Weather Data Publication on the LOD using SOSA/SSN Ontology

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Abstract. This paper presents a RDF dataset on meteorological measurements. The measurements come from one weather station of the Irstea experimental farm located at Montoldre. Some measurements produced during the year 2017 are transformed and published as Linked Open Data. The data schema is based on the new version of the Semantic Sensor Network ontology (SSN). This ontology version integrates the Sensor, Observation, Sample, and Actuator pattern (SOSA). We first present the ontology network used to organize the data. Then, the transformation process to publish the dataset is detailed. To conclude we present some querying use cases related to Irstea research projects.

Keywords: Semantic Sensor Ontology, Sensor, Observation, Sample, and Actuator, Climate Linked Data, meteorological observation

1. Introduction

In our previous work [1], we have published meteorological observations using the Semantic Sensor Network Ontology (SSN) [2]. This ontology has been updated and became a W3C recommendation in 2017 [3]. Now, SSN integrates the Sensor, Observation, Sample, and Actuator (SOSA) pattern. This paper describes a new meteorological dataset based on the SOSA/SSN ontology. We publish measurements from the Vantage Pro 2 weather station in use at our experimental farm located in Montoldre (France). We have followed the usual steps in Linked Data publication, as discussed in [4]. We reuse as much as possible existing ontologies or thesauri related to meteorological observations and phenomenons.

This paper is organized as follows: Section 2 describes our weather station and its measurements. Section 3 briefly presents the network of ontologies. Some examples of how the data are organized using these ontologies are described in section 4. Section 5 describes the populating processes and the links to other datasets. Section 6 presents some use cases to query this dataset. Finally we conclude by presenting an analysis of our work and perspectives.

2. Montoldre's Weather Station Description and Data Sources

Irstea has a research and experimentation site located at Montoldre. This experimental farm is part of the innovation lab of the AgroTechnoPôle. One of its goals is to run different types of experiments: For example, agricultural equipment and machines are tested under the conditions which are the most similar to the real operating conditions. Another example is to deploy wireless sensor network prototypes in outdoor environment to test the accuracy of their measurements. This farm has its own weather station, a Vantage Pro 2 [1] from Davis Instruments. According to the documentation of Vantage Pro 2, the station contains the following sensors: a barometer, two temperature sensors (inside and outside), two humidity sensors (in-

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[1] https://www.davisinstruments.com/solution/vantage-pro2/

side and outside), an anemometer, a wind direction sensor, a rain collector to measure the amount of precipitation and the precipitation rate, a solar radiation sensor and a clock. These external sensors use wireless communication to send their measurements to a console located inside a building. This console calculates other measurements (wind chill, dew point, etc.), as well as weather forecasts. These calculations correspond to virtual sensors. The console is connected to a computer to store the measurement values. The measurement storage is automatically done according to the user parameters (intervals of time, units, etc.). These data are extracted to generate a CSV (comma-separated values) file as shown in 1.

CSV files were generated for the year 2017 from January to December 2017. Files contain the following measures: outside temperature, atmospheric pressure, outside relative humidity, wind direction, wind speed, precipitation quantity, precipitation rate and solar radiation. The frequency of measurements has varied during 2017. First, the frequency was one measurement per minutes, as shown in 1 and then it became one measurement per 10 minutes around July.

3. An Ontology Network for Meteorological Data Publication

The SOSA/SSN ontology [3] can be used as a core ontology for meteorological data publication. This ontology should be linked with other ontologies to create an ontology network. Our ontology network is composed of:

- Ontologies to describe the different types of sensors.
- Ontologies to describe units of measurement.
- Ontologies to describe geographical places and their location.
- Ontologies to describe temporal entities.

In this section we describe the ontologies that we have reused for the publication of our meteorological data. We describe briefly these ontologies and their elements that we have reused.

3.1. The W3C Semantic Sensor Network (SSN) Ontology

The Semantic Sensor Network (SSN) ontology is a generic ontology related to sensor observation [2]. The first version of this ontology was created by the W3C Semantic Sensor Network Incubator Group. Then this ontology has been updated to become a W3C recommendation. A simpler ontology dedicated to sensor and actuator description has been generated. It was called Sensor, Observation, Sample, and Actuator (SOSA) pattern. The link between SSN and SOSA is described as follows in [3]: "SOSA provides a lightweight core for SSN and aims at broadening the target audience and application areas that can make use of Semantic Web ontologies. At the same time, SOSA acts as minimal interoperability fall-back level, i.e., it defines those common classes and properties for which data can be safely exchanged across all uses of SSN, its modules, and SOSA."

The classes we have reused from SOSA/SSN ontology are:

- *sosa:Observation* to describe the measurement context,
- *sosa:FeatureOfInterest* to specify the observed phenomena (e.g. wind),
- *sosa:ObservableProperty* to specify the measured property of the observed phenomena (e.g. wind speed),
- *sosa:Platform* to describe the weather station,
- *sosa:Sensor* to describe the sensors of the weather station,
- *sosa:Result* to provide the sensor measurement value.

We have also used the main properties associated to these classes: *sosa:observedProperty*, *sosa:madeBySensor*, *sosa:hosts*, *sosa:hasFeatureOfInterest*, *sosa:hasResult*, etc.

3.2. The AWS Ontology for Meteorological Sensors

The Ontology for Meteorological Sensors [5] (AWS) extends the old version of SSN ontology by specializing its class *ssn:SensingDevice*. It is focused on the description of different types of sensors that can be used to measure meteorological phenomena.

More specifically, we mostly reuse the following classes:

- *aws:AtmosphericPressureSensor* to define the barometer,
- *aws:CapacitiveThinFilmPolymer* to define the outside humidity sensor,
- *aws:Pyranometer* to define the solar radiation sensor,
- *aws:Thermistor* to define the outside temperature sensor,

Date	Time	Temp Out	Out Hum	Wind Speed	Wind Dir	Bar	Rain	Rain Rate	Solar Rad.
01/01/17	0:00	-3.3	96	0.0	—	772.6	0.00	0.0	0
01/01/17	0:01	-3.3	96	0.0	—	772.6	0.00	0.0	0
01/01/17	0:02	-3.3	96	0.0	—	772.6	0.00	0.0	0
01/01/17	0:03	-3.3	96	0.0	—	772.6	0.00	0.0	0
01/01/17	1:06	-3.3	96	1.6	ESE	772.4	0.00	0.0	0
04/01/17	21:21	1.7	93	6.4	WNW	769.0	0.25	1.5	0
05/01/17	13:43	1.9	91	0.0	—	773.0	0.00	0.0	77

Table 1

Example of a CSV file

Prefix	Name	URI
ssn	Semantic Sensor Network Ontology	<http://www.w3.org/ns/ssn/>
sosa	Sensor, Observation, Sample, and Actuator Ontology	<http://www.w3.org/ns/sosa/>
geo	OGC GeoSPARQL 1.0: A Geographic Query Language for RDF Data	<http://www.opengis.net/ont/geosparql>
locn	ISA Programme Location Core Vocabulary (Second version)	<http://www.w3.org/ns/locn>
qudts	Quantities, Units, Dimensions and Types Ontology (version 1.1) schema	<http://qudt.org/1.1/schema/qudt>
qudt	Quantities, Units, Dimensions and Types Ontology (version 1.1) vocabulary	<http://qudt.org/1.1/vocab/unit>
aws	Ontology for Meteorological sensors	<http://purl.oclc.org/NET/ssnx/meteo/aws>
time	Time Ontology in OWL	<http://www.w3.org/2006/time#>

Table 2

Reused vocabularies and ontologies

- *aws*:*TippingBucketRainGaugeTbrgWithout Correction* to define the precipitation collector sensor; this sensor is able to produce two separate measurements: the quantity of precipitation whatever the precipitation is (snow, rainfall, hail) and the precipitation rate,
- *aws*:*WindVane* to define the wind direction sensor,
- *aws*:*CupAnemometer* to define the anemometer (wind speed sensor),

We have noticed that AWS proposes lots of sensor types. In our case AWS provides all the sensor descriptions we need for our purpose.

3.3. Quantity, Unit, Dimension and Type

The Quantity, Unit, Dimension and Type (QUDT) is a collection of OWL ontologies and vocabularies [6]. QUDT schema defines the base classes, properties, and restrictions used for modeling physical quantities, units of measure, and their dimensions in various measurement systems. QUDT also contains a set of vocabularies to define units for different domains. We reuse the *unit* vocabulary that categorizes units in different subClass of the *unit* class. This vocabulary also provides individuals of those classes, so as to identify units such as *qudt*:*Millimeter*, *qudt*:*Percent*, etc.

3.4. The ISA Location Core Vocabulary (LOCN) and GeoSPARQL

Currently, several ontologies exist for the publication of spatial data. We decide to use the GeoSPARQL vocabulary [7]. GeoSPARQL is the result of a standardization process at the Open Geospatial Consortium (OGC). It first focuses on querying geographical data. It also propose the model to describe geometries of spatial objects: through the object property *hasGeometry* and the data properties *hasGML* or *hasWKT*. GeoSPARQL extends the WGS84 vocabulary and proposes different types of geometries like: point, polygon, multipolygon, etc. It also allows defining topological relationships between spatial objects.

The ISA Core Location vocabulary [8] (LOCN) was released in November 2013, and has recently been given a W3C-owned namespace, although it was initially generated outside the consortium. This RDFS vocabulary focus on the description of places and their address. It provides a set of three classes and several properties. Note that the geometry description of places is still in an unstable state, and may change in the future. This ontology is used to describe the address of the experimental farm.

3.5. The W3C Time Ontology

The W3C Time ontology [9] enables the description of time instants and intervals. Hence it may be useful when we need to describe the timestamps or the time period associated to the measurements made by the weather station. We reuse the classes *time:Interval* and *time:Instant*, and the associated properties *time:inXSDDateTimeStamp*, *time:hasBeginning*, *time:hasEnd*, etc.

4. Populating the Ontology Network

Based on the ontology network described in the previous section, we are now able to create a dataset containing all the individuals describing measurements of our weather station. Now we explain the decisions taken in order to create resource URIs (Section 4.1) and we provide examples on the measurement descriptions according to our ontology network (Section 4.2).

4.1. Resource URIs for our Weather Station Data

URIs have been designed with several principles in mind, such as simplicity, stability and manageability. We follow common guidelines and recommendations [10]. This section presents the main URI design decisions and conventions used. Table 3 provides a summary of the main types of URIs that we generate. The first column presents the type of resources. The second column indicates the associated class which types the resource. The last column contains the name pattern used to generate the resource URI.

The base URI for our new weather dataset is http://ontology.irstea.fr/weather2017/resource/. It is prefixed by atpw17.We have another base URI for generic information shared between several datasets called http://ontology.irstea.fr/society/resource/, prefixed as irstea.

Our generic name pattern to produce URI for each object is {Base URI} +'/'+ {nameOfClass} +'/'+ {objectIdentifier}. The object identifiers and class names are written in camel case. The '_' character is used between two object identifiers. For example, the URI to identify the experimental research farm of Montoldre is: http://ontology.irstea.fr/weather/resource/organization/
irsteaCenterMontoldre. Note that all the URI about time description is compliant with the ISO 8601 format [11] except that the '/' character is replaced by '_' character .

4.2. Excerpts of our Weather Dataset

The following subsections provide some examples to illustrate the use of our ontology network to describe meteorological data.

4.2.1. Weather Station Description

In this section we provide a general overview of the weather station description. The individual that represents the weather station is an instance of the *sosa:Platform* class. The GeoSPARQL vocabulary is used to describe the precise location of the weather station. As shown in figure 1, the geometry of the weather station is a point expressed by a WKT string. This string is linked to a *geo:Geometry* instance by the *geo:asWKT* property. The *geo:hasGeometry* property links the *sosa:Platform* instance to the *geo:Geometry* instance. The ISA Core Location Vocabulary (LOCN) is used to define the address where the Montoldre experimental farm is located. As shown in figure 1, the *geo:sfContains geo:sfWithin* properties express the spatial inclusion relationship between *geo:Feature* instances. The *locn:address* property links *geo:Feature* instance to the *locn:Address* instance.

4.2.2. Sensors Description

Each sensor of the weather station is represented by an instance of the class *sosa:Sensor*. The Figure 2 presents the description of the barometer. The barometer is identified by an URI that finishes with *barometer*01. This URI is an instance of the class *aws:CupAnemometer* and of the class *sosa:Sensor*. The *sosa:host* property links the *sosa:Platform* instance to the barometer URI. The *sosa:observes* property links the barometer URI to an instance of *sosa : ObservableProperty* that is labelled by the string "air pressure".

4.2.3. Observation Description

Observations describe the context of a measurement done by a sensor. Figure 3 represents an observation done by the barometer on the air pressure at a given point in time. The properties *sosa:observedProperty*, *sosa:hasFeatureOfInterest*, *sosa:madeBySensor* and *sosa:hasResult* link our specific observation with its corresponding observed property, natural phenomenon, sensor and measurement value. Note that we create an individual, instance of *sosa:FeatureOfInterest* class that represents the air phenomenon.

4.2.4. Phenomenon Time of Observation

A measurement can be instantaneous. For example, the barometer measures the air pressure in an in-

Object	Class	local ID pattern
Weather Station	*sosa:Platform*	*atpw17:platform/{stationType}{locationName}{stationID}*
Sensor	*sosa:Sensor*	*atpw17:sensor/{stationType}{locationName}{stationID}_{sensorType}{sensorID}*
Feature of Interest	*sosa:FeatureOfInterest*	*atpw17:featureOfInterest/{NaturalPhenomenonLabel}*
Observable Property	*sosa:ObservableProperty*	*atpw17:observableProperty/{NaturalPhenomenonLabel}_{propertyLabel}*
Instant	*time:Instant*	*atpw17:instant/{date}T{time}{timeZone}*
Duration	*time:Duration*	*atpw17:duration/P{duration}*
Interval	*time:Interval*	*atpw17:interval/P{duration}_{endInstant}*
Observation	*sosa:Observation*	*atpw17:observation/at_{time}_of_{sensor}_on_{NaturalPhenomenonLabel}_{propertyLabel}*
Result value	*sosa:Result*	*atpw17:result/value_{measurementValue}_{unit}*
Geometry	*geo:Geometry*	*{Base}/geometry/{geometryType}_{objectName}*

Table 3

URI generation templates for resources

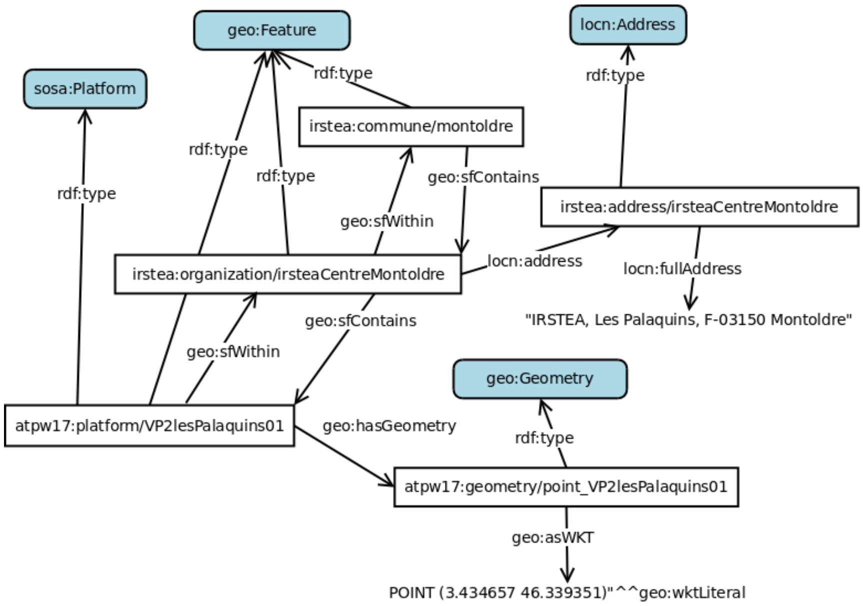

Fig. 1. Location of the weather station

stantaneous manner. Figure 3 presents an observation produced by the barometer. The range of the property *sosa:phenomenonTime* is an instance of the class *time:Instant*. The property *time:inXSDDateTimeStamp* connects the *time:Instant* instance to an *xsd:dateTime* value. This value is expressed in the ISO 8601 format.

Sometimes a measurement is related to a period of time. For example, the rain collector measures the quantity of precision that fall down during an period of time. Figure 4 presents an observation made by the rain collector sensor. The property *ssn:phenomenonTime* links the *sosa:Observation* instance to an instance of the class *time:Interval*. The properties *time:hasBeginning*, *time:hasEnd* and *time:hasDuration* specify the beginning, the end and the duration of the interval.

Table 4 contains a summary of the type of timestamp that we have associated to each type of measurement that our weather station perform.

5. Data Transformation Process

This section describes briefly the processes involved in RDF dataset generation.

As explained in the section 1, measurements produced by the weather station sensors are stored in CSV files. These measurements are performed every minute or every 10 minutes.

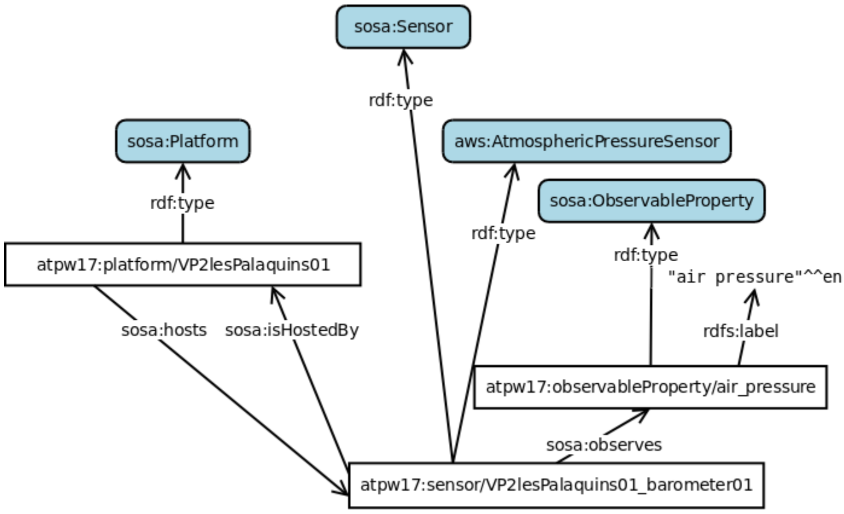

Fig. 2. Barometer Description

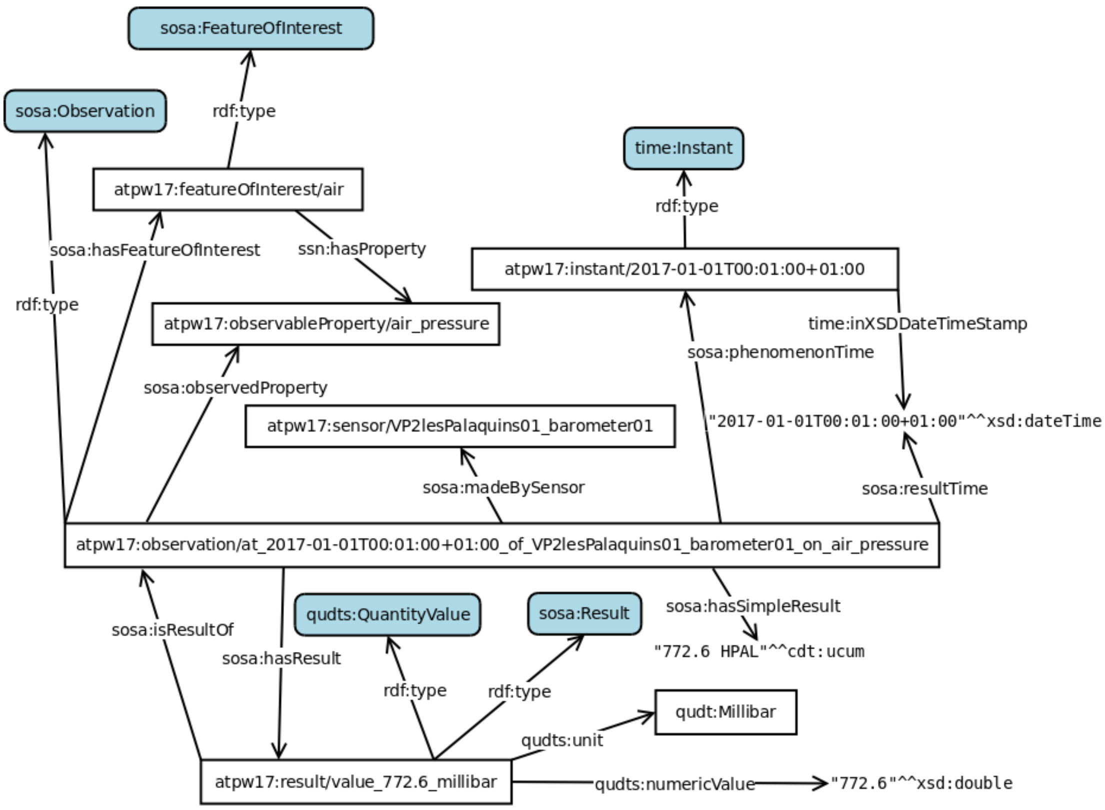

Fig. 3. Example of observation made by the barometer

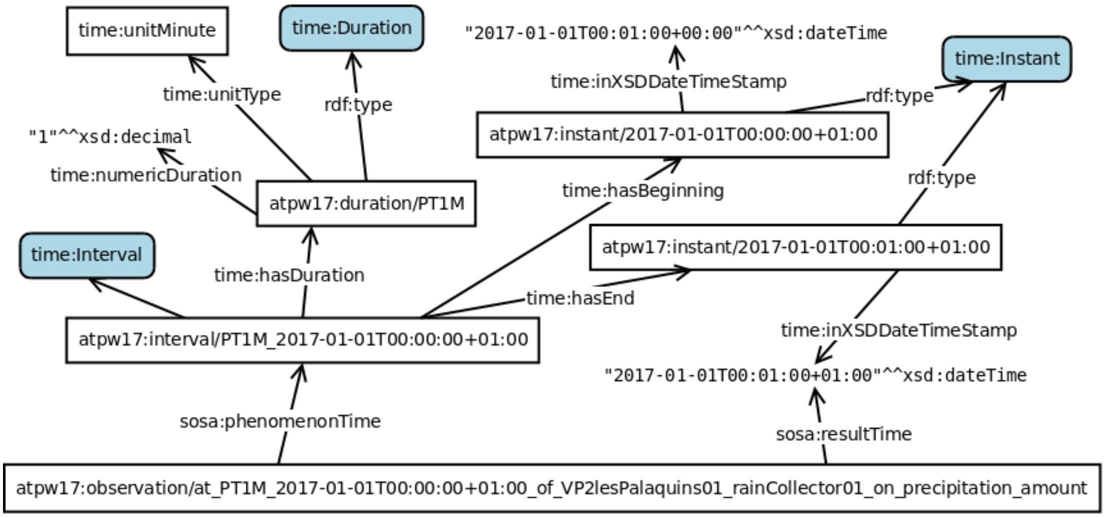

Fig. 4. Example of interval

Measured property	timestamp
outside temperature	instant
atmospheric pressure	instant
outside humidity	instant
wind direction	interval
wind speed	interval
quantity of precipitation	interval
rain rate	interval
solar radiation	interval

Table 4

Types of timestamps associated to the measured properties

URL	http://ontology.irstea.fr/weather2017
Documentation	http://ontology.irstea.fr/pmwiki.php/Site/Weather2017
SPARQL End Point	http://ontology.irstea.fr/weather2017/sparql/
Datahub name	datahub.ckan.io/fr/dataset/irstea-weather2017-dataset-of-the-m
VoID	http://ontology.irstea.fr/weather2017/page/metadata
Licensing	https://www.etalab.gouv.fr/licence-ouverte-open-licence
5 star rating	*****

Table 5

Technical details

Category	Resources
Total Nr. of triples	26.000.000
Nr. of observations	2.380.749
Nr. of classes	26
Nr. of properties	57
distinct subjects	3.000.000

Table 6

Key Statistics

The transformation process is done by a small program written in python. The goal of the program is to update a RDF triplestore available on a Jena Fuseki server. This program uses three main libraries :

– *requests* : for HTTP protocol, which is used to communicate with the triplestore,
– *datetime* : to work with datetime objects, making possible to do some time calculations and write them in a true compliant ISO-8601 format,
– *arrow* : to be able to get current timezone.

The flow of data processing in this piece of software consists to :

– read one line from the CSV file,
– compare the date and time to the previous line to extract the duration (the duration of the first entry is a parameter of the program),
– extract the data,
– convert the wind direction into degrees,
– write an *"INSERT DATA"* SPARQL query and send it to the triplestore through an HTTP POST frame.

During this process, new `sosa:Result` individuals are stored in a stack and a test is performed to avoid creating them twice.

Our dataset characteristics are listed in Table 5 and Table 6.

5.1. *Interlinking*

We align our dataset to several resources:

- SWEET ontology network: the Semantic Web for Earth and Environmental Terminology [12],
- CF thesaurus: the Climate and Forecast Standard Names [13],
- Geonames: the GeoNames geographical database[2].
- DBpedia:a dataset extracted from Wikipedia InfoBox [14].

All the instances of *sosa*:*FeatureOfInterest* are linked to class defined in SWEET using a *rdf*:*type* link. SWEET is a collection of OWL ontologies that include both orthogonal classes (space, time, earth realms, physical quantities, etc.) and integrative science knowledge classes (phenomena, events, etc.) [12]. As shown in table 7, we linked our instances to classes related to meteorological phenomena: *Rain*, *Wind*, *Air*, *SolarFlux* defined in different ontologies of the version 3.2.0 of SWEET network[3]. Note that the instance labels are based on the class name of SWEET ontologies.

All the instances of *sosa*:*ObservableProperty* are linked to an *skos*:*Concept* instance of CF thesaurus using a *skos*:*exactMatch* or *skos*:*closeMatch* property. CF stores terms used for identifying measured phenomena in climate and forecast conventions [13]. The thesaurus is published on the LOD using the SKOS vocabulary [15]. The label of *skos*:*Concept* instances was very precised. Thus the label of our *sosa*:*ObservableProperty* instances are almost based on the label of related *skos*:*Concept* instances. The table 8 presents the links between our dataset and CF thesaurus. The first column present the measurement types of the Vantage Pro 2 station. The second column present the URI of our *sosa*:*ObservableProperty* instance. The last column presents the label and ID of the *skos*:*Concept* instances defined in CF thesaurus.

The individuals, that are parts of the society namespace (prefix *irstea*), are as mush as possible linked to others datasets with the *owl*:*sameAsproperty*. For example, the individual that represents our institution Irstea is linked to its DBPedia representation. All the individuals that represent geographic features are linked to GeoName individuals if it exists.

[2]https://www.geonames.org/

[3]SWEET files are available on a github located at https://github.com/ESIPFed/sweet/tree/master/src

6. Meteorological Dataset Querying Use Cases

Irstea is involved in several agricultural research projects. For example, an automatic irrigation system for maize crop is under development [16]. Crop development stages can be computed automatically based on the minimal and maximal temperatures of the day. Thus SPARQL queries will be applied on our dataset to determine the minimal and maximal temperatures of each day. According to Meteo France recommendations, the minimal temperature of a d day is computed from [$d - 1$ 18:00, d 18:00] due to the fact that the minimal temperature of a d day comes just before the sun rise. The following query determines the minimal temperature for all the days in June 2017.

```
SELECT ?day (MIN(?t) AS ?min_temp)  WHERE {
?o a sosa:Observation ;
   sosa:resultTime ?timeStamp ;
   sosa:observedProperty
   <http://ontology.irstea.fr/weather2017/resource/ob
   sosa:hasResult [ qudt:numericValue ?t ] ;
   BIND (DAY(?timeStamp+"PT6H"^^xsd:duration) AS ?day
   FILTER (YEAR(?timeStamp)=2017
        && MONTH(?timeStamp)=06)
} GROUP BY ?day ORDER BY ?day
```

Moreover some researchers are in charge of robotic experiments. They need to access precised weather data in order to explain some of their results. For example, they need to know the wind direction and wind speed in order to explain some robot or machinery moves. Moreover, for wireless sensor network communication experiments, bad weather conditions could explain strange energy consumption.

7. Conclusion and Perspectives

The AgroTechnoPôle of Irstea contains an experimental farm where researchers can test their prototypes like robots, machinery, wireless sensor network and so on. A weather station is located on the experimental farm. Weather data is useful for farmer activities but also for the documentation of researchers experiments. We want to facilitate the access of weather archive to any AgroTechnoPôle users. Thus we decide to test the publication of our weather archive on the LOD. We have already published a weather archive from 2010 to 2013 using the old version of SSN [1].

This paper presents a new meteorological dataset based on the new version of SSN ontology, that is to say SOSA/SSN ontology. To do so, we have selected a new network of ontologies to describe our weather

FeatureOfInterest instance		SWEET class
label	URI	URI
air	*atpw17:featureOfInterest/air*	sweet:matr.owl#Air
wind	*atpw17:featureOfInterest/wind*	sweet:phenAtmoPrecipitation.owl#Wind
precipitation	*atpw17:featureOfInterest/precipitation*	sweet:phenAtmoPrecipitation.owl#AtmosphericPrecipitation
solar flux	*atpw17:featureOfInterest/solarFlux*	sweet:propEnergyFlux.owl#SolarFlux

Table 7

Meteorological phenomena

Measurement	Property	CF skos:Concept	
type	URI	label	ID
outside temperature	*atpw17:observableProperty/air_temperature*	air_temperature	SDN:P07::CFSN0023
atmospheric pressure	*atpw17:observableProperty/air_pressure*	air_pressure	SDN:P07::CFSN0015
outside humidity	*atpw17:observableProperty/air_relativeHumidity*	relative_humidity	SDN:P07::CFSN0413
wind direction	*atpw17:observableProperty/wind_direction*	wind_from_direction	SDN:P07::CFSN0036
wind speed	*atpw17:observableProperty/wind_speed*	wind_speed	SDN:P07::CFSN0038
quantity of precipitation	*atpw17:observableProperty/precipitation_amount*	precipitation_amount	SDN:P07::CFSN0452
rain rate	*atpw17:observableProperty/precipitation_rate*	rainfall_rate	SDN:P07::CFSN0410
solar radiation	*atpw17:observableProperty/solarFlux_density*	downward_heat_flux_at_ground_level_in_soil	SDN:P07::CFSN0689

Table 8

Measurable properties of meteorological phenomena

archive. We have build a dataset based on the measurements of the weather station from january 2017 to december 2017. This dataset is queryable on a dedicated sparql-end point.

The next steps will be, first to develop a user interface to improve the query ergonomy for french user that do not know semantic Web technologies. Second, we will have to determine the frequency of the weather archive uptodate process. We know that we do not need a real time process, but we may have to decide if our weather archive should be updated every week or every month or even less. This will depend of the information needs of AgroTechnoPôle users. Moreover our dataset contains lots of duplicate values. The final step will be to aggregate all the duplicates in order to save space storage without damaging speed querying.

References

[1] C. Roussey, S. Bernard, G. André, O. Corcho, G. De Sousa, D. Boffety and J.-P. Chanet, Weather Station Data Publication at Irstea: an implementation Report, in: *Terra Cognita - Semantic Sensor Networks TC-SSN 2014*, Vol. 1401, CEUR-WS.org, Ride Del Garda, Trentino, Italy, 2014, pp. 89–104. http://ceur-ws.org/Vol-1401/paper-07.pdf.

[2] M. Compton, P.M. Barnaghi, L. Bermudez, R. Garcia-Castro, O. Corcho, S. Cox, J. Graybeal, M. Hauswirth, C.A. Henson, A. Herzog, V.A. Huang, K. Janowicz, W.D. Kelsey, D. Le Phuoc, L. Lefort, M. Leggieri, H. Neuhaus, A. Nikolov, K.R. Page, A. Passant, A.P. Sheth and K. Taylor, The SSN ontology of the W3C semantic sensor network incubator group, *J. Web Sem.* **17** (2012), 25–32.

[3] H. Armin, J. Krzysztof, S. Cox, D. Le Phuoc, K. Taylor and M. Lefrançois, Semantic Sensor Network Ontology, W3C OGC, 2018. http://w3c.github.io/sdw/ssn/.

[4] K. Janowicz, P. Hitzler, B. Adams, D. Kolas and C. Vardeman II, Five Stars of Linked Data Vocabulary Use. Editorial, *Semantic Web Journal* **0** (2014), 0–1. http://www.semantic-web-journal.net/content/five-stars-linked-data-vocabulary-use.

[5] Ontology for Meteorological sensors, Accessed: 2014-06-30.

[6] Library for Quantity Kinds and Units: schema, based on QUDV model OMG SysML(TM), Version 1.2, Accessed: 2014-06-30.

[7] OGC GeoSPARQL - A Geographic Query Language for RDF Data, Accessed: 2014-06-30.

[8] ISA Programme Location Core Vocabulary, Accessed: 2014-06-30.

[9] J.R. Hobbs and F. Pan, Time Ontology in OWL, W3C recommendation, OGC 16-071r2, 2017. https://www.w3.org/TR/owl-time/.

[10] G. Atemezing, O. Corcho, D. Garijo, J. Mora, P.-V. M., P. Rozas, D. Vila-Suero and B. Villazon-Terrazas, Transforming meteorological data into linked data, *Semantic Web journal, Special Issue on Linked Dataset descriptions, 2012. IOS Press, ISSN: 1570-0844* (2012). http://www.semantic-web-journal.net/content/transforming-meteorological-data-linked-data-0.

[11] T.. ISO, Data elements and interchange formats – Information interchange – Representation of dates and times, ISO Standard, 2004.

[12] R.G. Raskin and M.J. Pan, Knowledge representation in the semantic web for Earth and environmental terminology (SWEET), *Computers & geosciences* **31**(9) (2005), 1119–1125.

[13] A. Leadbetter, NERC Vocabulary Server version 2.0, 2017, Accessed: 2018-12-04. https://www.bodc.ac.uk/resources/products/web_services/vocab/documents/nvs2.0_documentation.pdf.

[14] S. Auer, C. Bizer, G. Kobilarov, J. Lehmann, R. Cyganiak and Z. Ives, DBpedia: A Nucleus for a Web of Open Data, in: *The Semantic Web: The 6th International Semantic Web Conference ISWC and the 2nd Asian Semantic Web Conference ASWC*, LNCS, Vol. 4825, Springer Berlin Heidelberg, Busan, Korea, 2007, pp. 722–735. ISBN 978-3-540-76297-3 978-3-540-76298-0.

[15] M. Alistair and B. Sean, SKOS Simple Knowledge Organization System, W3C Recommendation, 2009. http://www.w3.org/2004/02/skos/core.html.

[16] M. Poveda-Villalon, Q.-D. Nguyen, C. Roussey, C. De Vaulx and J.-P. Chanet, Besoins ontologiques d'un système d'irrigation intelligent : comparaison entre SSN et SAREF, in: *29es Journées Francophones d'Ingénierie des Connaissances, IC 2018*, S. Ranwez, ed., 29es Journées Francophones d'Ingénierie des Connaissances, IC 2018, AFIA, Nancy, France, 2018, pp. 21–36. https://hal.archives-ouvertes.fr/hal-01841316.