Remote Sensing of Fire Intensity and Burn Severity in Forests of Central Siberia

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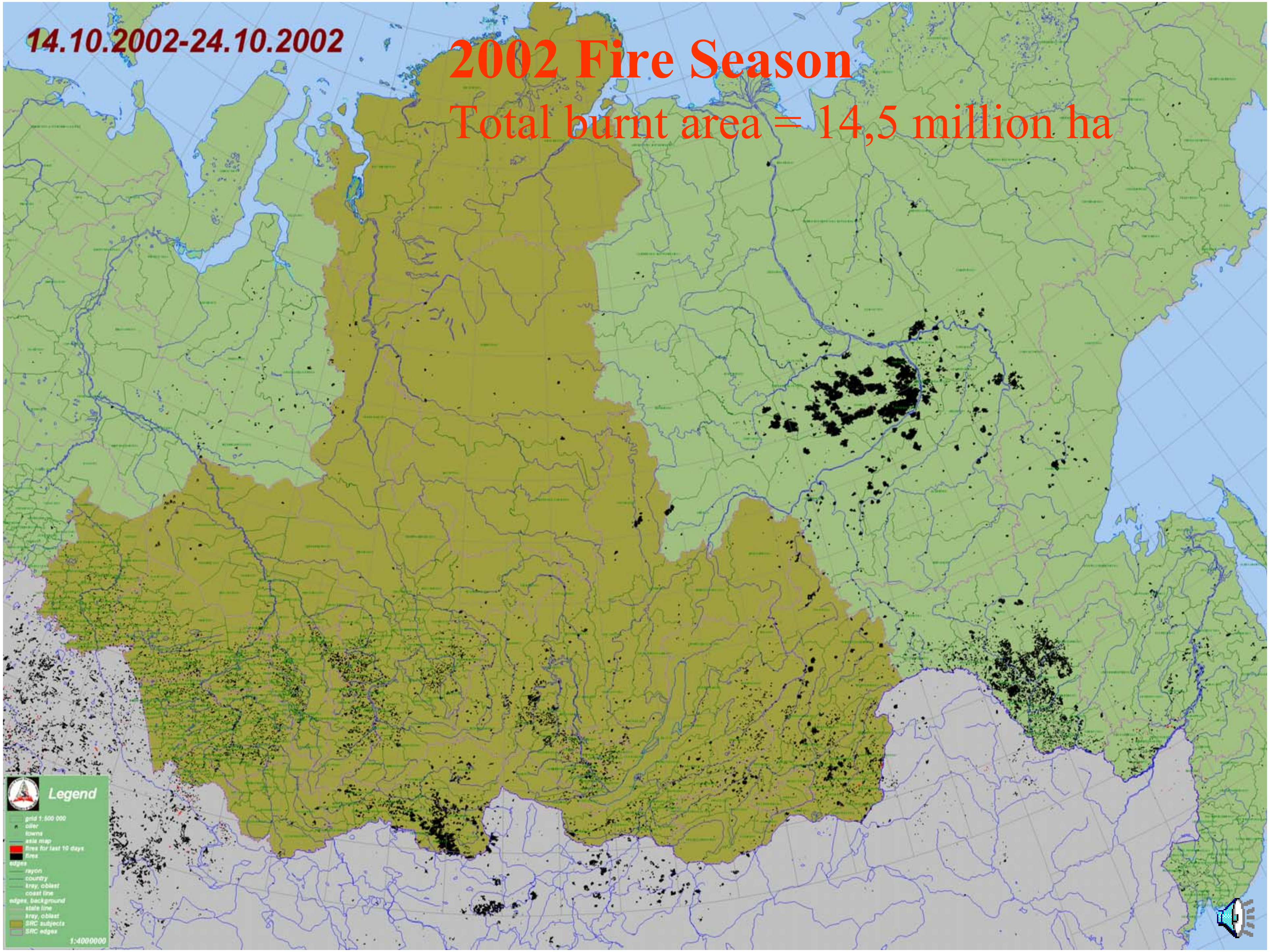
Smoke area over Yakutia (14.08.2002)

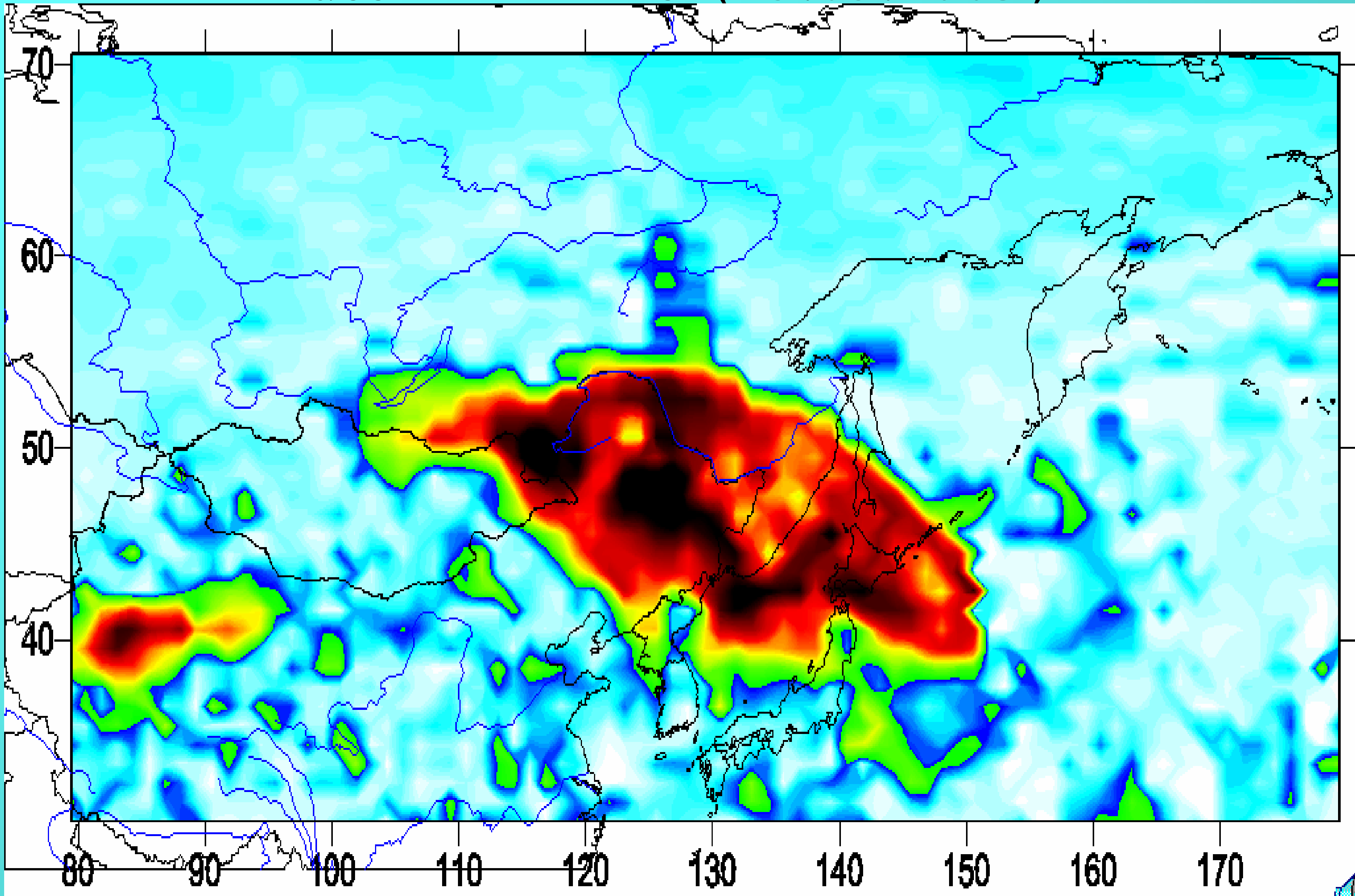
Fire activity in Yakutia during the 2002 fire season as depicted by NOAA AVHRR (14 August 2002).

2002 Fire Season

Total burnt area = 14,5 million ha

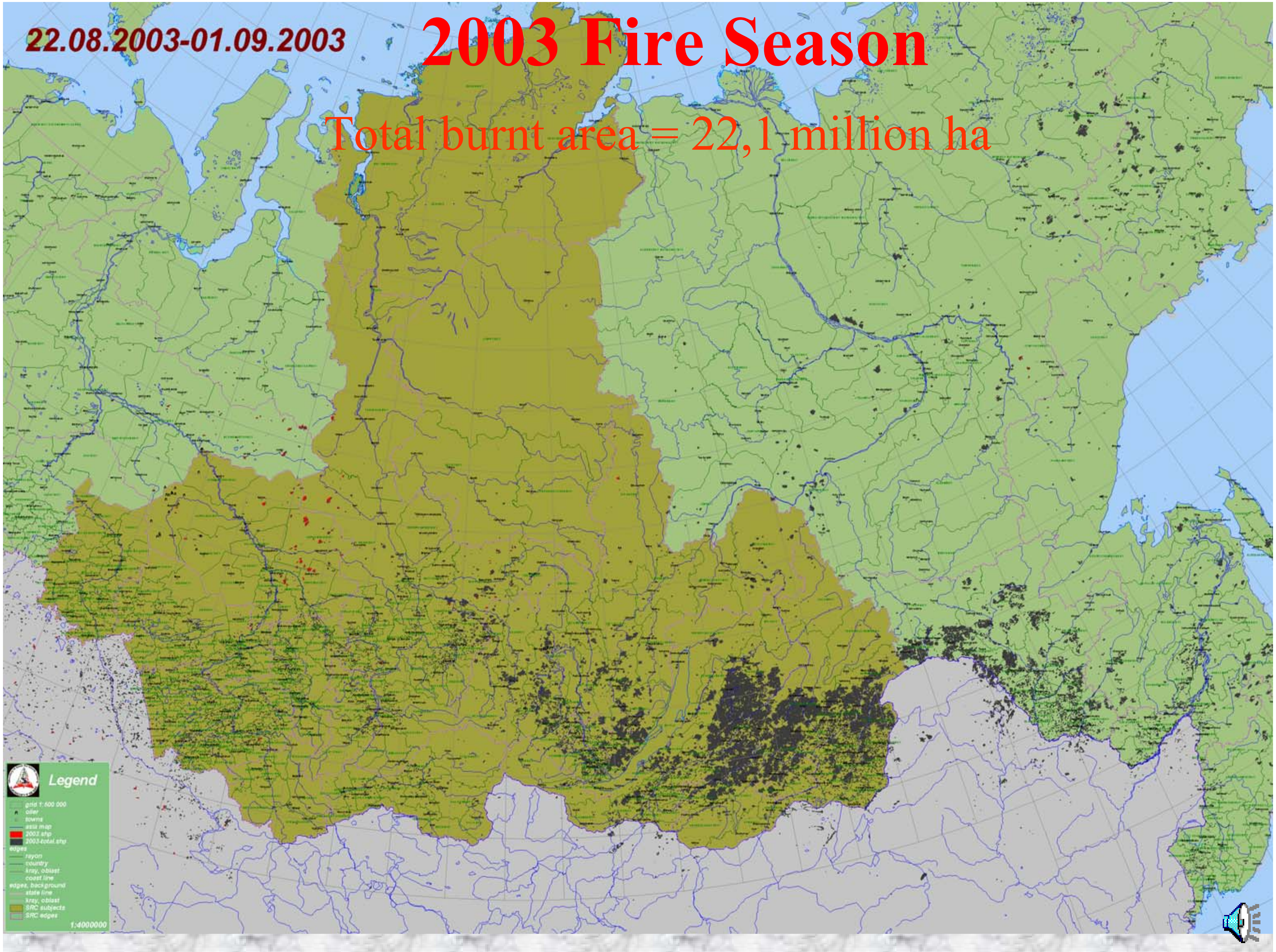


TOMS Aerosol Index Distribution over Russian Far East (15.05.2003)

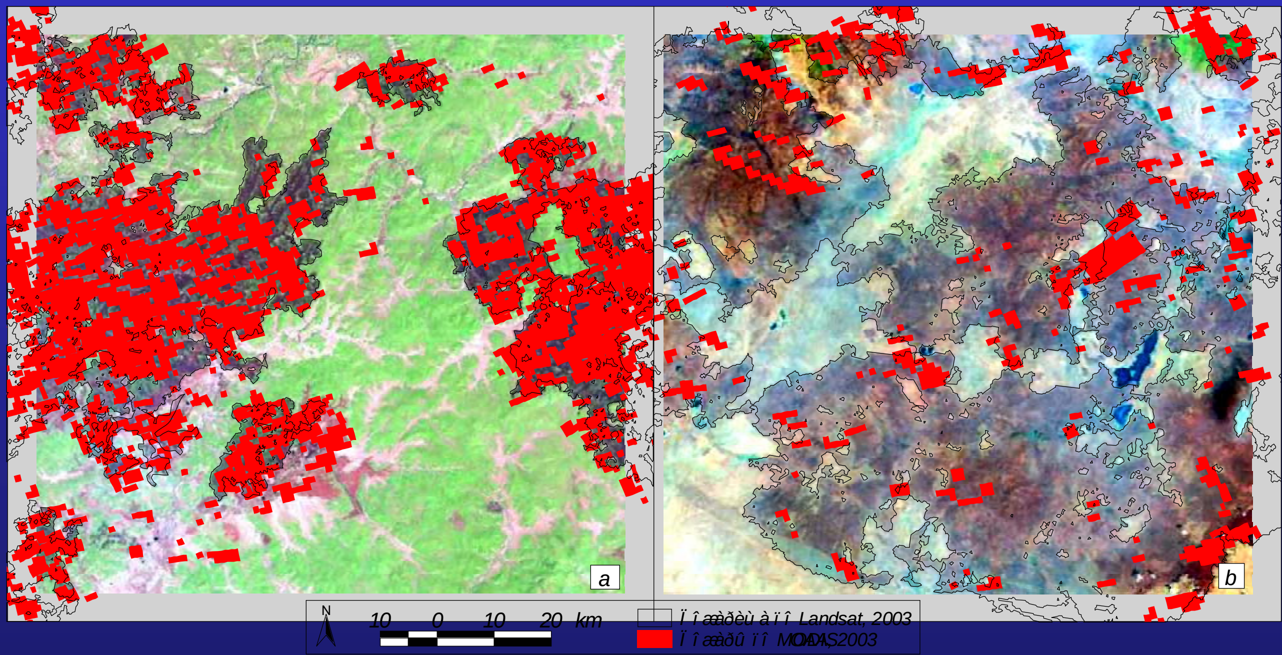


2003 Fire Season

Total burnt area = 22,1 million ha



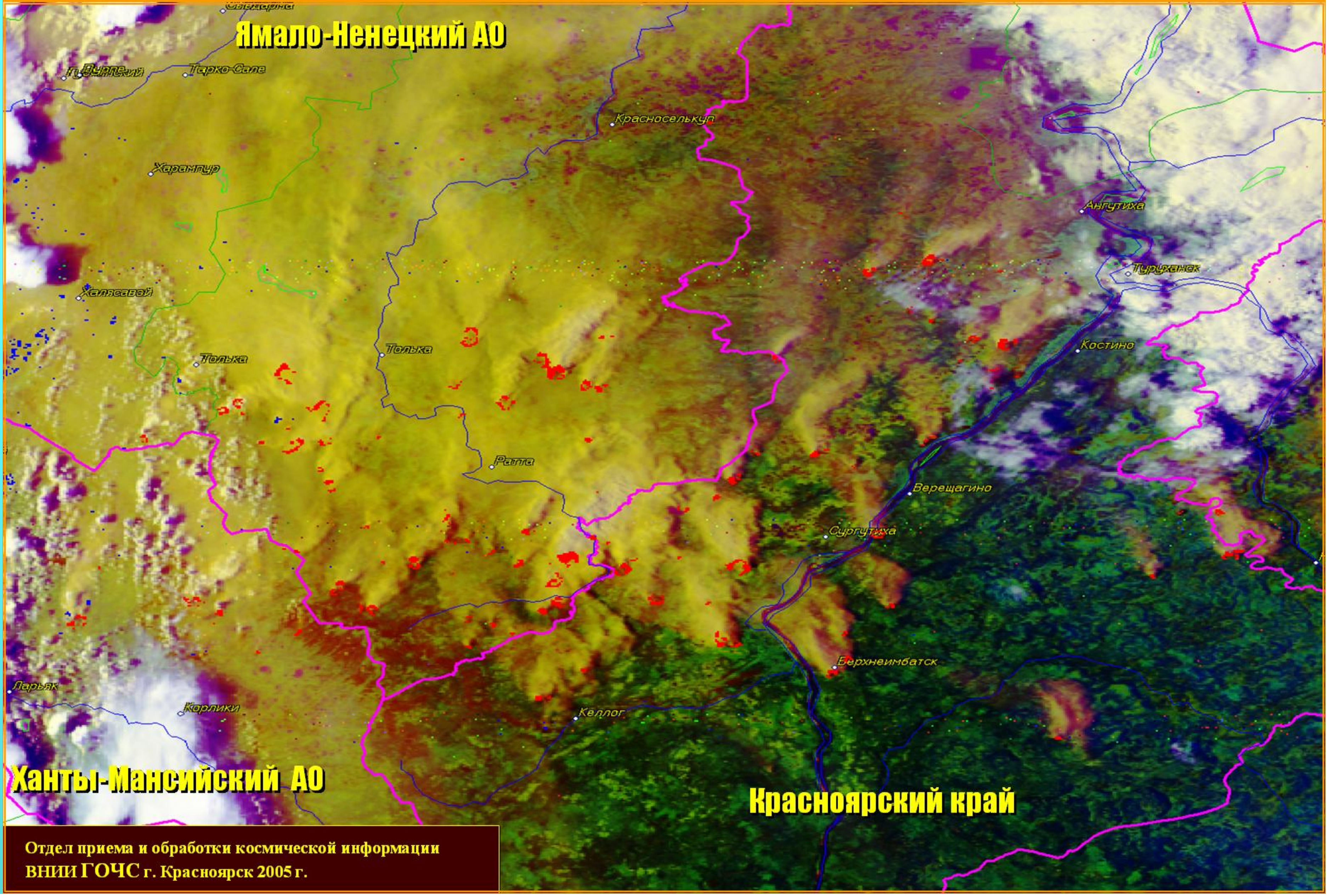
Verification of MODIS information by Landsat ETM+ for (a) forest, (b) forest step territory



(a) *Landsat = 1.02*MODIS – 601,* *(R^2=0.91)*

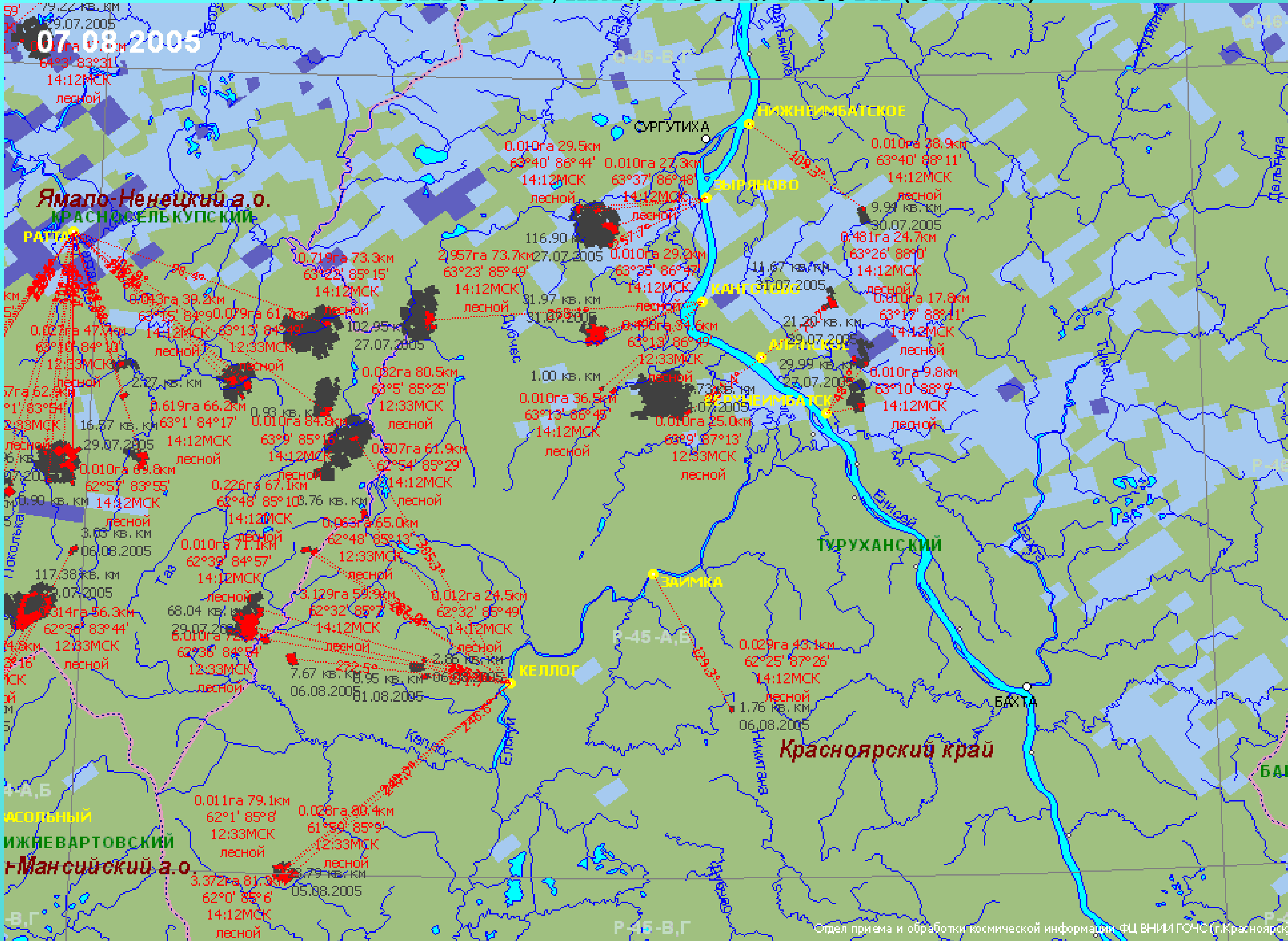
(b) *Landsat = 8.62*MODIS – 5986,* *(R^2=0.84)*

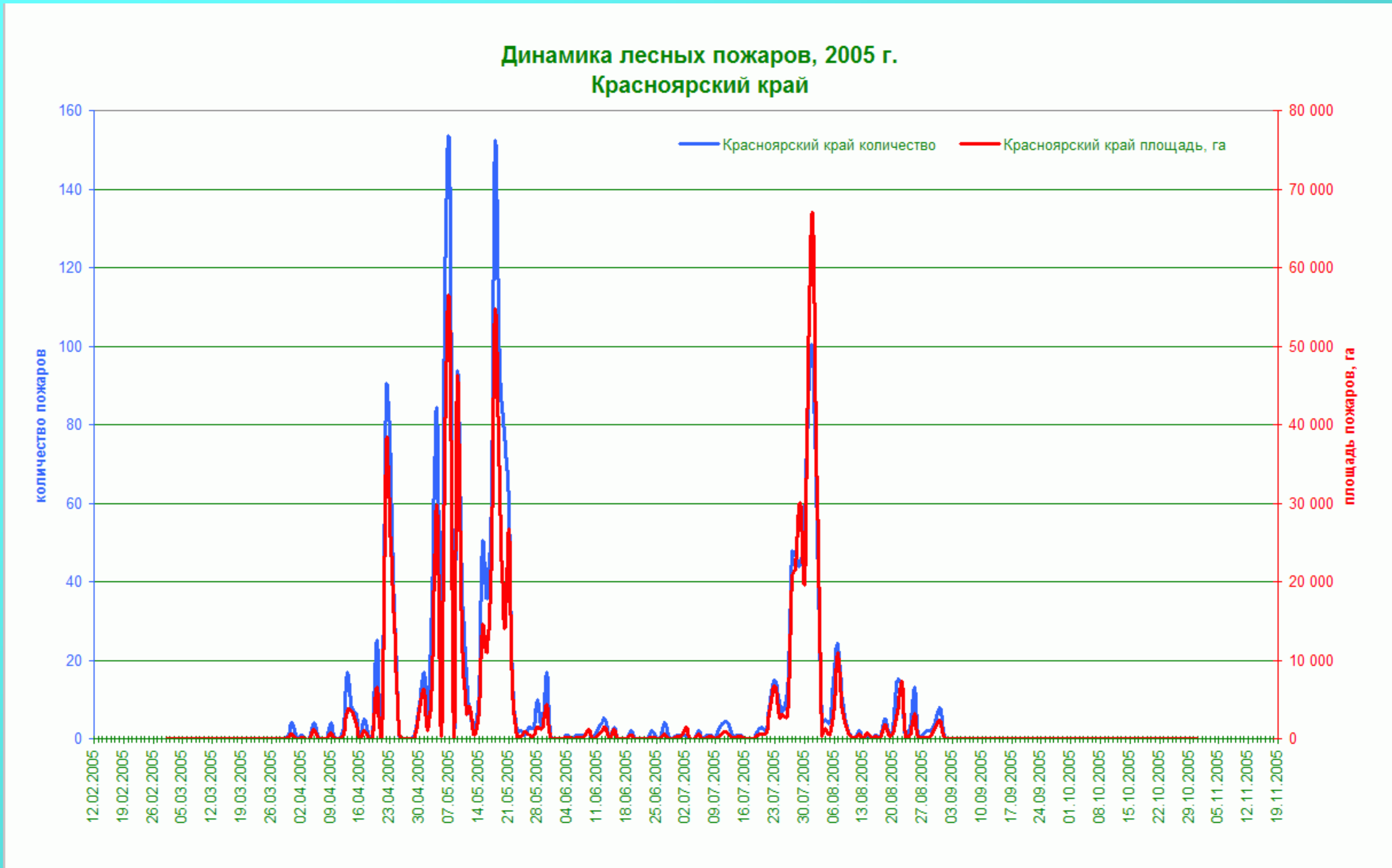
Очаги пожаров с дымовыми шлейфами в Красноярском крае, Ямало-Ненецком А.О. и Ханты-Мансийском АО
Спутник NOAA-12 13:20 МСК 01.08.2005



Отдел приема и обработки космической информации
ВНИИ ГОЧС г. Красноярск 2005 г.

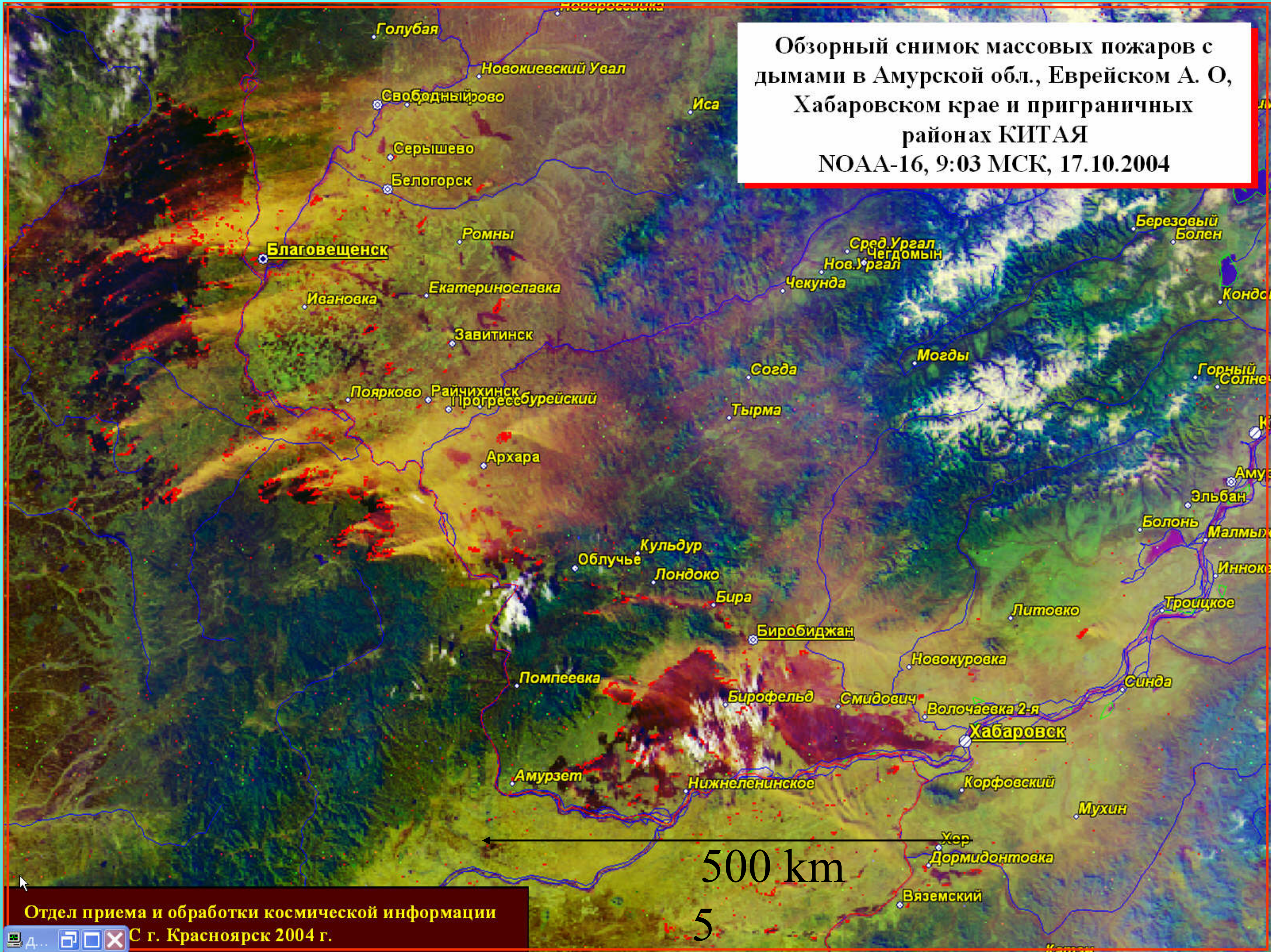
Картосхема распределения лесных пожаров в Красноярском крае за 07.08.05 М=1:500000 (Р-45-А,Б) с указанием ближайшего населенного пункта и облачности (синий)





Динамика лесных пожаров, 2005 г.
Красноярский край
Красноярский край количество
Красноярский край площадь, га
количество пожаров
площадь пожаров, га
0
20
40
60
80
100
120
140
160
0
10 000
20 000
30 000
40 000
50 000
60 000
70 000
80 000
12.02.2005
19.02.2005
26.02.2005
05.03.2005
12.03.2005
19.03.2005
26.03.2005
02.04.2005
09.04.2005
16.04.2005
23.04.2005
30.04.2005
07.05.2005
14.05.2005
21.05.2005
28.05.2005
04.06.2005
11.06.2005
18.06.2005
25.06.2005
02.07.2005
09.07.2005
16.07.2005
23.07.2005
30.07.2005
06.08.2005
13.08.2005
20.08.2005
27.08.2005
03.09.2005
10.09.2005
17.09.2005
24.09.2005
01.10.2005
08.10.2005
15.10.2005
22.10.2005
29.10.2005
05.11.2005
12.11.2005
19.11.2005

Fires in China, Amur, Khabarovsk territory 17 October 2004



5

0

Trace gas emission model (the 1st approach)

$$E=A_o*Bfa*\beta, \quad (1)$$

where

E - emissions (kg)

A_o- burned area (m^2)

Bfa - fuel loading potential (kg/m^2)

β - fuel consumption coefficient.

(*Seiler and Crutzen, Erick Kasischke and Nancy French et al)*

Or using thermal image:

$$\mathbf{E= N*\Sigma_{ij} \{Bfa*\beta(w)\}|_{ij}} ,$$

Where N - total amount of pixels, i – pixel number, j – fuel type,

w – fuel moisture content, depended of weather conditions

$$\varepsilon \;=(Bfa*\beta/\tau_o)*Q, \quad (2)$$

where

ε **-** energy release ($J/m^2*s = w/m^2$)

τ_o , sec - time of the fuel consumption and combustion (residence time)

Q – heat of combustion (J/kg)

We know that for moderate fire intensity the total energy release is:

$$\varepsilon = Radiation\ (40\%) + Convection\ (50\%) + Conduction\ (10\%) \qquad (3)$$

Radiation=0.4ε, from our fire behavior model,

So:

$$\varepsilon \approx 2.5\ Radiative\ flux = 2.5 \int_o \varepsilon \sigma T^4 dA$$

T – flame temperature (ºK), ε – coefficient of radiance, (σ) – Stefan- Boltzmann const

Total rate of emission of radiative energy from the fire can be presented by the relationship between the emitted energy and the detected temperature difference in the 4 μm channel MODIS (*Yoram Kaufman and Chris Justice,1998*)

$$E_f = 4.34 \cdot 10^{-19} (T_4^8 - T_{4b}^8) \qquad \text{(MWatt per pixel)}$$

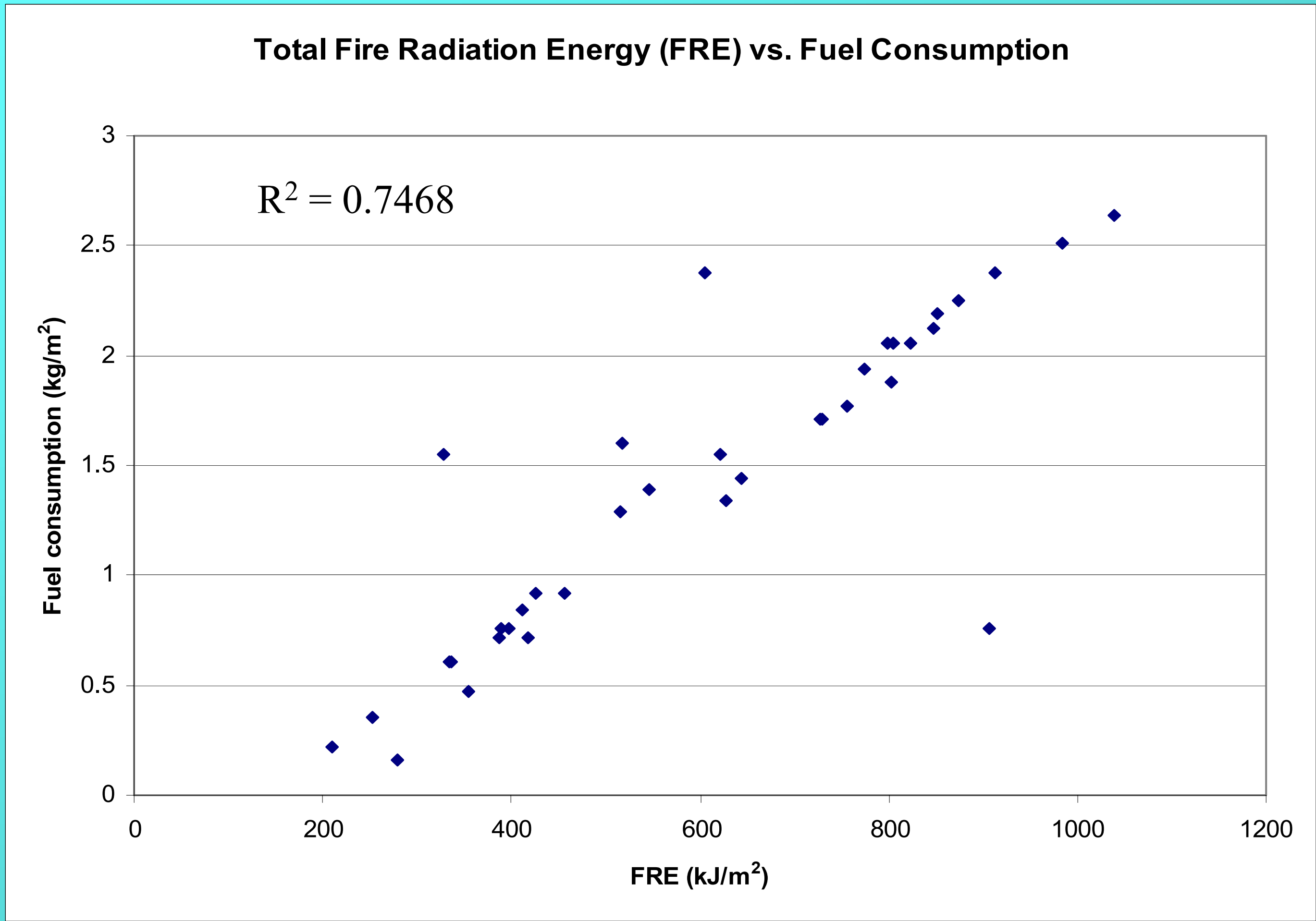
So:

$$Bfa \cdot \beta = ((2.5 \int_{Ao} \varepsilon \sigma T^4 dA)/Q)) \cdot \tau_o \qquad (4)$$

We know that $\tau_o \approx$ 60-:-300 sec, is approximately constant and depends primarily on the fuel size *(d $_{fuel\ particle}$ – equivalent particle diameter)* and *Q≈4500 cal/g* is almost constant for the different forest fuels.

So, for calculating of *E* we need to know A_o ,T, Q, τ_o *using thermal image* :

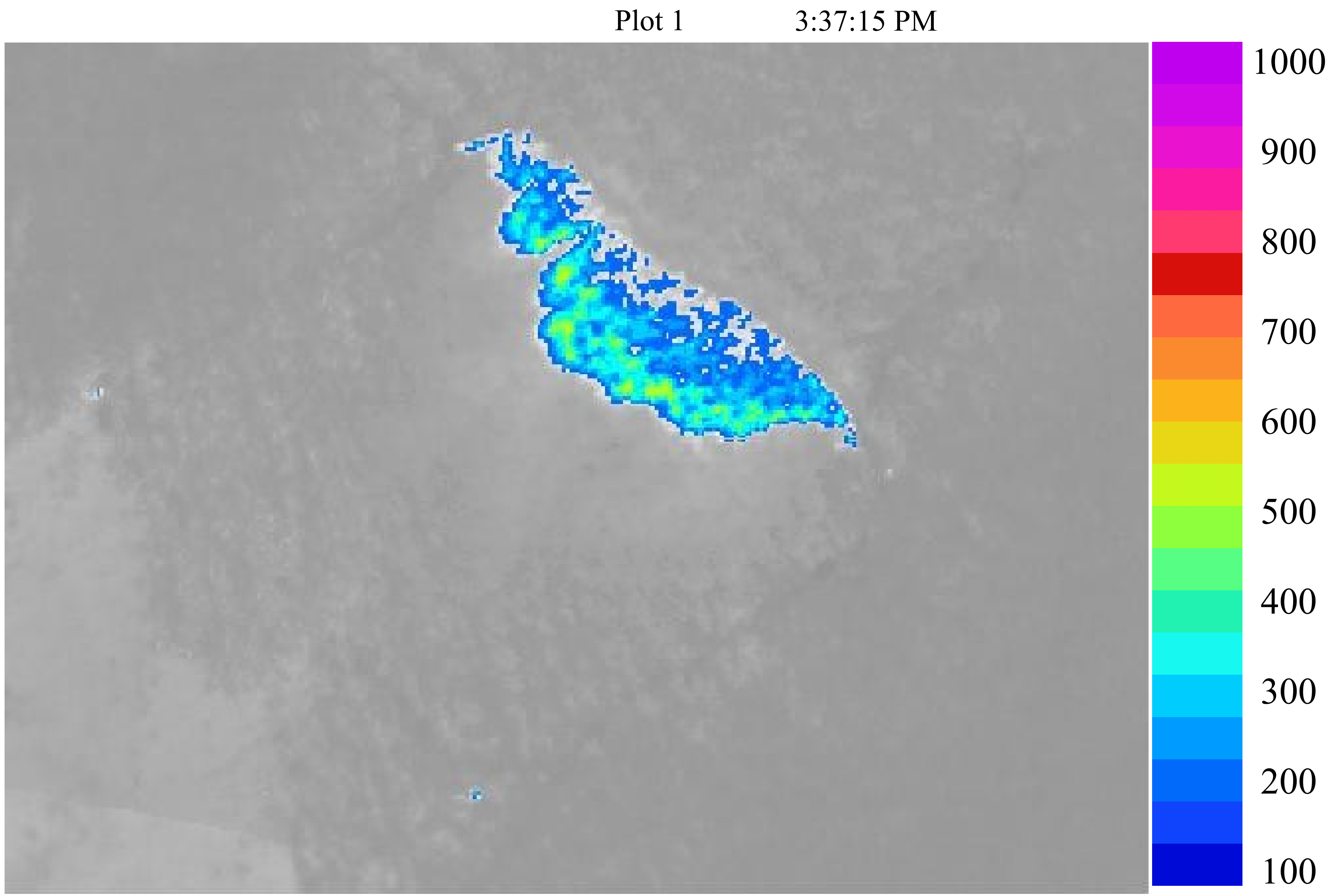
$$E = A_o \cdot ((2.5 \int_{Ao} \varepsilon \sigma T^4 dA)/Q)) \cdot \tau_o \qquad (5)$$


Total Fire Radiation Energy (FRE) vs. Fuel Consumption
R2 = 0.7468
Fuel consumption (kg/m2)
FRE (kJ/m2)
0
0.5
1
1.5
2
2.5
3
0
200
400
600
800
1000
1200

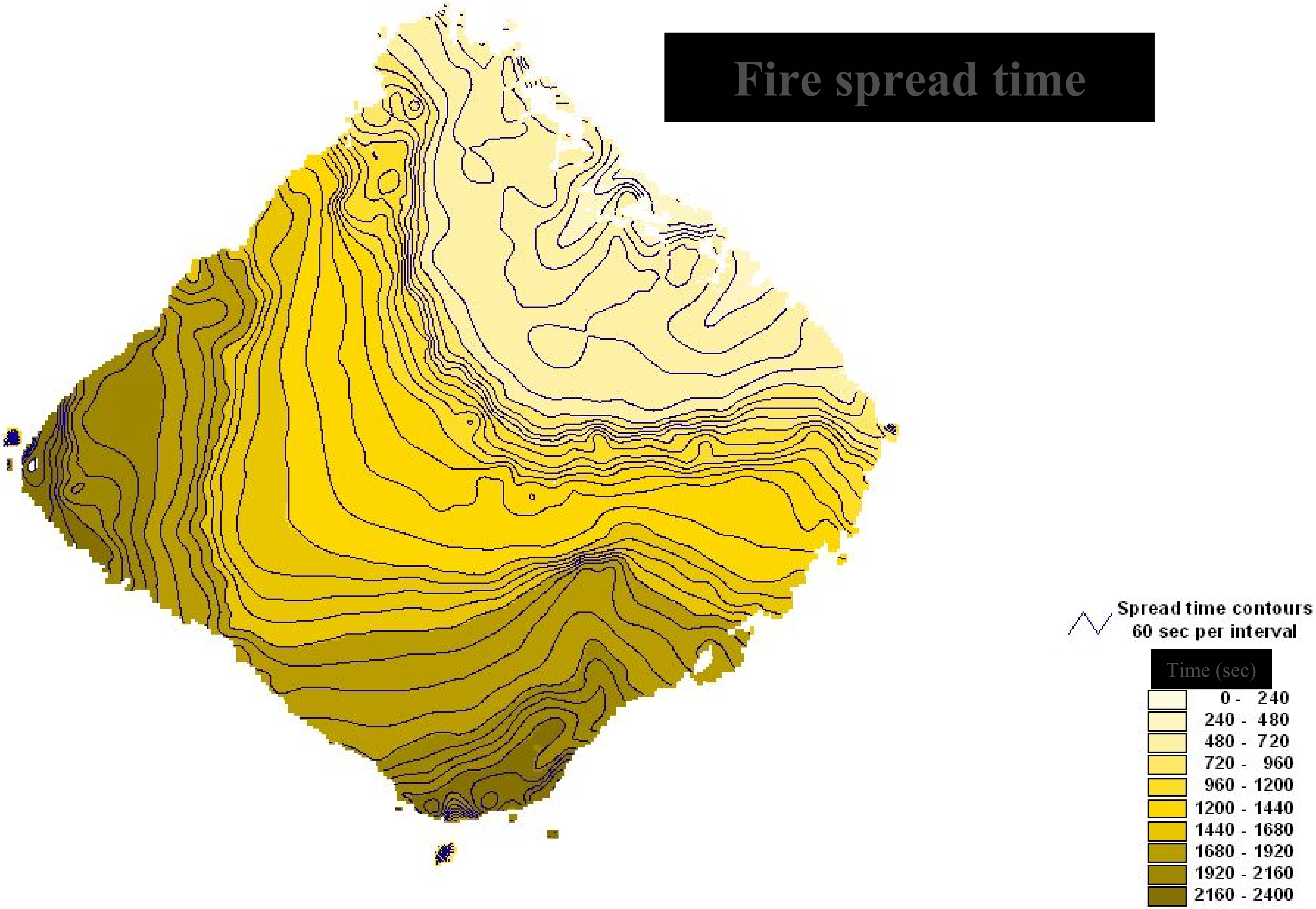
Infrared FLIR ThermCam P695 camera used for fire monitoring


FLIR
SYSTEMS

Boguchany, Russia, 18 June 2002

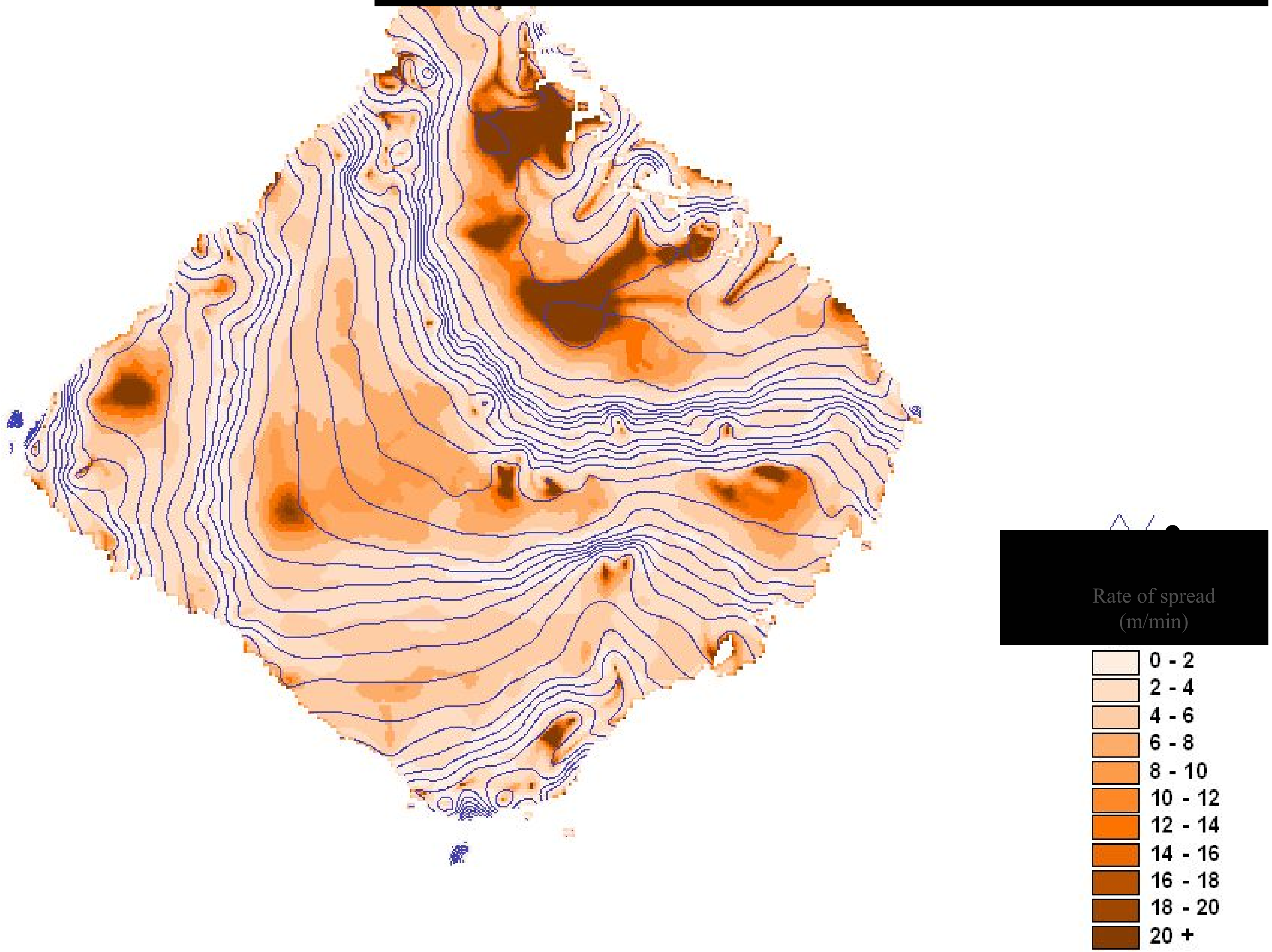


Spread time, sec. plot 1, Boguchany, Russia
June 18, 2002

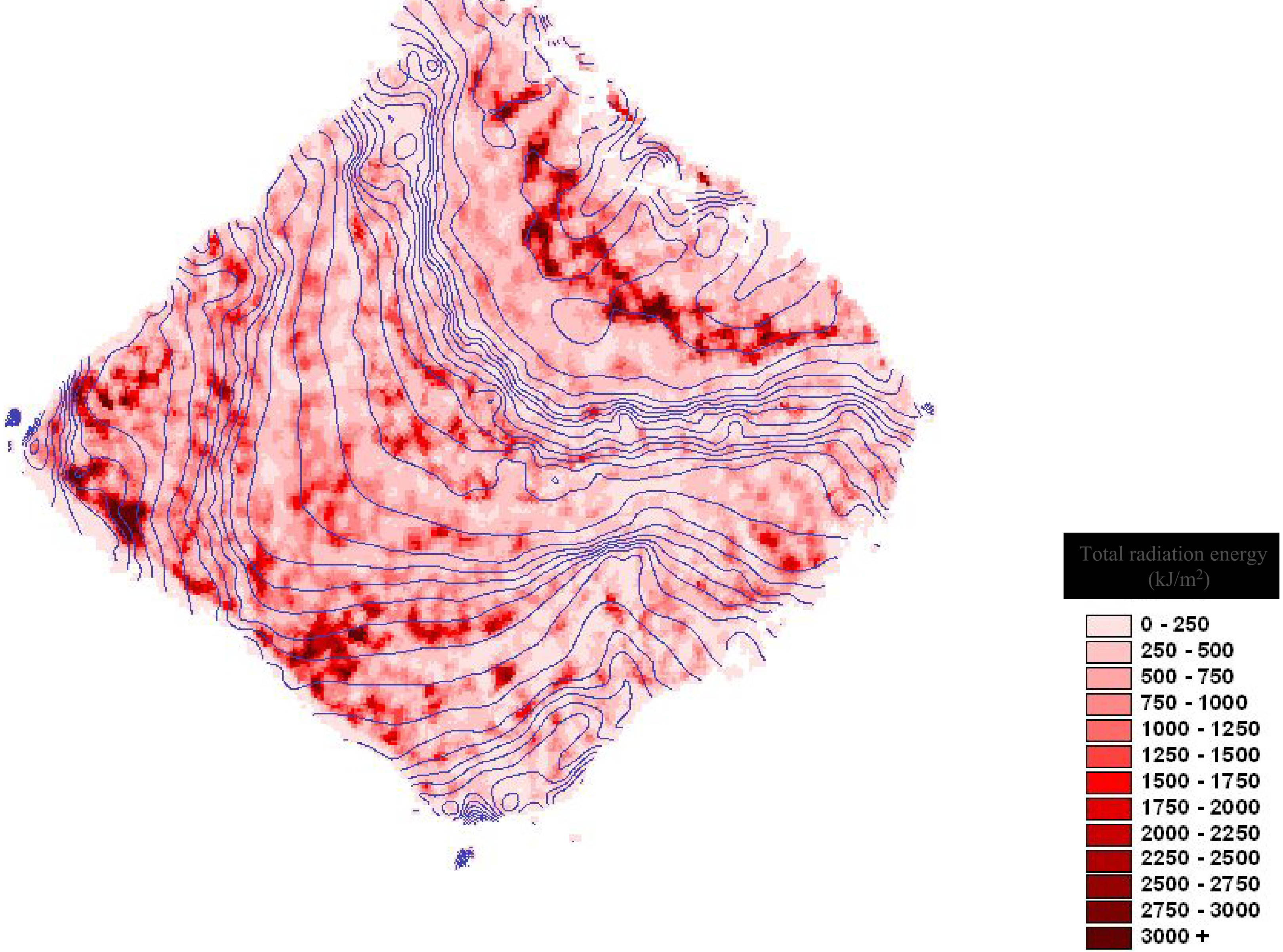


ROS (m/min.), plot 1, Boguchany, Russia
June 18, 2002

Rate of spread

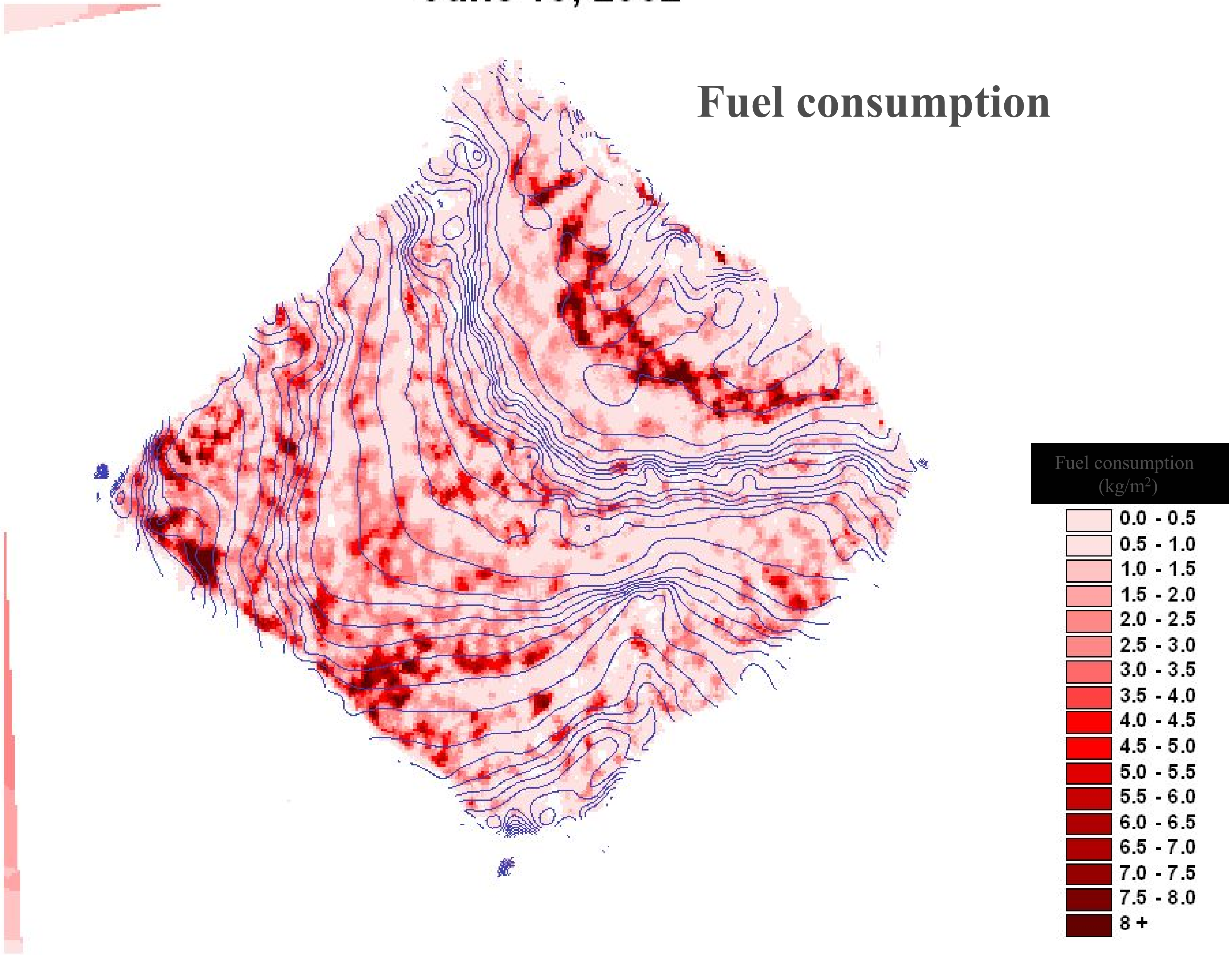


Total fire radiation energy

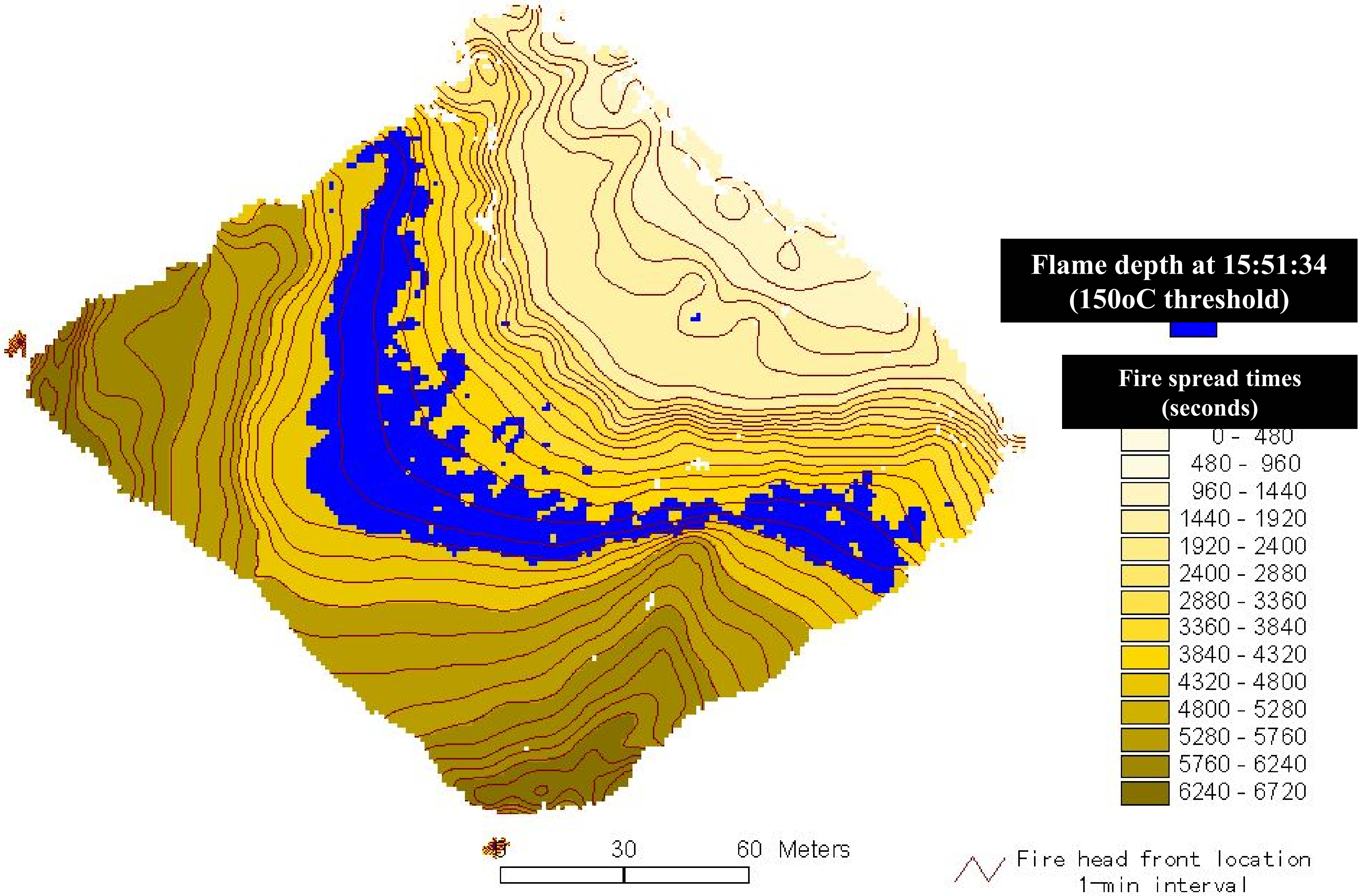


Fuel consumption (kg/m2), plot 1, Boguchany, Russia
June 18, 2002

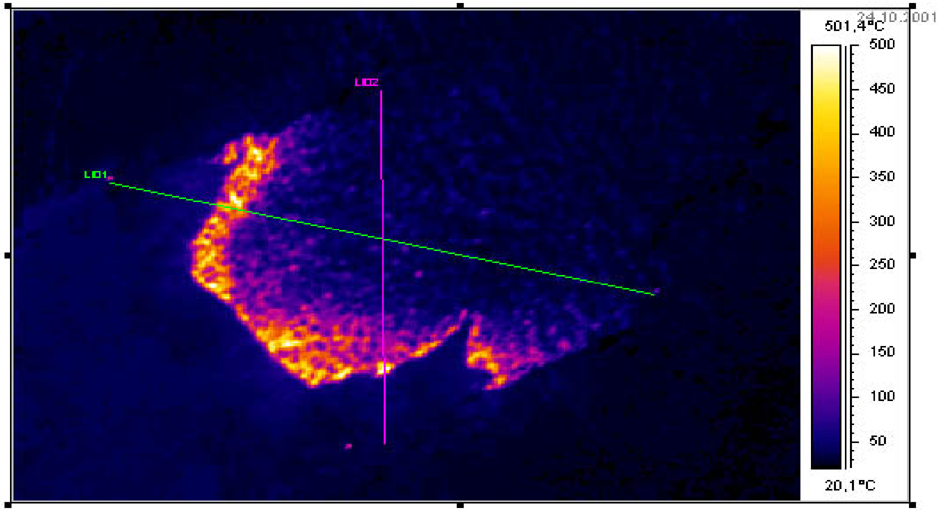
Fuel consumption



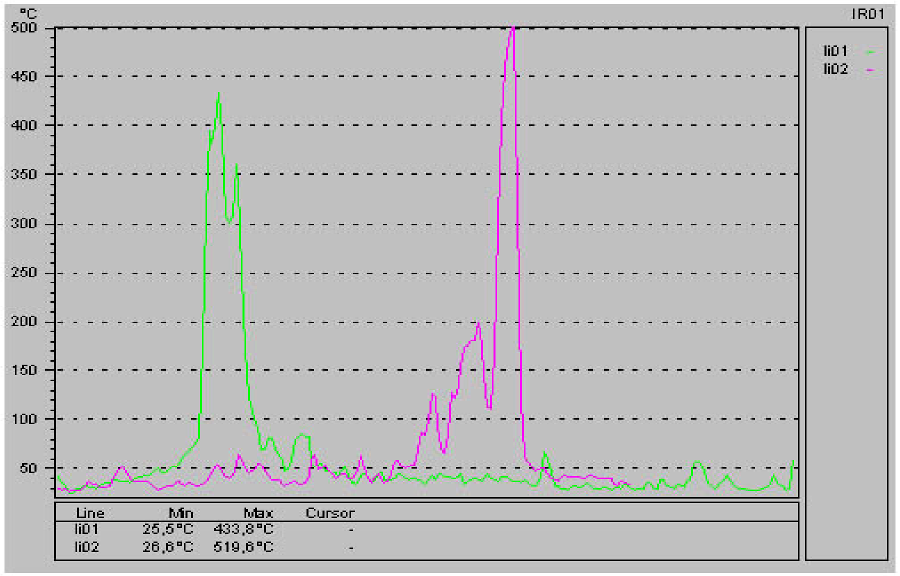
Infrared data analysis



High-intensity fire front, Test Plot 1, Boguchany (18.06.2002)



Line 01 length 210 m, line 02 length 160 m



File name	Time	Date
C0618-36.img	14:58:34	18.06.2002

Fire intensity

According to Byram, fire intensity (*I*) is:

$$I = Bfa*\beta*U*Q, \qquad (6)$$

I – fire intensity,

where $Bfa*\beta$ - fuel consumption, U – fire line spread rate, Q – heat of combustion.

So,

$$\varepsilon_{energy\ release} = I/X_o \qquad (7)$$

(see fig.1 and the formula 2, 6, ***and*** $U=X_o/\tau_o$)

and $\varepsilon=(Bfa*\beta/\tau_o)*Q*(X_o/X_o) = I/X_o$,

but $\varepsilon = 2.5Radiative_{flux}=2.5\int_{Ao}\varepsilon\sigma T^4dA$,

$$I= 2.5 *X_o * \int_{Ao}\varepsilon\sigma T^4dA =Bfa*\beta*U*Q \qquad (8)$$

and

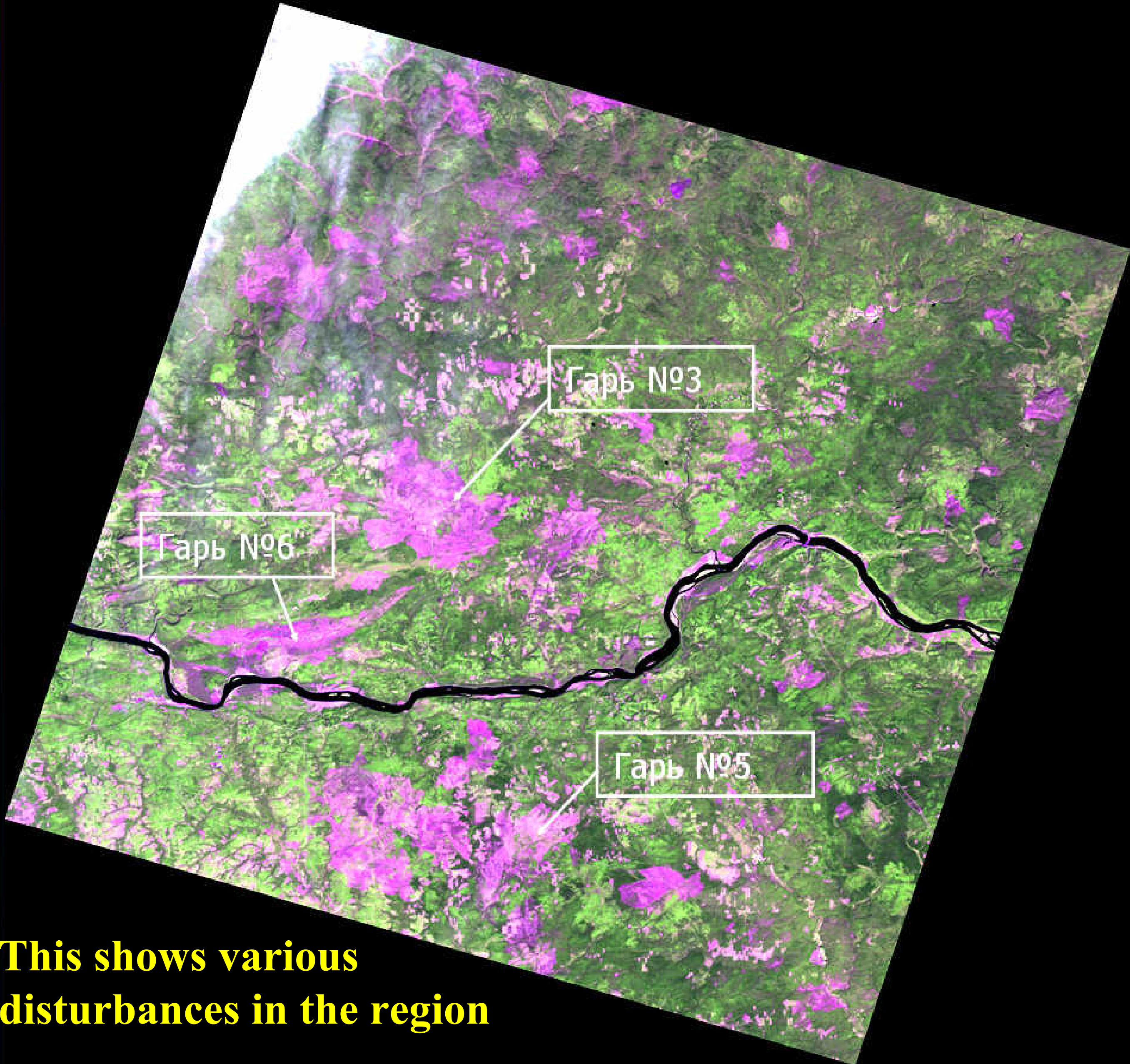
$$Bfa*\beta = I/(U*Q) =2.5 *X_o * \int_{Ao}\varepsilon\sigma T^4dA /(U*Q) \qquad (9)$$

Fuel consumption can be estimated if you calculate I and U, using BEHAVE, FARSITE (USA), Canadian Forest Fire Danger System – or you can measure $\int_{Ao}\varepsilon\sigma T^4dA$ and X_o from infrared images. Finally, we have:

$$I= 2.5 *X_o * \int_{Ao}\varepsilon\sigma T^4dA \qquad (10)$$

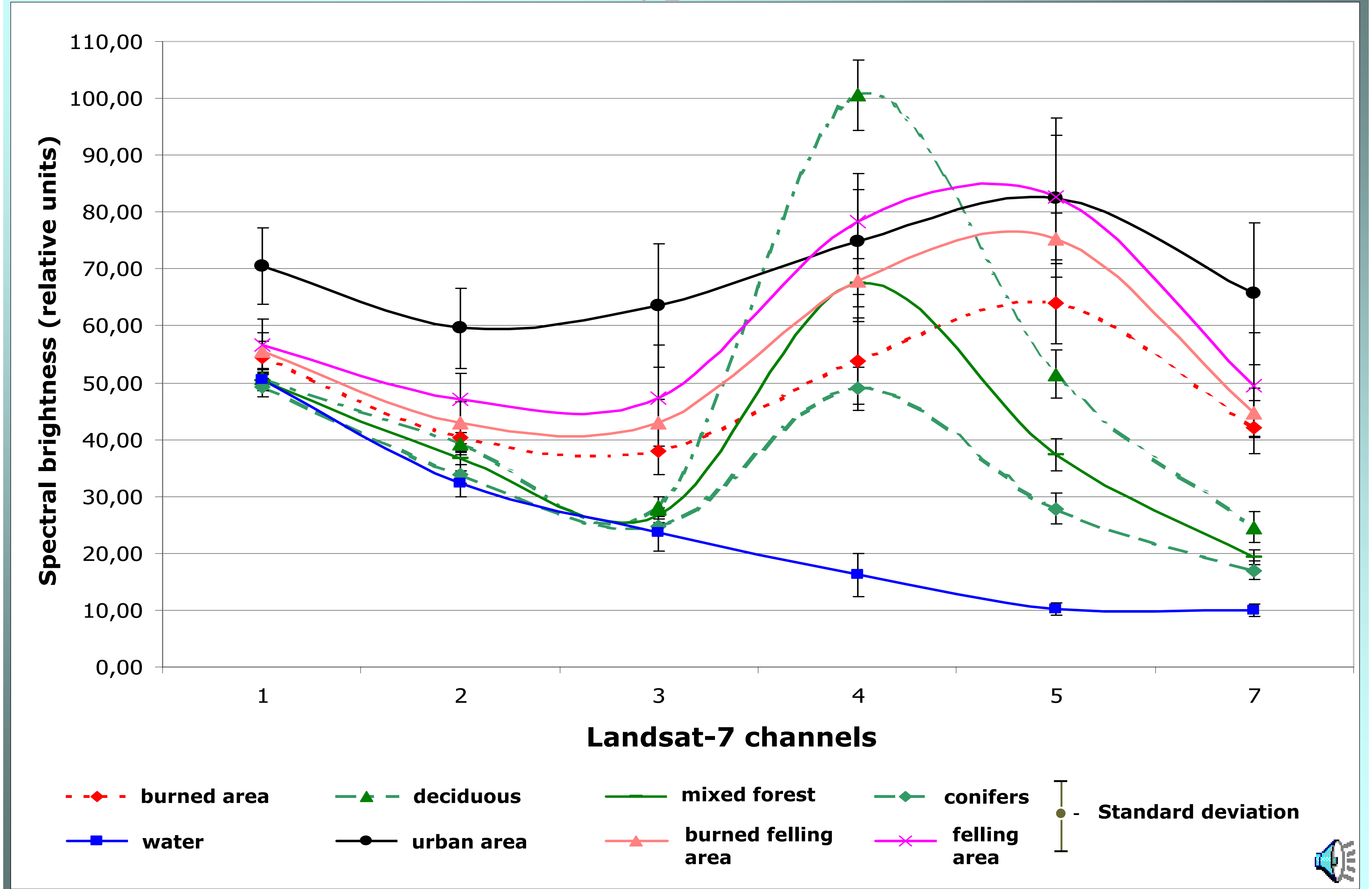
Canadian NWT high-intensity experimental fire (July 1998, Test Plot 9)

Angara Region Landsat ETM image
(27.08.2000; channels 5, 4, and 7)

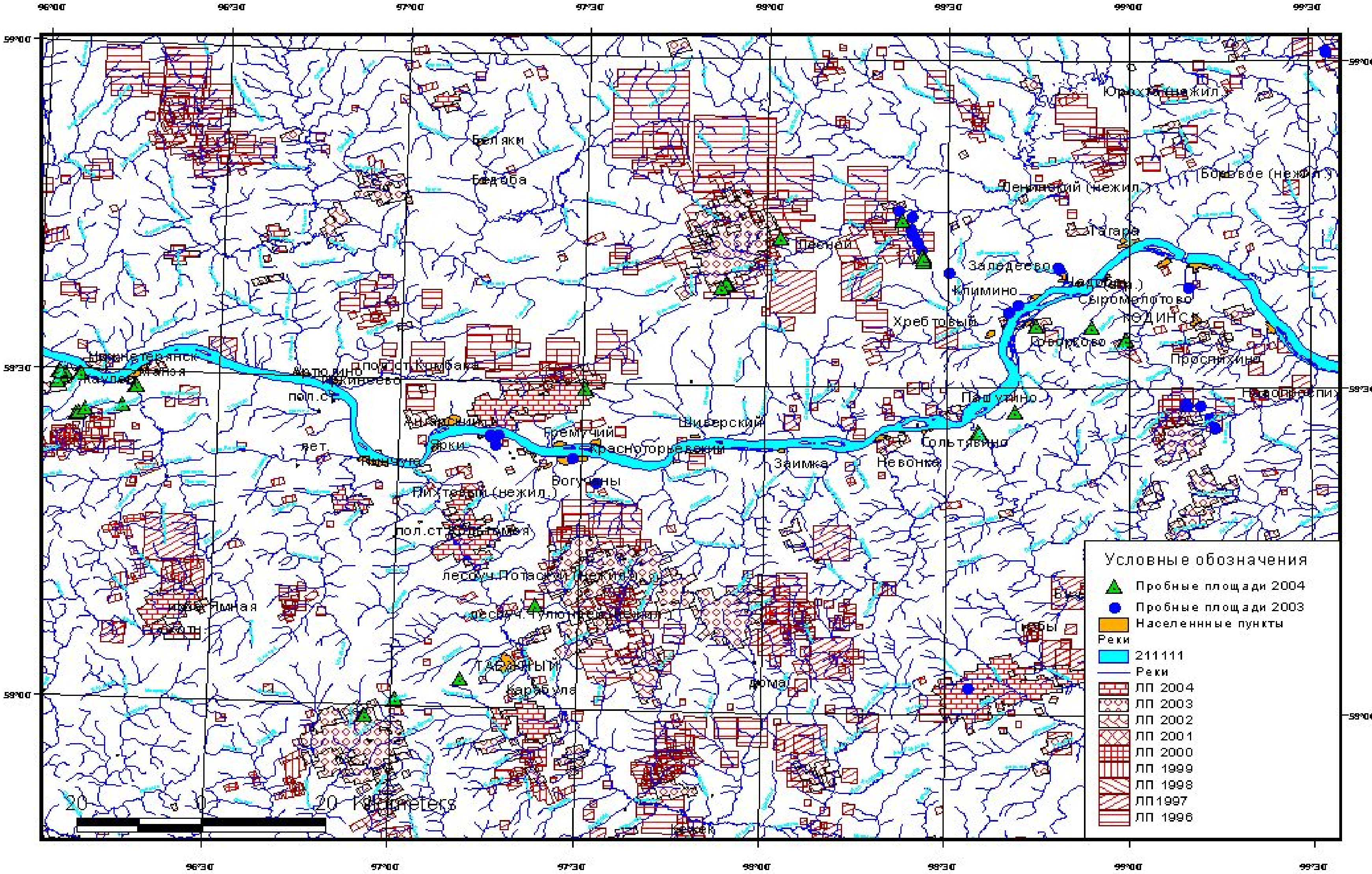


This shows various disturbances in the region

Spectral signatures for the main identified land-type classes



Объекты исследования



Влияние пожаров на древостои хвойных насаждений

- В данных лесорастительных условиях в случае возникновения пожаров в весенний период или при невысоких классах пожарной опасности по условиям погоды при незначительном прогорании подстилки вывала деревьев не происходит.
- Так, при обследовании в 2004 году экспериментальных участков, выжженных в 2003 году, вывалившихся с корнем деревьев не наблюдалось, однако имелось достаточное количество упавших деревьев в результате прогорания гнилей у основания ствола.

Влияние пожаров на древостои хвойных насаждений

Карры

Засмоления

Подсушины

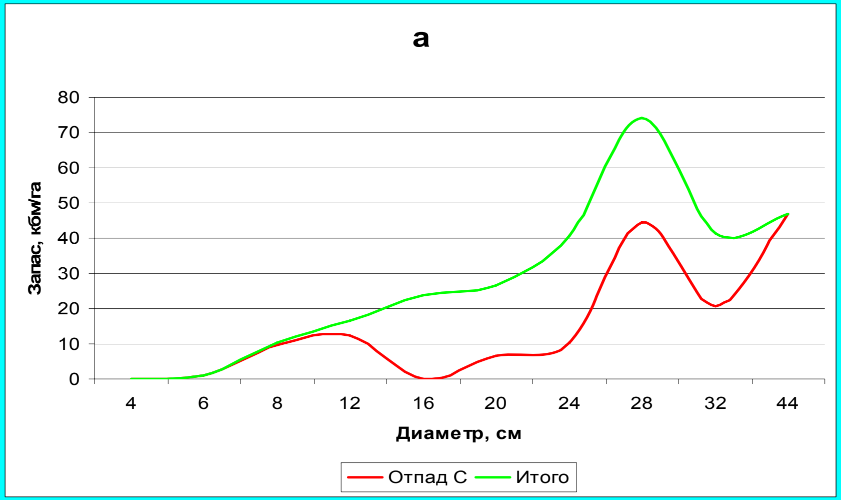
- Во всех условиях местопроизрастания наиболее уязвимыми к воздействию огня оказываются деревья, имеющие огневые и другие повреждения. Пожарные подсушины, по нашим наблюдениям, проведенным во время экспериментальных выжиганий в Хребтовском лесхозе, могут гореть несколько часов после прохождения огня, интенсивно прогорают карры и засмоленные места.
- Температура пламени при горении засмоленных пожарных подсушин достигает 900○С и более.

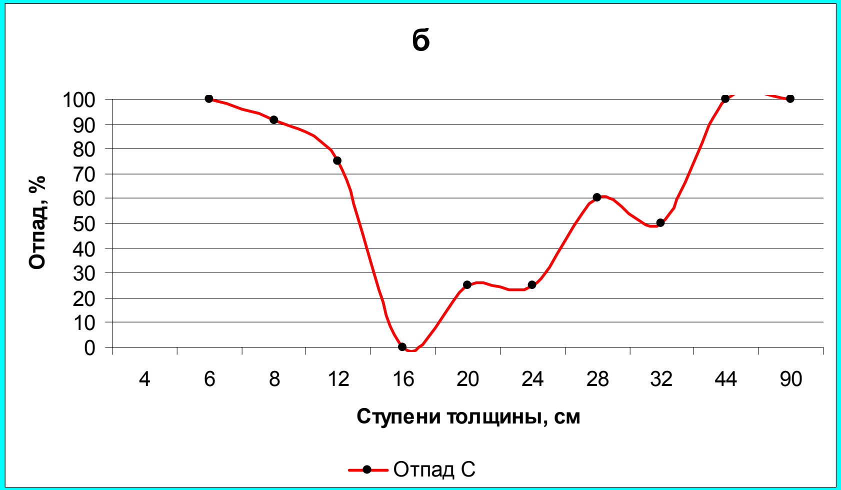
Влияние пожаров на древостои хвойных насаждений

- После воздействия устойчивых низовых пожаров, при заглублении огня в подстилку лиственница повреждается в большей степени. Это происходит из-за особенностей строения корки, которая, не смотря на значительную толщину, в результате неоднократного воздействия пожаров у основания деревьев зачастую бывает истончена.
- При переходе пожаров в устойчивую форму, в результате длительного воздействия огня, основания стволов лиственниц повреждаются до обгорания корки и омертвения луба.

Влияние пожаров на древостои хвойных насаждений

- В результате проведенного анализа выявлено, что наибольший процент отпада свойственен деревьям в наименьших ступенях толщины (низших классах по Крафту). Они менее устойчивы к воздействию огня.
- Наименьший процент отпада у одного поколения обычно наблюдается в средних ступенях толщины.
- В крупных ступенях толщины, по нашим данным, послепожарный отпад несколько возрастает по сравнению со средними ступенями. Эту закономерность для разных древесных пород мы наблюдали на многих пробных площадях.





2003 Fire scar

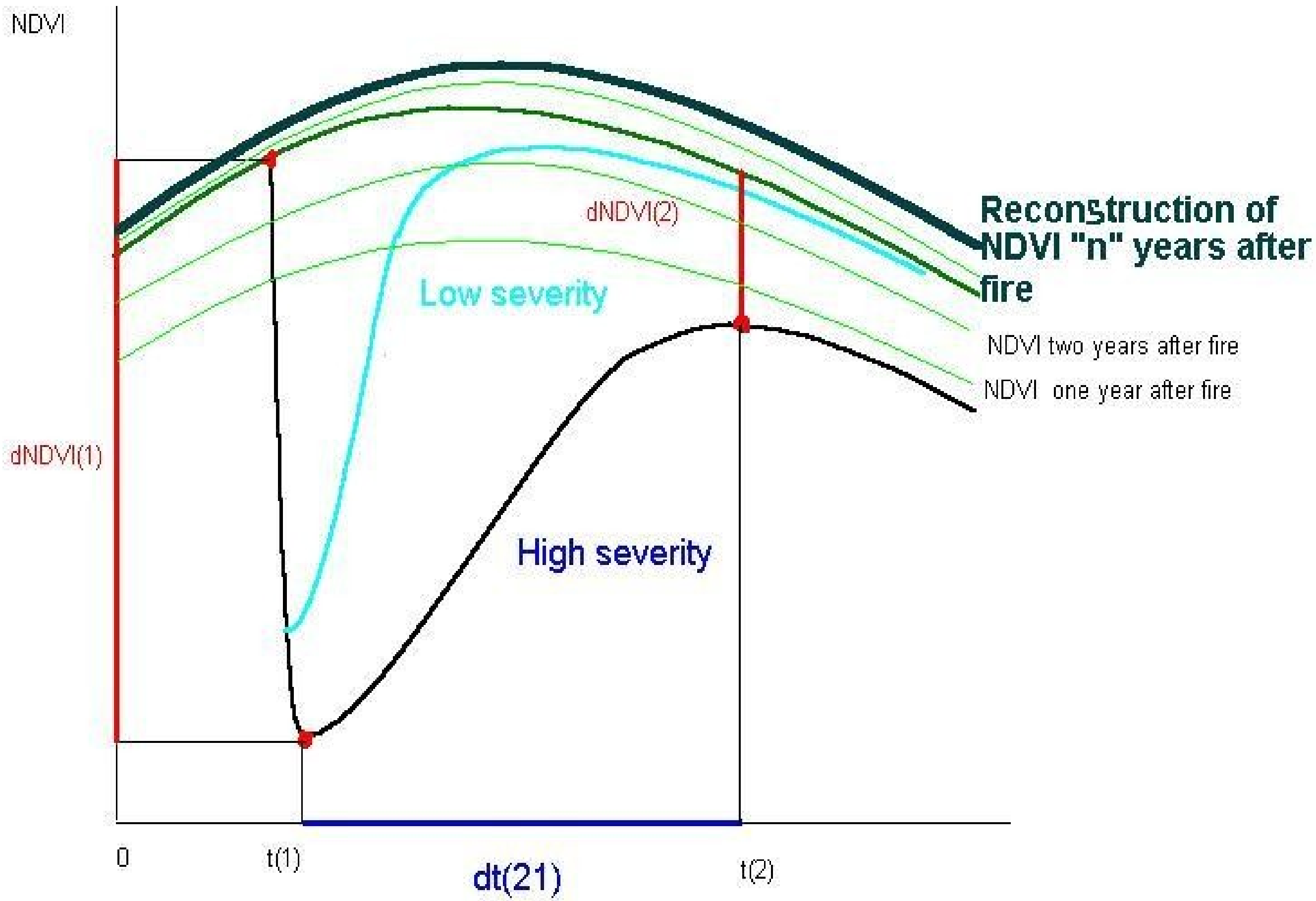
Test Plot № 22

(58°28‘W; 99°11‘N)

Trees with shallow root systems fall over immediately after the fire.

Seasonal NDVI dynamics for different fire intensity

$$\text{Fire Severity}=F\{\text{Fire Intensity} * \tau_0 * dNDVI(1) * dNDVI(2) * dt(21) * n\}$$



- Early Fire Detection System (EFDS) must satisfy to main requirements of Fire Management System

Fire Management System concerns of the different questions, including:

- **To suppress or not suppress the detected fire**
- **To ignite on not ignite the forest fuel for prescribe burning**

If we have the task to suppress the fire, which can appear in the point with high total fire damage, we need to detect it very early, when the fire size is less then critical.

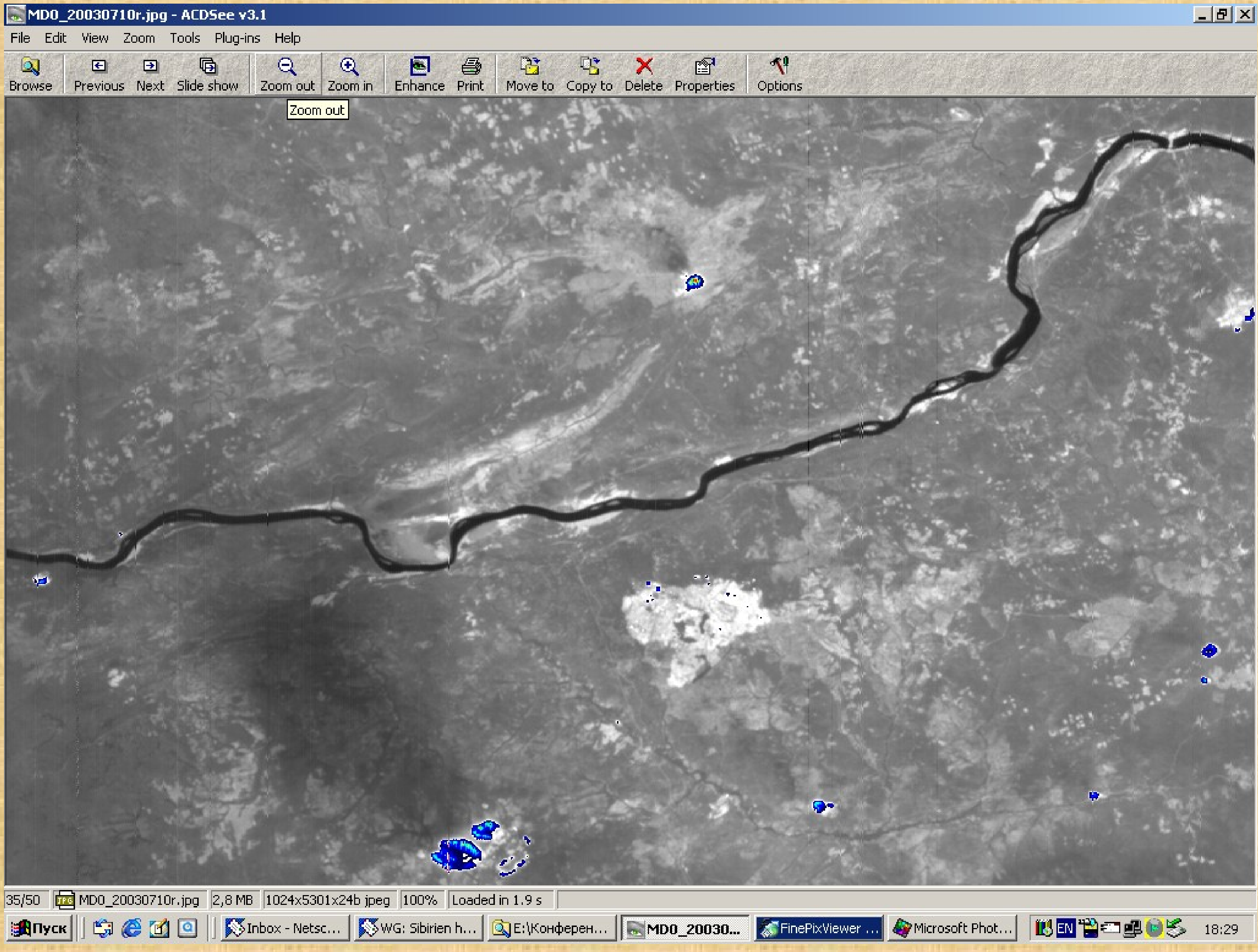
Critical fire size is corresponded to the moment, when the fire perimeter growth becomes more, than fire line suppression velocity. In Siberian aircraft observing patrol practice the Critical Detected Fire Size is 0.1-4.0 ha

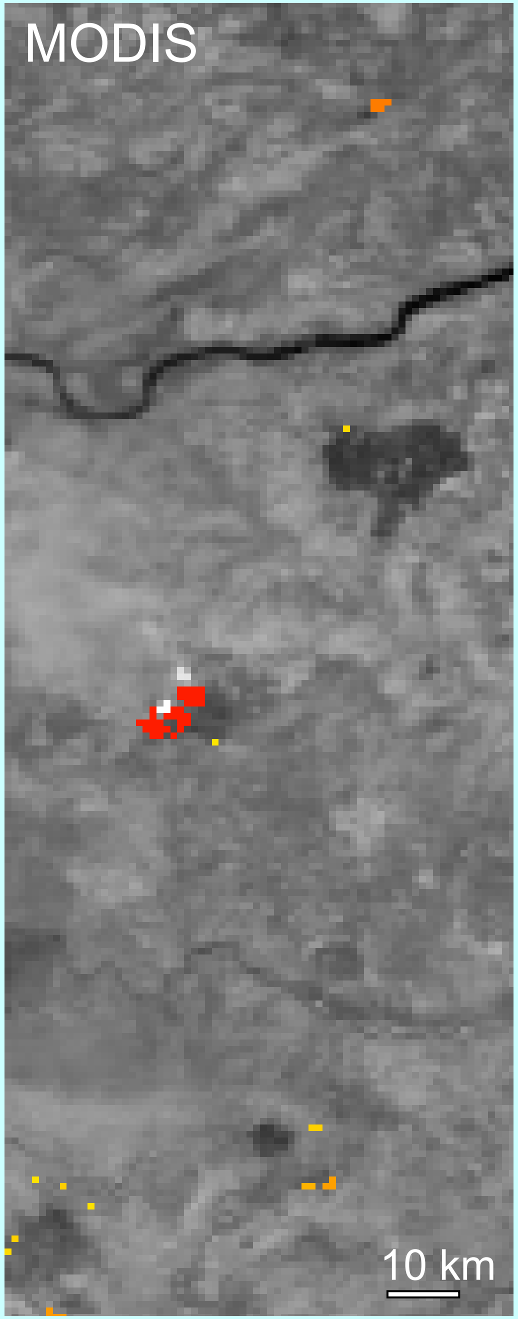
So, Detectability of the instrument, which necessary want, must be higher then MODIS. BIRD instrument satisfy to this condition, primarily due to high spatial resolution

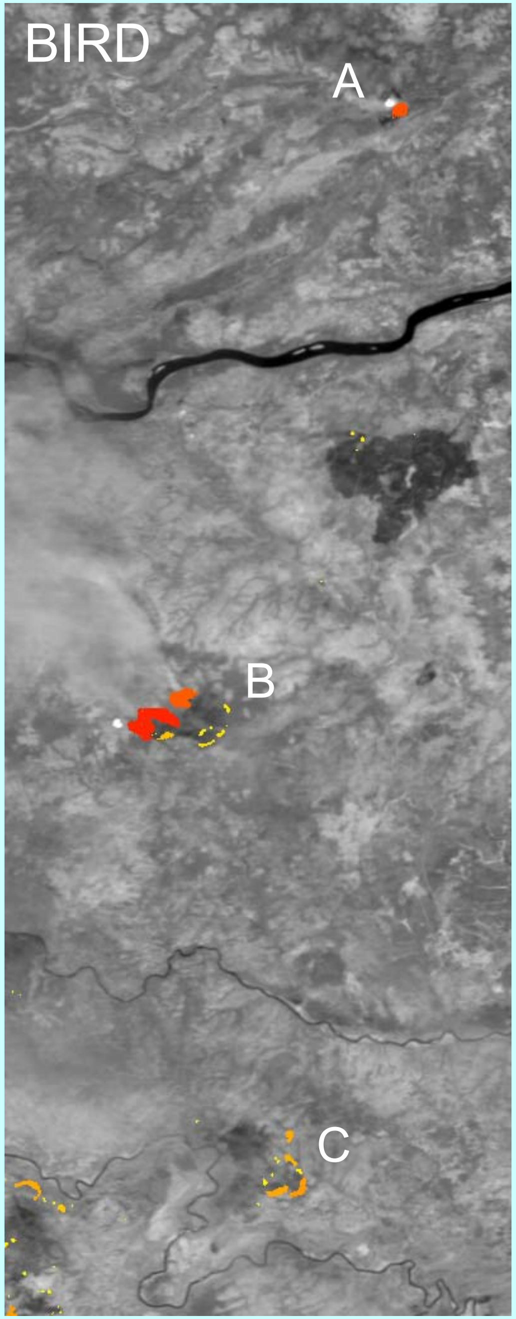
300 – 100 m is sufficient spatial resolution for providing high signal to noise ratio (equal 5 –10 for detection of 0.1 –4.0 ha fire size).

Revisit time must be less than the time of critical fire size is achieved, practically it must be 1-3 hours in the middle day, when the ground cover temperature have the maximum value.

BIRD Satellite Fire Detection in Angara River Basin, 10.07.03







Zoomed fragments of forest fire images at Angara, obtained by MODIS and BIRD on 16 July 2003

For early fire detection BIRD Detectability is about 4 times higher, than MODIS, due to high spatial resolution (see B) – A.Sukhinin

Projection on the NIR band

Conclusions

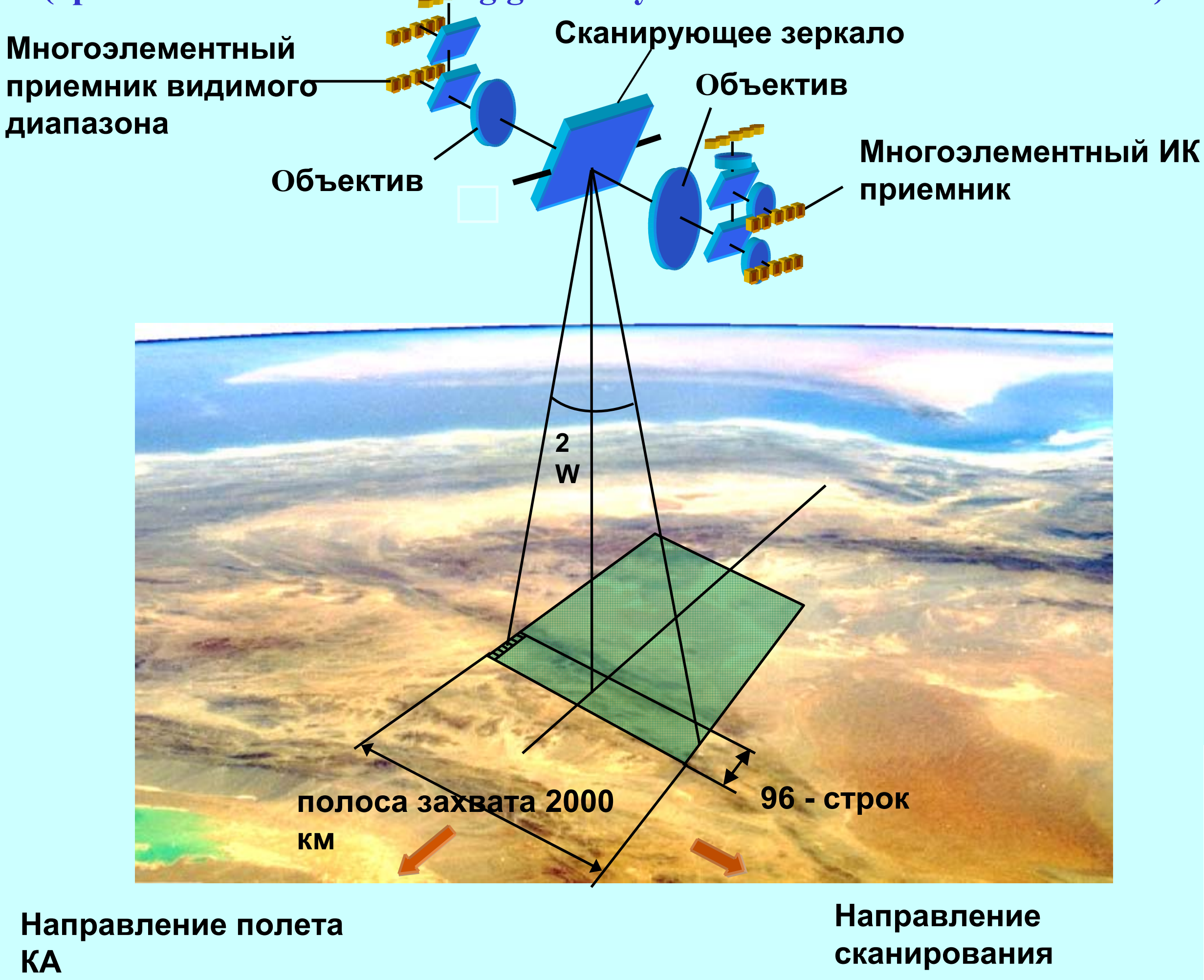
1. Validation of the MODIS fire data was performed in a number of typical fire scenes using higher-resolution BIRD data
2. The Fire Radiative Power (FRP), which is related to the amount of burning biomass and of gas and aerosol emissions, is a suitable parameter for fire characterisation from satellite data. In most cases, FRP can be estimated with an accuracy within ~30%
3. The FRP of more than a half of the hot clusters, which were detected by BIRD, is below the detection limit of MODIS
4. Nevertheless, MODIS may only slightly underestimate the cumulative FRP in ecosystems where large fires take place
5. Though MODIS is hardly suitable for an early fire detection, it is an adequate instrument for cumulative FRP estimation

We have the affirmative proposition:For early fire detection BIRD Detectability is 4 times higher, than MODIS, due to spatial resolution

So, we propose to develope ***The Special Operational Fire Recognition System*** with **Spatial resolution = 100-300 m,** and **Revisit time 1- 3 hours**

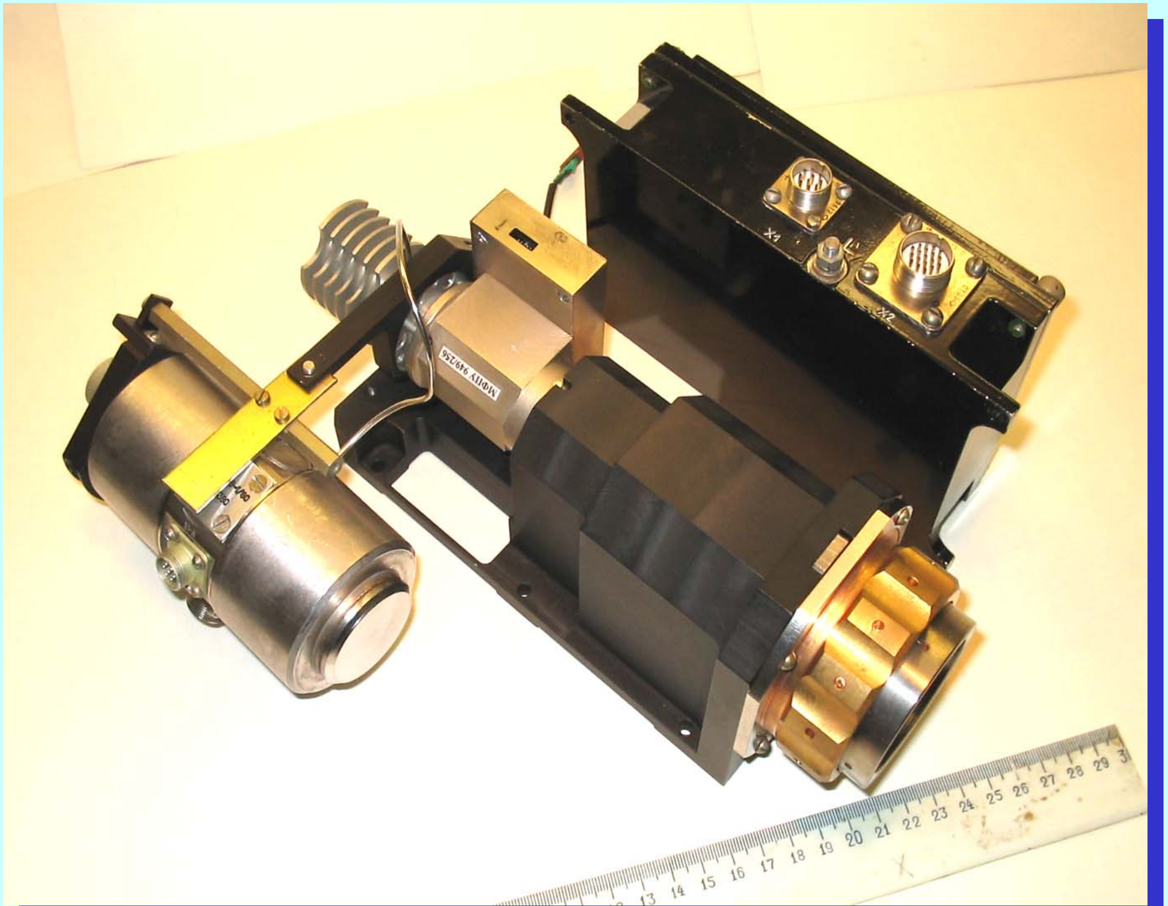
Necessary Revisit time may be realized, using infrared radiometer GLOBUS, which is developed in Space Devices Developing Institute of Russian Space Agency (Author is Gektin Yuri, **presentation in Moscow, november 2004, Space Research Institute RAS**)

(optical scheme and scanning geometry of the IR Radiometer GLOBUS)



Model of the optical-electronic infrared radiometer GLOBUS, which is developed in Space Device Developing Institute of Russian Space Agency (Author is Gektin Yuri)

МФПУ с МКС



Thank you very much for your attention

"Bor Island" 1993 fire experiment in Krasnoyarsk region