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Original Article

Information retrieval through a knowledge base system: Semantic web based approach in South-Eastern Coastal areas of India

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Abstract

The rapid growth in sensor observations results in copious satellite data, which makes information retrieval and decision making difficult tasks. Research addressing Decision Support Systems (DSS) for climatic change is needed. The traditional knowledge repositories work on static models but are challenged by dynamic fields. This paper presents a Sensor Observation Service (SOS) to analyze environmental conditions among south-eastern coastal areas of India. The challenges in an ocean observation system, like semantic heterogeneity and knowledge retrieval, are addressed using Semantic Web (SW) technology to present the data in a standard format. Similarly, the ocean knowledge base is provided by developing weather ontology for knowledge retrieval and DSS. This helps in analyzing the spatial data to provide data and knowledge to researchers, meteorologists and other users. The proposed approach has been experimentally tested on Indian Meteorological Satellite INSAT-3D's ocean data collected along the south-eastern coastal areas of India.

Keywords: heterogeneous satellite data, machine understandable format, semantic web, knowledge representation, data retrieval

1. Introduction

Ocean weather is a prominent factor affecting sectors like fishing, navy, marine, government authorities, academic researchers etc. Efficient access to ocean information helps provide a better understanding for the management of marine environment (Armah, 2019). Hence, research on ocean areas has gained attention during the past decades. Analysis of accurate information in different time scales helps maintain the wellbeing of a coastal population. Coastal areas are monitored by sensors like Agro Floats, Buoys, Coastal Radars, Gliders, Sondes, and so on. This research focuses on the south-eastern coastal areas of India. Approximately 1200 weather stations are deployed across India and data has been generated on regular intervals.

According to recent research, the Indian Ocean is said to be the warmest among all the five oceans, and it generates 7% of the total world's cyclones (Gupta, Jain, Johari, & Lal, 2019). Climatic change in the Indian Ocean results in an increased number of severe cyclones (Sarkar, 2020). India holds the second place in accessing and utilizing ocean data for various aspects. Once upon a time the weather conditions were hand calculated depending upon changes in weather parameters, but nowadays this action is computer-based. Numerical Weather Prediction (NWP) applies most powerful computer algorithms for weather prediction.

This paper proposes ontology based ocean data and knowledge retrieval. Ontology is preferred over a relational database because the voluminous data are difficult to manage in a relational database. In a relational database each table shares at least one field with another table through one-to-one, one-to-many or many-to-many relationships. Hence, building up a relation is very complex and time-consuming. Also querying is difficult to obtain accurate results. Ontology has the potential to help manage huge datasets. It offers a convenient vocabulary that provides meaning to each dataset (Stanford Knowledge Systems Laboratory, 2001). Similarly, the user can access a heterogeneous schema and data formats simultaneously.

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Further, the paper is organized as follows: section 2 explains literature related to the current research area, section 3 depicts proposed oceanographic ontology, section 4 incorporates results and discussion, and finally the paper concludes along with future scope in section 5.

2. Literature Review

Various websites such as Indian Metrological Department (IMD), AccuWeather, and Open weather map are providing weather data. World Wide Web (WWW) grants rights to use the globally distributed data. SW is an advanced form of WWW, which offers prepared datasets to share and reuse information. Information is arranged in such a way that it is understandable to a machine. The term SW was introduced and developed by Tim Berners Lee (Tim, James, & Ora, 2001). The remotely accessed datasets can be used for climate monitoring, likely implemented in Asia and South-West Pacific (Yuriy, 2018). The main intention of SW standards and linked data is to develop the significance of data.

The Intergovernmental Panel on Climatic Change (IPCC) suggests distinguished risk assessment for characterizing climate change. However, there are major challenges in using conventional risk-based approaches for climate change. For instance, long time scales and the intrinsic vulnerability are thorny issues. Further challenges incorporate distinguishing pattern risk in presence of climate variability. Unfortunately, these challenges are often the greatest motives for powerful adaptation. Further refinement of present computer-based assessing techniques needs to be addressed.

Many studies have provided new representations of data that are understandable and usable by web agents. Some works have proposed converting tabular data into file formats like Resource Description Framework (RDF), RDF-Schema (RDF-S) or Web Ontology Language (OWL) (Ivan, Christopher, Peter, & Benjamin, 2011) and (Kumar, Ujjal, & Utpal, 2015). Through SW the satellite data can be made available to mobile developers (Bereta *et al*., 2019). This paper concentrates on converting heterogeneous files to RDF (*.rdf).

RDF standard was developed by the World Wide Web Consortium (W3C) in order to depict the metadata. It is generally represented as a graphical structure to present resources on the web. The RDF format can be described through a triplet: subject, predicate and object. Triples refer to anything in the world identified by a unique name: the Uniform Resource Identifier (URI) (Narni, 2019). Subject and predicate represent any resources on the web, whereas the object is either a resource or a value. For instance, let us consider the information "Sea surface temperature at morning time is 17°C" represented in RDF notation as per Equation (1).

Triplet: <URI1#Sea surface temperature><URI2#at morning time><URI3#is 17°C> (1)
(Subject) (Predicate) (Object)

SW addresses semantic interoperability through developing ontologies. WebOnto, NeOn, SWOOP, WebODE, OilEd, Protégé and OntoEdit are some of the tools available (Youn *et al*., 2006) for creating an ontology. Among these, Protégé was analyzed to be the best choice with various functionalities (Sunitha, & Suresh, 2013). It offers a rich set of knowledge-modelling structures and domain-friendly support for creating Knowledge Base System (KBS) using Java-based Application Programming Interface (API).

A ground level ontological model is created by extracting concepts from a dictionary (Sleeman, Finin, & Halem, 2018). Ontological representation is promoted for climatic and meteorological data collection (Fazliev *et al*., 2017). Bjerkne's and Richardson's computation helps to trace science of weather forecasting from early civilizations to modern operational NWP (Wiston, & Mphale, 2018). Szabo and Groza (2017) aimed to present climatic domain knowledge based on translating logic dictum into lexical rules for textual residual algorithms. Climate ontologies are converted into an adequate format for API.AI model (Toniuc, & Groza, 2017). Considering the assets and liabilities of above mentioned ontology development approaches this paper deals with developing Oceanographic Weather Ontology (OWO).

3. Proposed Weather Data Model

This section evidently depicts the ocean Weather Phenomenon Prediction (WPP) through SW technologies. The main objective of this research is to access the data, and process, store, and provide knowledge about the data through ontology. This helps any researchers, end users, or meteorologists to analyze the historical data and understand the nature of data. Architecture of the proposed system is represented in Figure 1. Satellite data are organized by meaningful combinations through ontological framework; providing details about domain knowledge in terms of concepts, abstracting data sets, and relations between them.

The proposed method has been experimentally tested on the Indian Meteorological Satellite INSAT-3D's ocean data. It contains information about ocean weather parameters like air pressure, wind speed, precipitation, relative humidity, sea surface temperature, etc., with geospatial information on latitude and longitude. The proposed method consists of four phases, namely data collection and preprocessing, system design by creating ontology, SOS service implementation, and evaluation of knowledge retrieval. Data collection and preprocessing involve the collection of ocean data from satellite. The collected Network Common Data Form (NetCDF) data are converted to a standard machine understandable format namely RDF. Any NetCDF file is represented as per Equation 2.

$$F_{NC}(u) = (H, B) \quad (2)$$

Here '*H*' represents header and '*B*' represents body of file. The header includes dimensions ('*D*'), variables ('*V*') attributes ('*A*') and groups ('*G*') as per Equation 3. The variable '*V*' consists of '*n*' number of geospatial data stored in it.

$$H = \{D, V, A, G\}, \forall \in H \quad (3)$$

File information like dimensions, attributes and variables are fetched using nc.read option. A Subject, predicate and an object are assigned for each variable and a position is added for each value. Finally, by generating namespace and dimension properties it is written as RDF. Process of conversion of NetCDF in to RDF is shown in Figure 2.

Weather parameters have different naming conventions for different sensors. The concepts used in proposed ontology follow the Integrated Ocean Observing System (IOOS) standard (Haines *et al*., 2012). For instance, the observed datasets have names like Rain, rain fall, precipitation, intensity, precipitation rate, etc., whereas IOOS offers a standard naming convention as "precipitation_ intensity". The two basic needs for naming conventions are; the data providers can understand, describe and provide services in an index through a standard model. Secondly, it helps integrated delivery systems, which are machine readable and available for automated discovery.

In system design, the ontology is created using the Protégé 5.0 tool. Top-level concepts include geographical location, date and time, weather attributes, and weather phenomenon; then sub-concepts were created, namely latitude and longitude under geographical location, etc., per Table 1. Further instances are created under each sub-concept through an object property, where each instance holds a range of values through a data property.

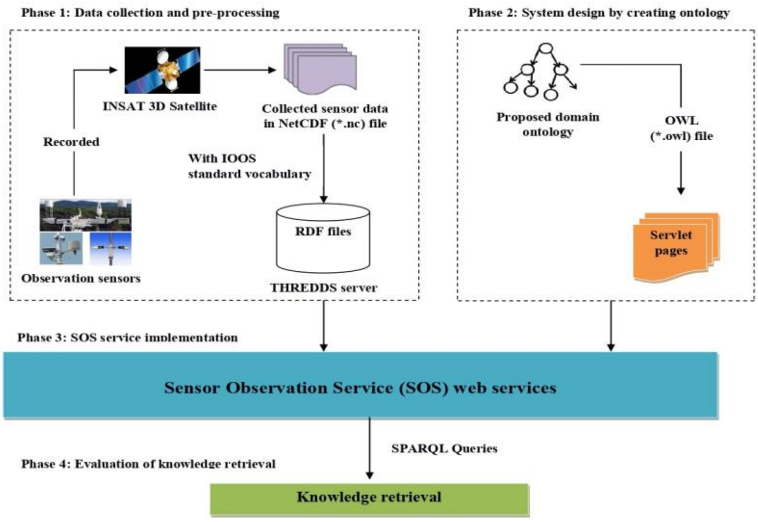

Figure 1. Architecture of the proposed Weather Phenomenon Prediction (WPP)

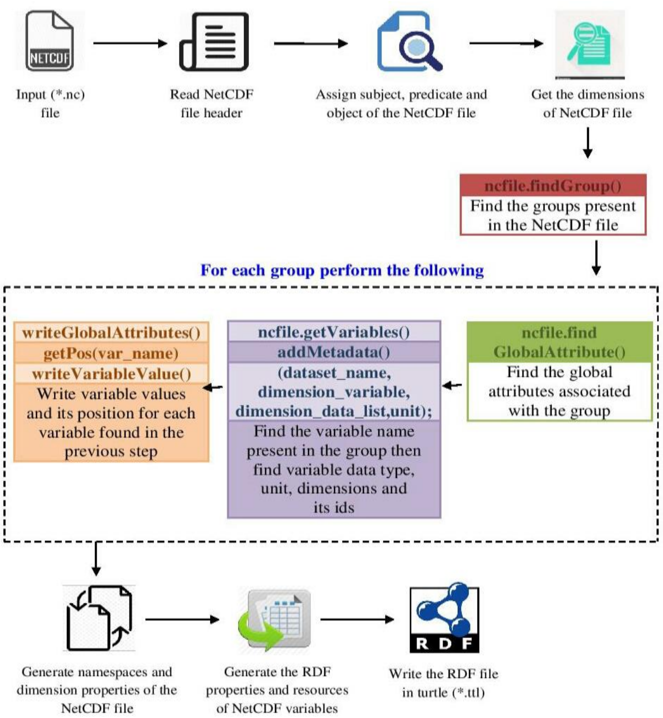

Figure 2. Flow of conversion of NetCDF to RDF file format

Table 1. Concepts and sub-concepts of the developed OWO ontology

S.No	Top-level concept	Respective sub-concepts
1	geo_location	latitude, longitude
2	date	instances, date, year
3	time	interval, hours, minutes, seconds
4	weather_attributes	fog, aerosol_optical_thickness, cloud_cover, precipitation_rate, relative_humidity, wind_speed, wind_direction, wind_gust, barometric_pressure, atmospheric_pressure, sea_surface_temperature, air_temperature, conductivity, solar_irradiance, uv_index
5	weather_condition	good, bad, severe
6	weather_phenomenon	cyclone, storm, water spout, marine heat waves

The existing satellite data retrieval systems are effective in executing queries based on location, date, time, weather attributes, etc. In that case, retrieving additional domain-specific concept-based data is a challenging task. For instance, the values of weather parameters like wind speed can be retrieved using API, but retrieval of specific knowledge-based data such as fresh gale or gentle breeze is a complex task. To facilitate an efficient retrieval system, it should be designed to support semantic concepts and knowledge-based data retrieval through ontology. The proposed OWO consists of 37 concepts, 112 instances, 85 relations and 126 attributes.

The weather concepts, namely wind_speed, precipitation, relative_humidity, sea_surface_temperature, etc., are related to each other using relations like is-a or has-a. The concept dictionary of the developed ontology is shown in Table 2. The instances and values for each concept namely, wind_speed (Beaufort, 1946), precipitation_rate (Taalas, 2018), barometric_pressure (Haby, 2019), Humidity (Engineering Tool Box, 2019) and sea_surface_temperature (Shenoi *et al*., 2009), etc., are collected from various analysis reports. According to the Beaufort scale various instances of wind speed and its values are illustrated in Table 3. For instance, if the wind speed falls below the range from 0.3 m/s to 0.5 m/s it is categorized as “Light Air” and from 3.4 m/s to 5.5 m/s it is specified as “Gentle Breeze”. These ranges specify the nature and characteristics of wind speed. They are provided to acquire knowledge about the data, which specifies the conditions of ocean weather with respect to wind speed.

In addition to that, the proposed OWO incorporates four different ocean weather disasters namely storm, cyclone, water spout, and marine heat waves. The weather factors related to each phenomenon are acquired from various weather reports provided by meteorologists and government web sites. The details of storm (Staroch, 2013), cyclone (Roy, 2017), water spout (Smith, 2016) and marine heat waves (Hobday, 2016) are illustrated in Table 4. For instance, cyclone depends on the factors like barometric_pressure in range from 998 hPa to 1007 hPa, relative_humidity in range from 81 % to 89 %, wind_speed > 72 m/hr, precipitation_rate > 100 mm/h, and sea_surface_temperature > 26 ºC.

The instances are related to sub-concepts through an object property and related to data values through a data property. The object properties deployed in this ontology are owl:hasDate, owl:hasTime, owl:hasGeoLocation, owl:has Condition, owl:hasPhenomenon, and owl:hasAttributes. Similarly, the data properties are owl:hasInterval, owl:has Instance, owl:hasLat, owl:hasLong, owl:hasPrecIntensity, owl:hasIrradiance, owl:hasUVindex, owl:hasWindSpeed, owl:hasConductivity, owl:hasOpticalThickness, owl:hasBaro Pressure, owl:hasCloudCover, owl:hasSurfaceTemp, owl:has FogIntensity, owl:hasHumidity, owl:hasWindGust, owl:has Direction, owl:hasAirTemp and owl:hasAirPressure. The developed OWL (*****.owl) file is included in servlets for querying process.

Table 2. Concept dictionary and instances of weather_attributes

S.No	Concept of weather_attributes	Instances under the specific concept
1	precipitation_rate	VeryLightRain, LightRain, ModerateRain, HeavyRain, ViolentRain
2	relative_humidity	DryHumidity, OptimumHumidity, MoistHumidity
3	wind_speed	NoWind, LightAir, LightBreeze, GentleBreeze, ModerateBreeze, FreshBreeze, StrongBreeze, ModerateGale, NearGale, FreshGale, StrongGale, WholeGale, Storm, ViolentStorm, Hurricane
4	cloud_cover	NoCloudCover, UnknownCloudCover, PartlyCloud, MostlyCloud, OverCast
5	barometric_pressure	LowBarometricPressure, HurricanePressure, AverageSeaLevelPressure, HighBarometricPressure, VeryHighBarometricPressure
6	sea_surface_temperature	VeryCold, Cold, Warm, Medium, High, VeryHigh
7	aerosol_optical_thickness	ClearSky, Medium, Coarse, Hazy, VeryHazy
8	fog	DenseHaze, LightFog, ModerateFog, ThickFog, DenseFog, AdvectionFog
9	conductivity	DemineralizedWater, LowConductivity, MediumConductivity, BrackishWater, PollutedWater, HighlyPolluted, HighlyConductivity, VeryHighConductivity
10	air_temperature	BelowZeroTemperature, ZeroTemperature, AboveZeroTemperature, VerySevereFrost, SevereFrost, ModerateFrost, SlightFrost, BelowRoomTemperature, ModeratelyWarm, Warm, VeryWarm, RoomTemperature, AboveRoomTemperature, Heat, VeryHeat, ExtremeHeat
11	wind_from_direction, wind_to_direction	North, NorthNorthEast, NorthEast, EastNorthEast, East, EastSouthEast, SouthSouthEast, South, SouthSouthWest, SouthWest, WestSouthWest, West, WestNorthWest, NorthWest, NorthNorthWest
12	air_pressure	Normal, Stormy, Rain, Change, Fair, VeryDry, HighPressure
13	wind_gust	NelectibleGust, NonSevere, Severe, HurricaneForce, SignificantSevere
14	solar_irradiance	NoRadiance, NegligibleRadiance, MediumRadiance, HighRadiance, ExtremelyHighRadiance
15	uv_index	Low, Medium, High, VeryHigh, ExtremelyHigh

Table 3. Instances/Indviduals of the concept wind_speed

S.No	Concept	Individuals/ Instances	Value	Value type	Unit
1	wind_speed	NoWind	[<0.3]	xsd:decimal	m/s
2		LightAir	[>=0.3,<=0.5]		
3		LightBreeze	[>=1.6,<=3.3]		
4		GentleBreeze	[>=3.4,<=5.5]		
5		ModerateBreeze	[>=5.6,<=7.9]		
6		FreshBreeze	[>=8.0,<=10.7]		
7		StrongBreeze	[>=10.8,<=13.8]		
8		ModerateGale	[>=13.9,<=17.1]		
9		NearGale	[>=13.9,<=17.1]		
10		FreshGale	[>=17.2,<=20.7]		
11		StrongGale	[>=20.8,<=24.4]		
12		WholeGale	[>=24.5,<=28.4]		
13		Storm	[>=24.5,<=28.4]		
14		ViolentStorm	[>=28.5,<=32.6]		
15		Hurricane	[>=32.7]		

Table 4. Weather factors affecting the weather phenomena

S. No	Name of the phenomenon	Weather parameters in IOOS standard	Range of values	Name of individual in ontology
1	Cyclone	barometric_pressure	998 – 1007 (hPa)	Hurricane pressure
		relative_humidity	81 – 89 (%)	Moist humidity
		wind_speed	> 72 (m/hr)	Hurricane
		precipitation_rate	> 100 (mm/h)	Violent rain
		sea_surface_temperature	> 26 (ºC)	Warm
2	Storm	barometric_pressure	< 998 (hPa)	Hurricane pressure
		precipitation_rate	21 – 50 (mm/hr)	Heavy rain
		wind_speed	64 – 72 (m/hr)	Hurricane
		cloud_cover	> 80 (%)	Over cast
3	Water spout	relative_humidity	> 60 (%)	Moist humidity
		wind_speed	5.6 – 7.9 (m/hr)	Moderate breeze
		air_temperature	10.7 – 4.9 (ºC)	Warm
		water_temperature	21.8 – 31 (ºC)	Warm
4	Marine heat waves	relative_humidity	> 60 (%)	Moist humidity
		sea_surface_temperature	> 32 (ºC)	Medium
		water_temperature_100m	19 – 25 (ºC)	Warm
		water_temperature_200m	1.2 – 17 (ºC)	Cold
		cloud_cover	= 0	No cloud cover
		precipitation_rate	= 0	No precipitation

Servlets offer a Component Based System (CBS) for designing and building web applications in independent platforms. They are java programs that run on a web servers in dynamic mode. Java Servelet Pages (JSP) adds java code to the Hyper Text Markup Language (HTML) code using JSP tags. In SOS service implementation a web service is created using JSP where the information can be queried. SOS web services provide querying real-time sensor data with three core operations, namely Get Capabilities, Get Observation function, and Describe Sensor.

Finally, the evaluation of knowledge retrieval of ocean data is carried out using SPARQL queries written in JSP pages. SPARQL can be used to express queries across diverse data sources (Rashmi, & Clara, 2016), which can be processed over a large RDF graph. Query consists of PREFIX for namespace, SELECT clause specifying return value and WHERE clause with triples pattern that matches the variable in RDF becomes the query result. Data from RDF file is retrieved and particular knowledge is accessed from OWL file.

4. Results and Discussion

The proposed research was performed on a 64-bit Intel core i5 processor with 4GB of RAM, 2TB hard disk and deployed in LINUX (Ubuntu version 16.04) Operating System. The java (jdk 1.8.0_181) code was developed on Eclipse 5.0. SOS Service was implemented in server technology called Apache Tomcat 9.0.12 and JSP was selected as the development tool. Hence, JSP acts as a server and Internet Explorer or any web browser as a client. The collected NetCDF data files are 213.24 MB in size with 358,374 records. These datasets are presented in RDF per Figure 2. The first line of output file indicates prefix which refers Internet Resource Identifiers (IRIs) followed by RDF statements where the data in NetCDF file are presented as triples. Conversion time for different numbers of records is calculated by incorporating the java command.

Factors like reliability and algorithm complexity wes also measured and results are summarized in Table 5. Reliability was calculated by recording the probability of

Table 5. Experimental results on converting NetCDF files to RDF

File format	Number of records	Average time to represent in to RDF (Min)	Reliability	Algorithm Complexity
NetCDF (*.nc)	50,000	0.057	Relatively High	High
	100,000	0.065		
	150,000	0.097		
	200,000	0.456		
	250,000	0.781		
	300,000	1.578		
	350,000	1.892		

failure during the conversion process in a given time period per Equation 4. A range of values were taken and reliability factor was analyzed to be relatively high and excellent. Reliability and stability of system and algorithm are considered high. Similarly, the algorithm complexity is assessed by considering the number of loops in conversion process and number of times it has been executed. By assuming a statement in the algorithm as O(1), the total time for the loop is N*O(1), hence O(N) overall. Here the outer loop executes N times, the inner loop executes M times. NetCDF is designed to execute higher number of loops and hence the complexity is higher.

$$\text{Reliability} = \frac{\text{Total operating time}}{\text{No of failures}} \qquad (4)$$

A sample NetCDF file converted to RDF is shown in Figure 3. It can be noted that the longitudes "38.75" and "41.25" are represented as RDF statement through data type "xsd:float", and qb:hierarchyRoot represents RDF data cube vocabulary for multi-dimensional data publishing. A resource representing the entire data set is created using the name space qb:DataSet and linked to the corresponding data structure via qb:structure property. Similarly other namespaces included are "xsd" representing XMLSchema, "dct" represents terms, "nc" represents netcdf file, "*CF_INTERNAL*" represents cf-conversions, "float, int, long, short, double, byte, string, char" represent the data types of the satellite data, "rdf" represents rdf syntax, "*NS_STRUCT_INTERNAL*" represents rdf structure and "*NS_DATA_INTERNAL*" represents rdf data. Sensor data vocabularies like "Latitude" or "lat" are also represented in IOOS standard format like "latitude".

Further, a knowledge base is developed for ocean WPP through ontology indicating hierarchy of weather attributes, time, weather conditions, attributes related to weather conditions and relationship between them. By referring to Table 1 and Table 2 OWO ontology is created using Protégé. The overall onto graph of the proposed ontology is presented in Figure 4 (a) and onto graph of concept **"wind_speed"** is presented in Figure 4 (b). For instance, wind_speed is a sub-concept of weather_attribute, which holds as instances No Wind, Light Air, Light Breeze, Gentle Breeze, Moderate Breeze, Fresh Breeze, Strong Breeze, Moderate Gale, Near Gale, Fresh Gale, Strong Gale, Whole Gale, Storm, Violent Storm and Hurricane.

Each instance holds a range of values through a data property "hasWindSpeed" of data type "xsd:decimal" measured in "m/s". Similarly, the factors of weather phenomenon are also deployed in proposed ontology as in developed through JSP tags using the servlets. A servlet includes web page design in which SPARQL queries are embedded to retrieve the data from RDF files stored in THREDDS server. The sample query for Figure 5 is as follows:

```
PREFIX : <http://localhost/climate.owl#>
SELECT   ?wind_speed
WHERE {
     ? wind_speed   a:climate   ? wind_speed.
FILTER ( ?latitude = 7.007 && ?longitude=88.005).
FILTER ( ?date > = "2015-01-01T00:00:00z" ^^xsd:dateTime &&
         ?date < = "2018-04-07T06:00:00z" ^^xsd:dateTime).
         }
```

In JSP pages both RDF as well as OWL file are incorporated in order to map the user queries with the source datasets. The home page consists of latitude and longitude tab under which the values are selected for the particular location. Similarly, the User can also choose the period of time and

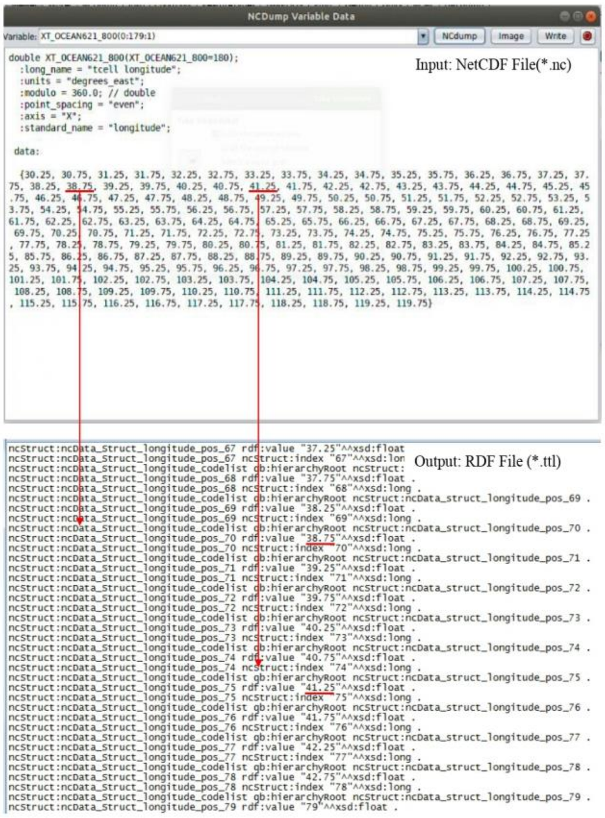

Figure 3. Conversion output of NetCDF file to RDF

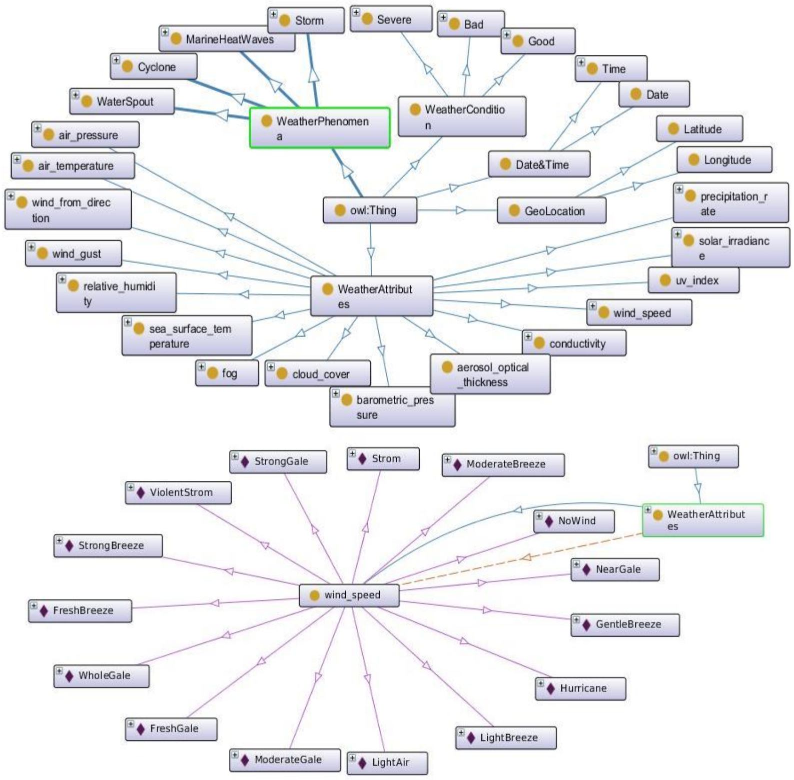

Figure 4. Onto graphs of (a)proposed OWO ontology and (b)concept “wind_speed”

result format in which to displaye, namely Java Script Object Notation (JSON), XML or Table. For instance, “latitude” given is “7.007”, “longitude” is “88.005”, period is “from 01/01/2015, 00:00 IST to 03/01/2015, 06:00 IST” and output format is “JSON”. The values given in respective tabs are updated to SPARQL query written in JSP pages. First the server queries for the value of “wind_speed” recorded in specified geo-location and date and time from RDF and found to be “1.91”. Further, in evaluation of knowledge retrieval the server maps the value “1.91” retrieved from RDF source with that of OWL knowledge base. This mapping identifies the range of values under which this particular value falls and returns instance name, i.e., knowledge of the data. Since, the value “1.91” falls in the range “1.6 to 3.3 m/s” the instance name given is “Light breeze”. Finally, the result will be displayed in “JSON” format with latitude, longitude, date and time, resultant value “1.91” and instance name “Light breeze” as presented in Figure 5.

Similarly, weather phenomenon tab helps to retrieve knowledge about weather conditions. For instance, the user queries for cyclone information by giving date and time in a particular location. The retrieved data is compared with all the weather factors included for cyclone. If all the five conditions are satisfied for ranges of values in Table 4 then it returns “Cyclone affected”, else “Cyclone not affected”. Threshold values to identify phenomena with reference to various scientists, researchers and meteorologists have been used to develop the ontology. For instance, according to Brenda Ekwurzel, Senior Climate Scientist, Director of Climate Science, tropical cyclones are generated in the warmer temperatures (i.e., >26ºC). Hence, the results obtained are approximately correct. The proposed method is used to provide access to data for researchers, academicians, managers, etc., in a human readable format like XML/JSON for ocean weather applications.

5. Conclusions

Data play a vital role in day-to-day life, with major access to them over the web, but they lack being web understandable and analyzable. Semantic web is an excellent technology for making data understandable to both humans and machines. Not only addressing the semantic relations, it also exhibits relations among different data concepts. This paper developed a knowledge base through ontology with four basic ocean weather phenomena. Future work will focus on implementing the strengthening of weather phenomena e.g., cyclones results with refinements like Depression, Deep depression, Cyclonic storm, Severe cyclonic storm, Very severe cyclonic storm, Extremely severe cyclonic storm and Super cyclonic storm. In the future, sensors can be extended with multiple microcontrollers that perform faster data processing and delivery.

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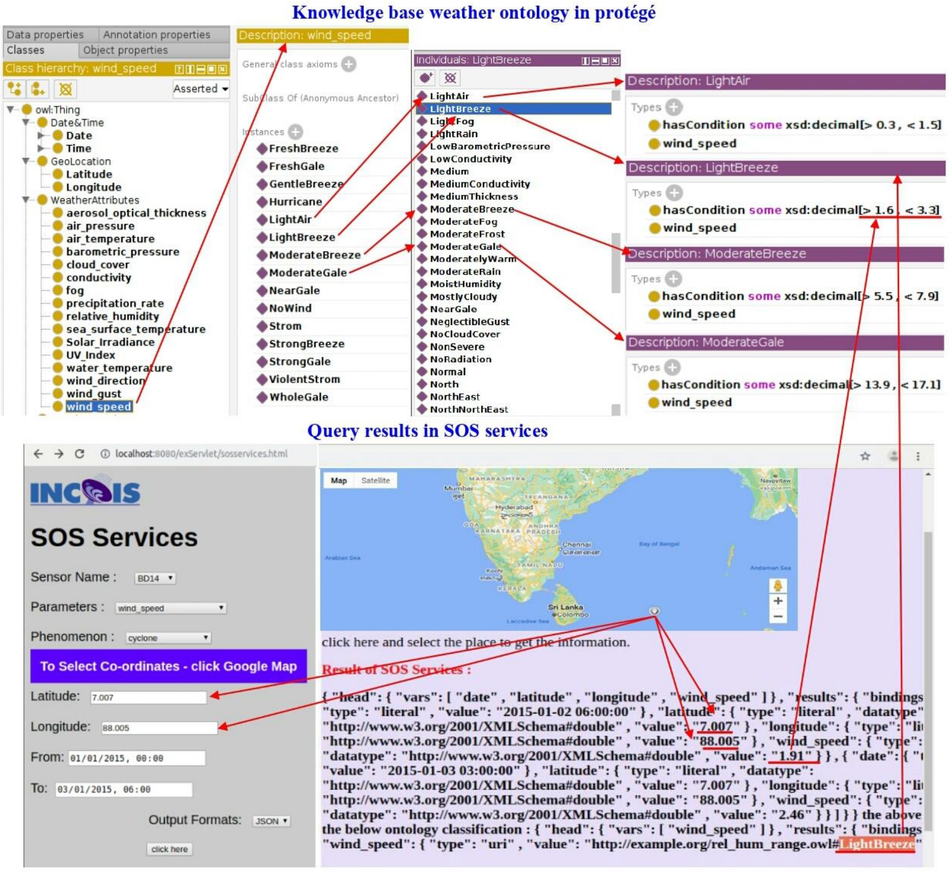

Figure 5. Retrieval of values and ontology concept of wind_speed

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