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Ecologic assessment of air pollution by nitrogen dioxide over the territory of Europe using Earth remote sensing data

For the first time, using satellite Earth remote sensing data, the maps of air pollution risks by nitrogen dioxide (NO_2) over the territory of Europe with spatial resolution of 0.25°×0.25° (approximately 27.5 km × 18 km for the 48° latitude) were created. The suggested risk calculation technique is simple yet delivers extensive understanding of typical air pollution character. It is shown that the highest risks of air pollution by nitrogen dioxide in Europe are observed over Germany, Belgium, Netherlands and southern part of the North Sea as well as over large cities.

Keywords: *Earth remote sensing data, atmospheric air, nitrogen dioxide, time series, maps of risk.*

Introduction

Nitrogen dioxide (NO_2) is a very toxic gas [1] and is one of the major air pollutants in Europe [2]. Today, open nitrogen dioxide air pollution data come mainly from irregularly spaced network of ground-based stations (point measurements) [3]. Many European countries have large areas without nitrogen dioxide measurement stations. The measurements of the pollutant in the air over the European seas are even scarcer. Chemical reactions, air transport of pollutants in the atmosphere and other factors lead to low reliability of numerical modeling in the areas without air quality control stations. It is impossible to obtain a complete and consistent picture of typical air pollution pattern by nitrogen dioxide over the whole territory of Europe using only ground-based air pollution data.

Satellite Earth remote sensing data provide atmospheric pollutant concentrations with high spatial and temporal resolution. Today, these data are not widely used for solving practical tasks of ecologic monitoring due to extremely high complexity of accessing to them, their visualization and analysis.

Climate Wikience provides time series of daily nitrogen dioxide concentrations for each cell of regular latitude-longitude grid with 0.25º×0.25º spatial resolution [4]. The time series are easily accessible from R environment [5]. This offers opportunities not available before for solving urgent tasks of environmental protection.

A comprehensive study of nitrogen dioxide pollution over United States, Europe and China was carried out using remote sensing data from GOME and SCHIAMACHY radiometers [6]. A considerable increase in nitrogen dioxide concentration over China was found and no trend for USA and a decreasing trend for Western Europe were observed.

The goal of the research carried out in this paper is to derive the "typical" picture of air pollution by nitrogen dioxide over the whole territory of Europe instead of climatological mean or study of individual pollution episodes. The approach proposed below allows reducing considerably the influence on the resulting risk map the nitrogen dioxide concentration values not typical for the air over the territory under investigation.

High resolution maps of air pollution risks allow answering many important questions in the domain of ecologic safety. For example, what countries have the highest level of air pollution and what is the relative level of air pollution between different regions inside a country.

Satellite Earth remote sensing data

Daily tropospheric column amounts of nitrogen dioxide are derived from OMI radiometer measurements (Aura satellite). They are available from NASA as NO2d level 3 product on regular 0.25º×0.25º latitude-longitude grid. Cloud screened (less than 30% of cloud cover) daily data during 01.10.2004–31.12.2012 were used [7].

The NO_2 concentration is given in molecules per cm^2. In this paper all measurements are converted to Dobson units (1 Dobson unit (DU) equals to 2.69×10^{16} molecules/cm^2).

For the first time nitrogen dioxide time series were obtained for each cell of regular 0.25º×0.25º latitude-longitude grid [4]. Time series are directly available within R analysis environment [5].

Studying nitrogen dioxide concentration patterns to select pollution categories

A broad range of nitrogen dioxide concentration values is typical for the air over large European cities (fig. 1–3). Thus, the distribution of a pollutant in their atmosphere may hint the levels for defining pollution categories.

Figures 1–3 give nitrogen dioxide histograms at 0.1 DU intervals for several European cities and a

presumably clean region within Ukraine. Seems like interval 0.1 DU captures the general pattern of the pollutant distribution in the air over the cities. The coordinates of the grid cells (0.25°×0.25° resolution) are given for each location. Coordinates correspond to the south-western corner of a grid cell. The major part of a city under investigation is located inside the selected cell.

Brussels, as will be shown further on the risk map, reveals a typical pattern of heavy nitrogen dioxide pollution over Europe. London (England) and Milan (Italy) reveal the same nitrogen dioxide concentration distribution as Brussels, although slightly higher. Paris has the same pattern as Belgium. Milan is similar to Moscow but with no cases over 3 DU.

Analyzing figures 1 – 3, pollution categories can be experimentally and subjectively defined as: [0.0..0.2] – low, [0.2..0.4] – moderate, [0.4..0.6] – high, [0.6..0.8] – very high, over 0.8 – disastrous. The numbers in given intervals are Dobson units.

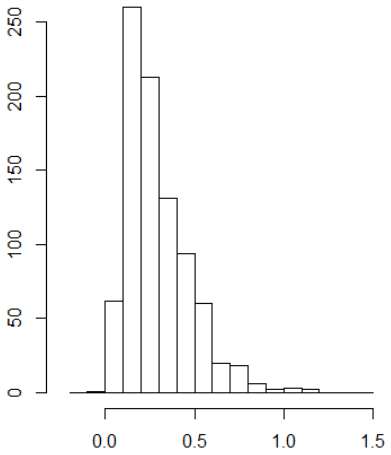

Figure 1 – Histogram of nitrogen dioxide concentration over Brussels, Belgium (50.5°, 4.25°)

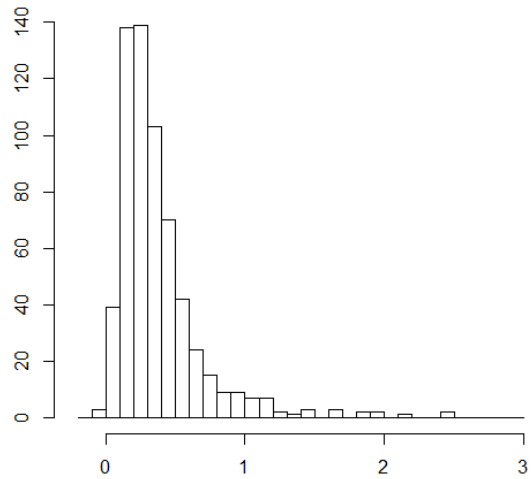

Figure 2 – Histogram of nitrogen dioxide concentration over Moscow, Russian Federation (55.75°, 37.5°). Cases over 3.0 DU are filtered out.

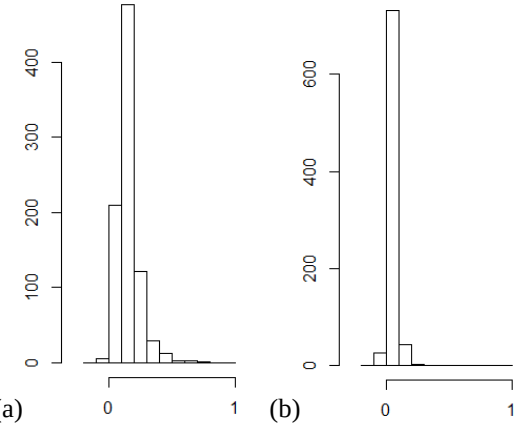

Figure 3 – Histogram of nitrogen dioxide concentration over (a) Donetsk, Ukraine (48°, 37.75°) and (b) clean region, Ukraine (49.5°, 28.5°)

Step 0.2 DU for pollution categories allows capturing the majority of features of nitrogen dioxide pollution distribution over Europe. This also keeps the number of pollution categories acceptable.

Risk calculation method

In this paper, the air pollution risk is defined as the probability of observing a pollutant concentration in a given interval over the territory under investigation. The risk is calculated for each grid cell.

The risk of pollution for a grid cell equals to $R(a, b)=S(a, b) / T$.

In the formula above, $S(a, b)$ is the number of days with nitrogen dioxide concentration in $[a..b]$ interval, and T is the number of days for which nitrogen dioxide measurements are not missing due to clouds or other reasons. Both $S(a, b)$ and T are calculated for each grid cell.

The notation "moderate air pollution risk" will be used to denote the risk value for moderate air pollution level, i.e. nitrogen dioxide concentration between 0.2 DU..0.4 DU.

Results and discussion

Probably, the map of moderate air pollution risk is the most representative for "typical" nitrogen dioxide distribution over Europe (fig. 8). The map spans the territory of Europe approximately from London (England) on the west to Baku (Azerbaijan) on the east and from St. Petersburg (Russian Federation) on the north to Republic of Malta on the south. To better perceive the geographical context of the research, the map of Europe spanning the same area under investigation is given on figure 9.

The most noticeable areas with high pollution risks include large cities and industrial zones. The most distinguishable large cities are Moscow (Russian Federation), Rome (Italy), Barcelona (Spain), Naples (Italy), Paris (France), Katowice (Poland), Istanbul (Turkey).

The air over eastern part of United Kingdom, Belgium, Netherlands and western Germany is exposed to the highest risks in Europe (moderate air pollution category by nitrogen dioxide). Germany is most susceptible to air pollution by nitrogen dioxide since considerable risk levels are observed all over its territory.

High risk levels also inherent to the air over North Sea between United Kingdom, Belgium and Netherlands.

Daily fields and seasonal means

The goal of the proposed risk method is to derive the typical picture of air pollution by a gas over a given territory. The need for applying the proposed assessment strategy is motivated by the following observations.

First, daily satellite maps are highly cluttered due to gaps caused mainly by clouds (fig. 4).

Second, the noise inherent to satellite measurements of trace gases distorts the overall pollution picture for a single day.

Third, high pollution events that are extremely rare for a given region must be filtered out and must not contribute to "typical" air pollution picture.

While daily data are very important for understanding the peculiarities of a gas distribution, it is quite difficult to infer the typical pollution character using a single daily map.

Forth, composite maps of several consequent daily maps or seasonal means of trace gas concentrations do not consider other periods of year. Also a composite map does not always give a good feeling of typical gas concentrations inherent to a region.

Sometimes it is even impossible to select a period for creating a composite map as in case with sulphur dioxide (SO_2) since the number of days with SO_2 concentration between 1.5..2.5 DU account for less than 10% of days during 7.5 years for a region inside Ukraine [8]. At the same time, SO_2 concentrations between 1.5..2.5 DU are up to 5 times more frequent for the air over eastern Ukraine than its other parts as can be readily concluded from the risk map (fig. 7). In contrast, a composite map of SO_2 concentration for a period gives a uniform pollution picture over the whole territory of Ukraine with low (below 1.5 DU) sulphur dioxide concentration (fig. 5) or shows pollution distribution not "typical" for the country (fig. 6).

Risk map (fig. 7) clearly distinguishes eastern part of Ukraine as being its industrial region while a composite map (fig. 6) reveals only a rare case with higher SO_2 concentrations in its western part.

Sulfur dioxide data are also derived from OMI Aura and have the same units, spatial and temporal resolution as described above for nitrogen dioxide.

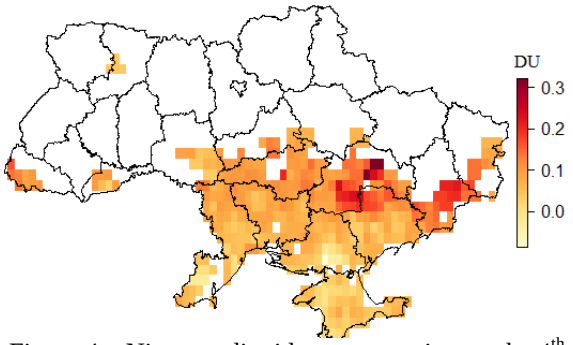

Figure 4 – Nitrogen dioxide concentration on the 4th of October, 2004

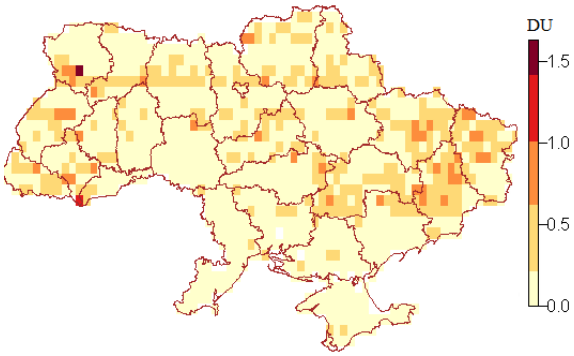

Figure 5 – Composite map of average SO_2 concentration during 9–15 August, 2008

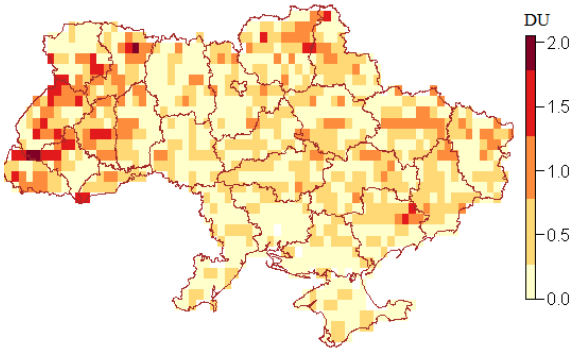

Figure 6 – Composite map of average SO_2 concentration during 11–17 October, 2008

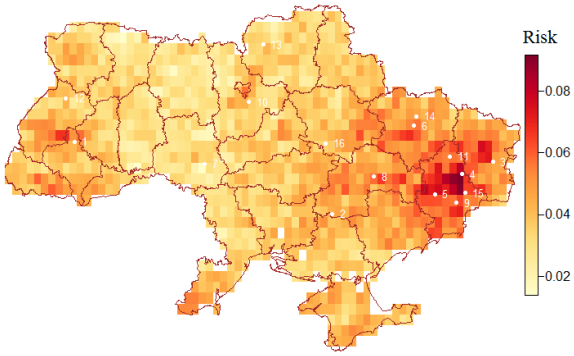

Figure 7 – Risk map of SO_2 concentration in 1.5..2.5 DU interval for 01.10.2004–20.06.2012 period

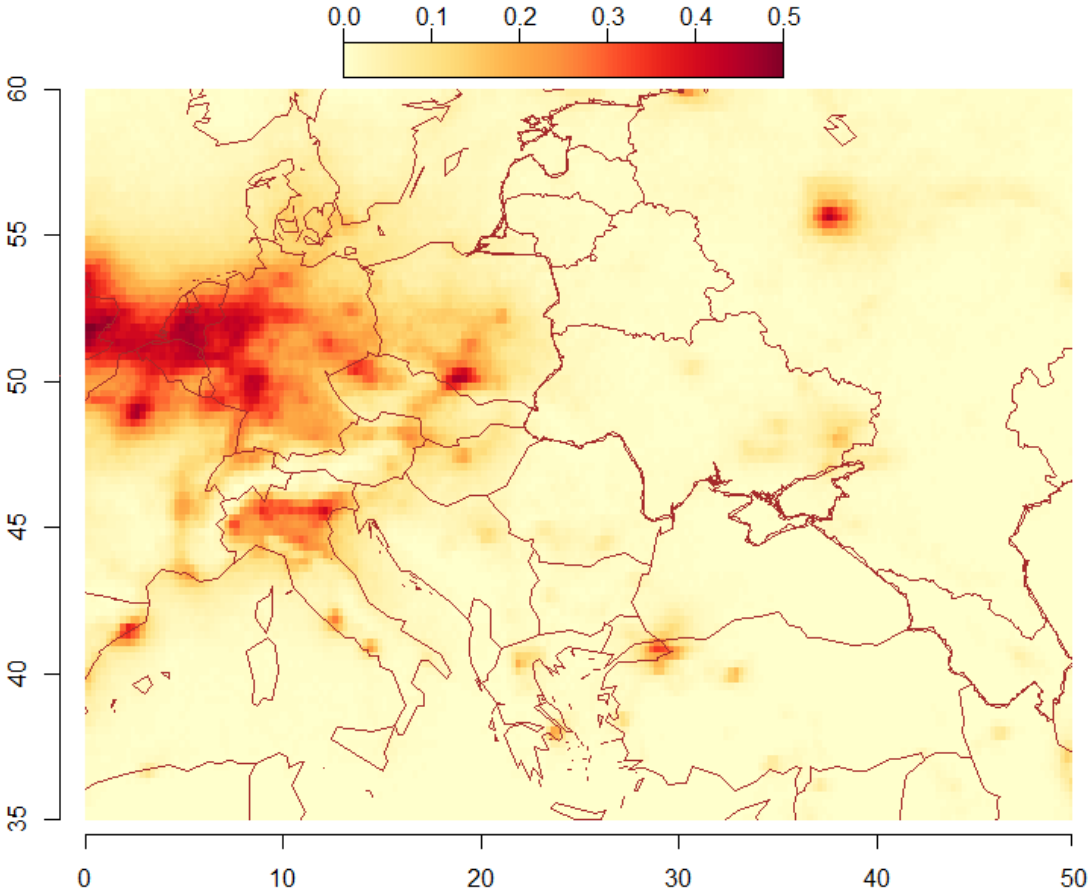

Figure 8 – Map of moderate air pollution risk by nitrogen dioxide (0.2..0.4 DU) over the territory of Europe with spatial resolution 0.25º×0.25º

Figure 9 – The political map of Europe corresponding to the area for which air pollution risks by nitrogen dioxide are shown on figure 7

Conclusions and further work

The paper presents simple yet informative approach for estimating typical picture of air pollution over a territory using Earth remote sensing data. The approach considers retrospective air pollution data for a region and calculates the probability (risk) of a pollutant concentration being in a given interval.

The air pollution risk maps generated by applying the proposed technique allow comparing areas according to typical air pollution conditions.

A researcher must perform exploratory analyses of the gas distribution over the territory before subjectively defining air pollution categories.

Further work may be directed to rating European countries according to their risk of air pollution by nitrogen dioxide. The rate of a country can be calculated by aggregating risk values of grid cells inside the administrative boundaries of a country.

Acknowledgements

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Paper availability

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ЕКОЛОГІЧНА ОЦІНКА ЗАБРУДНЕННЯ АТМОСФЕРНОГО ПОВІТРЯ ДІОКСИДОМ АЗОТУ НАД ТЕРИТОРІЄЮ ЄВРОПИ ЗА ДАНИМИ ДИСТАНЦІЙНОГО ЗОНДУВАННЯ ЗЕМЛІ

Вперше з використанням даних дистанційного зондування Землі побудовано карти ризиків забруднення атмосферного повітря над територією Європи діоксидом азоту (NO_2) з просторовим дозволом 0,25º × 0,25º (приблизно 27,5 км × 18 км на широті 48º). Запропонована методика розрахунку ризику є простою, але надає наглядне розуміння типового характеру забруднення повітря. Показано, що найвищі рівні забруднення повітря діоксидом азоту в Європі спостерігаються над Німеччиною, Бельгією, Нідерландами та південній частині Північного моря, а також великими містами. ***Ключові слова: дані дистанційного зондування Землі, атмосферне повітря, діоксид азоту, часові ряди, карти ризику.***

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ЭКОЛОГИЧЕСКАЯ ОЦЕНКА ЗАГРЯЗНЕНИЯ АТМОСФЕРНОГО ВОЗДУХА ДИОКСИДОМ АЗОТА НАД ТЕРРИТОРИЕЙ ЕВРОПЫ ПО ДАННЫМ ДИСТАНЦИОННОГО ЗОНДИРОВАНИЯ ЗЕМЛИ

Впервые с использованием данных дистанционного зондирования Земли построены карты рисков загрязнения атмосферного воздуха над территорией Европы диоксидом азота (NO_2) с пространственным разрешением 0,25º × 0,25º (примерно 27,5 км × 18 км на широте 48º). Предложенная методика расчета риска является простой, но предоставляет наглядное понимание типичного характера загрязнения воздуха. Показано, что высокие уровни загрязнения воздуха диоксидом азота в Европе наблюдаются Германией, Бельгией, Нидерландами и южной части Северного моря, а также крупными городами.
Ключевые слова: данные дистанционного зондирования Земли, атмосферный воздух, диоксид азота, временные ряды, карты риска.

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