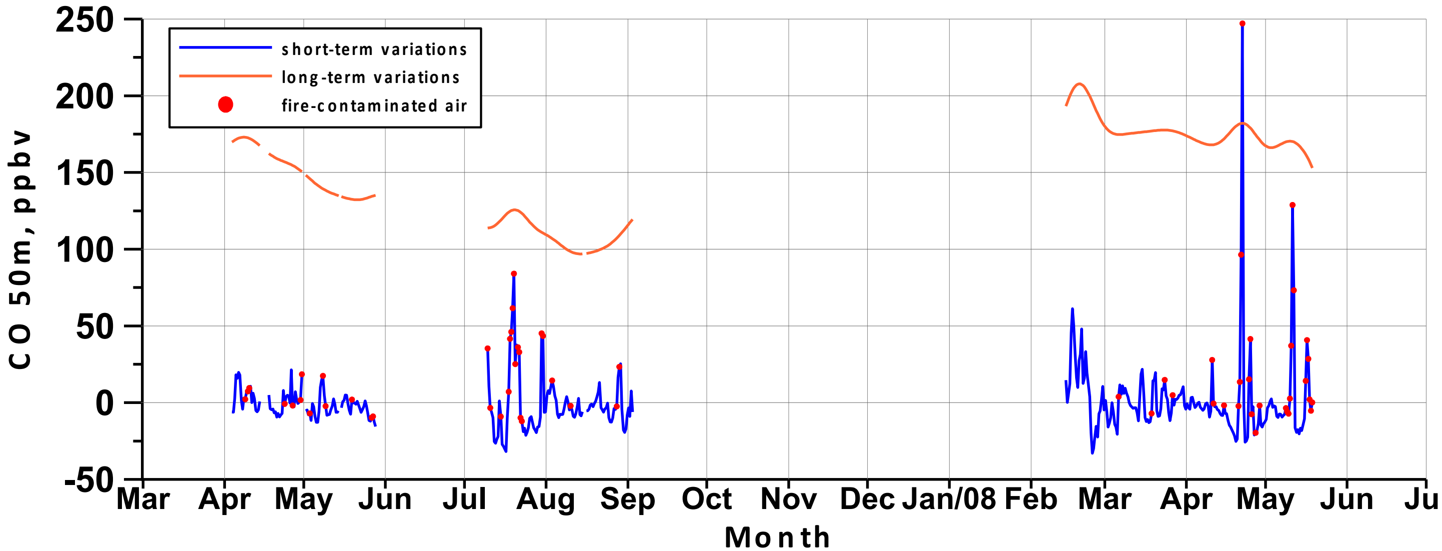


Amplitude of seasonal cycle (winter – summer) ~110 ppb well agrees to:

- TROICA observations (*Elanskii et al*., 2006);
- Mondy station, 1997 - 1999 (*Pochanart et al*., 2003);
- Ryori, Japan (*Kim et al*., 2010);
- Oki, Japan (*Pochanart et al*., 1999)

This manifests for weak spatial gradients of CO (and ozone) over the continent at seasonal scales.

Decomposition of original CO data into synoptic and seasonal components



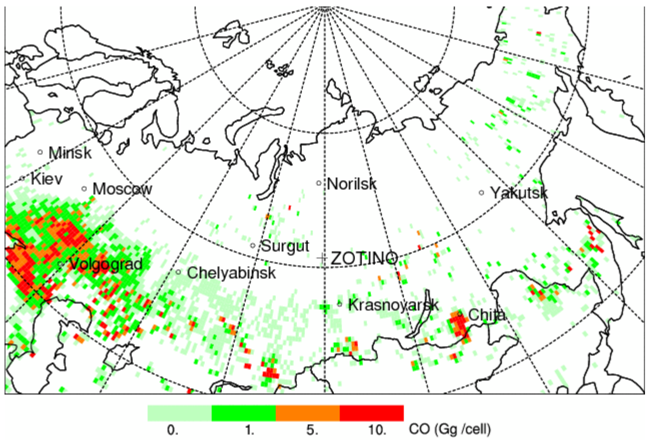
Red dots show episodes of air transport from wildfires.

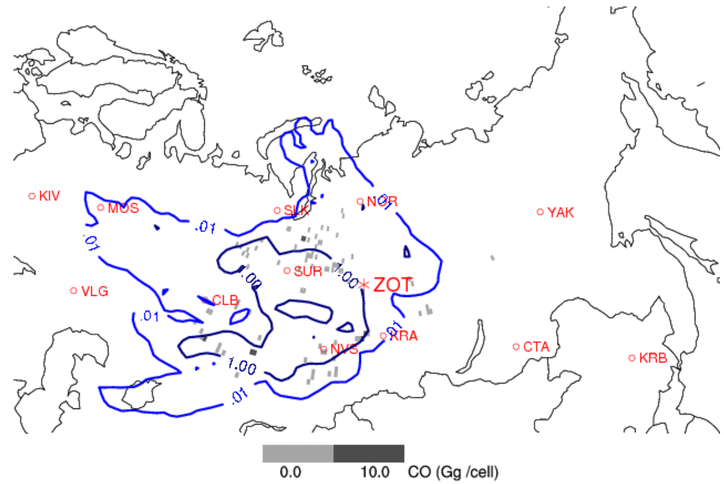
Long-term (>30 days) component

Short-term (<30 days) component

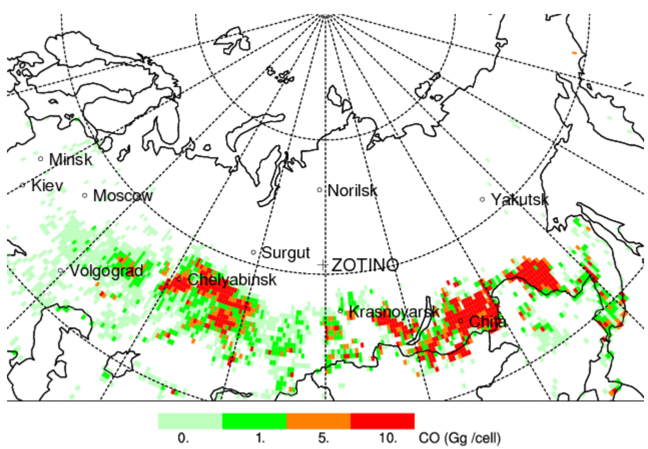
CO emissions (left) and source contribution function (P_{75} SCF) for ZOTTO (right)

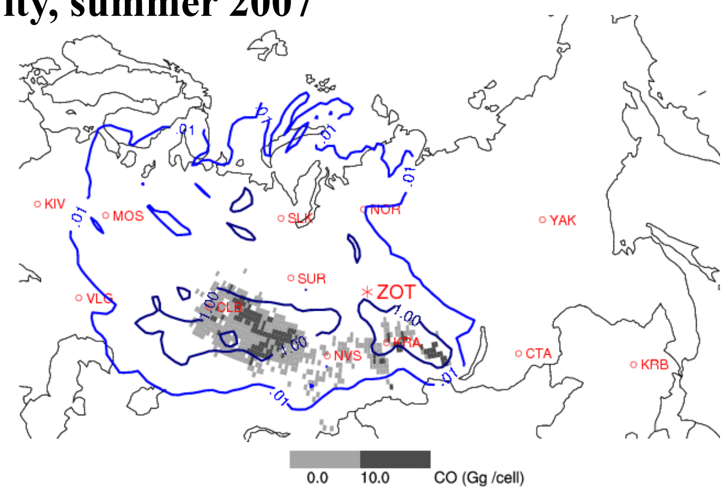
Weak fire activity, summer 2007



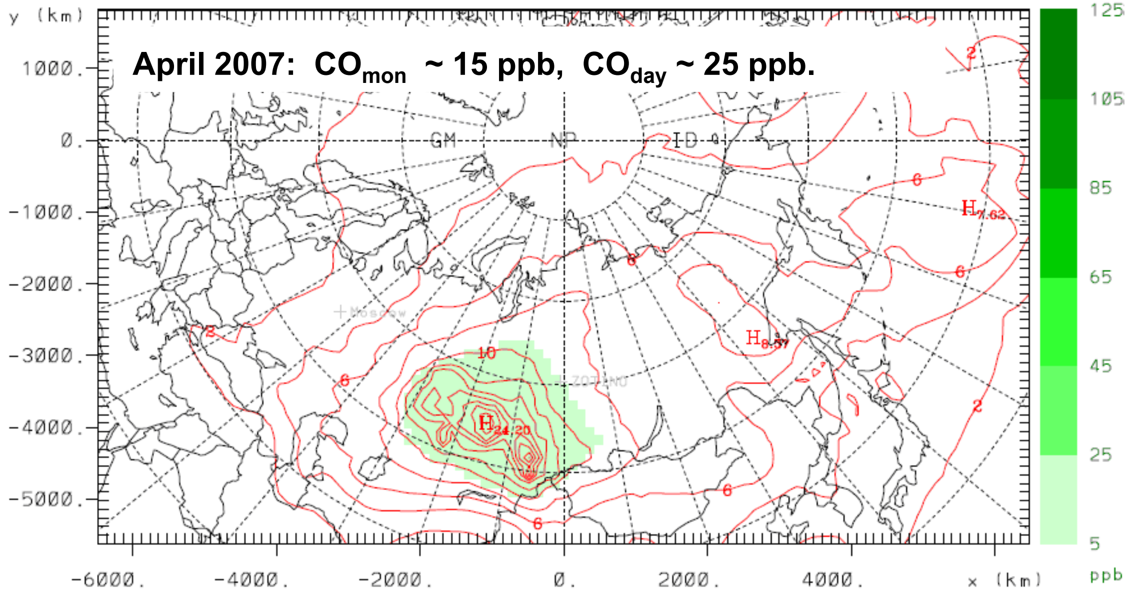


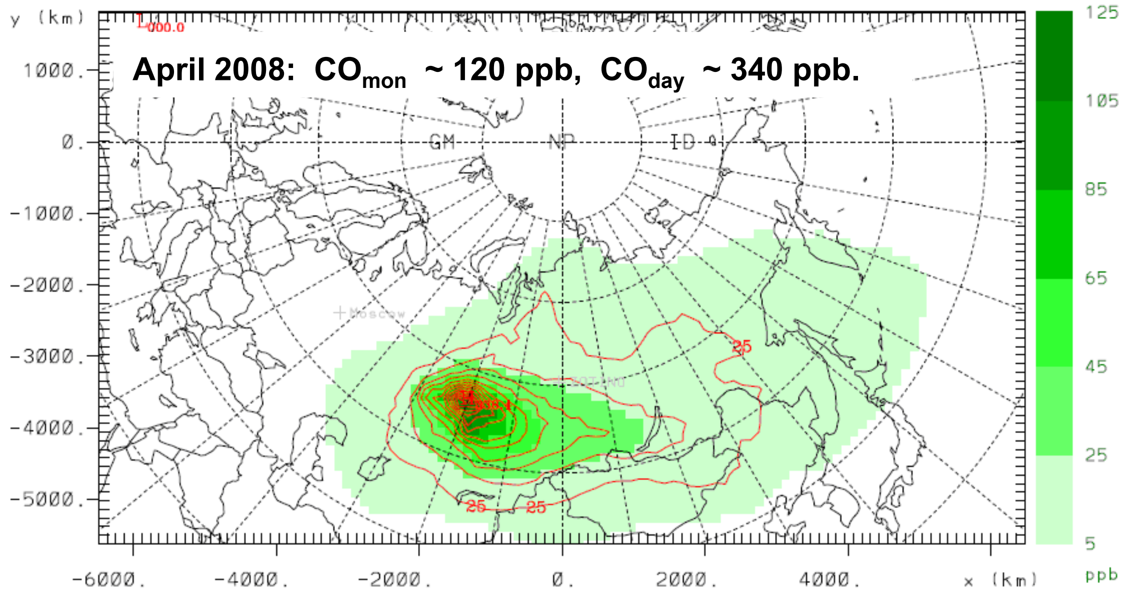
Strong fire activity, summer 2007



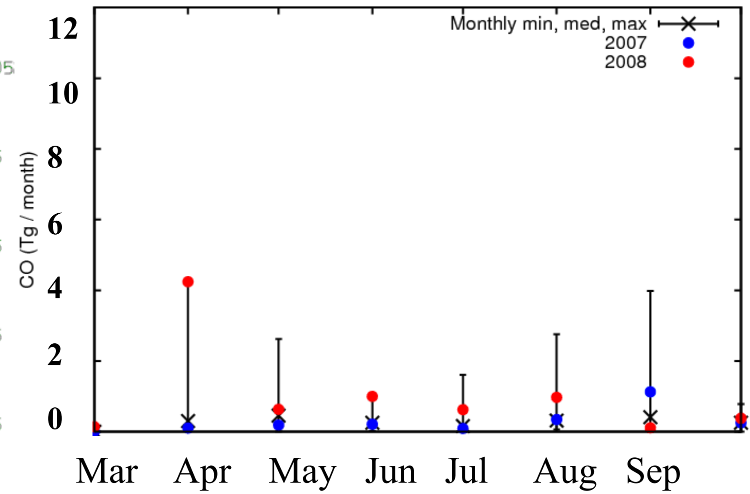


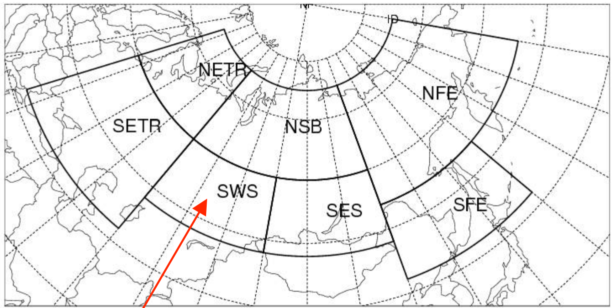
Near-surface CO response to wilfires in West Siberia during April 2007 and 2008





Emissions CO Tg/month

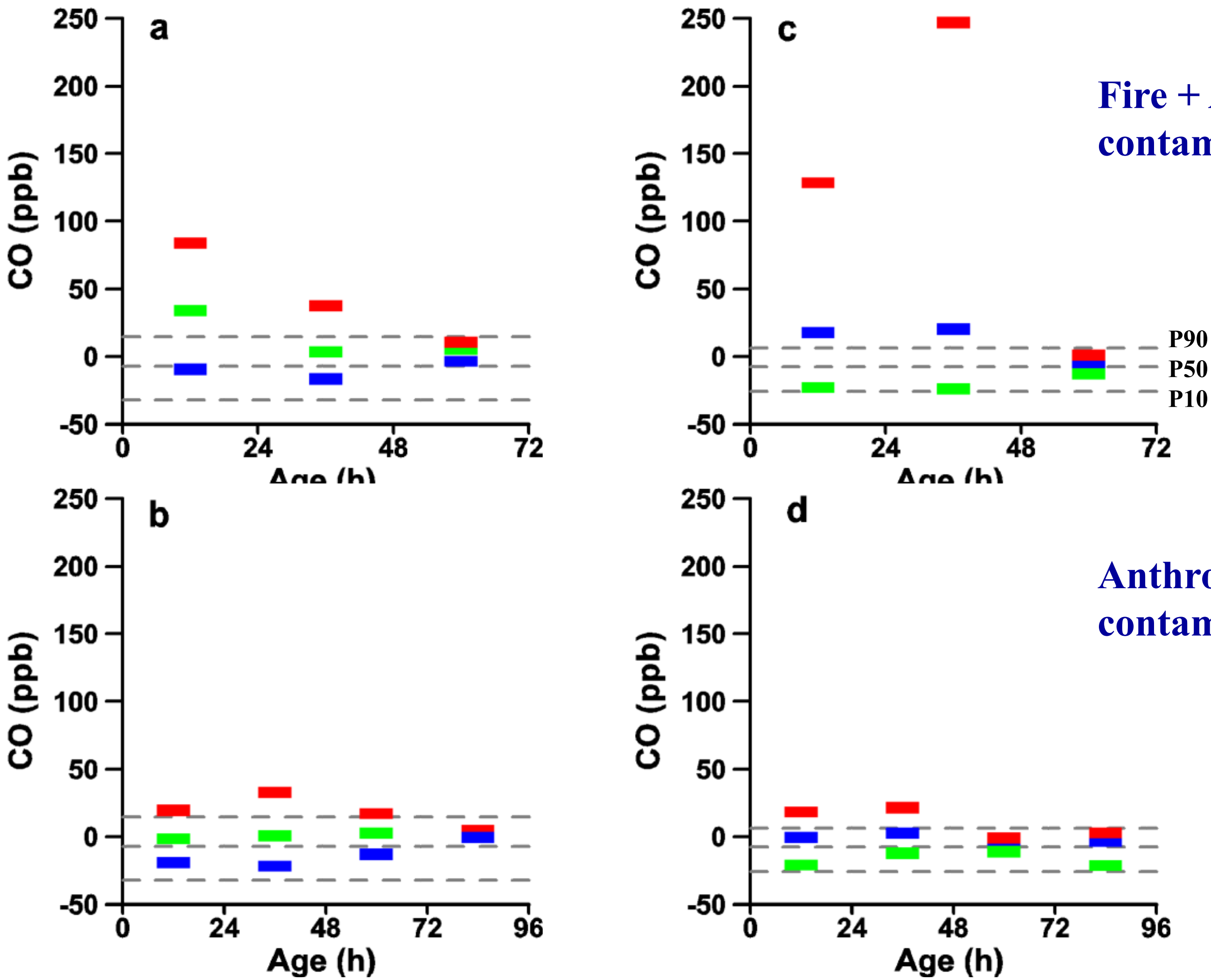




Region of wildfires (SWS)

Distribution of CO concentrations in different air masses

Summer 2007, weak fire activity **Spring 2008, strong fire activity**



Fire + Anthropogenic contaminated (a,c)

Anthropogenic contaminated (b,d)

Mean (±σ) and median synoptic CO fluctuations (ppb) at ZOTTO for 12-hour episodes of air transport from anthropogenic sources and wildfires (from Vasileva et al., 2011, JGR)

	Anthropogenic		
Time Period	Mean ± std (ppb)	Median (ppb)	N[a]
April–May 2007	2.5 ± 7.6	1.9	33
July–August 2007	2.5 ± 9.0	1.6	39
April–May 2008	0.7 ± 5.3	1.5	14

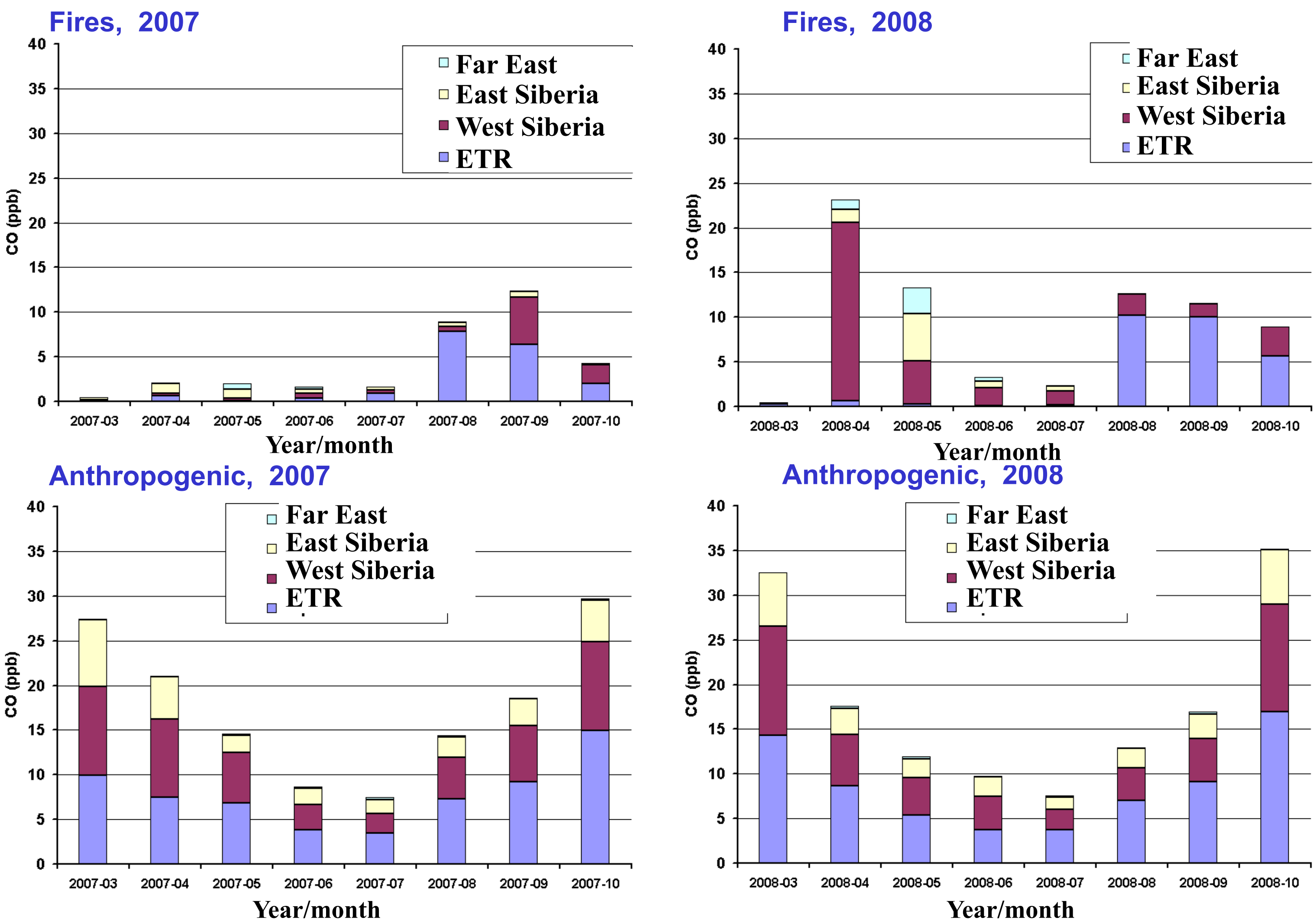
	Fires + Anthropogenic		
Time Period	Mean ± std (ppb)	Median (ppb)	N[a]
April–May 2007	6.1 ± 7.9	7.5	6
July–August 2007	43.4 ± 29.8	51.7	15
April–May 2008	39.9 ± 56.4	24.0	26

[a]Number of 12 h episodes.

Higher background CO in 2008 lead to lower CO relative increase in anthropogenic and wildfire plumes compared to that in 2007 warm season

Input of wildfire and anthropogenic emissions into observed ZOTTO near-surface CO (calculations with HYPACT)

Background CO:
In winter ~200 ppb
In summer ~100 ppb



Atmospheric spring time response to increase in wildfire CO emissions:

$$\Delta \mathrm{CO}_{\mathrm{fires}}^{(\mathrm{median,mean})} = \mathrm{CO}_{\mathrm{fires+anthrop.}}^{(\mathrm{median,mean})} - \mathrm{CO}_{\mathrm{anthrop.}}^{(\mathrm{median,mean})}$$

ΔE = EMIS_{2008}-EMIS_{2007}=5Tg CO (in south Siberia, spring)

Estimates	2007 ppb	2008 ppb	ΔCO ppb	ΔCO/ΔE ppb/Tg
ZOTTO obs., in plumes*	3.6	39.2	35.6	6.7
ZOTTO obs., seasonal	149.1	164.8	15.7	2.9
HYPACT**, seasonal	2.1	18.2	16.1	3.0

* For airmass age up to 2 days

** Numerical calculations with RAMS/HYPACT modeling system.

Publications

- Vasiljeva A.V., Moeseyenko K.B., Mayer J.-C., Jurgens N., Panov A., Heimann M., Andreae M.O. Assessment of the regional atmospheric impact of wildfire emissions based on CO observations at the ZOTTO tall tower station in central Siberia // J.Geophys. Res. 2011. 116. D07301.
- Vasiljeva A. Wildfires in Russia in 2000-2008: estimates of burnt areas using the satellite MODIS MCD45 data // Remote Sensing Letters. 2011. Vol.2(1). P.81–90.
- Васильева А.В., Моисеенко К.Б., Панкратова Н.В. Оценки эмиссий оксида углерода от природных пожаров в Северной Евразии в приложении к задачам регионального атмосферного переноса и климата // Изв. РАН. Физика атмосферы и океана. 2010. Т.46. №3. С.307–320.
- Васильева А.В., Моисеенко К.Б., Шумский Р.А., Скороход А.И. Идентификация антропогенных источников эмиссий окислов азота по расчётам Лагранжевых траекторий и данным наблюдений на высотной мачте в Сибири весной – летом 2007 г. // Изв. РАН. Физика атмосферы и океана. 2009. Т.45. №3. С.325-336.

THANKS FOR YOUR ATTENTION

Параметры расчетов среднесуточных приземных (39 м) концентраций CO с помощью моделей RAMS и HYPACT

Периоды: 1 янв – 31 дек 2007, 1 янв – 31 дек 2008.

Расчетная область: Северная Евразия, 40–90° с.ш., 20–180° в.д., сетка 120 х 120 км, 65 х 111 узлов, 40 уровней по вертикали от 0 до 20 км (из них 9 уровней ниже 1 км) в σ_z системе координат.

Входные данные:

Метеополя – данные реанализа NCAR FNL на сетке 1°x1° за 00:00 и 12:00 GMT,

Эмиссии CO – разработанная система усвоения данных EMIS3.

Расчеты:

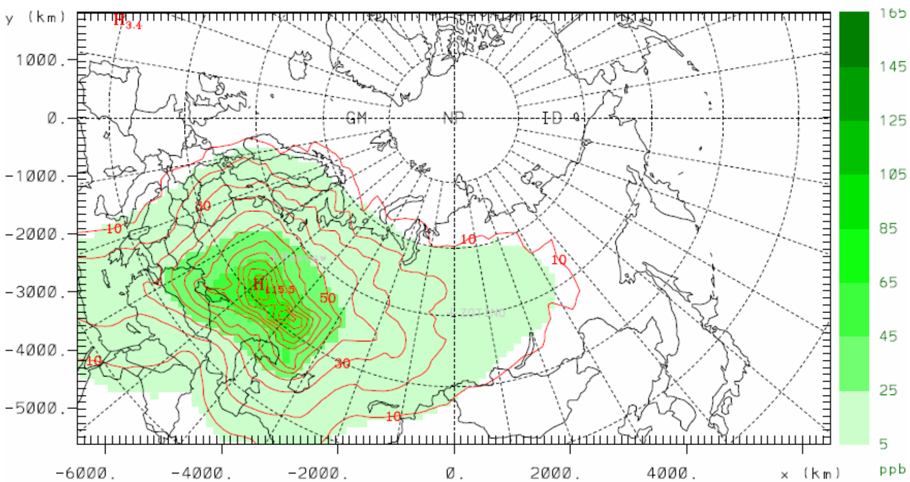
Метеополя, коэффициенты турбулентной диффузии – по модели RAMS в режиме 12-часового прогноза с выводом результатов каждые 3 часа.

Фотохимическое время жизни CO – из работы *Holloway et al*. (2000).

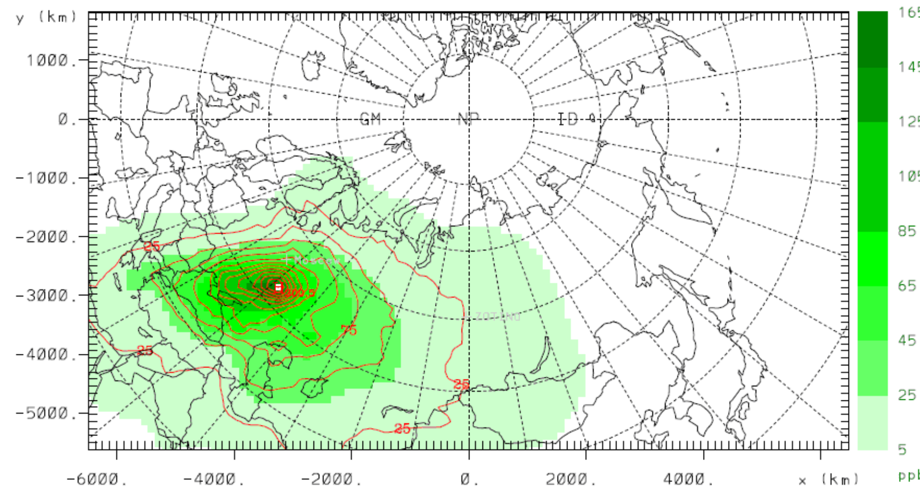
Среднесуточные приземные (39 м) концентрации CO – по модели HYPACT.

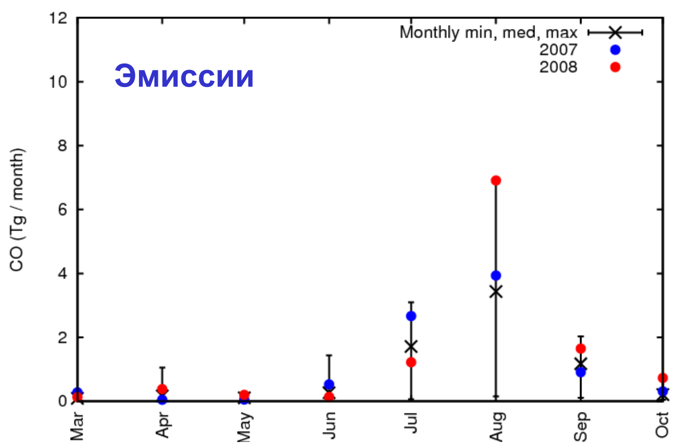
Эмиссии (MODIS) и приземные концентрации (HYPACT) СО от природных пожаров на юге ЕТР

Август 2007: CO_{mon} до 80 ppb, CO_{day} до 115 ppb.



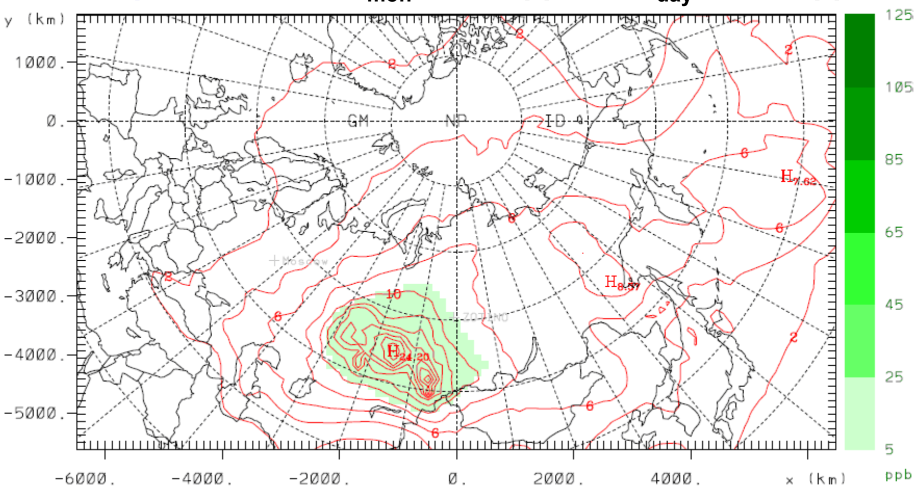
Август 2008: CO_{mon} до 170 ppb, CO_{day} до 300 ppb.



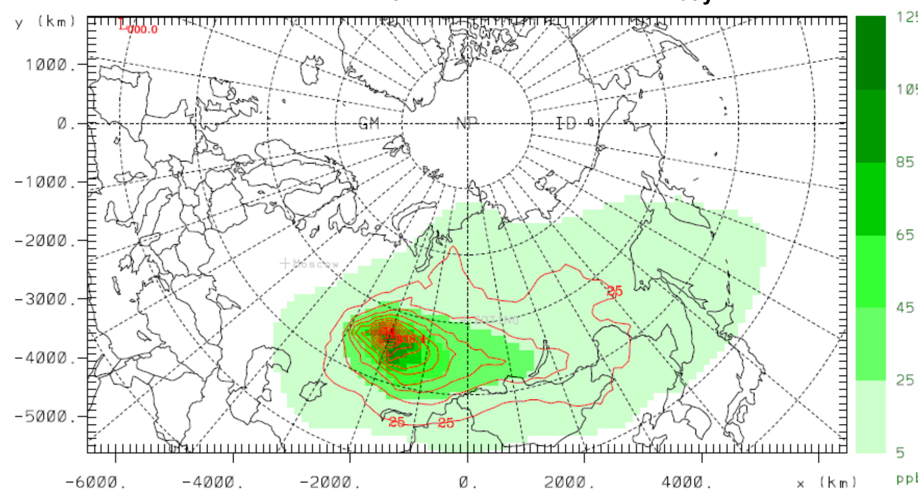


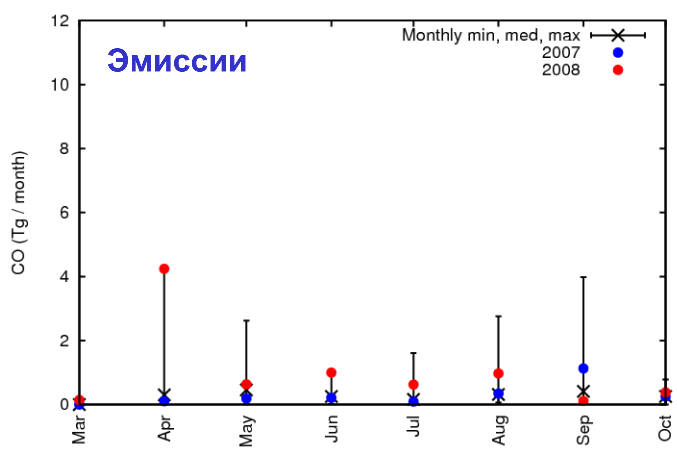
Эмиссии (MODIS) и приземные концентрации (HYPACT) CO от природных пожаров на юге Западной Сибири

Апрель 2007: CO_{mon} до 15 ppb, CO_{day} до 25 ppb.



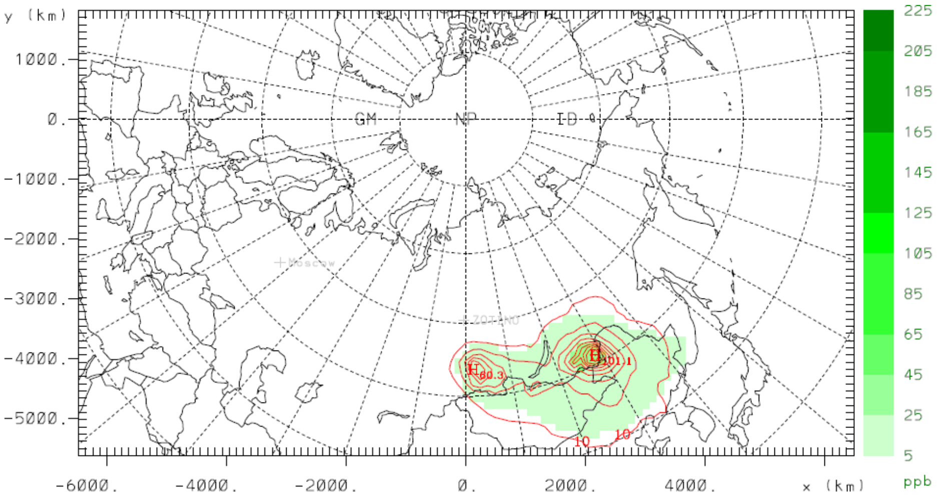
Апрель 2008: CO_{mon} до 120 ppb, CO_{day} до 340 ppb.



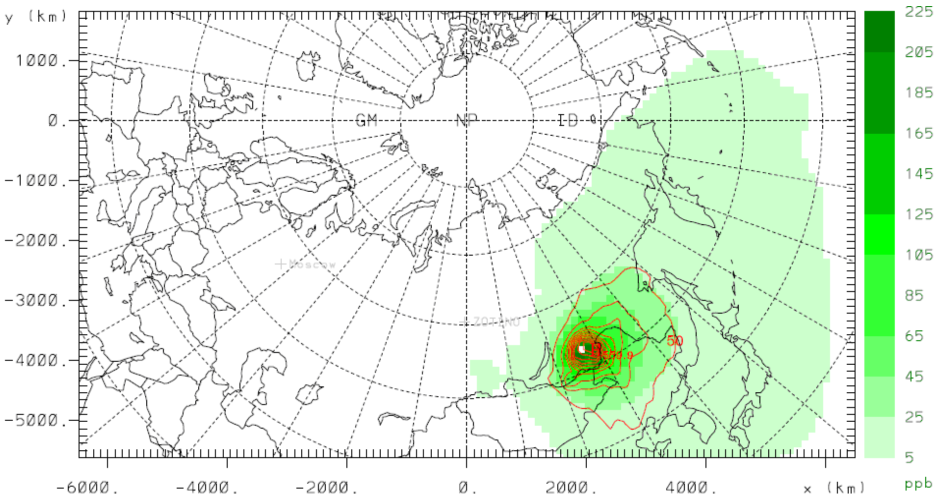


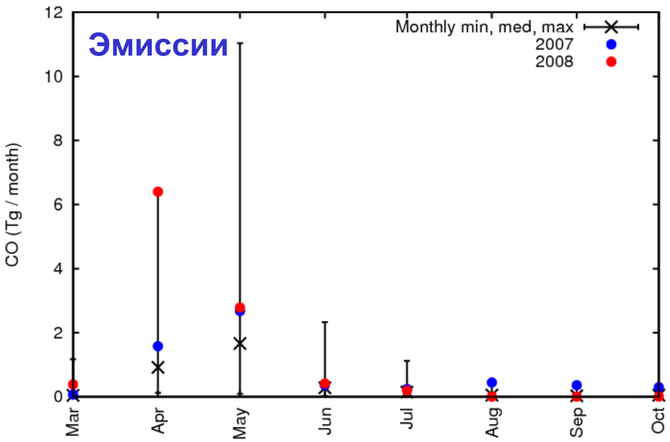
Эмиссии (MODIS) и приземные концентрации (HYPACT) CO от природных пожаров на юге Восточной Сибири

Апрель 2007: CO_{mon} до 40 ppb, CO_{day} до 100 ppb.

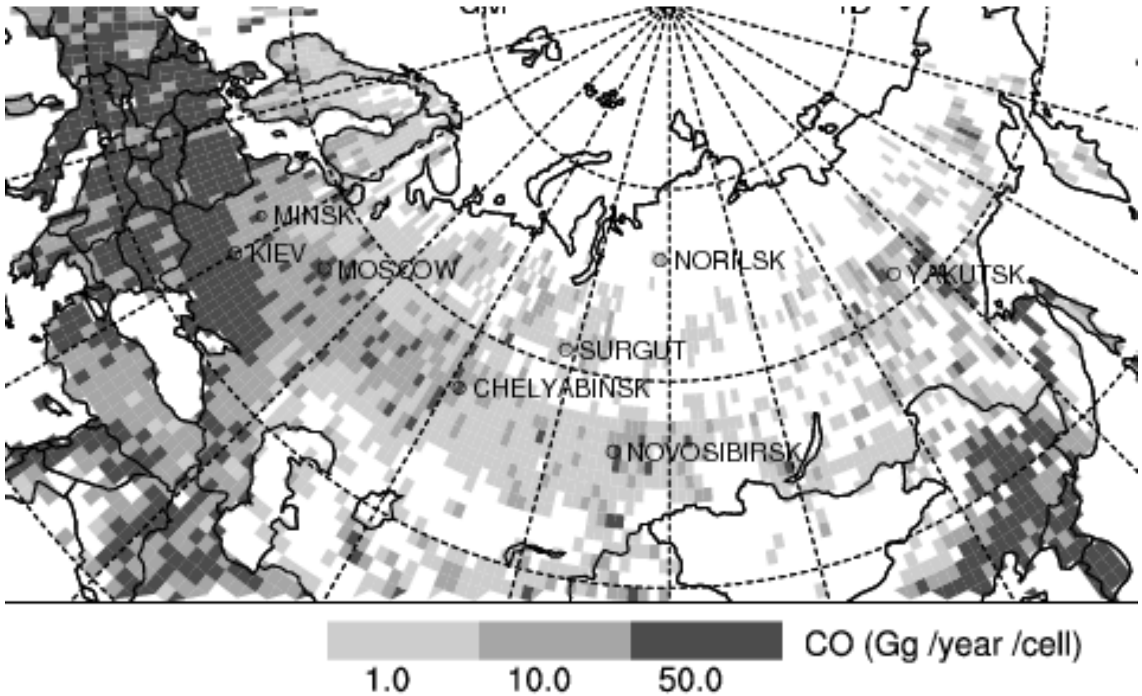


Апрель 2008: CO_{mon} до 225 ppb, CO_{day} до 560 ppb.





Оценки крупномасштабных эффектов от пожаров на фоне антропогенных источников

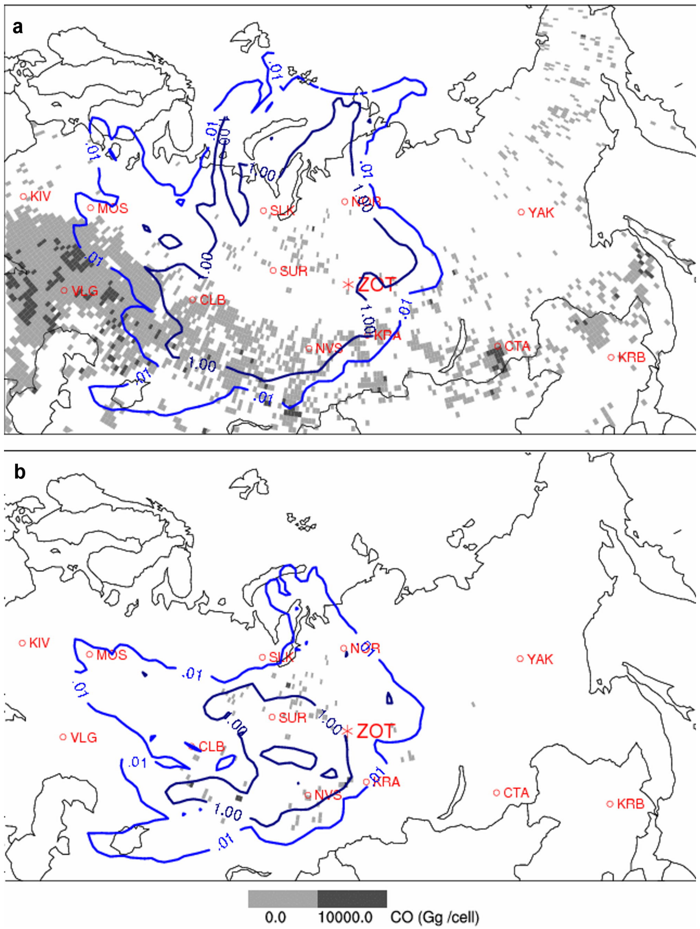


Антропогенные эмиссии CO по данным EDGAR-2000.

CO source contribution function (SCF) for ZOTTO

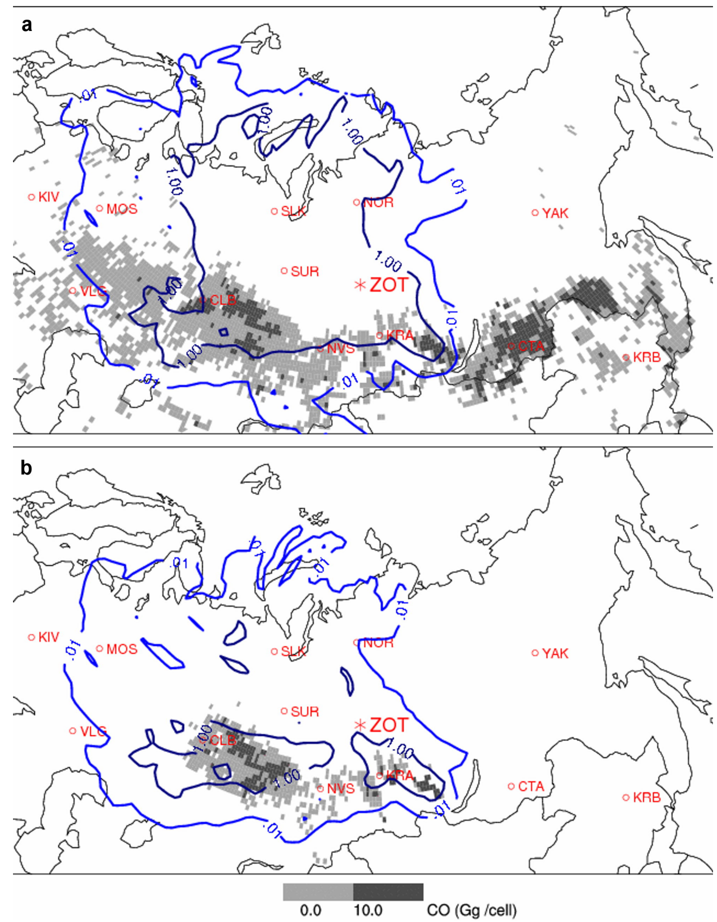
Weak fire activity

JUL-AUG 2007



Strong fire activity

APR-MAY 2008



Top: SCF and total wildfire CO emissions in summer 2007 (left) and spring 2008 (right).

Bottom: SCF for the upper quartile 12-hour CO and fire pixels crossed by backward trajectories.

Rationale: Wild land fires as a source of atmospheric emissions

√ Boreal forests in 45º – 70º N belt constitute 1/3 of the total forest area on the planet, with carbon storage in vegetation and soil constituting 10 – 17 % of the planetary budget.

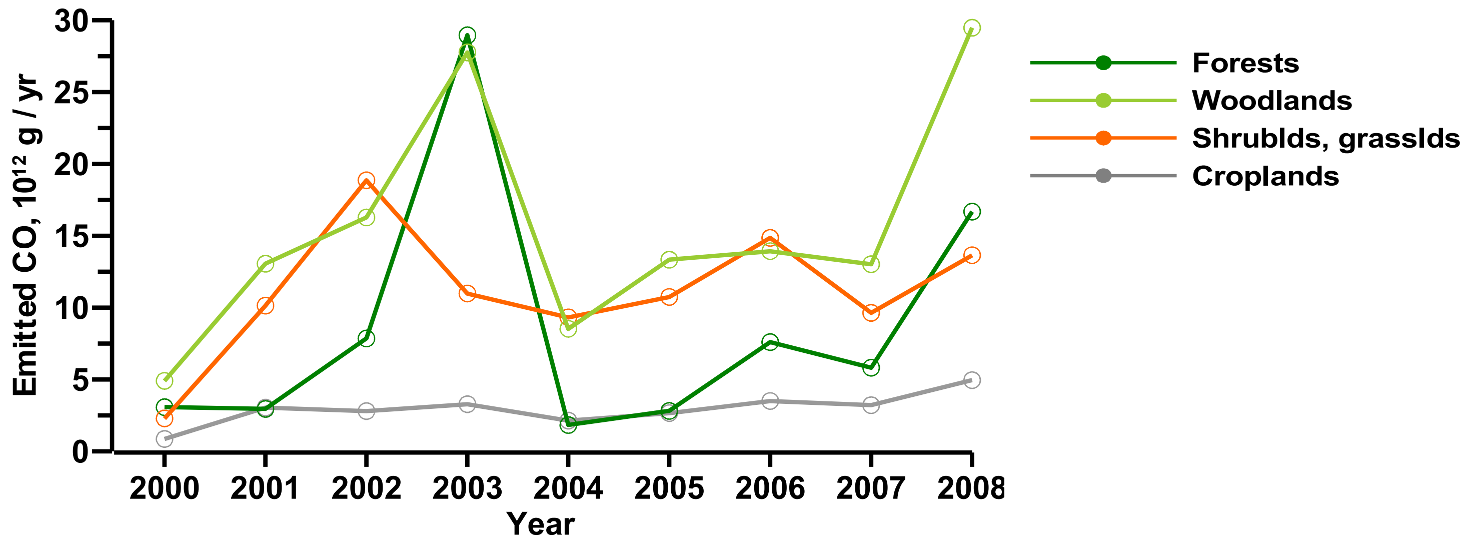
√ Russian boreal forests contribute 22% to the overall forest area on the planet;

√ Boreal forest fires contribute 4 – 12% to the global biomass burnt annually, with emissions of soot and organic aerosols in individual years contribute up to 9% and 20% respectively, and of non-organic carbon (mainly as CO and CO2) – up to 20% of annual global emissions.

√ Large fires (>200 ga) play important role

√ Climatic temperature rise → prediction of increase in wildfire intensity → increase in number of severe pollution events and ecological hazards

Annual total CO emissions due to wildfires in Russia



- Total CO emissions from wildfires are from 7–43 Tg/year which is about 20–120% of anthropogenic CO emissions
- Fires in forests and woodlands are from 5–35 Tg/year and consist 15–50% of all wildfire emissions.