VAS. A Semantic Model for Earth Observation data

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ABSTRACT

This paper discusses a segment of the "Artificial Intelligence and Semantics of Earth Observation (EO) data for the establishment of the Valencia Anchor Station as a supersite of the CEOS LPV Program (ASOTVAS)." The ASOTVAS project aims to apply AI and data semantics algorithms to the Valencia Anchor Station's control zone (10 km x 10 km). A data semantics analysis explores concepts such as vocabularies, ontologies, and knowledge maps, with an emphasis on the reuse of existing models. Crucially, an ontological model with clear data definitions is developed to correlate Copernicus Program data with station parameters (e.g., FAPAR, LST, soil moisture, etc.). Using the ontology, the actual data are aggregated to create a knowledge map, which includes both an assertion model (concepts and properties) and an instance model (specific instances for ontological relationships). The main task is to develop an ontology-based representation scheme for terms of the application domain, which facilitates knowledge capture, distribution, and maintenance. The scheme enables computer processing for tasks related to information handling and supporting information exchange. Widely accepted ontology specification methodologies are employed. To avoid unnecessary efforts, emphasis is put on the reuse of existing ontologies or vocabularies, expanded, and adapted to the described case study. The optimal granularity is chosen for efficient ontology operation. The conceptual and technological requirements of the representation scheme are discussed. The methodology is based on software quality standards.

CCS CONCEPTS

• Computing methodologies → Ontology engineering; **• Information systems → Graph-based database models**; **Web services**; **• Hardware → Sensors and actuators**.

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1 INTRODUCTION

The content of this paper details part of the development within the project "Artificial Intelligence and Semantics of Earth Observation (EO) data for the establishment of the Valencia Anchor Station as a supersite of the CEOS LPV Program (ASOTVAS)".

The main objective of the ASOTVAS project is the application of artificial intelligence algorithms and of data semantics on the control area of the Valencia Anchor Station (10 km x 10 km in the natural region of La Plana de Utiel-Requena). In order to achieve this objective, an analysis of data semantics applied to EO data has been carried out. Various concepts related to data semantics such as vocabularies, ontologies, knowledge maps, etc. were studied, with emphasis on those models that already existed and that allowed their reuse in the project.

The definition of an ontological model in which all data are clearly defined (classes, relations and attributes) was crucial in order to be able to relate the complementary parameter data of the different Copernicus Programme products with those of the station itself (e.g. FAPAR (Fraction of Absorbed Photosynthetically Active Radiation), LST (Land Surface Temperature), soil moisture, etc.).Therefore, by using the ontology as a framework, it was possible to aggregate real data to create a knowledge map. In this way, with the data from the station or from the Copernicus Programme itself and the ontology that has been defined, it was possible to create, on the one hand, the assertional model, i.e. concepts and properties, and, on the other hand, the instantial model, i.e. the creation of specific instances for each of the ontological relationships.

Basically, this work sought to develop a representation scheme, in the form of an ontology, of the set of terms related to the application domain, which would allow the knowledge contained in it to be captured, distributed, and maintained, and which would enable its computer processing for the performance of the various tasks related to the treatment of this information in the proposed management system. In other words, a scheme that contains the semantics that enables the exchange and processing of the available information. For this purpose, widely accepted ontology specification methodologies were used when specifying the ontology infrastructure.

In order not to reinvent the wheel and avoid unnecessary efforts, priority was given to the reuse of existing ontologies or vocabularies, extending and adapting them in such a way that the case study described was framed within it and, at the same time, so that it was possible to capture the main elements that may intervene in the typical interactions between the different actors in the system: sensors, observed data, etc. An optimal granularity was chosen in order not to fill the ontology with concepts and thus to be able to operate with it efficiently. The conceptual and technological requirements that the representation scheme must fulfill to model and implement the information required by the system were discussed. For this purpose, based on software quality standards, the following methodology was followed, in which the following phases are included:

(1) Analysis of a possible conceptual infrastructure to organize and connect the information elements corresponding to the different sub-domains that affect the collection and processing of this type of data. Posing of competence questions.
(2) Modelling the structure and semantics of the previously defined elements, establishing the relationships between them and instances.
(3) Implementation of the ontological model.
(4) Testing the robustness of the model, using queries, based on the competence questions.
(5) Determination of the publication process of the ontologies defined to allow their access to the services that need them, enabling their reuse by other semantic applications of future implementation.

This document is organized as follows: Section 2 details the state of the art of some of the most prominent vocabularies related to this project. Section 3 discusses the models found and the choice of some of them. Section 4 describes the definition and implementation of the data model called VAS, showing, using snapshots, some of its definitions. Section 4 describes the procedure to validate the ontology through queries based on competence questions and, finally, Section 5 concludes with key observations and the next steps to be taken in the project.

2 STATE OF THE ART OF RELATED DATA SEMANTICS

According to the W3C definition [37] "ontologies" (or "vocabularies" in simple terms) unambiguously define concepts and relationships for specific fields of interest.

Consequently, with a set of defined terms, a semantic layer is formed consisting of operational human describable terms on the data.

In order to compile the state of the art on data semantics, different sources related to the subject of the project were analyzed. Initially, and given the project objectives of semanticizing data from field and satellite sensing, those basic vocabularies that serve to instantiate observations made by sensors during certain periods of time were taken into consideration, showing the associated results with their corresponding quantities and units of measurement. Furthermore, allowing the location of the stations and sensors involved. Therefore, our first task was to analyze these vocabularies that have been used in most of the related works.

In the following, we will show the vocabularies analyzed through the main sources from which the information was obtained. For the sake of clarity, they are grouped according to the specific domain of application.

2.1 General Concepts

DBpedia [17] is a semantic Web version of Wikipedia. The information is stored with the Resource Description Framework [30]. We can query the database through SPARQL [32].

2.2 Sensorisation in general

Vocabularies that allow describing sensors and their observations, the procedures involved, the characteristics of interest studied, the samples used to do so, and the properties observed, as well as the actuators. Although various vocabularies have been appearing for this purpose, the *Semantic Sensor Network* ontology, whose standard dates from October 2017 [33], was created by OGC and W3C. Work is currently continuing on this standard and the latest version of its draft can be found in [8]. In turn, we can find quite a lot of documentation on W3C SSN / SOSA. For example, an analysis of its use can be found in [36], for which namespaces for its terms can be found in [35] and [34]. A particularly relevant article on SOSA is [22].

2.3 Road traffic sensing

It is interesting to see how sensorization vocabularies have been applied in other domains which, although different from the ASOT-VAS project, are nevertheless illustrative examples to be considered. For example, the use of ontologies that allow the instantiation of sensorics related to road traffic. We highlight the TRAFAIR project [19] where mappings and tools used to model, integrate, semantically enhance, and exploit traffic data are presented. Also worth mentioning is “Tráfico” [14], a vocabulary that makes it possible to represent data on the traffic situation in a city.

2.4 Remote Sensing

Ontologies related to satellite remote sensing. The rationale for using ontologies for this particular domain can be found in [9]. Some of the research publications on semantic modeling or the use of ontologies for satellite remote sensing are worth mentioning. In [38], RSISO, an ontology-based framework for integrating remotely sensed imagery, imagery products, and in situ observations, was developed. It was developed by extending the W3C SSN / SOSA ontology with spatial, temporal, and thematic rules.In [7], the RESEO ontology is proposed for semantic modelling of remotely sensed data and metadata in the field of Earth observation. This ontology is designed to cover multiple types of remote sensing image data products and their associated metadata. Furthermore, RESEO is linked to other existing ontologies in the field of Earth observation, as well as ontologies dedicated to meteorological open data, resulting in an enriched knowledge framework. Another interesting publication related to the same domain is [16].

2.5 Geographical information

On the other hand, given the nature of the data to be processed in the ASOTVAS project, it was essential to use vocabularies that would allow their georeferencing. In this sense, the main standards for representing geospatial data in RDF were taken into account, such as GeoSparql [28] and W3C WGS84 Geo Positioning [21], as well as controlled vocabularies proposed by the Government of Spain to represent geographic resources of the Spanish territory at the level of autonomous communities or cities and provinces. Available at [18].

2.6 Water Management

In [27] a prototype water management platform was presented, consisting of an automated irrigation system for residential lawns and gardens that applies semantic and IoT technologies. The resulting system incorporates real-time sensor data, weather forecasts, and geological and environmental information to infer the precise amount of water needed to minimize water waste without compromising the health and well-being of the lawn or garden.

2.7 Time / Temporality

Ontologies of temporal concepts, to describe the temporal properties of resources. Any observation must have associated with it the time instant in which it was taken, therefore, the use of the vocabulary defined for this purpose by the W3C becomes transcendental [15]. An explanatory guide to its use can be found in [3].

2.8 Quantities / Units of Measurement

They provide semantic specifications for units of measurement, type of quantity, dimensions, and data types. Numerous vocabularies have been appearing on units of measurement, such as [4], [29] or [26]. However, for some time now, QUDT has become the most widely used, due to its simplicity of use, allowing the value or quantity to be specified separately from the associated unit of measurement. At the same time, an analysis was made of those vocabularies and/or research works that, making use of some of the previously mentioned vocabularies, allowed the conceptualization of terms and relationships in different application domains and that would allow us to focus more precisely on the semantic modeling that was intended to be built in our project. Again, the main sources analyzed are listed, and grouped by their specific domain.

2.9 Climate and Meteorology

Vocabularies related to the specification of meteorological data, for example, the one defined by the Spanish Meteorological Agency (AEMET), as well as other non-Spanish vocabularies, such as those defined to establish air quality, etc. [10], [39], [11], [24] and [23].

2.10 Standard climate and forecast names (CF)

In any model that allows the specification of observations, it is necessary to establish what type of properties are being observed, therefore, an exhaustive analysis led us to determine some of the most interesting vocabularies or thesauri. The following allows the ontological representation of the generic characteristics defined by the CF vocabulary: Marine Metadata Interoperability. Climate and Forecast [13], NERC Vocabulary [12] and W3C CF features [20].

3 ANALYSIS OF THE MAIN ONTOLOGIES FOUND

The W3C SSN /SOSA ontologies set adopt a modular architecture with SOSA as a self-contained core that is extended by SSN and other modules to add expressiveness and breadth. Together they describe sensor and actuator systems, observations, the procedures used, the concepts and their properties that are observed or acted upon, the samples and the sampling process, etc. After studying the two vocabularies, given the application domain, it was concluded that only the use of SOSA was necessary for our model [34]. SOSA, for example, allows to classify different types of sensors by simply naming them 'Anenometer', 'Barometer', etc. And the corresponding observations can be connected by creating links, e.g. 'has result' which allows to specify the result for a given observation, or 'made by sensor' to specify which type of sensor has made that observation. In addition, any property has its inverse property, so the reasoning system can infer new knowledge from such relationships. For example, if a given station hosts a given sensor, then it could be inferred that a sensor is hosted by ("*isHostedBy*") the given station.

On the other hand, after studying the different vocabularies on "units of measurement" and "quantities", it was decided to use QUDT-Quantities, Units, Dimensions, and Data Types Ontologies [4]. The decision was taken because, out of the three, QUDT is considered to be very complete and, in addition to allowing the specification of quantities. Furthermore, it has an extensive vocabulary on the different units of measurement that exist, including derived ones. This vocabulary is called "Standard units of measure for all units" [5] and its terms have a namespace [6]. A very interesting presentation that allowed us to have a much broader perspective on the use of the analyzed vocabularies was the presentation on the use of QUDT and CDT [25]. The rest of the ontologies were taken into consideration and some of their elements were considered for incorporation into the model. For the specifications of the geophysical features, in most cases, it was decided to use [13], since its update is much more recent than the other two and is very complete, and its parameters are related to those of NERC vocabularies.

4 ONTOLOGICAL MODEL DEVELOPED

A semantic model has been developed that allows mapping between CSV (sensor observations) and RDF/OWL data.

This vocabulary extends the W3C semantic sensor network ontology (SOSA) with a set of properties that are specific to the specific domain of the ASOTVAS project (semantic model called VAS).

In Figure 1 we can see a screenshot from the Protégé tool of the general description of the model.

First, we have taken into account the Technical Interoperability Standard NTI-RISP [2] and the ENI [1] of Spain, which aims to establishing common conditions on selection, identification, description, format, conditions of use and provision of documents and

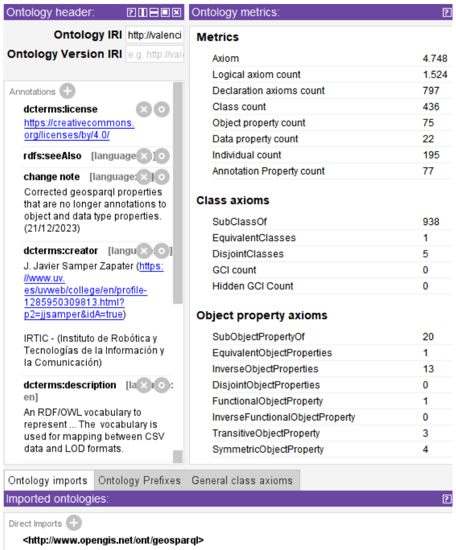


Figure 1: Descriptive view of the VAS model.

information resources produced or held by the public sector. NTI-RISP uses its own controlled vocabulary and establishes specific metadata (mandatory or not) and determines several taxonomies for specific metadata. For example, NTI establishes the W3C Time ontology [15], to specify time-related property values, or metadata values based on standards such as: ISO-8601 (date-time) or RFC4646 (tags to identify languages). It also establishes the possible values assigned to "Geographic Coverage" properties. That is, the use of identifiers related to the geographical resources of the Spanish territory at the level of autonomous communities or cities and provinces [18]. Regarding the latter, we can see a view (Figure 2) of the administrative units in our model.

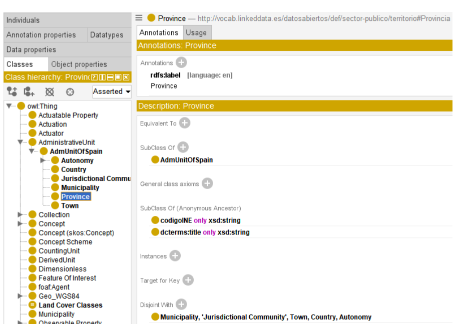


Figure 2: View of the administrative units, specified in our model.

In addition to the above, we list here some of the main ontologies and open vocabularies in the climate domain ultimately used to achieve our purpose in the project.

SOSA Ontology. This ontology is applied in VAS for the representation of sensor-related vocabularies such as stations, sensors, observations, results, etc. Below, we can see some of the model snapshots taken from the Protégé tool (Figures 3-4):

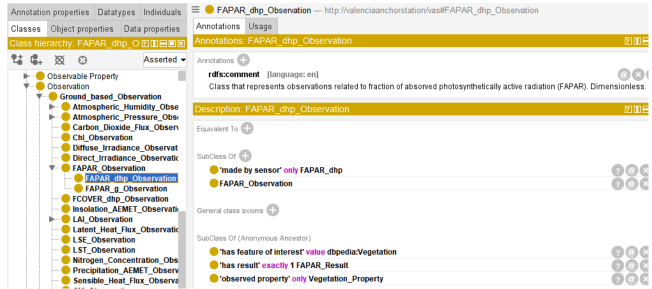


Figure 3: View of an observation.

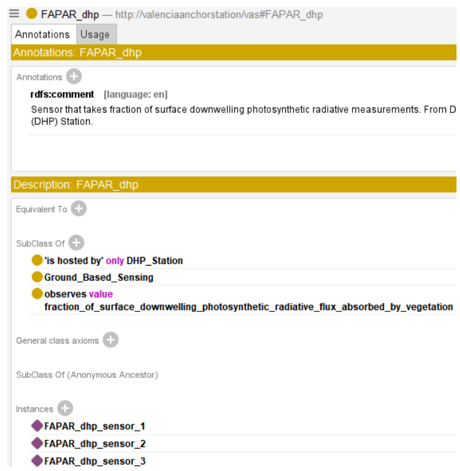


Figure 4: View of a field or ground sensor.

In addition to SOSA, let's look at other vocabularies used:

DBpedia. Some concepts from dbpedia.org such as Air, Atmosphere_of_Earth, Land_surface, Radiation, Soil and Vegetation were used to specify the features of interest (Feature Of Interest) determined in the SOSA ontology (Figure 5).

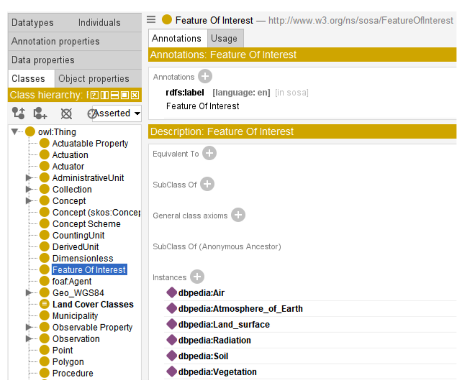


Figure 5: Feature of Interest view.

Marine Metadata Interoperability Climate and Forecast Vocabulary (CF). Most of the Observable Property types according to the SOSA model (e.g. 'Normalized Difference Vegetation Index' or NDVI) in this document are defined according to CF (Figure 6).

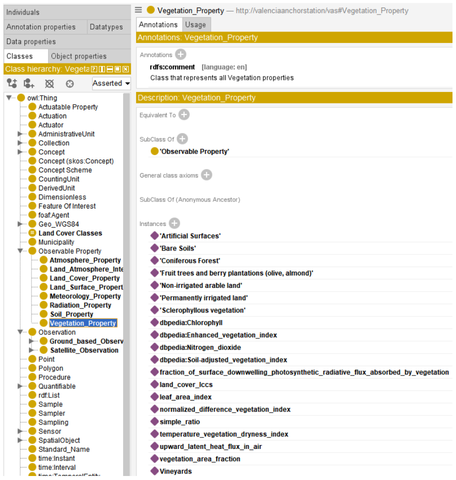


Figure 6: View of the Observable Properties and types of one of them.

In addition, other complementary ontologies have been used, such as **WGS84** and **GeoSparql** for geographic locations, and the '**QUDT**' unit vocabulary for units of results observed by sensors. For example, all stations and the control area in which they are located have WKT (Well-known text representation) for the geometry. In the future, this feature will allow, thanks to GeoSparql functions, to find other points of interest near them, at a certain distance, within a certain area, around it, etc. Figure 7 shows the different stations (field and satellite) defined as "Platform" with geometric characteristics (inherited from GeoSparql Feature).

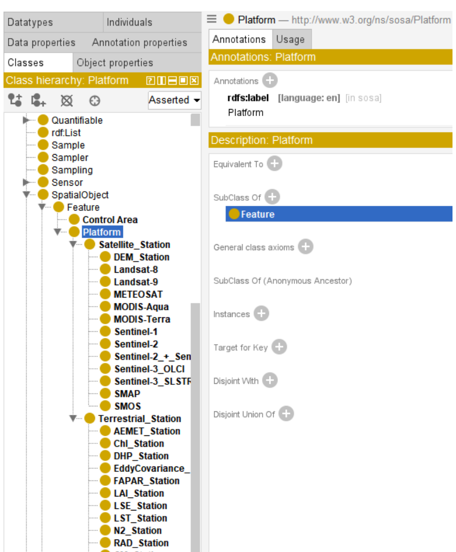


Figure 7: View of the different stations (field and satellite) defined as "Platform".

Figure 8 shows the property that allows setting the location in coordinates, municipality or province of any platform or station.

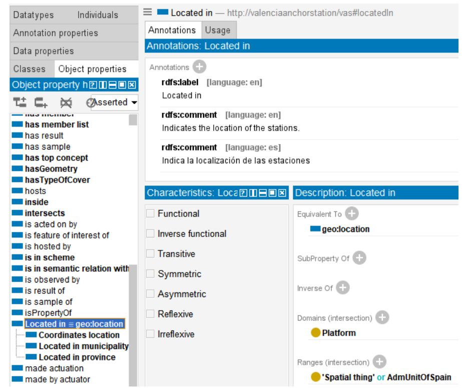


Figure 8: View of the property allowing to set the location in coordinates.

Figure 9 shows one of the instances of a FAPAR-type station, and Figures 10 and 11 show details of the geometry of a DHP station itself (point) and the area in which it is located (polygon), respectively.

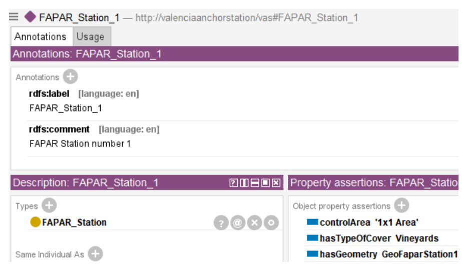


Figure 9: View of the FAPAR Station 1 instance.

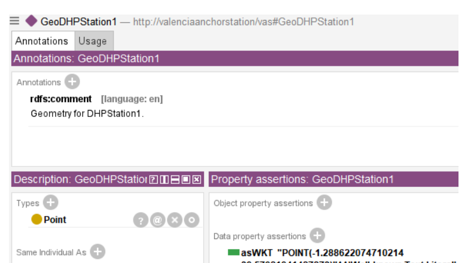


Figure 10: Geometry view of DHP Station 1 (Point).

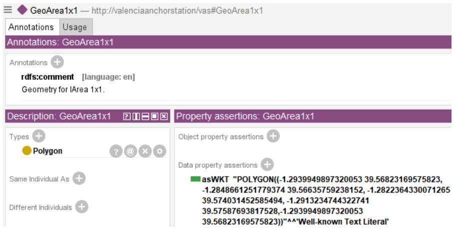


Figure 11: Geometry view of Area 1 (Polygon).

In Figure 12 below we see the definition of a result, consisting of its numerical value and its units of measurement. Details of the numerical value and unit properties (Milligram Per Hectare) can be seen in Figures 13 and 14 respectively.

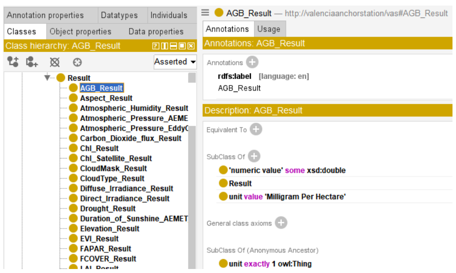


Figure 12: View of a result type based on QUDT.

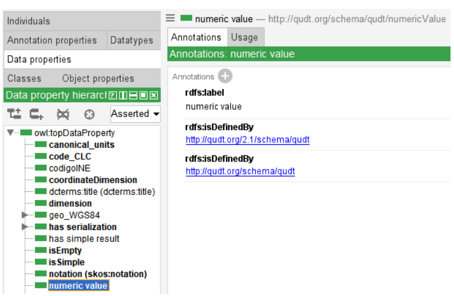


Figure 13: Vista de la Data Property "numericValue" de [5].

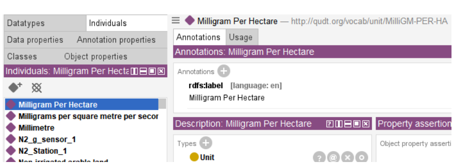


Figure 14: View of the individual "Milligram Per Hectare" of [6].

In turn, for the definition of the time instant in which the observation was taken, W3C Time [15] was used to represent if necessary, the start time and the duration of the measurement.

5 MODEL VALIDATION USING SPARQL QUERIES

With the view to testing the robustness and validity of our model, numerous SPARQL queries [32] were carried out, based on the competence questions raised at the beginning of the project and indispensable for the development of the model.

- Obtaining all stations (limit 2) and their property values, including their location and the sensors they host (Figure 15).
- Obtaining geometries of both the station itself (point) and the control area where it is located (polygon) from instances of "EddyCovariance" type stations (Figure 16).
- Where and which sensors host EddyCovariance stations and what properties they observe (Figure 17).
- Obtaining the values and units of observations of type "Wind_Speed_EddyCovariance", as well as the time instant at which they were taken, the sensor that took it and the properties it covers and, finally, the station and its geometry (Figure 18).

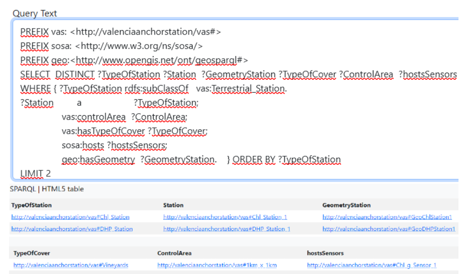


Figure 15: All stations and their property values.

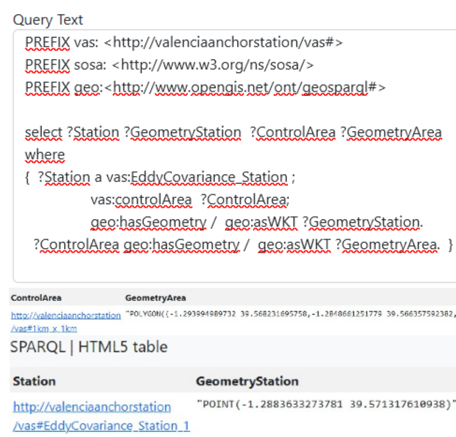
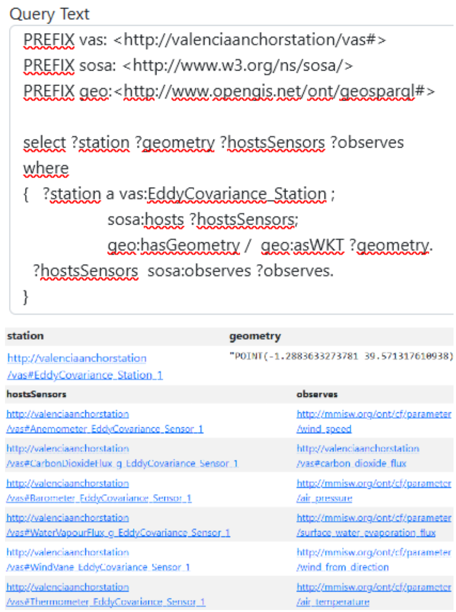


Figure 16: Obtaining geometries.



Query Text

```
PREFIX vas: <http://valenciaanchorstation/vas#>
PREFIX sosa: <http://www.w3.org/ns/sosa/>
PREFIX geo:<http://www.opengis.net/ont/geosparql#>

select ?station ?geometry ?hostsSensors ?observes
where
{   ?station a vas:EddyCovariance_Station ;
            sosa:hosts ?hostsSensors;
            geo:hasGeometry /  geo:asWKT ?geometry.
  ?hostsSensors  sosa:observes ?observes.
}
```

station	geometry
http://valenciaanchorstation /vas#EddyCovariance_Station_1	"POINT(-1.2883633273781 39.571317610938)

hostsSensors	observes
http://valenciaanchorstation /vas#Anemometer_EddyCovariance_Sensor_1	http://mmisw.org/ont/cf/parameter /wind_speed
http://valenciaanchorstation /vas#CarbonDioxideFlux_g_EddyCovariance_Sensor_1	http://valenciaanchorstation /vas#carbon_dioxide_flux
http://valenciaanchorstation /vas#Barometer_EddyCovariance_Sensor_1	http://mmisw.org/ont/cf/parameter /air_pressure
http://valenciaanchorstation /vas#WaterVapourFlux_g_EddyCovariance_Sensor_1	http://mmisw.org/ont/cf/parameter /surface_water_evaporation_flux
http://valenciaanchorstation /vas#WindVane_EddyCovariance_Sensor_1	http://mmisw.org/ont/cf/parameter /wind_from_direction
http://valenciaanchorstation /vas#Thermometer_EddyCovariance_Sensor_1	http://mmisw.org/ont/cf/parameter /air_temperature

Figure 17: Detail of EddyCovariance type stations.

Query Text

```
PREFIX vas: <http://valenciaanchorstation/vas#>
PREFIX sosa: <http://www.w3.org/ns/sosa/>
PREFIX geo:<http://www.opengis.net/ont/geosparql#>
PREFIX qudt:<http://qudt.org/schema/qudt/>

select ?observacion ?time ?numericValue ?unit ?sensor ?observes ?station ?geo ?asWKT
where { ?observacion  a  vas:Wind_Speed_EddyCovariance_Observation;
            sosa:madeBySensor  ?sensor;sosa:hasResult ?result;sosa:resultTime ?time.
  ?result qudt:numericValue ?numericValue;qudt:unit ?unit.
  ?sensor sosa:isHostedBy ?station;sosa:observes ?observes.
  ?station geo:hasGeometry ?geo.  ?geo geo:asWKT ?asWKT. }
```

observacion	time	numericValue	unit
http://valenciaanchorstation /recurso /vas/WindSpeedObservation /28097	2023-01-08T18:00:00Z	2.9022	http://qudt.org /vocab /unit/M-PER-SEC
http://valenciaanchorstation /recurso /vas/WindSpeedObservation /24564	2023-01-27T03:30:00Z	1.56692	http://qudt.org /vocab /unit/M-PER-SEC
http://valenciaanchorstation /recurso /vas/WindSpeedObservation /18843	2023-01-26T11:00:00Z	6.3804	http://qudt.org /vocab /unit/M-PER-SEC

sensor	observes
http://valenciaanchorstation /vas#Anemometer_EddyCovariance_Sensor_1	http://mmisw.org /ont/cf /parameter /wind_speed

station	geometry
http://valenciaanchorstation /vas#EddyCovariance_Station_1	"POINT(-1.2883633273781 39.571317610938)

Figure 18: Results of Wind_Speed_EddyCovariance observations.

6 CONCLUSION

In conclusion, the ASOTVAS project has succeeded in providing semantics to the observation data in the Valencia Anchor Station (VAS) control area. An ontological model has been developed based on the W3C SOSA ontology, extended with specific properties of the ASOTVAS domain (semantic model called VAS). A methodology has been followed that includes the analysis of a conceptual infrastructure, structure and semantic modelling, implementation of the ontology model, robustness testing by means of SPARQL queries and determination of the ontology publication process. Priority was given to the reuse of existing ontologies, such as SOSA, GeoSparql, WGS84, QUDT, CF, and others, adapting them to the case study. Concepts and relationships have been successfully specified in the domain in question, considering other application domains such as general sensing, road traffic sensing, remote sensing, geographic information, water management, time/temperature, quantities/units of measurement, climate, and meteorology. The SPARQL queries performed demonstrated the model's ability to retrieve key information on stations, sensors, observations, properties, locations, and results. The use of widely accepted standards and vocabularies, as well as adaptation to the specific needs of the project, has enabled interoperability and efficient exchange of semantic information.

In summary, the project has contributed to the advancement of the semantic representation of observational data in the context of Earth Observation, applying data semantics to improve the management and understanding of the information collected by the VAS.

As a next task, it is proposed to introduce SWRL rules [31] that allow for proper management of the distribution of resources. For example, a typical scenario could consist of building a rule that, based on observations on a vineyard area, compares the observed values with the thresholds specified according to certain criteria or regulations and instantly classifies this area as hydro-deficient and then applies the set of actions most in line with this scenario. Finally, a SPARQL interface will be designed to allow direct and federated queries against data stored in a Virtuoso Open Server Endpoint. It will allow direct queries and via APIs.

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