Sentinel-1 Based Near-Real Time Flood Mapping Service

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ABSTRACT

Globally floods are categorized as one of most devastating natural disasters and annually causing a major loss to human lives and economy. For rapid damage assessment and planning relief activities a large scale spatio-temporal overview is required to assist local authorities. This paper aims to provide an overview of a Sentinel-1 based near-real time flood mapping/monitoring service; which is implemented as an operational service under the framework of I-REACT (Improving Resilience to Emergencies through Advanced Cyber Technologies) project.

Keywords

Sentinel-1, EODC, Flood mapping service, SAR, Azure Service Bus.

INTRODUCTION

In recent years, the volume of data acquired by Earth observation (EO) satellites has been growing exponentially. Apart from the increasing number of satellites orbiting the Earth, the contribution of improved spatiotemporal resolution to the data volume is also significant. Therefore, in this age of big EO data, the domain of data driven applications is also quickly expanding (Chi et al. 2016). Key to any operational application are scalable and highly efficient data management and processing systems.

The advantage of using synthetic aperture radar (SAR) data instead of optical imagery is due to its weather independent data acquisition capability (Ulaby et al. 2014). At the time of flooding (especially caused by heavy rains) weather is mostly overcast and acquisition of cloud free optical data is a challenging task. For search and rescue operations it is very important for first responders to get the big picture of the spatial extent of the flooded areas (Martinis et al. 2009). This is a key information for the first responder to organize relief activities.

In this paper we present an overview of a near-real time computation of flood delineation map from Sentinel-1 data. The Earth Observation Data Center (EODC[1]) platform offers an environment for EO data processing and includes

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[1]https://www.eodc.eu

a Petabyte-scale EO data archive, a high performance computing infrastructure and virtual machines for remote data handling and visualization (Naeimi et al. 2016). Here we discuss the system infrastructure and integration of different components of SAR processing chain.

I-REACT project–concept and big picture

The I-REACT project has a multi-tier architecture which is called I-REACTOR. Based on the presentation, application process and data management tasks I-REACTOR's functions are logically separated into different loosely coupled modules that can be easily modified without affecting the other modules. However, in case of S-1 flood mapping service the point of contact to I-REACTOR is IDI (I-REACT Data Interface), where final products are pushed onto the front-end for further data harmonization, processing and visualization. Figure 1 shows the different components of I-REACTOR and their internal associations and dependencies.

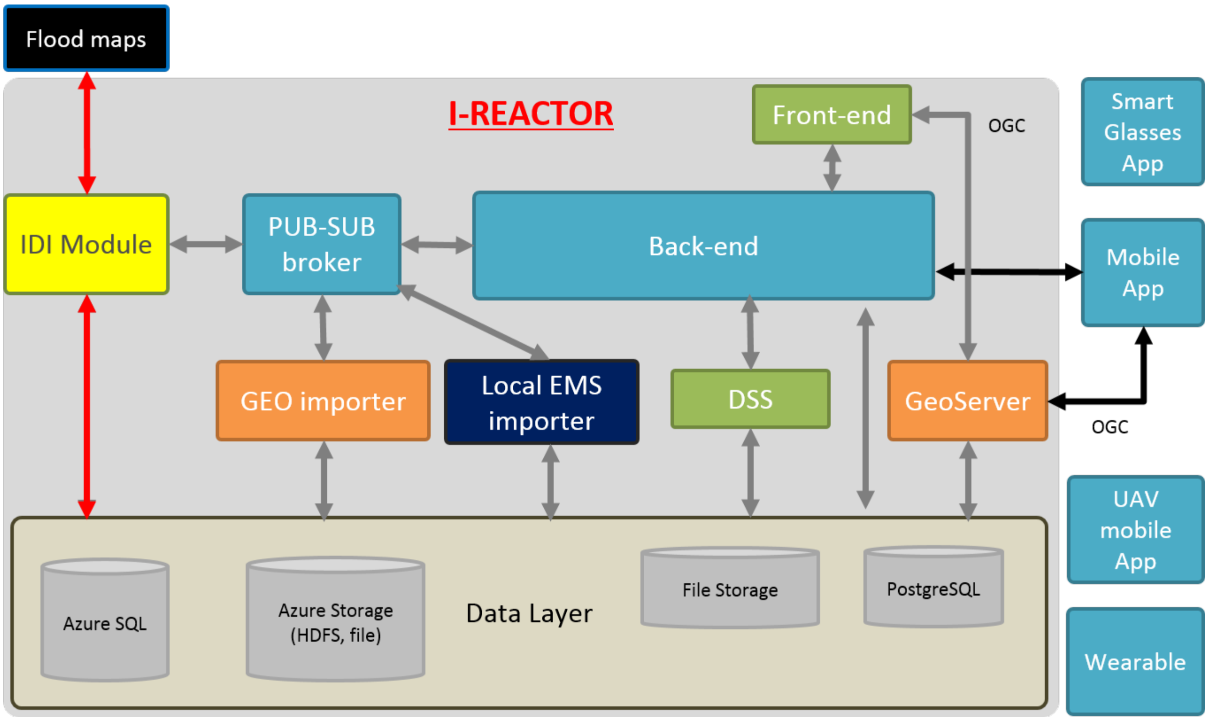

Figure 1. An overview of I-REACTOR framework.

TU WIEN SAR TOOLBOX AND PRODUCTS

SAR Geophysical Retrieval Toolbox (SGRT)

The SAR Geophysical Retrieval Toolbox (SGRT) is a software package developed by the Vienna University of Technology (TU Wien) for extracting geophysical parameters from Synthetic Aperture Radars (SARs) data. The version 2.0 of the SGRT, written in Python programming language, is an adaptation to Sentinel-1 (S1) of the earlier SGRT 1.0 developed for ENVISAT Advanced Synthetic Aperture Radar (ASAR) data, incorporating optimizations intended for handling the considerably higher spatial resolution and resulting explosion in data volumes foreseen of Sentinel-1 relative to ENVISAT ASAR (Naeimi et al. 2016). SGRT consists of four types of processing chains where different number of workflows are defined under each type, namely:

- *Pre-processing:* calibration, radiometric correction, georeferencing and terrain correction, resampling and tiling, quality control
- *Analytics:* time series analysis to extract model parameters
- *Production:* generates level-2 and higher-level products from preprocessed data using model parameters.
- *Near-Real-Time (NRT):* this component is designed to integrate different workflows and SGRT functionalities in a fully automatic processing chain for product generation.

Furthermore, SGRT is equipped with several image and signal processing components. Some of the SGRT modules are used in external utilities and plug-ins. e.g. the Python based Time Series Analyzer is an in-house tool, developed and integrated with the open source QGIS software to visualize Sentinel-1 time series. SGRT is under continuous development and with every new release, new functionalities and workflows are introduced.

Supporting products and modules

In order to develop an operational service a reliable quality control mechanism is essential to minimize the artifacts in the final product. In mountainous areas, topographic noise is very common which is due to steep slopes and shadow effect caused by the SAR side looking acquisition geometry. In order to remove topographic errors, the HAND (height above the nearest drainage) index (Nobre et al. 2011) was used. Figure 2 shows an example of flood map before and after applying the Hand Index mask.

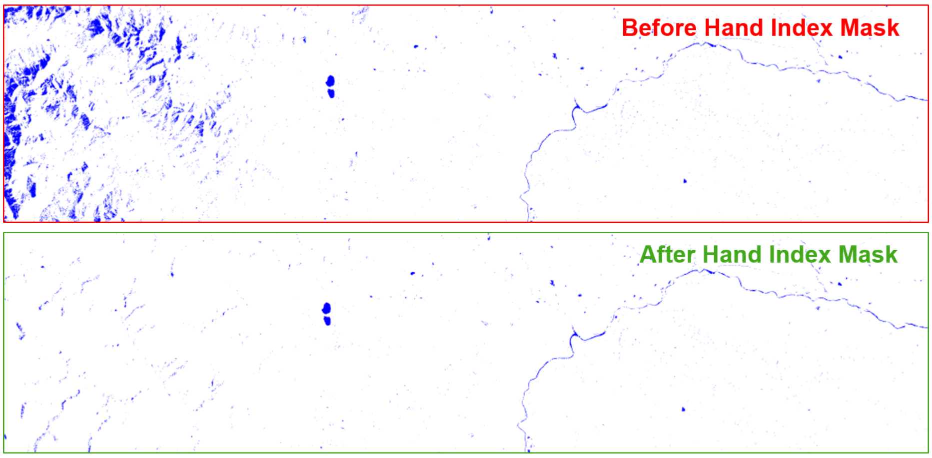

Figure 2. Application of Hand Index mask to remove the topographic noise.

Border noise in S1 A/B and ENVISAT ASAR is quite consistent which is a major source of error in time series analysis. In order to handle this error source an independent border noise removal module (Ali et al. 2018) was developed and integrated into the SGRT. Figure 3 shows an example for S1 border noise removal mask (border noise removal mask shown in magenta colour).

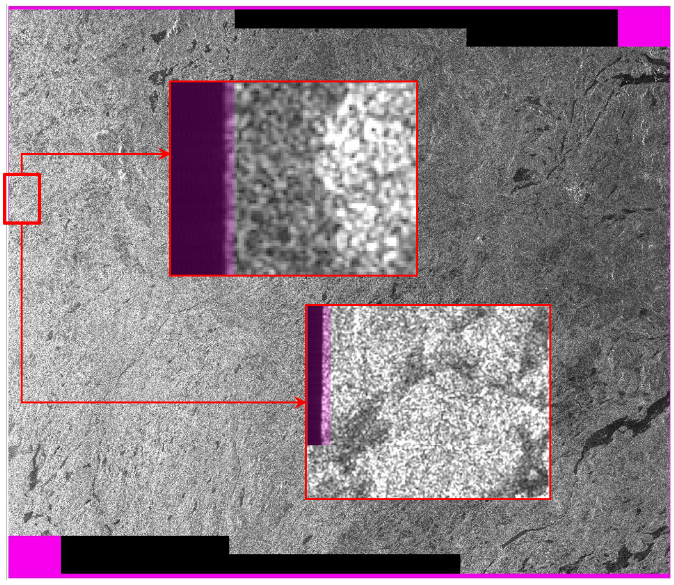

Figure 3. An example S1 border noise removal mask.

TEST SITES AND DATASET

Test sites in Europe

Currently the flood mapping service is mainly being tested in different countries in Europe. Study sites include United Kingdom, Malta and pre-defined regions of interest (red polygons) in Italy, Spain and Finland as shown in Figure 4.

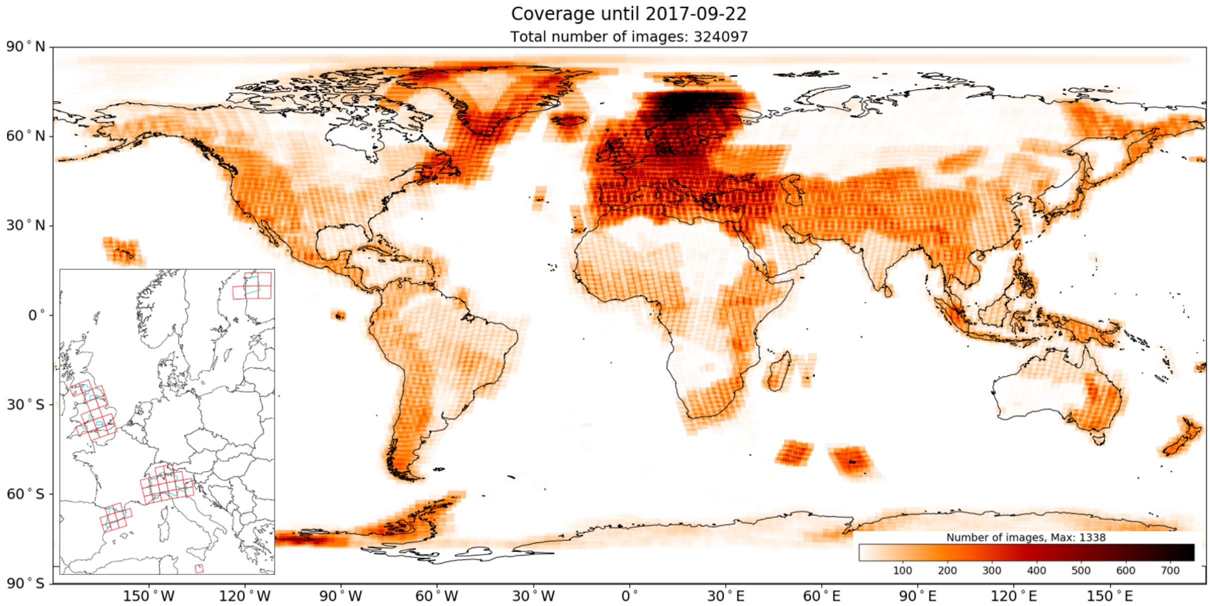

Figure 4. Primary regions of interest (inset, red tiles) for I-REACT flood mapping service, and Sentinel-1 Interferometric Wide Swath (GRD product) coverage map.

Data acquisition and management

The data acquired by the Sentinel-1 satellites is downlinked to the collaborative ground segment from where via ESA network it is being distributed to other sources like Scientific Hub[2] and ESA Server ZAMG (Zentralanstalt für Meteorologie und Geodynamik). From ZAMG, data is pushed to the national mirror and then to the EODC (Earth Observation Data Centre) data storage. The S1 data at the EODC warehouse are currently available approximately 2.5 hours after the initial signal processing by ESA (level-1 product) and 6.25 hours after the acquisition.

The S-1 level-1 data are archived on fast discs storage and backed up using a robotic tape library on a regular basis. In order to manage the raw and processed S1 data files a dedicated meta-database (EOMDB: Earth Observation Meta-DataBase) has been established, which allows tracking of data availability and processing status (see Figure 4).

METHODOLOGY: REAL-TIME FLOOD MONITORING / MAPPING SERVICE DESIGN

The Sentinel-1 based flood mapping and monitoring service is an external module which has been developed and maintained by TU Wien for I-REACT project, which can be triggered upon request via Azure Service Bus[3]–a cloud messaging service between applications and services.

Infrastructure and service logic implementation scheme

Within the framework of I-REACT project, the Sentinel-1(S-1) data processing chain for flood mapping service is implemented within a virtual machine hosted by the Earth Observation Data Centre (EODC). The processing chain and dataflow includes following steps as illustrated in Figure 5

- *Flood mapping processor:* The flood mapping algorithm is developed by TUWien and implemented within a virtual machine at the Science Integration and development Platform (SIDP) hosted by EODC. The

[2] `https://scihub.copernicus.eu/`
[3] `https://azure.microsoft.com/en-us/services/service-bus/`

processing chain includes pre-processing of the SAR data, data quality controls, flood mapping, and necessary post-processing steps. The SIDP is connect to the Vienna Scientific Cluster with more than 2000 computing nodes which might be used for heavy processing tasks that need parallel processing. The final products are flood and flood frequency maps.

- *Service on request and triggering mechanism:* this service is established to provide rapid post disaster flooding status and inundation extent maps, which can be used for post-disaster management and relief activities. In this service the user/customer will contact TU Wien through I-REACT coordination (e.g. via Azure Service Bus) to trigger the flood mapping/monitoring service. The requested product will be delivered to the IDI. The flood mapping/monitoring service is fully automatic and can be triggered over a defined location with the message received via Azure Service Bus.
- *Watchdog:* after getting the triggering message–with a bounding box of an area of interest and monitoring period (start and end date)–via Azure Service Bus, the program will automatically connect to the EOMDB and get the available raw files. Then the processing chain will be activated for available files. If there is/are no file(s) then a watchdog will be activated and and it will update EOMDB after every two hours and look for new files for the area of interest. Every time when it will find new file(s) a new independent processing chain instance will be launched. This process will continue until the image acquisition date is less than or equal to the end date defined in the message.

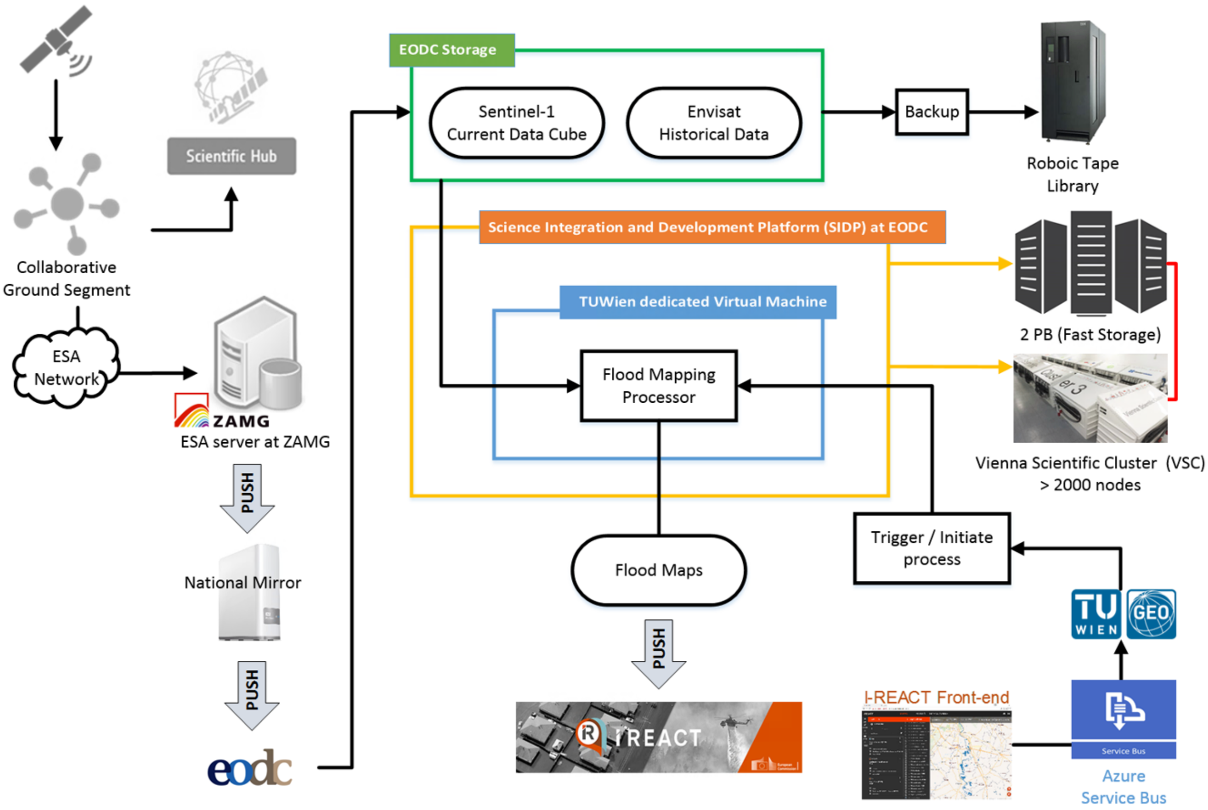

Figure 5. An overview of infrastructure and service logic for near-real time flood mapping/monitoring.

RESULTS AND PROTOTYPE

The stability of the processing chain and the implemented service logic was tested by triggering the service for three different requests simultaneously. The processing chain ran successfully and processed 21 Sentinel-1 scenes. The final product of 2.5 GB was uploaded to the IDI database. Due to the limited number of cores on the test machine, the processing chain ran for more than 24 hours. In case of multiple requests the processing time can be minimized by increasing the computing power.

Sentinel-1 based flood and flood frequency maps were produced for all five test site. Figure 6 shows an example of Sentinel-1 based flood frequency product for a test site in Italy (Emilia–Romagna).

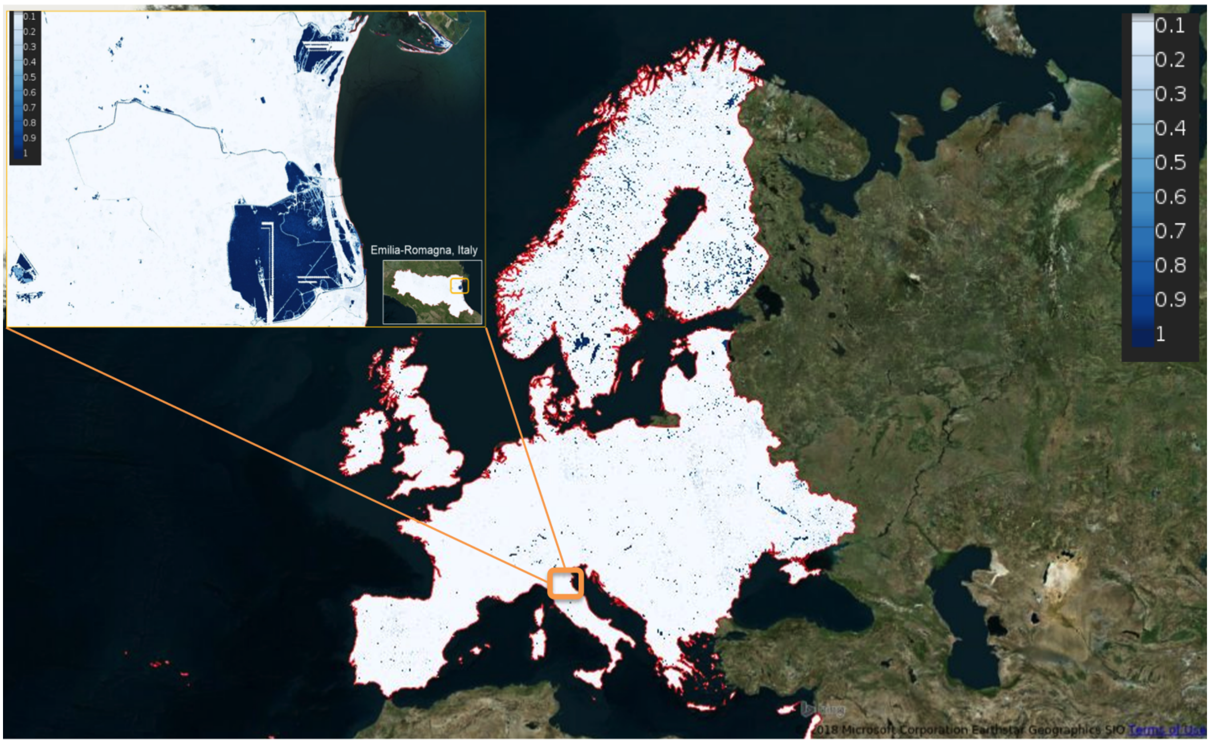

Figure 6. An example of multi-temporal flood frequency layer for Europe.

In addition to the final product–flood or flood frequency maps–that will be delivered to the IDI, different Sentinel-1 based intermediate products will also be produced. The intermediate products includes pre-processed data and various biophysical and statistical parameters as well. In order to query the data/product a pre-defined set of minimum required metadata is also pushed to the IDI.

After data harmonization step flood maps become available for visualization on the front-end (I-REACT main web-page) of the I-REACTOR. Figure 7 shows the display of the flood frequency product on the front-end of the I-REACT emergency service management website.

CONCLUSION

In this short paper we have demonstrated a framework and feasibility of setting up an operational flood mapping and monitoring service by exploiting a big-data infrastructure and high performance computing facility. This service will be operational under the framework of I-REACT project, and new development in terms of algorithm improvement and performance enhancement will be integrated into the SGRT.

ACKNOWLEDGMENT

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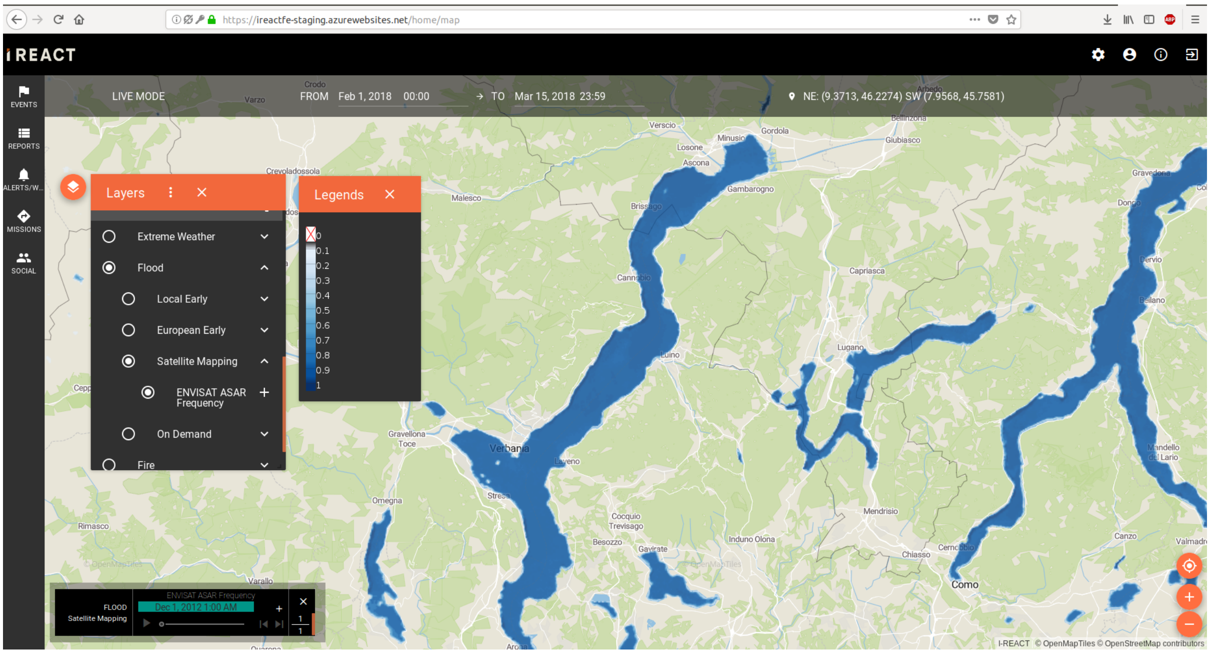

Figure 7. Front-end of the I-REACT emergency service management system where the water frequency product (in blue colour) is over-laid to the base map. Water frequency with spatial resolution of 75 meters is calculated by using Envisat ASAR data cubes covering 10-years time spam (2002–2012).

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