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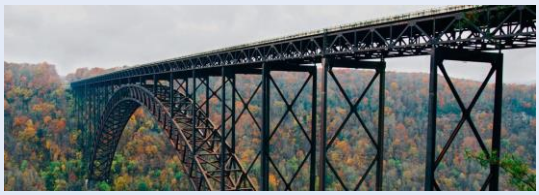

IoT Solution for Monitoring and Early-warning of Displacements

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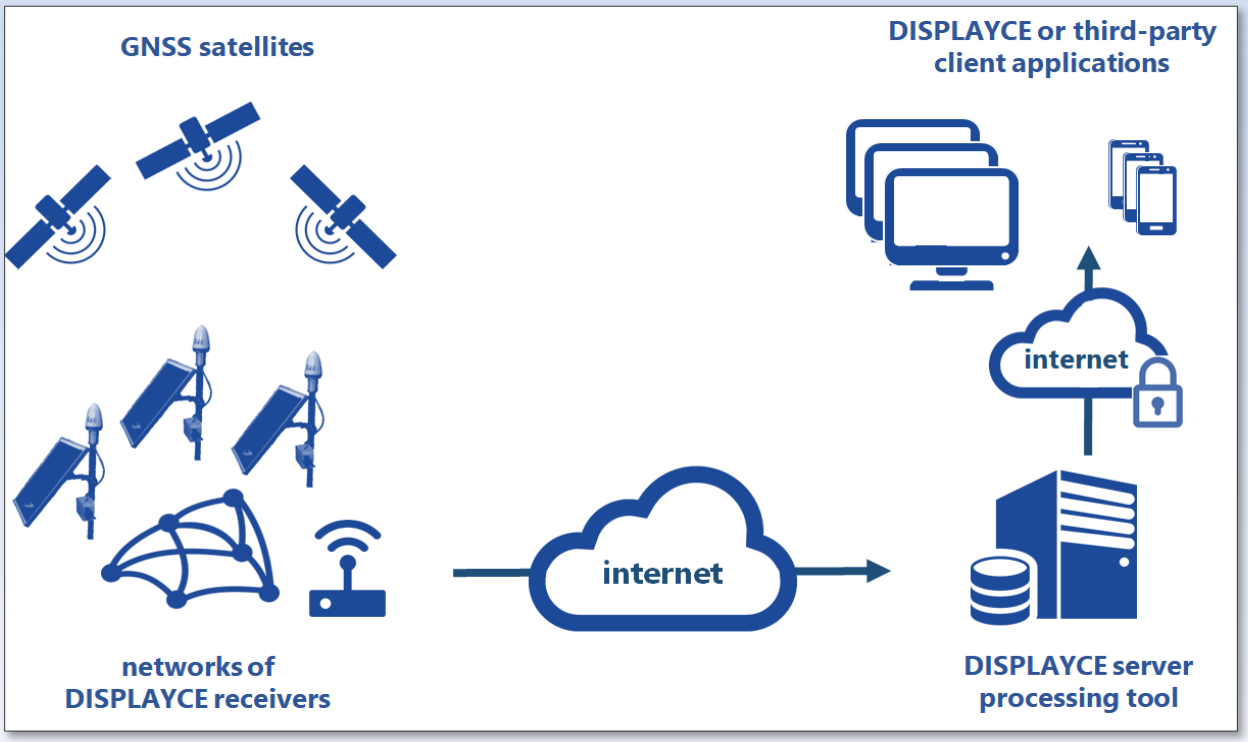
DISPLAYCE

DISPLAYCE is a solution for the automatic and continuous **monitoring** and **early-warning** of surface deformations of **ground**, **buildings** and **critical infrastructures** caused, for example, by landslides, subsidence or seisms.

DISPLAYCE integrates all the components, hardware and software, needed for the monitoring activity.



DISPLAYCE monitoring system architecture.

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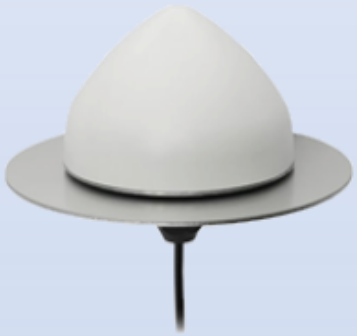
The architectural elements of DISPLAYCE are:

- **Network of GNSS** (Global Navigation Satellite System) L1 receivers to be installed in the area subject to deformation; the sensors can be installed directly on ground on a building or on an infrastructure and allow to continuously measure the movements to which they are subjected.

  DISPLAYCE sensors are based on GNSS U-BLOX NEO M8T modules (https://www.u-blox.com/en/gps-modules/u-blox-6-timing-module/neo-m8t-lea-m8t.html) able to acquire GPS and Galileo observables. Each node is able to save data on an internal memory. The monitoring solution is completed by a low-cost/high performance single-frequency Tallysman GNSS antenna.



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- **Wireless data transmission** system from one node to another (quasi-mesh network). Data transmission takes place in ISM band (UHF at 868 MHz), wireless connection with power <0.5W and proprietary TDMA transmission protocol. The wireless connection, when conditions of optical visibility is available, can transmit data at more than 3 km. The data acquired by each node are transmitted back to a gateway, which represents the collector and the single interface of the network to the remote DISPLAYCE server.

DISPLAYCE stations monumented to the ground in areas subject to landslide. In the photos the receiver and the battery housed in a cabinet with IP67 protection anchored to a pole through suitable fixing brackets.

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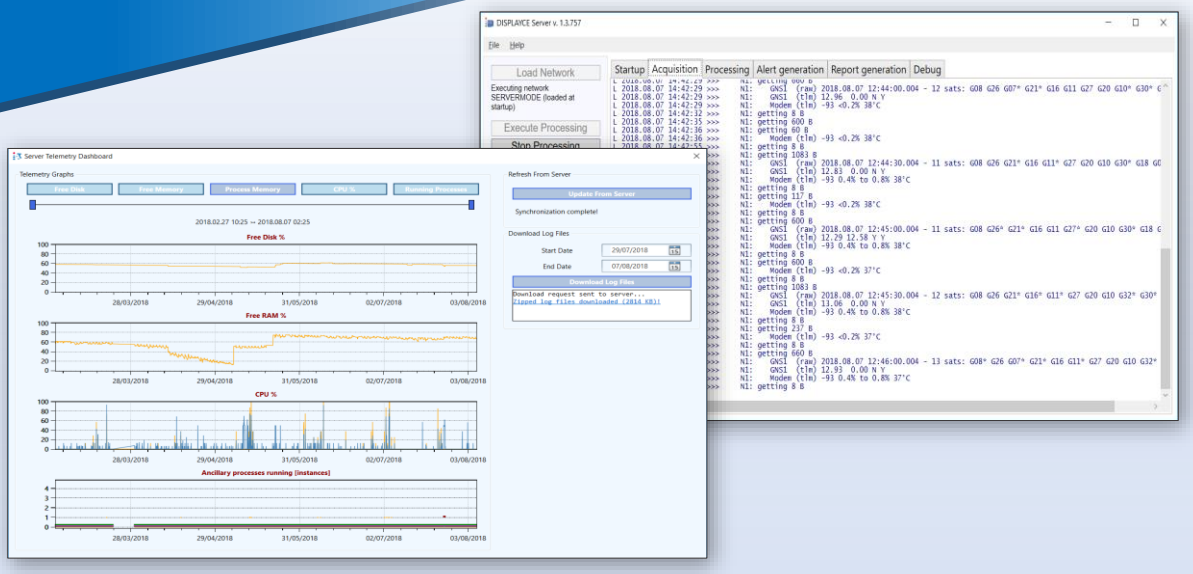
- System for transmitting data acquired from the gateway to a remote computing server (which can be hosted on PCs owned by the customer or on cloud servers) via **GPRS/UMTS modem** (hosting an M2M SIM card) in real time mode (every 30s) or deferred (every hour). DISPLAYCE gateways are equipped with low power consumption modems and are equipped with firmware optimized to maximize the autonomy of the monitoring system. Based on the customer needs, the gateway can be configured to establish a connection and transmit data to the DISPLAYCE server (**client mode**) independently or to accept connections and respond to requests from the remote server (**server mode**). In the latter case, the modem implements a **configurable firewall** to accept incoming connections from a specific IP address or range of IP addresses: this configuration prevents other unauthorized users from connecting to the modem and accessing the data generated by the receivers.
- Fully autonomous power supply system based on small **photovoltaic panels** (20W) and **rechargeable batteries** (12V, 12Ah). The power consumption of a DISPLAYCE node (non-gateway) is on average 380mW including wireless data transmission.

Left: detail of a DISPLAYCE receiver, configurable as "node" or "gateway". Right: detail of a UMTS modem that can be interfaced with the gateway.

DISPLAYCE



Screenshots of the server application.

Server-side software:

- Acquisition of data transmitted by the network and storage of GNSS data in RINEX 2.11 format (Hatanaka + UNIX compression).
- Acquisition of RINEX files (2.10 or higher format or 3.0) of GNSS external (non-DISPLAYCE) receivers, e.g. geodetic receivers to be used as additional reference stations or rovers. The acquisition of RINEX files can be performed from public or password protected FTP servers.
- Post-processing of raw GNSS data. Computation of 3D displacements with a periodicity of between 1 hour and 24 hours and computation of quality indices of GNSS measurements. The repeatability (RMS) of displacement measurements for daily solutions is between 1 and 3 mm.
- Calculation of telemetry measurements (e.g. battery and photovoltaic panel voltage, quality of data transmission, quality of acquired GNSS signals, etc.).
- Publication of displacement and telemetry measurements using REST web services.
- Generation and transmission (by e-mail) of periodic reports in PDF format on the status of the network.
- Generation and transmission (by e-mail and/or SMS) of alert messages raised when exceeding a threshold both for displacements and/or system health parameters. The thresholds are fully configurable by the user.

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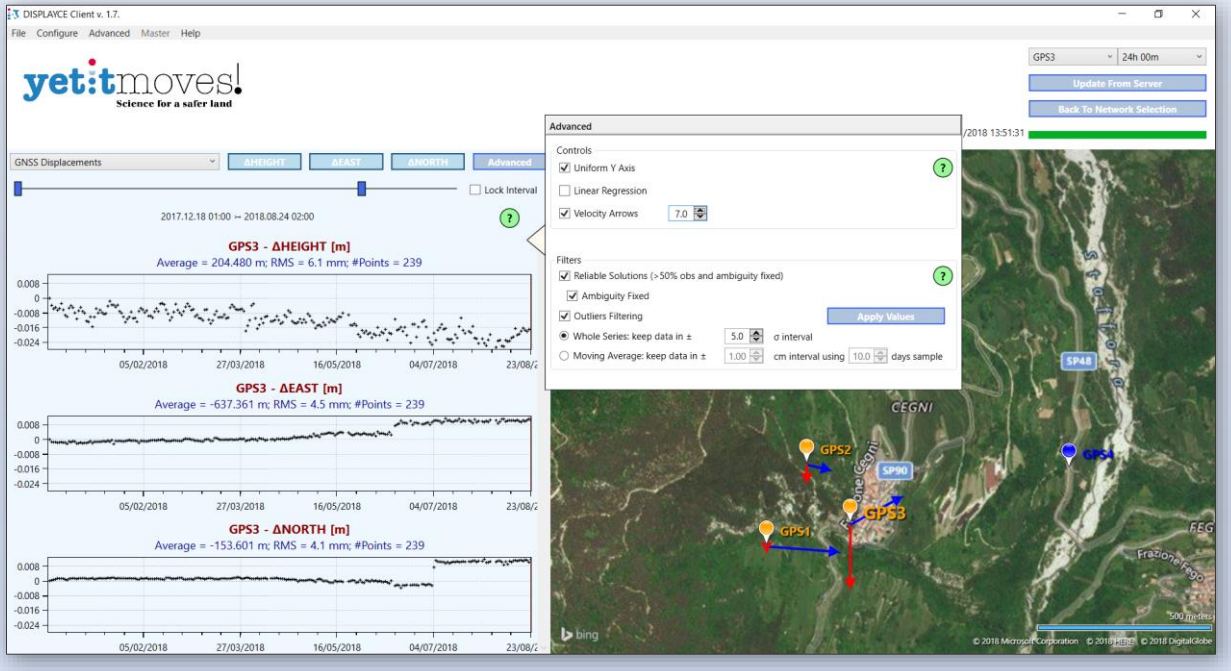

DISPLAYCE client interface.

- **Client-side software** for the visualization and analysis of data published by the server and relevant to the monitoring network (3D displacements, telemetry parameters, quality of GNSS data, etc.). The software also allows the display data acquired from local sensors (strain gauges, inclinometer chains, piezometers, weather stations, etc.). Using the same application it is possible to configure the thresholds for generating alerts and reports on the calculation server. Access to monitoring data through the client application is password protected. A single application instance allows data visualization and management of all monitoring networks for which a user is enabled.

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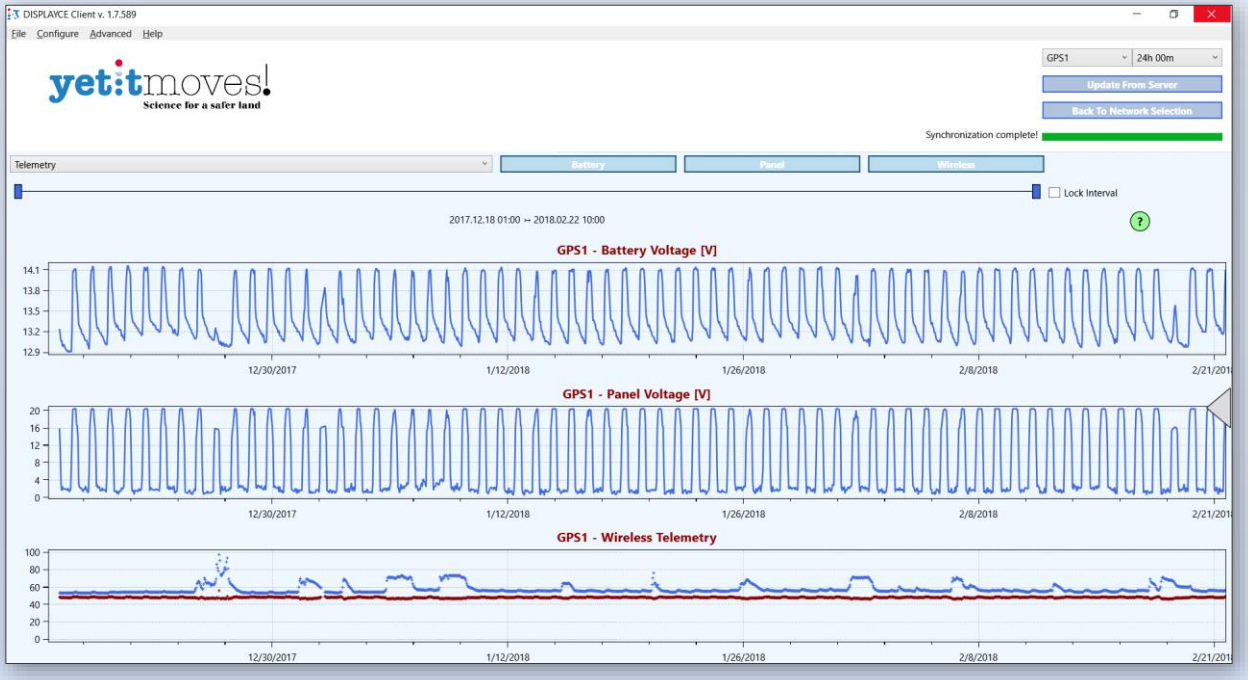
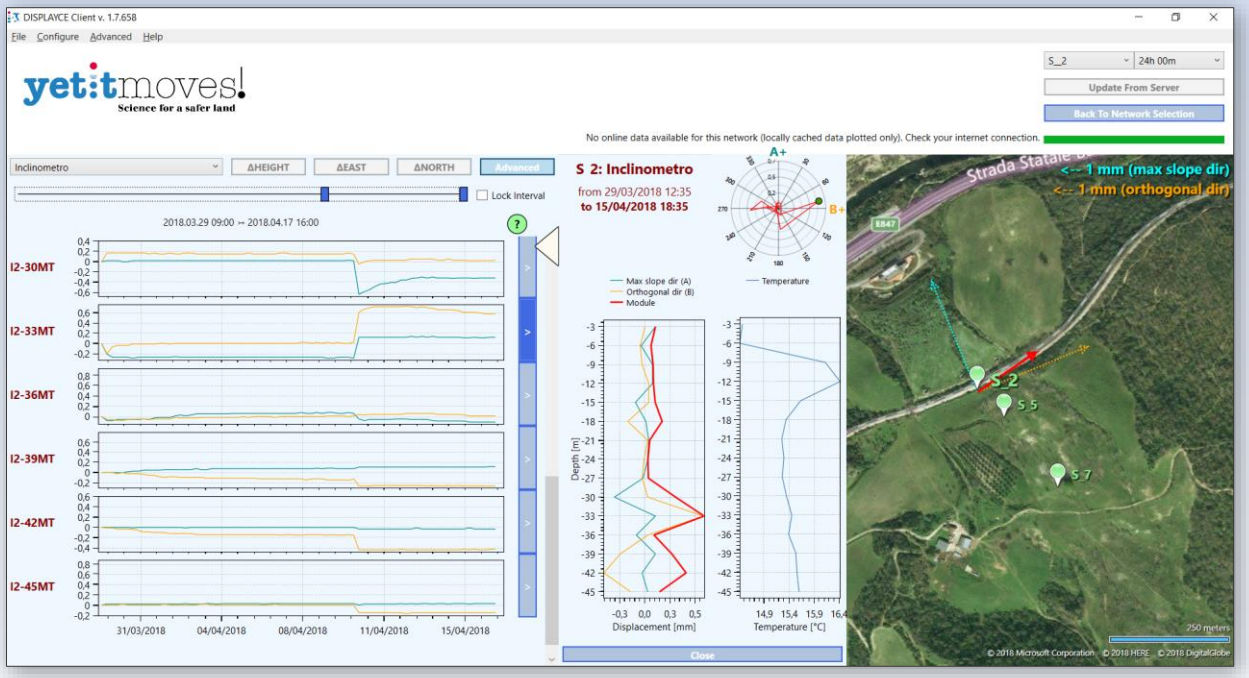


Telemetry data of a DISPLAYCE station.



Inclinometer chain data.

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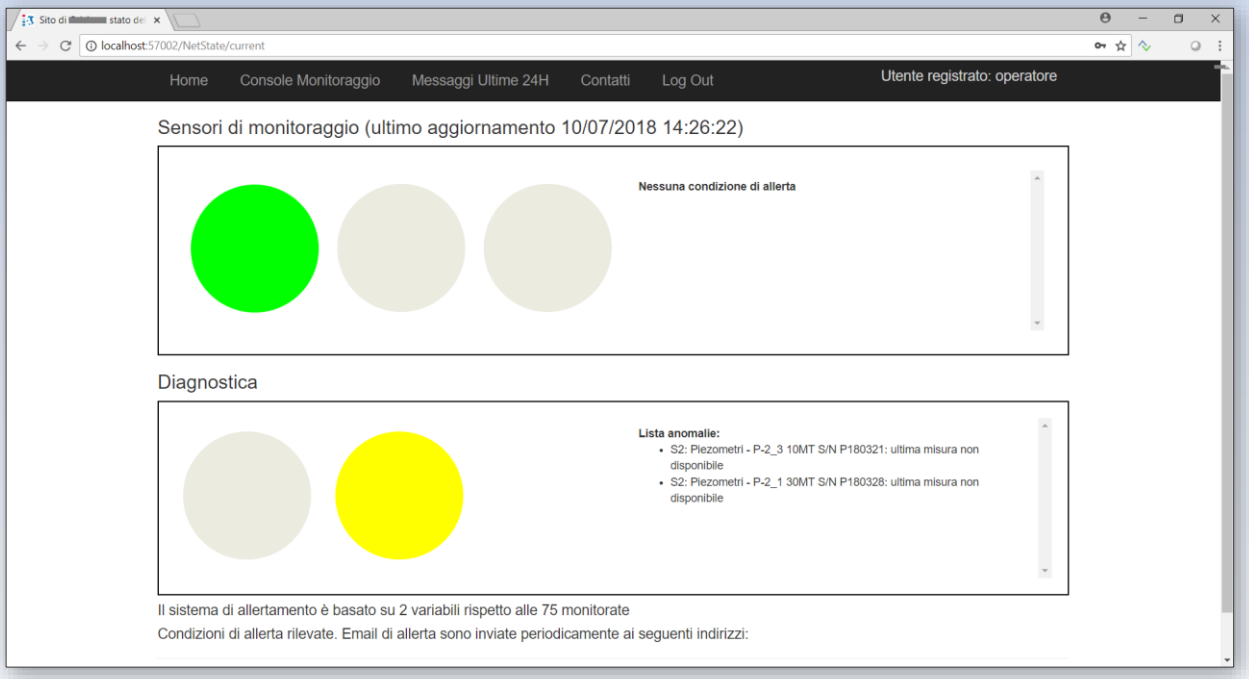
- **Web application for the alert**. Simple and intuitive web application designed for use in operation centers: after user authentication, it automatically interfaces with the REST services published by DISPLAYCE server and shows, by means of semaphores, the status of the monitoring in terms of sensors measurements (upper panel) and possible malfunctions (bottom panel).

  The thresholds used to generate alerts and alarms can be configured by an "expert user" using the client application described previously.

  Only in the presence of anomalous conditions specific messages are displayed. The application is able to save all alert, alarm and anomaly messages recorded in the last 24 hours.



Web application for the alert.

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Why to choose DISPLAYCE

Respect to GNSS commonly used for geophysical and structural monitoring applications, DISPLAYCE presents a series of innovative technological features:

- DISPLAYCE sensors are **light, small** and completely **autonomous** from the point of view of data transmission and power supply (the battery is dimensioned to guarantee an autonomy of at least 10 days in the absence of an external power supply). These features make them easy and quick to install on the ground or on buildings or infrastructures.
- The DISPLAYCE system is **complete**: it includes everything needed for monitoring: GNSS sensors, real-time data transmission system, measurement acquisition and calculation software, client applications for displaying the measurement time series and monitoring network status, e-mail alert system in case of anomalous malfunctions or anomalous movements detected.
- DISPLAYCE receivers are **cost-effective** if compared to instrumentation traditionally used for these applications. They have comparable performances in terms of displacements repeatability. Even with a low budget it is possible to implement widespread monitoring networks on the area of interest.

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Applications

To date DISPLAYCE has been used mainly for monitoring of **landslides, river erosion, dams, subsidence and natural gas storage sites**. However, it is possible to use it for the monitoring of **bridges or viaducts**. It is possible to install an arbitrary number of sensors on the critical infrastructure to be monitored and/or in the neighborhood, in particular in areas considered at risk due to slope instability or subsidence.

Likewise, DISPLAYCE sensor networks can be installed on "sensitive" buildings such as schools, hospitals or historic buildings for which probability of damage induced by seismic events is not neglectable. DISPLAYCE can monitor possible slow deformations or structural failures over time in the post-seism phase.

Certifications

DISPLAYCE is compliant with the European standards (CE marking).

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Main installations, customers and users

Customer	Description	Site	N. points
Research	Landslide	Italy	3
Public Administration	Landslide	Italy	4
Transports	Landslide	Italy	4
Energy	Natural gas storage site	Italy	11
Research	Subsidence	Italy	2
Research	Deep seated gravitational slope	Italy	13
Public Administration	Landslide	Italy	5
Public Administration	Landslide	Italy	3
Energy	Penstock landslide	Italy	3
Research	Lanslide	Italy	3
Research	Subsidence	Italy	3
Energy	Penstock landslide	Italy	9
Research	Landslide	Italy	5
Energy	Arc dam	Italy	4
Transports	Landslide	Italy	13 (to be installed)
Research	Seismic monitoring	Iceland, Romania, Netherlands, Greece, Italy	26 (to be installed)
Public Administration	Landslide	Italy	5 (to be installed)

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Technical specifications

GNSS	
Receiver	U-BLOX M8T
Antenna	Tallysman TW3740/3742; GPS/QZSS L1, Galileo E1; gain 40/42 dB; wire lenght 3.0 m (other options at request).
Connettori Antenna	2 x SMA female; 3.3V (other options at request)

Power	
Photovoltaic panel	20Wp (nodes), 50Wp (gateway)
Battery	12V 12Ah (node), 12V 24Ah (gateway). Charge from -15 to 50 Celsius
Autonomy	Potentially unlimited (considering 2 hours of sunlight per day – 20Wp panel); a fully charged battery at 20 Celsius can power up the station for more than 12 days in case of total dark
Power consumption	380mW on average for node (including antenna)

Local wireless link	
Type	UHF ISM band at 868MHz, link wireless 0.5W. TDMA proprietary transmission protocol
Antenna	Directional with gain 13dBi or omni-directional with gain 3dBi; SMA female connector; 3.3V (different options on request)
Range	8 km LoS (theoretical data)
Networking	Up to 14 nodes connected to a single gateway; mesh network; each receiver can be configured as node or gateway

Remote data transmission	
Type	TPC/IP protocol
Mode	Two remote data transmission modes between the gateway and the server are available: 1. modem as **client**: the GPRS/UMTS modem installed on gateway is configured to open a data connection with the server (the IP address must be public and static). It periodically transmits all raw data acquired from nodes (and eventually gateways) belonging to the monitoring network. ***Pros***: it does not require specific M2M SIM cards with public address. ***Cons***: possible security problems on server side due to the need to maintain a logic port opened for each connected modem, without the possibility to use one IP address (or range of IP addresses) for the clients. 2. modem as **server**: the GPRS/UMTS modem installed on the gateway is configured as server and accepts inbound connections by the remote server. The modem is equipped with a configurable firewall to accept connection requests only from the static IP address of the server. It is possible to use a specific commercial dynamic DNS services (optional) which guarantee the connectivity even when using dynamic IP address SIM card. ***Pros***: no security weakness on server-side. ***Cons***: need of a M2M SIM with public IP address.

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Other	
Protection	IP65 for receiver, IP67 for external box
Dimensions	GNSS Unit (17x10x4.8)cm GNSS Antenna (8x13)cm Photovoltaic panel (20Wp): (34x50x2.4)cm Photovoltaic panel (50Wp): (67x54x2.5)cm Wireless antenna (Yagi): +13dBi Whip. (63x18)cm External box: (40x30x21)cm

GNSS data processing software

DISPLAYCE GNSS Core	
Programming language	C and C++
3rd party libraries	RTKLIB (v. 2.4.2, BSD-2 license); used for GNSS data acquisition and clocks synchronization
Processing	Proprietary double-differences batch least square estimator developed to reach maximum performances in term of displacements repeatability for static monitoring applications
Repeatability	From 1 (planimetry) to 3 (height) mm RMS for 24 hours batch of data (according to distance and height difference between reference and rover and to satellite visibility and possible multipath)