RÉSIF-SI: A DISTRIBUTED INFORMATION SYSTEM FOR FRENCH SEISMOLOGICAL DATA

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Abstract

The Résif project, which started in 2008, aims at gathering under a common research infrastructure the French seismological, GNSS and gravimeter permanent networks, as well as the mobile instrument pools. A central part of Résif is its seismological information system, Résif-SI (started in 2012), which is in charge of collecting, validating, archiving and distributing seismological data and metadata from seven national centers. Résif-SI follows a distributed architecture, where the six data collection and validation centers (A-nodes) send validated data and metadata to a national data center (Résif-DC) which is the central point for data archiving and distribution. Résif-SI is based on international standard formats and protocols and is fully integrated into European and international data exchange systems (EIDA, EPOS, IRIS, FDSN). In this paper we present the organization of Résif-SI, the technical details of its implementation and the catalog of services provided to the end users. The paper is aimed both at seismologists, who want to discover and use Résif data, and at data center operators, who might be interested in the technical choices made in the implementation of Résif-SI. We believe that Résif-SI can be a model for other countries facing the problem of integrating different organizations into a centralized seismological information system.

Introduction

Résif (Réseau sismologique et géodésique français – French seismological and geodetical network – https://www.resif.fr) started as a project in 2008, with the aim of grouping into a single research infrastructure all the major national and regional seismic, GNSS and gravimeter permanent networks and mobile pools in France. Hand in hand with this objective was to improve and rationalize the data distribution system. GNSS data from all Résif partners is distributed from the national Résif data center for GNSS data (Résif, 2017), which also hosts the EPOS GNSS data gateway, while the Résif data from permanent gravimeters are directly integrated into dedicated international data centers (Voigt et al., 2016). In this article we focus on the seismological part of the Résif Information System (Résif-SI), for which the architecture, technical implementation and governance structure has proven to be adequate to address data distribution through a coordinated national cooperative. Note that the present article refers to seismic waveform data and metadata: higher-level earthquake products in France are now also being integrated into Résif, as discussed in Masson et al. (2021).

Prior to Résif, French seismic waveform data was distributed from five institutions:

- CEA (Commissariat à l'énergie atomique et aux énergies alternatives), commissioned by the French ministry of the Interior to establish earthquake alerts towards the national authorities, operated (and still operates) a dedicated seismic network with high availability data transmission (Massinon and Plantet, 1976; Résif, 2018). Data from this network was available through direct cooperation with CEA.

- ISTerre (then: LGIT) in Grenoble distributed data from the national strong motion network (RAP – Résif, 1995) via the RAP National Data Centre (RAP-NDC – Pequegnat et al., 2008). ISTerre also ensured national distribution of data from temporary seismic deployments using the national instrument pool, but most research laboratories also ran their own, smaller instrument pools.

- IPGP (Institut de physique du globe de Paris) distributed data from the GEOSCOPE network (IPGP and EOST, 1982), via the GEOSCOPE data center, with a historical strong role of

GEOSCOPE in the promotion of open data distribution at a worldwide level (Roult et al., 1999). IPGP also operates three seismic networks in the Antilles (IPGP, 2008a,d,b), and one in Reunion Island (IPGP, 2008c), and those datasets were at the time planned for integration in the IPGP data distribution.

- Géoazur and EOST (École et Observatoire des Sciences de la Terre): the metropolitan French broadband and short period data were loosely integrated in a national cooperation related to long term Earth Observations, but each regional network was operated independently, with no joint instrumentation policy, and distributed mainly by these two institutions.

The principle of transparent access to data through the common international distribution tool `netdc` (Casey, 1999) was agreed as a common goal, through an additional transparent layer to a virtual data center, FOSFORE (Shapiro et al., 2008). Practically, the national French Broadband network was underperforming, for a lack of sufficient station coverage and homogeneous instrumentation policy. Also, the difference in technical implementation of data and metadata distribution, data holdings and data center availability between the five locations meant that the federated approach in practice needed to evolve to a new system.

When Résif was created as a concept, it moved under the direct supervision of the French Ministry of higher education and research, and integrated 18 organizations into a national consortium, which was signed in 2011. As a first success of this coordination effort, Résif obtained the funding (9.3 M€, with approximately the same amount committed by the partners in terms of staff time) for a project with four main components: the construction of a national broadband network; the extension and renewal of the GNSS network and of the different mobile pools; the creation of a national Résif information system. The constraints from labor policies and civil servants meant that the permanent staff would transfer without relocation from the old system to the new, with additional temporary staff provided to accompany the changes.

The result of this effort is presented in this article. The architecture of the Résif information system (French: système d'information, hereinafter Résif-SI, re3data.org, 2016) is fully distributed, matching the distributed architecture of the French seismic networks, which relies on CEA and on regional operators (mainly Observatories hosted at universities, and with strong CNRS involvement) for production and validation of data and metadata. These operators, through the so called "A-nodes", have full responsibility of pushing data and metadata into the data distribution center, via an automated procedure which allows for regular updates and automatic replacement in the data bases, as instruments are replaced, errors (timing, instrument responses, . . .) are corrected, and data gaps are filled. The system is at the same time fully integrated, with a national management team (Executive Committee), a technical board which meets monthly and which adopts joint technical solutions, a single national data distribution facility (hosted by the University of Grenoble), and a coordinated participation in international and European and collaborative instances such as FDSN (https://www.fdsn.org) and ORFEUS (https://www.orfeus-eu.org). In particular, the national data distribution facility is part of the EIDA federation, a service within ORFEUS which gives federated access to data from European data centers. EIDA is described in Strollo et al. (2021).

Résif-SI has provided, within the constraints given, remarkable results, with a stable and high quality data distribution and a full integration into the international collaborations. The data holdings and download statistics are on par with other large data centers in Europe.

We believe that the Résif-SI implementation can be a model for countries which face the challenge of regrouping observation networks and data distribution, and particularly those countries where the need for regional and institutional visibility and independence remain strong, but where each institution alone does not have critical mass for running a high availability data center.

The paper is structured as follows: we start describing the overall Organizational structure of Résif-SI, for then discussing the Data management: Résif-DC system and in particular the technical choices behind the Résif-SI data center and how they have been functional to integrate Résif-SI into the international data exchange systems. The section “New developments” illustrates four areas (Large-N experiments, Marine data, Building and infrastructural monitoring, and a StationXML metadata editor) for which Résif-SI is at the forefront of current development in seismological data management. We conclude by presenting the upcoming challenges and the strategy to meet them. An Appendix (“Appendix: Data access details and examples”) is provided with details and practical examples on the different ways to access Résif-SI data.

Organizational structure of Résif-SI

Résif-SI archives and publishes seismological data from eleven permanent networks and approximately seventy temporary networks (Fig. 1).

Seismological data and metadata are collected and validated by six centers run by Résif partners which are called “A-nodes” (Fig. 2), which are also responsible to secure a copy of the data for two years. The data and metadata are then transmitted to the Résif seismological Data Centre (Résif-DC –also called the "B-node") hosted by the University of Grenoble Alpes for archiving (storage and remote archive) and distribution (services, portal). Résif-DC is designed and operated by a technical team from ISTerre and from the Observatoire des Sciences de l’Univers (OSUG). Table 1 illustrates the typology of data available from each of the 6 operational A-nodes, while Fig. 3 shows the proportion of data archived at Résif-DC by type: accelerometric, velocimetric and other. A 7th A-node, MARINE, operated by IPGP (Institut de physique du globe de Paris) and OCA (Observatoire de la Côte d’Azur), is in its implementation phase, and will collect and validate the data from ocean bottom seismometers (OBS).

Résif-DC, the national Résif data distribution center, is one of nineteen global centers distributing data and metadata using formats and protocols which comply with International Federation of Digital Seismograph Networks (FDSN –https://www.fdsn.org) standards. It is also one of the twelve nodes of the European Integrated Data Archive (EIDA –http://www.orfeus-eu.org/data/eida/).

From the very beginning of Résif-SI in 2012, it was defined that the quality of data and metadata and their rapid and regular availability was the responsibility of the A-nodes, while the quality and continuity of data services depended on the national data center. This principle is still at the core of the organization of Résif-SI, but all of Résif-SI jointly takes action to continuously improve data and metadata quality.

Data and metadata workflows

A-nodes take care of data validation and production of associated metadata for the observatories and instruments they are responsible of, according to their own workflows and objectives of completeness and quality.

Data integration is initiated, managed and controlled by the A-nodes which can add, modify or replace data and metadata (the removal being under the control of Résif-DC) at their own discretion and according to their rhythm, in an autonomous way. To this purpose, Résif-DC maintains the dedicated tool `ResifDataTransfer` (Volcke et al., 2013). An important and explicit rule of Résif-SI is that Résif-DC does not in any way modify the data or metadata provided by A-nodes. The data and metadata completion/validation process at A-Nodes is iterative. Since A-Nodes are responsible for retaining all raw data collected by any means (including data in proprietary formats) for at least two years, all or part of the processing phases can be easily reversed if necessary.

The integration protocol specifies:

- the *formats* allowed as input: *miniSEED* (Ahern et al., 2012) or *PH5* (Hess et al., 2018) for data, *StationXML 1.1* (FDSN, 2019) for metadata;
- the transfer modalities –based on *rsync* (Tridgell and Mackerras, 1996) *push*– and acknowledgment –based on *rsync get* or a *web service*;
- the *checks* carried out before the metadata and the data are integrated into the database and the data archiving;
- the integration modalities: a product submission is a *transaction*;
- the *structure of the integration report* to the partner.

The integration controls are implemented at the data center level and have been jointly specified.

From the point of view of A-nodes, any product submission (simple or complex) is a transaction, whose characteristics are preserved and can be retrieved by a web service. The integration of data and metadata is asynchronous and the consistency between them is re-evaluated at the end of each transaction. The submission of not-yet-described or incompletely described data is allowed, in order to secure them as soon as possible and according to the needs of the A-nodes, but Résif-DC data services do not deliver any data whose metadata is not available. This workflow is illustrated in figure 4.

From the point of view of Résif-DC, an integration of data or metadata is a succession of complex operations carried out by several independent workers (Fig. 5) that communicate with each other via an AMQP (Advanced Message Queuing Protocol) system (ISO/IEC 19464, 2014). Four databases are populated at this stage: (1) inventories of networks, stations, channels and responses; (2) waveform inventories (PostgreSQL databases, PostgreSQL Global Development Group, 1996); (3) metrics and data quality information (MongoDB - EIDA WFCatalog database, MongoDB, Inc., 2009; Trani et al., 2017); (4) elements for monitoring the integration operations (PostgreSQL). Consistency of information within and between databases (1), (2) and (3) is guaranteed by construction. Data is archived in a SDS structure (GFZ and gempa GmbH, 2008, if miniSEED data) or as HDF5 record (Folk et al., 2011, if PH5 data).

Résif-DC also computes on the fly, with each integration, some useful side-products. For instance, Power Spectral Density plots (PSD, McNamara, 2004) for the data manager and the end user to check the quality of the signal generated with PQLX (McNamara and Boaz, 2010), but also availability plots generated with the help of a SEED data indexer (`seedtree5`, Volcke et al., 2012).

Résif-DC exposes two web services for A-Nodes to manage their data and transactions:

- **https://ws.resif.fr/resifws/transaction/1**: to retrieve transaction records, for example to analyze and correct rejected data or metadata;
- **https://ws.resif.fr/resifws/orphanfile/1**: to identify orphan data (without metadata) in the Résif archive for corrective action.

Other operations have to be requested through a help desk because either they are rare, or there is no safe way to automate (e.g., data removal).

Metadata enhancement

Résif-SI has progressively improved the quality and consistency of metadata by establishing a controlled vocabulary and recommendations for standardizing the content of text fields in metadata. Initially, the metadata of A-nodes were managed in local databases and formatted using the open source PDCC tool by IRIS (Casey, 2016) or in-house tools. Each A-node has its specificity regarding metadata. In particular, SISMOB and RAP have to deal with a large diversity of instruments and very complex metadata. With this context, in-house tools to manage the metadata was mandatory. Indeed, all the constraints on the metadata for Résif-SI networks could not be included into any standard software (e.g., SeisComp, GFZ and GEMPA GmbH, 2008) at the time.

Before 2019, metadata were edited and submitted in SEED dataless format (Ahern et al., 2012) and Résif-DC ingested the metadata and delivered it in the normalized StationXML format (FDSN, 2019). Today, all A-nodes produce StationXML metadata and most of Résif-SI is moving toward a common toolbox and database for metadata edition. Section "Metadata editing made easy: YASMINE" gives additional information on this project, which has high priority in Résif-SI, since StationXML gives visibility and full acknowledgment of all dataset contributors –from station to data distribution (see section "Data fairness"). This normalized information is automatically exported to the Résif-SI web portal and to other services. Moreover, StationXML allows referencing to persistent network identifiers to facilitate citation, and includes new fields necessary, for example, for OBS data (see section "Marine data").

Data collection and completion

The management of data flows is specific to each A-node. However, Résif-SI offers its own tools that are generic enough to be deployed outside their initial context. An example is MORUMOTTO (MOdular aRchive bUilder from Multiple Origin Temporal Traces & Other stuff – Geber, 2019), developed by IPGP for A-node VOLCANO. MORUMOTTO is used by network operators to quality control a data archive, and in particular to detect and correct data gaps and overlaps. Data is regularly fetched from a pool of different sources.

Data validation

Data validation procedures are specific to each A-node.

Data from networks FR and RA is qualified "M" ("data center modified, time-series values have not been changed" –see Ahern et al., 2012, page 108), and is made available 3 to 5 days after collection by A-nodes, after having undergone the following checks:

- data has been completed as much as possible;
- there is no overlap, even at the sample level;
- instrument response validity epochs do not overlap;
- the power spectral density of the signal is in accordance with what is expected for each particular station.

Data from networks G, GL, MQ, WI and PF is made available with the quality label "Q" ("quality controlled data, some processes have been applied to the data" –see Ahern et al., 2012, page 108), and undergoes additional checks, namely:

- waveform modeling of teleseismic earthquakes of magnitude larger than 6 through the SCARDEC method (Vallée et al., 2011) shows a good agreement between the observed and predicted signals;
- for multi-parametric stations, the acceleration-converted seismometer and accelerometer waveforms are identical for a selection of suitable earthquakes.

Because of the complexity of these additional operations, validated data from these networks is available 6 to 12 months after its collection.

Availability of validated data from SISMOB temporary networks depends on the specificity of each experiment and generally varies between 1 and 6 months (note that SISMOB data might be under embargo for up to three years).

Table 2 summarizes the latency for the production of validated data by A-nodes, and their data quality label. Note that, for networks collected in real-time (see section "Real-time: SeedLink"), raw data is immediately available and eventually replaced with validated data.

Quality of Service

The Résif-SI organization does its best to implement a set of high quality services with high operational performance, i.e. as continuously available and robust as possible. To achieve this, we developed a culture of quality of service, based on a set of best practices, among which:

- a single help desk, accessible by email at resif-dc@univ-grenoble-alpes.fr. Users are typically scientists searching for data, data or metadata producers needing help to access the services, or network managers needing assistance.
- a clear presentation and documentation of our services through the website https://ws.resif.fr;
- an automated system which tests thoroughly our services and infrastructure, and monitors the overall activity in order to alert the relevant personnel of Résif-SI as early as possible in case any potential issues or anomalies are detected.;
- an RSS feed to publish news or scheduled downtime events.

The website http://seismology.resif.fr is also the place to browse all the available metadata, to get information about citations, data and metadata access. It is also used for announcements regarding operational news of Résif-DC, like maintenance down times or new services availability.

The monitoring system checks all the Résif-DC services, mimics user access for testing and alerts the operational team if necessary. It also monitors lower levels of the infrastructure of Résif-DC. The gathered information is used in reports to publish the overall availability of the data center.

Measuring and publishing the availability of our services is an ongoing project that will be completed in 2021. Service level agreements (SLA) will be defined by the Executive Committee for our main services and the data center's yearly report will show the metrics. Table 3 provides a rough estimate of service availability at Résif-DC in 2020, based on network reachability. Based on feedback from the EIDA User Advisory Group, EIDA is presently working on a periodic test bench of all the nodes based on random requests of data and metadata which will be more representative of the services availability.

Data management: Résif-DC

The construction of Résif-SI is patterned on a Data Management Plan (e.g., Michener, 2015) describing the responsibilities of each partner, how long data should be stored, how metadata is managed, how data is accessed. Résif-DC has a central role to play in this plan: it ensures that data is securely stored and easily accessible.

Data archive description

Résif-DC stores the data in miniSEED (using the SDS structure, Ahern et al., 2012; GFZ and gempa GmbH, 2008) or PH5 format (Hess et al., 2018). The latter is designed by IRIS PASSCAL (Portable Array Seismic Studies of the Continental Lithosphere), is based on HDF5 (Folk et al., 2011) and widely used by the temporary experiments using dense arrays.

Résif-DC holds miniSEED data from 1986, all accessible through the FDSN `dataselect` web services. Fig. 6 shows the volume of miniSEED and PH5 data, by network, held for each year as of January 2021. We account for 68% of data from permanent networks versus 32% from temporary experiments.

The increasing amount of data stored came from two major factors: first, the deployment of approximately 150 new permanent broadband stations; second the increasing number of temporary experiments associated with SISMOB. We anticipate a strong data growth in coming years due to increasing number of experiments using dense arrays and the foreseen integration of data from Distributed Acoustic Sensors, but the numbers are still difficult to quantify, as discussed in Quinteros et al. (2021).

The data management description has been used to design an efficient central storage at Résif-DC. Data is kept on two classes of storage, ensuring the same data security but with different levels of performance. While seldom requested data is still quickly accessible, it is kept on a less powerful and less expensive media. This storage tiering is one of the many features of our storage provider SUMMER and is totally transparent for the data center systems, thanks to a storage abstraction layer (`autofs`). Once a year, the data that can be transferred to less powerful storage media is selected according to the seismic network's data management plan and manually moved.

Securing the data

When it comes to store the data securely, one has to identify and address several types of risks. Résif-DC is concerned about:

1. hardware failures;
2. unintentional or malicious alteration/deletion of the data by an operator;
3. local disaster destroying physically the archive located in Grenoble (flood, earthquake, . . .).

Risks 1 and 2 are addressed *de facto* by Résif-DC through the choice of storage provider SUMMER (Université Grenoble Alpes, 2016), operated by the university of Grenoble Alpes, which secures the data in three different data centers and offers a daily snapshot service. By using the university storage service, we also ensure that all the data is kept on an academic and publicly funded platform .

The risk 3 of a local destruction has been addressed by copying twice a year a snapshot of our archive to tapes stored at a distant place. At this juncture, we have secured a collaboration with the the Computing Centre of the National Institute of Nuclear Physics and Particle Physics (CC-IN2P3, IN2P3/CNRS, 1976) located in Lyon, to serve as this remote site. Although the recovery plan is not fully formalized, we guarantee that the data hosted at Résif-DC will survive the mentioned risks, as long as it has been stored for at least six months. An additional copy for recent data is ensured by A-nodes, which are committed to keeping a secure copy of their datasets for a duration of two years.

Altering or destroying the data hosted by Résif-DC would require an operator or an attacker to get access to high privileges on three independent infrastructures, namely:

- Write access to the Résif-DC infrastructure would allow to delete live data in the archive. The data can in that case be retrieved from SUMMER snapshots or backups;
- Write access to the SUMMER infrastructure would allow to destroy backups, snapshots and live data. The data and metadata can in that case be recovered from a distant copy made twice a year at CC-IN2P3;
- Write access to the CC-IN2P3 infrastructure would allow to destroy the distant copy.

Résif-SI considers that the scenario of the combined access to these three infrastructures is unlikely to happen.

Data distribution services

Résif-SI data distribution is based on a small set of elementary and very robust data services, which can be divided into: real-time data access, asynchronous data access, and web services. These base services constitute the building blocks for higher-level data services and products provided by Résif-SI, or by European and international partners. Résif-SI is fully integrated into EIDA through its elementary data services. EIDA offers a wide set of additional services and tools, including smart clients, federated archive access and web interfaces. A full description of EIDA can be found in Strollo et al. (2021).

The Résif-SI web portal (http://seismology.resif.fr) provides information about Résif-SI, documentation on how to use the elementary and additional services, licensing, etc. It also provides URL builders for the web services and dynamic search options for browsing the seismic networks, station metadata, data availability, data quality, etc.

Résif-DC has implemented most of its data models and workers in order to preserve the specificity and accuracy of the metadata produced by A-nodes. In particular, care was taken to be able to export the rich Résif-SI metadata. This *a priori* expensive solution proved to be profitable in the long term, as it enabled Résif-SI to integrate from early on the description of non-seismological channels (polynomial responses), and to manage all station and channel comments, as well as OBS metadata. In this way, additional services are effective across all the data types managed by Résif-SI.

The two initial FDSN web services `station` and `dataselect` (FDSN, 2013) were put into production in 2013. Their implementation is based on IRIS WebServiceShell (IRIS, 2016), which we interfaced (via Python) with our databases and archives. All the other web services have been implemented in Python and ObsPy (Beyreuther et al., 2010; Megies et al., 2011; Krischer et al., 2015) within the FLASK framework (Ronacher, 2010) and their codes are fully available on public code repositories (see Data and Resources).

The basic Résif-DC data services are:

- A SeedLink server (GFZ and gempa GmbH, 2008), accessible at `rtserve.resif.fr` (standard port 18000), for real-time access to miniSEED data. This service, based on IRIS `ringserver` (Trabant, 2011), provides a single access point to all the real-time data streams of the A-nodes for which metadata is publicly available;
- The standard `fdsn-dataselect` web service (FDSN, 2013) to access validated or near real-time data –public or restricted– for all of the miniSEED archive.
- The FDSN-compliant `ph5-dataselect` web service (Résif, 2019a), which serves large-N data (stored in PH5 archives) as miniSEED or SAC format on the fly (useful for small subsets of the PH5 datasets);
- The standard `fdsn-station` web service (FDSN, 2013) to retrieve station metadata;
- The standard `fdsn-availability` web service (FDSN, 2013) to interrogate the miniSEED data inventory;
- The FDSN-compliant `ph5-availability` web service (Résif, 2019a), to interrogate the PH5 data inventory;
- The `eidaws-wfcatalog` web service (Trani et al., 2017) to retrieve data availability as well as other metrics (e.g., gaps, overlaps, RMS);

- The standard `fdsn-event` web service (FDSN, 2013), operated by BCSF-RéNaSS (Bureau Central Sismologique Français, French Central Seismology Bureau – Réseau National de Surveillance Sismique, National Seismic Monitoring Network), which gives access to event parameters located by BCSF-RéNaSS (Masson et al., 2021).

Résif-DC also allows the retrieval of a complete dataset, by network, using `rsync` protocol. The user is granted read-only access to the part of the archive exposing the dataset. This is particularly useful to retrieve entire datasets in PH5 format. Fig. 7 shows the amount of waveform data served by `fdsn-dataselect` and SeedLink.

Built on top of these base services, the following additional web services are available from Résif-DC:

- The `timeseries` and `timeseriesplot` web services (Résif, 2019a) to obtain pre-processed waveforms or plots;
- The `resp`, `sacpz` and `evalresp` web services (Résif, 2019a) to obtain or plot instrumental responses;

A complete catalog of the Résif-DC web services is available on https://ws.resif.fr. More details and usage examples are given in the "Appendix: Data access details and examples".

Data fairness

Data fairness refers to the FAIR (Findable, Accessible, Interoperable, Reusable) guiding principles for scientific data management and stewardship (Wilkinson et al., 2016). We here discuss how far we are complying to those best practices.

The **findability** of our data and metadata is ensured by the international standard web service `station` (FDSN, 2013), accessible via any web browser, http client, and the community's most popular tools like ObsPy (Beyreuther et al., 2010; Megies et al., 2011; Krischer et al., 2015), EIDA's `fdsnws_scripts` (Heinloo, 2018) or the Web Service Fetch scripts (Hutko, 2013). In addition, most of the Résif datasets have DOIs (Digital Object Identifiers) associated with their seismic network, according to the standard procedure approved in 2014 by the FDSN (Evans et al., 2015). Within Résif-SI, much effort has been dedicated to manage the quality of the published metadata, as stated in section "Metadata enhancement". The seismological metadata is very descriptive, allowing scientists to identify precisely the data needed. In addition, the `station` web service provides a rich set of options to make selections in the metadata catalog, such as time period, geographical region, or update time. Findability of Résif-SI data is also guaranteed by the ORFEUS European metadata catalog (ORFEUS, 2020a), implemented by EIDA and maintained by ETH-Zürich, which enables users to fetch metadata from all the EIDA's data centers in one request, at one entry point. Finally, within FDSN, a large effort in establishing data routing tables has been achieved. Now, each seismological network has a well known reference data center, and this information is made publicly available by each data center, and can be consulted for each network on the FDSN's network details page (FDSN, 2020).

The **accessibility** of the data is ensured by the international standard web service `dataselect` (FDSN, 2013) that gives access to all Résif's archive, except for data in PH5 format, which has its own non-standard web service `ph5-dataselect` (Résif, 2019a). Authentication is also provided for restricted data, with local methods or with EIDA's authentication system.

The **interoperability** is ensured inside Résif by adopting a common vocabulary for StationXML metadata, which makes it possible to expose on the the Résif portal significant parts of the StationXML content coherently across all the operators. For the services to the user, interoperability is first and foremost ensured by web services in strict adherence to FDSN standards when available. This is the key for universal data and metadata access through interoperable additional layers across many data centers offering the same services. At a service level, EIDA offers such interoperable services (e.g. WebDC3, ORFEUS 2020b, which gives transparent access to the data of all the EIDA nodes) while many users develop workflows based on the FDSN web services interfaces (e.g., Zaccarelli et al., 2019; MacCarthy et al., 2020). Cross-disciplinary interoperability requires challenging standardization of metadata vocabulary, both for data and services. The interoperability between the different Résif data types (seismology, GNSS, gravimetry) is delegated to the EPOS infrastructure, into which Résif is fully integrated. National technical discussions are undertaken across different EPOS activities in France, rather than strictly within Résif perimeter, and the Résif seismology and GNSS community actively contribute to EPOS. The EPOS cross-disciplinary interoperability is achieved through a dedicated layer that connects different services through a metadata catalog which uses standardized vocabulary to describe the services. Additionally, the scientific users of Résif data are already observed to mix data and data products from different domains (e.g., seismic waveforms with environmental data, such as weather condition or ocean wave activity) within smart clients that they create, or by mixing data from local files downloaded from different sources with direct download of waveform data. The main condition for the success of these applications is meticulous application of domain standards and the effective data and metadata accessibility.

The data provided by Résif-SI is also made **reusable** in respect of the FAIR guidelines. The rule of Résif-SI is to distribute all open data under the Creative Common Attribution 4.0 license (Creative Commons, 2013) CC4.0:BY, coherent with French Law. StationXML specification (currently at version 1.1 –FDSN 2019) does not provide a field to indicate the data license, but we made this information easily accessible by systematically exposing the DOI of a network via the `<Identifier>` tag in StationXML metadata. As an example, metadata from RAP network (network code "RA", accessible from https://ws.resif.fr/fdsnws/station/1/query?network=RA&level=network) contains the following tags:

```
<Description>RESIF-RAP Accelerometric permanent network</
   Description>
<Identifier type="DOI">10.15778/RESIF.RA</Identifier>
```

License information is provided in the DataCite XML document (DataCite, 2019) of each network via the `<rightsList>` tag. For instance, the "RA" network DataCite XML (https://data.datacite.org/application/vnd.datacite.datacite+xml/10.15778/RESIF.RA) contains the following tags:

```
<rightsList>
```

```
    <rights rightsURI="info:eu-repo/semantics/openAccess">Open
       Access</rights>
    <rights rightsURI="https://creativecommons.org/licenses/by
       /4.0">Creative Commons By 4.0 Universal</rights>
</rightsList>
```

Citation instructions are available on the DataCite page (e.g., https://search.datacite.org/works/10.15778/RESIF.RA) and dynamically presented by several portals (e.g., FDSN network details, FDSN 2020, or Résif seismic data portal, re3data.org 2016). Résif-DC provides a list of citation instructions in the portal's citation page (Résif-SI, 2020). We strongly encourage scientists to cite data producers and distributors in their papers.

The use of licenses for seismic waveform data is presently only at its beginning, with licenses being put in place for many seismic networks in Europe. A strong motivation are the citations (see above), but also to handle liability issues in the case of erroneous data or metadata. Résif-SI is actively working, within the framework of a cooperation between ORFEUS and IRIS, to promote good citation usage to scientific users of waveform data, and to inform publishers of these progresses, as the introduction of licenses engages the liability of the journals and of the publishing scientists, even though this liability is not yet reinforced.

An accompanying issue is that data centers who hold copies of the datasets need to expose the license information in a proper way. For this to be practically possible, Résif-SI has, with the agreement of the involved organizations, stopped all data copies to other data centers which were previously put in place, and asked for the old copies to be deleted. The only exception is GEOSCOPE data archived at the IRIS Data Management Center, due to a strong user base of GEOSCOPE data through this data center. Overall, the seismological community worldwide still needs to efficiently communicate license information to users, but if the citations (see above) are properly done, the license CC4.0:BY is respected.

Citation through the use of DOIs is only meaningful if the associated metadata is sufficiently rich to include all the parties that contribute to the data production, management and distribution. Résif-SI uses the `contributor` field of DataCite metadata (DataCite, 2019) to acknowledge different types of contribution and roles within each seismic network, and more specifically the `contributorTypes` *DataManager* (Résif-SI), *Distributor* (Résif Data Center), *HostingInstution* (Université Grenoble Alpes), *DataCurator* (the relevant A-Node), *DataCollector* (organisations that operate the seismic network) and *Sponsor* (funding sources).

From logging to usage statistics

Data usage statistics are important information for the different persons associated with data production, management and distribution. For example, the Résif-DC team needs to have real-time usage statistics, correlated with IT system metrics in order to catch anomalies or anticipate requests growth while data producers, project principal investigators and funding agencies need compiled usage statistics in a larger view and for larger time span, such as overall statistics (for example number of requests, users, shipped volumes, countries of request) or network relevant information (for example network level download statistics, the most accessed stations, countries of requests).

In order to satisfy all the needs for statistics we built a system that concentrates the information, builds statistics and gives access to dashboards (Fig. 8).

The constraints come from the variety of data access methods, each one having their own log formats which are not always compatible with real-time processing. Another difficulty is to analyze the data served through web services. It's easy to capture the quantity of data shipped by the web server, but it's not possible to know what it is made of (which network, station, location or channel). Consequently, we have to analyze each request and evaluate the typology of the response. All the gathered information is stored in a PostgreSQL database, aggregated and anonymized. The anonymization concerns the client's IP address and consists of hashing it as soon as it enters the databases. Then, when the requests are aggregated, we only keep HyperLogLog objects (Flajolet et al., 2007) in order to compute the cardinality of the clients. Therefore, our databases respect the European legislation (General Data Protection Regulation, GDPR), as there is no way to retrieve an

IP address nor any kind of personal data.

The statistics can be accessed through several means: we provide a web service for end users (see Appendix: Data access details and examples), and interactive dashboards for internal usage (e.g., analyzing operational events in real time, usage and performance evaluation –Fig. 9). Fig. 10 is an example of rendering statistics in a geographical map. Recently, we published a system allowing automatic creation of plots and usage statistics in form of a report (`resif-delivery-stats-plotter`, Bollard 2021). This program is aimed at network managers or principal investigators seeking information on data and metadata usage.

New developments

Large-N data management

Large-N data are produced by temporary experiments deploying small, self-contained seismometers (the so called "nodes") in dense arrays, with high sampling rate (i.e., above 100 samples per second, e.g., Brenguier et al., 2016; Dougherty et al., 2019; Gimbert et al., 2020). The raw data generated by those experiments is approximately 1 GB per day per node, and an experiment can use hundreds of nodes for several months. In addition, the data management needs specific workflows and data format treatments.

In order to host and distribute this new kind of data, the SISMOB A-node developed a specific workflow which produces validated data in PH5 (Hess et al., 2018), a data format developed at IRIS by PASSCAL and commonly used for Large-N data. In order to ingest this new data format, Résif-DC also adapted the integration mechanisms and storage repositories, since PH5 data cannot be indexed nor referenced in the same way as miniSEED data. Furthermore, in order to host the foreseen volumes, a dedicated archive storage has been setup.

The metadata, on the other hand, is created in classical StationXML format, as other miniSEED data, and submitted at Résif-DC using the standard procedures described above.

The PH5 archive is served to end users by two means:

- `rsync` access for a restricted set of users needing to download the entire dataset;
- the `ph5-dataselect` web service (Résif, 2019c) allowing the selection of a subset of the data in miniSEED format with the same options and syntax as the FDSN `dataselect` web service specification

Résif-DC also provides the `ph5-availability` web service (Résif, 2019b) for the users to get the time span of the available data.

Marine data

Marine data collected on autonomous sensors such as ocean-bottom seismometers follow specific guidelines developed and distributed through the FDSN “Mobile instrumentation” working group and the European Union projects EPOS/ORFEUS, ENVRI-FAIR and SERA. These guidelines include: data quality labels indicating whether the data were corrected or not for the instrument clock drift; standards for post-implementing leap seconds; component code standards for horizontal channels that are not geographically oriented; orientation/dip standards for pressure channels, and station naming rules for repeated deployments at the same station (see Clinton et al. 2018, Appendix B, for the latest published version and Crawford 2019 for the latest proposed version). These guidelines have been adopted already by some OBS parks and EIDA data centers. The AlpArray OBS component has been archived following these guidelines.

Résif has been working since 2017 on the integration of data from French Ocean Bottom Seismometer (OBS) parks. This integration will be accomplished very soon by the commissioning of the dedicated MARINE A-node. Within this frame, a system for for creating FDSN-standard data and metadata for ocean bottom seismometers using standardized, easy-to-read information files is currently in development (Crawford et al., 2019). A specific visual quality control is also in development (Goubier and Crawford, 2021) to allow the instrument providers and scientific users to verify instrument responses, noise levels and time corrections.

To date, Résif-DC distributes data from two temporary campaigns:

- RHUM-RUM (Barruol et al., 2017): 57 OBS for 2 months of data, 3 components at 50 Hz
- AlpArray (AlpArray Seismic Network, 2015): 8 OBS for 8 months of data, 3 components at 50 Hz.

Two other datasets are in the process of validation and integration:

- SISMANTILLES (Laigle et al., 2007): 20 OBS for 4 months, 3 components at 50 Hz.
- EMSO-MOMAR (IPGP, 2007): 5 OBS for 10 years 3 components at 50 Hz

OBSs cannot obtain precise GPS timing during their deployment. The instruments are equipped with a very accurate clock to minimize the problem, however this clock drifts on the order of 1-2 seconds/year (e.g., Loviknes et al., 2020). The standard protocol for OBS time correction is to synchronize an OBS with a GPS signal immediately before deployment and after recovery. The measured timing deviation is assumed to have accumulated linearly over the deployment interval, therefore the applied correction for time drift is linear. This assumption has been checked by Hable et al. (2018) for the instruments used during the RHUM-RUM Experiment (French and German pools) using ambient noise correlations.

Some users, however, prefer to have the data "unmodified", even if this means that there are timing errors of the order of a second. That’s why Résif-DC delivers both types of data, giving quality label “Q” (Quality Controlled Data, some processes have been applied to the data –see Ahern et al., 2012, page 108) to those that are corrected and “D” (the state of quality control of the data is indeterminate –see Ahern et al., 2012, page 108) to those that are not (see “Specificity of OBS data and metadata” in the Appendix).

Organizing and improving archival of data from building and infrastructure monitoring

Since 2010, Résif has been involved in specifying metadata and solutions for building and infrastructure monitoring (Clinton et al., 2018). More and more high quality seismic sensors are deployed across structures, with the same technical issues than for classical seismological networks (in large numbers, with continuous recordings) and using therefore seismological standards. The StationXML metadata specification (FDSN, 2019) can be used to include specific information on the structure, allowing the engineering seismology community to integrate infrastructure monitoring data into standardized practices. The building description, which is key for engineering purposes, can be included at two levels: (1) following the European Macroseismic Scale typology of buildings, based on the material of construction (Grünthal, 1998), and (2) through a full description of the building characteristics according to the GEM Building taxonomy (Brzev et al., 2013).

To date, Résif-DC distributes seismic data from five instrumented buildings:

- City-hall of Grenoble, France (Michel et al., 2009; Guéguen et al., 2020): 6 three-component (3C) accelerometric sensors since 2004 (stations `OGH1` to `OGH6`), and one additional 3C sensor at intermediate height (station `OGH7`) and one weather station at the top since 2019 (station: `OGH8`)
- Ophite Tower in Lourdes, France (Michel and Guéguen, 2018): 3 3C accelerometric sensors and 15 1C accelerometric sensors distributed over the building height since 2008 (station: `PYTO`) plus one temperature sensor at the top.
- Prefecture building in Nice, France (Lorenzo et al., 2018): 2 3C accelerometric sensors and 18 1C accelerometric sensors distributed over the building height since 2010 (station `NCAD`), including one free-field station.
- Basse-Pointe College in Martinique Island: 2 3C accelerometric sensors and 18 1C accelerometric sensors distributed over the building height since 2010 (station: `CGBP`) including one temperature sensor and one free-field station.
- Centre de découverte de la Terre in Martinique Island (Gueguen, 2012): 2 3C sensors in trigger mode in a specific building with rubber bearing since 2005 (stations: `CGCP` and `CGLR`).

Metadata editing made easy: YASMINE

For almost 20 years, the IRIS Portable Data Collection Centers toolkit (PDCC, Casey, 2016) was the main standalone GUI tool available to create and maintain station metadata in SEED dataless format (Ahern et al., 2012). In 2017, several years after the adoption of the FDSN new StationXML metadata standard (FDSN, 2019), there was still no solution widely available to edit and create native StationXML files. This slowed down the adoption of StationXML by, at least, all Résif-SI contributing A-nodes and forced us to use an interim SEED dataless to StationXML conversion solution. This problem was hindering Résif-DC being able to export rich metadata to the user, including for example the DOI of the network, or the contributing organizations.

Résif-SI first collected the metadata creation and edition needs among the French community and closest partners. The requirements were then generalized so that they fulfill not only Résif-SI needs but also a much broader international community.

In 2018, IRIS-DMC contracted Instrumental Software Technologies, Inc. (ISTI) to build a tool for StationXML creation and editing and this first software was already satisfying some of Résif-SI requirements. Résif-SI then contracted ISTI to continue the development of YASMINE (Yet Another Station Metadata INformation Editor) in order to satisfy our requirements. The results are two independent pieces of software: `yasmine-GUI` and `yasmine-CLI`.

One of the main innovations was the introduction of the new Atomic Response Object Library (AROL, Wolyniec et al., 2019). This library, written in YAML, is contributed by Résif-SI and is the conversion of the long maintained PZ format library. Each stage of a device is only defined once and then linked to the definition of the many different instrument configurations possibilities.

The web-based GUI `yasmine-GUI` offers the user the ability to create and edit StationXML metadata. The user can create files from scratch through a guided wizard process and can import response files from either NRL (Nominal Responses for seismic instruments Library, Templeton, 2017) or AROL. The user can also modify any part of the instrument response. A comparison mode allows the user to compare the instrument response of two StationXML files sharing the same Station-Channel-Network-Location (SCNL). Often used description elements (vault, geology, comments) can be stored in the General ATomic lIbrary of Tiny Objects (GATITO, in YAML, Saurel et al., 2019) to simplify the task of homogenization of those elements over several StationXML files. Finally, the user can store any of the Network, Station or Channel elements in a User Library that will store them as templates for further re-use.

The command-line based `yasmine-CLI` allows the user to modify an existing StationXML file. The user can add, delete or modify StationXML elements, except for the instrument response elements. The user can also split a complex StationXML into multiple simpler files (e.g., split a network StationXML into several per-station files) and print the instrument responses of each channel/epoch contained in the StationXML. This tool will allow many automated StationXML file modifications from scripts.

The two pieces of software are written in Python and rely heavily on ObsPy for the StationXML content manipulation. They are both compatible with the latest StationXML 1.1 standard and are released under the GNU GPL v3 license and distributed as Python packages. The Résif-SI installation of YASMINE is reachable at https://yasmine.resif.fr.

Conclusion and Future challenges

The choice of a distributed yet strong architecture for the national Résif information system in seismology, with clearly identified roles and responsibilities, has proven effective for France to deliver seismic waveform data to users worldwide. The service to users has significantly improved in terms of features offered and service robustness with minimal changes of running costs and keeping the same number of permanent staff members. The advantage of the system is that it capitalizes on the distributed human resources and competence nationwide, and maintains visibility for each involved institution. The cost of this architecture is the continuous efforts needed to maintain the technical coherency and cooperation across all institutions, and to overcome communication difficulties across the distributed system. The choice made very early on to preserve original data models allowed us, despite the initial cost, to respect the specific constraints on data and metadata for all the French networks, an important consideration for the cohesion of Résif-SI and for the scientific users. Based on this experience, the Résif board of directors has recently chosen a similar architecture for information on earthquakes, with identified roles of different operators responsible for warning, bulletins, catalogs, and shake maps, rather than each institution creating their own (Masson et al., 2021).

Résif faces future challenges, related to two main issues. First, the success of the system at a national level means that the quantity and complexity of collected and distributed data is ever-increasing. For example, all broadband Ocean Bottom Seismometer data will in the future be integrated into Résif. The second issue is an order of magnitude change in data integration associated with Large-N and distributed acoustic sensing (DAS) equipment. These challenges are international, and Résif will continue to engage in international discussions on how to tackle them (see Quinteros et al. 2021). We believe that the Résif architecture is sufficiently solid to accommodate the changes through engagement of all the partners. The experience from Résif shows that a distributed but strongly organized information system is a good architecture for countries that face the challenge of integrating and distributing data across many organizations.

Data and Resources

All the software produced by Résif-SI is open source and available via https://gitlab.com/resif and https://gricad-gitlab.univ-grenoble-alpes.fr/OSUG/RESIF.

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Table 1: Typology of stations by networks within Résif A-nodes.

RLBP: French broadband permanent network (FR) co-hosted by École et Observatoire des Sciences de la Terre (EOST) and Observatoire de la Côte d'Azur (OCA); also receives data from partner permanent networks (CL, ND, MT).
RAP: Permanent Accelerometric Network (RA, FR), hosted by Observatoire des Sciences de l'Univers de Grenoble (OSUG).
GEOSCOPE: GEOSCOPE Global Observatory (G), hosted by Institut de physique du globe de Paris (IPGP).
VOLCANO: Seismological instruments from the Observatories of Piton de la Fournaise (Reunion Island, PF), Guadeloupe and Martinique (GL, MQ, WI), hosted by Institut de physique du globe de Paris (IPGP).
SISMOB: Land mobile instruments, hosted by ISTerre; it also receives data from partner laboratories. Data can be embargoed up to three years after the experiment start.
CEA: CEA broadband stations (RD).
NRT: number of stations with at least one near-real time stream. BB: number of stations with at least one broad band channel (NRT or not). SP: number of stations with at least one short period channel (NRT or not). SM: number of stations with at least one accelerometric channel (NRT or not). Others (NRT or not): tiltmeter, weather, hydrophone, wind, rotational sensor, mass position, etc. Note that for SISMOB the "Others" category includes very short period "node" geophones (channel codes starting with "`DP`").

Résif A-node	*FDSN network codes*	*stations*	*NRT*	*BB*	*SP*	*SM*	*Others*
RLBP	FR	167	145	167	6		3
	CL	39	15	37	19	4	3
	ND	10	1	10		7	
	MT	16	10	16	5		1
RAP	FR	49	39			49	
	RA	232	93			232	
GEOSCOPE	G	54	30	54		10	36
VOLCANO	WI	15	11	15		15	
	PF	46	36	29	20		
	GL	22	9	11	18		
	MQ	14	12	8	8		
SISMOB	70 temporary network codes	2482		1271	277	63	1022
CEA	RD	19	13	19		1	
	Total	*3165*	*414*	*1637*	*353*	*381*	*1065*

Table 2: Latency for the production of validated data by A-nodes

A-nodes	*data quality*	*latency*
RLBP	M	3-5 days
RAP	M	3-5 days; 1 year for the data from stations in buildings and borehole
GEOSCOPE	Q	6 to 12 months
VOLCANO	Q	6 to 12 months
SISMOB	M	1 to 6 months

Table 3: Average service availability for year 2020 based on network reachability. Availability of 0.1% corresponds to 9 hours.

service	*availability (%)*
fdsnws-dataselect	99.84
fdsnws-station	99.62
fdsnws-availability	99.60
real time data	99.87
resifws-timeseries	99.66
resifws-timeseriesplot	99.65
eidaws-wfcatalog	99.29

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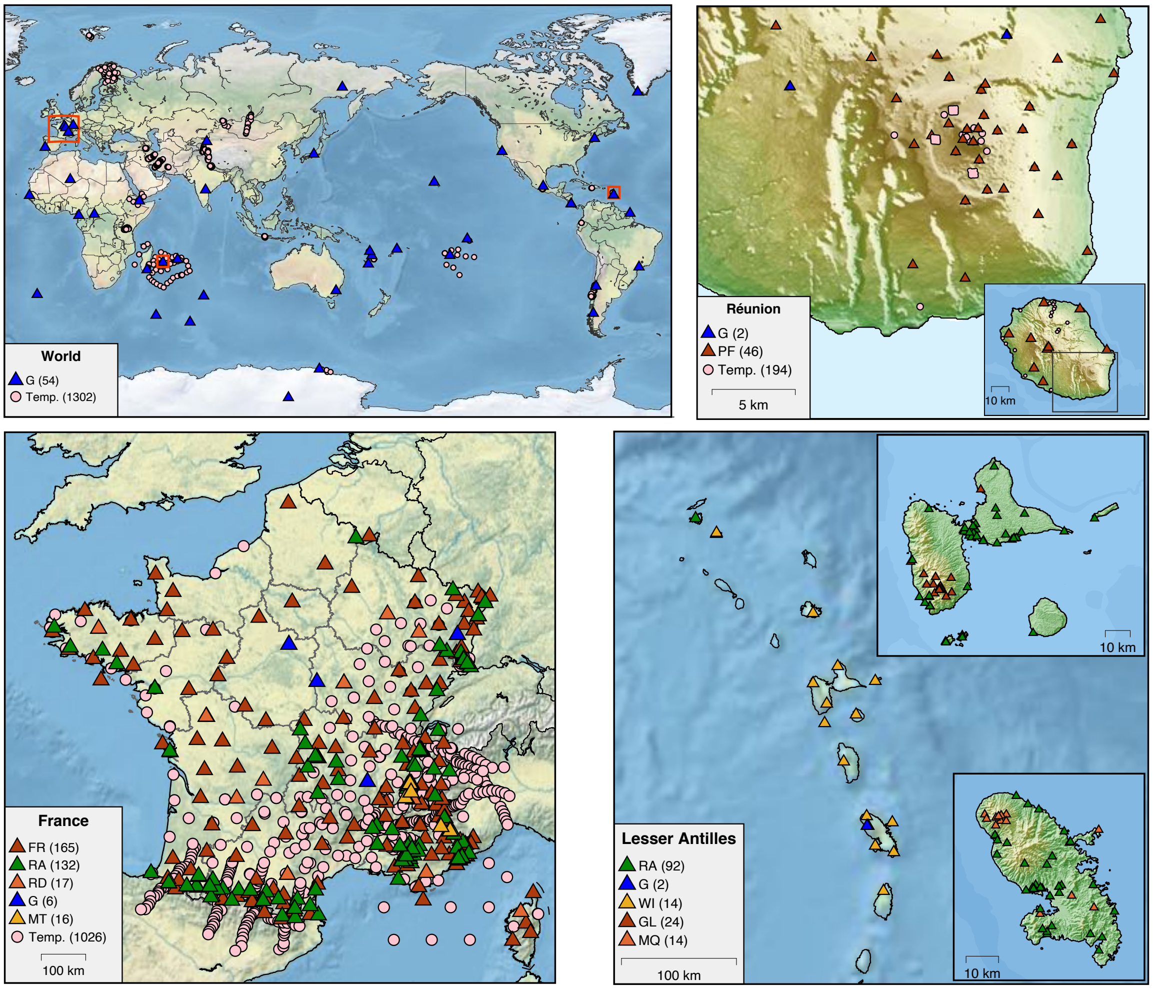


Figure 1: Seismic stations distributed by Résif-SI worldwide, in metropolitan France and in overseas Réunion and Lesser Antilles regions (location of these regions is indicated by the red boxes on the world map). Symbols and colors according to the network; number of stations for each network indicated in parentheses (see Table 1 for details on the network codes). The "Temp." label includes all temporary deployments (land mobile instrument pool SISMOB and ocean bottom seismometer instrument pool). The three pink boxes on the "Réunion" map are deployments of 100 sensors each (see Brenguier et al., 2015). Note that the maps do not show all the Résif-SI data holdings worldwide and other stations are available from permanent or temporary deployments in Europe, Chile and Pacific Ocean. Note also that the maps include stations which are temporary or definitively closed.

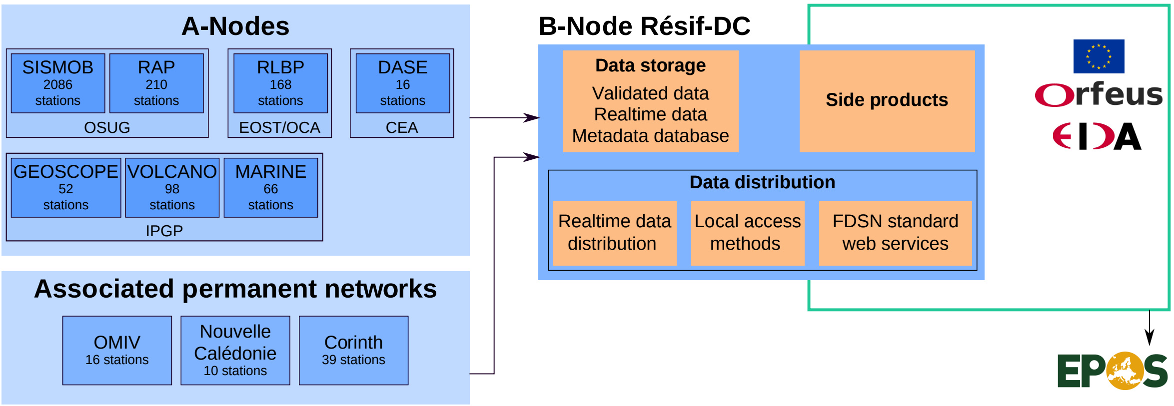


Figure 2: Structural architecture of Résif-SI. The A-nodes collect and validate data and metadata from permanent and temporary networks. They are also responsible to secure a copy of the data for two years. Data and metadata are then submitted to the B-node Résif-DC, which is responsible for long-term storage and distribution. Résif-DC also computes side-products (e.g., Power Spectral Density plots, McNamara, 2004), and is member of EIDA. Overall interoperability between data from different observations within a large part of Solid Earth in Europe is ensured by EPOS.

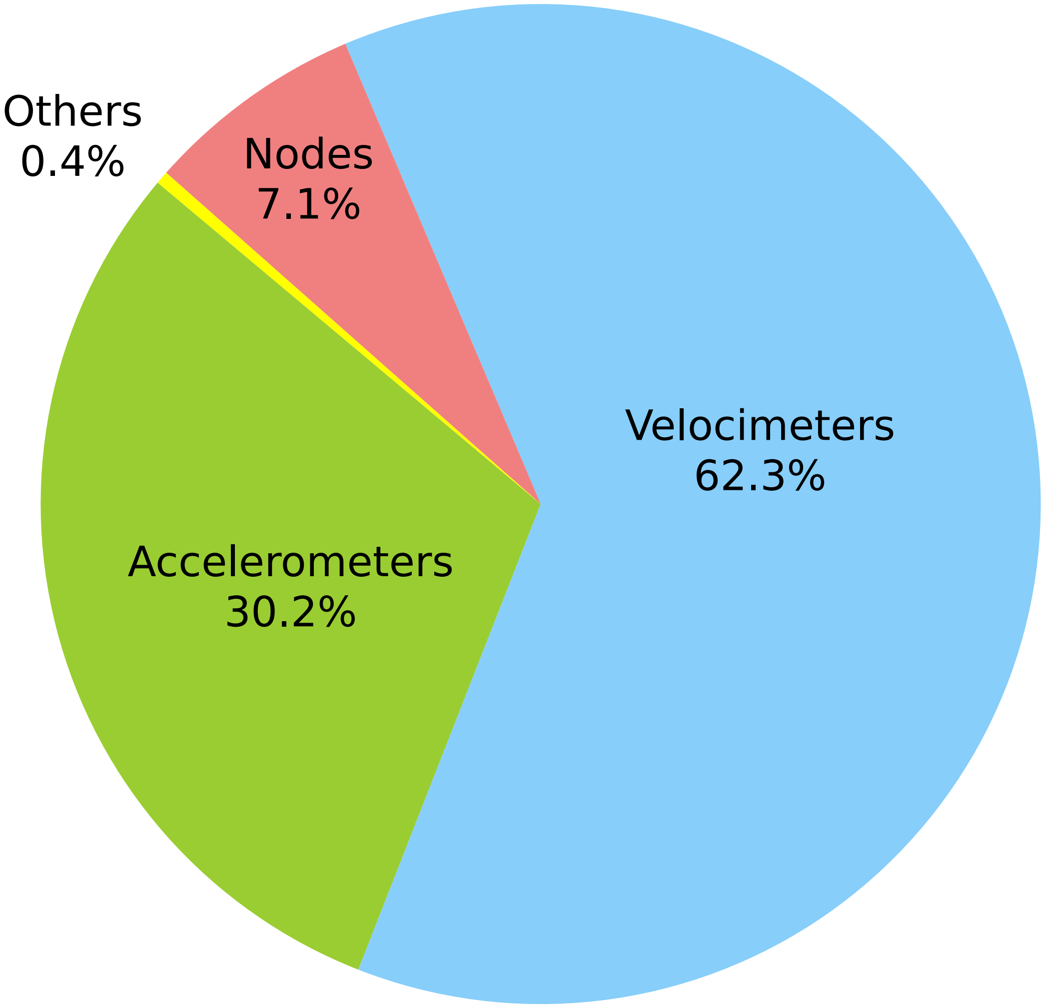


Figure 3: Distribution of data volumes in Résif archive, as of January 1st, 2021. Velocimetric data represents 62.3%. Accelerometric data represents 30.2%, Data from very short period "node" geophones represents 7.1% and other data, like meteorological time series, accounts for 0.4%.

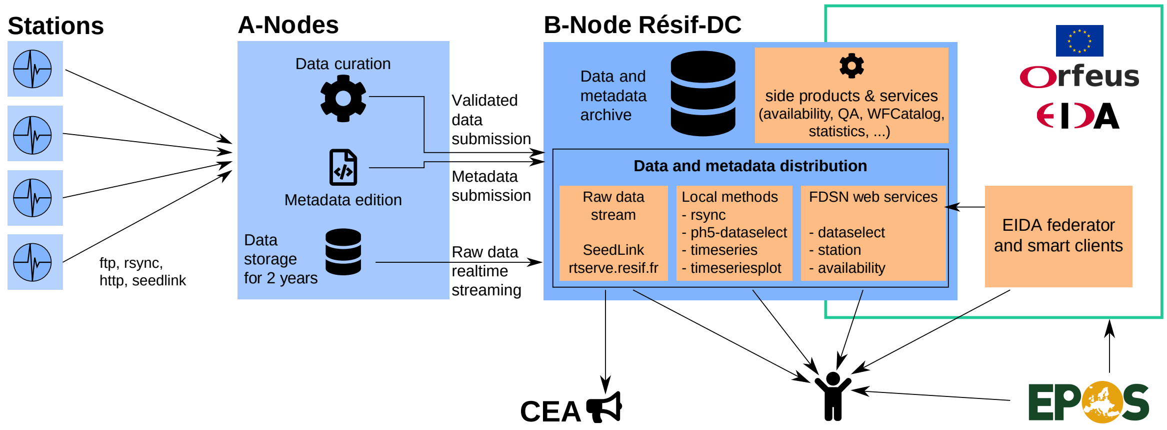


Figure 4: Technical architecture of Résif-SI. A-nodes collect and validate the raw data, manage real-time data flow, edit the metadata and submit them to the B-node Résif-DC. Résif-DC concentrates the real-time data flow which is used by the national seismic alert system operated by the CEA (on top of their own dedicated data flow for the networks they manage), stores data and metadata in the long term, distributes it through standardized and specific media, develops side-products. Federated into EIDA, open data and metadata are accessible by end-users through a federator.

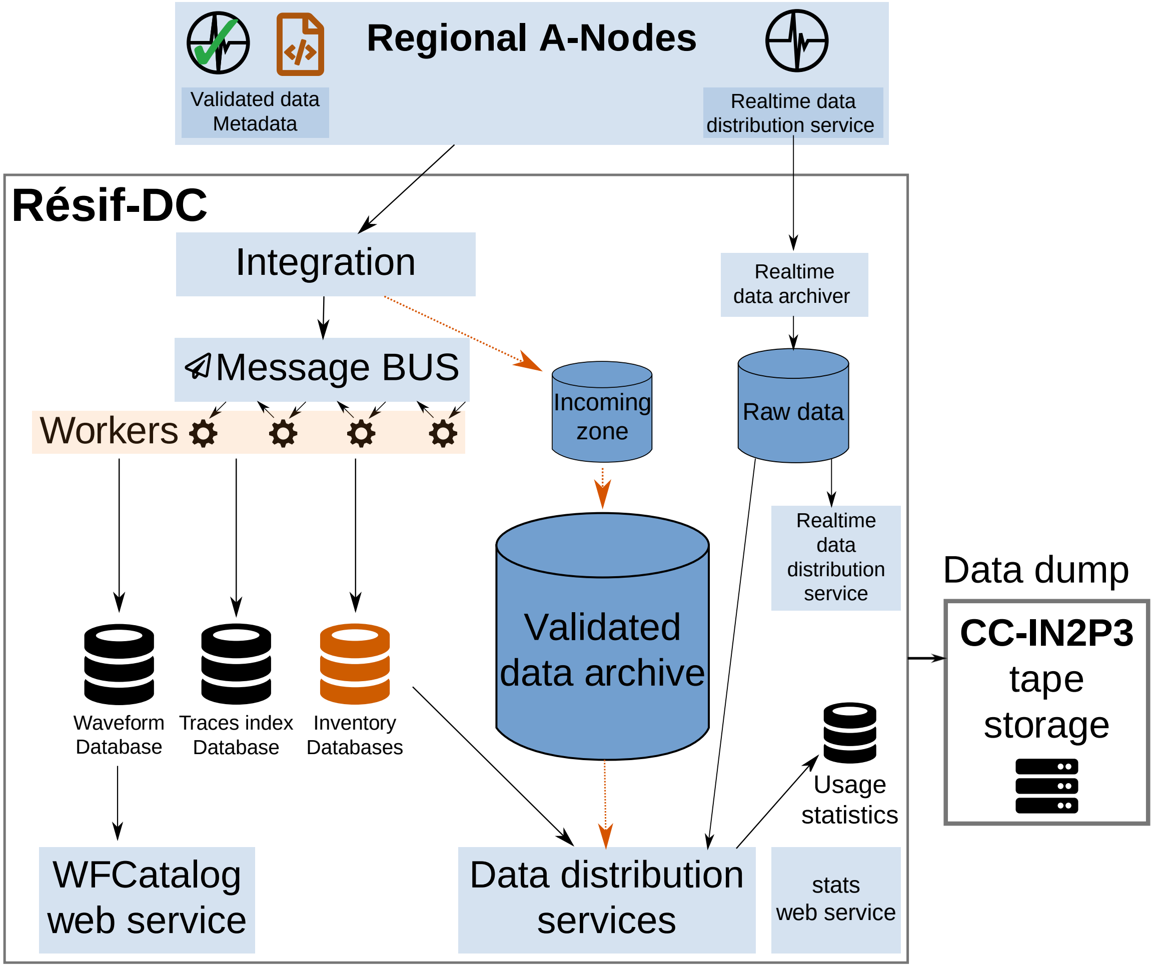


Figure 5: Validated data and metadata are integrated at Résif-DC by passing through a series of workers which ensure that the data and metadata conforms to the specifications, register it in the archive and in the database, index it and create the side-products. Raw data is concentrated, registered and made available through standardized web services with very low latency (around 10 seconds). Data, metadata and other assets are dumped on a distant tape system at the Computing Centre of the National Institute of Nuclear Physics and Particle Physics (CC-IN2P3, Lyon) to secure them from a local disaster.

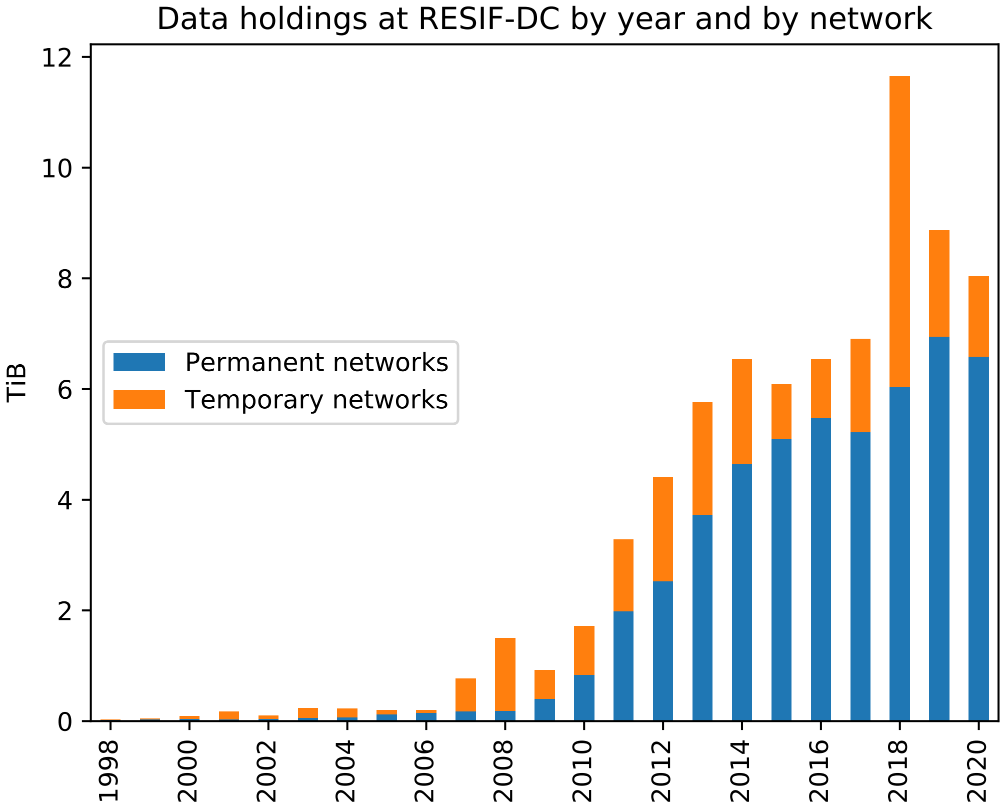


Figure 6: Current validated data holdings at Résif-DC grouped by year. This figures illustrates the growth of the data produced by seismological networks since 1998.

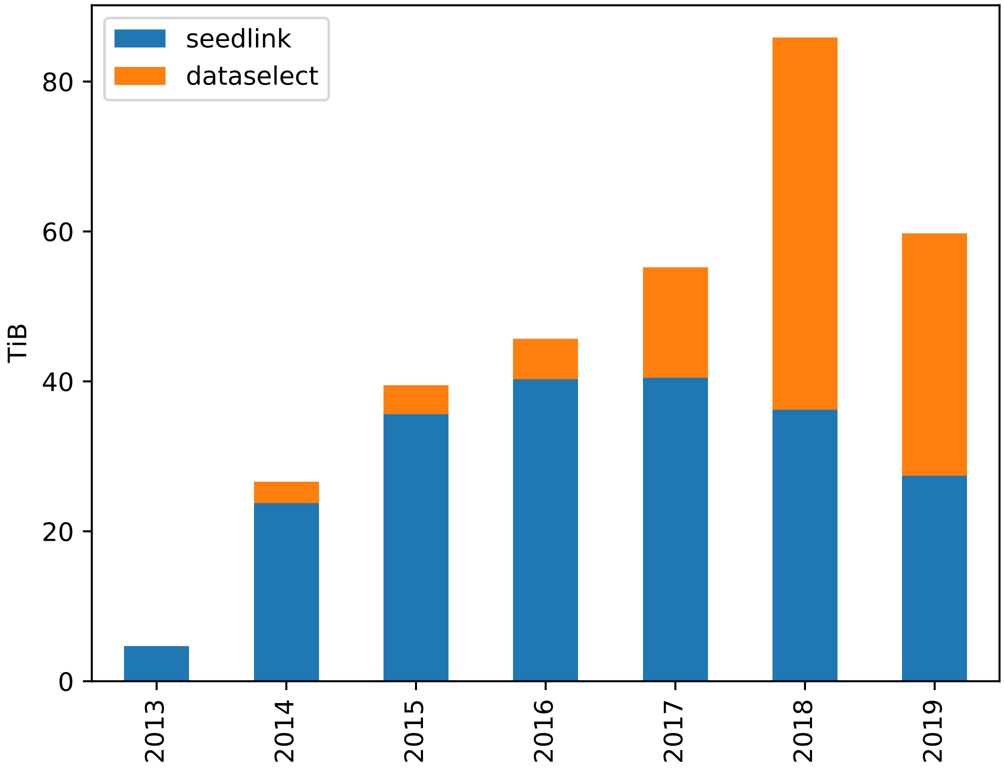


Figure 7: Amount of waveform data distributed yearly through SeedLink (real-time) and FDSN `dataselect`. Note that statistics from the now retired EIDA Arclink services are not included.

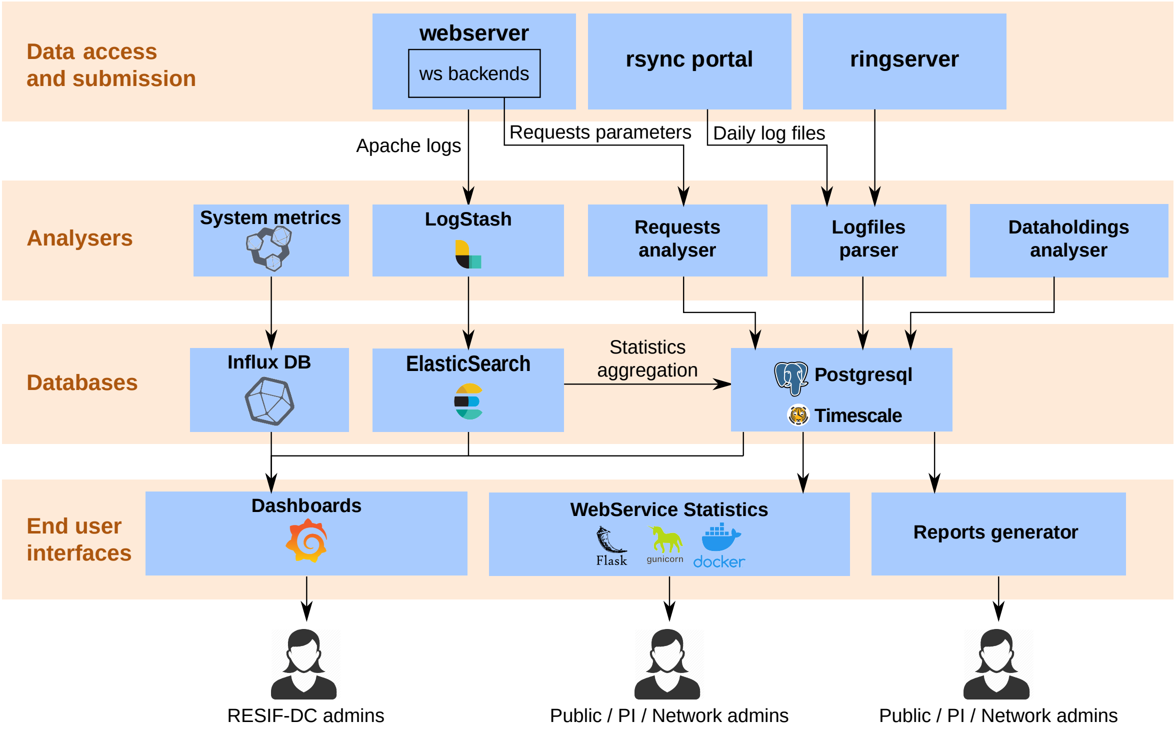
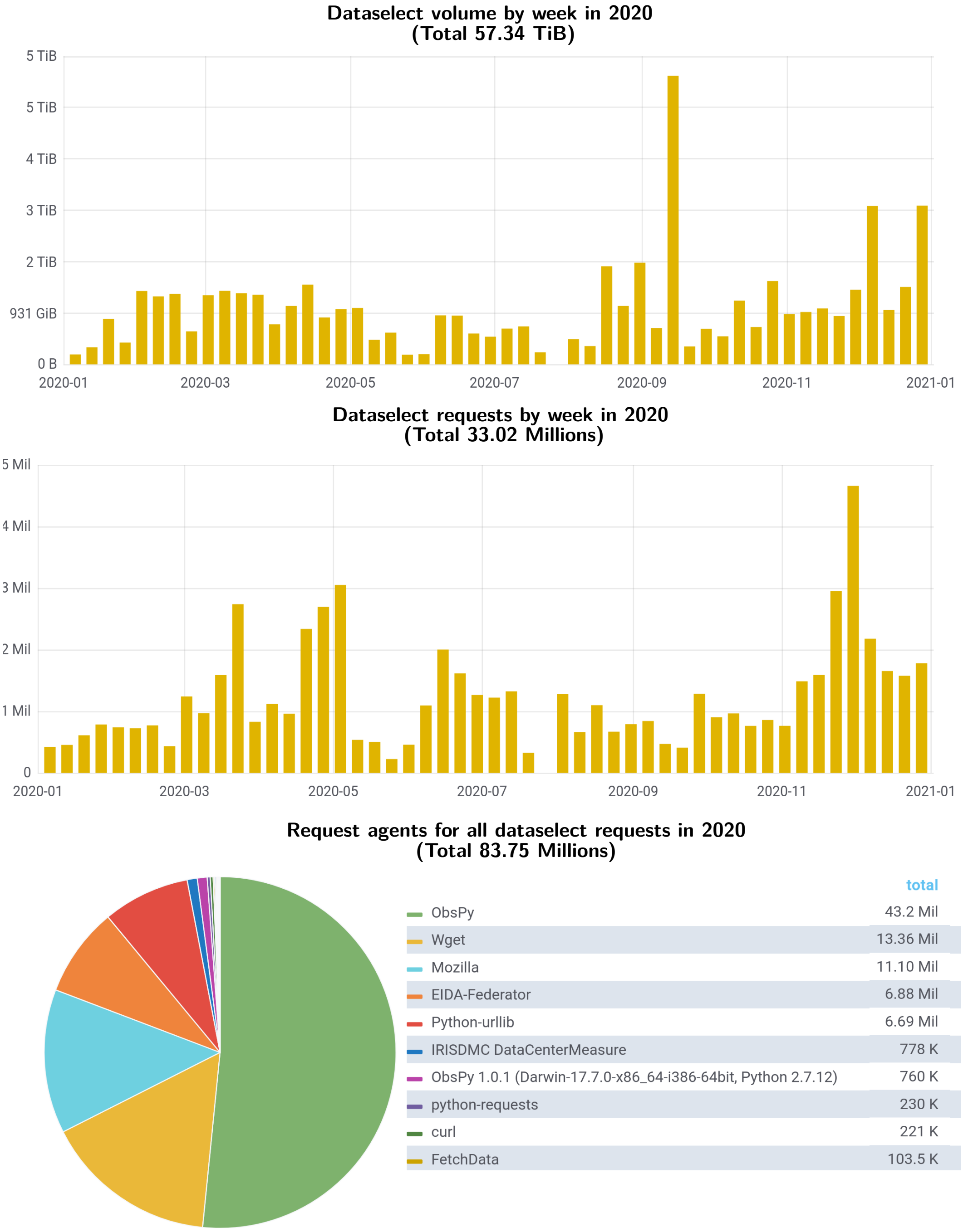


Figure 8: The logging system analyzes events from heterogeneous sources (e.g., web access logs, web services requests, server logs); the statistics are computed by different analyzers and aggregated in one central database (Postgresql). The statistics can be queried by various interfaces intended for different audiences; in particular a public web service `resifws-statistics` is available.



	total
ObsPy	43.2 Mil
Wget	13.36 Mil
Mozilla	11.10 Mil
EIDA-Federator	6.88 Mil
Python-urllib	6.69 Mil
IRISDMC DataCenterMeasure	778 K
ObsPy 1.0.1 (Darwin-17.7.0-x86_64-i386-64bit, Python 2.7.12)	760 K
python-requests	230 K
curl	221 K
FetchData	103.5 K

Figure 9: This dashboard view is an example of the web interface presenting some of the Résif-DC distribution metrics. Here, the figures focuses on the `fdsnws-dataselect` web service during 2020, showing the volume sent (51.34 TB), the number of successful requests (33.02 millions) and the distribution of user agent requests for all the requests (83.75 millions). This last number accounts for the successful requests to the `/query` and `/queryauth` methods (HTTP 200), the requests returning no data (HTTP 204 and 404), the requests to other methods (documentation, `/auth`, wadl file), the requests producing errors due to improper parameters (HTTP 400 and 401) or insufficient permissions (HTTP 403).

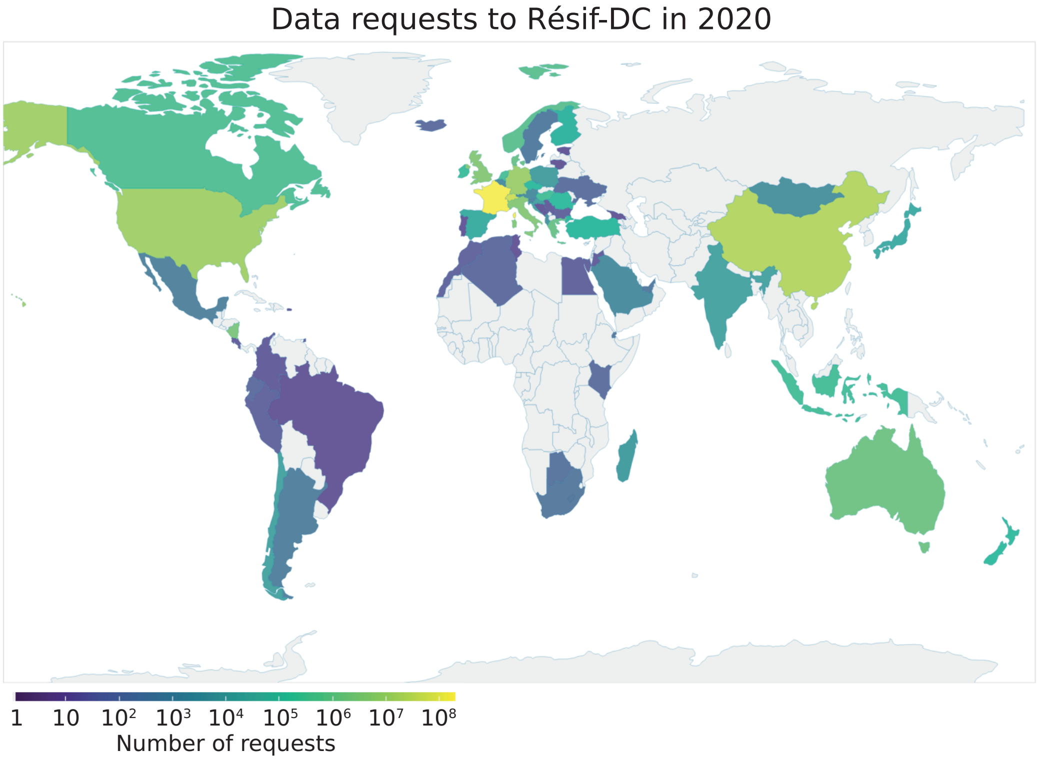


Figure 10: Geographical distribution of data requests to Résif-DC in 2020.

Appendix: Data access details and examples

In this appendix we present the different ways for end users to access Résif-SI data and metadata.

Real-time: SeedLink

Résif-DC real-time data service (SeedLink server, GFZ and gempa GmbH, 2008) provides access to data for the following permanent networks: FR, RD, RA, MT, G, WI, ND, CL, MQ, PF, GL. Data from temporary campaigns are usually not distributed in real-time unless acquired in the context of a post-seismic campaign for which Résif does not accept any data embargo time. The lifetime of the near real-time data in the internal memory buffer is about 3 hours. By convention, Résif-DC does not distribute any raw data for which the corresponding metadata is not available through the FDSN web service `station`.

The SeedLink service is available at: `rtserve.resif.fr` (TCP port 18000).

Web services

Web services are the base delivery mechanism for most Résif data and metadata. Résif-DC exposes the four web services standardized by the FDSN (FDSN, 2013), an EIDA web service common to all EIDA DCs, as well as other more specific web services (Résif, 2019a).

FDSN web services

The FDSN web services are characterized by common and standardized interfaces and thus constitute a homogeneous means of access to data, regardless of the data center involved. Those services are all accessible with the prefix https://ws.resif.fr/fdsnws/ (Table A1).

Examples:

- All Résif stations, XML formatted: https://ws.resif.fr/fdsnws/station/1/query?level=station

- One hour of data for network ZH (516 Mb): https://ws.resif.fr/fdsnws/dataselect/1/query?network=ZH&starttime=2003-06-01T00:00:00&endtime=2003-06-01T01:00:00
- Available Data from network G, station SSB2, channel BHZ for a given time interval: https://ws.resif.fr/fdsnws/availability/1/query?network=G&station=SSB&channel=BHZ&start=2010-02-23T00:00:00&end=2010-03-23T00:00:00

FDSN web services can be accessed by standard tools and libraries, like ObsPy (Beyreuther et al., 2010; Megies et al., 2011; Krischer et al., 2015). As an example, we provide in the Appendix an example Python script to retrieve data and metadata through the FDSN web services.

EIDA web services

Résif-DC exposes the EIDAWS *wfcatalog* web service (Trani et al., 2017). This web service provides detailed metrics on waveform data (e.g., gaps, overlaps, RMS, SEED data quality flag). The WFCatalog interface can be used for data discovery as it supports range filtering on all available metrics. The EIDAWS web service is accessible with the prefix https://ws.resif.fr/eidaws/ (Table A2).

Examples:

- waveform metadata documents with a daily granularity from network CL between 2018-01-01T00:00:00 and 2018-01-10T00:00:00, in JSON format: https://ws.resif.fr/eidaws/wfcatalog/1/query?network=CL&include=sample&start=2018-01-01&end=2018-01-10

Other web services

Résif-DC has implemented additional web services, whose functionalities have been inspired by the services provided by IRIS Data Services (Weertman, 2010) or needed by the French users of Résif-SI. The former are accessible with the prefix https://ws.resif.fr/resifws/ while the latter are accessible with the prefix https://ws.resif.fr/resifsi/. Tables A3 abd A4 show complete lists of these two groups of services.

Examples:

- five minutes of data for station PYTO, channel HN2, with demean and response deconvolution, ASCII format: https://ws.resif.fr/resifws/timeseries/1/query?net=RA&station=PYTO&cha=HN2&loc=02&demean&correct&start=2017-11-02T13:35:00&end=2017-11-02T13:40:00&format=ascii
- interactive plot of five minutes of data for station PYTO, channel HN2, location code 02, with demean and response deconvolution: https://ws.resif.fr/resifws/timeseriesplot/1/query?net=RA&station=PYTO&cha=HN2&loc=02&demean&correct&start=2017-11-02T13:35:00&end=2017-11-02T13:40:00&iplot
- plot of instrument response for station CIEL, network FR, channel HHE, location code 00: https://ws.resif.fr/resifws/evalresp/1/query?net=FR&sta=CIEL&loc=00&cha=HHE&time=2017-01-01T00:00:00&format=plot
- response (RESP format) for station RUSF, channel ??N, location code 06: https://ws.resif.fr/resifws/resp/1/query?net=FR&sta=RUSF&loc=06&cha=??N&time=2017-01-01T00:00:00&nodata=404
- data availability for an experiment stored as PH5 archive: http://ws.resif.fr/resifws/ph5-availability/1/extent?net=3C
- miniSEED data from a network stored as PH5 archive: http://ws.resif.fr/resifws/ph5-dataselect/1/query?net=3C&starttime=2019-12-09T00:00:00&endtime=2019-12-09T00:00:10
- quantity of data stored for year 2020 by network FR: http://ws.resif.fr/resifws/statistics/1/query?request=storage&net=FR&type=validated&year=2020
- quantity of data shipped via `dataselect` for network WI: http://ws.resif.fr/resifws/statistics/1/query?request=send&media=dataselect&net=WI

Specificity of OBS data and metadata

Ocean Bottom Seismometer (OBS) data is archived both in time-corrected format (quality label "Q") and in original, unmodified format (quality label "D"). The following request (with no `quality` parameter specified), delivers both corrected (Q label) and raw data (D label):

```
wget --http-user=USER --http-password=PASSWORD "https://ws.
   resif.fr/fdsnws/dataselect/1/queryauth?network=Z3&station=
   A4*&starttime=2017-08-01&endtime=2017-08-01T01:00:00" -O
   mydata.miniseed
```

By specifying the `quality=Q` parameter, only corrected data (Q label) is retrieved:

```
wget --http-user=USER --http-password=PASSWORD "https://ws.
   resif.fr/fdsnws/dataselect/1/queryauth?network=Z3&station=
   A4*&starttime=2017-08-01&endtime=2017-08-01T01:00:00&
   quality=Q" -O mydata.miniseed
```

With `quality=D`, only raw data (uncorrected) is delivered.

The StationXML metadata associated with the OBS are progressively refined with information on time corrections, instrument positioning uncertainties, water column depth and precise instrument description (sensor, data logger). A typical example of OBS metadata at Résif-DC at the station level is the following:

```
<Station code="A401A" startDate="2017-06-22T01:59:00" endDate
   ="2018-02-16T00:01:00" restrictedStatus="closed" resif:
   alternateNetworkCodes="Z32015">
```

```
    <Comment><Value>{"clock_correction": {
        "linear_drift": {
            "time_base": "Seascan MCXO, ~1e-8 nominal drift",
            "reference": "GPS", "start_sync_instrument": 0,
            "start_sync_reference": "2017-06-21T06:36:00Z",
            "end_sync_reference": "2018-02-16T01:44:00.146Z",
            "end_sync_instrument": "2018-02-16T01:44:00.00Z"
        }
    }}</Value></Comment>
    <Latitude minusError="4.5e-05" plusError="4.5e-05" unit="
       DEGREES">42.647</Latitude>
    <Longitude minusError="6.12e-05" plusError="6.12e-05"
       unit="DEGREES">5.0198</Longitude>
    <Elevation minusError="10" plusError="10" unit="METERS">
       -1619.0</Elevation>
    <Site><Name>N/W Mediterranean Sea</Name></Site>
    <Vault><Name>Sea floor</Name></Vault>
    <WaterLevel minusError="10" plusError="10" unit="METERS">
       1619.</WaterLevel>
</Station>
```

Table A1: The FDSN web services provided by Résif-DC, with base URL https://ws.resif.fr/fdsnws/. Note that the `event` web service is operated by RéNaSS (Réseau National de Surveillance Sismique – National Seismic Monitoring Network).

web service/version	*comment*	*format*
station/1	metadata inventory	StationXML or text
dataselect/1	time series data	miniSEED
availability/1	data inventory	text, json, geocsv
event/1	event parameters	quakeML

Table A2: The EIDAWS web services provided by Résif-DC, with base URL https://ws.resif.fr/eidaws/.

web service/version	*comment*	*format*
wfcatalog/1	data quality and metrics	json

Table A3: The RESIFWS web services provided by Résif-DC, with base URL https://ws.resif.fr/resifws/.
Note: ph5-dataselect and ph5-availability comply to the FDSN Web Services specification (FDSN, 2013) and might therefore be migrated in the future to a standard URL. For up-to-date information on Résif web service URLs, please refer to https://ws.resif.fr.

web service/version	*comment*	*format*
timeseries/1	time series data	miniSEED, sac, text, png
timeseriesplot/1	time series data	jpeg or png
ph5-dataselect/1	time series data	miniSEED, sac, geocsv (converted from PH5)
ph5-availability/1	data inventory	text, json, geocsv
evalresp/1	response information evaluated from Résif metadata	text or png
resp/1	channel response information	resp (text)
sacpz/1	channel response information	sacpz (text)
statistics/1	data download statistics from Résif-DC	text

Table A4: The web services provided by Résif-DC for data providers, with base URL https://ws.resif.fr/resifsi/.

web service/version	*comment*	*format*
transaction/1	status of an data or metadata integration transaction; this service is for Résif data providers	text, json
orphanfile/1	Data (SDS files) without metadata in Résif archive; this service is for Résif data providers	text
assembleddata/1	historical and validated collections of the permanent accelerometric network (1995-2013)	tar.gz