Remote sensing
in monitoring wildfires in Siberia

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Actualities

I. Wildfire impact is the main natural disturbances in forests of Russia and mostly in Siberian boreal zone.

In Siberia the annual area burned makes up to 17 million ha. The increasing trend of forest burning is evaluated over recent years. (Conard et al. 2002; Soja et al. 2004; de Groot et al., 2013; Ponomarev, Kharuk, Ranson, 2016).

II. There are 4 zones of forest fire monitoring in Russia today.

According to them more than 50% of forests in Russia is under remote monitoring only. Satellite imagery and remote sensing estimations are the only available data on wildfire activity there.

Satellite monitoring allows to obtain real-time data on forest fires and provides with attributive information on all detected active burnings and their daily dynamics.
Territory zoning in terms of wildfire monitoring and preventing

A) Levels of Natural fire danger

I – ground-based fire monitoring (7%),

II – aerial monitoring (42%),

III – satellite monitoring and selective fire extinguishing (20%),

IV – satellite monitoring and fire extinguishing in cases of settlement threats (31%)

V – protected areas (State reserves, National parks etc.)

B) Anthropogenic impact levels

C) Percentage of forest cover

D) Types of preventing monitoring
Tasks for the system of remote fire monitoring

**Daily real-time monitoring**

- Fire Weather condition analysis and weather fire danger estimation;
- Thermal anomalies detecting and wildfire attributive data collecting;
- Real-time mapping of fire activity and dynamics.

**Analysis of fire ecology and post-fire effects**

- Long-term wildfire database preprocessing and uploading in GIS;
- Geospatial analysis of wildfire, current trends and prognoses;
- Assessment of fire impact on the scale of ecosystems / post-fire forest monitoring;
- Direct carbon emissions estimating.
Remote sensing data on wildfires in Russian Federal agencies

«Kaskad» (Cascade)
Emergency Situations Monitoring agency-level portal of EMERCOM of Russia
Supported since 2009 by the Regional department in Krasnoyarsk
Reduced version is available at:
http://space.akadem.ru/int/

«ISDM - Rosleskhoz»
Remote Monitoring Information System of Federal Forestry Agency
Available at:
Monitoring data on wildfires for science

GIS of Wildfire monitoring

V.N. Sukachev Institute of Forest, Siberian Branch of Russian Academy of Sciences

Available for 1996 – 2018

Daily information for every wildfire is available as GIS layer also.

The database contains over $2 \times 10^4$ records per year and $\sim 5 \times 10^6$ in total for 24 years.

The main topics

1. Spatio-temporal characteristics of wildfire frequency (fire weather, heat and moisture supply, natural fire danger)
2. Estimating the wildfire energy characteristics, intensity of burning, crown burning
3. Instrumental assessment of direct fire emissions of carbon based on real-time satellite data
4. Post-fire effects monitoring and prognosing (thermal anomalies, impact on thawing depth of the seasonal thawed layer, forest mortality/recovery)
Agreement between The Global Fire Monitoring Center and Sukachev Institute of Forest, 2017

The Global Fire Monitoring Center (GFMC), Max Planck Institute for Chemistry, Freiburg / Mainz, Germany
Associated Institute of the United Nations University, Tokyo / Bento, and Freiburgh University

Sukachev Institute of Forest (SIB), Siberian Branch, Russian Academy of Sciences, Krasnoyarsk

The Global Fire Monitoring Center serves as the regional center for the Monitoring of forests and forest fires in the field of wildland fire science, global wildfire, and international policy support, serving the United Nations.

IN WITNESS WHEREOF, the undersigned, duly authorized thereto, have signed this Agreement.

DONE in duplicate, in English language, in Freiburg and in Krasnoyarsk on 17 March 2017.

For the Global Fire Monitoring Center

For the Sukachev Institute of Forest SB RAS, Siberian Branch, Russian Academy of Sciences

Central Siberia, Yenisey transect

South Siberia Altai-Sayan Region

AOI of Regional Eurasia Fire Monitoring Center / The Global Fire Monitoring Center
Satellite imagery for wildfires monitoring

A. Raw data on thermal anomalies/burned areas

Terra/MODIS
2017

Landsat-8/OLI
2017

Sentinel-2
2016

B. Pre-processing

C. Wildfire database in GIS

D. Analysis

AQUA/Modis
SNPP/VIIRS
GIS layer of long-term history of wildfires

**Probability** of active burning detecting vs the area and target temperature

![](chart.png)

**Data pre-processing in GIS**

- final fire polygon aggregating;
- polygons of area burned re-calculating;
- total fire scar area validating;
- additional attributive information (region, forestry, forest type, nearest settlements etc.)
Categories of Wildfires in database

A histogram of data on forest fire events:

a) taking into account all detected thermal anomalies,

b) after the exclusion of «short-living» objects registered during the spring

Categories of fires in terms of size:

1. Wildfires up to 1000 ha;
2. «short-lived» objects/ agricultural burning;
3. large-scale wildfires
To estimate the heat radiation power from the zone of active burning the Terra/MODIS data in the range of 4 mkm / standard product MOD14 were employed (Kaufman et al., 1998; Justice et al., 2002).

The method was adapted for burning conditions in Siberia; The threshold technique was implemented to classify fires in term of burning intensity: low-, medium- and high-intensity including crown burning (probability ~60%).

The characteristics strongly correlated with a burnup rate and fire front velocity (initial data for modelling of scenario of a wildfire).
Extreme and crown wildfires in Siberia

Thermal anomalies from the Terra/MODIS imagery of an active burning

Annually extreme intensity burning zones were classified presented up to 10-13% of total area of Siberian wildfires.

Averaged estimation for crown burning is 5.5±1.2% of the total fire number, that is about 8.5% of total area burned annually.
Wildfires of Siberia under climate change

The current dynamics of fire regimes in Siberia is determined by a complex of factors, such as temperature anomalies, change and redistribution of precipitation.

The first decade of the 21st century is characterized by an increase in frequency of fires and burned areas.

According to forecasts in the 21st century, direct wildfire emissions of carbon under current trend can rise from **120-140** Tg at present (*Shvidenko et al., 2011*) up to **230-240** Tg per year (*Zamolodchikov et al., 2011*).

Remote system for fire monitoring is the main source of data for analysis and forecasting of fire impact at the scale of ecosystems of Siberian forests and globally while the quota (contribution) of forest burning in Eurasia is strongly significant.
Wildfires vs meteorological anomalies and climate trends

Long-term averaged relative burned area (RBA) per year, %

Relative burned area per year is in the range of 0.1% — 14.5%
Averaged for Siberia — 1.19%, for western Canada — 0.56% (deGroot et al., 2013).

<table>
<thead>
<tr>
<th>Fire season scenario</th>
<th>P{E} (min–max)</th>
<th>Period, years</th>
<th>RBA, % (Min–Max)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I extreme</strong></td>
<td>0.18–0.20</td>
<td>8 ± 3</td>
<td>4.5–14.5</td>
</tr>
<tr>
<td>IIa moderate/spring</td>
<td>0.24–0.57</td>
<td>4 ± 1</td>
<td>0.5–1.5</td>
</tr>
<tr>
<td>IIb moderate/summer</td>
<td>0.24–0.38</td>
<td>3 ± 1</td>
<td>1.0–4.0</td>
</tr>
<tr>
<td>III low</td>
<td>0.19–0.48</td>
<td>4 ± 2</td>
<td>0.01–0.3</td>
</tr>
</tbody>
</table>
Assessment of fire impact and monitoring of post-fire changes could provide "traditional" methods for analyzing vegetation indices, as Normalized Difference Vegetation Index (NDVI); Normalized Burned Ratio differencing (dNBR) etc.

The real time classifying can be produced using the FRP technique data.

The approach can be used for estimating the initial fire impact and for the further prognosing of the post-fire vegetation cover state.

Vegetation cover classification for the post-fire scar:
- a) initial Landsat image
- b) uncontrolled classification
- c) NDVI classifying
- d) dNBR classifying
- e) Real-time classification using Fire Radiative Power data / intensity estimates
Post-fire effect monitoring

Larch forest recovery process monitoring (Evenkiya, Siberia)

Averaged characteristics of thermal and vegetation anomalies for Larch forests of permafrost zone

<table>
<thead>
<tr>
<th>Year after the burning</th>
<th>∆NDVI relative, %</th>
<th>Absolute temperature anomaly, °C</th>
<th>∆T relative, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>53.5±10.7</td>
<td>6.5–7.2</td>
<td>47</td>
</tr>
<tr>
<td>5</td>
<td>21.0±7.8</td>
<td>3.8–4.9</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>9.0±5.0</td>
<td>3.4–4.6</td>
<td>20</td>
</tr>
</tbody>
</table>

Modeling the fire impact

Rate of loss from thermal anomalies

\[ y_2 = 41.7e^{-0.08x} \]
\[ y_1 = 57.6e^{-0.2x} \]
\[ R^2 = 0.81 \]
\[ R^2 = 0.98 \]

\[ r = 0.7 \]

Z, % - estimations of depth of the seasonal thawed layer
The power of heat radiation is linearly related to the amount of burnt biomass (Wooster et al., 2002).

Fire Radiative Power data are the initial information for calculating the amount of emissions during different stages of each wildfire.

The ratio of fire areas in **terms of intensity**

Fractiles of intensity:
- I) \( < \text{FRP}_{\text{mean}} - \sigma \),
- II) от \( \text{FRP}_{\text{mean}} - \sigma \) до \( \text{FRP}_{\text{mean}} + \sigma \),
- III) \( > \text{FRP}_{\text{mean}} + \sigma \)

\( \sigma \) - is standard deviation
Evaluation of wildfire emissions

Burned biomass (*Seiler, Crutzen, 1980*)

Variation of the registered radiation power (FRP)
in relation to fire parameters in model equations

<table>
<thead>
<tr>
<th>Stand</th>
<th>S, mln ha per year</th>
<th>&quot;Standard&quot; season</th>
<th>Extreme season</th>
<th>% of emission (min–max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larch</td>
<td>2.765</td>
<td>42.9</td>
<td>15.5</td>
<td>52.0</td>
</tr>
<tr>
<td>Pine</td>
<td>0.656</td>
<td>11.0</td>
<td>16.7</td>
<td>11.8</td>
</tr>
<tr>
<td>Dark coniferous</td>
<td>0.153</td>
<td>1.9</td>
<td>20.4</td>
<td>3.1</td>
</tr>
<tr>
<td>Deciduous/mixed</td>
<td>0.275</td>
<td>3.8</td>
<td>13.7</td>
<td>4.7</td>
</tr>
</tbody>
</table>

a) FRP vs burnup rate (kg/m²/sec) for different sub-pixel active burning area: 1) 1000 m², 2) 500 m², 3) 250 m²;

b) FRP vs fire front velocity and fuel load (kg/m²): 1) for 1.5 kg/m² and β = 0.55, 2) for 1.5 kg/m² and β = 0.4, 3) for 2.5 kg/m² and β = 0.55, 4) for 0.7 kg/m² and β = 0.4
Long-term emission estimates

<table>
<thead>
<tr>
<th>Method</th>
<th>Burned biomass (M)</th>
<th>Direct emissions (C)</th>
<th>$\Delta M_{rel}$ и $\Delta C_{rel}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$10^{12}$ kg</td>
<td>$\sigma$</td>
<td>$\varepsilon$ for $\alpha=0.1$</td>
</tr>
<tr>
<td>&quot;Standard&quot; (Seiler, Crutzen, 1980)</td>
<td>0.192</td>
<td>0.131</td>
<td>0.067</td>
</tr>
<tr>
<td>Standart+ FRP classification of fires</td>
<td>0.159</td>
<td>0.108</td>
<td>0.055</td>
</tr>
</tbody>
</table>

Direct emission $83 \pm 21$ Tg C/year is less in comparison with assessment for Siberia $112 \pm 25$ Tg C/year, according to standard method (Soja et al., 2004).


The total emission statistics includes $33–37\%$, $47–49\%$ and $14–17\%$ from wildfires of low-, moderate- and high intensity in terms of FRP. And specific emission values were $8.7$, $12.0$ and $15.4$ tons C/ha correspondingly.
Variations of direct carbon emissions from Siberian fires in the time interval 2002-2016:

a) trend based on the multi-year series (p <0.05);
b) In relation with air temperature anomalies for Siberia

The updated estimates of direct fire emissions in Siberia during 2002–2016 were 83 ± 21 Tg C/year in average. Current linear trend (R²=0.56) was evaluated for the last 15 years.

A trend of significant increase in direct fire emissions is observed. According to the trend fire emissions in Siberia at the end of 21 century will rise up to 220, 700 and 2300 Tg C/year in RCP2.6, RCP4.0 and RCP8.5 scenarios, correspondingly.
Conclusion

Satellite data and GIS technology is the important part of fire preventing and monitoring system for Siberia.

Real-time data on forest fires is available for different agency including the Federal forest service, EMERCOM and fire ecology science as well.

Precise database of wildfires in Siberia is available for 1996 – 2018 in GIS layer format. And number of technologies for fire characteristics assessment were adapted to the conditions of burning in boreal forests of Siberia at present time.

Remote system for fire monitoring is the main source of data for analysis and forecasting of fire impact at the scale of ecosystems of Siberian forests and globally since the assessment of forest burning in Eurasia is strongly significant.
Publications


Remote sensing in monitoring wildfires in Siberia

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