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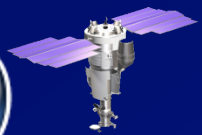

Ministry of Education and Science of the Russian Federation
Russian Academy of Sciences

Institute for Scientific Research of Aerospace Monitoring
"AEROCOSMOS"

SATELLITE IMAGERY PROCESSING METHODS FOR THE ESTIMATION OF TRACE GAS AND AEROSOL EMISSIONS DUE TO WILDFIRES

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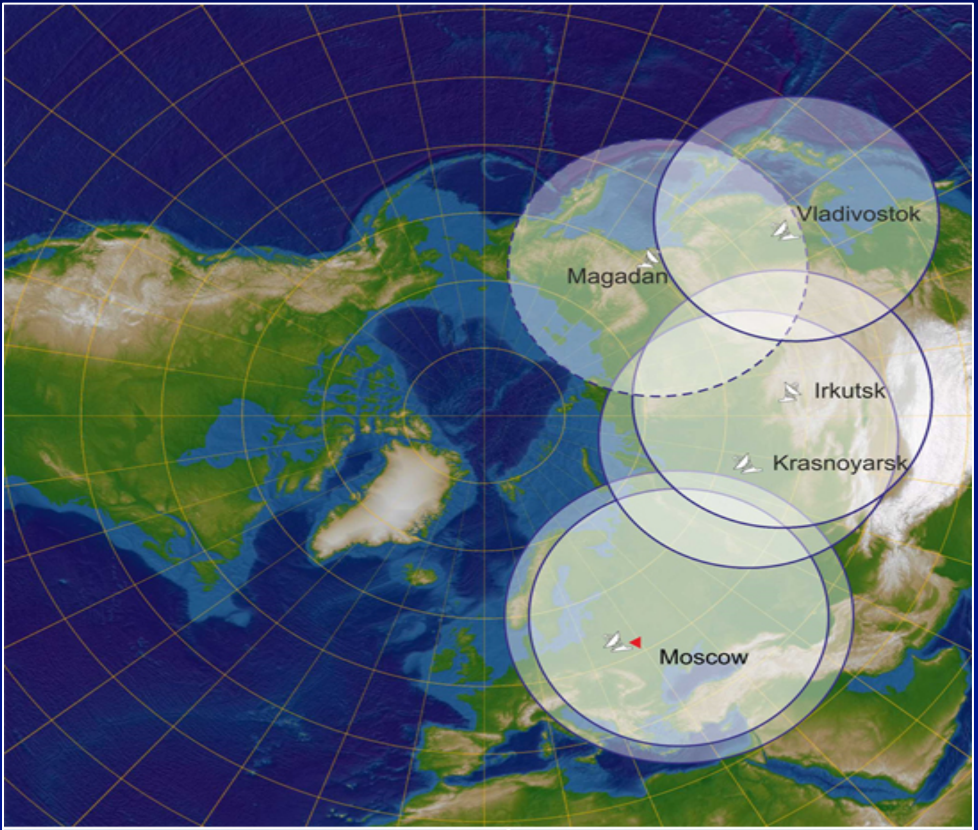
Atmospheric Emissions Of Hazardous Pollutants Due To Wildfires

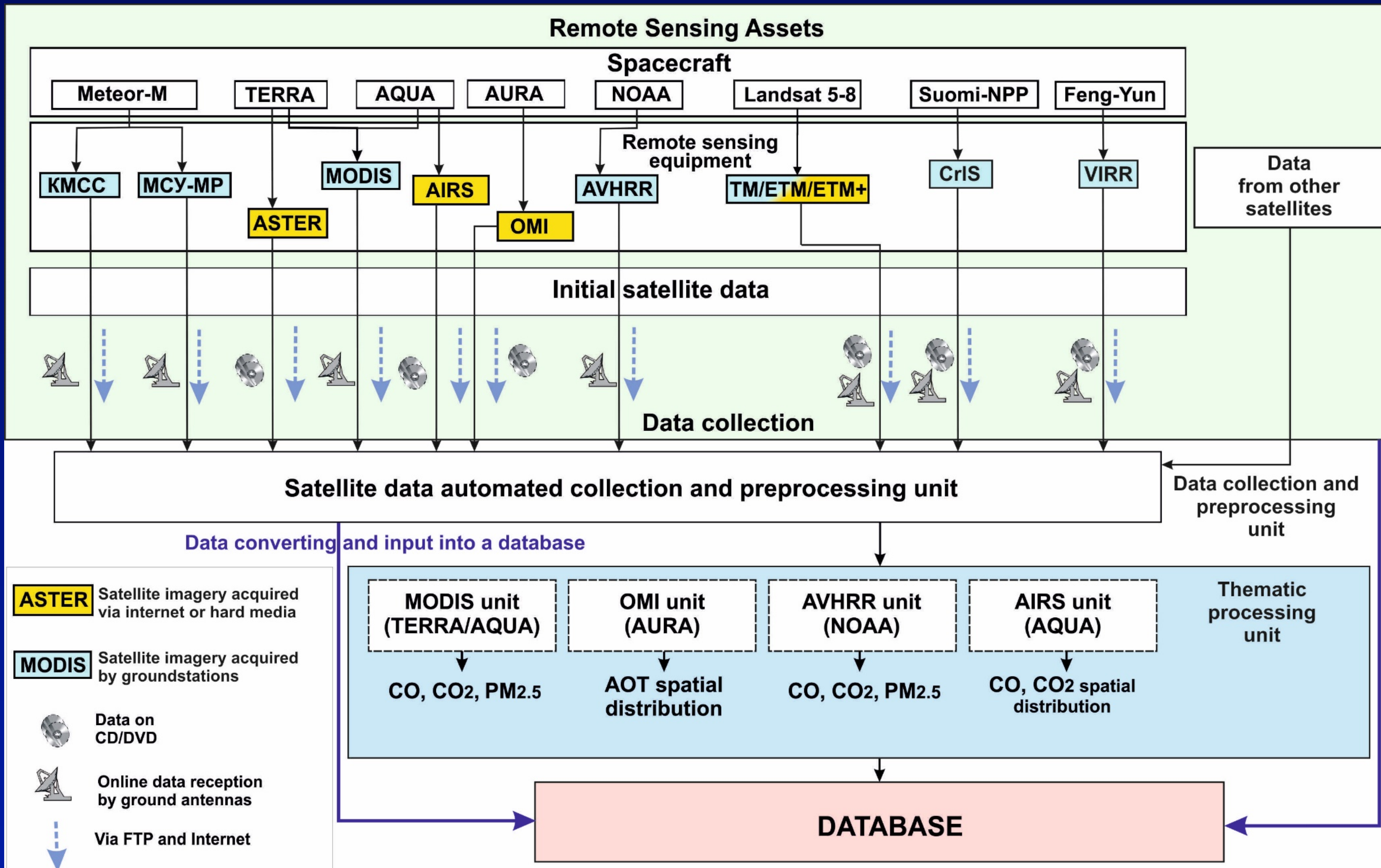
A wildfire is one of the most important sources of various trace gas and aerosol emissions into the atmosphere. The bulk of these emissions consists of CO, CO_2, and fine aerosols ($PM_{2,5}$). Polluting the atmosphere, these emissions disrupt the planet's radiation balance and negatively affect human health. Totally, 20 % of global emissions on the planet are due to wildfires.

For the regions of Northern Eurasia, with huge reserves of carbon stored in biomass, the problem of wildfire monitoring and emission volume estimation is particularly significant.

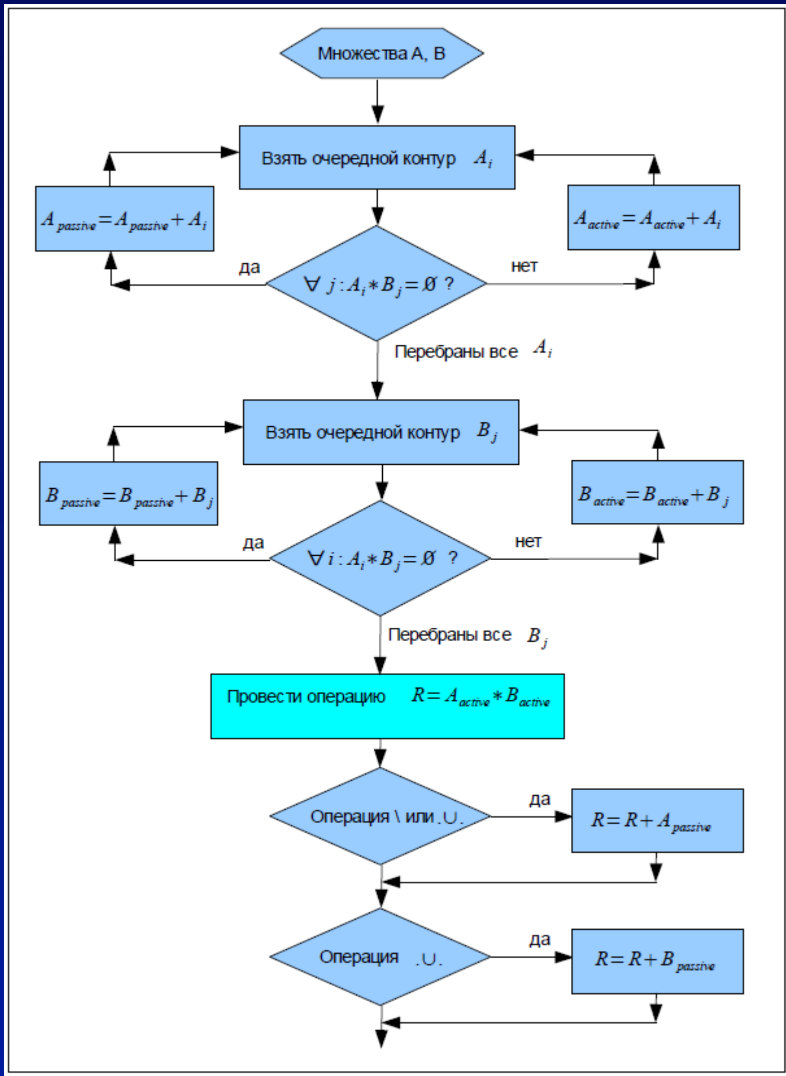
Reception area of satellite data by ground station of ISR «AEROCOSMOS»



Functional scheme of the system of wildfires space monitoring and evaluation of emissions volumes, developed at ISR «AEROCOSMOS»



Linear-nodal algorithm for analysis of low-resolution data



Block diagram of overlay calculation taking into account the non-overlapping blocks in a linear-nodal algorithm

A_{active} B_{active} Subsets of operand contours having intersection with another operand and respectively involved in the calculations according to the algorithm

$A_{passive}$ $B_{passive}$ Contours having no intersections with the contours of the other operand

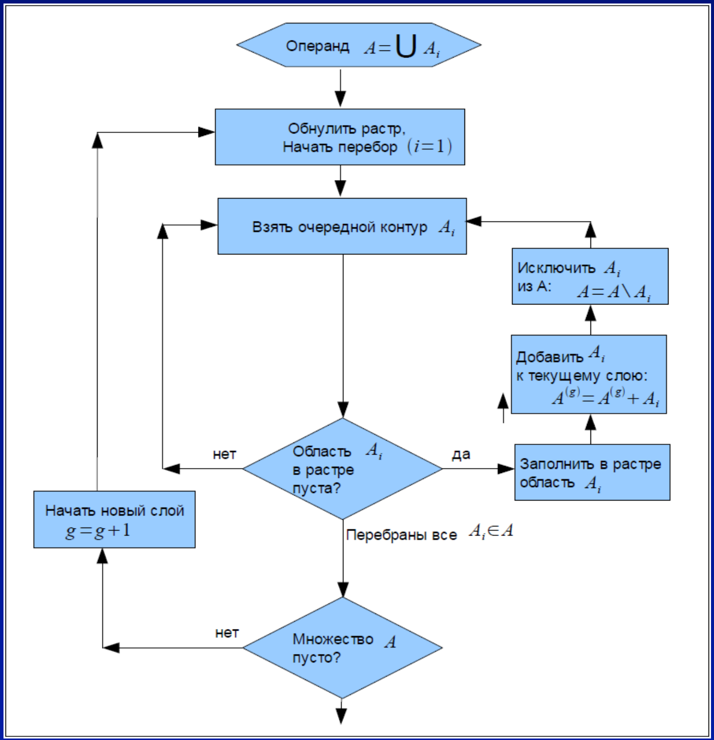
$A_i \cap A_j \neq \varnothing$

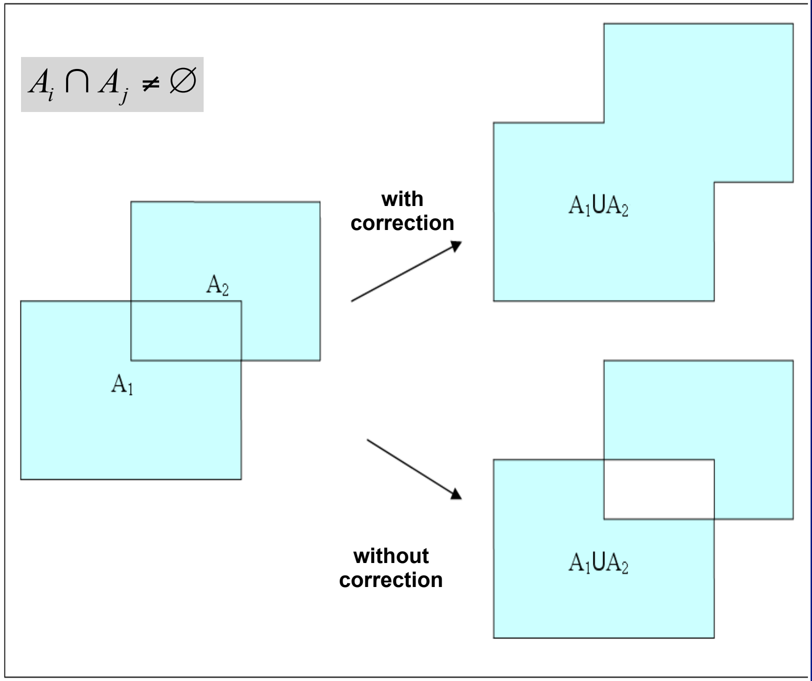
Линейно-узловой алгоритм анализа данных низкого разрешения

Каждый из операндов предварительно разбивался на группы контуров (далее такая группа называется слоем), такие, что внутри каждой такой группы контуры не пересекались:

$$A = \sum_{g=1}^{G} A^{(g)} \qquad A^{(g)} = \sum_{s=1}^{S_g} A_s^{(g)} \qquad \forall g : A_s^{(g)} \cap A_t^{(g)} = \varnothing \Leftrightarrow s \neq t$$

Далее слои последовательно объединяются: $A^{(g)}, g = G...1$





Пример работы линейно-узлового алгоритма при условии наличия пересекающихся фигур в одном операнде

Алгоритм разбиения на слои. В результате исполнения алгоритма получается несколько слоёв, в каждом из которых содержатся взаимно непересекающиеся контуры. Слои с большим порядковым номером содержат меньшее количество контуров, поскольку основное количество пожаров детектируется сравнительно малое число раз, а многократные обнаружения есть лишь для нескольких из них. Поэтому слои объединяются начиная с меньших номеров, с целью уменьшения количества вычислений.

Classification of burnt areas

C(T, p) - classifier, function that has a value of 1 for the pixel of the burnt area, 0 - if otherwise. It is possible to have the value of the classifier in the range [0, 1] - the probability that it is the pixel of burnt area;

p - pixel;

T - set of precedents

For a timepoint t_n , the precedents are a set of pixels where the fire was recorded at the studied time interval, but extinguished some time ago.

Denote this time as τ . Then, t_l

$$t_n - t_l > \tau \qquad t_n - t_{l-1} \leq \tau$$

$$T = \bigcup_{k=m}^{n} \Omega_k \setminus \bigcup_{k=l}^{n} \Omega_k = \bigcup_{k=m}^{l-1} \Omega_k \setminus \bigcup_{k=l}^{n} \Omega_k$$

Алгоритм уточнения данных низкого пространственного разрешения по данным среднего разрешения

Для каждого изображения среднего пространственного разрешения рассчитывается три индекса: NDVI, GEMI и BAI. Далее происходит вычитание одноимённых индексов, которое выявляет площадь пройденную огнём. Данная операция проделывается для каждого из трёх индексов. Общая площадь, пройденная огнем, агрегируется по трём разностным индексам и переводится в векторный формат. Площади, пройденные огнем, по данным низкого разрешения уточняются по данным среднего разрешения.

NDWI (Normalized Difference Water Index)

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

NIR - near-infrared wavelengths

GEMI (Global Environmental Monitoring Index)

$$GEMI = E * (1 - 0,25 * E) - \frac{RED - 0,125}{1 - RED}$$

$$E = \frac{2 * (NIR^2 - RED^2) + 1,5 * NIR + 0,5 * RED}{NIR + RED + 0,5}$$

BAI (Burned Area Index)

$$BAI_i = \frac{1}{(\rho c_R - \rho_{i,R})^2 + (\rho c_{NIR} - \rho_{i,NIR})^2}$$

pc_R $p_{i,R}$ reflectivity of the center of convergence to the burned areas in R and NIR, with values of 0.1 and 0.06.

Обозначим оценку площади выгоревшей области с координатами *(x, y)* в момент времени *(t)*:

- по данным низкого разрешения

$$S^L(x,y,t) = S_i^L$$

- по данным среднего разрешения

$$S^H(x,y,t) = S_{i_k}^H$$

$$i = 1 \ldots N, k = 1 \ldots M, M < N$$

Далее используется метод усреднения по всем данным:

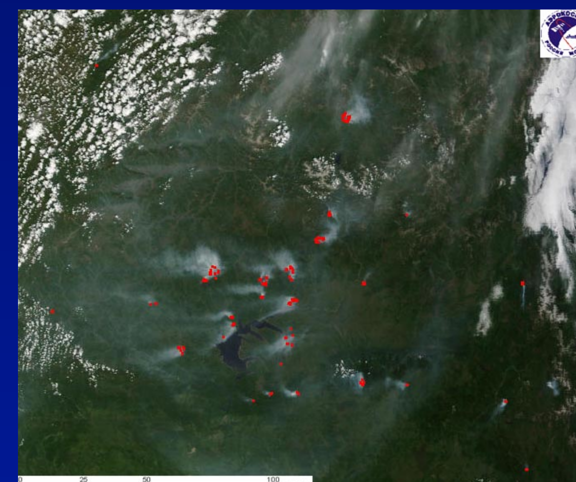
$$S_i^H = S_i^L \frac{\frac{1}{M}\sum_{k=1}^{M} S_{i_k}^H}{\frac{1}{N}\sum_{i=1}^{N} S_i^L}$$

Данный метод позволяет получать точное значение площади, пройденной огнём по данным низкого разрешения.

Detection of Fire Sites and Calculation of Wildfire Areas Using Low Resolution Data

1 km resolution and 2300 km swath MOD14/MYD14 product of MODIS instruments of Terra and Aqua satellites is used to detect fire sites and calculate wildfire areas.

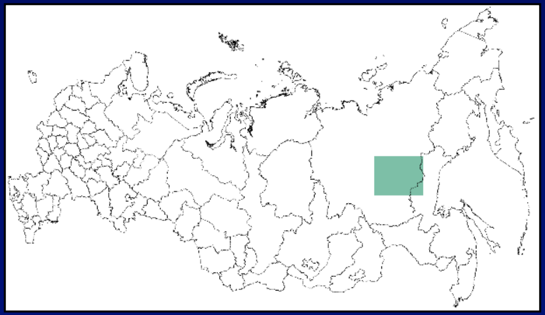
Wildfire sites in Russia detected by MODIS instrument in May 2015



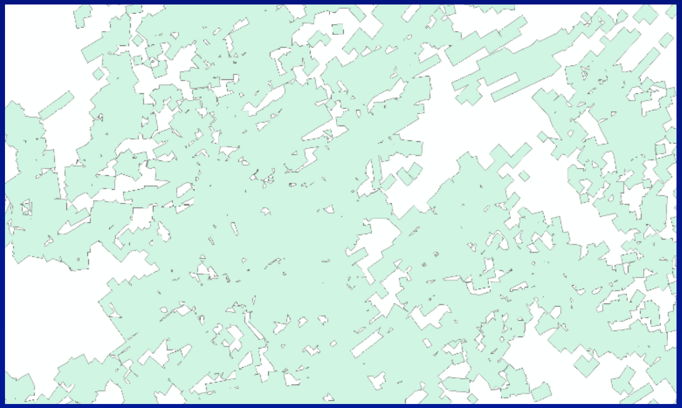
Fires in the Amur Region June 22, 2015

Verification Of Wildfire Area Estimation Using Low And Mid Resolution Satellite Data

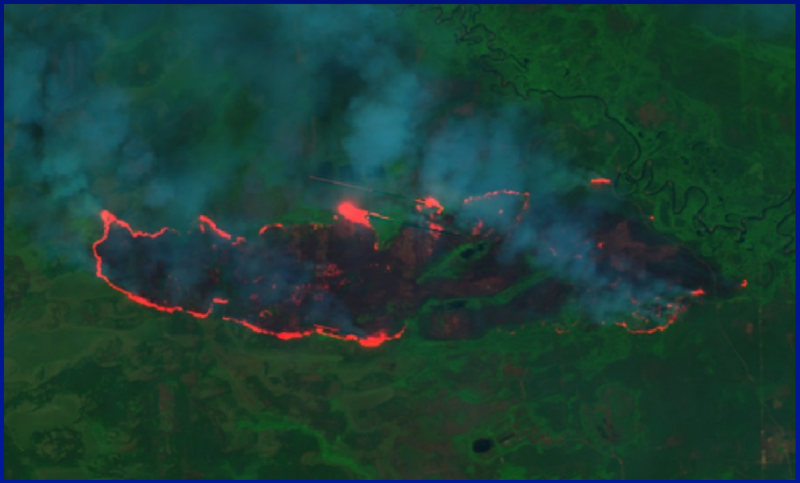
1. Selection of the survey region (a locality in Yakutia, April – May 2011)
2. Calculation of wildfire areas using low resolution (1 km) data (MODIS instruments of Terra and Aqua satellites)
3. Calculation of wildfire areas using mid resolution (30 m) data Landsat 5 Thematic Mapper



Survey region

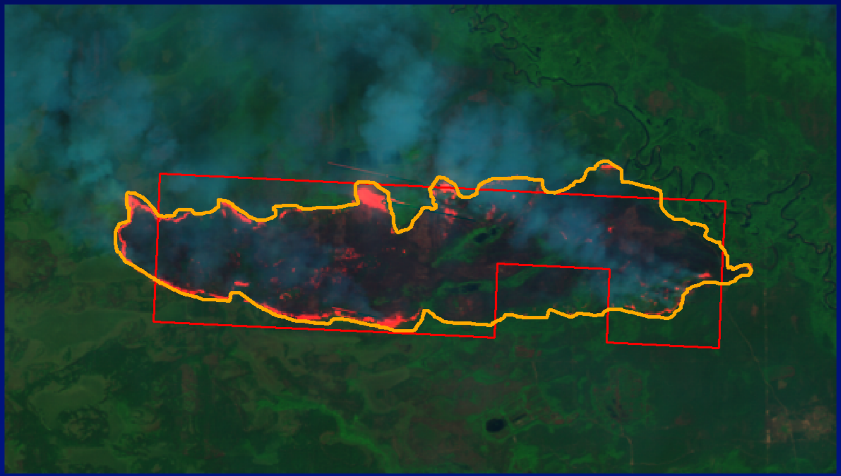


Wildfire areas in the surveyed region using low resolution data (MODIS, Terra and Aqua satellites)



Satellite image with highlighted burned area in the surveyed region obtained by TM instrument of Landsat 5 satellite

Verification Of Wildfire Area Estimation Using Low And Mid Resolution Satellite Data



Satellite image with highlighted burned areas in the surveyed region obtained by TM instrument of Landsat 5 satellite and MODIS instruments of Terra and Aqua satellites

Burned area according to MODIS data	**39884 km²**
Burned area according to TM (Landsat 5) data	**35416 km²**

By the comparison of the results from wildfire area calculations obtained using various spatial resolution data, a correction factor k equal to 0.889 has been derived. Such a correction coefficient can also be calculated for every area of the studied region and used for the correction of wildfire area calculation results using low resolution satellite data.

METHODS FOR THE ESTIMATION OF TRACE GAS AND AEROSOL EMISSIONS DUE TO WILDFIRES

Method of estimation of the volume of CO, CO2 emissions and aerosols by wildfires, based on the application of the formula Seiler-Crutzen, supplemented with the correction coefficient *k*, obtained as a result of experimental studies.

$$E = k \times A \times B \times C \times D$$

A – fire area (m^2);

B – biomass density in the burned area (kg/m^2);

C – biomass combustion completeness (%);

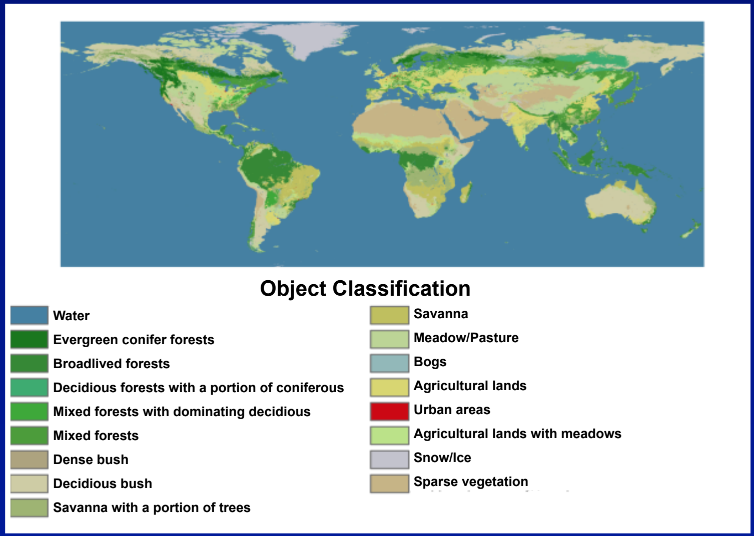
D – emission factor (mass of the matter emitted into the atmosphere during combustion of 1 kg of biomass (g/kg);

E – total matter emitted into the atmosphere during a wildfire (g).

k – **correction coefficient obtained by low and mid resolution data comparison**.

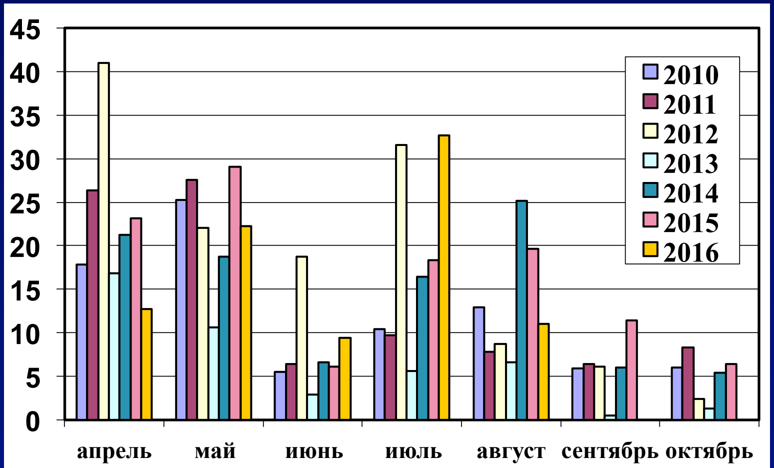
A, fire area is calculated based on satellite data and accounts for *k* coefficient.

To determine vegetation types and characteristics within the selected research area, the state-of-the-art Land Cover Type Yearly L3 Global 500 m SIN Grid vegetation map (500 m resolution) is used.

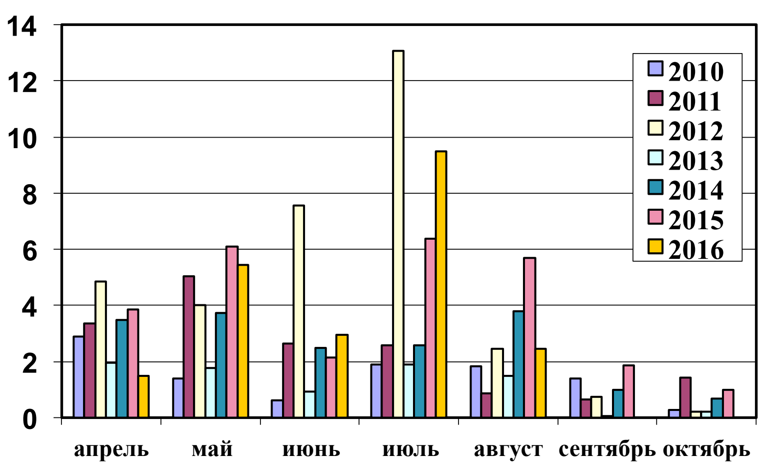


Land Cover Type Yearly L3 Global 500 m SIN Grid Vegetation Map

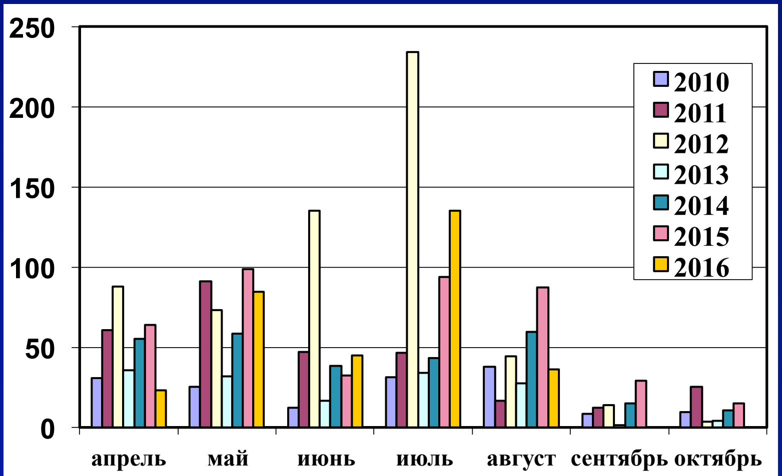
Burned Areas and Emission Volumes in the Russian Federation Due To Wildfires (2010 - 2016 гг.)



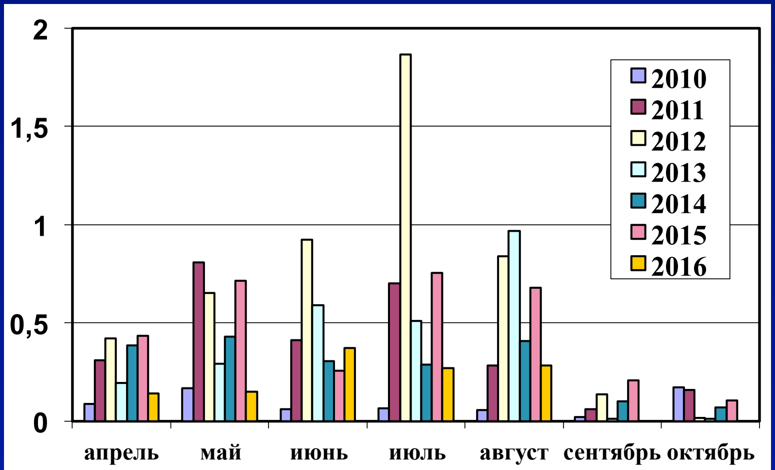
Burned areas in 2010-2016 in the Russian Federation (thous. km[2])



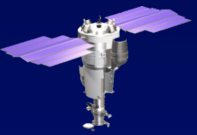
CO emissions in 2010 – 2016 in the Russian Federation (mln. tons)



CO_2 emissions in 2010 – 2016 in the Russian Federation (mln. tons)



$PM_{2,5}$ emissions in 2010 – 2016 in the Russian Federation (mln. tons)



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Thank You!