The Ocean Sound monitoring Sub-system

Giorgio Riccobene, Simone Sanfilippo and Salvatore Viola

on behalf of the LNS-INFN marine acoustics group

INFN – Laboratori Nazionali del Sud

sanfilippo@lns.infn.it

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Sud

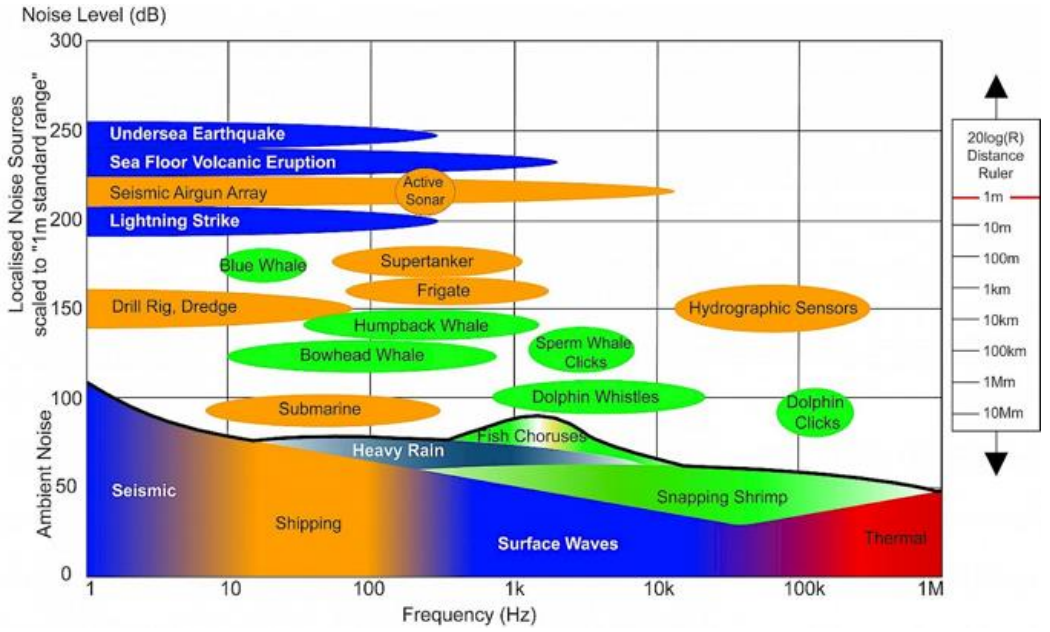
IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-Mission 4 "Education and Research" - Component 2: "From research to business" - Investment 3.1: "Fund for the realisation of an integrated system of research and innovation infrastructures"

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani

Why is sound an important variable for observing the ocean at a global scale?

Ocean Sound carries information on several sources and processes in the ocean:

- Climate Change: wind, waves, rain; sound propagation; ice-cap status
- Ocean Health: anthropogenic acoustic pollution, monitoring of soniferous species
- Safety, security: geophysical events (tsunamis earthquakes,..), illegal/banned activities, disasters,..



Attempts at international scale:

https://oceanexpert.org/downloadFile/45461

https://repository.oceanbestpractices.org/handle/11329/2405

Integrate Ocean Sound in the IIOOS (Italian Integrated Ocean Observing System)

Implementation

Data collection

(raw data inhomogeneity):
Sensor type, depth, location, sensor calibration, sampling frequency, duration of acquisition, duration of experiment, time sampling,...

Data Sharing/Exposure

Harmonise IR data sharing resources
Avoid sharing of strategic/sensible data

Data Analysis:

Definition of physical quantity, common/shared algorithms

Data FAIRness

Metadata defintion for raw and analised data

Algorithms and codes for analysis should be shared over a project code sharing platform

Integrate Ocean Sound in the IIOOS (Italian Integrated Ocean Observing System)

Implementation

Harmonise data harvesting strategy:

Record not less than 5 continuous minutes of data every hour during the experiment
Use calibrated sensors (uncalibrated sensors should be used for a limited subset of analyses)

Definition of physical quantity to be derived from raw data

Sound Pressure Level (to start with)

Path for data analysis

Spectral analysis in octave thirds comprising 63 and 125 Hz (EU MSFD).
When possible supplemented with higher ones.
Spectral resolution of 1Hz should be provided for fmax<1 kHz
Spectral resolution of 100 Hz should be provided for fmax>1 kHz
Average and median values of SPL should be calculated together with the 25^{th}, 50^{th}, 75^{th} and 95^{th} percentiles

ITINERIS WP5.7 @ INFN – LNS

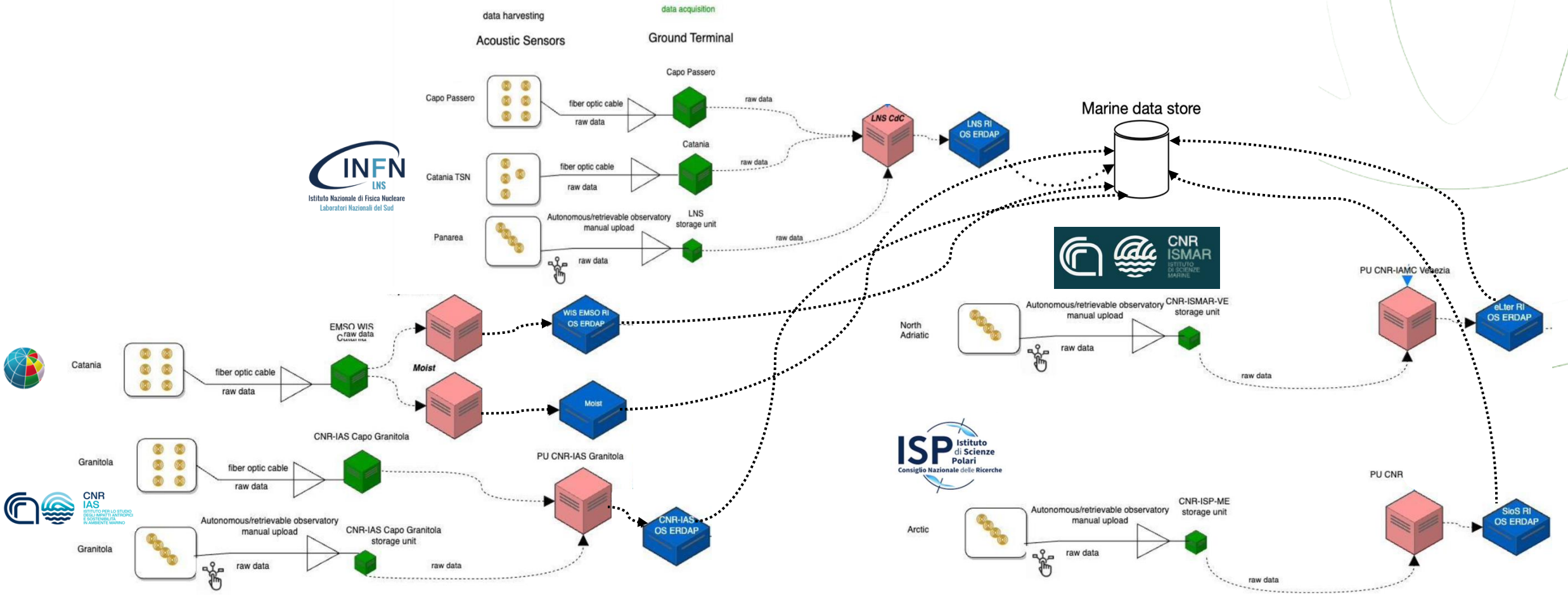
INFN – LNS provides:

- Python algorithms for data analysis (available on Git with permissions)
- Best practices to ensure FAIR data use

Analysis chain:

- Save 5 minutes acoustic data every 5 min (60 GB/day)
- (Real time or delayed mode) data analysis
  - Produce Spectrograms
  - Calculates Sound Pressure Level (dB re 1µPa) in 1/3-octave frequencies bands
    - Mean, 25th, 50th, 75th and 95th percentiles
  - Save outputs in PNG and HDF5 formats including metadata
    - Fill an ERDDAP server (https://erddap.lns.infn.it/erddap)
  - Produce WAV and MP3 files for outreach purposes

ITINERIS WP5.7 @ INFN – LNS
Ocean Sound monitoring Sub-system flow chart



ITINERIS WP5.7 @ INFN – LNS
Data analysis: SPL calculation

Sound Pressure Level (dB re 1µPa) in 1/3-octave frequencies bands is defined as:

$$SPL_{t_j}(\tau_i) = 10\ log_{10}\left(\sum_{f=f_{ini}}^{f_{end}} 10^{\frac{PSD_{t_j}(f)}{10}} \cdot F_{bin}\right)$$

represents the SPL value at time t_j for the frequency band τ_i, and

F_{bin} is calculated by:

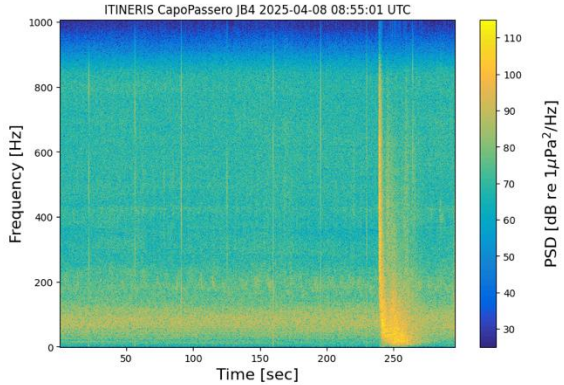
$$F_{bin} = \frac{f_s}{NFFT}$$

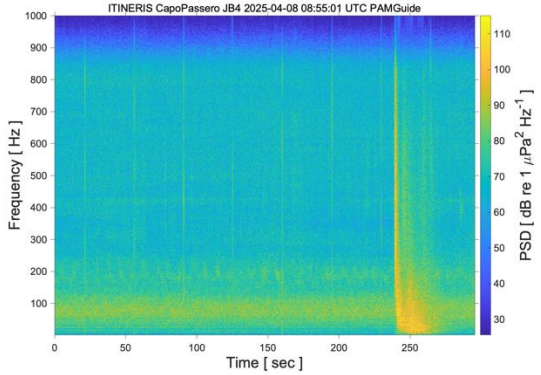
D. Diego-Tortosa et al., "Strategies for Automatic Analysis of Acoustic Signal in Long-Term Monitoring", J. Mar. Sci. Eng. 2025 (https://doi.org/10.3390/jmse13030454)

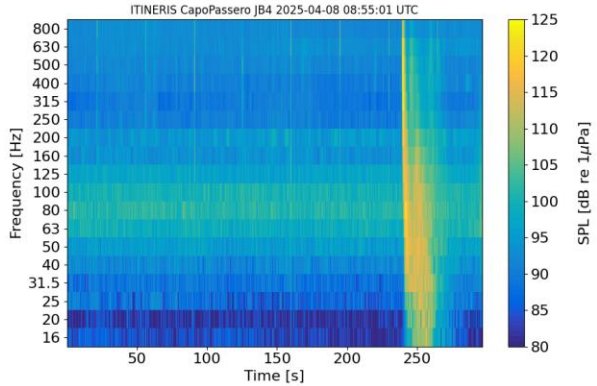
```
def spl_spec(nfft, fs, f, t, psd_spect, Freq_valid, SPLlim=0, plot=0):

    # SPL calculation
    # Calculation of central frequencies in octave band:
    octave = 1/3
    fcs = FreqBandsCalculation(octave, fs=fs)
    nominal_frequencies = [16, 20, 25, 31.5, 40, 50, 63, 80, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000,\
                           1250, 1600, 2000, 2500, 3150, 4000, 5000, 6300, 8000, 10000, 12500, 16000,\
                             20000, 25000, 31500, 40000, 50000, 63000, 80000, 100000]
    yticks_str = []

    spl_mean = np.ones([len(fcs),len(t)])*np.nan
    for j in range(0,len(fcs)):
        fc = fcs[j]
        if fc>0:
            fmax = fs/2
        else:
            fmax = max(fc)
        flow,fup = FreqBandLimits(fc, octave)
        if flow>=Freq_valid and fup<=fmax:
            indx_flow = (np.abs(f - flow)).argmin()
            indx_fup = (np.abs(f - fup)).argmin()

            psd = psd_spect[indx_flow:indx_fup,:] #[dB re A^2/Hz]

            spl = 10*np.log10(np.sum(10**(psd/10) * (fs/nfft), axis=0)) #[dB re A]

            # SPL in each octave band:
            spl_mean[j,:] = spl

    # Removing nan values:
    fcs = fcs[~np.isnan(spl_mean[:,0])]
    spl_mean = spl_mean[~np.isnan(spl_mean[:,0]),:]
    y = np.arange(len(fcs)+1) - 0.5
    yticks=[str(int(f//1)) for f in fcs]

    yyy = [int(value) for value in yticks]
    for ii in yyy:
        diff = min(nominal_frequencies, key=lambda x: abs(x - ii))
        yticks_str.append(str(diff))
```

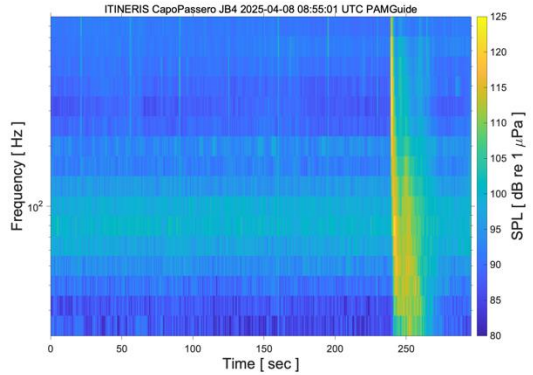
ITINERIS WP5.7 @ INFN – LNS
Comparison with PAMGuide

- PAMGuide is an open source code (*https://sourceforge.net/projects/pamguide/*), written in Matlab and in R, based on the work of Merchant et al. (*https://doi.org/10.1111/2041-210X.12330*) widely used in the field of bioacoustics. Among the other features, it provides calculations of PSD and SPL in 1/3-octave frequency bands
- In the framework of ITINERIS and the IT-OS sub-system, INFN - LNS is developing a similar code in python for the calculation of SPL in 1/3-octave frequency bands (*https://doi.org/10.3390/jmse13030454*) in order to standardise the analysis methodology among the ITINERIS community
- Test case: PAMGuide and INFN are using the same approach to calculate PSD and SPL?









$$\Delta(PSD) = (-1.5e^{-4} \pm 0.1)dB$$

$$\Delta(SPL) = (1.48 \pm 0.24)dB$$

ERDDAP: Metadata vocabulary https://erddap.lns.infn.it/erddap

ERDDAP > info > Data_prova_06f6_0323_cbfd

Grid DAP Data	Sub-set	Table DAP Data	Make A Graph	WMS	Source Data Files	Title	Sum-mary	FGDC, ISO, Metadata	Back-ground Info	RSS	E mail	Institution	Dataset ID
data			graph		files	Portopalo di Capo Passero Hydrophone data		M	background	RSS		Istituto Nazional...	Data_prova_06f6_0323_cbfd

The Dataset's Variables and Attributes

Row Type	Variable Name	Attribute Name	Data Type	Value
attribute	NC_GLOBAL	acknowledgement	String	Funded by EU - Next Generation EU PNRR IR00000032 ITINERIS, Italian Integrated Environmental Research Infrastructures System
attribute	NC_GLOBAL	area	String	Mediterranean Sea
attribute	NC_GLOBAL	array	String	Capo Passero
attribute	NC_GLOBAL	cdm_data_type	String	TimeSeries
attribute	NC_GLOBAL	cdm_timeseries_variables	String	midgid,instrument_id,longitude,latitude,depth
attribute	NC_GLOBAL	contact	String	riccobene at lns.infn.it
attribute	NC_GLOBAL	contributor_name	String	Giorgio Riccobene; Simone Sanfilippo; Salvatore Viola
attribute	NC_GLOBAL	Conventions	String	COARDS, CF-1.10, ACDD-1.3
attribute	NC_GLOBAL	creator_email	String	riccobene at lns.infn.it
attribute	NC_GLOBAL	creator_name	String	RICCOBENE
attribute	NC_GLOBAL	creator_type	String	institution
attribute	NC_GLOBAL	date_created	String	2025-09-04
attribute	NC_GLOBAL	date_modified	String	2025-09-04
attribute	NC_GLOBAL	defaultDataQuery	String	&time>=now-60minutes
attribute	NC_GLOBAL	featureType	String	TimeSeries
attribute	NC_GLOBAL	history	String	fixed mooring
attribute	NC_GLOBAL	infoUrl	String	local files
attribute	NC_GLOBAL	institution	String	Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud
attribute	NC_GLOBAL	keywords	String	acoustic, hydrophone, portopalo_di_capopassero, sound_pressure_level
attribute	NC_GLOBAL	keywords_vocabulary	String	SeaDataNet Parameter Discovery Vocabulary
attribute	NC_GLOBAL	license	String	Creative Commons Attribution 4.0
attribute	NC_GLOBAL	licenseURL	String	https://creativecommons.org/licenses/by/4.0/legalcode
attribute	NC_GLOBAL	processing_level	String	Instrument data that has been converted to geophysical values
attribute	NC_GLOBAL	publisher_email	String	riccobene at lns.infn.it
attribute	NC_GLOBAL	publisher_name	String	Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud
attribute	NC_GLOBAL	publisher_url	String	www.lns.infn.it
attribute	NC_GLOBAL	source	String	fixed mooring
attribute	NC_GLOBAL	sourceUrl	String	(local files)
attribute	NC_GLOBAL	standard_name_vocabulary	String	CF Standard Name Table v72
attribute	NC_GLOBAL	subsetVariables	String	device,model,instrument_id,serial_no
attribute	NC_GLOBAL	summary	String	Hydrophone SPL data from fixed acoustic monitoring.
attribute	NC_GLOBAL	title	String	Portopalo di Capo Passero Hydrophone data


```
{
   "Sensor":{
      "Number of sensors": 1,
      "Nickname": "JB4",
      "Sensor ID": 164,
      "Manufacturer Name": "co.l.mar.",
      "Manufacturer Info": "https://www.colmaritalia.it/it/home/",
      "Part number or model": "DG1330 HP",
      "Serial number": "SN164",
      "Sensor LF cutoff": "N.D.",
      "Sensor HF cutoff": [700,"[Hz]"],
      "Sensitivity":{
         "Average value": [-156,"[dB re V/1uPa]"],
         "Curve": "N.D."
      }
   },
   "Mooring":{
      "Mooring name": "JB4",
      "Mooring type": "CABLED",
      "Seabed depth": [3455,"[m]"],
      "Sensor depth": [3452.4,"[m]"],
      "Easting": [587733.30,"[m]"],
      "Northing": [4016810.84,"[m]"],
      "WGS84 Zone": "33N",
      "Date of installation": "October 2024",
      "Date of recovery": "N.D."

}
```


All the output files contain metadata information to ensure FAIR(ness):

ERDDAP: Datasets https://erddap.lns.infn.it/erddap

ERDDAP

ERDDAP is a data server that gives you a simple, consistent way to download subsets of scientific datasets in common file formats and make graphs and maps. This particular ERDDAP installation has oceanographic data (for example, data from satellites and buoys).

Easier Access to Scientific Data

Our focus is on making it easier for you to get scientific data.

Different scientific communities have developed different types of data servers.

For example, OPeNDAP, WCS, SOS, OBIS, and countless custom web pages with forms. Each is great on its own. But without ERDDAP, it is difficult to get data from different types of servers:

- Different data servers make you format your data request in different ways.
- Different data servers return data in different formats, usually not the common file format that you want.
- Different datasets use different formats for time data, so the results are hard to compare.

ERDDAP unifies the different types of data servers so you have a consistent way to get the data you want, in the format you want.

- ERDDAP acts as a middleman between you and various remote data servers. When you request data from ERDDAP, ERDDAP reformats the request into the format required by the remote server, sends the request to the remote server, gets the data, reformats the data into the format that you requested, and sends the data to you. You no longer have

Start Using ERDDAP:
Search for Interesting Datasets

- **Do a Full Text Search for Datasets**

Search

- View a List of All 5 Datasets
- **Search for Datasets by Category**

Datasets can be categorized in different ways by the values of various metadata attributes. Click on an attribute (cdm_data_type, institution, ioos_category, keywords, long_name, standard_name, variableName) to see a list of categories (values) for that attribute. Then, you can click on a category to see a list of relevant datasets.

- **Search for Datasets with Advanced Search**
- **Search for Datasets by Protocol**

Protocols are the standards which specify how to request data. Different protocols are appropriate for different types of data and for different client applications.

ERDDAP > Files > Hydro4_d2cf_ac94_1acb > colmar_DG1330HP_164_16Hz_800Hz/

ERDDAP's "files" system lets you browse a virtual file system and download source data files.
("files" documentation, including "How can I work with these files?")

Dataset Title: **Sound Pressure Level (SPL) from Capo Passero site**
Institution: Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud (Catania) (Dataset ID: Hydro4_d2cf_ac94_1acb)
Information: Summary | License | Metadata | Background | Subset | Data Access Form | Make a graph

Name	Last modified	Size	Description
Parent Directory		-	
INFN-LNS_ITINERIS_CapoPassero_HYDROJB4_20241114_114001_SPL.h5	24-Feb-2025 12:08	57448	
INFN-LNS_ITINERIS_CapoPassero_HYDROJB4_20241114_121001_SPL.h5	24-Feb-2025 12:08	57296	
INFN-LNS_ITINERIS_CapoPassero_HYDROJB4_20241114_155001_SPL.h5	24-Feb-2025 12:08	57144	
INFN-LNS_ITINERIS_CapoPassero_HYDROJB4_20241114_160001_SPL.h5	20-Jun-2025 09:11	57144	
INFN-LNS_ITINERIS_CapoPassero_HYDROJB4_20241114_170001_SPL.h5	20-Jun-2025 09:12	57144	
INFN-LNS_ITINERIS_CapoPassero_HYDROJB4_20241114_180001_SPL.h5	20-Jun-2025 09:12	57144	
INFN-LNS_ITINERIS_CapoPassero_HYDROJB4_20241114_190001_SPL.h5	20-Jun-2025 09:12	57144	
INFN-LNS_ITINERIS_CapoPassero_HYDROJB4_20241114_200001_SPL.h5	20-Jun-2025 09:12	57448	
INFN-LNS_ITINERIS_CapoPassero_HYDROJB4_20241114_210001_SPL.h5	20-Jun-2025 09:13	57448	
INFN-LNS_ITINERIS_CapoPassero_HYDROJB4_20241114_220001_SPL.h5	20-Jun-2025 09:13	57448	
INFN-LNS_ITINERIS_CapoPassero_HYDROJB4_20241114_230001_SPL.h5	20-Jun-2025 09:13	57296	
INFN-LNS_ITINERIS_CapoPassero_HYDROJB4_20241115_000001_SPL.h5	20-Jun-2025 09:13	57144	
INFN-LNS_ITINERIS_CapoPassero_HYDROJB4_20241115_010001_SPL.h5	20-Jun-2025 09:14	57448	
INFN-LNS_ITINERIS_CapoPassero_HYDROJB4_20241115_020001_SPL.h5	20-Jun-2025 09:14	57448	
INFN-LNS_ITINERIS_CapoPassero_HYDROJB4_20241115_030001_SPL.h5	20-Jun-2025 09:14	57296	

ERDDAP > tabledap > Make A Graph

Dataset Title: **Portopalo di Capo Passero NRT sensor feed, Hydrophone Sound Pressure Level data**
Institution: Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud (Dataset ID: ncprova_b718_37df_617a)
Range: time = 2024-12-31T23:00:00Z to 2025-01-01T03:04:53Z
Information: Summary | License | Metadata | Background | Data Access Form | Files

Graph Type: markers
X Axis: time
Y Axis: spl_full
Color:

Constraints

	Optional Constraint #1		Optional Constraint #2	
time	>=	2025-01-01T00:00:00Z	<=	2025-01-01T00:05:00Z
frequency	>=	60	<=	63
spl_full	>=	60	<=	120
	>=		<=	
	>=		<=	

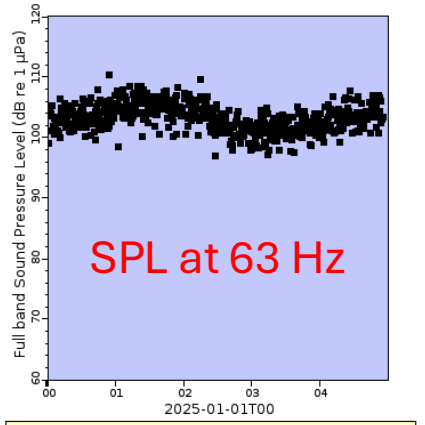
Server-side Functions
distinct()

Graph Settings
Marker Type: Filled Square Size: 5
Color:
Color Bar: Continuity: Scale:
Minimum: Maximum: N Sections:
Y Axis Minimum: Maximum: Ascending

Redraw the Graph (Please be patient. It may take a while to get the data.)

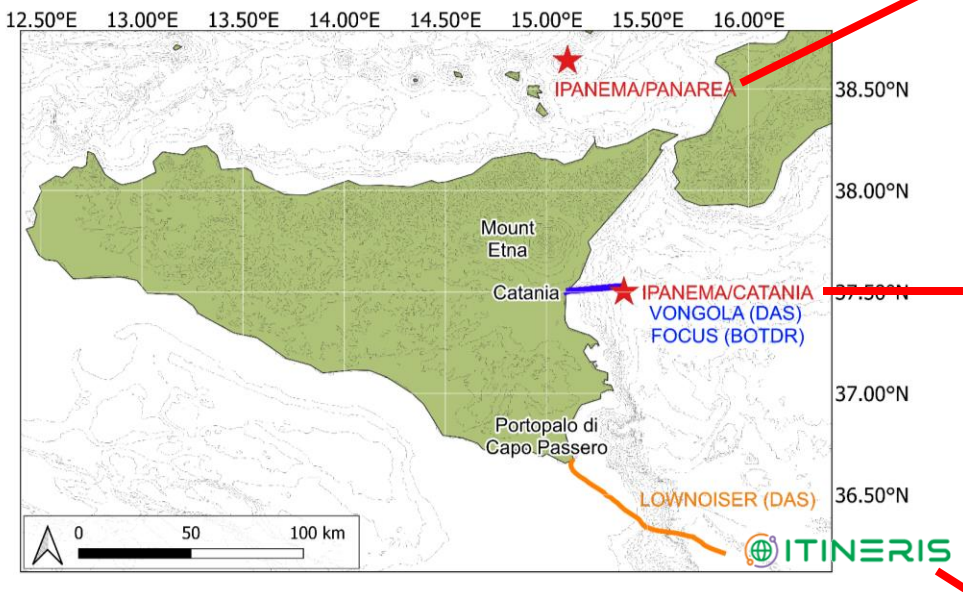
Optional:
Then set the File Type: .htmlTable (File Type information)
and Download the Data or an Image
or view the URL: http://192.84.151.12:8080/erddap/tabledap/ncprova_b718_37df_617a.htmlTable?tim
(Documentation / Bypass this form)

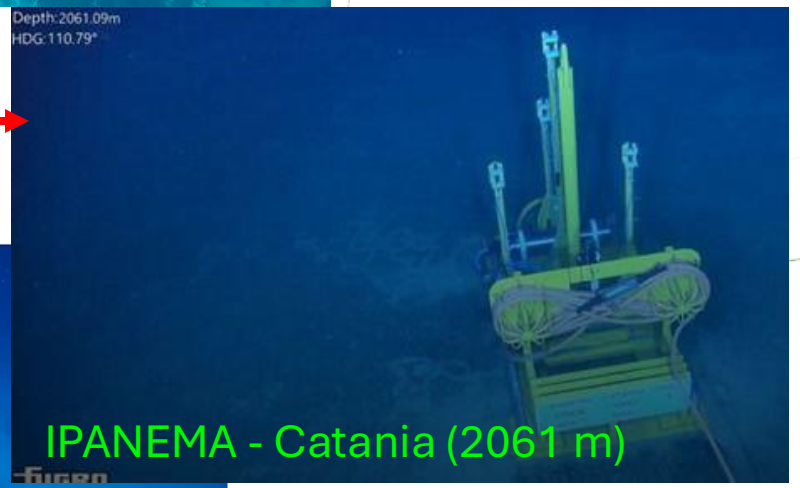
Time range: 5 minute(s)

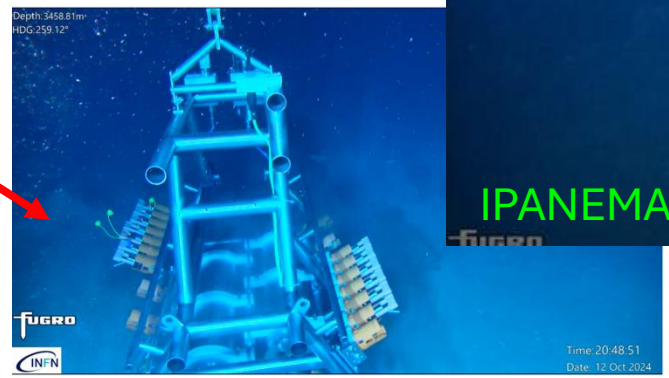


time	spl_full
UTC	dB re 1 µPa
2025-01-01T00:00:00Z	99.09989
2025-01-01T00:00:01Z	105.02949
2025-01-01T00:00:01Z	103.60222
2025-01-01T00:00:02Z	105.18926
2025-01-01T00:00:02Z	103.971146
2025-01-01T00:00:03Z	105.29775
2025-01-01T00:00:03Z	101.19441
2025-01-01T00:00:04Z	101.92854
2025-01-01T00:00:04Z	101.52653
2025-01-01T00:00:05Z	103.288376
2025-01-01T00:00:05Z	100.58737
2025-01-01T00:00:06Z	102.394066
2025-01-01T00:00:06Z	101.771355
2025-01-01T00:00:07Z	102.49946
2025-01-01T00:00:07Z	103.30969
2025-01-01T00:00:08Z	100.63378
2025-01-01T00:00:08Z	101.069786
2025-01-01T00:00:09Z	102.53612
2025-01-01T00:00:09Z	100.78773
2025-01-01T00:00:10Z	100.08307
2025-01-01T00:00:10Z	106.38793

ITINERIS WP5.7: INFN – LNS site nodes







Portopalo di Capo Passero (3450 m)

Ocean Sound monitoring sub-system: Research Infrastructures

- Consiglio Nazionale delle Ricerche - Istituto di Scienze Polari (**CNR - ISP**), Messina
- Consiglio Nazionale delle Ricerche - Istituto per lo studio degli impatti Antropici e Sostenibilità in ambiente marino (**CNR - IAS**), Capo Granitola (Trapani)
- Consiglio Nazionale delle Ricerche - Istituto di Scienze MARine (**CNR - ISMAR**), Venice Laguna
- Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud (**INFN - LNS**), Catania
- Istituto Nazionale di Geofisica e Vulcanologia (**INGV**), Catania
- European Multidisciplinary Seafloor and water column Observatory - European Research Infrastructure Consortium (**EMSO - ERIC**), Catania

Conclusions and outlook

- **INFN - Laboratori Nazionali del Sud is leading the WP 5.7 of ITINERIS:**
  - **Main goal** is the development of the Italian Ocean Sound monitoring Sub-system
    - We are efficiently storing, collecting and analyzing acoustic data from different moorings and involved RIs
    - **Preliminary results** are **compatible** with standard algorithm constantly used in the field (**PAMGuide**)
  - Acoustic data from all the INFN - LNS moorings are constantly feeding an **ERDDAP** server (https://erddap.lns.infn.it/erddap)
  - **Future steps** are the finalization of the system (by including also data from a **Distributed Acoustic Sensor** (**DAS**) system) that will demonstrate one of the most innovative scientific infrastructures for the continuous monitoring of the Mediterranean Sea soundscape.

THANKS!

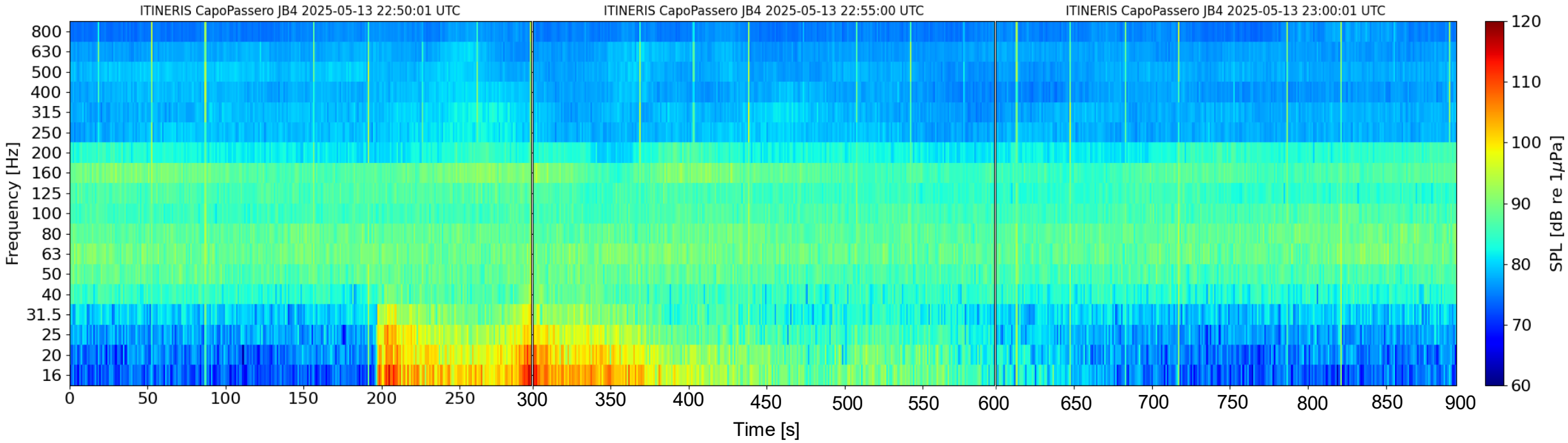
IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-Mission 4 “Education and Research” - Component 2: “From research to business” - Investment 3.1: “Fund for the realisation of an integrated system of research and innovation infrastructures”

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani

ITINERIS WP5.7 @ INFN – LNS
Preliminary results

- Earthquake (**Mwp 5.8**) recorded by hydrophones at Portopalo di Capo Passero facility on 13rd May 2025 coming from a seismic event in Crete (Greece) at 22:51:16 UTC (about 1000 km away from south Sicily)
  - The **P-wave** arrives about **200 seconds** after the event
  - The **S-wave** arrivers about **300 seconds** after the event
- It lasts for about 350 seconds

https://terremoti.ingv.it/event/42706112



ITINERIS WP5.7 @ INFN – LNS: status update

Ocean Sound monitoring Sub-system within the ITINERIS Data Portal:

- Python algorithms for data analysis (available on Git with permissions)
  - Best practices to ensure FAIR data use
  - Sound Pressure Level metrics (mean, 25th, 50th, 75th, 95th percentiles in third-octave bands)
- Metadata and vocabulary aligned with, and extending, SeaDataNet standards
- Collaboration with all involved RIs
  - Two-day training with CNR – IAS at INFN - LNS
  - Regular updates via remote connections

ERDDAP server development and maintenance:

- Data samples from INFN – LNS marine nodes available through ERDDAP (including new DAS recordings from Catania and Capo Passero)
  - Available at https://erddap.lns.infn.it/erddap