SEVENTH FRAMEWORK PROGRAMME

THEME 6

ENVIRONMENT (INCLUDING CLIMATE CHANGE)

EO2HEAVEN

Earth Observation and ENVironmental modelling for the mitigation of HEAlth risks

244100 - EO2HEAVEN CP-IP

D1.8 Final Report

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PROJECT FINAL REPORT

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Project acronym: EO2HEAVEN

Project title:

Earth Observation and ENVironmental modelling for the mitigation of HEAlth risks

Funding Scheme: Collaborative Project

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1 Final publishable summary report

1.1 Executive summary

The project EO2HEAVEN 'Earth observation and environmental modelling for the mitigation of health risks' advanced knowledge on the impact of environmental factors on public health outcomes. The multidisciplinary and user-driven project approach focused on the effect of atmospheric pollution (in case studies in Durban / South Africa and Saxony / Germany) on cardiovascular and respiratory diseases and the waterborne disease cholera (in a case study in Uganda). Public health stakeholders and practitioners were actively involved in the project activities and worked with technology and service providers in the areas of Earth observation (EO) and environmental monitoring.

EO2HEAVEN has developed methodologies, correlation models, spatial data services (using Standards of the Open Geospatial Consortium) and applications supporting the main activities involved in environmental health:

- discovery and acquisition of environmental data
- integration of heterogeneous Earth observations (satellite, in-situ and field data)
- extraction of time series and visualization of graphs and maps
- development of models of health effects
- development of risk maps
- development of predictions for early warning systems

EO2HEAVEN has specified and implemented a Spatial Information Infrastructure (SII). This is an open architecture based on international standards and geospatial web services supporting the large-scale initiative GEOSS of GEO (Group on Earth Observations).

These results are documented in publically available reports and best practice documents.

EO2HEAVEN contributed best practices and proof of concept implementations to GEOSS pilot activities. EO2HEAVEN had strong interactions with the GEO Community of Practice “Health and Environment” and led the SBA health activities in the GEO Architecture Implementation Pilot phase 5 (AIP-5).

Specific systems and generic components were realised aiding decision-making across the health and environmental domains. These EO2HEAVEN deliverables have proven to be valuable to end-user stakeholders such as health professionals as well as scientists and domain experts.

Special emphasis was placed on achieving sustainability through capacity building in stakeholder and user training workshops in Uganda, South Africa and Germany.

1.2 Project context and objectives

The two high-level project objectives were 1) the development of a methodological approach for cross-domain analysis of environment and health questions; and 2) to contribute to and support the large-scale initiatives GEOSS and INSPIRE. A number of specific objectives were defined to achieve measurable progress towards these high-level objectives as described below. The public reports referred to are available at http://www.eo2heaven.org/category/documents-categories/public-deliverables.

To develop a shared understanding of the problems between the interdisciplinary research groups

In order to facilitate the cross-domain work several tasks and associated reports were achieved:

- The project took a multidisciplinary approach involving experts from the domains of health, epidemiology, microbiology, geo-informatics, ICT, modelling and statistics.
- The three Case Studies shared a common structure and delivery planning split into three iterations. In collaboration with users, a detailed specification of the use cases for each of the EO2HEAVEN development cycles was provided. The specifications included functional and non-functional requirements, criteria for the validation and descriptions of the technical environment. In all, three full iterations of the Case Studies and use cases specifications were completed. For collecting and harmonising the user requirements from each use case specification there was a specific task producing a *Harmonised use case specification and user requirements report after each cycle*.
- To organise cross-domain workshops that address research topics from an environmental, health and ethical perspective as well as the geospatial technology and data viewpoint. The first training and stakeholder workshops of the project were held in South Africa on 7-10 November 2011. They were directed towards training on the project's intermediate results related to data integration and software use. The results of the workshops are documented in detail in specific reports with the *On-line Training materials* and *Training Workshops*.
- A second series of cross-domain stakeholder and training workshops addressing research topics from an environmental, health and ethical perspective as well as the geospatial technology and data viewpoint was organized and carried out with success in Uganda and South Africa. The participants encompassed IT and GIS experts, environmental scientists and experts in the field of health and the environment, as well as medical and health practitioners. An international group of cholera experts met under the auspices of EO2HEAVEN and now plan a longer term collaboration.
- EO2HEAVEN participated in a number of GEO related meetings that were attended by experts from many of the SBA domains. This promoted the exchange of experience and approaches.

Establish a new quality for environmental health studies. To develop new data fusion methodologies to integrate environmental data from EO and various other sources into an information product that is best suited for environmental health studies in the EO2HEAVEN Case Studies

- The work package about *Environmental Monitoring for Health Applications* provided recommendations on fit-for-purpose environmental information products and suitable and robust methods and models for risk map production or disease propagation simulations. The overall experience and gained knowledge in dealing with environmental data for health applications has been compiled into a set of public reports:
    - D3.11 Catalogue of EO/EI Data Products
    - D3.13 Methodologies for Health and Environment data fusion and data mining
    - D3.14 Processing Chains Prototypes
    - D3.15 Environmental Monitoring for Health Applications (provided at the end of the pro-

ject as an overall compilation of results)

- The task *Synthesis and Recommendations* put a strong emphasize on summarising the results in relation to the Case Studies. The objective was to collect information on the current status and experiences and provide an overview of activities and results which cross the boundaries of the Work Packages, but need to be treated as unified topics. This report is structured into three major sections: Definitions, project approach and case study outline; overview of health data and environmental data in the context of the case studies; and best practice recommendations for environment and health data correlation. This is available as public deliverable D3.15 Environmental Monitoring for Health Applications.
- The final project results have been compiled in a published book available as PDF or as a print medium.

Ensure that stakeholders know how to use the EO2HEAVEN data products and tools: organise training workshops that address the EO2HEAVEN Case Studies and provide practical tool exercises, and provide on-line materials for e-learning

- As preparation for the stakeholder training workshops held in South Africa during 7-10 November 2011, a collection of presentations and exercises was developed. The workshop participants were provided with a binder containing EO2HEAVEN project info, workshop program, participant list, presentation hand outs and hands-on exercises. In addition, these materials are available on-line on the workshop web site together with screen cast videos of software demos and reports of breakout sessions held during the workshop. The workshop web site is based on the Blackboard platform and can be accessed at http://bb.itc.nl under protected access. The workshop materials have also been published on the EO2HEAVEN website: http://www.eo2heaven.org in the subfolder 'workshops'.
- A second iteration of stakeholder and training workshops was held in Uganda and South Africa in February 2013:
    - The workshops in the cholera prone Kasese district of Uganda targeted local health workers.
    - The workshops in Kampala and Pretoria were designed for health and environment experts and responsible people at system organisation level. They focussed on methods and issues around the establishment of information and warning systems.
    - The workshop in Durban was directed at the local stakeholders from the eThekwini municipality, providing training on the use of an environmental health system
    - These events allowed us to strengthen the links established with the organisations and explore how to make the results sustainable. The various training materials and presentations are available on-line.

Specify, develop and validate methods for extraction of Environmental parameters based on EO data and In-Situ sensors

- Progress in these tasks is mainly reflected in the public report *D3.13 Methodologies for Health and Environment data fusion and data mining*. This document describes health and environment data fusion and data mining methodologies that are considered useful in the field of health and the environment. It provides guidance for the appropriate preparation, use and fusion of environmental in-situ and remote sensing data, and both forms of environmental data with health data. More precisely, the objective of this document is to identify and present relevant methods and tools to detect these correlations. The first section on the methods for health and environmental data fusion and mining describes time series extractions. Subsequent sections focus on spatial data fusion; air quality modelling; statistics such as descriptive statistics, non-spatial cluster analysis); validation, e.g. validation of remote sensing data, validation of health data, cross covariance analysis and the assessment of environment-health relationships; spatial statistics and proxy data. Information is also given on pre-processing methodologies, such as interpolation, aggregation, analysis of field and laboratory data.
- The description of scenarios includes the specific workflows and processing steps of each scenario. Thus each scenario contains all necessary input data, the processing steps and finally the results.

*Contribution to the objectives of the health task HE-01 Tools and Information for Health Decision-Making in the GEO workplan 2012-2015 (*http://www.earthobservations.org/geoss_imp.php)*:*

- Develop tools and information systems for the environment and human health.
- Advance the integration of Earth observations and forecasts into health decision-making processes.
- Engage with health users and decision-makers to identify needs.
- Carry out capacity building and the promotion and sustainable use of Earth information by the health user-community.
- Establish linkages with other Societal Benefit Areas such as Ecosystems, Biodiversity, Climate and Disasters

EO2HEAVEN contributed to the activities on components C1 (Air-borne Diseases, Air Quality and Aeroallergens) and C2 (Water-borne Diseases, Water Quality and Risk) in this HE-01 task. The EO2HEAVEN results are recorded in the corresponding GEO component sheets. EO2HEAVEN contributed to the definition of HE-01 and also led the health thread in AIP-5 (part of task IN-05 GEOSS Design and Interoperability) in the GEO Workplan 2012-2015. The EO2HEAVEN capacity building activities are recorded in the results of the GEO task ID-01 “Developing Institutional and Individual Capacity”.

The realisation of a cholera early warning system with components and knowledge from EO2HEAVEN is now being actively pursued together with the pivotal organisations WHO (coordinator of GEO task HE-01) and NOAA (point of contact for the component HE-01-C2 on water-borne diseases). This activity initiated in EO2HEAVEN will continue beyond the project.

EO2HEAVEN has shown involvement in the health task HE-01 through its continued participation in the GEO Health and Environment Community of Practice by representing the Health and Environment CoP at a meeting of the GEO Integrated Global Water Cycle Observations CoP. This will strengthen the linkage between the SBAs Health and Water. The participation in other GEO events has contributed to an increased awareness of the thematic links to other SBAs.

To provide an open and generic Spatial Information Infrastructure (SII) architecture: base the architecture on open specifications; continue and expand the architectures specified by ORCHESTRA and SANY; assure that the SII architecture complies with international standards; active and early contribution to standardisation working groups and feed specification and implementation experience back to standards bodies; include innovative technologies into the SII architecture and infrastructure

- The EO2HEAVEN Spatial Information Infrastructure (SII) is designed as a multipart document following agreement to structure the reports of the heavily interlinked tasks *Specification of the Spatial Information Infrastructure, Advance Sensor Web Enablement Concepts* and *Advance Distributed Geo-Processing & Spatial Decision Support*, such that there is a coherent and redundancy-free set of architectural specifications. Therefore the deliverables “Specification of the Advanced SWE Concepts” and “Advanced Distributed Geo-Processing & Spatial Decision Support” are integrated into the respective issues of the “Specification of the Spatial Information Infrastructure”.
- The SII continues the series of architecture specifications of the previous FP6 European projects ORCHESTRA and it builds upon agreed specifications of a geospatial service-oriented architecture (SOA) provided by ORCHESTRA and extended by a Sensor Service Architecture of the SANY project. The EO2HEAVEN extensions include topics on remote sensing, health data (access control, integration with environmental data) and mobile applications. EO2HEAVEN has submitted part of the SII to OGC as a proposal for an OGC Best Practices Document for Sensor Web Enablement - “Provision of Observations through an OGC Sensor Observation Service (SOS)” (OGC 13-015, status: candidate, voting ended on 22/06/2013 with all votes positive). This paper provides recommendations to simplify the provision of observation data based on the SOS 2.0 standard, especially for scientists and non-IT experts.
- The fourth issue of the SII was released as a set of public documents in April 2013: D4.13 Specification of the SII Implementation Architecture (issue 4), D4.14 Specification of the Advanced SWE Concepts (issue 4) and D4.15 Specification of the Advanced Geo-processing Services (issue 4).

To provide an operational infrastructure: iterative and cyclic development with explicit validation by end-users in each cycle

- The *SW- Component Development & Integration* work package structured its work into generic component development and specific component development for the three case studies. Attention was paid to technology for the different user classes (scientist vs. end user such as a policy or decision maker) and with different end devices (desktop with good internet connection vs. mobile platform such as smart phone or tablet, possibly with intermittent connectivity). Several generic components are available as open source software, thus setting up an environment to foster their sustainable development.
- Aligned with project work, EO2HEAVEN responded to the GEOSS AIP-5 Call, following the collaboration already initiated within the previous Architecture Implementation Pilots AIP-3 and AIP-4, with contributions to the following threads: (1) to lead the SBA Health Air Quality and Waterborne thread and (2) to provide a number of components and data sets to be used in the same SBA Health thread. The main aim was to facilitate the work of scientists by making data sets directly available via standardized interfaces. The activities have been complemented by a contribution of tutorials and best practice guides.
- A mobile application for health data collection in Uganda was specified and implemented. Currently, the recording of new cholera cases is an error prone and inefficient process. The data gets copied from one handwritten paper form to another, sometimes digitized and aggregated several times, and reported in weekly or monthly intervals only. The EO2HEAVEN client to record cholera cases on a mobile tablet computer shall facilitate the data acquisition process during the registration and further reporting of cholera patients. The mobile client was presented at the Stakeholder Workshop in February 2013.

1.3 Scientific &Technological results and foregrounds

1.3.1 Why EO2HEAVEN?

The project acronym EO2HEAVEN stands for Earth Observation and Environmental Modelling for the Mitigation of Health Risks and is a major collaborative project funded under the 7th Framework Programme of the European Commission.

EO2HEAVEN has the primary objective to contribute to a better understanding of the complex relationships between environmental changes and their impact on human health. To achieve this, the project followed a multidisciplinary and user-driven approach, involving public health stakeholders as well as technology and service providers in both the Earth observation and in-situ environmental monitoring domain.

As a result of this collaboration, EO2HEAVEN designed and developed methods and tools to correlate environmental data with exposure and health data, to support the collection and integration of data and to visualise results in their geographical context. The overall aim is to support research of human exposure and early detection of potential health endangerments.

EO2HEAVEN builds on the results of two preceding major projects funded by the European Union:

- The FP6 ORCHESTRA project, which was completed in 2006, developed a standards based reference architecture for risk management, with a focus on natural disasters, such as earthquakes or forest fires.
- The FP6 SANY project was completed in 2009 and focussed on the development of Sensor Web Enablement standards, complementing the work of ORCHESTRA.

Both, ORCHESTRA and SANY, supported the development of internationally recognised interoperability standards, that enabled exchange of information from heterogeneous IT systems across technological and administrational boundaries.

The underlying concepts and approaches, as well as the lessons learned from both of these projects, were leveraged by EO2HEAVEN to address the challenges of health and environment studies: whilst the former projects dealt primarily with IT aspects of the geospatial domain, EO2HEAVEN built a bridge that allows stakeholders from the health community to utilise the huge potential of gathering, mapping and analysing their data in the spatial and socio-geographical context.

The synergies of close cooperation between stakeholders from the health domain and the environmental studies domain and the use of common technology approaches are a major stepping stone to better informed decisions for a safe environment and good public health.

In the beginning there may be merely raw observation data, intelligible only to the scientists: a value for ozone or particulate matter concentration, observed as part of an environmental monitoring activity; a value for personal vulnerability of a patient, recorded as part of a medical study. The final result of processing this data should be information tailored to the specific needs of the targeted audience. This can be used on various levels of decision making: from large scale governance of a good and healthy environment, to the planning of individual preventive measures, such as sms alerts to asthma patients based on real-time air quality indices. Data from various areas of expertise needs to be integrated to derive actionable information.

Our biggest challenge is to ensure that observations can be turned from data into information; information leads to knowledge, to understanding and, ultimately, understanding may even lead us to the wisdom to act accordingly.

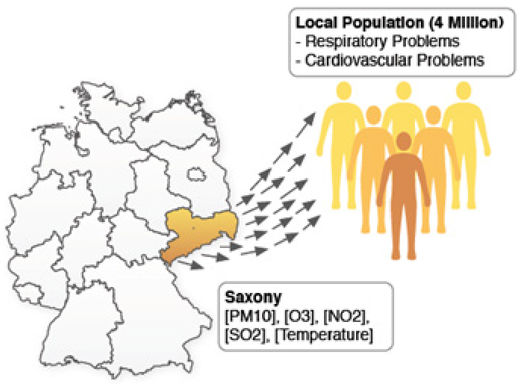
1.3.2 EO2HEAVEN Case Studies

EO2HEAVEN has identified three case studies and their stakeholders who are committed to actively engage in the work of EO2HEAVEN and to host and validate the results of the project.

Two of the scenarios address environment and health issues in the context of ambient air. The correlation between air quality and acute/chronic health effects were addressed by two Case Studies, one in Europe and one in Africa covering different geographic latitudes and different socio-economic and organisational contexts. These two air quality use case sites represent different settings from the point of view of the environmental conditions, the chemical composition of atmospheric pollution, land use, population exposure, and local climate.

The third case study investigated early warning factors for cholera outbreaks. Specific areas in Uganda served as test cases to study the integration of environmental, ecological, health and population data in prediction models for cholera. This case study highlights the integration of highly heterogeneous data from in-situ samples and earth observation resources in order to model the conditions for the onset and spread of an infectious disease that is perceived to be strongly influenced by climate, environmental and human factors.

1.3.2.1 The Impact of Air Quality on Respiratory and Cardiovascular Diseases in Saxony



The first case study focuses on respiratory and cardiovascular diseases in relation to the environmental parameters ground-level ozone, particulate matter and a number of meteorological conditions for the Federal State of Saxony, Germany.

The purpose of this Case Study is to study the potential impact of air quality on human health and to develop an online information system so that preventive measures can be taken to avoid adverse health effects resulting from environmental air pollution and extreme weather events.

An analysis of mortality and morbidity rates in Germany revealed that in the adult population cardiovascular diseases and respiratory diseases are among the most common causes of death. Both are known to be driven to some extent by environmental aspects such as exposition to air pollution and extreme weather events. Cardiovascular diseases and respiratory diseases such as asthma have been chosen as an EO2HEAVEN scenario, because they allow direct correlations between environmental factors, such as ozone and particulate matter exposition and resulting symptoms on a comparatively short time-scale (Meyer et al. 2007).

The percentage of people affected by allergies (i.e. bronchial asthma, contact allergies and others) has increased steadily in recent years. This is particularly true for younger age groups (25 to 29 year olds). The increase has been stronger in the male than the female population (7.7 % versus 3.1 %). About 13 % of the children and about 20 % of the adult population have been diagnosed with allergies. These rates are very much in accordance with the average prevalence rates in other European countries. Regarding cardiovascular diseases Saxony has one of the highest burdens of cardiovascular disease of all German federal states (211 cases of death per 100.000 inhabitants for women and 316 per 100.000 for men compared to the German mean of cases of death due to cardiovascular diseases: 192 per 100.000 inhabitants and 275 per 100.000, respectively) (Robert-Koch-Institut 2011).

Allergic asthma is one of the most common chronic diseases in childhood in Germany and hence in the investigated area. Several European and international studies have verified the association between health and environmental conditions. According to the German KIGGS study approximately 4.7 % of the children aged under 17 suffer from allergic asthma. There is a significant difference between genders, with 5.5 % of the boys and 3.9 % of the girls being diagnosed with asthma (Schlaud et al. 2007). The German Allergy and Asthma Alliance even states that 10 % of the children suffer from asthma (Deutscher Allergie- und Asthmabund 2010). About 5 % of the German adult population have been diagnosed with allergic asthma. The results of the national health survey suggest that the prevalence rate in the investigated area was lower than in the western part of Germany. During the past decade, however, there has been a steady increase in the East of Germany and thus in Saxony as well. Each year about 5.000 deaths are attributed to asthma in Germany and a literature review suggests that this figure is representative of European levels (Heinrich et al. 2002).

So far, there has been little sound evidence on how environmental hazards may influence human health in Saxony. A recent retrospective ecological study has investigated the association between particulate matter (PM10) and ultrafine particles (UFP) in the region of Leipzig, Saxony (Franck et al. 2011). The results revealed that there was an association between the diagnosis of a hypertensive crisis and exposition to UFP with a lag of two days. No associations were found regarding PM10 or PM2.5.

Data Acquisition

Statistical Data

In this Case Study, medical diagnosis and prescription data from a health insurance as well as morbidity and mortality statistics data were used. The medical diagnosis and prescription data was received from a German Statutory Health Insurance company, the AOK Plus, for the time period 2005 to 2007. This contains day specific information on the person insured (e.g. insurance status, gender, date of birth, place of residence etc.), the time and kind of treatment, the diagnoses and the prescription. For the purpose of our project, treatment data for the following medical conditions was extracted: Angina Pectoris, Ischemic Heart Disease (IHD), Bronchitis/Chronic Obstructive Pulmonary Disease (COPD), Pneumonia and Asthma.

Morbidity and mortality statistics data has been captured in Germany since 1993 for all patients who were either discharged from hospitals or died. The data was acquired from the Research Data Centre (RDC) in Dresden and the diagnoses of interest were classified according to the International Statistical Classification of Diseases and Related Health Problems, 10th revision (ICD-10).

Remote Sensing Data

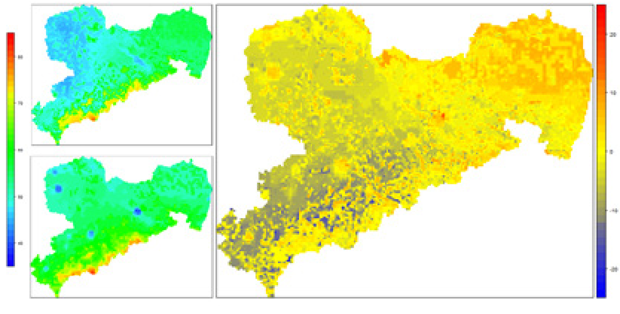
For the determination of PM10, Aerosol Optical Depth (AOD) products acquired from the National Aeronautics and Space Administration (NASA) instruments Terra MODIS (Moderate Resolution Imaging Spectroradiometer) and Aqua MODIS were compared with air pollution data from the 25 in-situ measurement stations. There is a significant correlation between AOD and PM10 only when high quality satellite images are available under cloudless conditions. Unfortunately, this applies to only about 8% of the data.

In-Situ Data

In-line with the EU-Directive 2008/50/EC, pollutant concentrations and additional meteorological parameters are measured half-hourly by an in situ station network operated by the Saxon State Office for Environment, Agriculture and Geology (LfULG). The data can be obtained from the LfULG Website or the European Air quality database (AirBase) as tabular data.

Air Quality Modelling - Application of the Air Pollution Model

To model air pollution, affinity area calculations based on in-situ measurements were applied. This approach has been successfully applied to air pollution modelling before by McGregor (1996) or the APMoSPHERE project (APMoSPHERE 2005). The underlying cross-correlation concept is that “everything is related to everything else, but near things are more related than distant things” (1st law of geography, Tobler 1970). Corresponding distance measurements are based on attributes which are likely to influence the air quality, such as land cover, elevation, traffic or background emissions.



The model is implemented by a multidimensional Inverse Distance Weighting (IDW) algorithm, using different areal attributes to calculate distances between an area of interest and the in situ stations. A detailed description on how the model works can be found in Wiemann et al. (2012).

Within the Saxony case study the previously described model has been applied to calculate air quality information for the years 2003-2007 as the basis for further health risk analysis. As input measurements for the study area the Saxon State Office for Environment, Agriculture and Geology (LfULG) provided measurements for PM10 (26 stations), ozone (23 stations), nitrogen dioxide (NO_2) (26 stations), sulphur dioxide (SO_2) (16 stations) and air temperature (33 stations). As target areas both the 1km INSPIRE reference raster and postal code areas were used.

Based on those input data, the optimal attribute weights were calculated by maximizing the correlation between the attribute distance and the correlation of measurements between each of the in-situ stations. Based on the calculated attribute weights, affinity areas for each station were determined, indicating whether and to which extent an in-situ station can represent a certain target area.

As the result, each target area is described by a weighted list of in-situ stations. By weighting the corresponding in situ measurements, an air quality map is generated using an IDW algorithm.

Health Risk Analysis - Results for Cardiovascular and Respiratory diseases

Whilst insurance data provides a wealth of information, it must be recognised that it is primarily structured for health insurance billing purposes and not for medical research. Depending on applicable legislation or organisational requirements for this process, it may for example not reflect adequately the point in time when a medication is needed by a patient, but rather when it was prescribed. This emerged during the data analysis when frequent quarterly prescription peaks appeared that could not be related to external, i.e. environmental conditions.

Accordingly, a valid and reliable determination of prevalent or incident cases, i.e. a measure of the population’s proportion of ill people and a measure of new occurrences of a certain disease, was not directly possible based on the insurance data. As an alternative approach, the ‘Load of Disease’ (LOD) was chosen as a surrogate parameter for incident/prevalent cases. LOD means the number of primary care physician consultations in a certain region on a certain day. An advantage of LOD in comparison to incidence/prevalence is that in chronic diseases, such as asthma bronchiale or chronic ischemic heart disease, a measure of incidence/prevalence is less meaningful in measuring the “Health related Quality of life” (HrQoL) than LOD.

The analysis of health insurance data has shown that deriving detailed case information from this data is challenging and that the data can be biased by external, seemingly unrelated aspects. Therefore in-patient-data of the official Saxon Morbidity and Mortality Statistics of the Research data centre (RDC) has been included in the analyses processes, which contains data of all people admitted to hospital in Saxony.

When analyzing the descriptive charts of the relative number of e.g. acute Angina pectoris diagnosis (ICD-10 I20), it became apparent that results could not possibly reflect the real world situation, since most of the given ICD-10 diagnoses per region-day occurred in the last month of each quarter. This occurrence could not be explained by descriptive analysis, but is most likely related to the previously discussed effects of the practice fee and billing process. Moreover, a weekday-effect was discovered, which is most likely influenced by the usual opening regime of German primary care physicians, who usually are open half-day on Wednesdays and Fridays and usually are closed on weekend.

Since these are effects of considerable size (up to 500 %), they are dominating the analysis, and it is therefore difficult to detect any environmental influences on health data, which are estimated to be much smaller. The main reason for this effect probably is that the secondary data, which is being used reflects no real incidences (a measure of the risk of developing some new condition within a specified period of time), but rather cases (i.e. physician consultations). The ICD-10 diagnoses, set up at the consultations, are prone to be biased by medical billing strategies and hence do not reflect reality in a valid way. Analysis of the health insurance data revealed a similar effect of quarters and weekdays for the ICD-10 diagnoses of bronchitis and chronic obstructive pulmonary disease (COPD).

Conclusions

- Despite the challenges posed by the used datasets, the model itself has good statistical properties, which were evaluated with model diagnostics. Organizations with access to primary health data could therefore further test this approach in future research activities.
- Although air quality modelling has already been studied for decades and is supported by a variety of tools on the market, the challenge of identifying the best solution for a particular use case still remains. The EO2HEAVEN approach requires an air quality model applicable on a large scale, at low costs and with good performance in both, quality and computation time. However, air quality models almost never meet all of those criteria. Thus, compromises have to be made.
- Future research activities should evaluate the use of low cost sensors as a solution for areas with either a low coverage of in situ stations or specific local characteristics. They might be a good opportunity to support models by including additional nodes for interpolation and in general increase the validity and reliability of results.

1.3.2.2 Relationship between Industrial Pollutant Exposure and Adverse Respiratory Outcomes

The second case study focused on the relationship between industrial pollutant exposure and adverse respiratory outcomes. Much debate exists around causality of effects, role of specific pollutants and the populations particularly vulnerable to elevated pollution. Although certain pollutants, such as oxides of nitrogen, particulate matter and sulphur dioxide are known to result in adverse outcomes, the ability to use this information in developing interventions to improve the life of affected and vulnerable sub-populations is limited.

The purpose of the case study is to develop a system, which permits ready access to pollutant and meteorological data that allows for the prediction of exposure of vulnerable populations in areas that are at risk for elevated excess ambient pollutant exposure.

The geographical focus is on the southern sections of Durban, known as the Durban South Industrial Basin (DSIB). This area is a densely populated area, consisting of approximately 250.000 people, is a key industrial hub for the city and the country as a whole. This residential-industrial complex arose during the era of apartheid governmental planning, and today represents a highly conflictual situation between stakeholders. This area has been reported to have a high unemployment rate, with approximately 52% of the population not economically active.

The Durban South Industrial Basin (DSIB) is at particularly high risk for exposure to significant levels of ambient air pollution because of its geographic relationship with certain stationary sources of air pollutants. Specifically, two major petroleum refineries are within the community, together with a pulp and paper manufacturer, a waste water treatment plant and several small to medium industries. Up to a few years ago, each of these refineries has emitted, on average, in the range of 35.000 to 40.000 kg of SO_2 per day. Through rigorous monitoring and enforcement, the total industrial SO_2 emissions were reduced from 107 tons per day in 2000, to 61 tons per day in 2005. Owing to a combination of its geographical relationship to the refineries, land contours, prevailing meteorological conditions, the use of a relatively short emissions stacks at these facilities (50 – 100 meters), the lack of or relative ineffectiveness of emission control devices on refinery stacks, the many sources of so-called fugitive air emissions at refineries, emissions from industrial and passenger vehicles, as well as the proximity of other industries and, until recently, the Durban International airport, the community is believed to be at risk for intermittent substantial exposure to ambient air pollutants. Available data on sulphur dioxide indicate that average and/or maximum exposures at sites in south Durban have frequently exceeded World Health Organization (WHO) and the South African Department of Environmental Affairs (DEA) standards.

Health studies in the area have indicated elevated risk for respiratory outcomes among those exposed. In a study among students and teachers at the Settlers' Primary School, unusually high prevalence rates were reported for asthma, with ranges of any type of non or probable asthma (symptoms assessed) from 53.5% to moderate to severe persistent asthma of 16.8%. In addition, approximately 20% of the study sample had marked airways hyperresponsiveness as diagnosed by methacholine challenge testing, the prevalence higher than any other population based reports in the scientific literature (Kistnasamy et al, 2008). This study found statistically significant associations between prior day and prior 48 hour PM10, SO_2, and NO_2 levels (continuously measured at the school) and increased respiratory symptoms and diminished pulmonary function measures (measured by digital recording peak flow meters) among students with persistent asthma. These effects were observed during a time period when all ambient pollutant measures were well within national and international standards.

In a more comprehensive study, ambient and indoor exposure monitoring was conducted in south and north communities during the study period, May 2004 to February 2005. Additional sources of pollutant and meteorological data covering January 2004 to October 2005 were accessed. Pollutants monitored included sulphur dioxide (SO_2), carbon monoxide (CO), volatile organic compounds (VOCs), particulate matter in two size classes (PM10 and PM2.5), ozone (O_3), metals, and semi-volatile organic compounds. The health data from that study suggested high prevalence of respiratory disease. Caregivers reported that 14.7% of children had been diagnosed with asthma by a doctor, 10.9% with hay fever, and 4.0% with chronic bronchitis. Based on symptoms described by the caregiver, 31.5% of children had some grade of asthma, with 7.9% having mild persistent asthma, and 4.1% having moderate to severe persistent asthma. Objective lung function assessments using methacholine challenge testing were well correlated with these reported assessments, with 7.6 % having marked bronchial hyperreactivity (BHR) (PC20 < 2 mg/ml) and a further 17% having either probable or possible BHR. The covariate-adjusted prevalence of marked BHR varied substantially between the south (8.0%) and north (2.8%). Logistic regression models adjusting for age, gender, race, caregiver education, household income and the presence of smokers in the household, found that attending a school in the south was statistically significantly associated with increased risk for persistent asthma (Naidoo et al., 2007).

The relatively moderate ambient concentrations of NO_2, NO, PM10, and SO_2 were strongly and significantly associated with decrements in lung function among children with persistent asthma and/or genetic polymorphisms associated with reduced ability to respond to oxidative stress. Moreover, attending primary school in south Durban, as compared to the north, was significantly associated with increased risk for persistent asthma and for marked airway hyper reactivity in covariate-adjusted regression models.

Data sources

Statistical Data

In this case study, the medical data used is derived from The South Durban Health Study conducted by the University of KwaZulu Natal (UKZN). This data contains geo-referenced information on the health response of children attending different schools throughout the South Durban Industrial Basin, compared with children from the north communities in the city, and was used in the multivariate risk analysis after undergoing statistical analysis.

Remote Sensing Data

MODIS data for Aerosol Optical Depth did not correlate with the PM10 in-situ measurements. Furthermore, the meteorological influence is much more dominating for the air quality situation in Durban. It was therefore decided to switch to a dispersion model to assess air quality.

In-Situ Data

The Pollution Control and Risk Management (PCRM) Unit currently manages the Air Quality Monitoring System (AQMS), which is a real time ground level monitoring system located in fixed "hotspot" locations of the City of Durban. The meteorological parameters from the in-situ monitoring stations are transferred from the eThekwini Municipality servers every 10 minutes.

Air Quality and Health Risk Modelling

Pollutant dispersion modelling is conducted using the Cambridge Environmental Research Consultants' (CERC) Atmospheric Dispersion Modelling System (ADMS Urban) as part of the EO2HEAVEN system for South Durban. ADMS Urban simulates a wide range of buoyant and passive releases to the atmosphere, drawing on the latest plume dispersion mathematics. Output for criteria pollutants has been extensively validated against field data sets in the European Union and the American Standard Test Methods, while consultants have proven its reliability against measured data in South African case studies. For the purposes of this study, an extensive emissions inventory (comprising multiple point, line, area and volume sources), on-site meteorological measurements, and a digital elevation model are inputted for dispersion calculations. The model is run with live meteorological data at ten-minute intervals to produce short-term pollution scenarios for sulphur dioxide and particulate matter. It is likely that this repertoire will be extended to include the oxides of nitrogen and benzene in the near future. The calculated plumes are then mapped with concentration contours for display purposes.

To aid with source identification, a pollution rose is also produced every ten minutes for each areal unit. This diagram indicates the average pollution concentrations from prevailing wind directions. Calculates are based on measured wind direction data and ADMS Urban pollution concentration outputs.

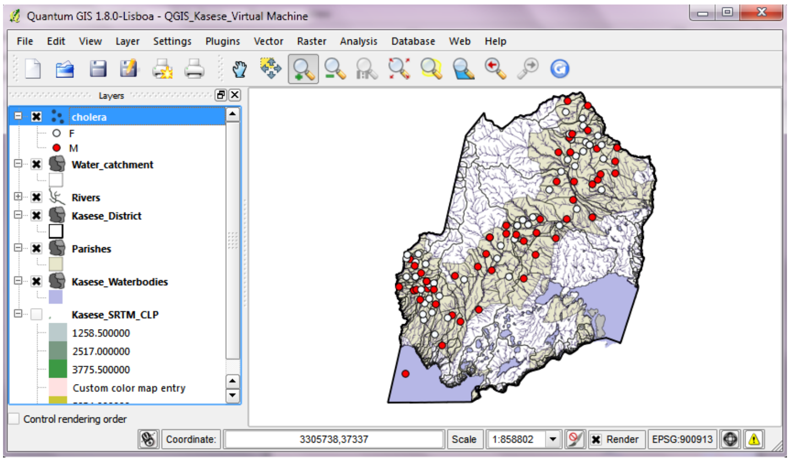
A model written in R language is used to determine the health relative risk pollution based on the concentrations from the ADMS and meteorological data from the eThekwini Municipality server. The outcome of this model is a health risk map and a graph indicating the pollution concentration and relative health risk.

The mathematical model describing the relation between health outcome and environmental exposure results in an estimate of expected respiratory morbidity. As such a measure is not easily interpreted, this measure is transformed based on the estimated baseline morbidity at when all pollutants were zero using a simple conversion algorithm. The final health indicator therefore represents the risk ratio over the background risk in the DSIB due to exposure to certain levels of air pollution.

Conclusions

- This case study provides a good example for the difficulties to characterize exposure throughout the city, and hence the challenge to predict adverse health outcomes. To provide a system that alerts users to the risk of childhood respiratory problems associated with air pollution, this needs to be recognised and addressed.
- Although certain pollutants, such as oxides of nitrogen, particulate matter and sulphur dioxide are known to result in adverse out-comes, the ability to use this information to improve the life of affected and vulnerable sub-populations is limited.
- The results from the validation studies concluded, that readily accessible remotely sensed data cannot be used to predict ground level pollution. Whilst this was a disappointment to researchers and agencies within local government, it emphasizes the need for better understanding the conditions under which the use of advanced technologies can be more widely used. Hence more robust methods, beyond using remote sensing are necessary for ground level air pollution monitoring.
- Nonetheless, the approach, methodologies and tools of EO2HEAVEN provided significant benefits to the stakeholders. The core components for a health and environment information system are available with the necessary interfaces to include new data sources, so that this can be extended to an operational system. The major challenge for a widespread deployment is ongoing engagement with end-users and that the necessary resources are available for end users to utilize the systems that have been developed.

1.3.2.3 Links between Environmental Variables and Cholera



The third case study of the EO2HEAVEN project focused on links between certain environmental, including climatic, variables and the outbreak of cholera in Africa. The Case Study includes the use of remotely sensed and in-situ data together with ex-situ data, i.e. data collected as part of a field sampling campaign and health data, e.g. cholera case data. Health data availability and accessibility and the costs and logistics associated with a field sampling campaign determined the final selection of a study area on the south western parts of Uganda, specifically the Kasese area close to Lake George and Lake Edward; the Kazinga Channel; the Lubila Tako Chaka River that forms the border between Uganda and Democratic Republic of the Congo and surrounding areas.

The relevance of scale, i.e. the aggregation of data at different temporal and spatial scales when investigating the association between different variables and the disease, is an important factor that has been addressed in this case study. Environmental factors and processes operate at different spatial and temporal scales, which necessitate the extraction and analysis of environmental data at different scales together with the health data.

Environmental factors such as the accumulation of rainfall water over a period of time and a large spatial extent correlate more closely with case data whereas daily sunlight and water temperature values are associated with the pathogen dynamics.

The purpose of Case Study 3 is to gain insights into the potential environmental and climatic drivers of cholera outbreaks in the Ugandan and central African context and the dynamics of the *Vibrio cholerae* pathogen in the natural environment.

The environmental risk of potential outbreaks in cholera endemic areas, i.e. areas which report regular outbreaks or areas where the outbreaks generally start, has been estimated by using satellite and in-situ data together with field and laboratory results and, where possible, by taking into account demographic and socio-economic factors. EO2HEAVEN has developed a guide to design a cholera monitoring programme and conduct cholera field sampling.

Weather data has been used to track changes in rainfall and air temperature over time, whereas predicted climate data, generated by the downscaling of global circulation models to a regional level in order to incorporate local conditions, has been used to determine areas potentially under threat of cholera outbreaks under changing climate conditions.

The level of vulnerability of communities in different areas due to the environmental conditions and the general socio-economic situation in these areas has been analysed and is highlighted in interactive online maps, which are based on current conditions and provide an indication in near real time. The environmental risk estimates can be used as the basis for further developments towards an early warning system.

Conclusions

A multi-disciplinary and national approach was adopted as part of the EO2HEAVEN project to address cholera in the Kasese district in Uganda. This included expertise from different countries and continents in the fields of microbiology, epidemiology, remote sensing, information technology, data standards, data analysis and modelling. Such a multi-national and multidisciplinary approach provides advantages as well as challenges.

This approach produced valuable insights into a complex environmental related infectious disease such as cholera. New insights were generated that provided new information regarding the dynamics of the disease and the pathogen, *Vibrio cholerae*, for

- an inland area or a landlocked country such as Uganda as compared to a coastal area and
- an area located close to the equator.

The different skills and expertise led to different approaches and ways of identifying underlying problems, developing solutions and integrating the solutions and results. These can form the basis for future research work and support for decision-making concerned with the development of optimal intervention strategies in terms of time, effort and cost. For infectious disease research and support for developing appropriate, cost-effective intervention policies and strategies, it is important to take advantage of capabilities and advancements in the supply and accessibility of data, computer hardware and software, and ICT tools and expertise in general, e.g. standardisation of data formats, capturing, reporting, provision and accessibility of data.

The major challenge of such a multi-disciplinary approach is the communication between experts from different fields and bias in the interpretation and understanding of what is required and what is technically feasible or not. Experts tend to be strong in a specific field or domain, rather than multiple fields and domains. However, it is becoming increasingly important that health domain practitioners and researchers are trained, from an early stage in their education establishments and workplaces, in aspects of computer science, data analysis and modelling. Likewise, data analysts, modellers and ICT practitioners need to make an effort to understand, to some extent, the application domain, such as health, ecology etc. This can help to limit technical confusion and misunderstanding. Another option is to have a project manager/technical leader with sufficient understanding of all the fields involved, in order to enable communication between experts from different fields and help with the interpretation of what is required and what can be done.

Especially in complex scenarios, such as the Uganda Cholera case study, another important aspect is the requirement that software development and implementation can react quickly to new or altered requirements. Whilst software developers are often concerned about finalising a “release quality” product, the scientist may need a quick prototype to address a new research model requirement. These two positions can create a deadlock very quickly. The software under development may ultimately not be used by a researcher, because a particular form or style of analysis is no longer suitable for the research problem or needs to be altered in some way. Both researchers and developers need to reduce the distance between them and look for small gains, made often. This allows more fruitful evolution of the project software and allows more ICT’s to be used in the end. Nonetheless, the emphasis should always be on building robust, reusable components, rather than ‘quick and dirty’ scripts - so patience and understanding is required on both sides.

EO2HEAVEN has addressed the requirements for improved information flow and corresponding mitigation responses in Uganda with the development of a mobile data collection application, as well as data processing and visualization services, which

- support health workers to collect and retrieve up-to-date cholera case data;
- visualize data and results for research purposes as well as decision making at different levels, using historical and current data.

1.3.3 Common Challenges

Cross Domain Communication

In a classical communication pattern, sender and receiver need to share the same understanding of a topic. However, this is not always true for cross domain communication because of different working methods, background knowledge or organisational structures of the participants. This needs to be bridged to avoid information loss or, even worse, misinformation.

In EO2HEAVEN, scientists from the environment, health and the IT domains joined forces. The challenge of building a common knowledge base for both groups needed to be addressed in order to get health and technical requirements across to all participants.

Spatial and Temporal Data Fit

To obtain meaningful results from the comparison and correlation of information from different sources, a common spatial and temporal reference is a key requirement. This applies to environmental data, such as in situ observations, remote sensing data or laboratory field data, as well as for health data on prescriptions, mortality or morbidity.

Having the same spatial reference usually means that information covers the same area of interest on the Earth's surface, like administrative units or postal code areas. On the other hand, the temporal reference describes a point or duration in time. The target scale for data analysis for both, spatial and temporal references, is determined by the lowest resolution of all input datasets. Thus, data needs to be interpolated or aggregated, if at least one input for data analysis is only available on a lower resolution.

In general, it is advisable, that a combined analysis of information from different sources should be based on the same spatial and temporal reference, to ensure that bounding conditions, which are not included in the analysis, are comparable.

Accuracy of Analysis Results

The accuracy of a scientific analysis depends on the accuracy of input data, the analysis or model used and the interpretation of results.

Unfortunately, uncertainty measurements and their meaningful documentation are often neglected at all of those stages, although such accuracy information is important to prevent misinterpretations of analysis results and improper decision making.

Uncertainty of input data usually depends on the accuracy of measurements and can be determined by conducting validation or descriptive statistical analysis on the data. It becomes more difficult when assigning uncertainty to models, as it requires extensive model validation, taking into account the uncertainty of input data and modelling workflows. Yet, the greatest challenge is to enable a correct interpretation of results, which heavily relies on personal background knowledge, expertise and subjective perception. Thus, decision making must be supported by a detailed documentation of the analysis and mechanisms for uncertainty propagation.

Data Privacy & Ethical Issues

Copyright and intellectual property rights apply in the same manner as in every other case citing data of extrinsic origin. These questions are always persistent in the evaluation of secondary data.

Furthermore data protection legislation may limit the access to and the publishing of health data. According to the professional codes for physicians in the different German states (based on state data protection laws, that have a guiding basis in the German federal data protection law, which itself has a legal basis in the European data protection directive [Directive 95/46/EC]) individual-related data and fully anonymised data have to be distinguished.

To process, use or publish individual-related data the corresponding individuals have to each give personally – his/her legally binding consent (for health data usually in written form). Fully anonymised data, which has been processed in a way that re-individualization is impossible with "normal" effort, may be used openly only with the limitations of the above mentioned copyright and intellectual property restrictions. However, this may adversely impact the spatial and temporal resolution.

Availability of Health Data

Although in most European countries various health data sources are available, data availability in countries such as South Africa or Uganda is much more limited. The absence of health insurance data for the majority of the population and the lack of district level health management information systems result in an inadequate characterisation of the impacts of exposure on health. This in turn impacts on health policy development, implementation of interventions or resource allocations.

The case studies within EO2HEAVEN on both cholera and respiratory diseases attempted to circumvent some of these challenges and provide alternative data approaches to address the health concerns.

IT Challenges

While working with researchers and stakeholders from different scientific disciplines, it became apparent that before the newest trends and developments in mainstream IT can be utilised for software development, the following three key aspects need to be addressed first:

- To gain user acceptance, the software usage needs to be as simple as possible. This means to reduce the number of available features to a minimum and focus on the important ones instead.
- Slow and unreliable Internet connections are a common problem, especially in developing countries. Software needs to be usable offline and be able to synchronize its data when an Internet connection is available.
- Landline Internet is often not readily available in developing countries, whereas accessing the Internet via mobile phones and smartphones is common and far more reliable. Accordingly, the development of mobile applications, which are usable on a tablet pc or smart phone, should be considered to provide access to traditional PC based software applications.

Researchers often face diverse challenges depending on many different factors and therefore want to stay in full control of their workflows. Accordingly, this user group usually does not look for a black box one-stop solution that solves them. To them, offline access is very important, because they want to use 'their' own software and just require access to the datasets. Providing this user group with help on finding suitable datasets, tools to import and export these datasets into and out of their own software, and meaningful information (metadata) about what has already happened with these datasets are important factors for acceptance.

1.3.4 The EO2HEAVEN Value Proposition

Monitoring environmental aspects and public health and correlating both starts with the collection, processing, and interpretation of data on hazards, exposures and health outcomes. The results can then be disseminated in various formats, ranging from processed data that may be used as input for further processing to reports or risk maps on specific topics. This process is illustrated below:

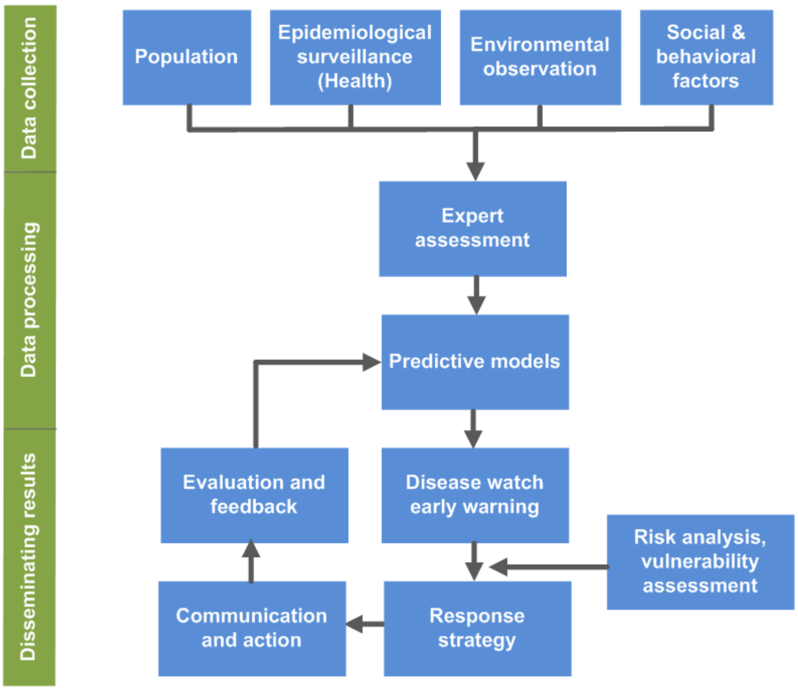


Figure 1: Data flows in environmental public health surveillance (Diagram adapted from Trtanj 2009)

Direct actors in the management cycle of environment and health threats include environmental and health managers, health practitioners and the research community. But also boundary institutions such as operators of sensor networks, environmental advocacy groups, etc. need to be addressed in any project that intends to make a lasting impact. Several challenges complicate environmental public health monitoring:

- The ability to link specific environmental causes to adverse outcomes is often limited by our poor understanding of disease processes, long lead times, inadequate measures of exposure, and multiple potential causes of a disease.
- Data collected for other purposes, e.g. Health Insurance Data, rarely includes sufficient information to meet a case definition for a condition caused by an environmental agent.
- Issuing a public alarm is often out of proportion to the hazard of concern, and sentiment will often influence public policy disproportionately to scientific information.

EO2HEAVEN tackled these challenges by providing methodologies, correlation models, spatial data services (OGC Standards) and applications (Service Oriented Architecture paradigm) supporting the main activities involved in environmental health:

- discovery and acquisition of data sets
- integration of heterogeneous Earth observations (satellite, in-situ and field campaign data)
- extraction of time series and visualization of graphs and maps
- development of models of health effects
- development of risk maps
- development of predictions for early warning systems

1.3.5 The Spatial Information Infrastructure

The specification of the implementation architecture of the EO2HEAVEN Spatial Information Infrastructure (SII) is the basis and starting point for all EO2HEAVEN developments.

The objective of the SII implementation architecture is to motivate and specify the basic design decisions derived from user requirements and generic architectural principles. Its focus is on a platform-neutral specification, i.e. it provides the basic concepts and their relationships as conceptual models and abstract specifications.

By abstract it is meant that the specification is independent of the specifics of a particular service platform or concrete implementation. Such an abstract specification comprises service specifications, information models and interaction patterns between the major architectural components, as illustrated below:

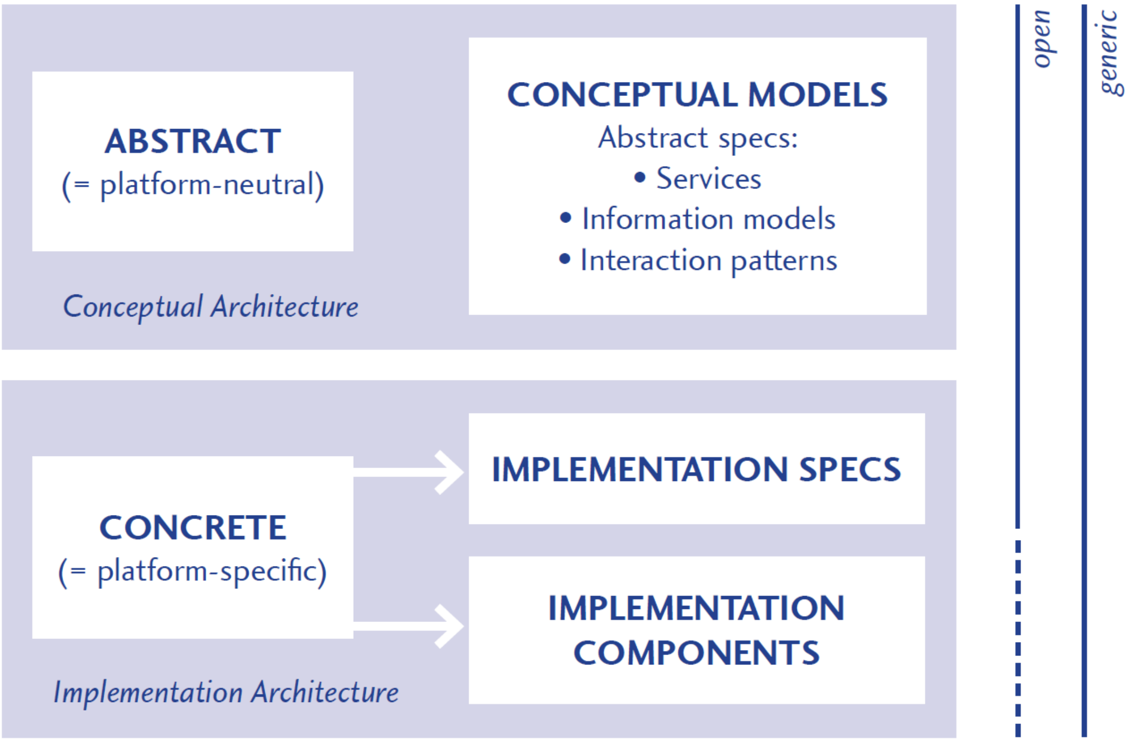


Figure 2: EO2HEAVEN Spatial Information Infrastructure (SII) Approach

The structure of the SII architecture is aligned with an interpretation of the five viewpoints of the ISO Reference Model for Open Distributed Processing (RM-ODP) (ISO 10746-1, 1998). The RM-ODP explicitly foresees an engineering step that maps solution types, such as information models, services and interfaces specified in information and service viewpoints, respectively, to distributed system technologies. We describe this mapping step in terms of engineering policies. These policies constitute architectural blueprints that enable a system engineer to specify implementation architectures according to given user requirements, as outlined in the lower part of this graphic.

These viewpoints were partly combined and specified in the six document parts of the SII architectural specification. As such, it continues the series of architecture specifications of previous European FP6 projects, which resulted in the following OGC documents:

- The Reference Model for the FP6 ORCHESTRA Architecture (RM-OA) was developed by the ORCHESTRA project and approved as an OGC best practices document (OGC 07-097).
- The RM-OA was extended by the FP6 SANY project in its Sensor Service Architecture (SensorSA), which is available as an OGC discussion paper (OGC 09-132r1).

Referring to the original copyrights of these documents and in agreement with their editors, the EO2HEAVEN project inherited and extended this work in form of the present SII implementation architecture specification. Particular emphasis is put on the support of distributed environmental and health monitoring. It also addresses the consequences of special health privacy and security requirements on the architecture, recognizing the fact that some of these requirements can and will only be tackled on organisational level, e.g. by aggregating and anonymizing data in non-distributed, offline computer centre environments, before this data can be offered to other applications via distributed online accessible service infrastructures.

The EO2HEAVEN architecture incorporates advanced concepts for OGC Sensor Web Enablement (SWE), distributed Geo-Processing and Spatial Decision Support. This includes event-based interactions across all functional domains and the inclusion of models from the environmental and health domains, e.g. as virtual sensors. The EO2HEAVEN architecture specification is structured as a six part (Part I to Part VI) document with a coherent and redundancy-free set of architectural specifications including concept developments.

The EO2HEAVEN SII architecture documentation takes into account emerging technologies, especially for the OGC SWE architecture and the geo-processing architecture and provides extensions and refinements, e.g. for the requirement to share and process huge amounts of datasets provided by Earth observation agencies and health institutions in order to investigate and assess correlated risks.

An important project aspect was to improve the applicability of the Sensor Web technology to the case studies of EO2HEAVEN and to facilitate the practical use of the OGC SWE framework. This included the definition of a lightweight SWE profile, an analysis of and contribution to the specification of the Sensor Observation Service (SOS) 2.0 as well as an approach as to how the data used within EO2HEAVEN could be integrated more easily into Sensor Observation Service instances. This work on improving the usability of the SOS service is targeted to be approved by OGC as a best practices document OGC 13-015 'Provision of Observations through an OGC Sensor Observation Service (SOS)'.

A second focus addressed the handling of different types of Earth Observation (EO) data, i.e. remote and in-situ data, within the SWE framework. Whereas the application of the SWE technology to in-situ data is quite common, there is a lack of best practice guidance on how remote sensing data can be handled. Accordingly, EO2HEAVEN provided a list of recommendations for developing such a best practice approach. This also includes potential extensions of the Sensor Model Language (SensorML) for remote sensing data and the linkage of SWE with the GEONETCast technology, a near real time, global network of satellite-based data dissemination systems designed to distribute space-based, airborne and in-situ data, metadata and products to diverse communities.

Further major topics of the SII are processing and fusion services, processing of quality information, handling of data uncertainty, its encoding and visualization, etc.

Design Principles

A service oriented architecture for a Spatial Information Infrastructure in the environment and health context cannot rely solely on existing design principles that are typically applied in commercial SOA environments (Erl, 2008). EO2HEAVEN therefore followed the refined architecture approach of SANY:

- Rigorous Definition and Use of Concepts and Standards
  The SII should make rigorous use of proven concepts and standards in order to decrease dependence on vendor-specific solutions. This helps to ensure the openness of an information network and supports the evolutionary development process.
- Loosely Coupled Components
  The SII should allow the components involved in a service network to be loosely coupled, in which case loose coupling implies the use of mediation to permit existing components to be interconnected without changes.
- Technology Independence
  The SII should be independent of technologies, their cycles and their changes, as far as practically feasible. Accordingly, it is possible to accommodate changes in technology (e.g. lifecycle of middleware technology) without changing the architecture itself. This also implies independence of specific implementation technologies (e.g. middleware, programming language, operating system).
- Evolutionary Development – Design for Change
  The SII should be designed to evolve, i.e. it shall be possible to develop and deploy the system in an evolutionary way. Hence it is able to cope with changes of user requirements, system requirements, organisational structures, information flows and information types in the source systems.
- Component Architecture Independence
  The SII should be designed in a way that service network and source systems (i.e. existing information systems, data sources and sensor networks) are architecturally decoupled. The ar-

chitecture shall not impose any architectural patterns on source systems for the purpose of having them collaborate in a service network, and no source system shall impose architectural patterns on a SII. Here it is important to point out, that a source system is seen as a black box, i.e. no assumptions about its inner structure are made when designing a service network.

- Generic Infrastructure
  SII services should be independent of the application domain, i.e. they can be used across different thematic domains and in different organisational contexts. Ideally, any update of integrated components (e.g. data sources, applications, systems, ontologies) requires no or only little changes to the users of the SII services.

Reference Model for Open Distributed Processing

The conceptual foundation for the SII was the Reference Model for the ORCHESTRA Architecture (RM-OA). The RM-OA provides a platform-neutral abstract specification of a geospatial service-oriented architecture that responds to the requirements of environmental risk management applications. It comprises generic architecture services and information models based on and extending existing Open Geospatial Consortium (OGC) specifications.

The design of the EO2HEAVEN architecture follows the guidelines and viewpoints of the ISO Reference Model for Open Distributed Processing (ISO/IEC 10746-1:1998). However, since the requirements from the EO2HEAVEN scenarios show the characteristic of a loosely-coupled network of systems and services instead of a 'distributed processing system based on interacting objects' as presumed by RM-ODP, the RM-ODP concept is not followed literally. The RM-ODP viewpoints are applied on a higher scale to the structuring of ideas and the documentation of the architecture itself, and on a small scale to the description of the data sources and models:

- The Enterprise Viewpoint reflects the analysis phase in terms of the business contexts, related system and the user requirements expressed in use cases as well as the assessment of the current technological foundation for the architecture. It includes rules that govern actors and groups of actors, and their roles.
- The Information Viewpoint specifies the modelling approach of all categories of information, with which the architecture deals, including their thematic, spatial, and temporal characteristics, as well as their meta-information.
- The Service Viewpoint specifies the interface and service types that aim at improving the syntactic and semantic interoperability between services, source systems and environmental applications.
- The Technology Viewpoint specifies the technological choices for the service platform, its characteristics and its operational issues, e.g. the specification of the platform 'Web Services' including a profile of the Sensor Model Language, or the physical characteristics of data sources, sensors and sensor networks.
- Finally, the Engineering Viewpoint specifies the mapping of the service specifications and information models to the chosen service platform, considers the characteristics and principles for service networks, e.g. synchronous or asynchronous interaction patterns, and defines engineering policies, e.g. about access control and resource discovery.

1.3.6 EO2HEAVEN contribution to GEOSS

The main engagement of EO2HEAVEN was facilitated through active participation in the GEOSS Architecture Implementation Pilot (AIP) and Community of Practice (CoP) activities. EO2HEAVEN has contributed results to HE-01-C1 Air-borne Diseases, Air Quality and Aeroallergens and HE-01-C2 Water-borne Diseases, Water Quality and Risk from its respective case studies. EO2HEAVEN placed a special focus on community and capacity building as a contribution to Task ID-02.

The GEOSS Architecture Implementation Pilot

A key contribution was made by EO2HEAVEN to the GEOSS Architecture Implementation Pilot (AIP) phases 3 to 5 of GEO Task AR-09-01b in the GEO 2009-2011 Work Plan and GEO Task IN-05 in the subsequent GEO 2012-2015 Work Plan.

The GEOSS Architecture Implementation Pilot (AIP) develops and deploys new process and infrastructure components for the GEOSS Common Infrastructure (GCI) and the broader GEOSS architecture.

EO2HEAVEN started its involvement with the AIP development at the very early stages of the project with AIP phase 3. The primary contribution focussed on the participation of our case study experts in the Societal Benefit Area Health Thread, discussing our project approach with expert teams who participated in the previous GEOSS AIPs to identify the lines of collaboration. This led to a generalization and extension of our three case studies to the health Societal Benefit Areas identified by the Pilot, i.e. Air Quality and Early Warning of Malaria scenarios. With this response EO2HEAVEN primarily strengthened its visibility within the GEOSS community and paved the way for a continuous working relationship through the lifetime of EO2HEAVEN and beyond.

In AIP phase four, EO2HEAVEN took a leading role in activity #1, 'Access to Priority EO Data Sources'. The goal of this activity was to bring datasets online, which are listed as priority EO data sources in the Critical Earth Observation Priorities report published by GEO task US-09-01a. Various existing lists of datasets and corresponding services have been merged and were processed by the AIP-4 consortium. EO2HEAVEN also supported the development of a number of tutorials as well as open source reference implementations, which intend to help both data providers as well as GEOSS users to work with GEOSS. The tutorials were developed in close cooperation with the Standards and Interoperability Forum (SIF), which has been established "to facilitate the interchange of information and the development of recommendations for standards and interoperability in GEOSS" (IEEE 2011).

In AIP phase five, EO2HEAVEN introduced three different scenarios that have been implemented to test the current GEOSS architecture, services, information models and knowledge representations in the context of health related scenarios.

The GEOSS Health and Environment Community of Practice

This Community of Practice (CoP) is an informal group of international experts in the health and environment field. It meets annually to exchange experience on investigating relationships between health and the environment and approaches to mitigating the burden on health. This includes assessment of relevant health and environment data, model- and data-driven analysis, application of GEOSS components and proposals to GEOSS for future work. The CoP members report on on-going activities and results of various projects and initiatives around the world. EO2HEAVEN has participated in the GEO Health and Environment CoP since 2011 and hosted the 2012 meeting in Karlsruhe. The GEO Health and Environment CoP was instrumental in formulating the current GEO Work Plan 2012-2015 in the health tasks HE01 and HE-02. Its members maintain the online GEO component sheets reporting on progress towards the task objectives. The CoP is also a forum for initiating collaborative proposals to funding agencies, e.g. on early warning systems.

The Health and Environment CoP liaises closely with the GEO Integrated Global Water Cycle Observations CoP since water and sanitation (WATSAN) are critical to health. The operation of both CoPs is supported by the GEO Secretariat.

The OGC Health Domain Working Group

OGC is initiating a new DWG (Domain Working Group) on health. EO2HEAVEN presented its proposals for the terms of reference and scope of the Health DWG. The draft terms of reference are available on www.opengeospatial.org as OGC document 13-009 'Proposing an OGC Health Domain Working Group'. The OGC Health DWG will support the development of OGC standards to be used in the GEOSS SBA Health.

1.3.7 Community and Capacity Building

The major aspect in any project is the acceptance of the results by stakeholders from all levels. As part of the EO2HEAVEN approach, it was important to ensure that all levels of stakeholders were included from an early stage. Involving potential end users to understand their requirements is quite self-evident and a common step to ensure, that software under development meets their actual requirements.

The approach of EO2HEAVEN was to educate stakeholders through a series of local workshops, which focussed on the particular requirement of each EO2HEAVEN scenario. The objective embraced the “train the trainer“ approach, i.e. building up sufficient local knowledge to enable participants to use and champion the basic concepts in their own organisational context in the long run.

In total, ten workshops were organised, which combined the principles of showing project results, inviting feedback from the audience and offering training on tools developed within the project. Uptake of project methods and system software on the longer term was supported by demonstrating the implemented methods in the local environment.

1.3.8 EO2HEAVEN Software

In this last part you can find a detailed description of the main software components, services and concepts that were developed by the EO2HEAVEN partners and used to implement the workflows described for each of the case studies.

Time2Maps

By using Web Service technology and standardized data exchange interfaces, the results of the different case studies can be made accessible to user stakeholders via the Internet. The concept following these principles is often called Geodata Infrastructure (GDI) or Spatial Data Infrastructure (SDI).

For the visualization of available datasets, a web application for the interactive mapping and display of spatial data and additional context information called Time2Maps has been implemented. Apart from the visualization of static data, the user can also explore maps provided by time-aware services to examine the temporal progress of measured data. The application has been deployed in two of the project studies:

- To access information on ozone, particulate matter and the modelled load of diseases caused by these environmental parameters in Saxony, Germany
- To access information on cholera cases, as well as prevailing environmental conditions in Kasese, Uganda

In both cases the underlying technology is the same, with adaptations to accommodate the specific datasets and analyses results.

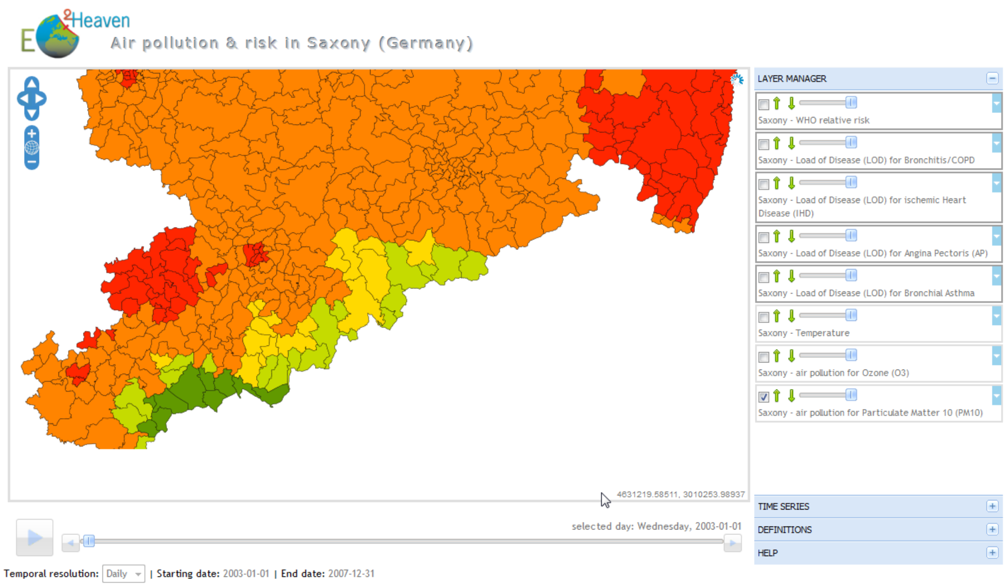


Figure 3: Air pollution and health risk in Saxony

The application primarily consists of a map area and tabs, which allows the user to select the datasets to be accessed and displayed, their legend and other metadata. Each available and selected dataset is listed and options include e.g. the definition of the layer order, drawing styles or layer opacity. For time series data, a time slider clearly indicates the current period displayed and enables the user to view a visualisation for a fixed point in time, or an animation for a time period. Depending on the selected data, the user can also retrieve additional information, such as statistics or detailed reports by simply clicking on according map features.

In addition to data visualisation and the retrieval of linked associated information, a data extraction module was implemented for the cholera scenario. This component allows the user to download TRMM datasets for a selected area of interest by drawing a polygon on the map, selecting a time period and the desired file format.

The web client for Time2Maps is accessible at the following URL: http://time2maps.dyndns.org.

Durban Web Client

Whereas the Time2Maps application has a primary focus on providing easy to use visualisation and retrieval capabilities, an alternative approach was evaluated in the context of the project. Here, a web client tool was designed to integrate further functionalities, on the fly addition of external layers, visualisation of time series in a video, visualisation of detailed information of the geometries of the layers, saving map contexts, downloading the results, execution of pre-defined web processing services (WPS) and exploring the outputs produced by the other services.

The EO2HEAVEN advanced generic client has been customised for the Durban case study to provide access to the main results for the Durban environmental health services managers, health practitioners, technical staff of the Pollution Control and Risk Management Unit and academics. The objective is to support the automated computing of pollutant concentration and health risks based on a predefined process workflow.

The web client includes login security. It presents OpenStreetMap as a background, and static layers such as clinics and the different primary health care (PHC) areas.

Pollution Concentration Map

The user has the option to select a pollution concentration map for SO2, PM10, or NO2 per point (250m x 250m grid) from the Layer Manager. The user may also select the mean or maximum concentrations per pollutant per PHC area. The legend for the pollution concentrations assists the users to determine the level of pollution for that period.

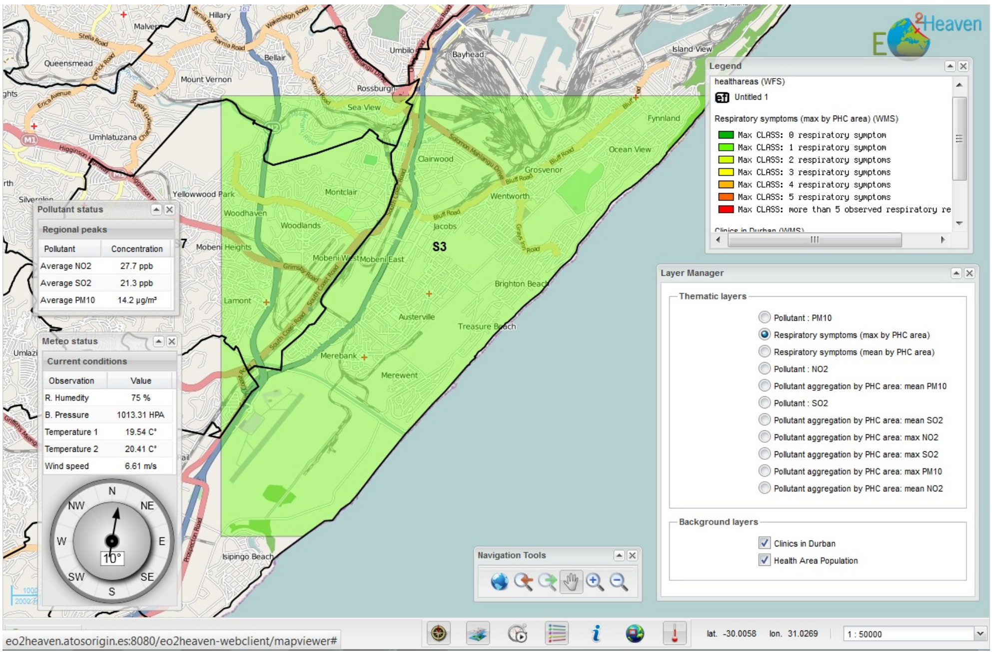


Figure 4: Air pollution and health risk in Durban

Health Risk Map

The user has the option to select a PHC area and determine what the health risks (mean and maximum) are for that area. The legend for the respiratory systems assists the users to determine the level of risk for that period. In addition, the user can explore information like:

- Maximum concentration of pollutants (SO2, PM10, NO2) for the entire Durban area
- Meteorological status (pressure, humidity, ambient temperatures, wind speed and wind direction depicted in a 360º chart)

Scientific data based on epidemiological studies suggests that a lag time from 24 hours to five days from exposure to effect can occur. Therefore a time slider function was implemented, that allows the user to visualise the respiratory symptoms for the last 4 days and the pollution concentration for the last 24 hours for SO2, PM10, and NO2 either for a given point in time or as a time lapse animation.

Summary Reports

Summary reports for the different pollutants and health per PHC area or grid point (250m x 250m) can be produced and saved by clicking on a point of interest.

Four pollutant reports are available for NO2, SO2, PM10. The NO2, SO2 or PM10 reports reflect a line graph of concentrations plotted against the hourly wind direction for the last 24 hours according to the point selected. A 24 hour pollution rose is also shown for each report. The pollution rose is created by a model using a given point and a given pollutant parameter computed for the last 24 hours from the ADMS model outputs and the meteorological data. Such a report is computed for a point of the grid (output of the ADMS model) or a PHC area.

The health report reflects a line graph of the mean pollution concentrations for every hour over four days plotted against the mean and maximum respiratory symptoms over a 24 hour period for last four days for a point or PHC.

Dira – Disease Incidence Reporting Application

The solution that EO2HEAVEN implemented to enhance the cholera case surveillance and reporting is based on three main components:

- A mobile app to record new cholera cases and upload it automatically to a server.
- A server that collects and stores all incoming new cholera cases sent by the mobile app devices.
- A simple web client to manage the server side, including export of the data to csv files and user account management.

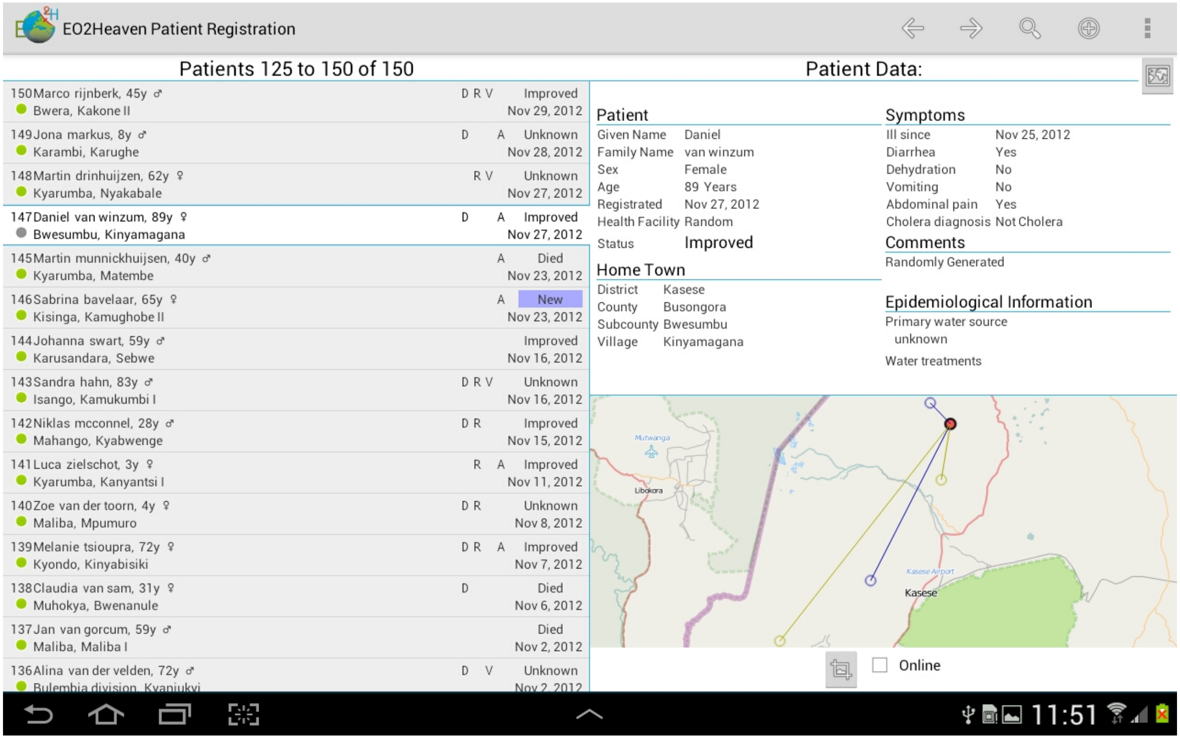


Figure 5: Disease incidence registration

Server Backend

The server receives the collected patient data from the mobile app as a JSON message over an encrypted HTTPS/REST internet connection. Successful receipt of the data set is acknowledged with a HTTP response 400-OK and the data is then stored in a database.

A simple web client on the server side provides administrational and maintenance functionality, such as the management of user accounts or data export to csv files. This ensures compatibility with the existing analogue system and allows users to maintain printed records on the reported incidents. The transmission of data to the client is currently not planned.

Mobile Application

The Disease Incidence Reporting Application, or Dira, was designed to run on almost all Android devices. In terms of usability, a tablet-pc with a 7”-10” display is recommended. All data is primarily stored locally, with copies transferred to the server when an internet connection, i.e. the mobile phone network or local WiFi-based internet, is available.

The application has an easy-to-use interface for entering patients. It also allows for the collection of epidemiological information, such as the patient’s primary water source, and which villages he or she has visited recently. The application has several ways to visualise the data, for instance patient movements animated over time on a map:

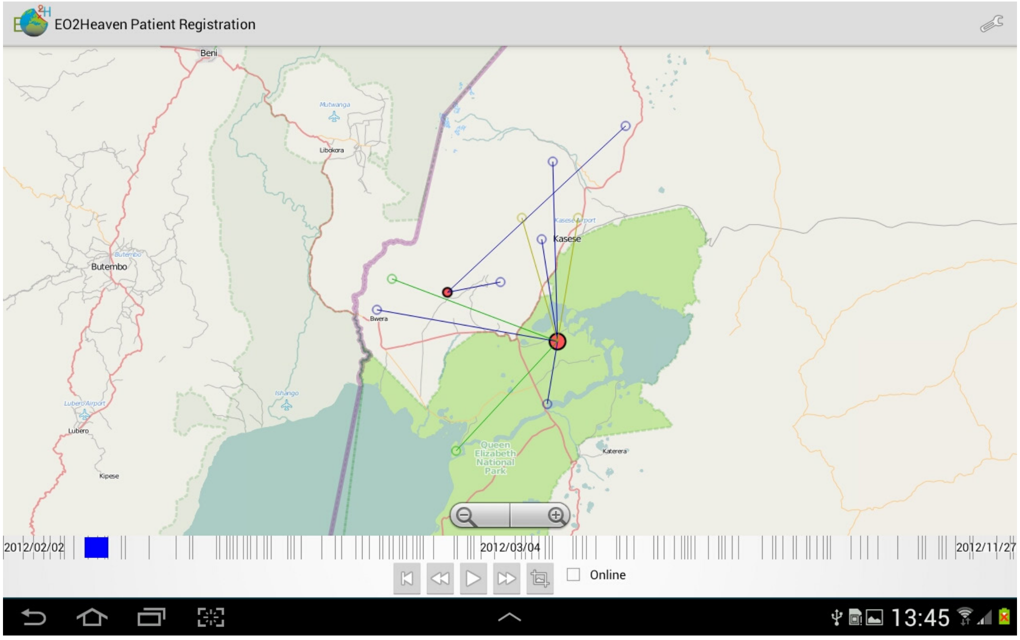


Figure 6: Patient movements as time animation

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1.4 Project impact, dissemination and exploitation of results

EO2HEAVEN produced a rich nature of exploitable results in order to achieve the above presented objectives. The project results include various best practices, methods and scientific and technical capacities for data collection, processing, analysis and dissemination in the domains of health and environment. Various software prototypes and components have been developed, such as several air quality and cholera monitoring web applications, a mobile application for health data collection, a catalogue, and sensor web components such as a new version of the Sensor Observation Service (SOS), an import tool for the SOS, or a SOS client.

EO2HEAVEN has developed and tested all components and tools under the requirements provided by the 3 case studies. However, since the project outcome is the optimization of a process, EO2HEAVEN results (in particular many software components) are not limited to the project case studies but can potentially be used in support of other environmental and health problems or even other domains.

EO2HEAVEN includes a rich nature of exploitable outcomes that can be grouped into three categories: 1) technical and architectural results, 2) educational material, and 3) software components.

Technical and architectural research results

The EO2HEAVEN public deliverables

D4.13 Specification of the SII Implementation Architecture

D4.14 Specification of the Advanced SWE Concepts

D4.15 Specification of the Advanced Geo-processing Services

extend or adapt existing spatial infrastructure specifications taking into account emerging technologies, especially for the Sensor Web Enablement (SWE) architecture and geo-processing architecture. The document set specifies how to build a service network including sensors and models in a geospatial information system.

The following documents of the Open Geospatial Consortium (OGC) address technical and architectural issues applied in EO2HEAVEN and to whose further development the project contributed:

- *Sensor Observation Service 2.0 Interface Standard*, published in 2012, defines a new version of the SOS, taking also into account experiences gained during EO2HEAVEN.
- *OGC Best Practices for Sensor Web Enablement*: Provision of observations through an OGC SOS (OGC 13-015). This Best Practice provides recommendations on the provision of observation data in a consistent way. It presents the advancements of the SOS 2.0, and introduces how data owners can easily publish their data on OSO servers through a graphical import tool.
- *Lightweight SOS Profile for Stationary In-Situ Sensors Discussion Paper* (OGC 11-169r1), published in 2011, describes a pragmatic and compact approach how to provide in-situ measurements through the SOS.
- *The OGC Web Processing Service (WPS) 2.0 Standards Working Group (SWG)* focuses on creating the next version of the WPS standard - WPS 2.0. This SWG currently simplifies and modularizes the existing 1.0.0 standard. In addition, WPS profiles and several extensions in order to enhance interoperability are discussed. The EO2HEAVEN intermediate and final results were directly communicated with this SWG. On the one hand, this is expected to improve the standard and base it on a more solid ground and on the other hand it created a sustainable manifestation of research outputs of this project in further applications.

Educational materials specifically developed for the different project workshops

EO2HEAVEN offered local training and organised several workshops for stakeholders in Africa and Europe to ensure the sustainability of the results after the completion of the project. Training material developed for the workshops contains self-study reading material and where applicable screencasts on software handling, as well as instructions for hands-on exercises. These materials are made available on-line on the Blackboard platform (EO2HEAVEN D6.8 Training and Stakeholder Workshops (issue 2)).

EO2HEAVEN results that can also be used for education purposes include all public deliverables, the EO2HEAVEN book and a manual for field sampling and laboratory methods for detecting *V. Cholerae* in environmental samples.

Software components

EO2HEAVEN has developed several software components that will be exploited by one or more partners. The following products are the result of the architecture specification and software implementation through different iteration cycles.

Further information on all software components can be found in Chapter 11 'EO2HEAVEN Software' of the EO2HEAVEN book.

Web Applications for Mapping, Exploring and Sharing Spatial Information

Two generic web applications have been developed and can be exploited in new projects as frameworks to easily develop new web GIS interfaces using OGC standards. In particular EO2HEAVEN web applications include features that serve to map, explore and share environmental and disease information. The EO2HEAVEN case studies validated their use for health authorities to: 1) monitor air pollution and receive more in-depth information on the impact of air quality on the human health, and 2) support the modelling of cholera risks by collecting and presenting predefined information relevant for the study of the cholera (e.g. rainfall, salinity, data from field campaigns, etc.).

- Web Application Based on the Advanced Client: This web client is described in scenarios 2 and 5 of the EO2HEAVEN Final detailed specifications (D5.14). It allows scientists to share data (environmental, health and socioeconomic) using the OGC standards (SOS, WFS, WMS) and a catalogue developed within EO2HEAVEN. The tool also allows users to easily add new information, visualize all layers, execute processes (e.g. NDVI), download data to local computer and save the context containing all the information displayed in order to restore it later. This product comprises several components in addition to the web client itself: the WebDAV, the catalogue service CSW, the visualisation module SOS control and the data discovery and repository module. The advanced web client is accessible from http://eo2heaven.atosorigin.es:8080/eo2heaven-webclient/
- Web Application Based on Time2Maps: The Time2Maps web client is described in scenarios 1 and 3 of D5.14. This web application allows interactive mapping and display of spatial data and additional context information. Apart from the visualization of static data, the user can also explore maps provided by time-aware services to examine the temporal progress of measured data. This product comprises the following components: the web client, the OpenDAP interface and the time series extraction. The Time2Maps web client is accessible from http://time2maps.dyndns.org/.

Disease Incidence Reporting Application (Dira)

The Dira application aims at enhancing the disease case surveillance and reporting. It is described in scenario 4 of D5.14 and comprises 3 main components:

- A mobile app to record new cholera cases and upload it automatically to a server.
- A server that collects and stores all incoming new cholera cases sent by the mobile app devices.
- A simple web client to manage the server side, including export of the data to csv files and user account management.

The latest version is available from Fraunhofer IOSB.

52°North SOS 4.0

This is an implementation of a standardised web-service interface that enables the interoperable, web-based access to sensors and real time geosensor data as well as sensor descriptions. Further information is available from http://52north.org/sos

52°North Sensor Web Client

The 52°North sensor web client is a web-based client that provides users with access to sensor data. This client offers a broad range of functionality including visualization methods such as diagrams and maps as well as a user interface for defining alerting/filtering rules for sensor data. Further information is available from http://52north.org/sensorwebclient

52°North SOS-Importer

This is a tool for uploading sensor data sets available locally as text (CSV) files. The GUI helps the user to define the structure of the CSV file. After the user has described the content and structure, the tool automatically converts the content of the CSV file to SensorML as well as O&M documents and uploads these documents to a user defined SOS server. Further information is available from https://wiki.52north.org/bin/view/SensorWeb/SosImporter.

52°North Sensor Event Service

This is an implementation of a web-service interface that enables the subscription to user defined alert conditions. For this purpose incoming sensor data streams are filtered according to these rules. This approach relies on the concept of complex event stream processing. Further information is available from http://52north.org/ses.

52°North WPS

This web service interface specification provides standardized access to geoprocessing functionalities in SDIs over the web. Further information is available from http://52north.org/wps

The consortium has looked at the full spectrum of exploitation opportunities, commercial and non-commercial, derived from the above project results. The impact of these results is recognised at 3 main application fields:

- **Policy making:** EO2HEAVEN contributed to the provision of timely data, information and expertise for assessing the state of the environment and the impact on health. This enabled policy-makers to decide on appropriate measures for protecting the environment and health and to monitor the effectiveness of policies and measures implemented. These processes involved many players at all levels of government, within the European Commission, the EEA, the WHO, WMO, ESA, GEO, and national, regional and local authorities.

- **Research:** EO2HEAVEN has produced scientific articles and publications that lead to new research challenges. These results are a valuable input for priority setting to the European Commission and international research agendas and also represent a very important asset for the on-going and future research projects involving the project partners.

- **Education:** EO2HEAVEN includes academic partners such as TUD, University of Twente ITC, UKZN, Makerere College of Health Sciences, or KIT that will use the scientific papers, software applications, software-focused e-learning methods and other materials in professional training. All these materials can be used in capacity building projects in Europe and beyond, mainly in lesser developed countries, through distance education projects.

In a first stage, the impact and adoption of results by stakeholders can be measured by 2 indicators: 1) the contributions to global initiatives such as GEOSS and INSPIRE and 2) the implementation and use of tools and results by the stakeholders in the three case studies. These strategic activities promote the uptake of project results by the target communities and strengthen the sustainability of the results after the finalisation of the project.

GEOSS

GEOSS initiative represents an opportunity to promote the use of EO2HEAVEN results among a wide community of policy makers, researchers and all types of organisations working with information and services related with observations.

EO2HEAVEN contributed to the GEO Work Plan for 2012-2015 in the task HE 01 'Tools and Information for Health Decision Making' through two GEO Work Plan components:

C1 Air-borne Diseases, Air Quality and Aeroallergens

The EO2HEAVEN consortium addressed these issues by investigating the value and feasibility of using remotely sensed information as a proxy for in-situ air pollution levels. Comparisons between in situ measurements of air pollutants (PM/SOx/NOx), satellite derived data and dispersion model derived estimates of air pollution have shown a potential, yet not convincing use of remotely sensed data to predict ground level air pollution. Estimating in-situ air pollution based on geo-statistical inferences of data derived from an extensive network of ground level measurement stations might offer a valuable alternative and is being investigated further.

Modelling the relation between local exposure to air pollutants, presumed to affect public health (PM/SOx/NOx), and different respiratory symptoms amongst children has allowed the strength of the associations to be quantified. Current results show that for different types of air pollution different time lags exist between the moment of exposure and the moment symptoms become present. Moreover, meteorological influences are found to significantly affect respiratory outcomes due to the presence of air pollutants.

C2 Water-borne Diseases, Water Quality and Risk

Cholera control has been a major issue for public health in many low and middle income countries in Africa and Asia. Although case treatment is relatively simple and can effectively reduce case mortality, early detection of an outbreak or a potential outbreak is essential to allow sufficient time for a proper national response and to increase preparedness. EO2HEAVEN has developed new methodological approaches and interdisciplinary tools to anticipate cholera epidemic outbreaks based on environmental, epidemiologic and microbiological information.

Results have shown that climatic signals, especially rainfall variations have great potential to predict cholera outbreaks on the continental scale. Still, however regional meteorological variations and local differences in the environmental conditions demand a further refinement of these models. Epidemiological investigations of the spatiotemporal patterns of cholera occurrence and the socio-economic factors driving these patterns add another level of detail to the macro-ecological risk models through the inclusion of environmental and public vulnerability to an outbreak. Current results have allowed the identification of spatiotemporal hot-spots of cholera infections which again are used to identify areas of high cholera risk. On a local (micro) scale, microbiological sampling has been used to identify sources and reservoirs of the infectious agent (*Vibrio Cholerae*).

The current multidisciplinary approach allows for a cross-cutting analysis and risk prediction by establishing links between environment (environmental/macro scale), host (epidemiological/regional scale) and agent (microbiological/micro scale). Future work will aim to develop a strong link between these fields to judge causality and to build a robust framework to predict and evaluate the likelihood of a cholera outbreak.

GEOSS Architecture Implementation Pilots (AIPs)

EO2HEAVEN has contributed to the consecutive GEOSS AIPs (3-5) helping to provide access to Earth Observation and health data sets used in the project and with a number of components and demonstrations targeting the SBA Health.

- Contribution to AIP-3: EO2HEAVEN project generalised and extended our three case studies to the health Societal Benefit Areas identified by the Pilot, i.e. Air Quality and Early Warning of Malaria scenarios. One example was the usage of CSIR's cholera in-situ data collection case in AR-07-02c and serve as contribution to AIP where appropriate. With respect to contributions to AR-09-02c EO2HEAVEN contributed directly through the development of a use case that tested the in-situ sampling of environmental parameters and how such data was brought into the sensor web. Although the work on cholera did not directly align with the malaria use case as outlined in the AIP-3 it did share some commonalities on environmental aspects. Part of the process of engaging the AIP-3 was to ascertain these commonalities. These commonalities included lessons learned in sensor web and techniques involved in the fusion of in-situ field samples and laboratory results, in-situ data and remote sensed data.

- EO2HEAVEN contributed to AIP-4 helping to provide access to Earth Observation and health data sets used in the project. The access was provided by OGC specified Web Services. Additionally, the project provided an import tool for sensor data sets (e.g. CSV or plain text files) into a OGC Sensor Observation Service. This tool is able to read existing data archives, helping users to specify how the data is encoded in these files and then converting the data sets into the according SWE data formats.
- EO2HEAVEN contributed to AIP-5 with a number of components and demonstrations targeting the SBA Health.

At the March 2013 Abu Dhabi OGC Technical Committee meetings, the members approved an electronic vote to release “OGC Best Practices for Sensor Web Enablement: Provision of Observations through an OGC Sensor Observation Service (SOS)” [OGC 13-015] with a companion document “OGC® Lightweight SOS Profile for Stationary In-Situ Sensors” [OGC 11-169r1] as OGC Best Practice documents. As of this writing the OGC members were asked to submit their vote by 22 June 2013 and all votes were positive. The achievement of a ‘best practice status’ heavily contributes to the visibility of EO2HEAVEN In the geospatial community and hopefully will help OGC to increase the acceptance of the OGC SOS.

It is therefore safe to say that the project will have a significant impact on the implementation of GEOSS, especially concerning the Health SBA.

INSPIRE

INSPIRE is currently in its implementation phase. Best Practice recommendations for realising SDI components, such as developed by EO2HEAVEN, serve as valuable input to the INSPIRE implementation process.

EO2HEAVEN has supported the INSPIRE implementation rules by making environmental and health data associated to the project case studies available to the general public and researchers in particular through INSPIRE compliant OGC services. These could be seen as prototypes for future INSPIRE Spatial Data Services. As invited INSPIRE experts and member of the INSPIRE Network Service Drafting Team EO2HEAVEN Partners linked and will link the project’s results to the actual developments of the INSPIRE Spatial Data Services. The results on the design and development of advanced distributed geoprocessing and a Geoprocessing Repository (WP 4) have been presented to the INSPIRE community as an input to future INSPIRE developments.

Furthermore, the EO2HEAVEN Sensor Web activities will influence the currently ongoing specification of INSPIRE Download Services in the context of e-Reporting of air quality measurements.

Case Studies Sustainability Plans

EO2HEAVEN results address the needs and requirements identified by the local community stakeholders of the three case studies. From an exploitation and impact perspective the objective is twofold: on one hand EO2HEAVEN aims at extending the results to other areas at a later stage. In addition, it is also important for the project to maintain and ensure the use of the tools and results by the local stakeholders of the case studies beyond the lifetime of the project, as a first reference account of sustainable implementations. For this reason the consortium has prepared a sustainability plan describing the tools that will be used and the organisations and users interested in maintaining and using those services and tools.

For the three case studies, the sustainability plans rely on adequate capacity building and training activities that the project started in 2011 and continued until May 2013. The details of the training and stakeholder workshops carried out can be found in deliverables D6.5 Training workshops (first issue), D6.8

Training workshops (second issue) and D7.6 Stakeholder Workshops Report.

Saxony Case Study Sustainability Plan

All software components developed for the case study in Saxony will be made sustainable by providing them via the 52ºNorth open source platform.

The following datasets and Web Services developed by TUD have been integrated in the regional INSPIRE implementation (GDI Sachsen[1]) in close cooperation with the responsible authorities:

- Time2maps as integrated client to animate the visualization of the health-environment analysis in maps and time series,
- Web Services showing the intermediate and final results of the health-environment analysis in Saxony (including exposure maps based on the developed air quality model, WHO risk maps and maps showing the LOD) for usage in Time2maps and external software and clients (e.g. for the expert tools used by the environmental and health authorities and the researchers in Saxony),
- Metadata of all clients, Web Services and datasets has been registered with the GeoMIS Sachsen representing the regional INSPIRE catalogue.

Durban Case Study Sustainability Plan

The users of the system are the Environmental Health Practitioners (EHP), part of the local government responsible for health promotion, health reporting as well as social and health advisory services. Additional users comprise the Pollution Control and Risk Management (PCRM) department and medical and environmental scientists. The PCRM is part of the eThekwini (Durban) Municipality. They are responsible for monitoring pollutant levels, and determining the sources of such pollutants, enforcing industrial practice regulations and identifying mechanisms to reduce exposure. This section currently manages the Air Quality Monitoring System (AQMS) for the city.

The workflow implemented for the case study 2 includes the following components:

- A web client
- Map server, publishing the following OGC services:
  - WMS and WFS with Durban health areas and clinics
  - WMS-T containing the following datasets:
    - Meteorological parameters
    - Pollutants (ADMS result), grid 250m*250m
    - Pollutants (ADMS result), aggregated by PHC area
    - Health indices, aggregated by PHC area
  - WMS of Open Street Map background for Durban
- ADMS model
- Rose model
- Health model to compute health index from meteorological and pollutant data
- Conversion and aggregation scripts

The hardware requirements to run the workflow are minimal, since all the scripts, models and server side components will be installed in a single server machine.

In the process of developing the above system, skills available locally in Durban (the site of Case Study 2) were accessed on an on-going basis. Each step of the web client development that was largely de-

[1] http://gdi-sachsen.de

veloped by the European based partners was shadowed by appropriate technical experts from the Durban based network of EO2HEAVEN. Therefore on-going maintenance and sustainability of the system will reside primarily with the UKZN partners. For this reason, the server on which the system is currently run is housed at UKZN.

Responsibility for each aspect of the system is as follows:

- UKZN will assume responsibility for the ADMS and Rose models
- Durban based consultants associated with UKZN will assist, under UKZN direction for further development of conversion and aggregation scripts
- The eThekwini Municipality (Durban's local government) will be responsible for the on-going input of the necessary pollutant and meteorological data to the UKZN server. This relationship between the Municipality and UKZN is based on an institution-wide Memorandum of Understanding.

A key aspect of sustainability is the exploitation and expansion of the system beyond the EO2HEAVEN framework. The system will be expanded to a greater geographical coverage of the city of Durban. Currently focusing on the heavily industrialised south of the city, the system does not provide information for the north of the city. Both the PCRM and UKZN have specific needs to increase this coverage. With increasing industrial and residential development in the north and west of the city, there is a need for local government to have a better understanding of exposure and source of pollution in these areas. As an academic institution, UKZN has a need to focus on the changing pollution profiles and associated health outcomes as part of a research agenda.

To achieve the above system expansion, the Durban partners will further develop the ADMS model, improving the pollutant profile of the under covered areas. Apart from improving the environmental management for the city, this expansion of the system will allow researchers at UKZN to use the data generated in the range of environmental health research projects underway and in planning. Central to this research programme is a birth cohort project which recruits pregnant females, following them through their pregnancy, and then continues to follow up the new-borns to infancy. The EO2HEAVEN system will allow the researchers to clearly define pollutant exposure of the pregnant females and their new-born in the different phases of the project, and determine health outcomes associated with exposure.

Uganda Case Study Sustainability Plan

In the Uganda case study there are three different stakeholders interested in using the different tools and training materials delivered as a part of the EO2HEAVEN project. The following tools were developed based on specific user requirements:

- Disease Incidence Reporting Application Dira
- Time2Maps web application for data exploration
- Advanced web client for data management and data access control.

The benefits of real time data access and reporting of standardised patient based data over the whole vertical range of the health system were recognised both at the Ugandan ministry of health (MoH) and the local district level stakeholders (DHO, NGO's). Future work should aim on extending the tools towards the framework for Integrated Disease Surveillance and Response (IDSR), as outlined in the International Health Regulations (IHR, 2005). Facilitating the surveillance of prioritized diseases and health services, could reassure the realization of this internationally adapted system.

The effective operationalization and adaptation of these tools by various stakeholders, however, depends on the provision of a simple, clear and concise best practices operating procedure for disease surveillance and a description of the procedures necessary to use each of these tools to address specific health issues. These supportive guidelines will provide an operational structure on how the tools can and should be used and how various information components can be objectively used for health risk mitigation. This will be one of the key activities expected to be continued by KIT after the EO2HEAVEN project is terminated. Moreover, to increase the impact and use of the tools and system, further development should focus to integrate these into a modular system which can be adapted to the user requirements.

A field sampling campaign also formed part of the Ugandan Case Study. The main aims of this campaign were to (a) determine if *Vibrio cholerae* is present in the water bodies in the study area; (b) if there are seasonal changes in the presence of the bacillus; and (c) which chemical, physical and biological factors are associated with the presence and absence of *Vibrio cholerae*. The presence of the bacillus in water bodies poses a risk to communities when people are exposed to it. A continuous monitoring programme that tracks the fluctuations in the presence of *Vibrio cholerae* in the larger area is an important input for an early warning system. A manual was developed with general instructions for setting up a monitoring programme for when and if required by health officials, academics or researchers in Uganda and South Africa. It provides details on how to collect samples in the environment and analyse the samples for *Vibrio cholerae* O1 and O139 and environmental strains using specific laboratory methods. It also includes guidelines on how to analyse the data collected.

1.5 Project contact details

The EO2HEAVEN Consortium

Participant organisation name	Country
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52°North Initiative for Geospatial Open Source Software GmbH	Germany
ATOS SPAIN SA	Spain
SPOT IMAGE (SI) SA	France
NEVANTROPIC[2]	France
COMMISSION OF THE EUROPEAN COMMUNITIES – DIRECTORATE GENERAL JOINT RESEARCH CENTRE - JRC	Belgium
COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH	South Africa
OPEN GEOSPATIAL CONSORTIUM (EUROPE) LIMITED	UK
BUREAU DE RECHERCHES GEOLOGIQUES ET MINIERES	France
UNIVERSITEIT TWENTE	Netherlands
UNIVERSITY OF KWAZULU-NATAL	South Africa
UNIDADE TECNICA DE IMPLEMENTACAO DA POLITICA DE INFORMATICA[3]	Mozambique
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[2] Project exit month: 14
[3] Project exit month: 4
[4] Project entry month: 18
[5] Project entry month: 18

2 Final plan for the use and dissemination of foreground (D1.9)

A plan for use and dissemination of foreground (including socio-economic impact and target groups for the results of the research) is provided as a separate document, *D1.9 Final plan for the use and dissemination of foreground*.

3 Report on awareness and wider societal implications (D1.10)

This is provided as a separate document, *D1.10 Report on awareness and wider societal implications*.

ANNEX. Short description of all Project Deliverables

- A general public **Glossary of Terms** for all project documentation is maintained at http://www.eo2heaven.org/sites/default/files/EO2HEAVEN_Glossary.pdf.
- **D2.1 Report on requirements and bounding conditions from relevant initiatives.** The report provides an overview of local, regional and global initiatives which are of relevance for the EO2HEAVEN case studies. The report lists the main characteristics of the identified initiatives and provides the appropriate analysis of the relevant aspects and potential implications for the EO2HEAVEN case studies.
- **D2.2/10/18 Saxony Case Study and use case specifications report.** This report describes the Case Study 1 focused on Saxony, Germany. This Case Study focuses especially on cardiovascular diseases in relation to the environmental parameters ozone and particulate matter.
- **D2.3/11/19 Durban Case Study and use case specifications report.** This Case Study specification provide the scientific background and the requirements to develop a system which permits ready access to in-situ pollutant and meteorological data that allows for the prediction of exposure of vulnerable populations in areas that are at risk for respiratory disease as a result of elevated excess ambient pollutant exposure.
- **D2.4/12/20 Uganda Case Study and use case specifications report.** This Case Study focuses on links between environmental, including climatic, variables and the outbreak of cholera in Africa and the dynamics of the *V. cholerae* pathogen in the natural environment. The specification provides the scientific background and the requirements for investigating these links in Uganda using satellite, in-situ and ex-situ sensor data factors and the dynamics of cholera outbreaks in Uganda.
- **D2.5/13/21 Harmonised use case specification and user requirements report after each cycle** (Public[6]). This document summarizes the specific as well as the common user requirements of the project and the methodology for their harmonization process. D2.21 supersedes D2.5 and D2.13.
- **D2.6/14/22 Saxony Validation report and fitness-for-purpose assessment.** This document evaluates components and methods developed with regard to Case Study 1 (Saxony). It has been included in D2.17 Feedback report after second cycle.
- **D2.7/15/23 Durban Validation report and fitness-for-purpose assessment.** This document evaluates components and methods developed with regard to Case Study 2 (Durban). It has been included in D2.17 Feedback report after second cycle.
- **D2.8/16/24 Uganda Validation report and fitness-for-purpose assessment.** This document evaluates components and methods developed with regard to Case Study 3 (Uganda). It has been included in D2.17 Feedback report after second cycle.
- **D2.9/17/25 Feedback report incorporating evaluation and validation outcome.** These deliverables contain the harmonized set of findings from the first, second and third iteration of evaluation reports from each case study of EO2HEAVEN. The reports evaluate if the implementations meet the requirements. The evaluation was carried out from the perspective of end users who will apply the end application of EO2HEAVEN. For D2.17 the evaluation results were documented in the validation reports and fitness-for-purpose assessments (deliverables D2.14, D2.15 and D2.16). The individual validation reports for the third cycle were removed in the third amendment to the contract and just a consolidated report (D2.25) is provided.
- **D2.26 Saxony Final report on fitness-for-purpose assessment** (Public).
- **D2.27 Durban Final report on fitness-for-purpose assessment** (Public).

[6] All Public deliverables are available in the publications area of the project website (http://www.eo2heaven.org/category/documents-categories/public-deliverables)

- **D2.28 Uganda Final report on fitness-for-purpose assessment** (Public).
- **D3.1 State of the art for environmental & health monitoring in air and water** (Public). This document provides an overview of the various aspects of Environmental health monitoring and surveillance. The main purpose is to address and highlight the multiple aspects that play a role in environmental health monitoring.
- **D3.2 EO and EI products needs** (Public). This deliverable introduces the environmental parameters to be studied in the context of EO2HEAVEN and proposes some EO data to be tested for each Case Study.
- **D3.3 Methodologies for Health and Environment data fusion.** Deliverable D3.3 introduces common and specific research questions belonging to the correlation and fusion of health and environmental data, identifying basic techniques.
- **D3.4 Methodologies for Health and Environment data mining.** This document introduces the data mining techniques that will be implemented in the context of the EO2HEAVEN project. These techniques include i) web mining technique for epidemiological surveillance, ii) sequential pattern mining on time series and iii) skyline queries.
- **D3.5 Health and Environment database templates.** This deliverable introduces the main expected challenges to be solved in order to build a health database and apply common processes. Building such a database is a complex task due to the heterogeneity of the health data obtained in the project. The different sources of heterogeneity are described in this document and potential solutions to attend these issues are discussed. Available health data is also described.
- **D3.6/11 Catalogue of EO/EI products** (Public). This deliverable describes environmental parameters which are relevant for health-environment studies. The document also contains the tests of some datasets and the conclusions on the data to be used, along with the relevant metadata to be included in the catalogue.
- **D3.7/12 EO/EI processing chains prototypes and validation results** (Public). This document introduces first processing chains implemented in the context of the EO2HEAVEN project. The processes studied are: opening and reading EO data, data format conversion, extraction of time-series, change in temporal resolution and EO data validation. This deliverable can be considered as a companion deliverable to the D3.10.
- **D3.8/15 Environmental Monitoring for Health Applications** (Public). This report summarises the results of WP3 with attention to its relation to WP2. The objective is to provide a roadmap to activities and results which cross the boundaries of the Work Packages, but should be anticipated as unified topics. A final version (D3.15) was provided at the end of the project.
- **D3.9/13 Methodologies for Health and Environment data fusion and data mining** (Public). This document introduces the main methods for the fusion of environmental and health data to be applied in the three Case Studies of the EO2HEAVEN project. D3.13 updates the previous document D3.9 and also builds on the results of D3.3 'Methodologies for Health and Environment data fusion'.
- **D3.10/14 Processing chains prototypes (with validation results on sampled health and env data)** (Public). This deliverable aims at describing the various Processing Chains Prototypes or scenarios, including the specific workflows and processing steps of each scenario, for each Case Study of the EO2HEAVEN project.
- **D4.1 Documentation of the Baseline Infrastructure.** This deliverable describes the critical analysis results of the state-of-the-art technologies and selects the most promising ones for the documentation of the baseline. D4.1 covers the results produced by GIGAS, INSPIRE, GMES, GEOSS and standard specifications such as W3C, OASIS and OGC.
- **D4.2/3 Specification of the Use Case Specification and Validation Methodology.** This document defines the methodology to be used to develop the EO2HEAVEN project. It specifically describes: i) steps to formalize a use case specification, ii) procedure to carry out different use cases specifications and iii) software tools to develop and manage the different phases of use

case development, elaboration, evaluation, and maintenance. D4.3 supersedes D4.2.

- **D4.4/7/10/13 Specification of the SII Implementation Architecture (Four versions)** (Public).
- **D4.5/8/11/14 Specification of the Advanced SWE Concepts (Four versions)** (Public).
- **D4.6/9/12/15 Specification of the Advanced Geo-processing Services (Four versions)** (Public).

  This deliverable is a six part document (Part I to Part VI) describing the 4 iteration cycles (and updating D4.4 provided in the first project period) results of the Architecture of the spatial Information Infrastructure. Parts V and VI are in separate deliverables respectively as shown in the following overview table. The Issues 2-4 are incremental updates; hence it is recommended to read the final Issue 4 deliverables first and to read the earlier issues only as seen necessary.

	Issue 1	Issue 2	Issue 3	Issue 4
Part I- Part IV	D4.4	D4.7	D4.10	D4.13
Part V	D4.5	D4.8	D4.11	D4.14
Part VI	D4.6	D4.9	D4.12	D4.15

  A summary of each document part is given next:

  a. **Part I Overview**: It contains a summary section of the six parts

  b. **Part II SII Enterprise Viewpoint**: It describes the specification of some generic "Architecture Analysis Use Cases (AAUC)" derived from the three EO2HEAVEN Case Studies.

  c. **Part III EO2HEAVEN SII Sensor Service Architecture (SensorSA)**: describes major concepts of the EO2HEAVEN SensorSA in order to facilitate the understanding of the subsequent specifications.

  d. **Part IV SII Engineering and Technology Viewpoint**: based on the major concepts of the EO2HEAVEN SensorSA, this Part IV provides definitions of policies for the setup and operation of the EO2HEAVEN Spatial Information Infrastructure. The Technology Viewpoint specifies the technological choices of the concrete service platform and its operational issues.

  e. **Part V Specification of the Advanced SWE Concepts (D4.5, D4.8, D4.11, D4.14)**. To improve the applicability of the Sensor Web technology and components to the use cases of EO2HEAVEN, Part V describes how to facilitate the practical use of the OGC Sensor Web Enablement (SWE) framework (i.e. use of a lightweight SWE profile, of the Sensor Observation Service (SOS) 2.0 and how the EO2HEAVEN data can be integrated more easily into SOS instances).

  f. **Part VI Advanced Distributed Geo-Processing & Spatial Decision Support (D4.6, D4.9, D4.12, D4.15)**. This last document series Part VI documents work in the field of geo-processing workflows and services to support data fusion for decision support, to integrate quality descriptions, encapsulate models and to handle large geo-databases.

- **D5.1/8 Detailed specifications (Two versions)** & **D5.14 Final detailed specifications** (Public). This deliverable presents several scenarios chosen by WP5 in cooperation with WP2 and WP3 in order to illustrate several technological aspects and to address different categories of end-users. D5.8 and D5.14 update D5.1 provided in the first project period. It is recommended to read D5.14 first, and then D5.8 if considered necessary.
- **D5.2 Open Source or proprietary license components report** (Public). This deliverable reviews and evaluates available Open Source and proprietary components to check their adequacy to meet the requirements. As a conclusion some advice to choose some components is pro-

vided.

- **D5.3/9 Generic components package (Two versions)** & **D5.15 Final generic components package** (Public). First, second and third release of the generic components developed in WP5 to implement the various scenarios identified by WP2 and described in the harmonized use case specification and user requirements report after each cycle. D5.9 and D5.15 are software, largely shown at the Conference on May 14, 2013. The associated **D5.10 Generic components documentation** and **D5.16 Final generic components documentation** present the documentation of the generic components delivered. It is recommended to read D5.16 first, and then D5.10 if considered necessary.
- **D5.5/11 Specific components package (Two versions)** & **D5.17 Final specific components package** (Public). First, second and third release of the specific components and software packages developed in WP5 to implement the various scenarios outlined by WP2 and described in the harmonized use case specification and user requirements report after each cycle. They complement the Generic components package (deliverables D5.9 and D5.15). Associated **D5.12 Specific components documentation** and **D5.18 Final specific components documentation** present the specific components documentation. It is recommended to read D5.18 first, and then D5.12 if considered necessary.
- **D6.1 Project Website** (Public).
- **D6.2/3/6/9 Dissemination Plan & Report.** This document provides a guideline for all dissemination activities carried out by EO2HEAVEN and the planned activities until the end of the project. The primary objective is to support sustainable uptake of project results by user communities and to receive feedback and validation on EO2HEAVEN activities and directions. Deliverable D6.9 is an update that supersedes the third issue D6.6.
- **D6.5/8 Training Workshops** (Public). The first EO2HEAVEN training workshop took place in South Africa between the 7th and 11th of November 2011. Two days were devoted in Pretoria and another day was spent in Durban as well. A specific Case Study 1 workshop took place in Dresden on 13th June 2012. D6.8 relates to the second iteration of the EO2HEAVEN workshops on IT-tools and epidemiological methods that were held in Kampala, Kasese (Uganda), Pretoria, Kruger Park and Durban (South Africa) on February 3-15, 2013.
- **D6.4/7 On-line Training materials** (Public). Materials from the workshops are available through the ITC Blackboard website at http://bb.itc.nl.
- **D6.10 EO2HEAVEN Book** (Public). The EO2HEAVEN Book provides a comprehensive compilation of project results in an easy-to-read language.
- **D7.1 Quality assurance plan.** This document is a handbook for how to be properly and efficiently involved in the project. All the administrative issues are explained, how reporting must be performed is described and how the overall project management is set up to ensure that the project reaches its goals in a timely and smooth manner.
- **D7.2/4/5 Exploitation & Use Plan.** This deliverable describes the exploitation strategy to support a successful uptake of the project results. It provides a vision of the project, the strategy to identify the potential exploitable results, a SWOT analysis and an analysis of relevant markets for EO2HEAVEN. D7.4 complements the first issue provided in period I and D7.5 is the final Exploitation plan provided at the end of the project.
- **D7.3/6 Stakeholder workshop reports** (Public). This report briefly summarises the exploitation activities that have been carried out and outlines the plans for the major activities scheduled towards the end of the project.
- **D7.7 GEOSS Activity report** (Public). D7.7 summarizes the EO2HEAVEN activities in the GEO Plenary meetings, GEO workplan symposium and the Health and environment Community of Practice as well as other GEO meetings.
- **D8.1 OGC and GEOSS demonstration report** (Public). D8.1 describes the GEO Architecture Implementation Pilots.