

Near Real-Time Geo-Analyses for Emergency Support: An Radiation Safety Exercise

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INTRODUCTION

A variety of well-established emergency support systems are employed for measuring and monitoring potential physical and chemical hazards such as radioactive radiation or toxic gases. Within such systems, real-time data from in-situ geo-sensor networks play a crucial role. The exchange of real-time data and, indeed, their integration into heterogeneous systems across different rescue organizations such as fire-fighters or military are significant time critical factors in the decision making process. Major problems within this integration include proprietary data formats and interfaces. We therefore use open and international standards in an entirely service-oriented workflow, from sensor-data acquisition to visualisation and dissemination of newly generated information.

Weaknesses of current approaches for near real-time spatial decision support systems (SDSS) comprise a.) lacking integration of open standards and service interfaces to allow for simple integrability of heterogeneous data sources, b.) limited support for near real-time data analysis in Geographic Information Systems (GIS) to perform advanced spatial processing using complex spatial algorithms, and c.) lacking ability of GIS products towards the integration of real-time measurement data. In the research presented in this paper we aim to tackle those shortcomings by the use of the open standards based data integration and analysis infrastructure, which is described in sub-section 'Methodology'.

Previous work in the field of geo-processing based on the Open Geospatial Consortium (OGC) Web Processing Service (WPS) includes, for instance, application related to water quality (Ninsawat et al., 2008) or bomb threat scenarios (Stollberg and Zipf, 2007). Although the current WPS 1.0.0 specification (Schut, 2007) has clear weak-points, for example its very broad scope and lack on restrictions (Michaelis and Ames, 2009; Stollberg and Zipf, 2007), or missing asynchronous processing (Resch et al., 2010b), it is the only established web-based processing interface standard in the geo-spatial domain. We therefore implement only mandatory elements of the OGC WPS 1.0.0 interface.

In this paper we demonstrate a real-time or near real-time – summarized by the term 'live' – workflow for geo-sensor information analysis based on open standards in order to enhance time-critical emergency support. Emphasis is put on live geo-processing and rapid information dissemination and visualisation. This workflow has been successfully applied as part of the 'G2real' project exercise 'Shining Garden' in Seibersdorf, Austria.

Geography to Reality – G2real

The overall aim of the FP6 ERA-STAR Regions project "G2real: Galileo based GMES¹ real time emergency support testbed, real time exercise and development of services" is the development and test of new pre-operational GMES services in the field of emergency and disaster management. The primary project objective is the validation and verification of the services developed through two real-time exercises – one relates to Galileo Navigation, the other to GMES services. Herein, we show scientific results of the latter exercise for radiation safety called 'Shining Garden'.

The G2real 'Shining Garden' exercise has been carried out in the radiation safety test area at Seibersdorf Laboratories in Seibersdorf, Austria. Two ¹³⁷Cs radiation sources were brought out in the test area for localisation. Subsequently, a person was moving through the test area sensing equivalent radiation dose rate with a standardised sensor pod (Figure 2). At the same time, these live sensor measurements were spatially interpolated and simultaneously visualized on several clients (s. sub-section Geo-Processing').

¹ Global Monitoring for Environment and Safety - <http://www.gmes.info>

METHODOLOGY

The overall workflow design as illustrated by Figure 1 is based on the ‘Live Geography’ approach introduced by Resch et al. (2009). We apply this workflow in order to maximize interoperability in using well-established OGC standards. Specifically, we employ Sensor Observation Service (SOS) to request live sensor measurements (Figure 1 ‘Data’), WPS (Schut, 2007) to transform data into information (Figure 1 ‘Processing and Simulation’), and Web Feature Service (WFS), Web Coverage Service (WCS), and Web Map Service (WMS), respectively, to rapidly disseminate and visualize analysis results for browser- and web-based platforms (Figure 1 ‘Presentation’).

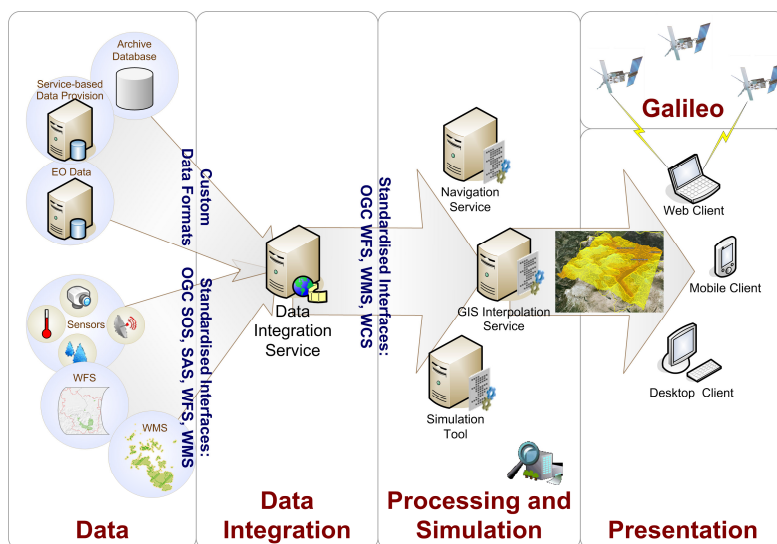


Figure 1: modular and service-oriented workflow from data (left) to presentation of information (right) based on standardized interfaces

Data: From Measurements to SOS Observations and Measurements

Quantitative properties of the physical or chemical phenomenon – in this case dose rate of radioactive radiation – need to be measured by an accurately calibrated sensors. In the proposed setting, the measurements have to be pre-filtered, tagged with their current spatial positions and time-stamps, and finally published via an SOS service for further use within the service-oriented infrastructure (Figure 1). The developed sensor pod framework is fully compatible with already existing sensors. As shown in Figure 2, we use a separate embedded system, the IGEPv2 single board computer, as central managing unit which manages data received from a sensing device (e.g. SSM-1²), and a Global Positioning System (GPS) receiver. Both sensors transmit raw data via serial interfaces, e.g. RS232 (SSM-1) or USB (GPS), to a software framework running on the embedded computer.

In essence, the measuring framework on the embedded computer manages quality assurance routines of raw measurements. These routines include filtering out non-fixed GPS positions as well as malformed values. After this first verification step the data are stored in a SQLite³ embedded database. The database is used to decouple the measurement phase from further processing steps. Additionally, the sensing framework and the database are set up to act in a round-robin scheduling manner. This very loose coupling enables concurrent actions such as measuring, and delayed data delivery using a HTTP service. The SOS interface on the integrated webserver is then used for further geo-processing and analyses steps (see subsection ‘Geo-Processing’). The services provided currently include SOS, Keyhole Markup Language (KML), and Geo Really Simple Syndication (GeoRSS). The entire functionality of this sensor pod approach complies with the OGC Sensor Web Enablement (SWE) initiative (Botts et al., 2007) and is described in detail by Resch et al. (2010a).

² Strahlenschutzmessgerät SSM Version 1

³ <http://www.sqlite.org>

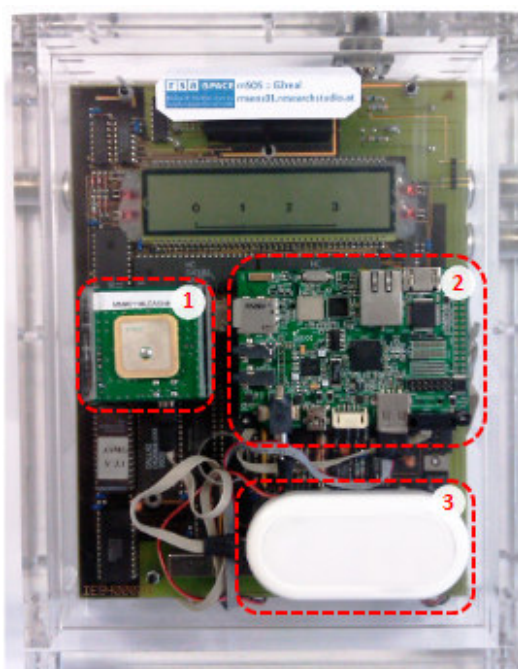


Figure 2: Sensor Pod: GPS receiver (1), IGEPV2 Single Board Computer (2), and UMTS modem (3) on top of SSM-1 (circuit board only)

Data Integration

Since the recent emergence of a variety of real-time data sources the ‘topicality’ parameter, i.e. the up-to-dateness of geospatial data, in addition to other quality criteria (accuracy, completeness etc.), is receiving a lot of attention. Although such real-time geo-data enhance spatial analyses, these are indispensable for time-critical decision support. The integration of real-time data into decision support systems, however, often requires pre-processing steps such as format conversions. Thus, a data fusion mechanism for live integration of real-time data is required. We therefore developed two ‘live-data-source-plug-ins’ for open source (GeoServer⁴) and commercial software packages (ESRI ArcGIS), respectively.

These ‘live-data-source-plug-ins’ enable the direct integration of SOS conform data structures into GIS applications. The open source software GeoServer recognises one version of the plug-in as a ‘data-store’ and converts the SOS input *on-the-fly* into a variety of output formats including KML, GeoRSS, PDF, and SVG (besides OGC WFS and WMS). ESRI ArcGIS as a commercial GIS product recognises a second version of the plug-in as a ‘simple point feature class’. This point layer contains live measurements which can be used for further spatial as well as temporal analysis. As a result, real-time data fusion as described above enables the direct integration of live measurements into a variety of systems, not necessarily GI analysis and visualisation systems.

Geo-Processing

Discrete live in-situ measurements are spatially represented as points. To convert these one-dimensional – geometrically zero-dimensional – measurements of continuous phenomena (e.g. dose rate of radioactive radiation) into multi-dimensional geo-information layers we employ the Inverse Distance Weighting (*IDW*) algorithm as a deterministic, and *Kriging* as a stochastic spatial interpolation technique. We therefore developed an integrated modular geo-processing workflow. The workflow’s three basic components are illustrated by Figure 3: (1) transformations of input data from its inherent spatial reference system (e.g. WGS84) to a projected coordinate system (e.g. UTM 33) – further metric calculations require a length-preserving map; spatial interpolation of projected point data.; (2) spatial interpolation of points to a continuous surface. The technique of interpolation (IDW, or Kriging) as well as its parameter (e.g. exponent of distance for IDW) is selectable and adjustable at

⁴ <http://www.geoserver.org>

run-time⁵ by the user; (3) classification (e.g. low, moderate, and high) of processing results according to user-specific thresholds. The first two components relate to ‘pure’ geo-processing. The third component reduces information to its essence for usability in time-critical decisions.

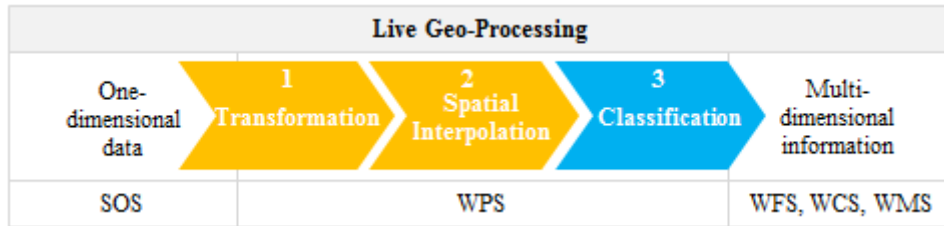


Figure 3: principal modular live geo-processing workflow

Based on that workflow, and in compliance with SOA, we establish geo-processing services as described by Mittlboeck et al. (2010). ESRI ArcGIS Server⁶ in combination with PyWPS⁷ acts as the live geo-processing engine. In the near future, due to the massive increase of real-time data, comprehensive architectures for distributed and cloud processing might be required (Friis-Christensen et al., 2007; Schaeffer et al., 2009). Depending on the format requested by the user, the geo-processing output includes vector or raster data. This results in an entirely service oriented live geo-processing workflow utilizing the following OGC standards: SOS to request one-dimensional in-situ data, WPS for geo-processing on-the-fly, and WFS, WCS, and WMS, respectively, for multi-dimensional information output (Figure 3 bottom).

Presentation: Information Dissemination and Visualization

Correct and easily interpretable visualisation of complex information is a central aspect in time-critical decision making processes. We prepare such information as standardized services and enable their rapid dissemination within internet-based environments. These services can therefore be easily integrated into other applications including GI Systems for enhanced visualisation.

In order to improve the situational awareness of decision makers and even rescue teams on-site with near real-time geo-analysis presented herein, we focus on widely accepted visualisation clients including Google Earth. Usability in terms of recognition of other browser-based user interfaces is of significant importance, especially when enhanced analysis capabilities are provided. We therefore emphasise on simple user interface design principles for both general and application-specific websites.

RESULTS

Results shown hereafter are outcomes of the ‘Shining Garden’ exercise. As mentioned in the introduction, two ¹³⁷Cs radiation sources were brought out for localisation. Prior to the exercise we measured a radiation dose rate of 6.3 micro-Sievert per hour (µSv/h) (western source), and 4.7 µSv/h (eastern source).

Web-Based Visualisation

Figure 4 shows a screenshot of the geo-processing web-application developed for the ‘Shining Garden’ exercise. The background within that screenshot shows a 2010 GeoEye satellite imagery integrated as a WMS. The radiation safety test area is located in the centre of the imagery (Figure 4 red frame).

⁵ changes take effect when a new geo-process task is triggered (running tasks are not affected)

⁶ www.esri.com

⁷ http://pywps.wald.intevation.org

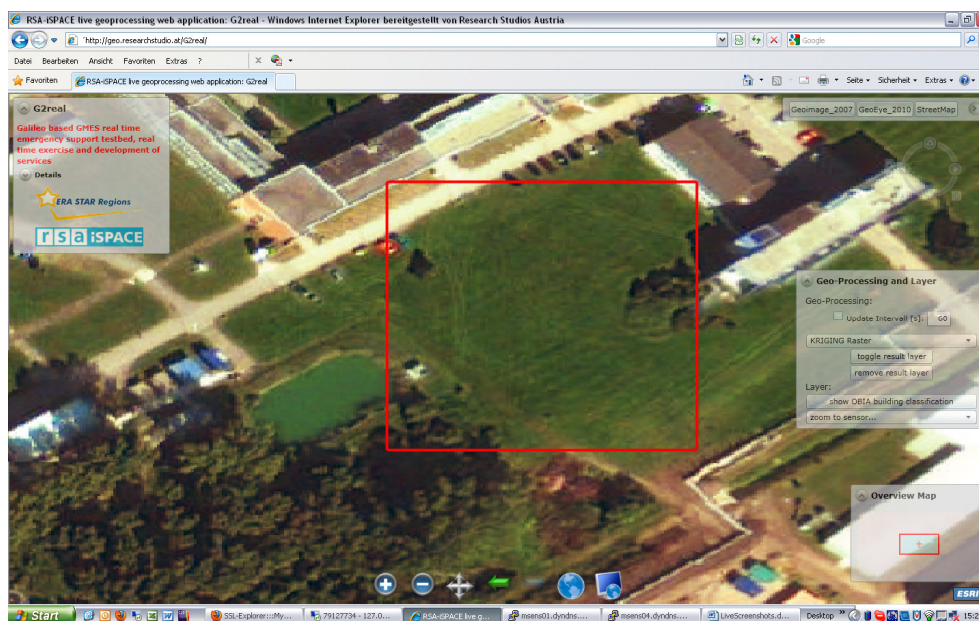


Figure 4: Screenshot of the G2real web-application (red frame: radiation safety test area)

The graphical user interface requires only two user interactions to trigger live analysis: (1) numeric entry of the update time-interval (in seconds) for the re-triggering of geo-processing; (2) selection of the preferred interpolation method (IDW or Kriging) and its output visualisation format (isolines with user defined step size, classified isoareas, or continuous surface). This selection can be changed by the user between the idle intervals of processing.

Figure 5 illustrates IDW (exponent of distance: 2) interpolation results in relative chronological order (1–6). In analogous manner, Figure 6 shows results based on Ordinary Kriging interpolation (using the spherical semi-variogram model). The violet points represent discrete locations of sensor measurements and thus the path taken by the person carrying the sensor pod. A proposed and significant difference between both figures is the path taken by the person carrying the sensing device.

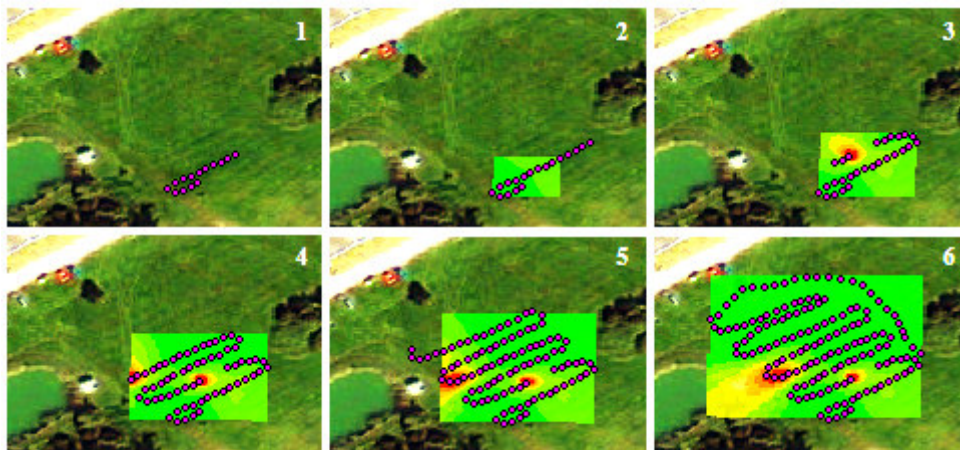


Figure 5: Screenshots of live IDW interpolation (green <math>< 0.5 \mu\text{Sv/h}</math>; gradient from green to red: >= 0.5...<= 3$\mu\text{Sv/h}$; red: > 3$\mu\text{Sv/h}$); points represent discrete sensor measurement locations

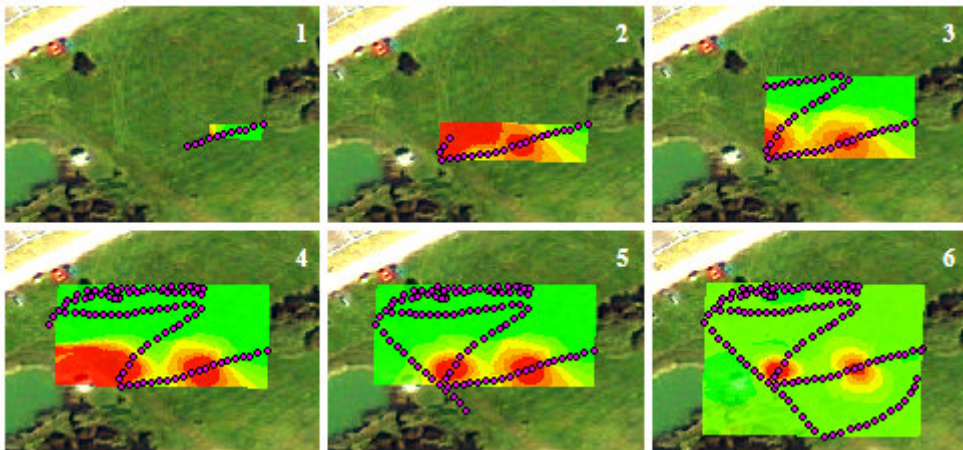


Figure 6: Screenshots of live Kriging interpolation (green < 0.5 $\mu\text{Sv/h}$; gradient from green to red: $\geq 0.5 \dots \leq 3 \mu\text{Sv/h}$; red: > 3 $\mu\text{Sv/h}$); points represent discrete sensor measurement locations

Post-Processing for In-Depth Analysis

Figure 7 shows interpolation results in a matrix manner: columns represent the interpolation method applied (IDW, and Kriging); rows represent the first and second phase, respectively, of the 'Shining Garden' exercise. These results have been generated after the exercise but are based on the same measurements as results presented in Figure 5 and Figure 6.

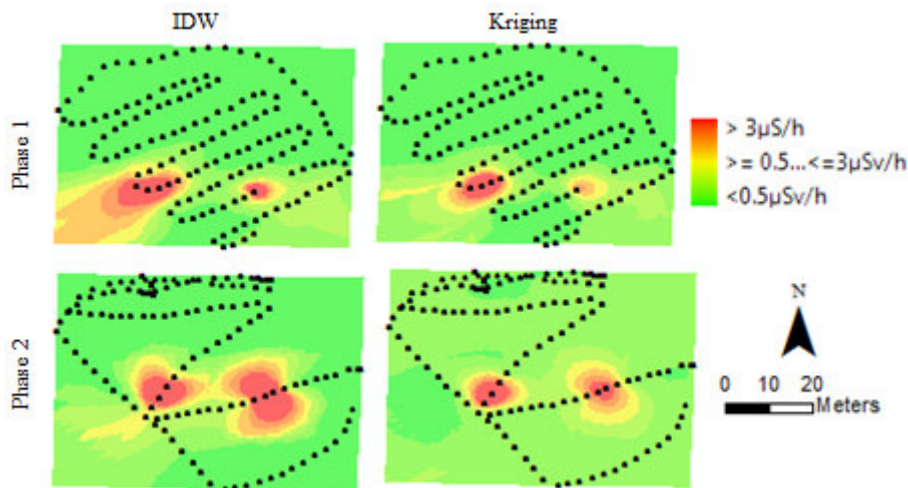


Figure 7: Comparison of interpolation results: IDW versus Kriging in Phase 1 and Phase 2

DISCUSSION

The overall workflow presented has been successfully verified in the course of the 'Shining Garden' real-time exercise on radiation safety. Interpolation results shown in Figure 5 and Figure 6 demonstrate gradually increasing spatial awareness of radiation dose rate in a live manner. The figures show the path taken by the person (e.g. used for reporting purposes) as combination of discrete sensor measurements represented as points, and their spatial interpolation results growing successively. Stepwise interpolation results shown in Figure 5 (1-6) indicate a correct and spatially explicit detection of radiation sources during the sensing scenario. The final interpolation result shown in screenshot 6, however, shows a considerable distortion in the south-western area. This is because of un-sampled locations within that area in combination with the interpolation method used (IDW). In contrast to Figure 5, intermediary interpolation results illustrated by Figure 6 indicate higher uncertainty in terms of spatial variability, especially by comparing red areas in screenshot 2 and 3, and 4 and 5. The final result (screenshot 6 in Figure 6) nevertheless

shows a spatially exact localisation of both radiation sources displayed for detection. The direct comparison of final interpolation results shown in Figure 7 takes the two different paths into account. It clearly indicates for both phases that Kriging rather than IDW fulfils an accurate localisation of radiation sources.

The phenomenon measured – radiation dose rate – has a favourable characteristic with respect to sensing: it has, within the time frame of the entire exercise (~ 3 hours), a constant spatial and temporal variability – a fixed position of the radiation source is assumed. Thus, the latency within in-situ measurements observed with ‘only’ one sensor device at different locations does not affect succeeding spatial interpolation. This aspect, however, must be taken into account when sensing phenomena with high spatio-temporal variability, for example the concentration of toxic gases.

CONCLUSION AND OUTLOOK

In this paper we demonstrated a verified live workflow for geo-sensor information analysis to enhance time-critical emergency support. The workflow is based on open and international standards for sensor-data acquisition (OGC SOS), geo-processing (OGC WPS), and visualisation and dissemination of newly generated information (OGC WMS and WFS). Geo-analyses results show that the IDW algorithm seems to be appropriate for interpolating measurements during the sensing process. After this process is finished, Kriging should be used to get the most suitable spatial assessment of radioactive radiation. This is in agreement with the outcomes of the study performed by Mabit and Bernard (2007).

We conclude that the presented standards-based workflow significantly improves information exchange for time-critical spatial decision support in terms of interoperability. In comparison to previous research, we integrate up-to-date measurements from highly mobile intelligent sensor pods on-the-fly into a fully service-oriented live geo-analysis workflow. Thus, with the given approach we are able to process dynamic measurements in addition to mostly static legacy geo-data.

In addition to the SOS used in this research, the OGC Sensor Alert Service (SAS), and the OGC Web Notification Service (WNS) are highly relevant interfaces for real-time emergency support. In contrast to the pull-based OGC SOS, SAS is based on the push principle, i.e. the sensor itself sends information triggered by an event – a detailed discussion is given by Resch et al. (2010a). This push-based service in combination with the asynchronous OGC WNS can enable Complex Event Processing (CEP) routines for the spatial domain, for example trigger further geo-processing operations. Currently, the Sensor Event Service (SES) is discussed for integration into the Sensor Web Enablement initiative (Bröring et al., 2011). A comparison between SAS and SES is presented in Resch et al. (2010a).

Further research will incorporate above mentioned eventing and alerting mechanisms for real-time decision support. Moreover, it will focus on performance issues of the geo-processing phase. In addition to the allocation of distributed and cloud processing capabilities, the data’s intrinsic spatio-temporal dynamics need to be considered. So far, all available measurements at a given time-stamp or period, and within a certain spatial extent, serve as input for analyses, independent if some values remain constant since the last analysis. The increasing volume of sensor measurement information, however, requires an effective and efficient mechanism for change detection of spatial temporal parameter that exceeds variable thresholds. Consequently, selected partitions of a previous analysis can be updated by fractional interpolation results considering significant changes only.

ACKNOWLEDGMENT

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