Data-intensive multiespectral remote sensing of the nighttime Earth for environmental monitoring and emergency response

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Abstract. All Most of the remote sensing applications rely on the daytime visible and infrared images of the Earth surface. Increase in the number of satellites, their spatial resolution as well as the number of the simultaneously observed spectral bands ensure a steady growth of the data volumes and computational complexity in the remote sensing sciences. Recent advance in the night time remote sensing is related to the enhanced sensitivity of the on-board instruments and to the unique opportunity to observe “pure” emitters in visible infrared spectra without contamination from solar heat and reflected light. A candidate set of the night-time emitters observable from the low-orbiting and geostationary satellites include steady state and temporal changes in the city and traffic electric lights, fishing boats, high-temperature industrial objects such as steel mills, oil cracking refineries and power plants, forest and agricultural fires, gas flares, volcanic eruptions and similar catastrophic events. Current satellite instruments can detect at night 10 times more of such objects compared to daytime. We will present a new data-intensive workflow of the night time remote sensing algorithms for map-reduce processing of visible and infrared images from the multispectral radiometers flown by the modern NOAA/NASA Suomi NPP and the USGS Landsat 8 satellites. Similar radiometers are installed on the new generation of the US geostationary GOES-R satellite to be launched in 2016. The new set of algorithms allows us to detect with confidence and track the abrupt changes and long-term trends in the energy of city lights, number of fishing boats, as well as the size, geometry, temperature of gas flares and to estimate monthly and early flared gas volumes by site or by country. For real-time analysis of the night time multispectral satellite images with global coverage we need gigabit network, petabyte data storage and parallel compute cluster with more than 20 nodes. To meet the processing requirements, we have used the supercomputer at the Kurchatov Institute in Moscow.

1. Introduction

When an emergency it is important to promptly and as fully as possible to assess the situation and the scale of the disaster to make the right decisions about the first respond to the disaster. Recent disasters, observed in different regions of the Earth, prove the urgency of the task. For example: 1) Hurricane Sandy [1], which led to large losses in the US in late October 2012 and in particular in New York on 29 October 2012, 2) War 2012 - 2015 in Syria and Iraq, which led to numerous casualties and partial destruction of infrastructure, and 3) an earthquake in Nepal on 25 April 2015, which led to more than 8,000 casualties [2]. In all these cases, the satellite observations of rapid changes and trends in the
brightness of the nighttime lights in different spectral bands allow to evaluate the nature and the scale of the consequences of emergency situations such as power outages and disruption of production processes.

Currently, only two US satellites are sensitive enough to provide data from the night side of the Earth in visible and infrared bands: DMSP F18 and Suomi NPP [3]. However, the number of satellites in the near future will grow. In 2017 NOAA and NASA will launch another satellite, JPSS-1, which will provide multispectral data at night, similar Suomi NPP, and later satellite JPSS-2. That means a possibility of continuous satellite monitoring of the nighttime lights of the Earth for decades.

Using time-series of pixel brightness instead of instant images increases the accuracy of assessing of the emergency extent, as it accounts for natural variability associated with the seasons, cloud cover, the moon light, and makes it possible to monitor the dynamics of the disasters and their socioeconomic and demographic consequences.

The scale and complexity of the problem arise from the need for statistical analysis of a large spatio-temporal dataset (collection of images), geolocated on a latitude-longitude grid of high resolution (from 15 to 30 arc seconds), especially the time series of brightness obtained for all pixels in the study region (administrative unit, the country or continent). The flow of "raw" data from the satellite Suomi NPP is about 3 terabytes per month. The volume of the raster database to be analyzed is more than 200 terabytes. With the launch in the 2016-2017 of the new satellites JPSS-1 and GOES-R, which will also provide the imagery of the Earth at night, suitable for detection of emergencies, the amount available for the data analysis will get close to 1 petabyte.

2. Data Model and Algorithms

To study rapid changes in the brightness of the nighttime lights and to assess the scale and dynamics of an emergency or a disaster, we use the following approaches and methods.

1. A geospatial database PostGIS that contains the images from the nighttime side of the Earth received from the Suomi NPP satellite with global coverage of the Earth's surface every night at spatial resolution of about 700 meters per pixel in the visible, near, mid and thermal IR bands (9 spectral channels).

   In the course of the creation of raster base we have to correct the satellite images for the terrain and to change the projection of the images from a satellite view into a regular latitude-longitude grid [4].

   In addition to the values of brightness in different spectral channels, the database contains information on the cloud cover, including the type and the optical thickness of the clouds, the orbital parameters and the orientation of the satellite, and other flags, which can be used to assess the quality of data for all images pixel by pixel.

   Data access interface can mosaic images from adjacent orbits and extract time series with pixel brightness in every spectral channel.

2. A new Nightfire algorithm is used to detect combustion sources at the night time surface of the Earth [5]. In many cases for the detected source we can estimate its temperature and size. The essence of the Nightfire is a non-linear fitting of the temperature and area of a combustion source using the simplex method. Combustion source observed by satellite is modeled as a black body. The size and temperature of the subpixel fire are found by minimizing the sum of squared residuals between the observed radiiances in the IR bands and the Planck curve model. The area of the combustion source may be substantially less (up to 1 m square, the sensitivity depends on the temperature of combustion) of surface area observed in the satellite image one pixel (about 1 km square).

   Compared to the previous fire detection algorithms developed by NASA for the MODIS sensors, the new algorithm at night detects an order of magnitude more sources in the same area of observation. Moreover, the Nightfire results provide not only a place, but also the temperature and the area of fire, explosion, or gas flare.
3. The task of detecting blackouts (or reduce power) by rapid changes of nighttime lights in the visible band is the most complex. It depends on many factors, among which the natural variation of the brightness of the nighttime lights of the villages and small towns, small transparency of atmosphere and clouds in the visible range as compared to the IR, additional illumination by moonlight (moon phases), the sun (summer in the polar latitudes) and air glow, as well as by fires when they occur during emergencies.

3. High Performance Computing Platform

To process the large volumes of the remote sensing data we have developed a parallel conveyor cloud-system. The system includes the MapReduce computing model, workflows, job queues, virtual computing nodes and cluster file system.

The main features of the parallel cloud conveyor are:

- The system monitors the state of the environment and starts the processing task only when there are all the necessary conditions. The system allows to track receipt and availability of all the files required for a certain stage of processing, updating some of the files processed before, user queries, the completion of the previous required steps of the processing flow, timer, etc.
- Using of composite tasks (workflows), in which any hosted applications hosted on operating system and called via the command line can be used. Workflows used in the system correspond to a MapReduce computational model. Using the MapReduce model is justified by the fact that the majority of workflows’ atomic tasks (jobs) can be parallelized on the data.
- Using templates to describe the workflows. Templates allow to define depending on names of input and output parameters, time and order of execution of jobs, the conditions of the beginning of each task/job, etc.
- Each workflow can be performed in conveyor mode on a potentially endless stream files: treating another dataset, the application takes the next one.
- The system allows control of the number of concurrent workflows and the volume of allocated computing resources.
- Using cloud computing platform and special program module for dynamic balancing resources by increasing and decreasing of the number and configuration of running virtual machines.
- Ensuring system reliability is guaranteed by locking states - the presence of restore points, queues, messaging and objectives, as well as a distributed file system allows you to increase the resiliency of the system.

Figure 1 shows the general structure of workflow management. The files from remote storage of satellite data pre-loaded into the buffer storage system. Incoming data are recorded in the database. Then the manager creates the conveyors instances according to templates. The conveyor instances take the input files from the input stream and activate the jobs. The jobs are sent to job distribution module that sends them to cluster nodes for execution under certain circumstances (presence of a specific software, available memory, processor cores and free disk space). We use SLURM [6] as the job distribution module.

Information module logs the workload of the job queue, the amount of RAM and processor cores, compute nodes, running and using virtual machines, their resources, and the total quota of the cloud provider.
4. Results

An example of the detection by algorithm Nightfire from the weather satellite Suomi NPP is the explosion in Chapaevsk, Russia, 18 June 2013 is shown in figure 2. Location of the explosion is shown in blue pushpin on the Google Earth map. Detected parameters of the combustion source at the time of flight of the satellite were:

Time = 18-Jun-2013 22:14:24 UTC Latitude = 52.991741 deg North Longitude = 49.800602 deg East Temperature = 1079 degrees K Energy combustion = 2.63 MW Area combustion = 34.22 sq m

The combustion source was detected through the cloud cover. The figures below show the explosion photo by witnesses from the scene and the result of the Planck curve fitting to the brightness recorded in the near infrared satellite channels.
Figure 2. Nightfire detection of the Chapaevsk explosion

The Figure 3 illustrates the preliminary results of the analysis of time series of the brightness of nighttime lights in the visible (400-800 nm) and near infrared (SWIR 1.6 m) bands from the satellite Suomi NPP of oil refinery in Syria controlled by ISIS for the time period from April 2012 to April 2015. From the spring of 2013 this area is located in a war zone. The site coordinates are 35.122955 deg North and 40.543999 deg East.

Joint analysis of the time series in the infrared and visible bands, taking into account the results of the Nightfire algorithm (temperature time series of the gas flare at the refinery) allows us to conclude that the cracking at the site was suspended in February 2013, but the site was illuminated with electric lights almost all the time during the observation period, possibly except for time periods from December 2013 to May 2014 and from October 2014 to January 2015.

5. Conclusion and Future Work
Development of the automated system to monitor changes in night time lights after disasters and in war zones is still a work in progress. We have most of the components in hand, including the parallel raw data processing conveyor, the geospatial database for data mining, multispectral detector of fires and flares. However, we still analyse visible night time light changes “by hand”, but this task is close to be automated in the nearest future.
Figure 3. Time series of flare temperature and visible brightness for an oil production site in Syria

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