Assessment of a Forest-fire Danger Index for Russia Using NOAA Information

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Introduction

To be efficient, modern forest fire managers require a reliable method for estimating fire danger. For large remote forested areas, such as found in Russia where a dense network of local weather station needed to calculate fire danger does not exist, this can be a major problem. However, remote sensing using satellite data can provide reasonable estimates of fire danger across Russia to allow for an understanding of the current fire situation. An algorithm has been developed that can assess current fire danger by inputting ambient weather conditions derived from remote sensing data obtained from NOAA-series satellites. Necessary inputs for calculating fire danger, such as surface temperature, dew-point temperature, and precipitation, are obtained from AVHRR and TOVS satellite data. By generating the final products as maps a concise picture can be presented of fire danger across Russia. In order to understand future fire suppression needs, fire danger predictions for an advanced 7-day period can be made using meteorological forecasts of near surface pressure and air temperatures. The only problem with this type of forecasting is the absence of knowing exactly what precipitation will occur during the forecasted period. This is resolved using an interactive method that continually updates the forecasted fire danger map using current precipitation. One important application of this product for remote sensing will be the ability to classify fire severity on burn scar areas for predicting carbon release better over the vast areas of Russia. This will require the development of fire behavior models that use components of the fire danger systems as key independent variables.

Modern wildfire prevention programs cannot be successful unless they are fully supported by fire-danger analysis acquired from detailed daily fire-danger mapping. This enables better coordination and potential success of limited suppression forces. Currently the existing network of weather stations in Russia, especially in remote areas, does not allow for the estimation of fire danger over the entire country. Thus, northern forests are deprived of badly needed fire protection information because of the lack of weather stations. Remote sensing analysis and diagnosis of forest fire danger conditions is an emerging field both in Russia and abroad. The V.N.Sukachev Institute of Forest, located in Krasnoyarsk, is supporting research this field and is proposing the development of methodology for generating daily fire weather danger maps based on the digital multispectral images obtained from NOAA satellites. This will allow the computation of fire danger for remote areas without the need for supplementary on-ground weather stations.

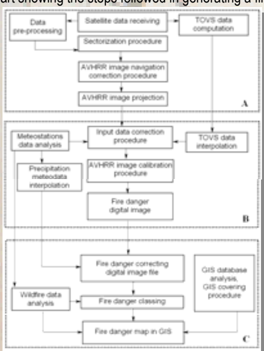
Preliminary satellite data processing

Raw satellite data obtained by the NOAA/AVHRR instrument has a spatial resolution of 1.1 km with a wide field of view of about 2 700 km across. Data is acquired for the same area twice a day by the same satellite. The wide spectral range of the AVHRR sensors allows for obtaining a number of parameters describing surface conditions of the Earth (e.g., radiative surface temperatures, vegetative indexes, etc.). In addition, the vertical sounding system (NOAA/TOVS) collects data on characteristics for the near-surface atmospheric layer (e.g., dew point temperature, wind parameters, pressure distribution, etc.).

The technology of fire-danger map generation consists of three interdependent stages. The first stage involving preliminary data processing includes acquisition and recording of the satellite signal, radiometric data calibration, sectorization (i.e., selection of a specific scene and AVHRR channel combination), geographical correction of imagery as well as cartographic projection of the chosen image scene.

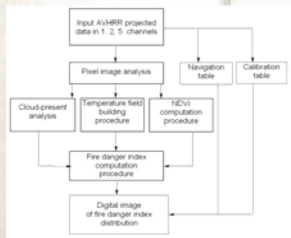
The estimation of a fire-danger index involves three AVHRR channels; the first two channels representing surface albedo and the fifth channel (thermal infrared range) allows for the restoration of the temperature field for the visible surface. The analysis of the visible and near-infrared channels allows for areas covered by either clouds or water bodies to be excluded from further consideration. This stage allows for a correction to the fire-danger index based on precipitation information obtained from local weather stations.

Flowchart showing the steps followed in generating a fire-danger map



A – Preliminary satellite data processing; B – Software development; C – GIS mapping

The block diagram of the NOAA-satellite data processing program for determining the forest fire-danger index



The estimation of fire danger index is accomplished using Nesterov's equation that has been slightly modified by us to improve its performance. The equation used is:

$$\Gamma_{ij} = \sum_i a_i \xi_i \sum_j t_{ij}(t_{ij} - \tau_{ij}) \qquad a = \left(\frac{A_3 - A_1}{A_3 + A_1} \cdot \frac{A_2 + A_1}{A_2 - A_1} \right)_{NOAA-16}$$

where Γ_{ij} is the fire danger index, τ is the dew point temperature (°C) from TOVS data, t is the radiative surface temperature (°C) from AVHRR data, ξ is the precipitation coefficient obtained from TOVS/GIS weather data, and A_n –is the albedo for AVHRR channels 1, 2, and 3ª from NOAA-16. The summation is done for every point in a scene (i) for each day (j) of the fire danger season.

Software Development

The second stage is where software was developed to allow all the pixel data to be projected as one image in a given cartographic projection, which results in a daily updated fire-danger index map. Radiometric parameters for the underlying surface obtained with the help of remote-sensing methods are used instead of actual meteorological parameters to estimate atmospheric bottom layer parameters. During the research high correlation between this data was discovered, which substantiates the development of a fire-danger index using remote sensing.

The advanced equipment contained on the NOAA-16 satellite gathers supplementary data giving an opportunity for estimation of visible surface moisture. This allows for the computation of a correction factor (a) that reflects both the vegetative index (AVHRR channels 1 and 2 data) and the quantitative estimation of visible surface moisture (AVHRR/NOAA-16 channel 3ª data).

Unfortunately cloudiness is not transparent to the AVHRR infrared wavelength. Thus radiometric data over regions obscured by clouds is not available for any computations. A solution to this situation is a proposal to use NOAA/TOVS instrument data. Unlike the infrared channels of AVHRR, the microwave range of TOVS data allows for the restoration of air moisture and temperature parameters for overcast regions.

Since TOVS data is presented as an irregular net of points, a piecewise-linear approximation method was utilized for the interpolation of parameter values at any arbitrary point in the NOAA image. The approximation consists of representing the surface defined by a function with a piecewise-linear surface consisting of triangle elements. For this purpose a net of non-intersecting triangles is created over a plane (x, y), where the projection of each point of space in the plane belongs to a particular triangle. The value of any function $f(x, y)$ is interpolated using the piecewise-linear function given Delaunay's triangulation node values. Delaunay's triangulation of the initial data is adequate in a continuous space where the piecewise-linear surface consists of triangles whose vertices represent points for the TOVS data.

The horizontal section for the continuous piecewise-linear surface will give isolines of the TOVS data. With the help of linear extrapolation using the three nearest data points (i.e., the vertices of a triangle containing the given point) it becomes possible to restore a parameter value at any point using the TOVS data.

During our research, close temperature correlation was observed between the NOAA measurements and data recorded at the on-ground weather stations. Coefficients of the correlation are very high (r = 0.7). The mean deviation for the TOVS temperature data from that registered at the weather stations was 4-6 °C. The coefficients of approximating equations were calculated for the satellite data in linear approximation taking into account temperature deviations. Hence, corrected TOVS data was used in the estimation of the fire-danger index.

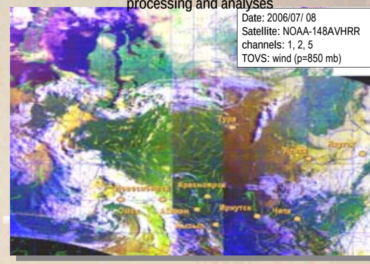
GIS mapping

The third stage takes advantage of Geographical Information Systems (GIS) technology to produce a final product. This stage is accomplished with the help of ARC/INFO 3.4.2 and ArcView 3.2 software packages. The classes of fire danger are selected according to the ranges of actual fire-danger index values. Further processing using GIS technology could combine the fire-danger maps produced here with forest fuel information to produce maps showing potential levels of fire behavior and fuel consumption. Such products would be useful in fire suppression efforts and for projecting carbon releases from fires in Russia.

Additional literature

Sukhinin A.I. and E.I. Ponomarev. 1998. Estimation of forest fuel moisture content from radiative temperature. VINITI (Moscow) №1144-В98. 26 p.
Sukhinin A.I., Kashkin V.B. and E.I. Ponomarev. 1999. Monitoring Forest Fire In Eastern Siberia From Space. Proceeding Of SPIE 3983: 206 – 214.
Ponomarev E.I. and A.I. Sukhinin. 2000. Integrated assessment of fire danger and wildfire energetic parameters forecasting by using GIS databases. Computation Technologies (Novosibirsk) 5: 58–68.
Ponomarev E.I. and A.I. Sukhinin. 2001. NOAA satellite data usage for spatial estimation of fire danger in forest. Siberian Ecological Journal (Novosibirsk) 5: 577 – 589.

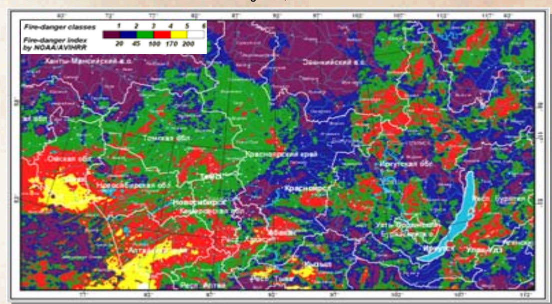
Preliminary NOAA Satellite data and weather data used in GIS weather database processing and analyses



Visible and near-infrared channels (1, 2) of AVHRR enable the detection of clouds and water body surfaces. With data from channel 5, the temperature field (thermal range) can be estimated. The analysis of TOVS data gives information on air moisture, wind velocity and direction.

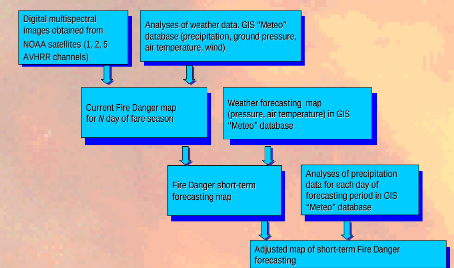
Fire burn area polygons showed that over 500000 ha burned in the Angara Region in 2006.

Fire Danger classes as estimated by NOAA-18 data for August 8, 2007



Fire danger classes are based on those used by the Russian Fire Service

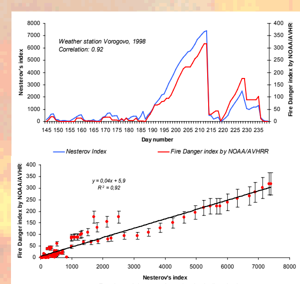
Method of fire weather danger prediction on the basis of satellite data and GIS "Meteo" datase



The test for any system that is designed for fire management is determined by its capability to predict the occurrences and fire behavior of any future wildfires. The prediction of forest fire-danger may be accomplished with the help of short-term meteorological prognoses. The short-term prognoses of air temperature and pressure over the periods of 12 to 168 hours are available as a part of the world database GIS "Meteo".

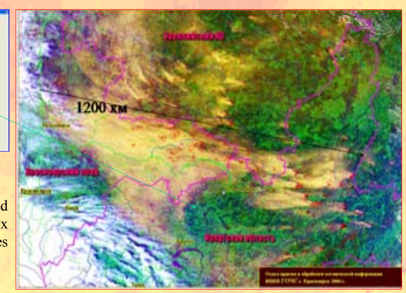
Our results provide a prediction map showing the upper limits of fire danger for Russia (i.e. the maximum values of fire weather danger in the absence of precipitation) over the next 1 to 7 days. On a daily basis, the prediction maps are updated using actual precipitation recorded at on-ground weather stations.

During the period of 1996-2006, data from 15 on-ground weather stations in the Krasnoyarsk Region were obtained. This data confirmed a close correlation (see the table below) between our fire-danger index created using remote-sensing data with the Russian Nesterov's index ($r \approx 0.9$) and indices of Canadian Forest Fire Weather Index System (BUI/FFMC, $r \approx 0.8$). These results support the accuracy of our fire danger index created from remote-sensing data and verified its use in remote areas of Russia to estimate the current fire danger.



Weather stations	correlation
Strelka	0.86
Motygino	0.74
Boguchany	0.97
Aban	0.88
Vorogovo	0.92
Alexandrovski shluz	0.97
Severo-Yeniseysk	0.96
Poligus	0.98
Baykit	0.95
Vanavara	0.93
B. Uluy	0.88
Kacha	0.89
Artemovsk	0.86
Nizhneusinskoye	0.89

Russian Moisture Index (PV-1) and Canadian Forest Fire Weather Index System Buildup Index (BUI) values over the 2006 fire season.



Smoke cover from 2006 catastrophic fires burning in the Angara Region of Siberia.

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