
Building Scalable Linked Data-Powered Virtual Earth Observatories

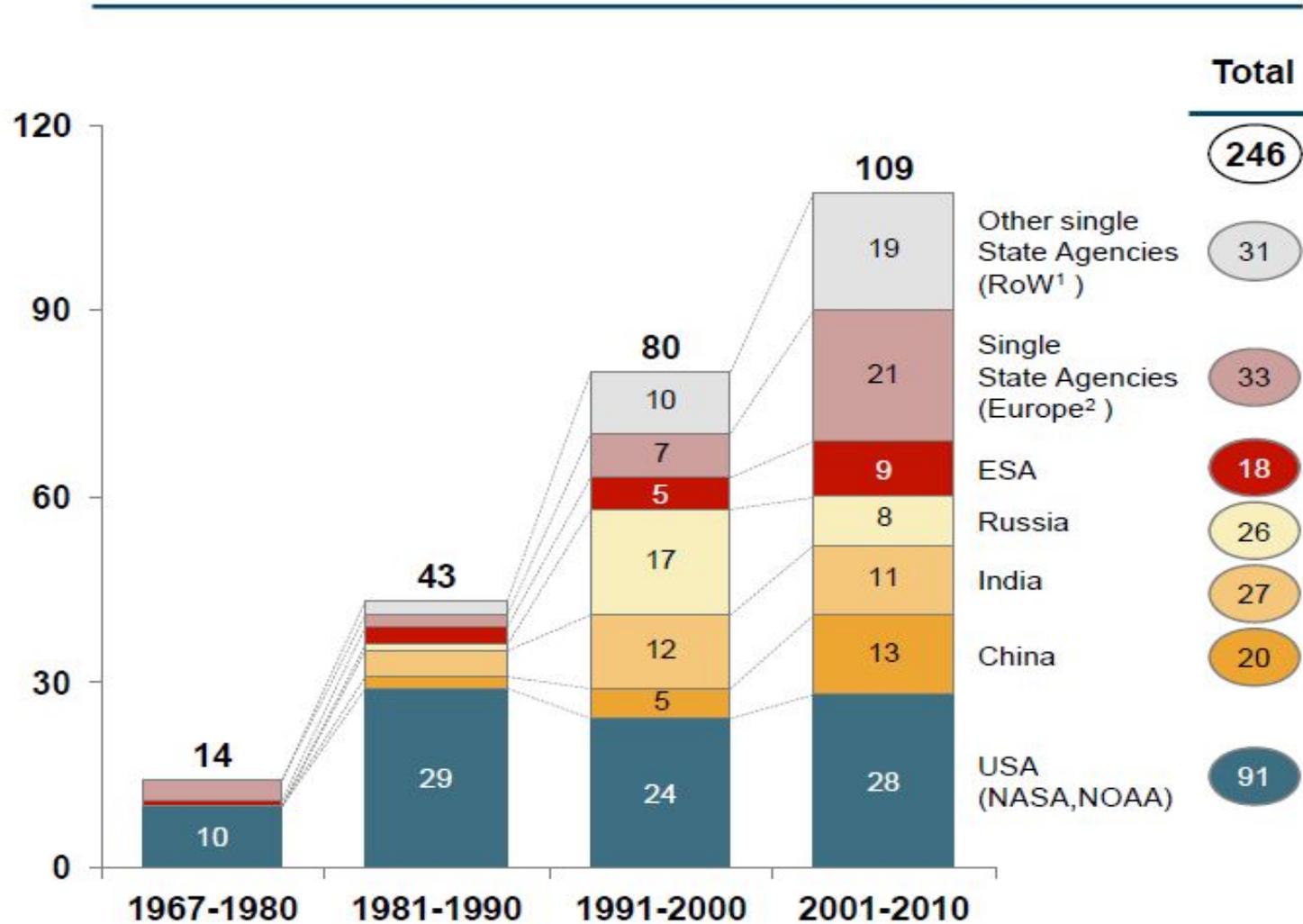
Kostis Kyzirakos
kk@di.uoa.gr

Dept. of Informatics and Telecommunications
National and Kapodistrian University of Athens

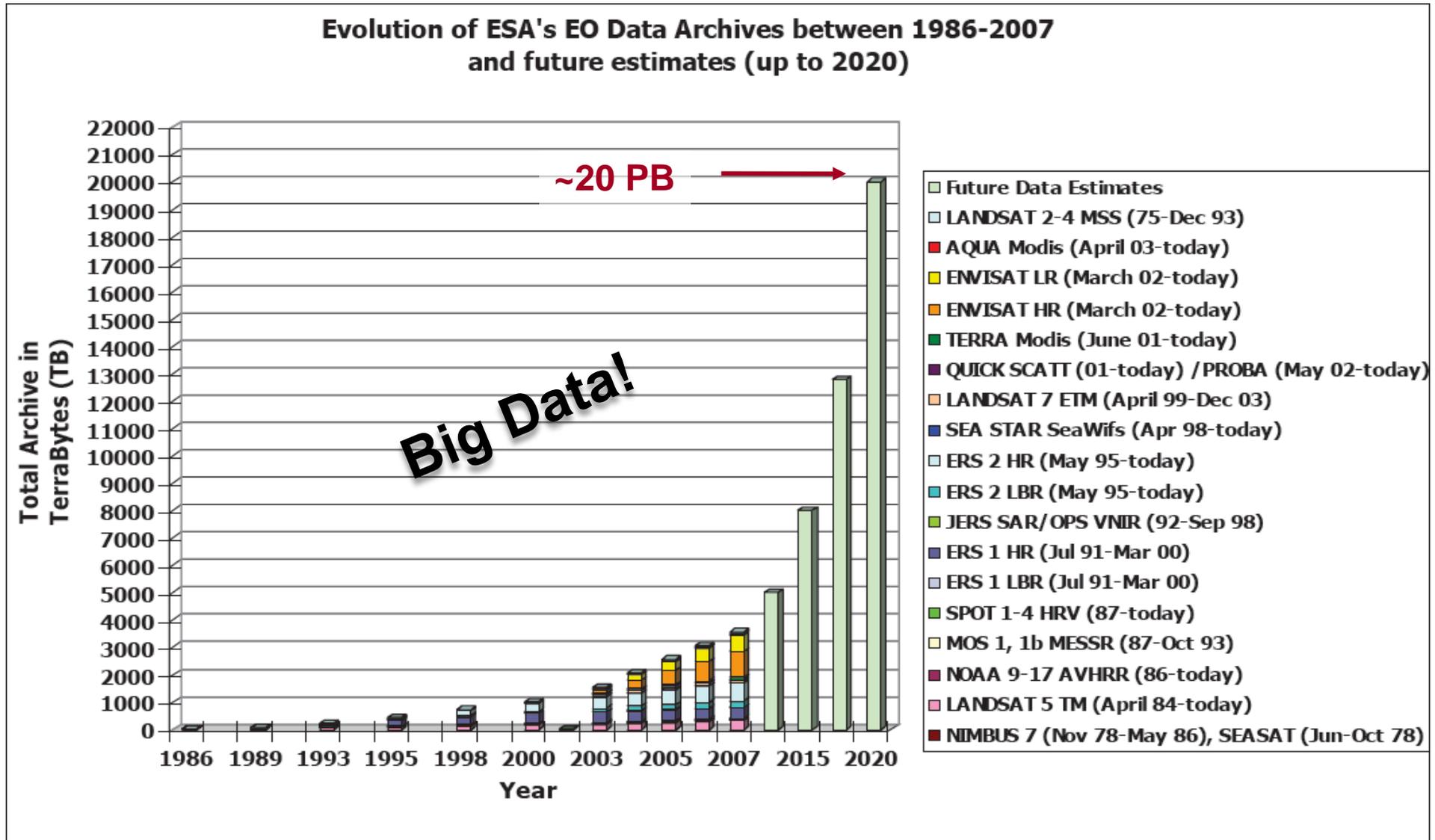


- Motivation
- State of the art in Earth Observation data centers
- The Fire Monitoring Service of the National Observatory of Athens
- Demo
- Evaluation
- Conclusions

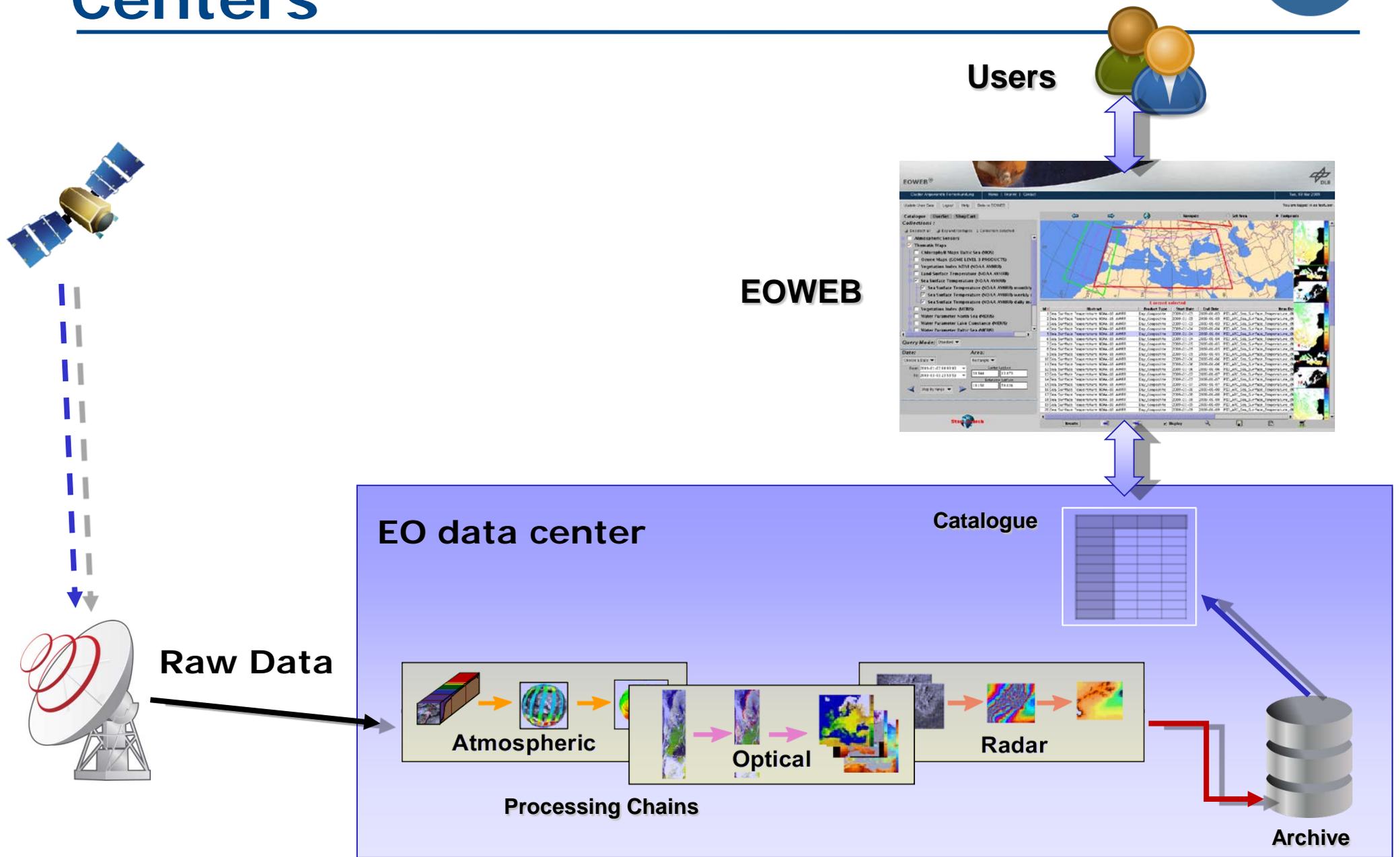
N. of Earth Observation satellites launched



Motivation (cont'd)



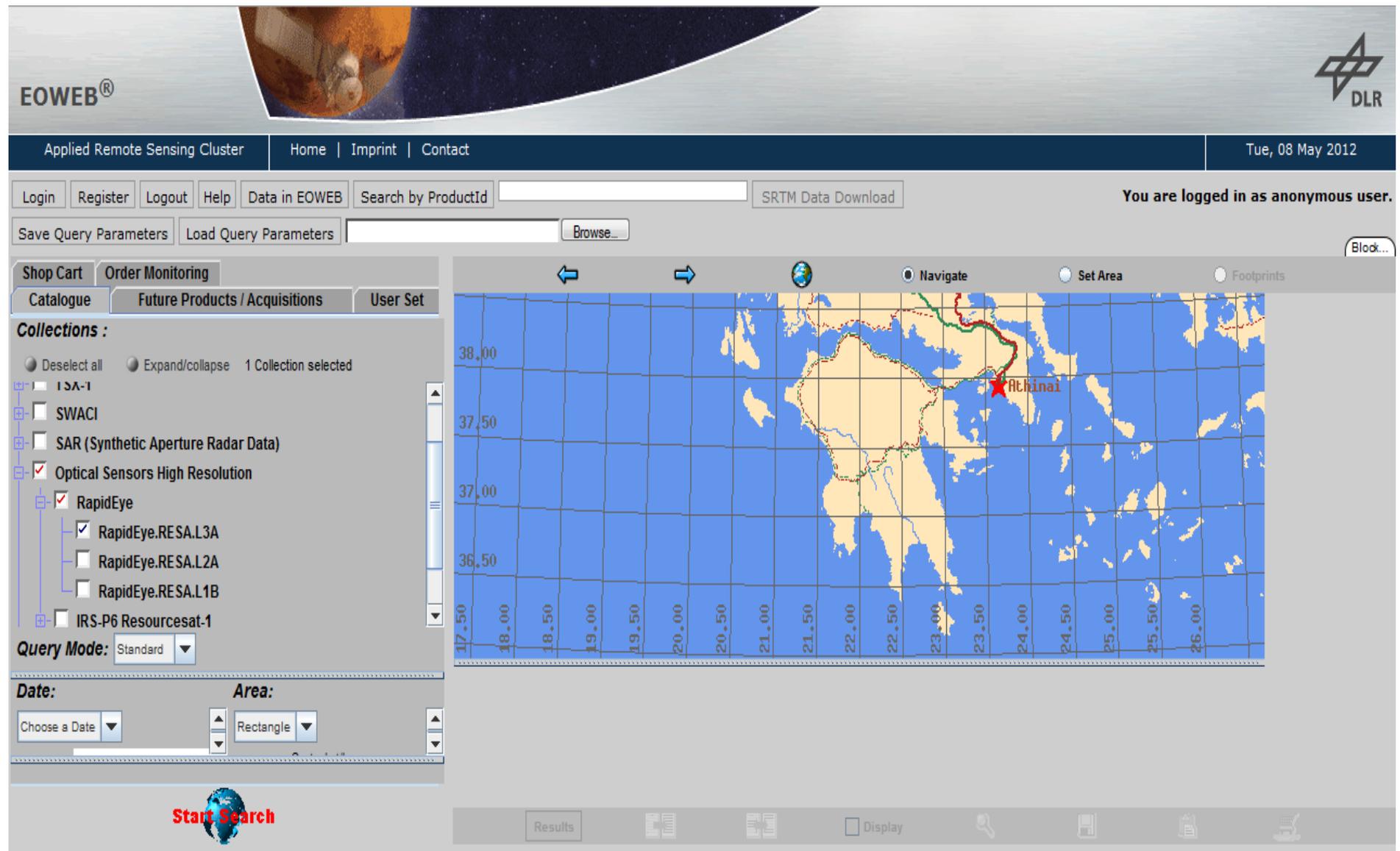
State of the Art in EO Data Centers



- Can I pose the following query using EOWEB?

Find images taken by the SEVIRI satellite on August 25, 2007 which contain fire hotspots in areas which have been classified as forests according to Corine Land Cover, and are located within 2km from an archaeological site in the Peloponnese.

Example (cont'd)



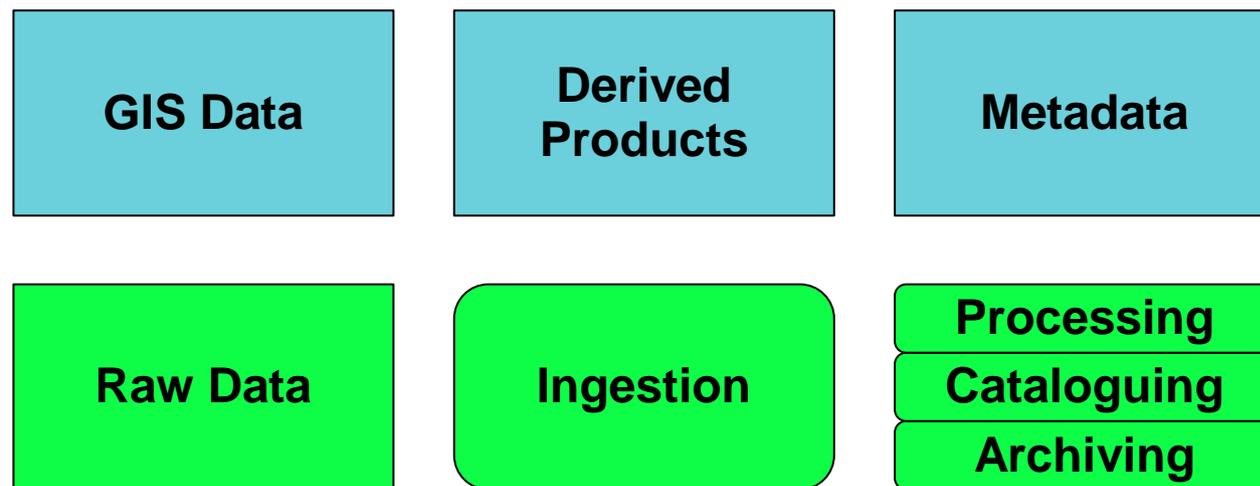
The screenshot displays the EOWEB (Earth Observation Web) interface. At the top left, the EOWEB logo is visible next to a satellite image. The top right features the DLR logo. A navigation bar includes links for 'Applied Remote Sensing Cluster', 'Home', 'Imprint', and 'Contact', along with the date 'Tue, 08 May 2012'. Below this, there are buttons for 'Login', 'Register', 'Logout', 'Help', 'Data in EOWEB', and a search box labeled 'Search by ProductId'. A 'SRTM Data Download' button is also present. A status message indicates 'You are logged in as anonymous user.' Below the search bar are buttons for 'Save Query Parameters', 'Load Query Parameters', and a 'Browse...' button. The main interface is divided into a left sidebar and a central map area. The sidebar contains a 'Shop Cart' and 'Order Monitoring' section, followed by 'Catalogue', 'Future Products / Acquisitions', and 'User Set'. Under 'Collections', there are checkboxes for 'ISA-1', 'SWACI', 'SAR (Synthetic Aperture Radar Data)', 'Optical Sensors High Resolution', 'RapidEye', and 'IRS-P6 Resourcesat-1'. The 'RapidEye' collection is expanded, showing sub-items 'RapidEye.RESA.L3A', 'RapidEye.RESA.L2A', and 'RapidEye.RESA.L1B'. Below the collections is a 'Query Mode' dropdown set to 'Standard'. At the bottom of the sidebar is a 'Date:' field with a 'Choose a Date' dropdown and an 'Area:' field with a 'Rectangle' dropdown. The central map area shows a satellite image of a region with a grid overlay. The grid has latitude labels from 36.50 to 38.00 and longitude labels from 17.50 to 26.00. A red star marks the location 'Athina'. Above the map are navigation controls: left and right arrows, a globe icon, and radio buttons for 'Navigate', 'Set Area', and 'Footprints'. At the bottom of the map area is a 'Start Search' button with a globe icon. Below the map is a toolbar with icons for 'Results', 'Display', and other functions.

- Well, only partially.

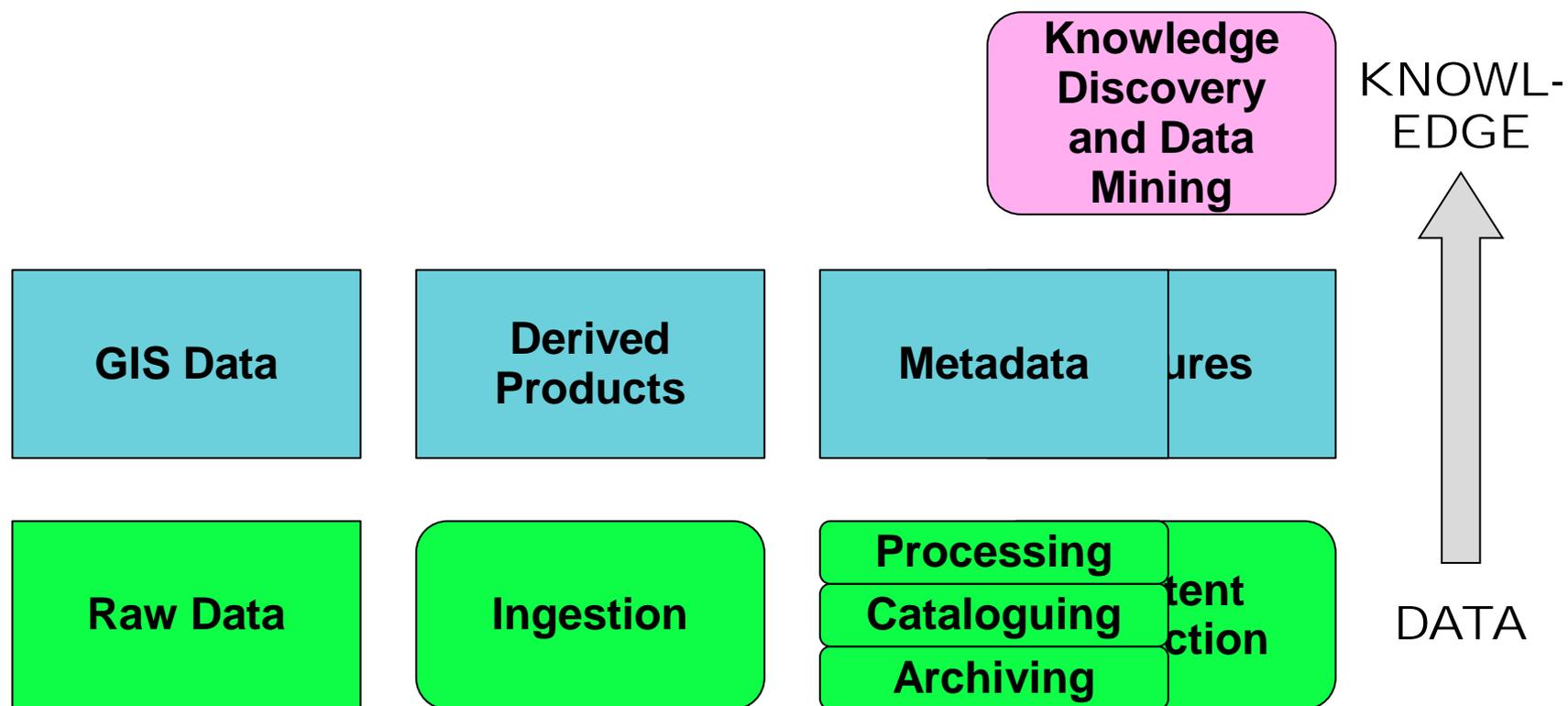
Find images taken by the SEVIRI satellite on August 25, 2007 which contain fire hotspots in areas which have been classified as forests according to Corine Land Cover, **and are located within 2km** from an archaeological site in the **Peloponnese**.

- But why?
- All this information is available in the **satellite images** and other **auxiliary data sources** of EO data centers or **on the Web**.
- However, EO data centers today do not allow:
 - **the mining of satellite image content** and
 - **its integration with other relevant data sources** so the previous query can be answered.

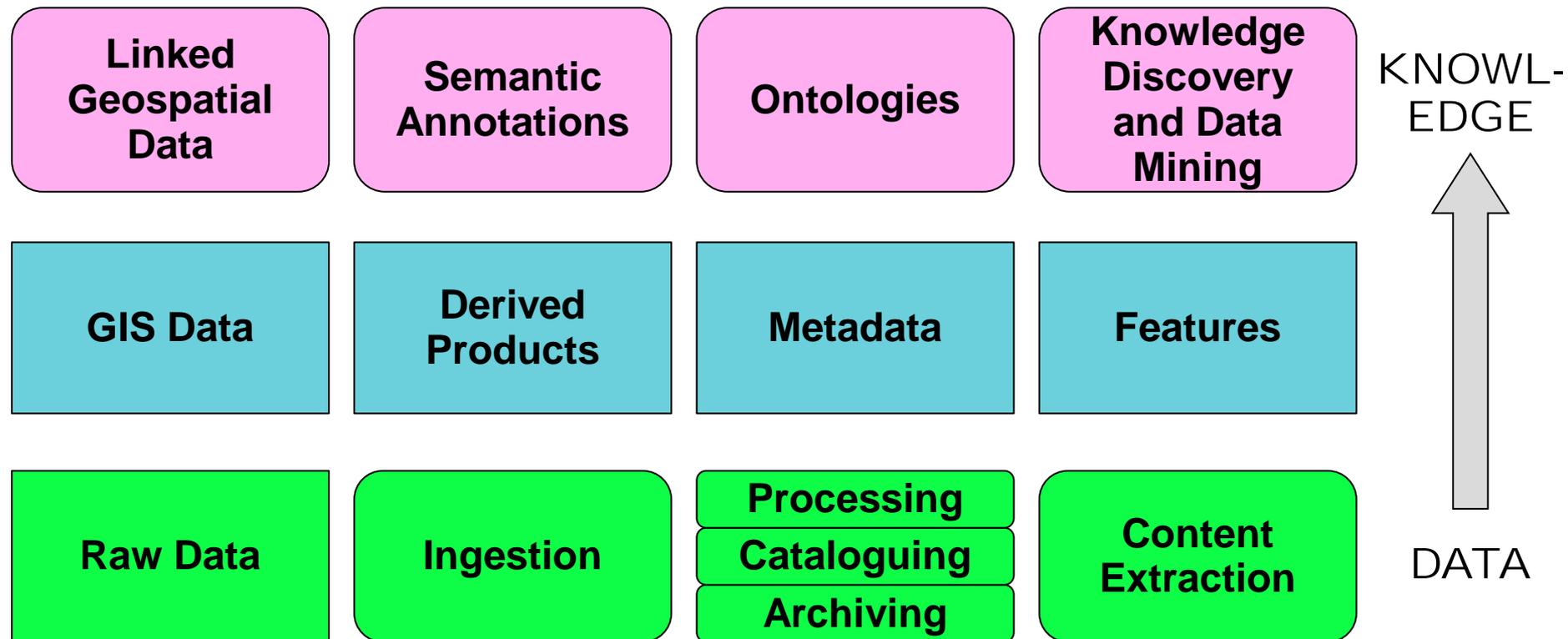
The TELEIOS Earth Observatory: Concept View



The TELEIOS Earth Observatory: Concept View



The TELEIOS Earth Observatory: Concept View



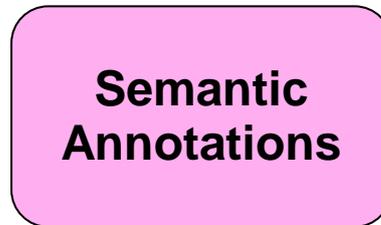
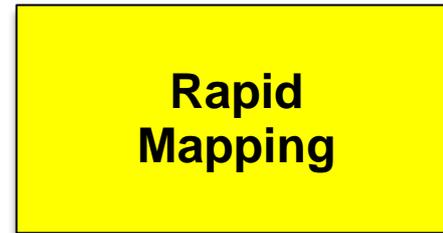
The TELEIOS Earth Observatory: Concept View



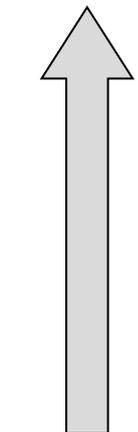
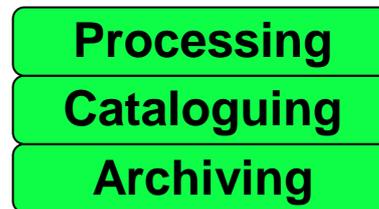
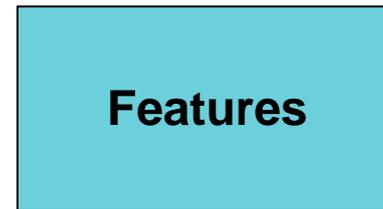
Scientists



Emergency Response Managers



KNOWL-
EDGE



DATA

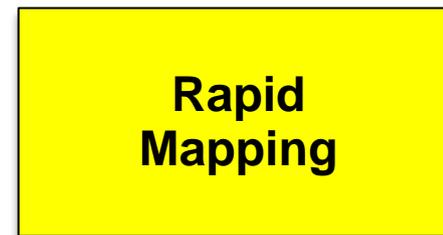
The TELEIOS Earth Observatory: Concept View



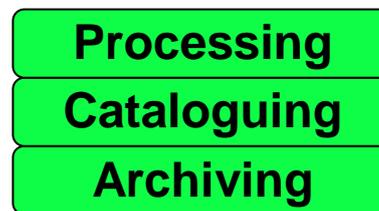
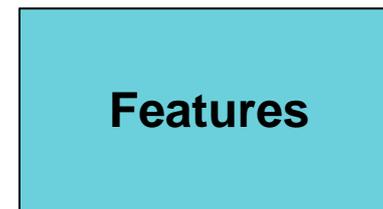
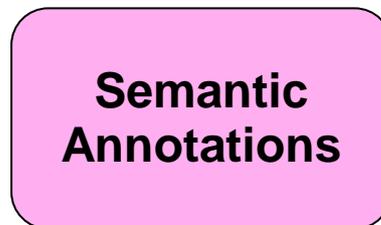
Scientists



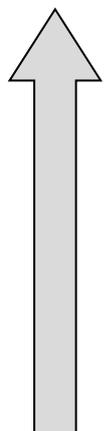
Emergency Response Managers



Scientific Database and
Semantic Web Technologies



KNOWL-
EDGE



DATA

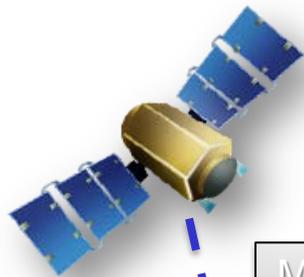
2007-08-25 07:00:00 UTC

Fire monitoring application

Pre-TELEIOS practice



Eumetsat @ 9.5°East



MSG-1 Seviri (5 mins)
MSG-2 Seviri (15 mins)

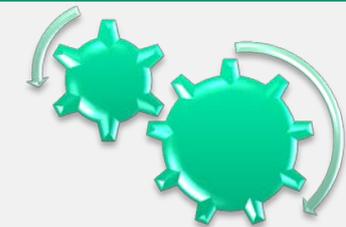
System users (Civil Protection Authorities etc.)



Disk Array



PostGIS



SEVIRI
Monitor

Manage SEVIRI data stream in real time:

- Describe & store raw file metadata
- Filter & dispatch raw MSG products
- Remotely trigger processing chain
- Dispatch processed products

Raw data are decoded and stored temporary as wavelet compressed images @...



SQLite

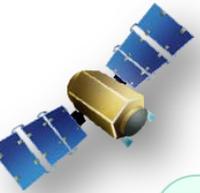
METEOSAT
Ground Station

Fire monitoring application

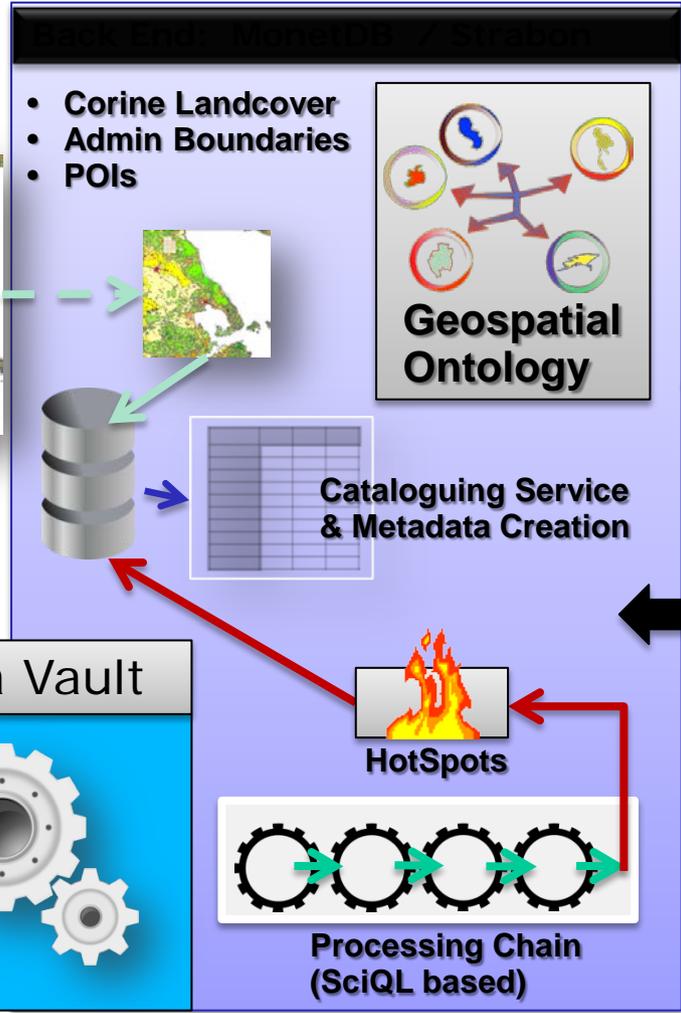
Advancements - Integration of the TELEIOS technologies



Eumetsat @ 9.5°East



External Sources



Web access based on Semantics

Linked Geospatial Data Semantic technologies



- Search & Display
- Search for raw & Processing
- Real-time Fire Monitoring
- Refinement (Post-Processing)
- Linked Data

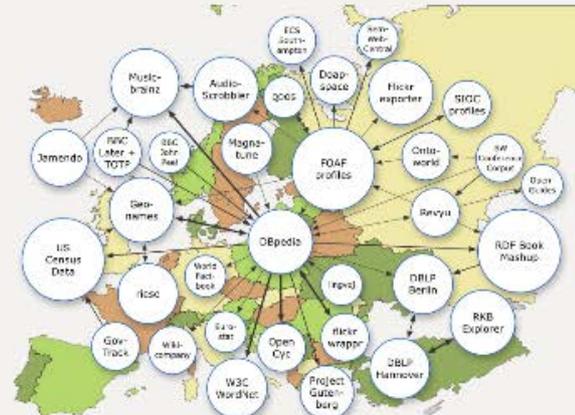
- Need for representing
 - Standard product **metadata**
 - Standard product **semantic annotations**
 - **Geospatial information**
 - **Temporal information**

- Need to link to other data sources
 - **GIS data**
 - Other information on the **Web**

Semantics-Based Representation and Querying of EO Data

- The data model **stRDF** and the query language **stSPARQL**
- The system **Strabon**

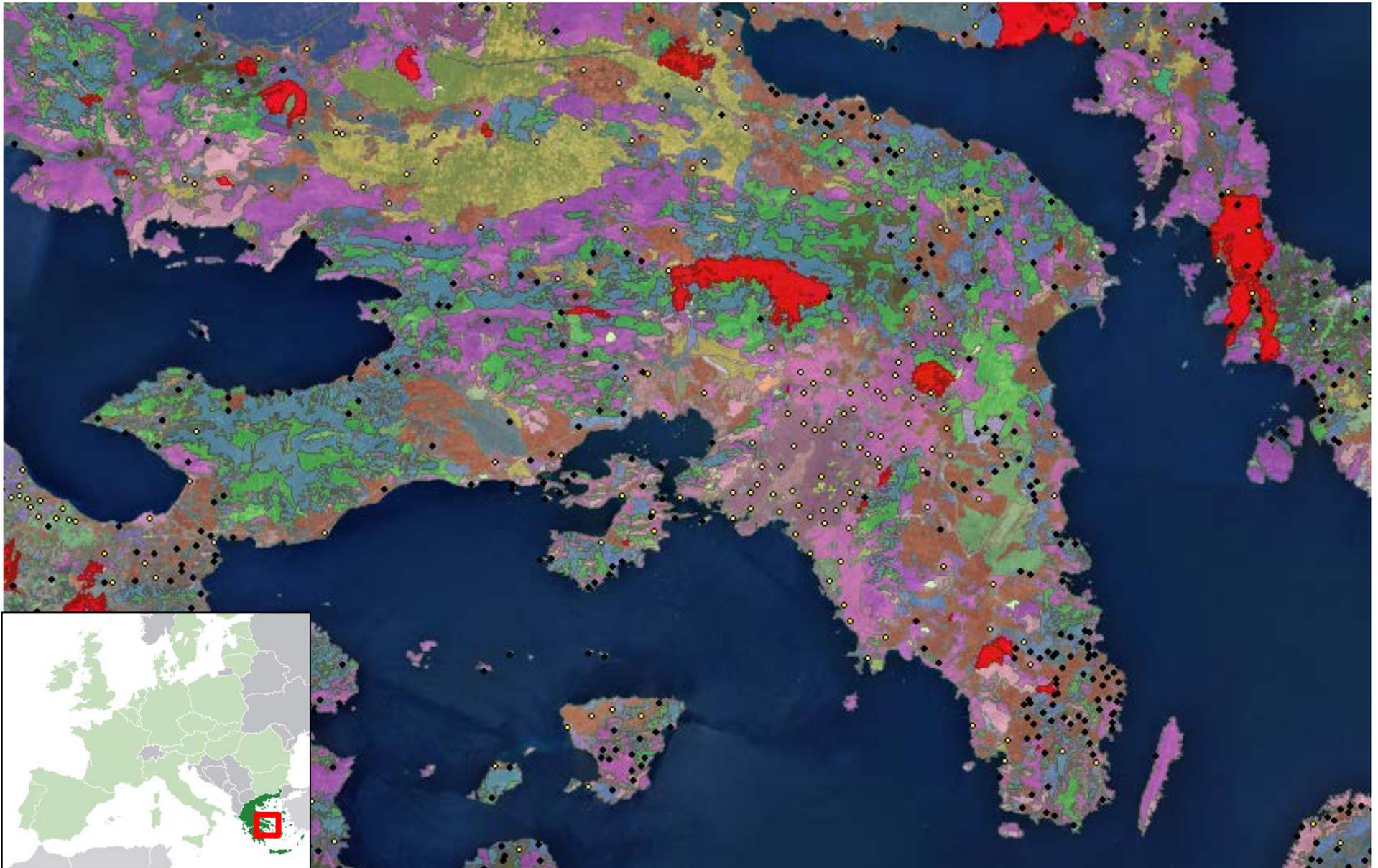
strabon.di.uoa.gr



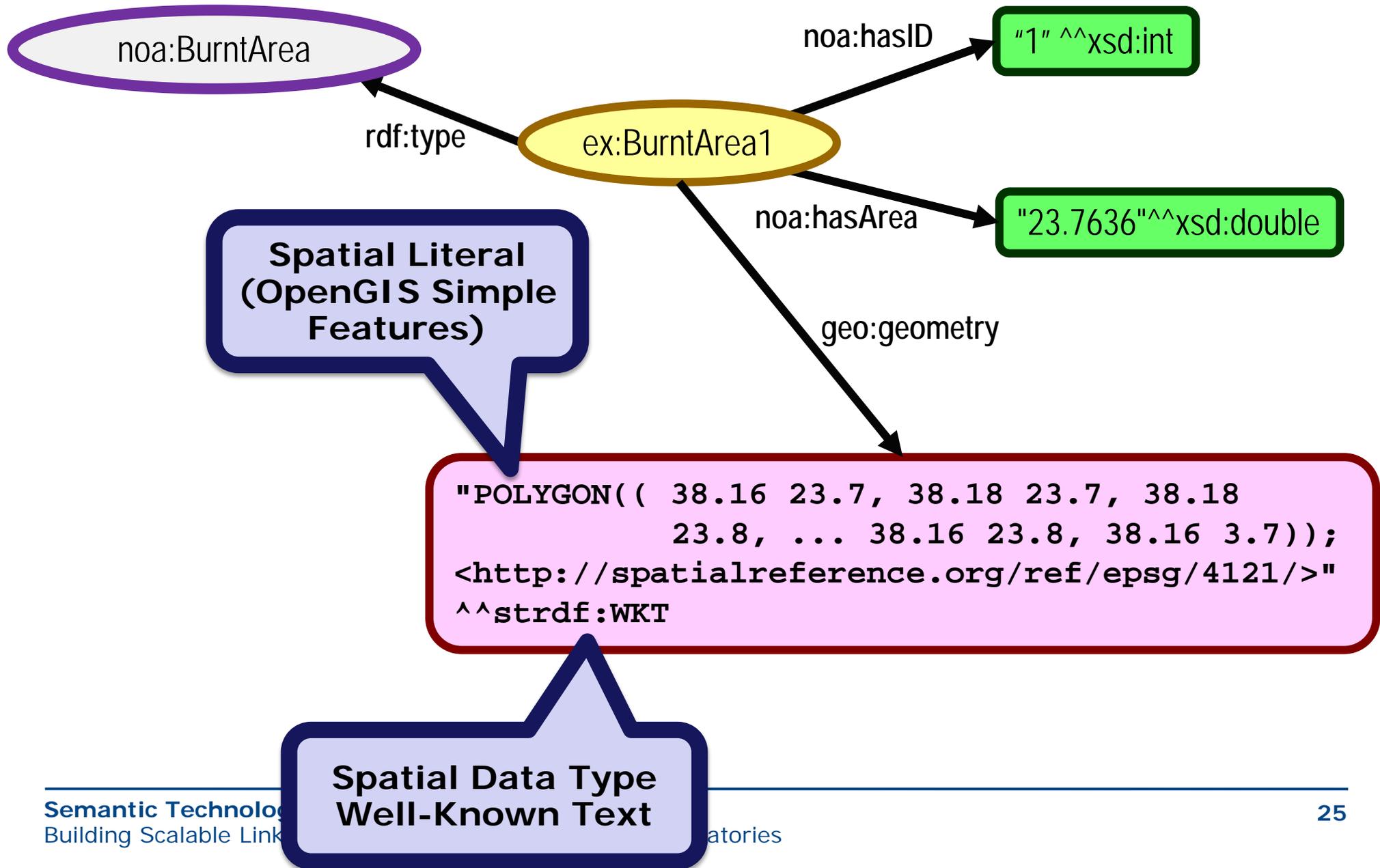
Home Demo Getting Started Download Publications Contributors

- **stRDF** stands for **spatial/temporal RDF**.
- It is an extension of the W3C standard RDF for the representation of **geospatial data that may change over time**.
- stRDF extends RDF with:
 - **Spatial literals** encoded in OGC standards Well-Known Text or GML
 - **New datatypes** for spatial literals (`strdf:WKT`, `strdf:GML` and `strdf:geometry`)
 - **Valid time of triples** (ignored in this talk)

stRDF: An example



stRDF: An example



stSPARQL: An example

- Find all burned forests within 10kms of a city

```
select ?BA ?BAGEO
```

```
where {
```

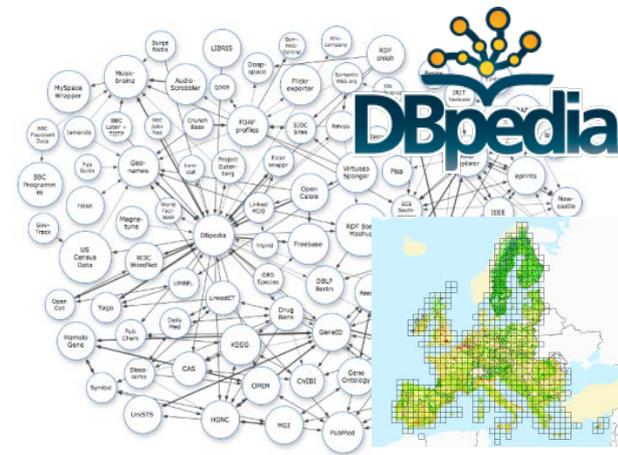
```
?R    rdf:type    noa:Region ;  
      geo:geometry ?RGEO ;  
      noa:hasCorineLandCoverUse ?F .
```

```
?F    rdfs:subClassOf    clc:Forests .
```

```
?CITY  rdf:type    dbpedia:City ;  
      geo:geometry ?CGEO .
```

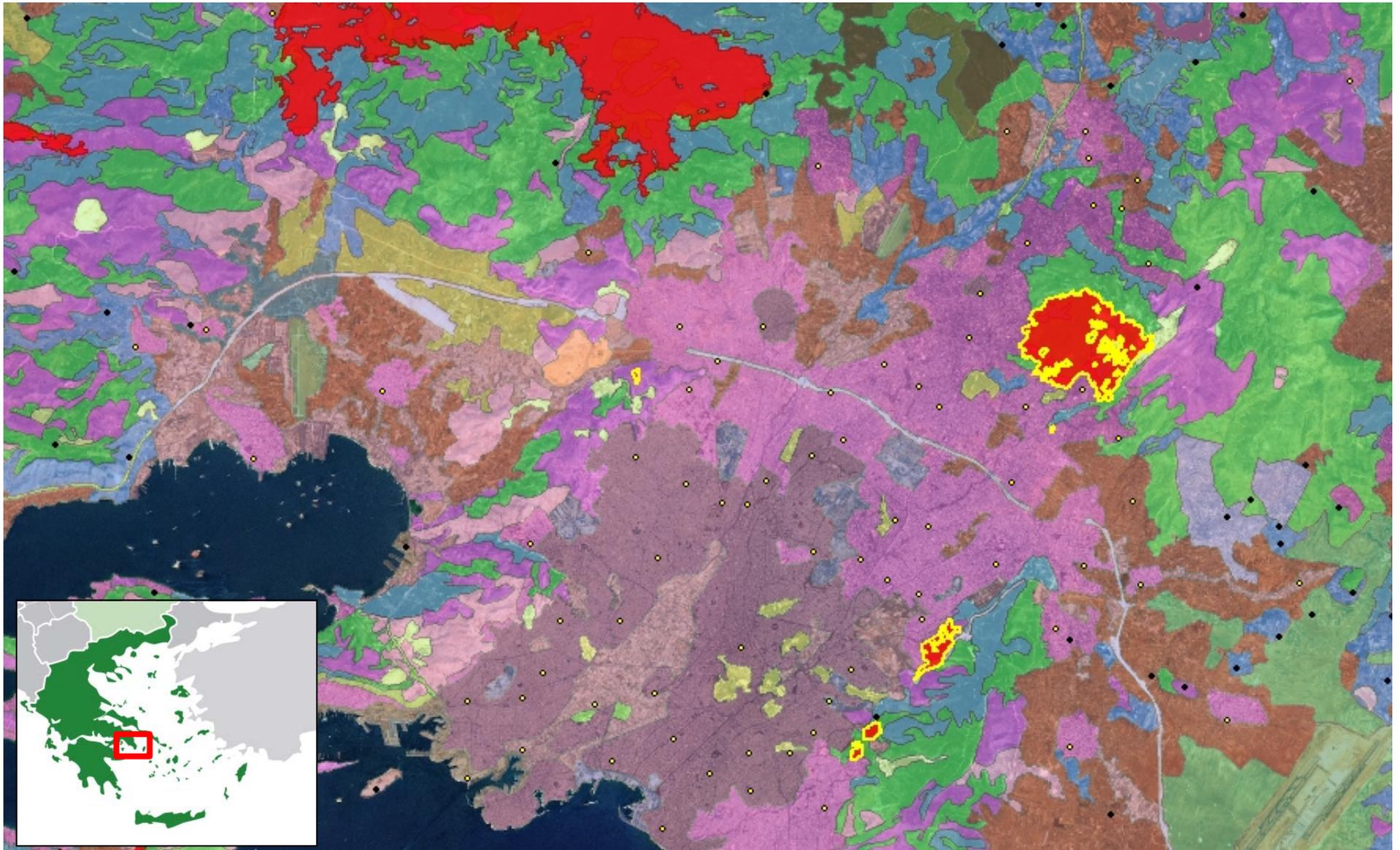
```
?BA    rdf:type    noa:BurntArea  
      geo:geometry ?BAGEO .
```

```
filter(  
  strdf:Intersect(?RGEO,?BAGEO) &&  
  strdf:Distance(?BAGEO,?CGEO,uom:km) < 10 ) }
```



Spatial Functions
(OGC Simple Feature Access)

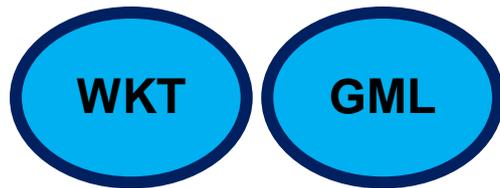
stSPARQL: An example



- We start from **SPARQL 1.1**.
- We add a **SPARQL extension function** for each function defined in the OGC standard **OpenGIS Simple Feature Access – Part 2: SQL option (ISO 19125)** for adding geospatial data to relational DBMSs and SQL.
- We add appropriate geospatial extensions to **SPARQL 1.1 Update language**

- GeoSPARQL is a recent effort by OGC to develop an extension of SPARQL for querying geospatial data expressed in RDF.
- stSPARQL and GeoSPARQL have been developed independently.
- stSPARQL geospatial query functionality is **very close to a subset of the recent OGC standard GeoSPARQL:**
 - Core
 - Geometry extension
 - Geometry topology extension

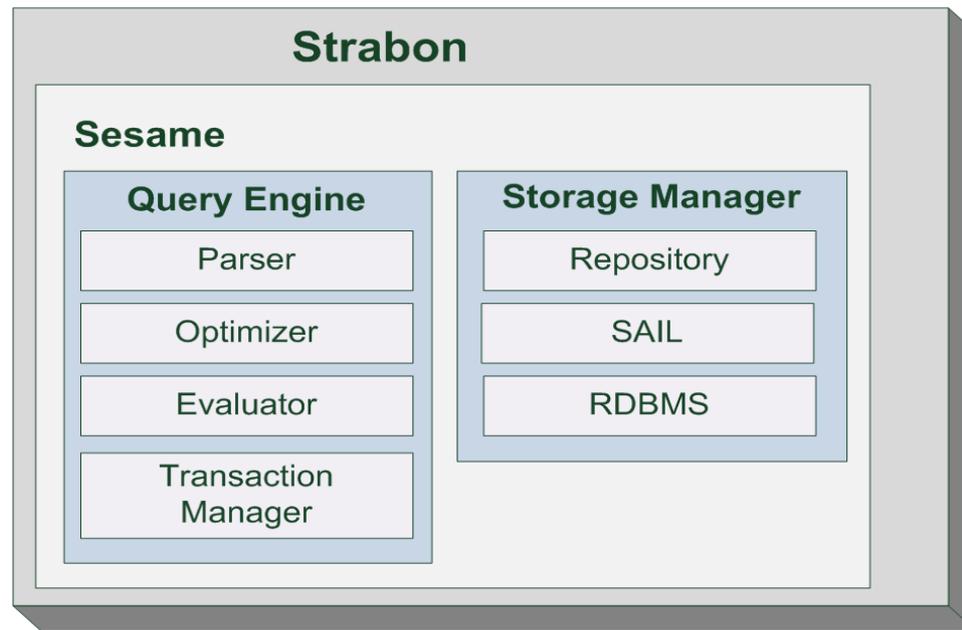
Strabon: A Scalable Geospatial RDF Store



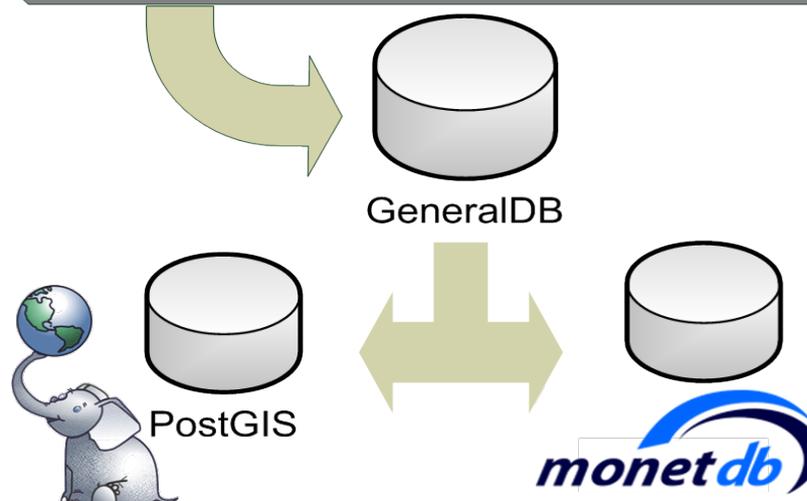
stRDF
graphs



stSPARQL/
GeoSPARQL
queries



[ISWC 2012]



<http://bit.ly/Strabon>

- Improving the fire monitoring service using Semantic Web technologies

*[ISWC 2012 Semantic
Web Challenge
3'rd place winner]*

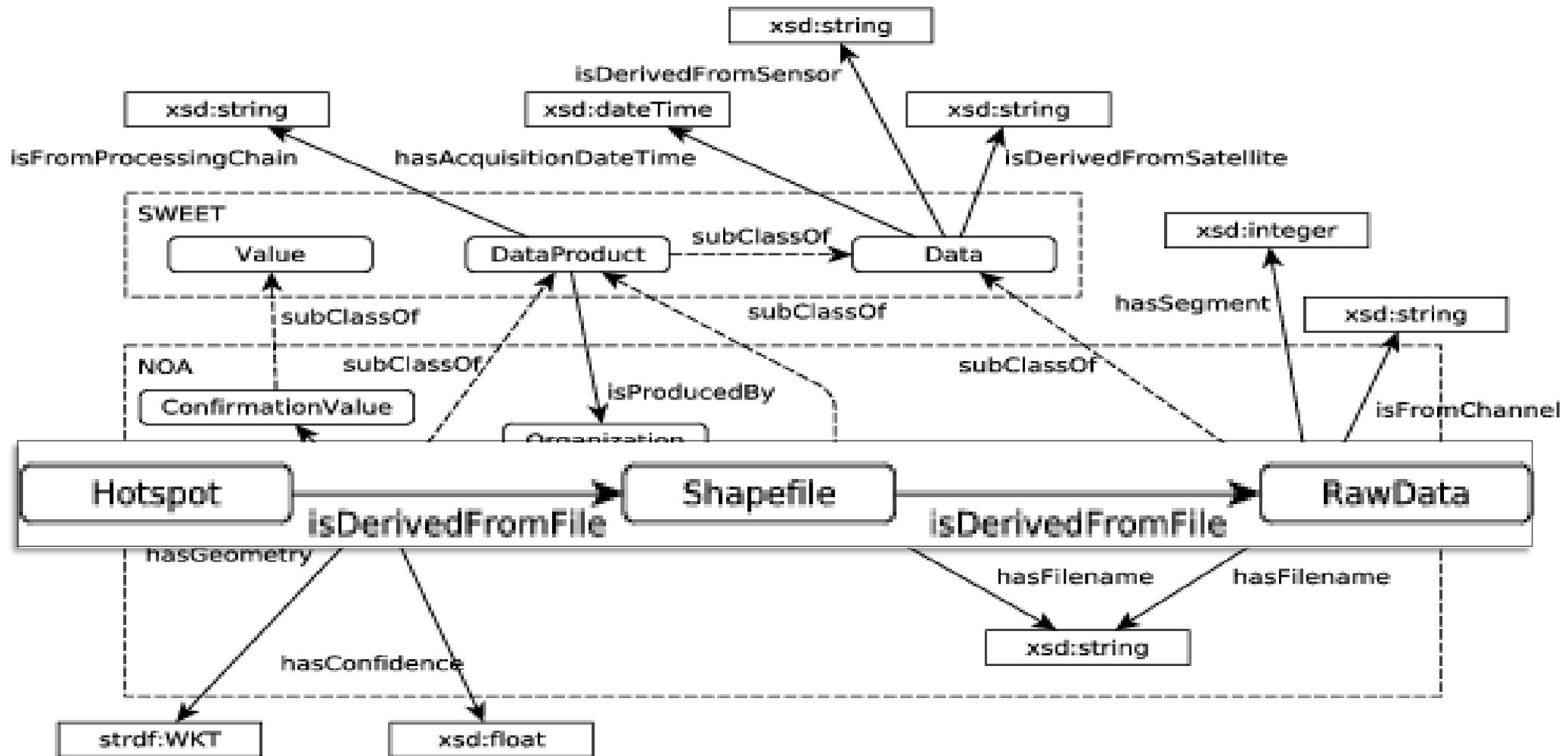
- **Representing** fire related products using ontologies
- **Enriching products** with linked geospatial data
- **Improving accuracy** with respect to:
 - Underlying land cover/land use
 - Persistence in time

<http://bit.ly/FiresInGreece>

- Producing **rapid mapping** products

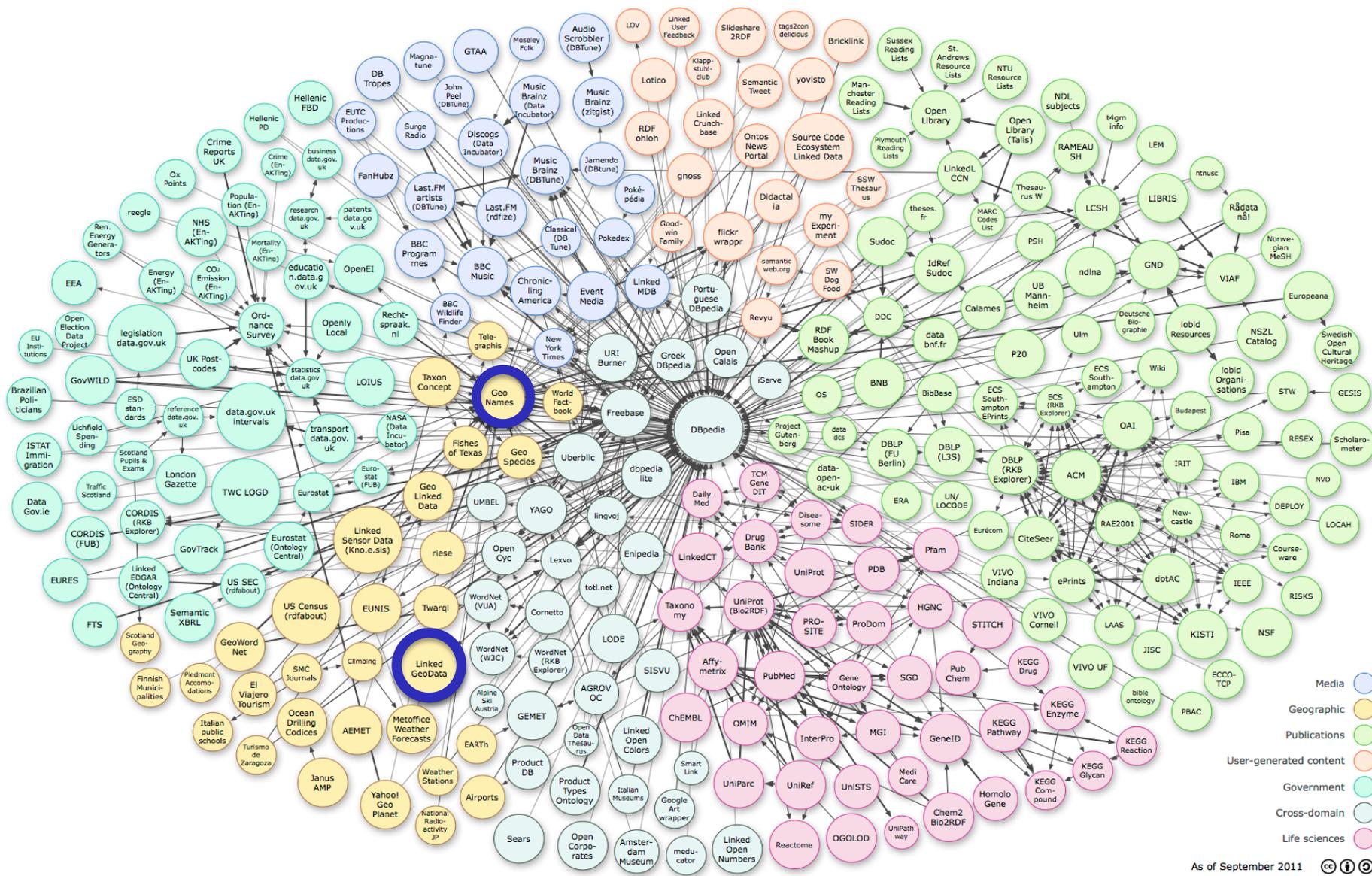
<http://bit.ly/SextantDemo>

*[ESWC 2013
Best Demo Award]*



- Datasets that we developed and published as linked data:
 - Corine Land Use / Land Cover
 - Coastline of Greece
 - Greek Administrative Geography
- Portal: <http://www.linkedopendata.gr/>
- Datasets from Linked Open Data Cloud
 - LinkedGeoData
 - GeoNames

Linked Open Data Cloud



GeoNames

Map center : N 37° 46' 31" W 122° 24' 11"

[google earth](#) [tagzania](#) [mapquest](#)

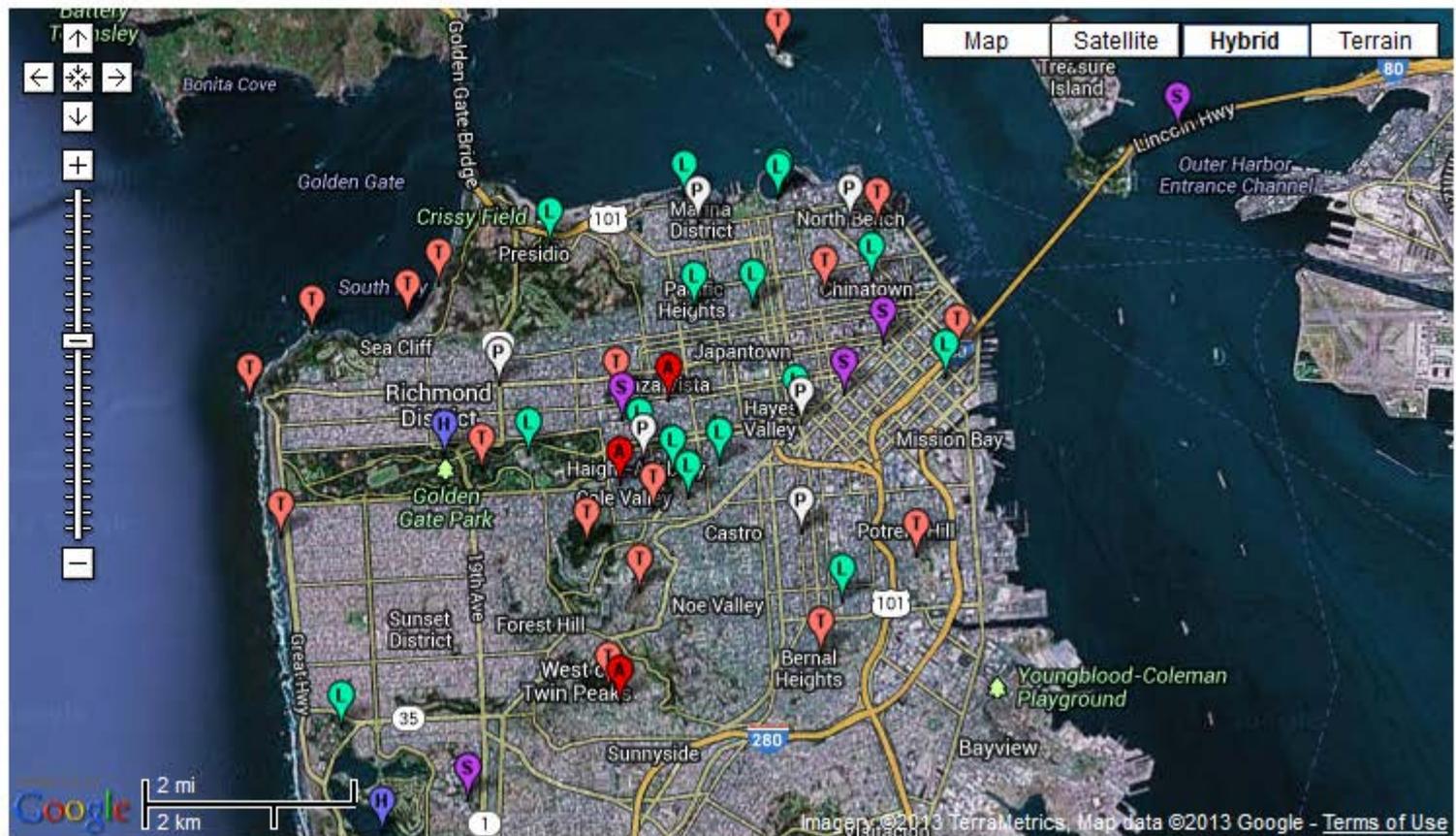


searching for "San Francisco, CA"

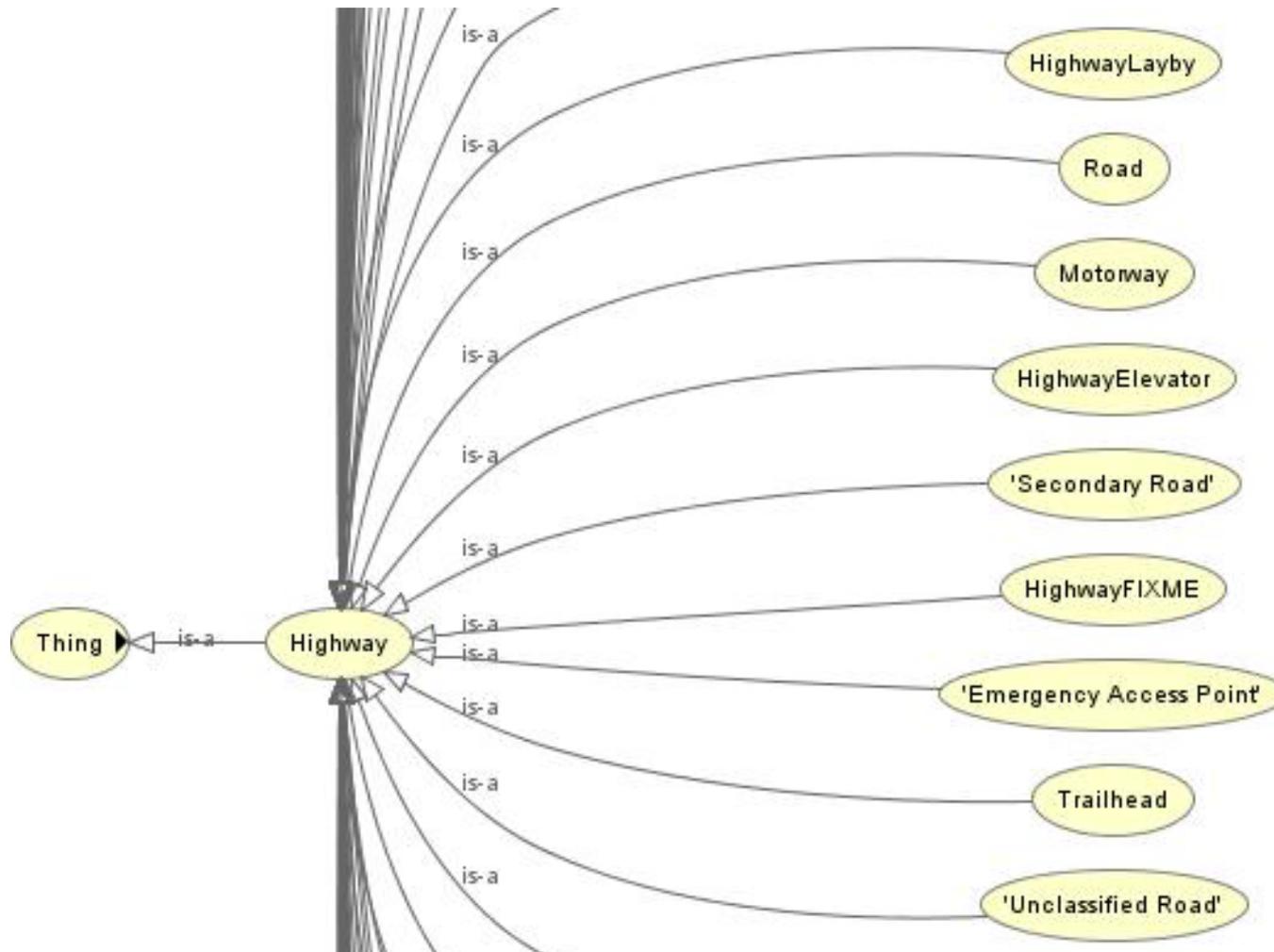
[GeoNames Wikipedia](#)

features

- city, village,...
- mountain, hill, rock,...
- stream, lake, ...
- country, state, region,...
- parks, area, ...
- road, railroad
- spot, building, farm
- forest, heath, ...
- undersea



OpenStreetMap



Linked Open Data (2/5)

Op

Instances

- 1: Embassy of the Czech Republic
- 2: Metro
- 3: Commission Européenne
- 4: Thon Parnasse Hotel
- 5: Au vieux Bruxelles
- 6: ING Marnix
- 7: ING Porte de Namur
- 8: La Maison des Cyclistes
- 9: Porte de Namur
- 10: Mondo Hotel Leopold Br
- 11: Restaurant Le Bretagne
- 12: ISS
- 13: Coaster
- 14: CEFA
- 15: Clinique des Chartreux
- 16: In 't Spinnekopke
- 17: Park
- 18: Twist
- 19: Bat. Administratif
- 20: Metro
- 21: Tunnel entre Gare Cent
- 22: EHSAL hogeschool
- 23: Gare du Congrès
- 24: BELGACOM
- 25: GALERIE RAVENSTEIN
- 26: Sint Michiels kathedraal
- 27: Nationale Bank van Belg
- 28: Radisson Blu Royal Hotel
- 29: The Office
- 30: ING
- 31: La Sirène
- 32: Congrès - Congres
- 33: Pizza Hut
- 34: A la Mort Subite
- 35: Ministère des Finances
- 36: Metro Porte de Hal
- 37: multiPharma
- 38: Rue de L'Epee
- 39: Rue des Renards, Bruss
- 40: Louise
- 41: RESTAURANT 'EL GRECO
- 42: Restaurant 'La Boule R
- 43: Ancienne Belgique
- 44: Cafe O'Reilly's
- 45: Interparking
- 46: RESTAURANT 'MINOS'
- 47: LA MAISON DU MIEL
- 48: Subway
- 49: Pathé Palace

Facets

- Node (400)
- ManMade (59)
- Amenity (251)
- Landuse (18)
- Tourism (31)
- Natural (35)
- Historic (3)
- Place (1)
- Leisure (1)

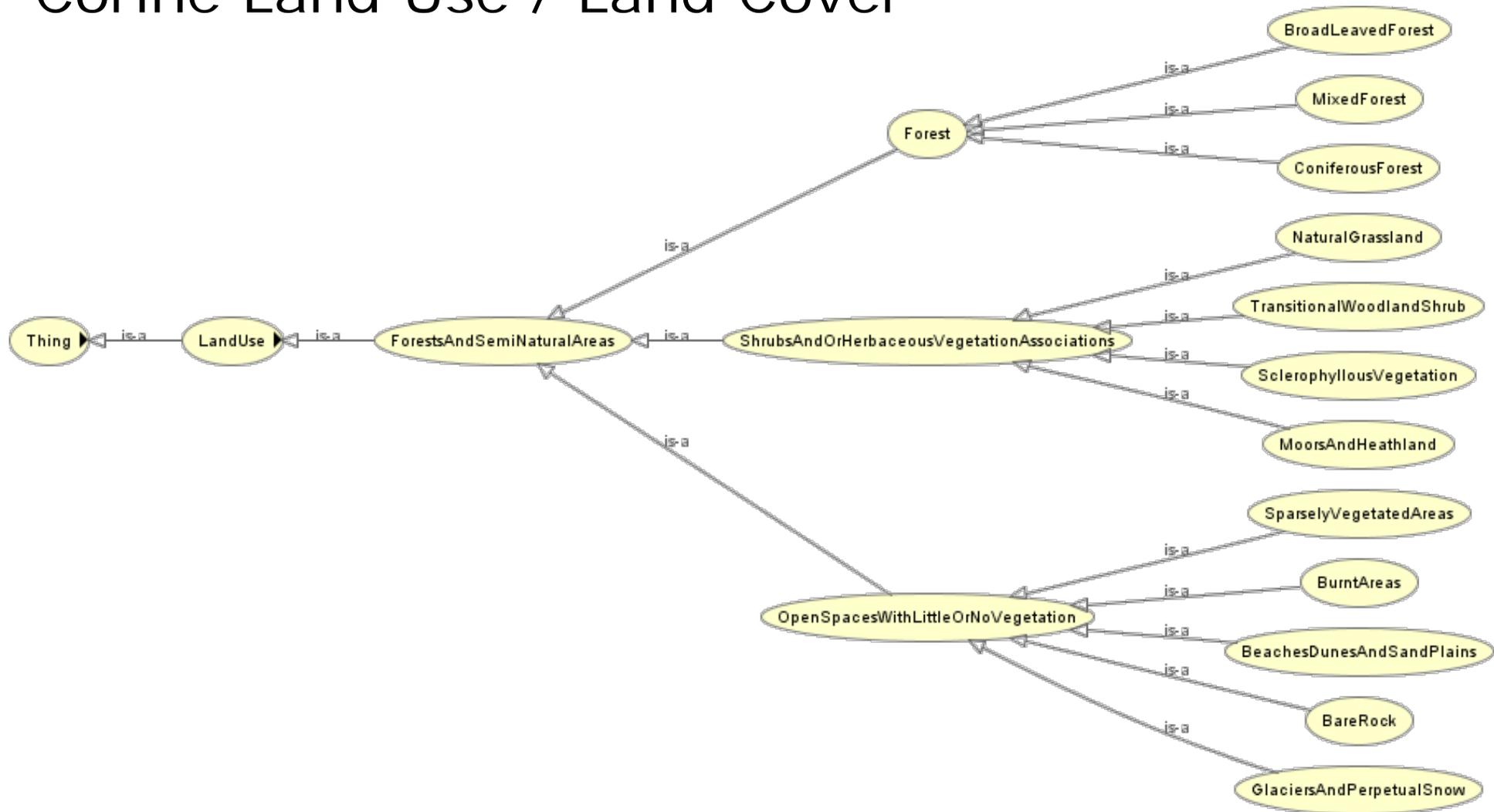
Chapelle - Kapellekerk
<http://linkedgeodata.org/triplify/node489098929>

rdf:type <http://linkedgeodata.org/ontology/Node>
rdf:type <http://linkedgeodata.org/ontology/Amenity>
rdf:type <http://linkedgeodata.org/ontology/BusStation>
rdfs:label@nl Kapellekerk
rdfs:label@fr Chapelle
lgdo:directType <http://linkedgeodata.org/ontology/BusStation>
geo:geometry POINT(4.34936 50.8417)
geo:lat 50.8417023
geo:long 4.349356
lgdo:contributor <http://linkedgeodata.org/triplify/user246>

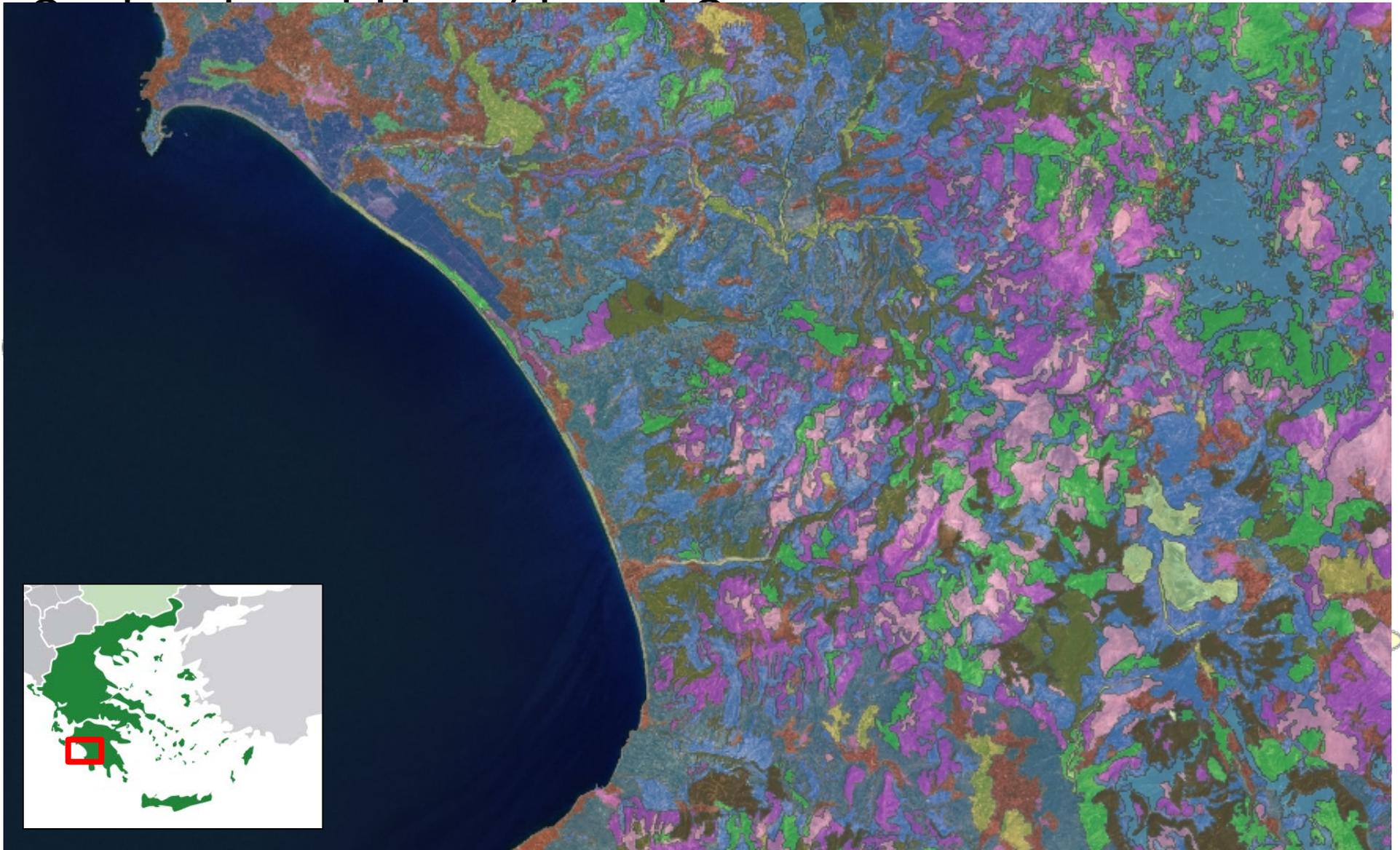
AKSW

4.36359, 50.84650

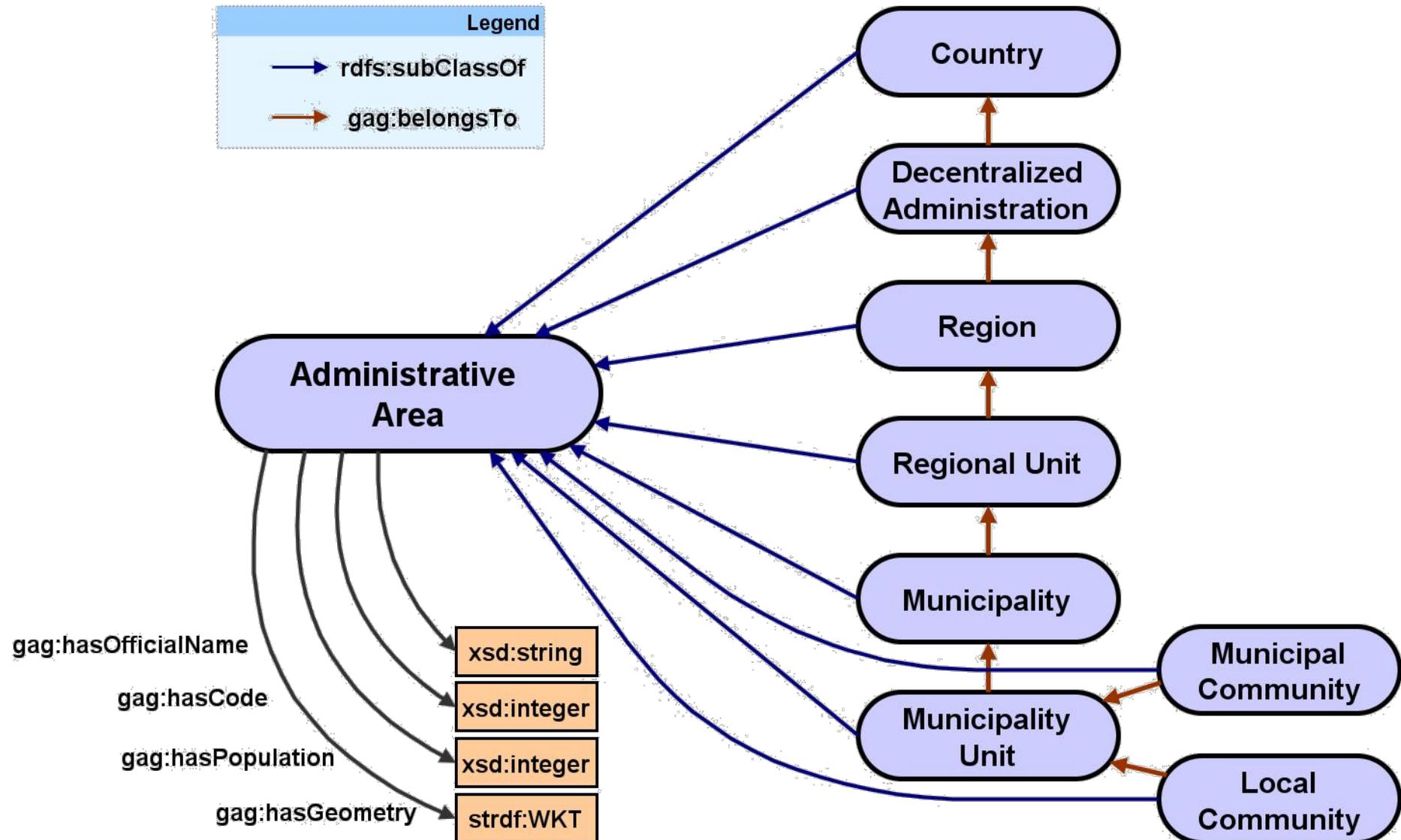
Corine Land Use / Land Cover



Linked Open Data (3/5)

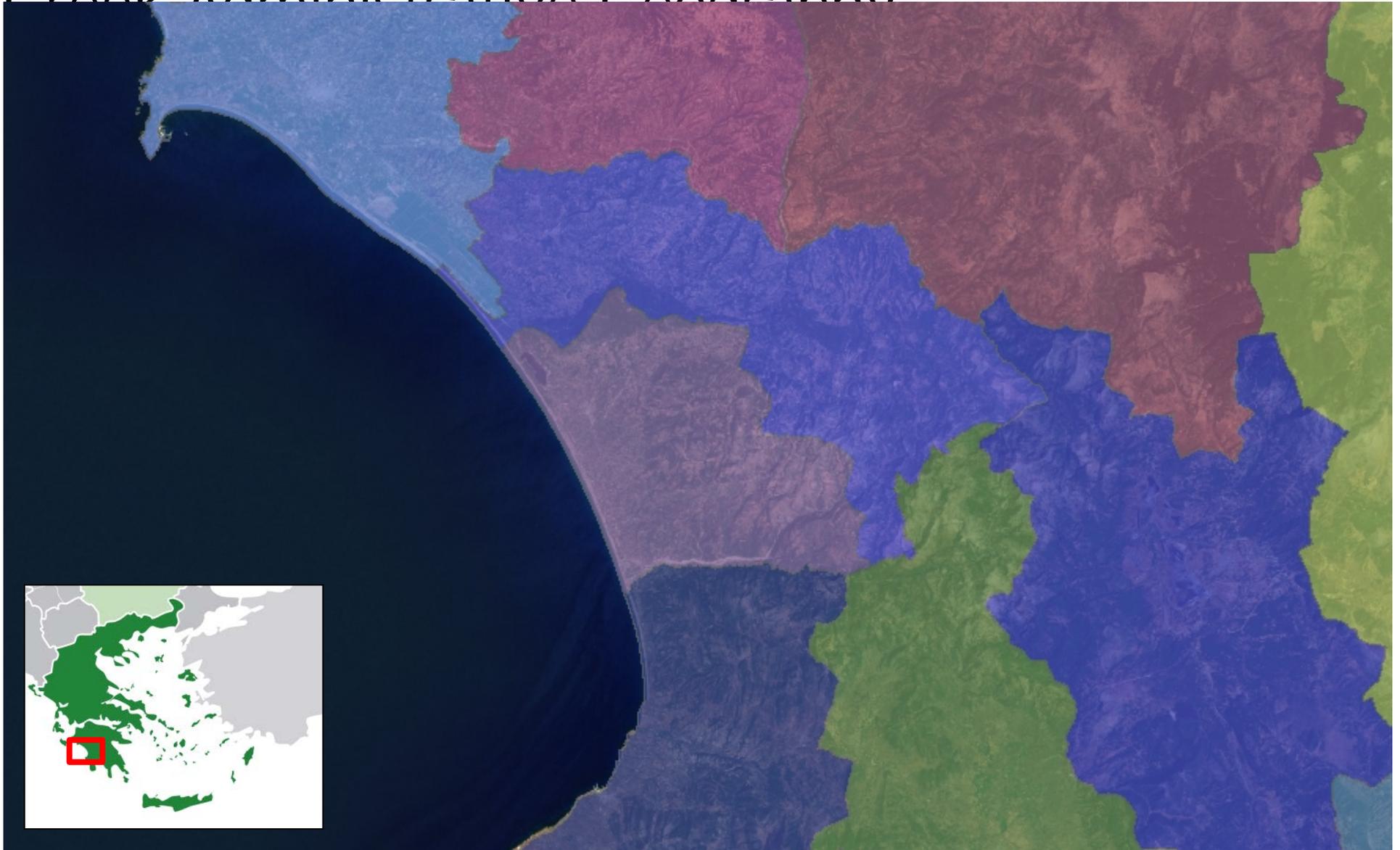


Greek Administrative Geography

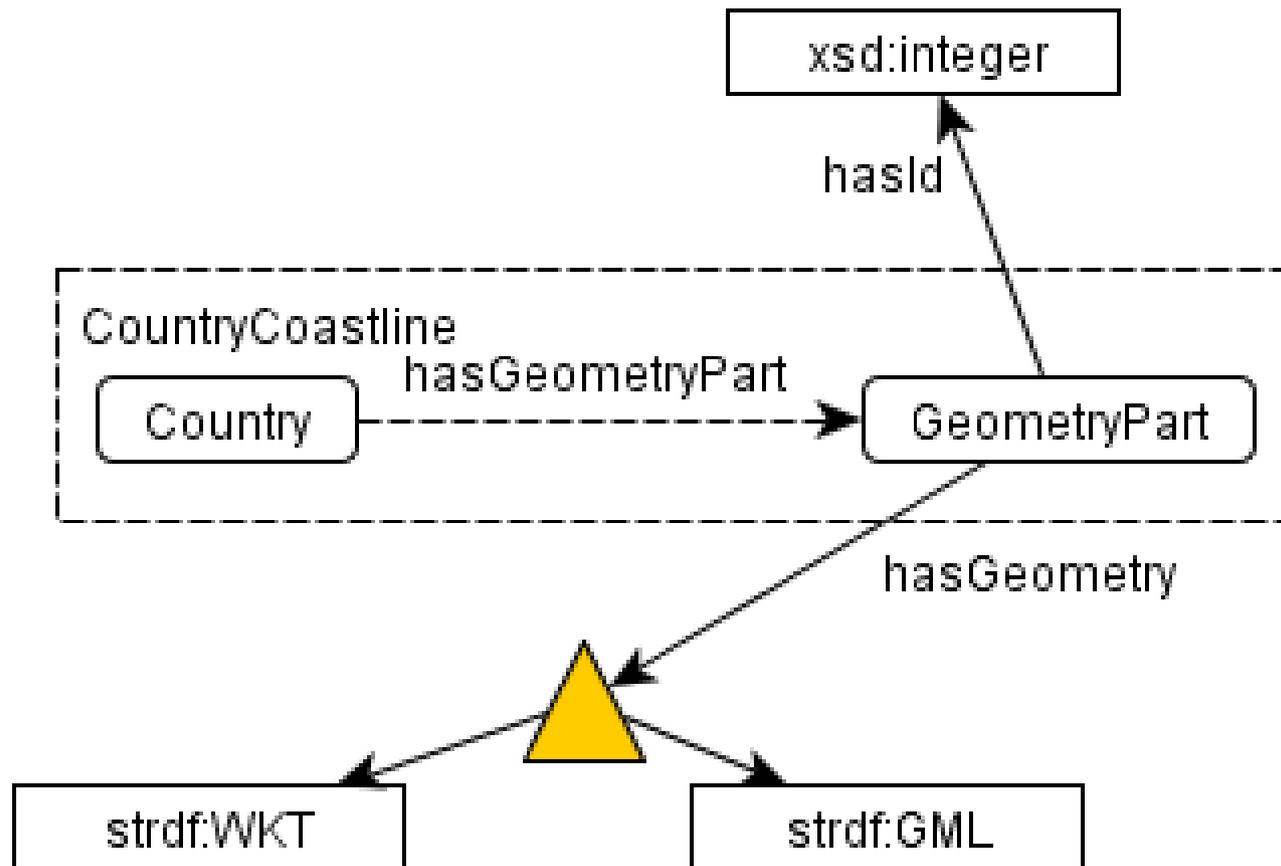


Linked Open Data (4/5)

Creek Administrative Geography



Greek Coastline



Greek Coastline



Using ontologies and stRDF to model knowledge extracted from satellite images, metadata of satellite images and auxiliary geospatial data can improve tasks like:

- **Generated maps** combining diverse information sources
- **Increase hotspot accuracy** correlating them with auxiliary data

- **Generating maps** combining diverse information sources
- Generating **Rapid Mapping** products
- **Semantic Enrichment** for Hotspots
- **Fire monitoring** application

DEMO!

<http://bit.ly/StrabonDemo>

Get all hotspots detected in Peloponnese on 24/08/2007.

```
SELECT ?h ?hGeo ?hAcqTime ?hConfidence ?hConfirmation ?hProvider
       ?hSensor ?hSatellite
WHERE {
  ?h rdf:type noa:Hotspot ;
  noa:hasGeometry ?hGeo ;
  noa:hasAcquisitionTime ?hAcqTime ;
  noa:hasConfidence ?hConfidence ;
  noa:isProducedBy ?hProvider ;
  noa:hasConfirmation ?hConfirmation ;
  noa:isDerivedFromSensor ?hSensor ;
  noa:isDerivedFromSatellite ?hSatellite .
  FILTER("2007-08-24T00:00:00"^^xsd:dateTime <= ?hAcqTime &&
         ?hAcqTime <= "2007-08-24T23:59:59"^^xsd:dateTime).
  FILTER(strdf:contains("POLYGON((21.027 38.36, 23.77 38.36,
                                23.77 36.05, 21.027 36.05, 21.027 38.36))"
                        ^^strdf:WKT, ?hGeo) ) . }

```


Get all coniferous forests in Peloponnese

```
SELECT  ?a ?aGeo
WHERE { ?a rdf:type clc:Area;
        clc:hasLandUse ?aLandUse;
        noa:hasGeometry ?aGeo.
        ?aLandUse rdf:type ?aLandUseType.
        FILTER(?aLandUseType =
                clc:ConiferousForest) .

        FILTER(strdf:contains("POLYGON((21.027
                38.36, 23.77 38.36, 23.77 36.05,
                21.027 36.05, 21.027 38.36))"
                ^^strdf:WKT,?aGeo)) .
}
```

Retrieving a map layer (1/3)

Get all o

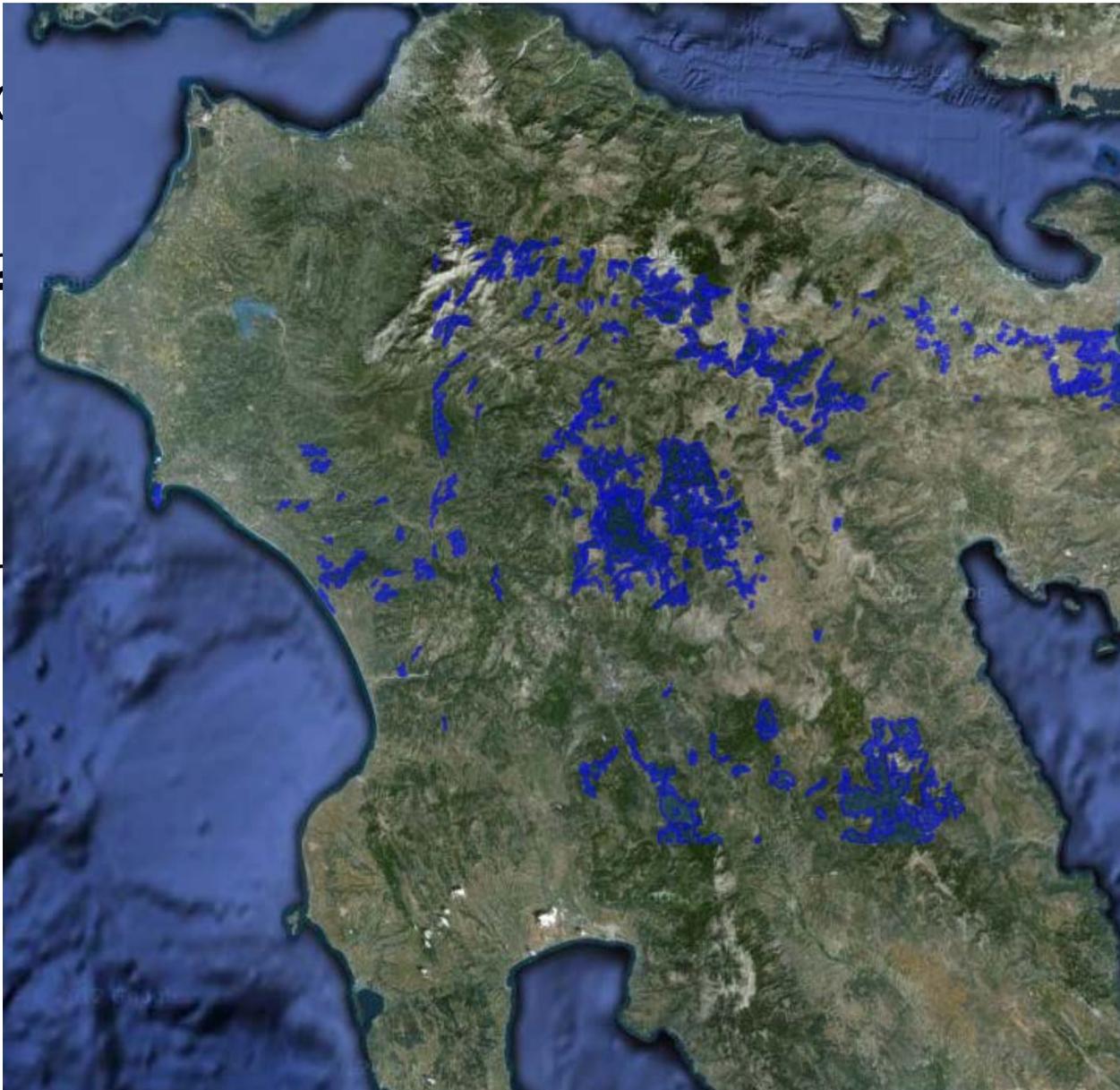
```
SELECT
```

```
WHERE { ?
```

```
FILE
```

```
FILE
```

```
}
```



pe .

```
1.027  
7 36.05,  
36))"  
(?aGeo)) .
```

Get all primary roads in Pelloponnese

```
SELECT ?r ?rGeo
WHERE { ?r a ?rType ;
        noa:hasGeometry ?rGeo .
        FILTER(?rType = lgdo:Primary) .
        FILTER(strdf:contains("POLYGON( (
            21.027 38.36, 23.77 38.36,
            23.77 36.05, 21.027 36.05,
            21.027 38.36) )"^^strdf:WKT,
            ?rGeo) ) .
}
```

Retrieving a map layer (2/3)

Get all pr

```
SELECT ?
```

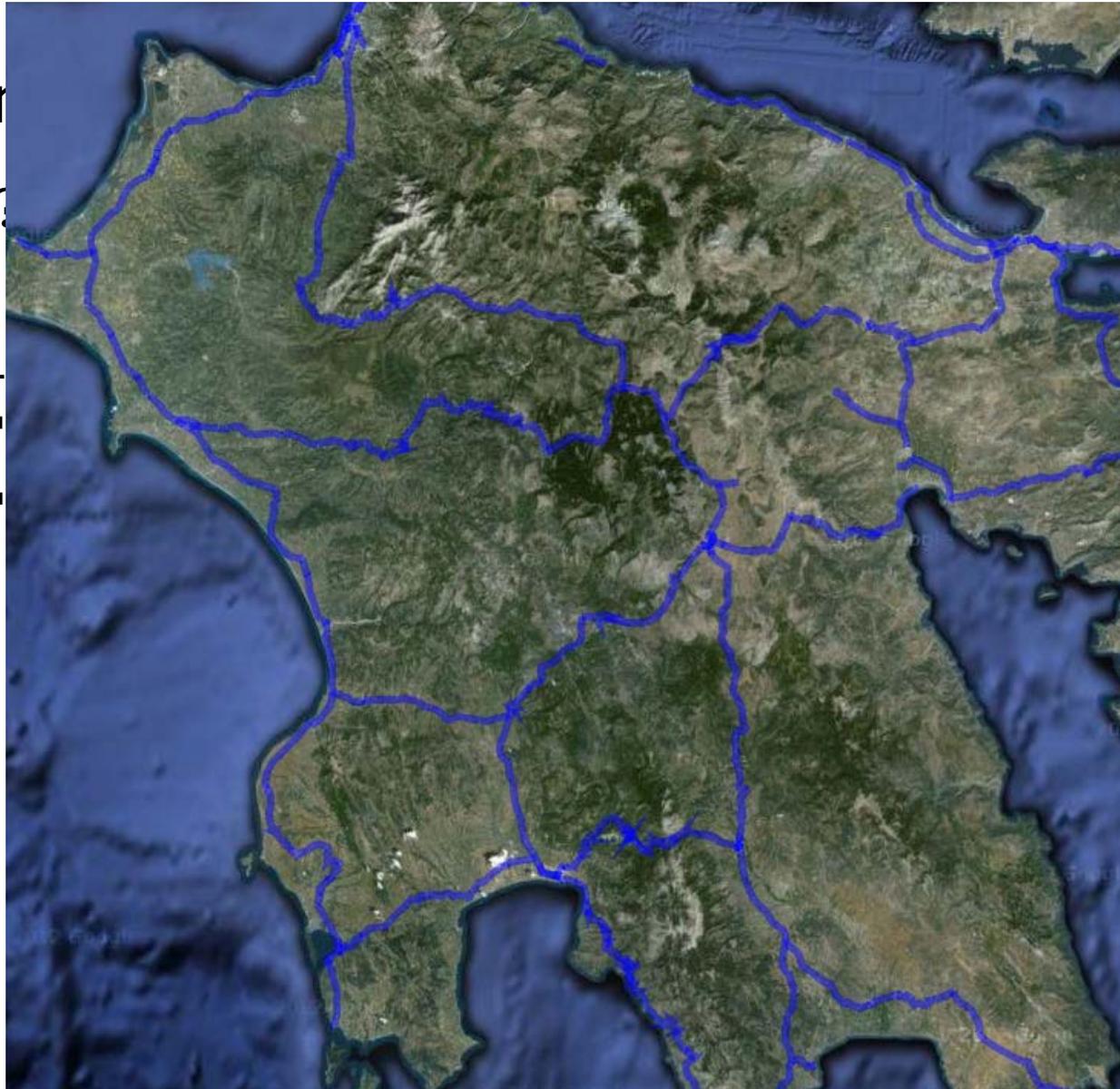
```
WHERE { ?
```

```
n
```

```
F
```

```
F
```

```
}
```



```
.  
ON ( (  
.36,  
.05,  
:WKT,
```

Get all capitals of prefectures of the Peloponnese.

```
SELECT ?feature ?fName ?fGeo
WHERE { ?feature rdf:type gn:Feature;
        noa:hasGeography ?fGeo;
        gn:name ?fName;
        gn:featureCode ?fCode.
        FILTER(?fCode = gn:P.PPLA
                || ?fCode = gn:P.PPLA2 ) .
        FILTER(strdf:contains("POLYGON((21.51
        36.41, 22.83 36.41, 22.83
        37.69, 21.51 37.69,
        21.51 6.41 ))"
                ^^strdf:WKT, ?fGeo)).
}
```

Retrieving a map layer (3/3)

Get all
SELECT
WHERE {



Japanese.

o i

.

) .

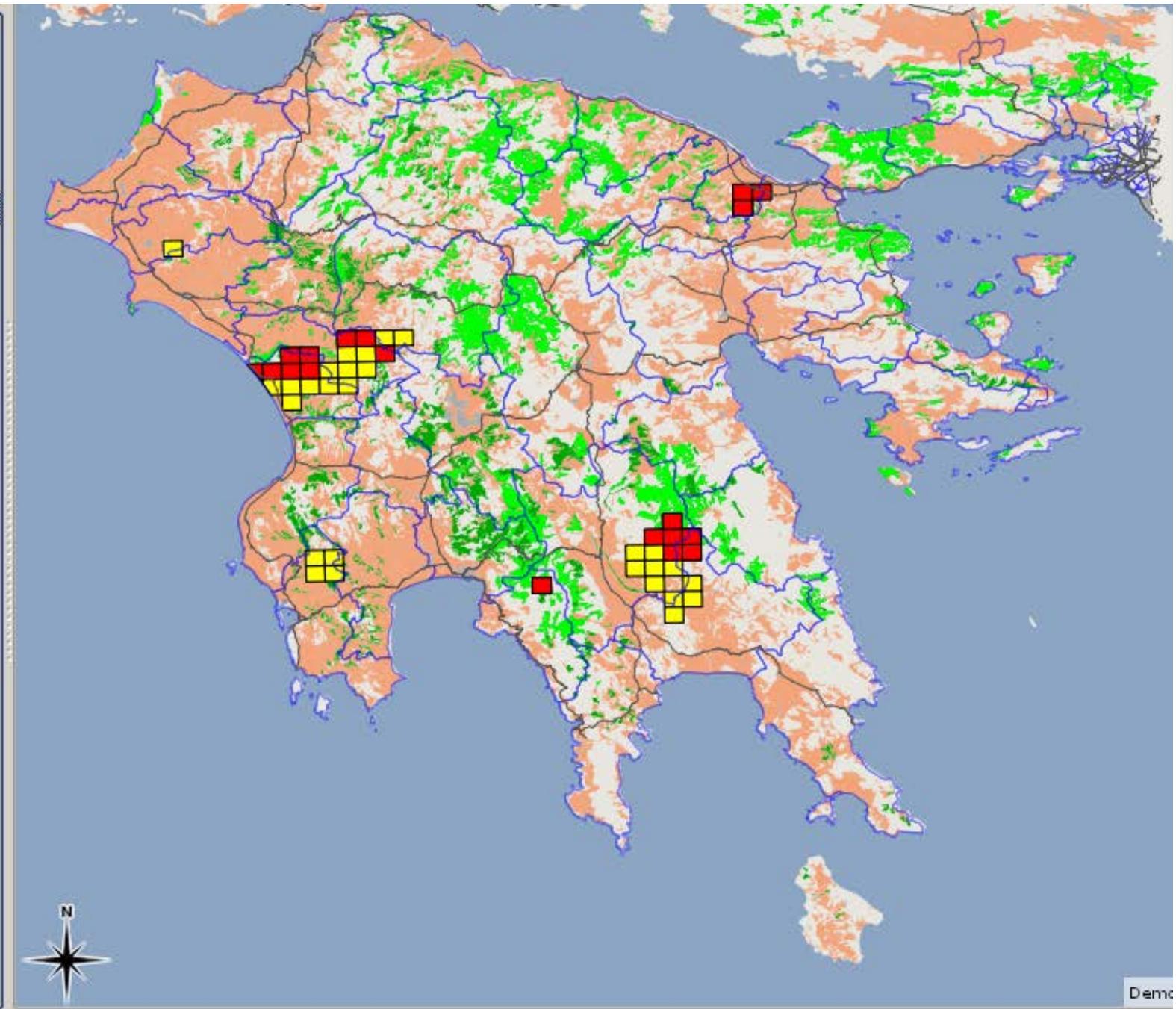
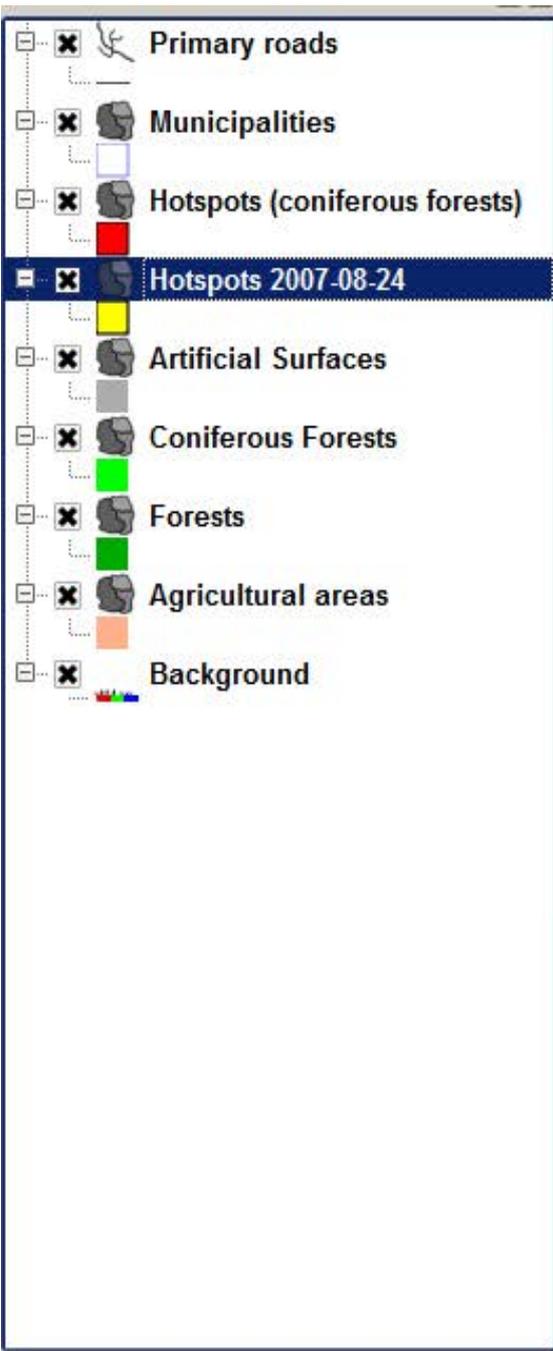
21.51

2.83

eo)) .

}

Final map



- **Generating maps** combining diverse information sources
- **Generating Rapid Mapping** products
- **Semantic Enrichment for Hotspots**
- **Fire monitoring** application

*[ESWC 2013
Best Demo Award]*

DEMO!

<http://bit.ly/SextantDemo>

Generating Rapid Mapping Products

ZKI (Center for Satellite Based Crisis Information)



Generating Rapid Mapping Products: Sextant



Sextant

Endpoints

Layers

- Fire Brigade
- Hospitals
- GeoNames
- Road E75
- Municipalities
- Urban Fabric
- Agricultural Areas
- Forest
- Shrubland

Query

Explore

Map KML Layers

Google 2 km 2 mi

Map data ©2013 Google - Terms

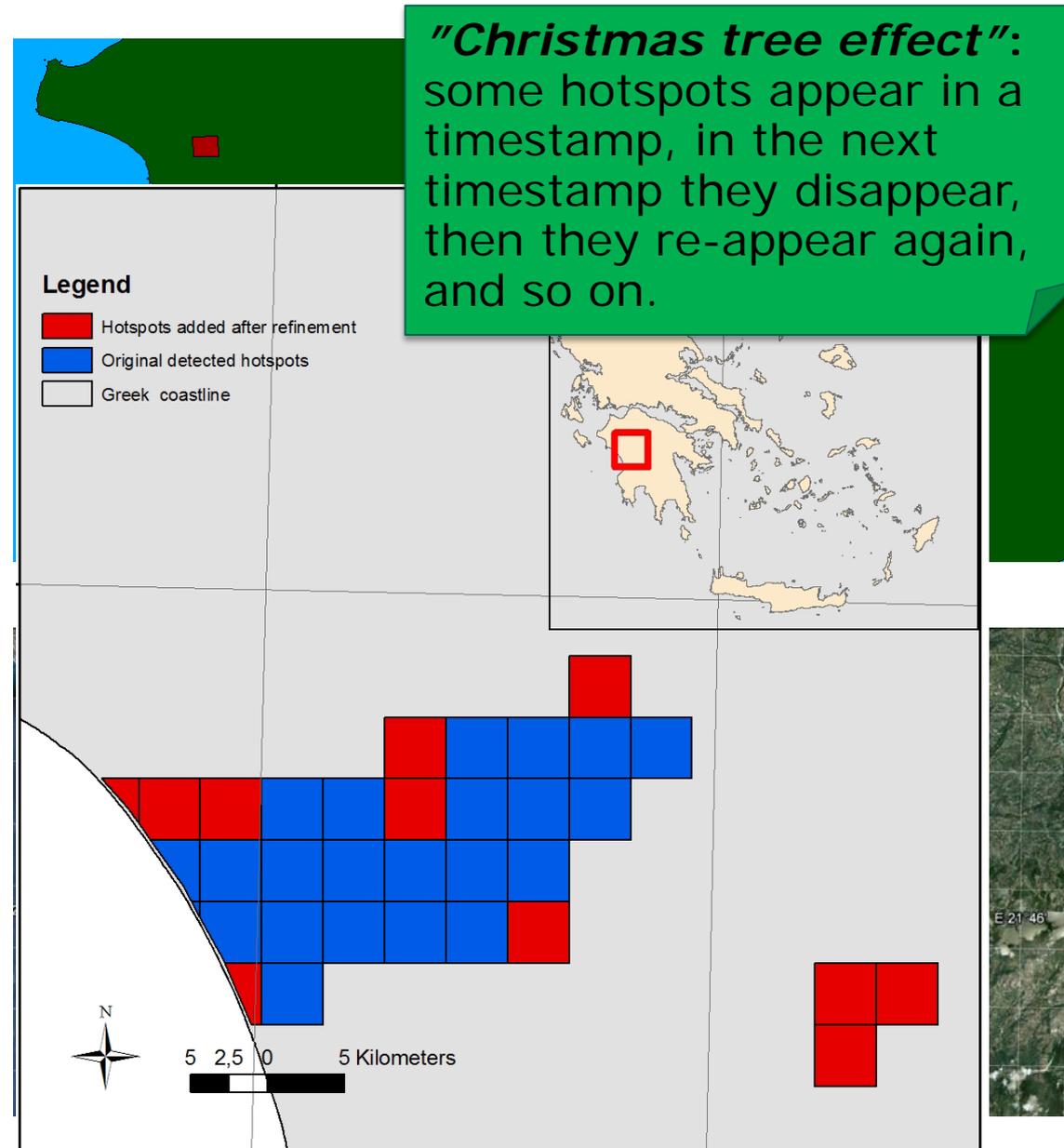
- **Generating maps** combining diverse information sources
- **Generating Rapid Mapping** products
- **Semantic Enrichment** for Hotspots
- **Fire monitoring** application

DEMO!

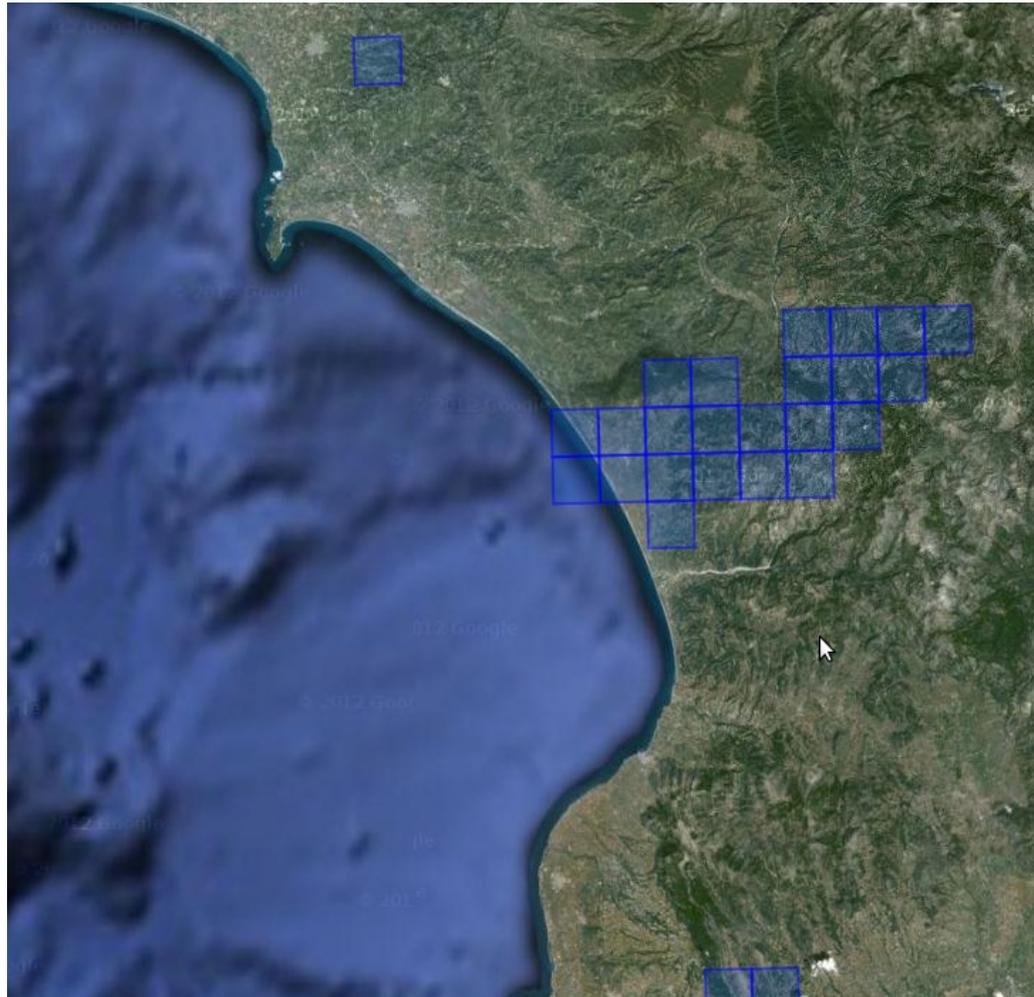
<http://bit.ly/StrabonDemo>

Semantic Enrichment for Hotspots

- **Enrich** hotspot products
 1. Connect each hotspot with a municipality that it is located
- **Improve accuracy** with respect to **underlying area**
 2. Eliminate false alarms in sea
 3. Keep land part of the polygon
 4. Eliminate false alarms in inconsistent land cover areas
- **Improve accuracy** with respect to **temporal persistence** of each hotspots
 5. Remove “Christmas tree” effects



Improve the accuracy of EO data



```
HAVING strdf:overlap(?hGeo, strdf:union(?cGeo)) }
```

- **Generating maps** combining diverse information sources
- **Generating Rapid Mapping** products
- **Semantic Enrichment for Hotspots**
- **Fire monitoring** application

*[ISWC 2012 Semantic
Web Challenge
3'rd place winner]*

DEMO!

<http://bit.ly/FiresInGreece>

Fire monitoring application



Status Info:
Mode: Archive
Beginning Time: 2012-08-17T13:00:00 GMT
End Time: 2012-08-23T13:00:00 GMT
Total #HotSpots: 8114
Latest #HotSpots: 8114

Aggregated Query Data

HID	RANK	Municipality	Duration	Ignition	End
2610384	6350	"ΔΗΜΟΣ ΧΙΟΥ"	0.08	2012-08-19 18:05:00	2012-08-19 18:10:00
2345374	508	"ΔΗΜΟΣ ΠΟΡΟΥ"	0.75	2012-08-21 03:30:00	2012-08-21 04:15:00
2345374	508	"ΔΗΜΟΣ ΠΟΡΟΥ"	17.00	2012-08-20 11:50:00	2012-08-21 04:50:00
2345374	508	"ΔΗΜΟΣ ΠΟΡΟΥ"	16.58	2012-08-20 11:55:00	2012-08-21 04:30:00
2349374	508	"ΔΗΜΟΣ ΠΟΡΟΥ"	14.75	2012-08-20 11:50:00	2012-08-21 02:35:00
2349374	508	"ΔΗΜΟΣ ΠΟΡΟΥ"	11.67	2012-08-20 11:55:00	2012-08-20 23:35:00
2353374	508	"ΔΗΜΟΣ ΠΟΡΟΥ"	0.92	2012-08-20 12:25:00	2012-08-20 13:20:00
2069378	330	"ΔΗΜΟΣ ΖΑΚΥΝΘΟΥ"	22.58	2012-08-20 10:20:00	2012-08-21 08:55:00

Fire Monitoring Service based on MSG SEVIRI

Raw **Refined** Realtime Archive

Year & Month of Reference: 2012 | May | Jun | Jul | Aug | Sep

Submit Ignition Fire End Duration

NOA Implementation Team: IAASARS :Haris Kontoes;Themistoklis Herekakis;Dimitris Michail;Ioannis Papoutsis;Argyros Argyridis ; IERSD :Kotroni Vasso; Contact Email: mailto:kontoes@noa.gr

- The fire monitoring service was used **operationally** during the **fire season** of **2012**
- Used in a **daily basis** by the
 - Greek civil protection agency
 - Greek fire brigade
 - Greek army
- Initial user feedback very encouraging!

Fire Monitoring Service

Preliminary evaluation – Thematic accuracy



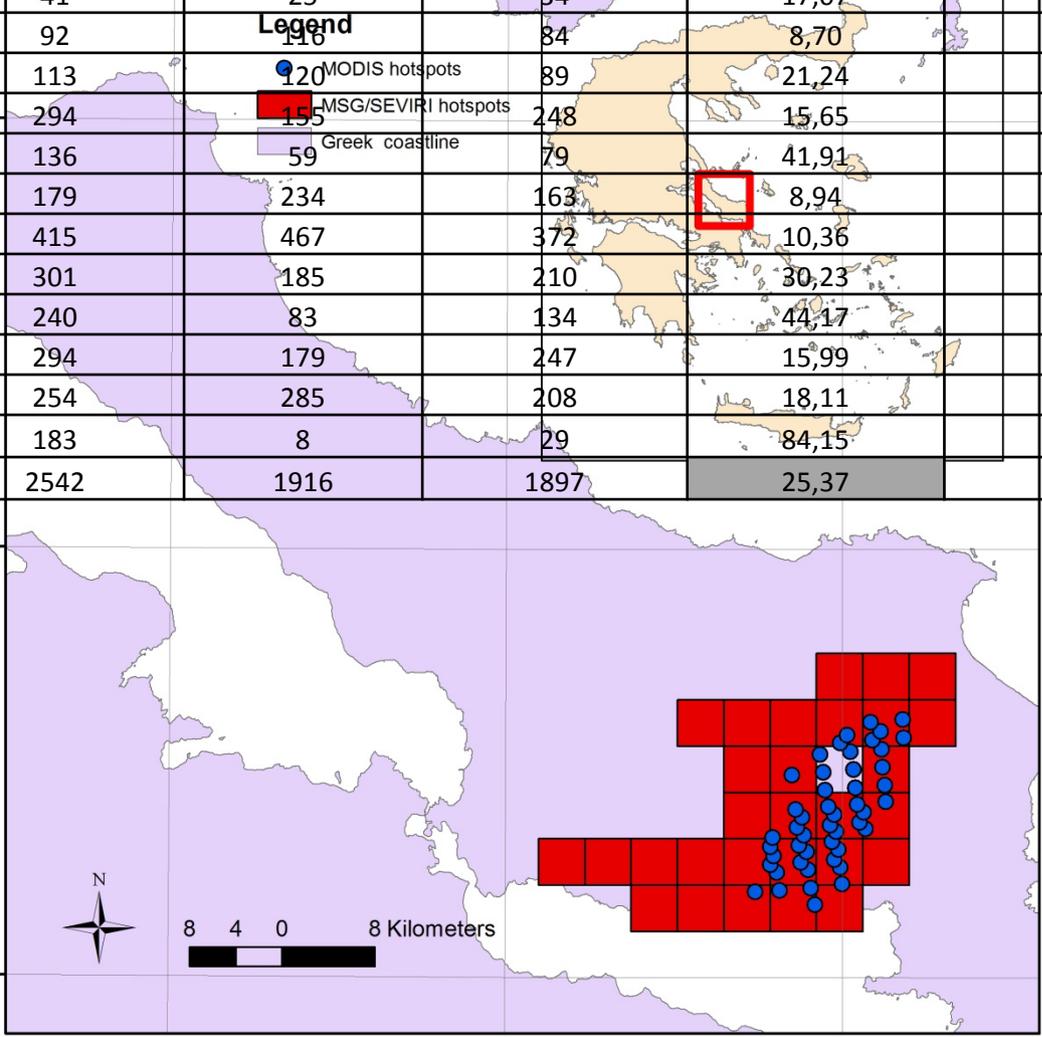
Static thresholds

Dynamic thresholds

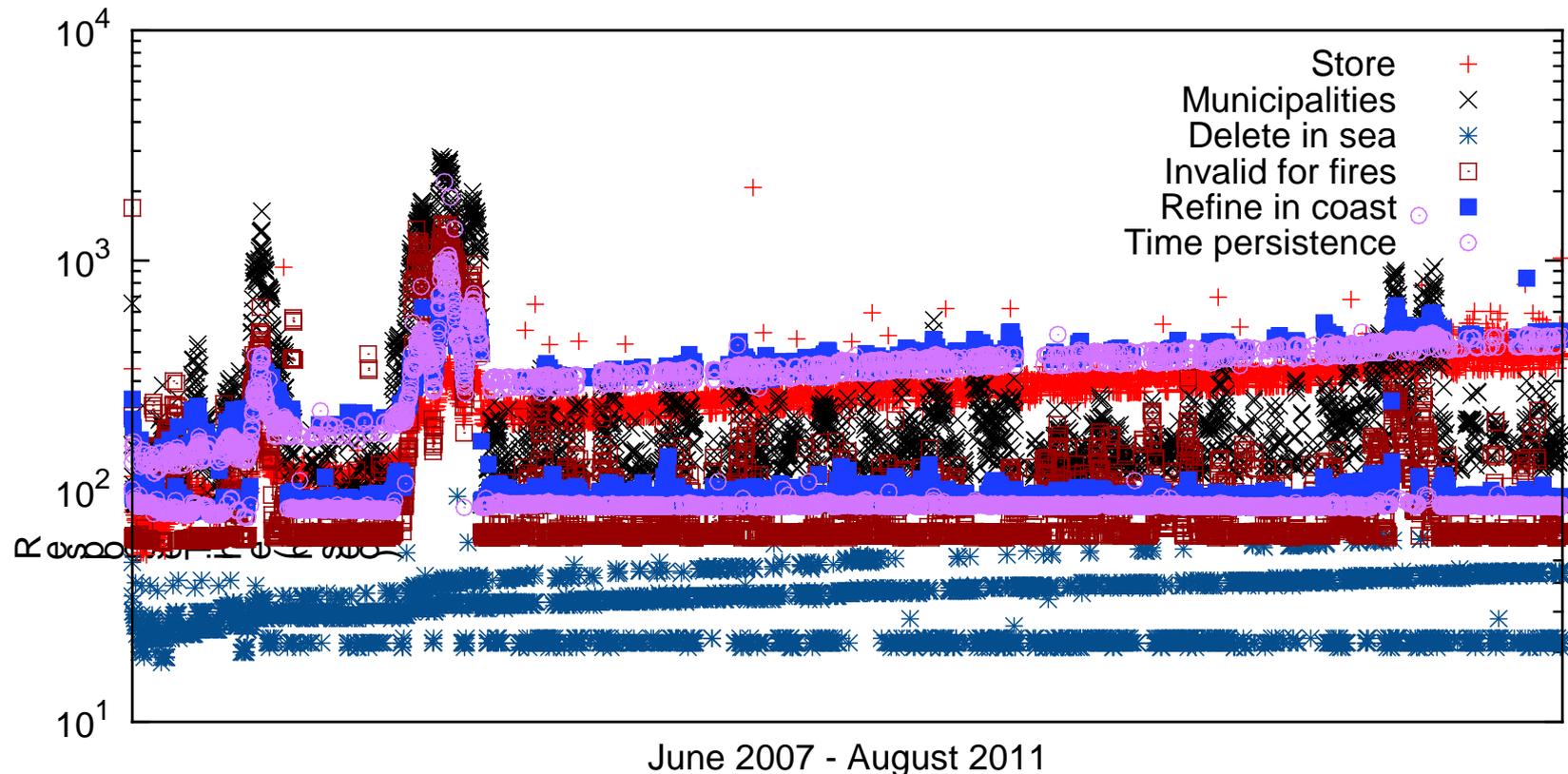
A typical example

Date	Time	Total No of FIRMS hotspots	Total No of MSG hotspots	No of FIRMS detected by MSG	Omission error (%)	No of MSG detected by FIRMS	False alarm rate (%)
24/8/2007	0:21	41	25	34	17,07	18	28,00
24/8/2007	9:46	92	116	84	8,70	83	28,45
24/8/2007	11:25	113	120	89	21,24	87	27,50
24/8/2007	20:51	294	155	248	15,65	126	18,71
25/8/2007	1:03	136	59	79	41,91	41	30,51
25/8/2007	8:51	179	234	163	8,94	172	26,50
25/8/2007	12:08	415	467	372	10,36	334	28,48
25/8/2007	19:55	301	185	210	30,23	166	10,27
26/8/2007	0:09	240	83	134	44,17	79	4,82
26/8/2007	9:34	294	179	247	15,99	132	26,26
26/8/2007	11:12	254	285	208	18,11	214	24,91
26/8/2007	20:39	183	8	29	84,15	8	0,00
Total		2542	1916	1897	25,37	1460	23,80

Date	Time	Total No of FIRMS hotspots	Total No of MSG hotspots	No of FIRMS detected by MSG	Omission error (%)	No of MSG detected by FIRMS	False alarm rate (%)
24/8/2007	0:21	41	25	34	17,07	36	40,00
24/8/2007	9:46	92	116	84	8,70	83	28,45
24/8/2007	11:25	113	120	89	21,24	87	27,50
24/8/2007	20:51	294	155	248	15,65	186	35,19
25/8/2007	1:03	136	59	79	41,91	153	29,17
25/8/2007	8:51	179	234	163	8,94	172	26,50
25/8/2007	12:08	415	467	372	10,36	334	28,48
25/8/2007	19:55	301	185	210	30,23	320	27,60
26/8/2007	0:09	240	83	134	44,17	216	15,95
26/8/2007	9:34	294	179	247	15,99	132	26,26
26/8/2007	11:12	254	285	208	18,11	214	25,44
26/8/2007	20:39	183	8	29	84,15	68	26,09
Total		2542	2757	2252	11,41	2001	27,42



- Product ingestion, processing and refinement is completed in less than 12 seconds
- More refinement operations to be added later given the five minutes time frame



- General architecture for EO applications enriched with semantic web technologies
- The Fire Monitoring Service of the National Observatory of Athens
 - Architecture
 - Improving the service using semantic technologies

- Use **higher-level languages**, stop worrying about how to store and manage metadata, just **focus** on the actual **processing**
- Express common earth observation operations easily using the **stSPARQL/GeoSPARQL queries** instead of using a lengthy **C** program
- **Rapid prototyping** and new refinement modules without the need to recompile everything