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Design and prototype of an interoperable online air quality information system

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ABSTRACT

This paper focuses on the design and development of a Spatial Data Infrastructure (SDI)-compliant online system for air quality information retrieval, including support for real-time monitoring. This system assesses exposure to ambient air to mitigate potential health risks, which is crucial for susceptible individuals, health practitioners and decision makers. Particular attention is paid to the development of an interoperable, applicable and transferrable approach to the application of robust and flexible air quality modeling as required for early warning systems on the Web. Moreover, the design provides different access levels to system components for both non-expert and scientific users and supports extension with external standard compliant services. The developed Web-client Time2Maps enables the user to view, analyze and download requested air quality information and serves as a portal to the designed online system.

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1. Introduction

The adverse impact of poor air quality on human health, especially the respiratory and cardiovascular systems, is well known and documented (e.g., Janssen and Mehta, 2006; EEA, 2012). During previous decades, various legislative initiatives and technical developments have helped to improve air quality in many countries. However, this topic is still considered a significant issue (WHO, 2009). Consequently, timely information about current air quality conditions is considered crucial, not only for individuals, who must be alerted about potentially adverse air pollution levels or meteorological extremes, but also for a vast group of stakeholders, such as health practitioners and decision makers, who monitor potential health risks and initiate mitigation strategies.

Today, a huge number of different online air quality information sources are already available (Johansson et al., 2015). Related information services are not only provided by weather services but also offered by various environmental administrations and different private or commercial providers. However, these sources still lack interoperable air quality information services that can easily integrate provided air quality maps and indicators into different information systems to efficiently support fusion with further data sources and related decision support tools. This paper describes and discusses the design and implementation of a flexible and interoperable online system to provide air quality information as a basis for subsequent exposure and health risk assessment in a timely fashion. Accordingly, the presented system design focuses on three key points:

1. *Interoperability*: The standards and specifications that are used for the development and establishment of Spatial Data Infrastructures (SDI) serve as the reference framework to achieve interoperability. Related standards from the International Standardization Organization (ISO) and the Open Geospatial Consortium (OGC) are applied and tested for their suitability to support the provision of spatio-temporal air quality information. By using and extending state-of-the-art technology and standards, this system is implemented as a set of interoperable Web Services, which can easily be integrated into existing SDI and Geographical Information Systems (GIS).
2. *Applicability*: Interoperability is one key aspect to ease applicability. Additionally, the system builds on available, official, in situ air quality observation networks, on remote sensing and on additional topographic, traffic and socio-economic data sources that are typically available. The application of easily understood and robust statistical methods to calculate air quality maps should support an easy and ad-hoc deployment of the developed components. The resulting system serves continuous

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spatio-temporal air quality information to both non-expert and scientific users. The information can be directly visualized via interactive Web maps or integrated into other information and analysis systems via the offered Web services.

3. *Transferability*: In addition to interoperability and applicability, the provision and usage of easily available software components (ideally well-maintained and open source) and commonly and globally available data sets (e.g., digital elevation models, remote sensing derived land cover, open street map data, etc.) should ease transfer towards other areas.

The methods and tools that are presented in this paper mainly focus on applications to describe the spatio-temporal distribution of particulate matter with diameters less than 10 μm (PM10), which is one of the most prominent pollutants in research and the media because of its well-known health implications. However, this system is expected to be easily extendable to other air pollutants or meteorological parameters.

Chapter 2 introduces air quality monitoring and the current state towards interoperable, Web-based environmental information services. The general design of the system components (chapter 3) includes a description of the applied statistical modeling approach and a discussion regarding the applicability of current remote sensing products for air quality monitoring. The actual system implementation is described in chapter 4. Chapter 5 concludes with related findings and identifies future research and development issues.

2. Air quality monitoring and web-based information systems

2.1. Air quality monitoring and modeling

Legislation and regulations provide the general framework for today's official air quality monitoring. As a prominent example, the European CAFE Directive (Directive 2008/50/EC on ambient quality and cleaner air for Europe; EU, 2008) mandates European Union member states to assess national ambient air quality by operating appropriate measurement systems (observations and models). The directive requires an implementation of clean air plans to keep harmful air pollution below defined thresholds. In addition to thresholds for a number of air pollutants, the directive defines general rules on the setup of observation networks, including the spatial and temporal resolution and requirements for the sampling locations. In the case of particulate matter, the distribution of stations is determined by population density and PM assessment thresholds. For example, a midsized city with approximately half a million inhabitants is typically monitored with two or three stations. Measurements shall be available on a daily or, where possible, on an hourly basis with a data availability of 90% and a maximum uncertainty of 25% at fixed measurement stations (EU, 2008).

For PM10, particles with a diameter less than 10 μm, an annual average of 40 $\mu g/m^3$ is defined as the threshold for the protection of human health. Moreover, a concentration of 50 $\mu g/m^3$ shall not be exceeded for more than 35 days a year. The annual average threshold for PM2.5, particles with a diameter less than 2.5 μm, is set to 25 $\mu g/m^3$. However, because PM2.5 is considered harmful at any concentration, the directive stipulates an explicit reduction target for all member states. In addition to the regulation of PM10 and PM2.5 concentrations, the measurement and assessment of the ultra-fine fraction of particulate matter (PM0.1) has become more important. A comprehensive review of corresponding studies together with recommended environmental actions are summarized by the WHO REVIHAAP report (WHO, 2013).

Continuous monitoring builds the foundation to observe the status of and changes in air quality. Existing in situ sensors typically provide time series of different air quality parameters as point-based measurements that are valid within the direct vicinity of the sensor station. Following the principle of subsidiarity, numerous national or regional environment agencies provide up-to-date air quality observations within their administrative areas. Because of legal reporting obligations, those observations are usually aggregated on higher levels (e.g., the European air quality database, Airbase[1]). Although the online availability of air quality data continuously increases, the harmonization of air quality monitoring standards and processes is recognized as a major issue (Engel-Cox et al., 2013). Many technical and organizational aspects are addressed by the INSPIRE directive (Directive 2007/2/EC establishing an Infrastructure for Spatial Information in Europe, EU 2007), which lays down a general framework for publishing environmental data in the European Union, comprising the application of open standards for data encoding and exchange and regulations regarding the general availability and accessibility of data. The INSPIRE data specifications on *Atmospheric Conditions* and on *Environmental Monitoring Facilities* are of particular importance in terms of air quality. As a logical consequence, the CAFE directive explicitly demands compatibility to the INSPIRE directive with regards to its implementation.

Even if in situ air quality monitoring is legally required, continuous measurements of current sensor networks provide rather coarse measurements to stay cost efficient. Accordingly, the derivation of spatially covering air quality maps typically requires a spatial densification of the air quality observations (Engel-Cox et al., 2013). Such a densification is typically achieved by using geostatistical models or a combination of geostatistical and deterministic models. Deterministic models are based on emission rates and simulate actual meteorological and chemical processes in the atmosphere and their effects on air pollutant distribution. However, exact emission rates and the distinction between anthropogenic and natural sources are often unknown or subject to uncertainty (Klingner and Sähn, 2008). In contrast, statistical models mainly rely on sensor observations and their statistical relationships and use interpolation methods or land-use regression. For reviews on corresponding approaches, refer to Ryan and LeMasters (2007), Hoek et al. (2008) and Gulliver et al. (2011). Models that involve Web-based implementation can be divided into two categories: (1) simple to use and automatable models that can directly be accessed and executed online and (2) complex, ideally automatable models that can be used for the calibration and validation of previous models.

By using remote sensing, information can be obtained from a distance (ex situ) by measuring and analyzing the interaction of electromagnetic radiation with a feature of interest, which results in certain spectral and radiometric properties. Remote sensing is used to measure the transmission characteristics of radiation throughout the atmosphere in terms of air quality. The transition is influenced by aerosols and trace gases and allows conclusions regarding the concentration and distribution of air pollutants. Compared to in situ measurement networks, remote sensing (1) promises not only point based observations but observations that cover an area (i.e., Pixel) and (2) could offer global coverage of observation products of an agreed and harmonized quality level, thus promising good applicability and transferability as required for the intended online system. However, the major challenge is to derive air quality at ground level, where it actually poses a risk to human health. An overview of satellite systems and their

[1] http://www.eea.europa.eu/themes/air/air-quality/map/airbase.

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