Enabling Quality Control of Sensor Web Observations

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Keywords: Quality Control, Observations, Sensor Web, TERENO, Environmental Sensing.

Abstract: The rapid development of sensing technologies had led to the creation of large volumes of environmental observation data. Data quality control information informs users how it was gathered, processed, examined. Sensor Web is a web-centric framework that involves observations from various providers. It is essential to capture quality control information within the framework to ensure that observation data are of known and documented quality. In this paper, we present a quality control framework covering different environmental observation data, and show how it is implemented in the TERENO data infrastructure. The infrastructure is modeled after the OGC's Sensor Web Enablement (SWE) standards.

1 INTRODUCTION

The Global Hydrological Monitoring Industry Trends Survey reveals that data consumers have a high demand for quality-controlled observation data (Aquatic Informatics, 2012). Quality Control (QC) is defined as "a part of quality management focused on fulfilling quality requirements" (ISO9000, 2005, cl. 3.2.10). We regard quality control of observation data as a process of identifying problems within the data, fixing or eliminating them, and documenting the processes involved. Raw data usually go through several quality control procedures before they are made available to end users. They are usually examined in terms of range, rates of change, and consistency checks between related quantities[1] observed at the same site. For example, in situ soil temperature measurements are used to detect spurious soil moisture observations due to frost (Dorigo et al., 2011). Similarly, empirical relationships between pan evaporation or lysimeter data and other physical quantities give indications of suspect data (WMO, 1994).

The term "Sensor Web" refers to web accessible sensors and their observations that can be discovered and accessed using standard protocols and application program interfaces (Botts et al., 2008). An open technical environment like the Sensor Web often involves observation data from various sources. Each provider may follow different data processing and validation mechanisms before publishing the data online. Quality control information conveys to users of the data how it was gathered and processed, assessed, what quality tests have been applied, what errors were found, and how the errors have been corrected or flagged (CEC and IODE, 1993). Integrating these kinds of information into the Sensor Web is valuable for later understanding of the observation data (DataONE, 2013). Data providers, for example, can use this information to validate how well their datasets meet the criteria set out in a product specification, and resolve current and future questions regarding alterations made to data (WMO, 1994, ch.9). Data consumers can select datasets best suited to their needs and avoid potential errors that might occur due to use of poor quality data (DataONE, 2013; IOC of UNESCO, 2013).

According to the Global Earth Observation System of Systems (GEOSS) 10-Year Implementation Plan, quality control is one of "components required to exchange and disseminate observational data and information" (Mitsos et al., 2005, pp.127). The plan also advocates that data providers should provide quality control information at the product level. A standardization of quality control procedures should also be developed and implemented in the context of environmental sensing (Mitsos et al., 2005).

The goal of this paper is to incorporate quality control information of observation data into the Sensor Web (Devaraju et al., 2013). This raises several questions:

a. *How are raw data of a property gathered and processed into quality-controlled observation data?* For this question, we present a common quality

[1] Quantities refer to observable properties.

Devaraju A., Kunkel R., Sorg J., Bogena H. and Vereecken H..
Enabling Quality Control of Sensor Web Observations.
DOI: 10.5220/0004707200170027
In *Proceedings of the 3rd International Conference on Sensor Networks* (SENSORNETS-2014), pages 17-27
ISBN: 978-989-758-001-7

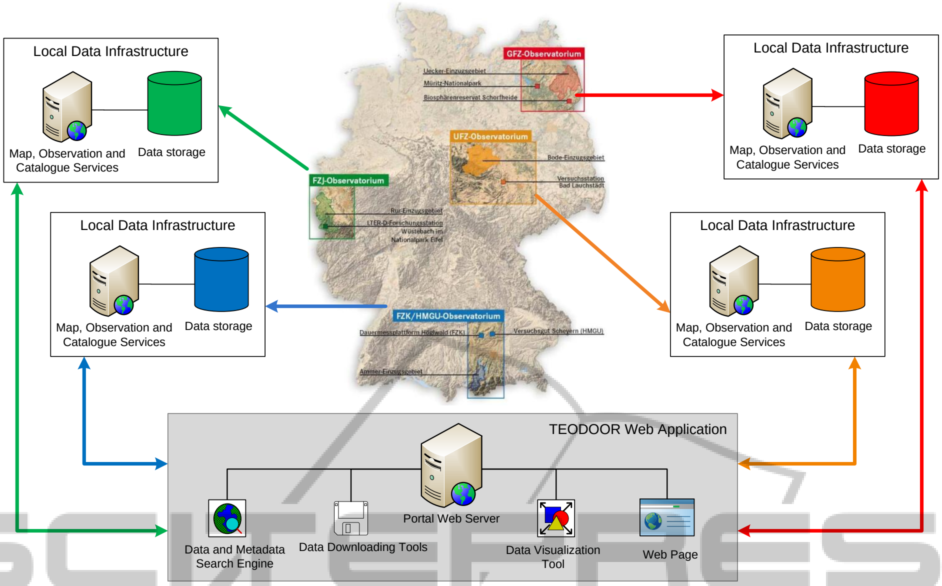


Figure 1: TEODOOR is developed to describe, manage and publish observation data within a distributed, scientific and non-scientific multi-user environment (Kunkel et al., 2013).

control workflow covering different environmental data within the TERENO observatory (Bogena et al., 2012) (see Figure 1), and an extensible quality flag scheme.

b. *What are the key aspects of data quality control and how can these be represented in an observational data model? How can this information be delivered to users via the Sensor Observation Service (SOS)?*
The observational data model of TERENO is designed after the CUAHSI Observation Data Model (ODM) (Tarboton et al., 2008). We specify changes made to the ODM to capture QC information. We modify an open source Sensor Observation Service (SOS) implementation, such that it delivers quality controlled observations with QC metadata to users.

The paper is organized in the following way: Section 2 presents related work and Section 3 delivers the quality control framework of TERENO observations. Section 4 describes the implementation of the framework. Section 5 provides a summary and recommendations for future work.

2 RELATED WORK

This section introduces existing work on representing quality control of Sensor Web observations. Several quality flag schemes for exchanging environmental data are also discussed.

2.1 Quality Control of Sensor Web Observations

Several Sensor Web infrastructures have been deployed in environmental contexts. The OGC's Sensor Web Enablement (SWE) offers standard specifications that support the integration of sensors and sensor networks into the Sensor Web (Botts et al., 2008). An overview of existing SWE-based projects is included in (Broering et al., 2011; Conover et al., 2010).

The Sensors Anywhere (SANY) project develops a sensor service architecture applying SWE services for air quality, coastal water management and geohazards monitoring (Stuart et al., 2009; Bartha et al., 2009). The architecture supports uncertainties information in terms of UncertML (Williams et al., 2009), which is included in a Sensor Model Language (SensorML) if it applies to the whole measurement process or in an Observation and Measurement (O&M) document if it refers to specific measurement values. (Bartha et al., 2009) defined generic quality flags, e.g., *Null, NaN, Out of Engineering Range* in the latter document. SANY's observation service uses *procedure*[2] to represent data processing, e.g., *raw data*, *automatically assessed data*, and *manually assessed*

[2] A *procedure* refers to a method, an algorithm or an instrument used to obtain measurement results (Botts et al.,

data. While a data processing activity can be conceptualized as a 'post' sensing procedure, it is unclear how this is linked to actual sensing procedures and offerings[3] within the implementation.

The Earth Observation and Environmental Modelling for the Mitigation of Health Risks (EO2HEAVEN) applies several observation services to study the links between environmental pollutions and their impacts on human health (Brauner et al., 2013b). The study adapts SANY's approach to express uncertainties of observations, however quality control information is not supported (Brauner et al., 2013a).

The NOAA Integrated Ocean Observing System (IOOS) established an observation service[4] to provide access to ocean and coastal measurements (Garcia, 2010). Among the seven quantities supported by the service, only ocean current measurements are accompanied with a set of quality flags (Garcia, 2010). The quality flags represent the results of certain quality tests applied to observation data. The metadata of flags can be obtained using the SOS *DescribeSensor* operation. However, differing quality flags for the same property measured by different models of sensor are not supported (Garcia, 2010).

The Quality Assurance of Real Time Ocean Data (QARTOD) is a multi-organization effort to address the quality control procedures for IOOS properties, including detailed information about sensors and procedures used to observe the properties. Q2O implements the QARTOD recommendations into the OGC Sensor Web Enablement framework providing SensorML profiles for data quality tests. The focus is on delivering quality control information at the level of the sensing process, where each quality test is defined as a process that is described with inputs and outputs (Fredericks et al., 2009). Unlike QARTOD, our focus is to capture QC information at the level of the individual observations. We incorporate metadata of quality flags and also data processing levels in an O&M document. References expressing these are attached to each observation value.

2.2 Data Processing Levels

Transforming raw data into data products includes data processing at several levels. Each data level may involve different quality control requirements. For example, the first level includes raw data, the second level refers to flagged data, whereas the next level suggests corrected data. There are several classifications of data levels of environmental data as proposed by Earth Observing System (EOS) Standard Data Product (SDP)[5], Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI)[6], Atmospheric Thematic Center[7], Earthscope[8], and Committee on Earth Observation Satellites (CEOS)[9]. These classifications usually comprise several levels. Some of these classifications lack a detailed description on how derivation and quality control are managed and implemented from one to another level. While data providers may have their own data levels, our data processing levels are kept simple, but remain consistent with the practice of other data systems. The data levels are part of the proposed quality control framework (see Section 3.2).

2.3 Data Quality Flags

Flagging is a procedure that adds a quality indicator to the original observation. Data quality flags (also known as qualifiers) imply the outcome of a QC process, which may either be computer- (i.e., automatic quality control procedures) or human-generated (i.e., visual inspections). Quality flag schemes are usually application-specific. For example, the WMO data qualification codes are available for qualifying hydro-meteorological data (WMO, 1994). The World Ocean Circulation Experiment (WOCE) defines parameter quality codes for water sampling (WOCE, 1994). The International Oceanographic Data and Information Exchange (IODE) Quality Flag Standard is defined to facilitate the exchange of oceanographic and marine meteorological data (IOC of UNESCO, 2013).

Some flag schemes are single-level lists and indicates the overall data quality, e.g., OceanSITES, COS Data Quality Flags, and SeaDataNet. Other flag schemes consist of two-levels. The primary level includes generic flags intended for any type of data, e.g., good, not evaluated, and bad. The secondary level is application-specific and complements the primary level flags by indicating, (i) the results of individual quality tests applied, e.g., excessive spike check and failed gradient check, or (ii) data processing history, e.g., interpolated values and corrected value, or (iii) some background conditions that affect data values, e.g., icing event, faulty sensor calibration. Concerning the secondary level, some flagging conven-

2008).

[3] An observation offering is a logical grouping of observations offered by a service (Na and Priest, 2007).

[4] http://sdf.ndbc.noaa.gov/sos/

[5] http://nsidc.org/data/icebridge/eos_level_definitions.html

[6] http://his.cuahsi.org/

[7] https://icos-atc-demo.lsce.ipsl.fr/node/34

[8] http://www.earthscope.org/science/data/access/

[9] http://www.ceos.org/

Table 1: Data processing levels.

Level	Descriptions	Data Source	QC	Data Editing	Availability
Level 1	Raw data	Automatic importing or manual upload	No	Not allowed	Internal (on request)
Level 2a	Externally quality controlled data; an expert approval is pending	Level 1 data (manual upload)	Yes	Not allowed, flagging only	Internal (on request)
Level 2b	Quality controlled data with automatic QC procedures	Level 1 data (automatic upload)	Yes	Not allowed, flagging only	Public
Level 2c	Externally quality controlled data with an expert approval	Level 2a data	Yes	Not allowed, flagging only	Public
Level 2d	Quality controlled data with automatic QC procedures and visual inspections	Level 2b data	Yes	Not allowed, flagging only	Public
Level 3	Derived data	One or more Level 2 data	Yes	Allowed	Public

tions include references to quality test and data processing (i and ii). However, they provide no information on the causes (iii) for variability of the measurement, e.g., IODE quality flag standard. Other flag schemes provide the latter but exclude the former, e.g., WMO data qualification code. It is important to capture these aspects of flagging. They would help users to combine data with different flag schemes while preserving existing quality control information, and make informed decisions with regard to data acceptance (Konovalov et al., 2012). A recent work in this direction is (Schlitzer, 2013) who specifies quality flag mappings between 15 widely-used flag standards in the oceanographic domain.

Our approach adopts a two-level flag scheme and separate flags associated with data quality from background conditions. Details about the flag scheme are included in Section 3.3.

3 QUALITY CONTROL FRAMEWORK

This section introduces TERENO and presents a QC framework comprising data levels, data quality control workflows and a two-tiered flag scheme.

3.1 TERrestrial ENvironmental Observatories (TERENO)

TERENO is an initiative funded by the research infrastructure program of the Helmholtz Association. The goal of TERENO is to create observation platforms to facilitate the investigation of consequences of global change for terrestrial ecosystems and the socioeconomic implications of these (Zacharias et al., 2011). Four observatories have been set up within the TERENO initiative: Northeastern German Lowland, Harz/Central Lowland, Eifel/Lower Rhine Valley, and Bavarian Apls/Pre-Alps. Each institution hosting an individual observatory maintains its local data infrastructure (Figure 1). The observatories are connected via OGC-compliant web-services, while the TERENO Online Data RepOsitORry (TEODOOR)[10] central portal application enables data searching, visualization and download (Kunkel et al., 2013). This paper focuses on time series data of soil, stream, climate, energy, water and gas fluxes from the Eifel/Lower Rhine observatory. Currently, this observatory provides free access to data from more than 500 monitoring stations. Figure 2 illustrates the basic components of the local data infrastructure.

3.2 Data Types and Processing Levels

There are two ways in which observation data from the Lower Rhine observatory is gathered into TEODOOR. Some data are automatically imported from sensing systems into the data infrastructure (e.g., timeseries of weather stations and soil monitoring networks), and other types are uploaded manually (e.g., eddy covariances and laboratory results). The first type of data initially undergoes automatic quality assurance procedures during the importing process and then manual inspections by domain experts. The second type of data is externally processed and quality-controlled using proprietary tools. They are gathered into the data infrastructure using a custom importing process. Expert approval from the responsible personnel is required before this type of data is released to the public. Further information on expert approval is included in Section 3.4.

Data providers may have a different concept of data level depending on their data types and processing workflow. Our data processing levels are kept simple, but representative of the data levels that are generally available (Table 1). Specifically, they are suitable for time series data from different sensing applications. The reason for this is that data series are grouped into a particular level mainly based on the way they are processed and assessed within the data infrastructure. Table 1 clarifies the relationships between processing levels and other aspects, e.g., data

[10] http://teodoor.icg.kfa-juelich.de/

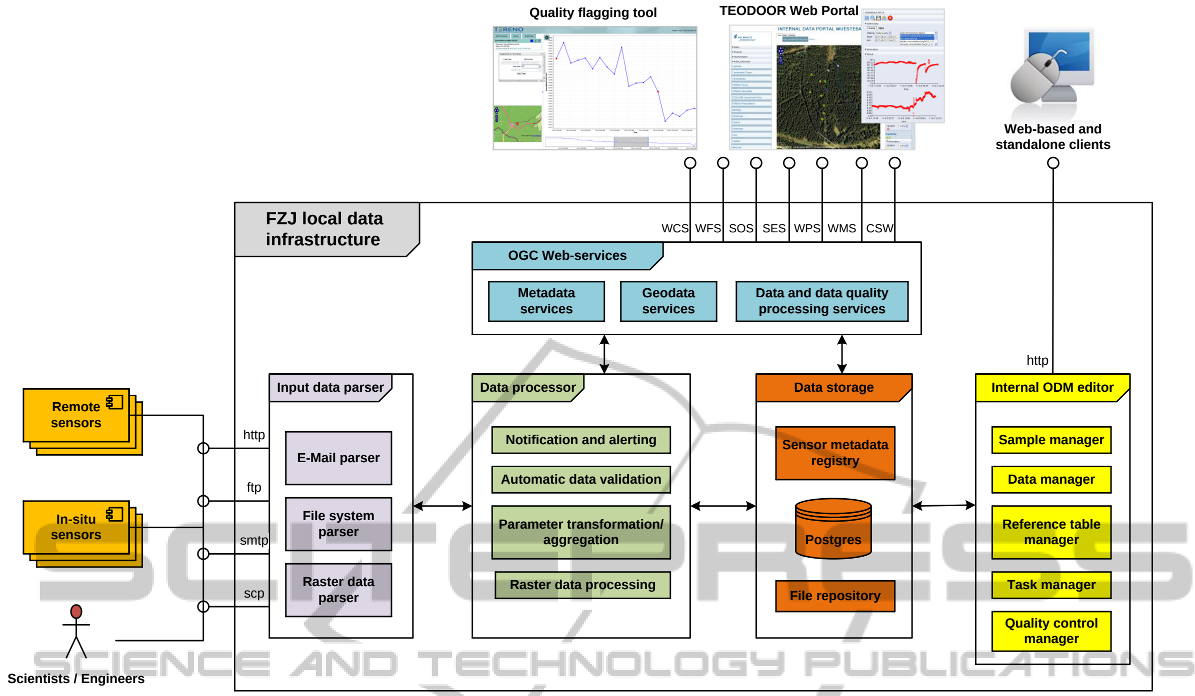


Figure 2: Components of the FZJ local data infrastructure.

source, assessment and accessibility. Level 1 refers to raw data that have not been quality assessed and remain intact for archive purposes. Level 2 includes raw data that have been quality controlled, either internally or externally. Here, the data values are flagged, but they cannot be edited. Level 3 contains derived data that are gathered from quality controlled data. In other words, Level 3 data can only be created from one or more data types of Level 2. This allows for increased ease in data organization and maintenance. Any updates to Level 3 data will be saved to that data level (Tarboton et al., 2008).

3.3 Flagging Convention

Due to the diverse nature of TERENO observations, we need a common set of quality flags that can be used by different sensing applications. Following (IOC of UNESCO, 2013), we adopt a two-level flag scheme. Flags are usually varied across observational values as they depend on the results of quality checks. Therefore, we assign flags with individual data values, not a data series. The first level defines the generic data quality flags, while the second level complements the first level by providing the justification for the quality flags based on validation tests and data processing history. In TERENO, the second-level flags are specified by the domain experts. The characterization of these flags can be sensor-specific or property-specific, depending on the application. For example, all data from eddy covariance stations are flagged with a standardized group of flags, whereas the water discharge measurements have their own data flags, which differ from the water temperature measurements. With the two-level flag scheme, existing applications are not required to change their flag systems as they extend the generic flags with their specific flags. Table 2 presents examples of quality flags. The first column of the table contains standardized generic flags of TERENO. The second column includes examples of specific flags that are applicable to time series from weather stations. The background conditions that cause abnormal measurements are not represented as flags, but rather as additional information supporting the flagging process.[11]

3.4 Quality Control Workflow

Figures 3 and 4 illustrate the data workflow of automatically and manually uploaded data. Both types of data undergo certain procedures. Accordingly, the data level and flags are updated. These descriptions are made available to users along with observation data via the sensor observation service (Figure 7).

[11] Representing background conditions as standardized flags is not investigated in this paper, but subject to a future investigation.

Table 2: Generic and specific data quality flags.

Generic Flag	Specific Flag
unevaluated	-
ok	passedautocheck
bad	outofrange, isolatedspike, minerror,maxerror, replicateval, unknownqcsource, excessivedifference, irregular
suspicious	same as ‘bad’ flags
gapfilled	interpolated, extrapolated
missing	(This generic flag is used as a place holder when data values are missing)

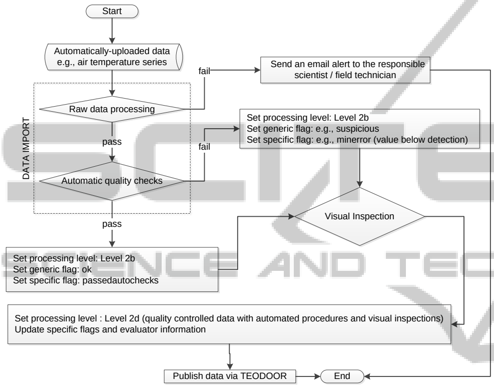


Figure 3: The workflow of automatically uploaded time series data.

Both types of data are easily imported into the observational database with our time series management system (TSM 2.0) (Kunkel et al., 2013). The system includes a highly configurable file parser and a data processor. The configuration details are captured in the database (Figure 5). Here, a controlled vocabulary (i.e., a prescribed list of terms describing observed properties, units, data types, and sensor types) is used to support the provision of heterogeneous data into the database. The system also includes an email notification component that alerts the data owner about the importing process and the problems occurred.

Checking of automatically uploaded data involves automated and manual (i.e., visual inspections) procedures (Figure 3). During the importing process, automated data validation such as transmission and threshold checks are performed, and measurements are flagged accordingly. This is followed by a visual examination by the respective scientist or field technician using an online data flagging tool (Figure 2). The tool is developed based on the 52°North Sensor Web Client v3.1[12]. We extend the client with a data inspection module that allows users to identify and flag

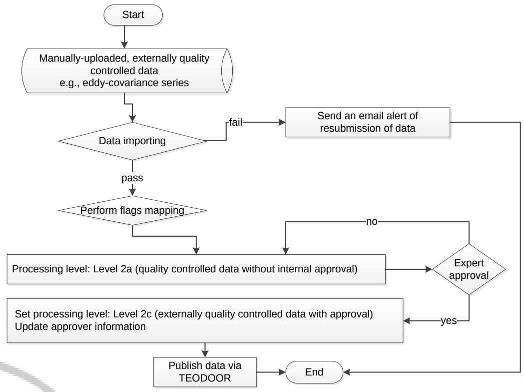


Figure 4: The workflow of manually uploaded and externally quality-controlled time series data.

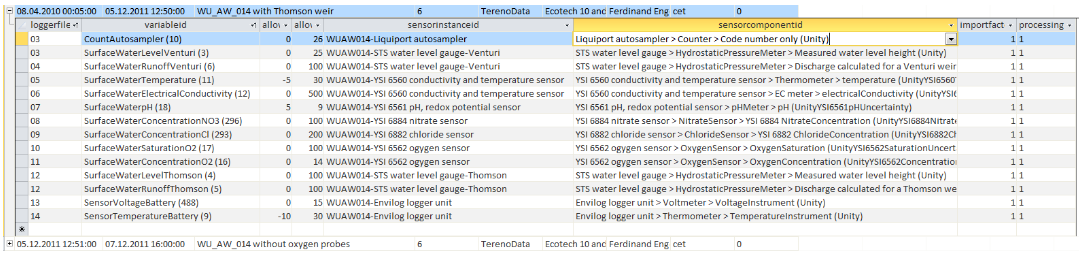
measurements.

Manually uploaded data are imported into the system without automated quality checks, as they have been assessed externally with standardized procedures (Figure 4). For example, a strategy has been applied for assessing quality of eddy-covariance measurements within TERENO (Mauder et al., 2013). The workflow also involves mapping between application-specific flags and the generic flags. Data series will be made available online when they are approved by the principal investigator. The data levels (Level 2a and Level 2c) distinguish data retained in the system from publicly available data. For some cases, an approval is embedded within the importing process. For other cases, due to data distribution issues, manually uploaded data are not released online until the data originator or the principal investigator approves them. For example, data associated with externally funded research and laboratory specimens are gathered into the data infrastructure to enable data sharing within the TERENO community. These data are released to the public until the investigations are completed.

3.5 Discussions

A data quality control framework enables a data provider systematically to assess observations coming from various sources. TERENO involves observations of various sensing applications; we distinguish them based on the way they are imported into the data infrastructure. Quality control is an embedded step in the data processing workflow. Automatically uploaded data undergo automated checks and visual inspections, whereas manually uploaded data are processed and assessed externally, and then imported into the infrastructure. An essential feature of this process is that whether it is imported manually or automati-

[12] http://52north.org/communities/sensorweb/clients/SensorWebClient/



08.04.2010 00:05:00	05.12.2011 12:50:00	WU_AW_014 with Thomson weir	6	TerenoData	Ecotech 10 and	Ferdinand Eng	cet	0

loggerfile	variableid	allow	allow	sensorinstanceid	sensorcomponentid	importfact	processing
03	CountAutosampler (10)	0	26	WUAW014-Liquiport autosampler	Liquiport autosampler > Counter > Code number only (Unity)	1	1
03	SurfaceWaterLevelVenturi (3)	0	25	WUAW014-STS water level gauge-Venturi	STS water level gauge > HydrostaticPressureMeter > Measured water level height (Unity)	1	1
04	SurfaceWaterRunoffVenturi (6)	0	100	WUAW014-STS water level gauge-Venturi	STS water level gauge > HydrostaticPressureMeter > Discharge calculated for a Venturi weir	1	1
05	SurfaceWaterTemperature (11)	-5	30	WUAW014-YSI 6560 conductivity and temperature sensor	YSI 6560 conductivity and temperature sensor > Thermometer > temperature (UnityYSI6560	1	1
06	SurfaceWaterElectricalConductivity (12)	0	500	WUAW014-YSI 6560 conductivity and temperature sensor	YSI 6560 conductivity and temperature sensor > EC meter > electricalConductivity (UnityYSI6	1	1
07	SurfaceWaterpH (18)	5	9	WUAW014-YSI 6561 pH, redox potential sensor	YSI 6561 pH, redox potential sensor > pHMeter > pH (UnityYSI6561pHUncertainty)	1	1
08	SurfaceWaterConcentrationNO3 (296)	0	100	WUAW014-YSI 6884 nitrate sensor	YSI 6884 nitrate sensor > NitrateSensor > YSI 6884 NitrateConcentration (UnityYSI6884Nitrate	1	1
09	SurfaceWaterConcentrationCl (293)	0	200	WUAW014-YSI 6882 chloride sensor	YSI 6882 chloride sensor > ChlorideSensor > YSI 6882 ChlorideConcentration (UnityYSI6882Ch	1	1
10	SurfaceWaterSaturationO2 (17)	0	100	WUAW014-YSI 6562 ogygen sensor	YSI 6562 ogygen sensor > OxygenSensor > OxygenSaturation (UnityYSI6562SaturationUncert	1	1
11	SurfaceWaterConcentrationO2 (16)	0	14	WUAW014-YSI 6562 ogygen sensor	YSI 6562 ogygen sensor > OxygenSensor > OxygenConcentration (UnityYSI6562Concentratio	1	1
12	SurfaceWaterLevelThomson (4)	0	100	WUAW014-STS water level gauge-Thomson	STS water level gauge > HydrostaticPressureMeter > Measured water level height (Unity)	1	1
12	SurfaceWaterRunoffThomson (5)	0	100	WUAW014-STS water level gauge-Thomson	STS water level gauge > HydrostaticPressureMeter > Discharge calculated for a Thomson we	1	1
13	SensorVoltageBattery (488)	0	15	WUAW014-Envilog logger unit	Envilog logger unit > Voltmeter > VoltageInstrument (Unity)	1	1
14	SensorTemperatureBattery (9)	-10	30	WUAW014-Envilog logger unit	Envilog logger unit > Thermometer > TemperatureInstrument (Unity)	1	1

05.12.2011 12:51:00	07.12.2011 16:00:00	WU_AW_014 without oxygen probes	6	TerenoData	Ecotech 10 and	Ferdinand Eng	cet	0

Figure 5: A screenshot of configuration details of an importing process.

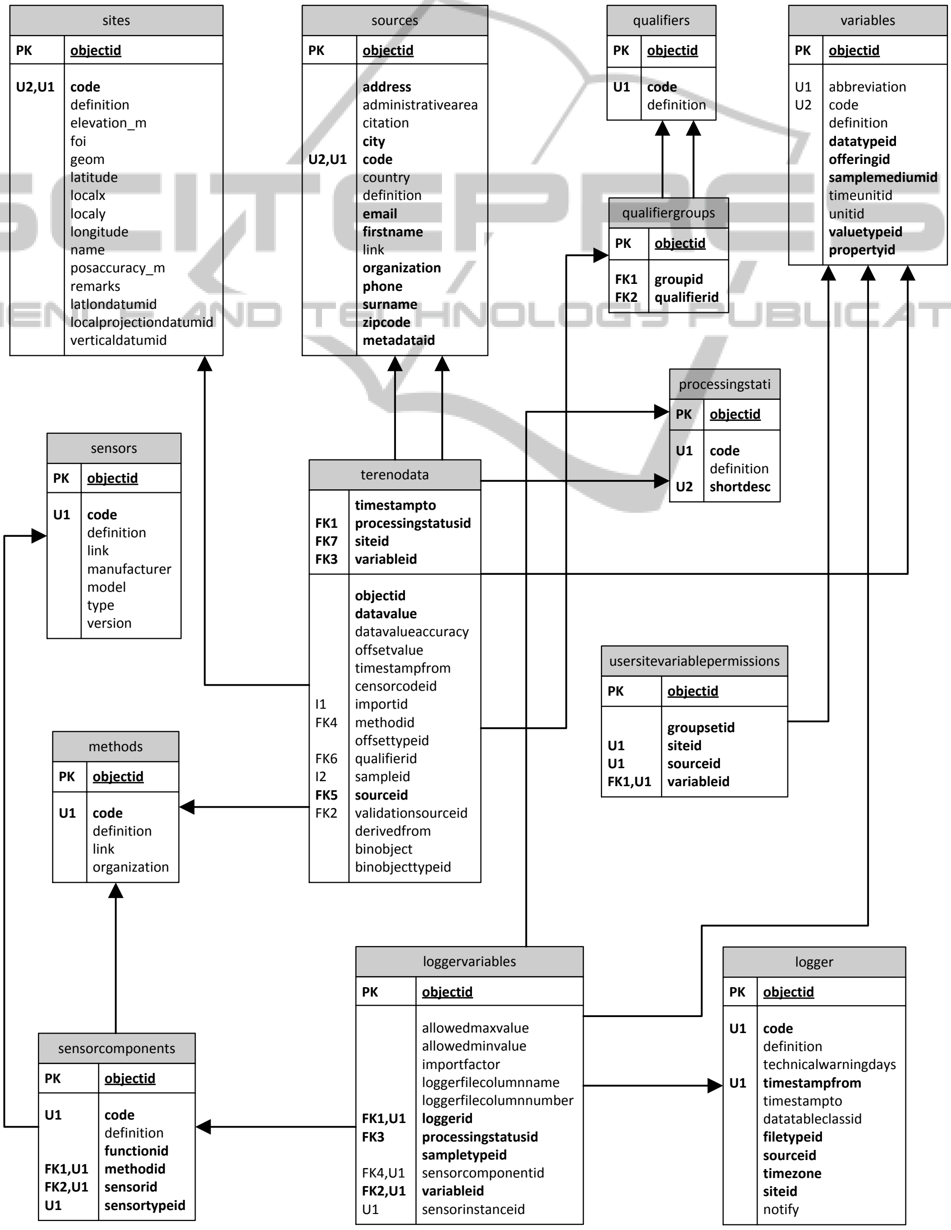


Figure 6: A partial view of the TERENO observational data model.

cally, all data are suitably flagged.

Similar to other classification schemas of data level, they imply the underlying data processing. However, in our approach the relationships between the data levels and other aspects such as assessment and accessibility are also clarified. At higher levels, data are quality checked and made available to the public. A two-level flag scheme is adapted to consider flag systems of different types of data. The data level and flag information is included at the level of the individual observations so that it is more convenient for applications to locate their data of interest, for example, a request for data that are quality assessed and that exclude bad and suspicious values.

4 IMPLEMENTATION

This section presents the implementation of the quality control framework. We modify the existing observation data model and observation service to support the delivery of quality control information in the Sensor Web.

4.1 Observational Data Model

The original data schema of CUAHSI ODM has been modified to represent sensor specifications, data importing and transformation procedures, loggers configurations, data access control and quality control information. Figure 6 illustrates a partial view of the data schema representing quality control of observations. Flags and a data level are associated with individual observation values. Generic and specific flags are listed in the *qualifiers* table; their mappings are specified in the *qualifiergroups* table. Similarly, tables specifying data assessment methods are represented. Data levels are described in the *processingstati* table. The *source* table includes information about data evaluators, e.g., field technicians and scientists.

In TERENO observatories, often two or more sensors are installed at the same location measuring the same type of physical quantity. For example, a pair of soil moisture sensors is installed at three different depths (within a vertical soil profile) at a particular location to improve detection quality and faults tolerance. The observed properties are distinguished with a unique naming scheme combining property type, sensor instance and several other parameters, e.g, *SoilWaterContent0.2mSensor1*, *SoilWaterContent0.5mSensor1* and *AirTemperature2m*. As the data model supports the characterization of specific flags at a property level, differing quality flags applicable for the same quantity measured by different models of sensor can be represented.

4.2 Sensor Observation Service (SOS)

The Sensor Observation Service (SOS) defines a service's model interface and encoding for the provision of sensor information and observation data (Na and Priest, 2007). For example, the SOS operation *DescribeSensor* requests detailed meta-information about a sensor and delivers a *SensorML* document accordingly. The *GetObservation* operation handles a data request and returns the observation data by means of an *Observation and Measurement (O&M)* document. We modify the open source implementation of the 52°North (52N) SOS[13] to deliver quality control meta-information along with observation data. To improve query performance on the server, metadata of flags and data processing levels are included in the *gml:metaDataProperty* section of an O&M document, whereas references expressing these are attached to each observation value encoded in the *om:result* section (see Figure 7). Here, the suggested scheme is to form a label combining a *data processing level id* and a *flag mapping id* for each individual data value. Our observational data model is different from the standard data model of SOS. Thus, *views*, i.e., virtual tables are used to relate our data model to the sensor observation service.

5 CONCLUSIONS

TERENO is an interdisciplinary observatory that involves observation data from various sensing applications, e.g., climate, water, and soil. Unlike operational systems run by weather or water agencies that follow a specific data processing procedures, we need an extensible approach to cater various sensing applications. In this paper, we have described a quality control framework for processing and assessing environmental time series within our data infrastructure. Starting with the way data are imported into the infrastructure, custom data workflows are defined. The data processing levels are kept simple and fulfill application needs. They imply underlying data processing, assessment and accessibility. A two-tiered flag scheme is adapted to represent flag systems of different sensing applications. The existing observation data model and the SOS are modified, so that observation data with metadata of quality control are accessible in the Sensor Web. Another application uti-

[13] http://52north.org


```
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  <swe:DataArray>
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    <swe:Count>
     <swe:value>15</swe:value>
    </swe:Count>
   </swe:elementCount>
   <swe:elementType name="Components">
    <swe:SimpleDataRecord>
     <swe:field name="Id"/>
     <swe:field name="GenericQualifier"/>
     <swe:field name="SpecificQualifier"/>
    </swe:SimpleDataRecord>
   </swe:elementType>
   <swe:encoding>
    <swe:TextBlock decimalSeparator="." tokenSeparator="," blockSeparator=";"/>
   </swe:encoding>
   <swe:values>13,bad,outofrange;15,bad,irregular;18,bad,isolatedspike;6,bad,maxerror;5,bad,minerror
12,suspicious,unknownqcsource;17,suspicious,maxerror;16,suspicious,minerror;9,missing,missingdata
4,gapfilled,extrapolated;3,gapfilled,interpolated;2,ok,ok;10,1,unevaluated,unevaluated</swe:value
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     <swe:field name="ProcessingStatus"/>
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   </swe:encoding>
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 . . . . . . . .
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        <swe:Count>
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        </swe:Count>
       </swe:elementCount>
       <swe:elementType name="Components">
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          <swe:Time definition="urn:ogc:data:time:iso8601"/>
         </swe:field>
         <swe:field name="feature">
          <swe:Text definition="urn:ogc:data:feature"/>
         </swe:field>
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          <swe:Quantity definition="SensorVoltageBattery">
           <swe:uom code="V"/>
          </swe:Quantity>
         </swe:field>
         <swe:field name="SensorVoltageBatteryQualityFlag">
          <swe:Category definition="SensorVoltageBatteryQualityFlag"/>
         </swe:field>
        </swe:SimpleDataRecord>
       </swe:elementType>
       <swe:encoding>
        <swe:TextBlock decimalSeparator="." tokenSeparator="," blockSeparator=";"/>
       </swe:encoding>
       <swe:values>2011-02-01T17:00:00.000+01:00,WU_CR_001,11.699999999999999,2_2;
2011-02-01T18:00:00.000+01:00,WU_CR_001,11.699999999999999,2_2;
2011-02-01T19:00:00.000+01:00,WU_CR_001,11.699999999999999,2_2;2011-02-01T20:00:00.000+01:00,
      </swe:DataArray>
     </om:result>
    </om:Observation>
   </om:member>
</om:ObservationCollection>
```


Figure 7: GetObservation O&M response. Some parts of the XML are omitted for clarity purposes.

lizing these is the customized Sensor Web Client that enables visual inspection and flagging of data series.

We plan to extend the *GetObservation* request of the SOS with a custom filter to enable data requests based on flag concepts. (Bastin et al., 2013) implemented a similar aspect focusing on uncertainty concepts. An end-to-end aspect of the quality control of observation data ranges from the selection and maintenance of instrumentations to the final assessment of data at the product level. Concerning this, planned future work is to incorporate descriptions about operation and maintenance sensing systems in the Sensor Web as they provides additional information about the causes of variability of measurements. Another interesting line of work to pursue is coupling the quality control metadata to relevant ontology concepts to support information discovery across disciplines. A related study in this direction is that of (Fredericks et al., 2009) who propose an ontology to form associations of quality tests of marine data between different authorities.

ACKNOWLEDGEMENTS

The TERENO (Terrestrial Environmental Observatories) funded by the Helmholtz Association. We would also like to thank Simon Jirka for his insightful comments.

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