Exploiting Satellite Data in the Context of Smart City Applications

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***Abstract*—In the context of smart city, there is the need of cheap approaches to get environmental and contextual data. IoT (Internet of Things) devices and sensors may be located in specific points of interest, while their costs is high for the installation, usage/licensing and maintenance. The satellite data can be a viable solution to have more data at the cheaper costs, some of them are open data, while in other cases the satellite data have a cost. In this paper, the exploitation of satellite data in the context of Smart City is analyzed and some examples are provided. The satellite data of the European Union's Earth observation program Copernicus can be used to calibrate the values of large sensors network data, and for new applications in which similar data cannot be recovered from the field. A demonstrative Dashboard has been provided to allow the users to perform a comparison of data coming from satellite with respect to those obtained from IOT Devices. This research has been developed in the context of PC4City project (Civil Protection for the City) of the *Fondazione Cassa di Risparmio di Firenze*.**

***Index Terms*—Satellite Earth Observation, Geospatial Data, Copernicus, Sentinel, ESA, GIS**

I. Introduction

In the context of Smart Cities, the data access and exploitation has been progressively demanded. Smart City solutions initially started exploiting the GIS (Geographical Information Systems) with the aim of providing services for final users: collecting and exploiting the geolocations of services, POI (points of interest), city roads, structure of city buildings, etc. Successively, a wave of Open Data arrived pushing the public administrations to provide their data and management KPI (Key Performance Indicator) as open data. Thus city management data and territorial GIS data have been largely used to populate the open data portal of major cities in the world and in Europe, by means of the hierarchy of open data portals from the city, region, national authority and Europe. These above-mentioned data were mainly static and quasi static (changing sporadically), representing the status of slow processes. In that period, the real time data streams have been limited to TV cameras monitoring critical points of the city, and rarely automatically extracting semantic information. A successive wave pushed the smart cities to install and exploit IoT technology to collect real time data by installing a large variety of IoT Devices sensors on the field (and maybe also locating them on GIS), which have been employed, for example, to assess the status and performance of: traffic flows, environmental data, people flow, energy status, solar irradiation, weather, locations of buses, arrival at bus stops, charging stations status, sharing vehicles locations, sharing services status, trajectories of public transportation means, public building energy consumption, and so on. The arrival of IoT Devices and technologies provided the possibility for Smart Cities of receiving real time data; thus, real time events arrived in the infrastructures, also including other streams: social media posts, news, accident reports from police, earthquakes. Therefore, most of the data collected from IoT Devices are also posted as Open Data and shared among the governmental portals. Thus also TV cameras became smarter counting entities (e.g., people, bikes, vehicles, unattended objects). With real time data, time series have been created and from them the possibilities of making predictions. Despite of the above-described complete scenario, most of the cities may experience problems of sustainability, since the costs of installation and maintenance are recurrent cost that may be not affordable, despite of the low costs of the devices. That means that cities may not have enough resources to instrument and maintain their infrastructures with the needed IoT sensors to monitor real-time the city status. One of the emerging technologies to partially solve some of the mentioned problems could be the exploitation of open data coming from satellites, provided as open data and public services. They can:

- provide a large number of periodically updated data, with a period of once a day;
- drastically reduce the costs for collecting geolocated measures on territory, avoiding in certain cases to install sensors;
- drastically reduce the maintenance costs;
- complement and validate data coming from ground sensors.

On the other hand, the services for accessing satellite data are complex to be used and far from the functional requirements of the data services for cities. In fact, cities are interested in data which can be: located at specific GPS coordinates, easily ingested, integrated with other data, and exploited in real time. Relevant technological and semantic gaps have to be overcome to allow the satellite data and services to become usable in the context of smart city.

In most cases, the satellite data are: (a) by product and thus large sections of data have to be downloaded in order to obtain the data in a specific/small GPS locations/area; (b) provided in specific formats that cannot be directly used with the same easiness of IoT Devices data coming from IoT brokers in push or from some data gateway.

In the context of smart cities, satellite data can be used as: (i) substitute of IoT Device data in certain specific context (environmental data mainly); (ii) validation reference for data collected by other means; (iii) take new kind of data that cannot be recovered from other sources and that may open the path for creating new smart services.

In this paper, the exploitation of satellite data in the context of Smart City is analyzed and some examples are provided. The satellite data can be a viable solution to have more data at the cheaper costs. Also satellite data may have a cost, while some of the satellite data version are open data. IoT data have relevant costs for installation and maintenance. We have demonstrated that the satellite data of the European Union's Earth observation Copernicus can be used to: (i) calibrate the values of large sensors network data; (ii) develop new applications in which similar data cannot be recovered from the field with the same density. To this end, a demonstrative Dashboard has been provided to allow the users to perform a comparison of data coming from satellite, with respect to those obtained from IoT Devices. This research has been developed in the context of PC4City project (Civil Protection for the City) of the *Fondazione Cassa di Risparmio di Firenze*, Italy.

This paper is organized as follows. In section II, a description of the capabilities of satellite data is reported. Section III reports the related work in the context of satellite data exploited for smart city solutions. Section IV describes the general architecture adopted for collecting data from satellite, detailing the data flow from satellite data ingestion to services, and satellite data harvester architecture. Section V describes some applications that have been developed into the Snap4City platform by exploiting satellite data, in order to validate and complement them with ground sensors related data, which were already ingested into the platform. Section VI draws conclusions and future work.

II. Satellite Data

The European Space Agency [1] has developed a set of missions called Sentinels [2] for the operational needs of the Copernicus program, approved by the Council of the European Union and the European Parliament with the Regulation (EU) No. 377/2014 [3]. Each of these missions consists of a constellation of two satellites providing Earth observational data. Sentinel missions feature radar and multi-spectral imaging tools for monitoring the land, the ocean, and the atmosphere with a relatively short revisit time (i.e., the time elapsed between observations of the same point on the earth).

- *Sentinel-1* is a polar-orbiting radar imaging mission for land and ocean monitoring, for weather observation purposes. It has a $4-40m$ resolution, 3 day revisit time at equator. Sentinel-1A was launched on April 3, 2014 and Sentinel-1B on April 25, 2016;
- *Sentinel-2* is a high-resolution polar and multi-spectral imaging mission for land monitoring, providing various types of images (e.g., vegetation, soil and water cover, inland waterways, coastal areas), and information for emergency services. It has $10-60m$ resolution, 5 days revisit time. Sentinel-2A was launched on June 23, 2015, and Sentinel-2B on March 7, 2017;
- *Sentinel-3* is a multi-instrument mission measuring sea surface topography, sea and land surface temperature, ocean and land color. This mission was developed with the goal of providing ocean forecasts and environmental and climate monitoring. It has $300-1200m$ resolution, < 2 days revisit time for the Ocean and Land Colour Instrument (OLCI) and < 1 day for the SLSTR (Sea and Land Surface Temperature Radiometer) instrument at the equator. Sentinel-3A was launched on February 16, 2016, and Sentinel-3B on April 25, 2018;
- *Sentinel-4* is a mission under construction (scheduled for launch in 2023), with the goal of monitoring key air quality trace gases and aerosols over Europe. It has $8km$ resolution, 60 minutes revisit time;
- *Sentinel-5 Precursor* (i.e., Sentinel-5P) is the precursor to Sentinel-5 providing timely data on various trace gases and aerosols involved in air quality and climate. It has $7-68km$ resolution, 1 day revisit time. Sentinel-5P was launched on October 13, 2017;
- *Sentinel-5* provides data for atmospheric composition monitoring, and it has been scheduled for launch in 2021 and 2022. It has $7.5-50km$ resolution, 1 day revisit time;
- *Sentinel-6* will provide high-precision altimetry sea level measurement. It has 10 day revisit time. Sentinel-6A was launched on November 21, 2020, and Sentinel-6B is scheduled for launch in 2025.

Furthermore, a second-generation of Copernicus satellites (i.e., Copernicus 2.0) consisting of six missions (Sentinel-$\{$7-12$\}$), is currently being studied by ESA.

Data access to Sentinel measurements is available through four access points: two managed by ESA (i.e., Scientific Data Hub - SCI Hub [4], and Copernicus Space Component Data Access - CSCDA [5]); two managed by EUMETSAT (i.e., EUMETCast [6], [7], and Copernicus Online Data Access - CODA [8]). In the context of the present work, data were obtained from Sci-Hub.

Access to services data and information is available through six free and open services upon registration: Copernicus Land Monitoring Service (CLMS), Copernicus Marine Environment Monitoring Service (CMEMS), Copernicus Atmosphere Monitoring Service (CAMS), Copernicus Climate Change Service (C3S), and the Emergency Management Service (EMS). A Security service has restricted access. Sci-Hub provides a Graphical User Interface and an Application Programming Interface (API) with two options: Open Data Protocol and Open Search. Some toolboxes are at disposal for Sentinel data processing. For example, the Atmospheric Toolbox that consists of tools for ingesting, processing, and analyzing atmospheric remote sensing data [9]

- CODA (Common Data Access toolbox), allows direct access to local product files;
- HARP, a toolkit for reading, processing, comparing and modeling satellite and ground based data;
- VISAN, a cross-platform application for visualizing and analysing atmospheric data;
- QDOAS, a cross-platform application for performing DOAS retrievals of trace gases from spectral measurements (i.e., satellite, ground-based, mobile or aircraft-based instruments).

III. Satellite Data in the Context of Smart Cities

In this section, the related work regarding satellite data, and in particular Sentinels, in the context of Smart City is presented. Satellite data has the advantage of being pervasive, albeit with a lower spatial resolution than a dense ground-based sampling. This is especially true in the case of atmospheric data and on particulates. In addition, satellite data can be used for the validation of ground-based data, and provides geographically detailed views of the metrics under investigation. In the following, some examples are reported about the usages of different kinds of data from the Sentinel missions, in the context of urban monitoring and Smart Cities.

Sentinel-5P includes the Tropospheric Monitoring Instrument (TROPOMI), a spectrometer in the UV-VIS-NIR-SWIR spectral range. TROPOMI provides measurements on Ozone, NO_2, SO_2, Formaldehyde, Aerosol, Carbonmonoxide, Methane and Clouds. Such metrics can complement those coming from IoT Devices on the ground and provide valuable insights, for example air pollution and weather forecasting [10] or monitoring of volcanic eruptions [11].

Sentinel-3 provides measures of sea surface topography, sea and land surface temperature, and ocean and land surface colour, with the goal of supporting ocean forecasting systems, climate and environmental monitoring. Sentinel-3 includes the OLCI instrument, which is the Ocean and Land Colour Instrument. Sentinel-3 OLCI Level 1B data products are available in Full (OL_1_EFR) and Reduced Resolution (OL_1_ERR). RGB True-Color and False-Color images can be generated from OL_1_EFR data. True-Color images include reflectances from the red, green and blue light, while False-Color images combine reflectances from visible and non-visible wavelengths. Sentinel-3 SLSTR Near-Real-Time Fire Radiative Power (FRP) product provides the location and measures of the radioactive power of hot-spots on land and ocean, radiating a heating signal within a pixel size of 1 km^2. Hotspots are identified within three hours of sensing time, mainly during the night. Only a few daytime granules, with non-saturated background radiance, are fully processed. This metric can be used for detecting fires. Sentinel-3 SLSTR Near-Real-Time (NRT) Aerosol Optical Depth (AOD) measures the abundance of aerosol particles in the air, and check aerosol global distribution, as well as long-range transportation, at the scale of 9.5 x 9.5 km^2. Aerosol Optical Depth is used as a metric for the cumulative amount of aerosols. These observations are only applicable during daytime, with a less than three hours sensing time. They can be useful for monitoring and analysing the amount of aerosols in the air during fires.

The Rheticus® cloud-based platform [12] processes the interferometric data of Sentinels, providing continuous monitoring services of the Earth's surface regarding the stability of dams, roads, pipelines and slopes, the quality of coastal waters, forest fires, and estimates of anthropic density. Radar monitoring can find trends in ground displacement, and Interferometric Synthetic Aperture Radar (InSAR) analysis can detect millimetric displacements of the ground surface and landslide areas, the subsidence due to groundwater withdrawal or entry.

Sentinel-1 data could be exploited for soil analysis, using observations in VV polarization to retrieve soil moisture. At this regard, the SAR instrument on the Sentinel-1 satellites provides land images with pixel spacing of 10m×10m and a radiometric accuracy of 1dB (3σ) [13], [14].

Data from the Sentinel-1 and Sentinel-2 satellites can be processed for identifying the crowded points on rivers, and for general ship monitoring on oceans and seas. The Romanian Lower Danube River Administration (AFDJ) [15] and the Romanian Space Agency (ROSA) [16] exploited these data finding a solution for characterising the ship traffic on the Danube [17], [18].

Sentinel-2 imagery can be used for detection of air traffic, by creating deep learning models to detect distinct rainbow patterns created by the airplanes flying at a high-altitude and the slight spatio-temporal differences in the spectral bands of the multi-spectral camera [19]. Airplane traffic is an important economic indicator, for example for determining the effects of the COVID-19 pandemic. It provides valuable insights, and allows to track the number of parked airplanes at airports with respect to the baseline. Sentinel-2 imagery was used to monitor the decrease of boat traffic in Venice's waterways. After the nationwide lockdown imposed by the Italian Government on 9 March 2020, boat traffic was reduced, including 'vaporetti' (i.e., water buses) and cruise ships. Sentinel-2 images showed the effects of the lockdown in Venice, with the Grand Canal and the Giudecca Channel almost empty compared to the same period of the previous year, and the absence of traffic between Venice and the Murano island. The effects of lockdown appeared almost evident by comparing the air pollution across Europe [20].

Some other European research efforts are ongoing, with the aim of building a geospatial framework filling the gap between statistical and geographical information in various domains (e.g., agriculture, built-up areas, land cover and settlements enumeration, and forestry) [21].

IV. General and Detailed Architectures

The above described satellite services and data (so called products) are complex to be accessed even by using Copernicus Open Access Hub [4]. Actually, in that case, in order to exploit REST API requests, a developer needs to know the satellite name (mission), the instrument name (e.g., OLCI, SRAL, SLSTR, SYNERGY), the product type (e.g., SLC, GRD, OCN, RAW), the date range, and so on. Thus, a large number of specific parameters have to be determined by studying the Satellite offerings in details.

In the context of smart cities, most of the collected data has to: (i) be geolocalized at specific GPS coordinates, for example, since they refer to a building or area, for instance for counting people but also for the estimation of pollutants; (ii) refer to measured values taken at the ground level, where people are living, and not referring to the value observed from space, neither referring to complex units of measure; (iii) be easily ingested, for example by using rest calls or arriving in push from some Broker; (iv) be easily aggregated with other data, and on the basis of the connection of other city entities with the measured metric (e.g., temperature taken into a given square, stably referring to that position); (v) be periodically measured to be exploited in real time, as those that may arrive from programmed periodic IoT Device sensors, and also be available in a timely manner (e.g., the response time since the data is requested and the data is provided must be minimized); (vi) data must be cleaned up to become spatially uniform, since satellites do not pass exactly over the same location from time to time, and instruments on board acquire data at different geographical locations.

Satellite data lack details about ground metrics and must be integrated with other models in order to provide reliable estimates. For example the CAMS analyses combine model data with observations using an atmospheric model, built following the laws of physics and chemistry and advanced mathematical methods called data assimilation (DA), used worldwide by air quality and weather prediction forecasting centres. CAMS analyses are combined every 12 or 24 hours (for the CAMS global analyses and the CAMS European analyses respectively) with newly available observations to produce a new estimate of the atmospheric status (e.g., PM10, PM2.5). It is worth noting that in areas with good quality data, the estimates are very close to the real observed values, but in areas lacking observations the analyses only reflect the model information, which can include systematic errors, caused by inaccurate emissions or simplifications of meteorological processes [22]. Test procedures for certified Automated Measuring Systems (AMS) for air quality (i.e., gases and particulate matter) are defined in European norms:

- EN 14211:2012 for NO_X
- EN 14212:2012 for SO_2
- EN 14625:2012 for O_3
- EN 14626:2012 for CO
- EN 14662-3:2005 for C_6H_6
- EN 12341:2014 for PM10
- EN 14907:2005 for PM2.5
- EN 16450:2017 for PM10 and PM2.5

For example, for determining the mass concentration of suspended air pollutants such as PM10 or PM2.5 in ambient air, the standard prescribes a process of filtering and weighing. Measurements should be made using samplers with specific nozzles, operating at a nominal sampling rate of 2.3 m_3/h for a nominal period of 24 hours. It is clear that satellite data cannot provide this information alone: they provide additional information to support terrestrial data and numerical models of the atmosphere.

Therefore, in order to make the satellite data service directly exploitable in the context of smart city, a semantic gap has to be filled.

One of the major issues regards the exploitation of data, as provided by Sci-Hub web portals [4], [23]–[25]. For example, the web interface directly allows the user to perform queries, and filter data by a set of different parameters (e.g., sensing and ingestion period, satellite platform, product level and type, polarisation, sensor mode, instrument). Also, it is possible to perform geographical queries by drawing the zone of interest on the map (i.e., selecting the area with a mouse click and drag), though the system does return a wider subset of data than requested, as a zip file. Since each file is the result of a satellite scan and covers an area that goes beyond the scope of interest, it is necessary to clean up these data from unnecessary locations and null values. Data acquisition is a somehow slow process, since results from Sci-Hub take a while to be returned. Consequently, data processing is a time consuming process.

In a Smart City context, satellite data can be used despite their complexity: (i) as substitute of IoT devices related data in certain specific contexts; (ii) for validation of specific services providing wide reference data; (iii) as brand new kind of data which cannot be recovered from other sources and that might enable the creation of new smart services.

For the above reasons, on Snap4City platform we have developed a module to simplify the access to satellite data and used them in the Smart City context. The general architecture is reported in Figure 1. It is an evolution of the Snap4City general architecture [26], and of the Snap4City solution for heatmap management [27], including both the IoT data ingestion and the management for heatmap productions and smart services, in addition to the needed modules to cope with satellite data. In the Smart City domain there is the need of supplying a data value at any provided GPS coordinates of the city, for a large number of pollutants as well as for weather data such as PM10, PM2.5, CO, CO_2, SO_2, O_3, H_2S, NO, NO_2, air temperature, air humidity, wind speed, and dew point. The values collected from the sensors are typically scattered in the area, and far from the GPS points in which the service is requested. Thus, a solution is to compute an interpolated grid of values at the resolution useful for generating heatmaps on mobile apps and dashboards, which are the typical maps requested by the majority of users. Furthermore, we decided to compute on demand a second level interpolation of the values at any GPS coordinate when a city user requests them (the caching of these computations is also viable). This workflow is described in Figure 1. In this manner, the service can be provided to several thousands of users. In fact, the GeoTIFF heatmaps are computed only once and distributed via a GeoServer, through the standard Web Map Service (WMS) protocol. In the cases in which the data are measured several times a day, it is possible to request an animated heatmap produced during the day.

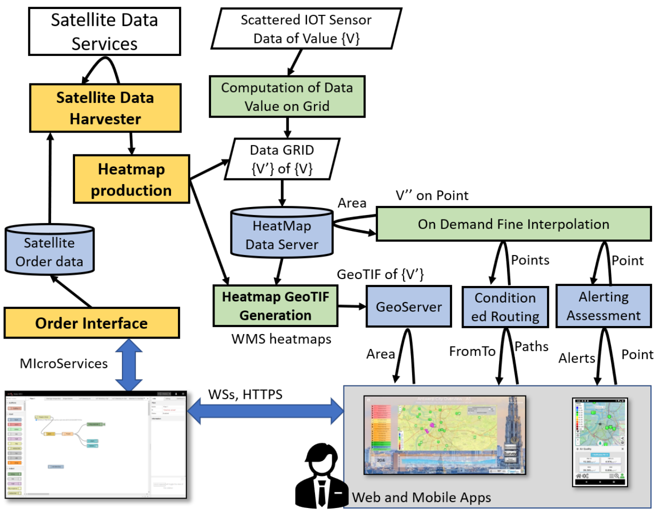

Fig. 1. General Architecture, from satellite data ingestion to services

The *On Demand Fine Interpolation* is activated on demand to produce results in real time exploiting the Heatmap Data Server, on the basis of: (i) GPS position for certain point of interest (POI) of the users, for computing an eventual alerting message if the user subscribes for the specific pollutant or weather data; (ii) Conditional routing (e.g., from–to geographical points and routes) to get back possible paths, minimizing the pollutant or weather variables. In the new version of the Snap4City microservices for Smart Cities [28] the GPS picking of an heatmap value, and the routing calculation providing from-to and eventual intermediate points are available as microservices (i.e., nodes in Node-RED). This allows to create smart services on the basis of the values collected from heatmaps, and thus with the work presented in this paper with the data provided from IoT Devices and Satellites.

A. Satellite Data acquisition and Preprocessing

According to Figure 1, the availability of Satellite data were managed by adding three modules described in this subsection:

- **Order Interface**: a microservice and API for requesting the download of satellite data, exposing logic information and hiding technical aspects of the satellite services. This approach allows to realize the data flow applications in Node-RED integrated with the large suite of Snap4City microservices for smart cities [28];
- **Satellite Data Harvester**: a process for requesting satellite data and processing them in order to prepare the data for creating a regular raster grid of data;
- **Heatmap Production**: a process to convert the data acquired from the satellite package to an array of data on a regular grid of equidistant points along longitude and latitude to produce a heatmap for WMS service.

The detailed architecture is reported in Figure 2. It aims to process Sentinels' data from European Union's Earth Observation Programme Copernicus.

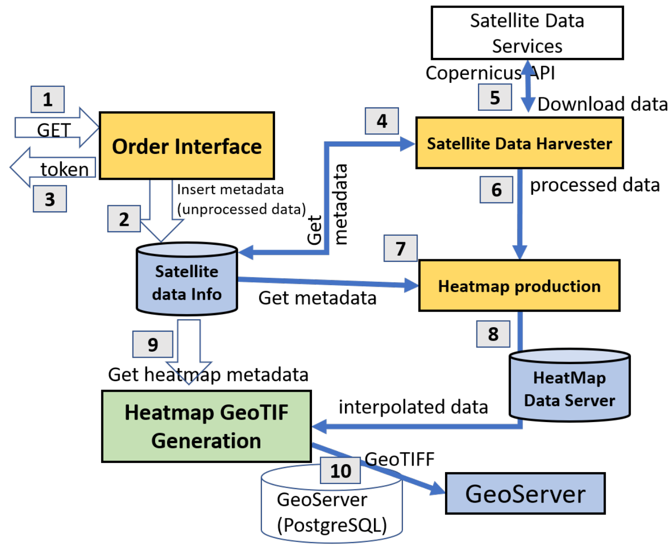

Fig. 2. Satellite Data Harvester Architecture

The **Order Interface** expose an API to plan a new job of the Satellite Data Harvesting (1). It was developed in Python and saves the metadata for job scheduling into a database (2) (e.g., date/time and time interval, location, map name, metric name, bounding box coordinates of the area of interest, grid size). Conceptually the job can be sporadic or periodic. If the time interval is wide enough, multiple maps corresponding to different passages of satellites can be produced and should not be merged each other since sampling time can be very distant, and thus the measure may refer to different contexts. Therefore, multiple maps are created. Once the request is performed an unique token is released to allow users and other process to control the status of the request (3). Note that the API was exploited by an implemented Node-RED MicroService node, to allow to perform the request from a Node-RED interface. In addition, the Node-RED has exposed a web interface to allow the user to book for satellite data into the Snap4City Platform for Smart Cities [28] (see Figure 3). The web interface is the first simplification, since the user only has to specify:

- **MapName** to refer to the data/maps in the following services. It is possible to specify already existing heatmaps to be updated or added in to the time serie of heatmaps;
- **Metric Name** (which uniquely refers to a satellite product on a satellite service, transparently for the user). The

following metrics are available to be exploited automatically from satellite data: Air Temperature, Humidity, Altitude, Vegetation Index (OGVI), Cloud Fraction, SO_2, O_3; NO_2, CO;

- **Description**: to save a textual description of the request from the user point of view;
- **Location**: select at which level the heatmap has to be created. It is possible to specify one of the following: City, Country, State and Postal Code;
- **Location Name**: geographical name: city, region, etc. It can be, for example, the name of a City or *Città Metropolitana di Firenze*, or *Toscana* as State or *Italy* as Country. It allows to produce the GPS coordinates, and to filter out data that do not belong to the selected area. To this end, a specific service that was integrated in the Snap4City Copernicus API (i.e., OpenStreetMap Nominatim [29]) was used for obtaining the bounding box from the geographical name of interest;
- **ColorMap**: to be used for showing the heatmap on the maps, from the drop down list, select the corresponding color map to be used for the heatmap visualization, according to the adopted standard and the accepted unit of measure;
- **Organization**: from the drop down list, select the organization in Snap4City to be assigned for the heatmap, to manage the service on the multitenancy framework;
- **FromDate – ToDate**: use these forms to specify the time period of the data to be downloaded. Please note that typically satellite data are updated once per day. If a longer period is specified, all data included in the period will be downloaded and, according to the available data, more heatmaps will be generated covering the specified time period;
- **Length**: the grid size of the final generated heatmap, in meters;
- **Write**: to save the data into the HeatMap Data Server for real time services or not. The real time services allow to recover the heatmap values using the picking services on the mobile App and on the Dashboards.

The **Satellite Data Harvester** is an asynchronous process which is capable to detect the presence of new jobs to be processed by browsing the data from database (i.e., satellite data info). Once a new job is found, the script downloads the data using the *dhusget* script [30], [31], which makes use of OData and OpenSearch APIs to query and download products from Data Hub Services. Moreover, it allows to filter out the products by ingestion time, sensing time, mission (e.g., Sentinel-1, Sentinel-2, Sentinel-3), instrument and product type. Downloaded data (i.e., netCDF4 binary files) are then extracted, read, combined (if they are divided in multiple files), cleaned up from duplicates, and converted to an array of maps to be passed to the Heatmap Production process.

The **Heatmap Production** process was implemented in RStudio and performs a multivariate interpolation using the Inverse Distance Weighting method (IDW [32]), using a regular grid of points with the requested distance. Data interpolation is used to produce regular grid heatmaps from the data crawled by satellites along their orbit (see Figure 4 for an example of Sentinel-3's orbit). This produces one map of each scanning which has to be passed to the Heatmap GeoTIFF Generator for the GeoServer, as well as to the HeatMap Data Server, to enable the services described in Figure 1. Each heatmap on the GeoServer can be accessed from the services by using the previously defined unique MapName, and the related DateTime. Note that at each step the Satellite Data Info are updated with the process status of each MapName.

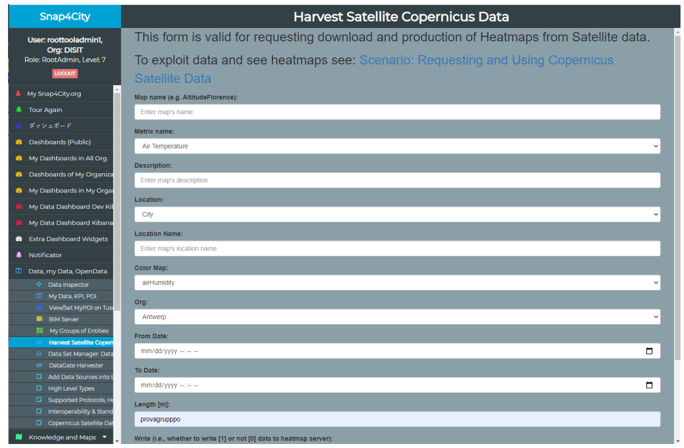

Fig. 3. User interface to book for Satellite Data Harvesting, on Snap4City.

Fig. 4. Sentinel-3 reference geocentric latitude and longitude, time step of 1 second

The **HeatMap GeoTIFF Generator** receives the maps to be processed for generating a GeoTIFF according to a defined ColorMap parameter, which allows to see the image overlapped on the map and aside a legend for reading the adopted color codes. In this process, the geographical name identified at the first step was used to filter out the points which are not included into the shape of the geographical area requested by the users. This allowed to construct heatmaps matching the GIS entities which the consumers are used to refer to.

V. Validation of Snap4City solution exploiting satellite data

In order to demonstrate the differences and the possibilities of the IoT vs Satellite data, a specific smart application was developed in Snap4City, exploiting the IoT data from the field, and the satellite service described above. As earlier illustrated, Copernicus data were tightly integrated into the Snap4City platform [33], [34]. With the aid of (i) the *Order Interface API* it is possible to plan the harvesting and download of the satellite data; moreover, with (ii) the Snap4City API it is possible to recover from heatmaps the values of the produced regular grid maps, in any point in real time. This scenario and applications was demonstrated by the dashboard reported in Figure 5. On the selector on the left different heatmaps can be visualized in the area of Florence, according to the reported legend. The transparency level of the heatmap overlapped on the map can be regulated as well. When clicking on a point on the map, the event is producing the values of the clicked heatmap in that position. The comparison is performed on the basis of NO_2, CO, O_3, air temperature and air humidity, while the satellite as well as the IoT devices can produce many other data maps which are presented as well. Please note that the differences are mainly due to the fact that satellite data are taken from 10Km, while the IoT are taken from ground level. The conversion is not straightforward, and many models and factors have to be taken into account.

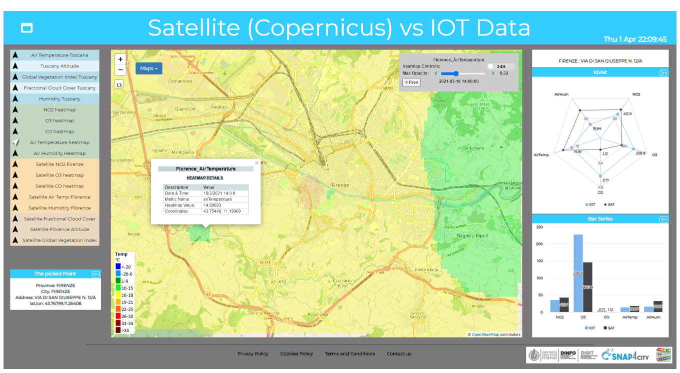

Fig. 5. Snap4City Dashboard for comparing Satellite and IoT data related heatmaps and picked point; map available at [35]

Upon clicking, an event with the coordinates is sent back to an event driven IoT app on the cloud, which was developed in Node-RED exploiting the Snap4City library. In Figure 6, the IoT App defining the business logic of the application in Node-RED is reported. In the IoT app, the values of all the heatmaps in the selected GPS coordinates from IoT and satellite heatmap data are queried from the Heatmap Server. The obtained values are dynamically formatted as Kiviat/spidernet and bar series diagrams for the comparison, as reported on the right side of Figure 5, resolving also the reverse geolocation, obtaining streets and civic numbers from GPS, by exploiting the Snap4City Knowledge Base modeled as Km4City ontology.

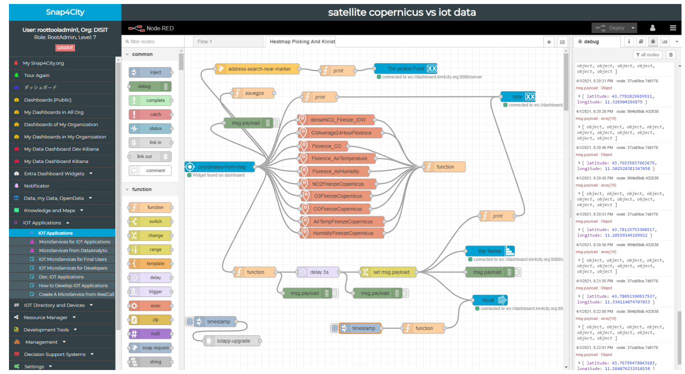

Fig. 6. IoT App view for defining the business logic exploiting HeatMap Server API, via Node-RED MicroService exploiting Snap4City services.

As demonstrated by the above described solution, it was possible to create a real time solution from exploiting satellite data. The satellite data are extremely complex to be exploited in the Smart City context, in which IoT data arrive georeferenced and in the real time. As described in the introduction, satellite data are not easy to be managed for: (i) the volume of the data obtained when requesting small regions; (ii) the complexity of the formats that need to be processed and converted; (iii) the computational time needed and difficulty in providing data in real time; (iv) for the lack of spatial resolution in providing the data.

To give you an idea of the processing time they are as follows. The crawling time (i.e., the time needed to query and download the data with the Sci-Hub API), measured for a medium-sized European city (such as Firenze, Italy, which is about 100Km2), is typically in a range of 3 minutes. The processing time to interpolate the data is a matter of 30-50s. The indexing time needed to create a GeoTIFF from the interpolated data matrix, and the indexing on the GeoServer is around 20-30 s. Therefore, the overall workflow has a typical execution time of about 5 minutes. This is a preprocessing, since for once performed all the data of certain measures are available in a dense grid in the whole area of observation. The computational costs and time does not increase much if the area is passing from 100Km2 to 3500Km2, as in the Florence Metro City area (province of Florence). In that case, the time is of 8 minutes. On the other hand, it is not a time which a service can afford to get each single data. If you have to collect data from 200 points, the processing accessing and processing every time Copernicus data is not affordable.

VI. Conclusions

In this paper, the exploitation of satellite data in the context of Smart City was analyzed. In addition, a large state of the art has been analyzed, and some examples have been provided. The satellite data of the European Union's Earth observation program Copernicus can be used to calibrate the values of large sensors network data and for new applications in which similar data cannot be recovered from the field. IoT data have relevant costs for installation and maintenance. We demonstrated that the satellite data of the European Union's Earth Observation Copernicus Program can be used to: (i) calibrate the values of large sensors network data; (ii) develop new applications in which similar data cannot be recovered from the field. On the other hand, satellite data are not easy to be managed for (i) the volume of the data obtained when requesting small regions; (ii) the complexity of the formats that need to be processed and converted; (iii) the computational time needed and difficulty in providing data in real time; (iv) the lack of spatial resolution in providing the data. To this end, a demonstrative Dashboard was provided to allow the users to perform a comparison of data coming from satellite with respect to those obtained from IoT devices. As demonstrated by the above described solution, it was possible to create a real time solution by exploiting satellite data, and providing comparison of what can be obtained with IoT, with respect to satellite data.

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