Sensing long-term environmental change through regional monitoring: the Long Term Ecosystem Research Network (LTER)

by Alessandro Campanaro, Alessandro Oggioni Alessandra Pugnetti*

THE VERY OBJECTIVE OF LTER IS THE ECOLOGICAL RESEARCH AND THE MONITORING OF VARIOUS ECOSYSTEM TYPES SPANNING BROAD RANGES OF ENVIRONMENTAL CONDITIONS AND HUMAN DOMINATION OF THE LANDSCAPE. IN THAT REGARD, LTER CAN SUPPORT THE FURTHER DEVELOPMENT AND IMPLEMENTATION OF GMES BY ACTING AS A VALIDATION NETWORK BUT ALSO *IN SITU* DATA PROVIDER FOR GMES PRODUCTS. LTER MONITORING ACTIVITIES ARE LED IN COORDINATION WITH LOCAL DECISION MAKERS AND TECHNICAL ENTITIES INVOLVED IN ENVIRONMENTAL MONITORING. THE DATA COLLECTED LOCALLY IN THE FRAME OF LTER ACTIVITIES CAN IN RETURN BENEFIT LOCAL END-USERS BY CONTRIBUTING TO FURTHER ENHANCE GMES SERVICES.

The LTER vision promotes collaborative initiatives with local decision makers

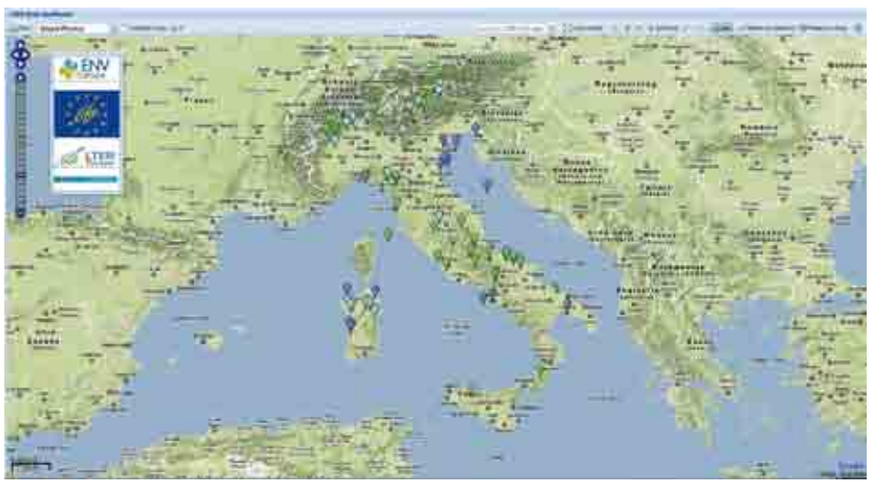
The essence of LTER is the collection of an extensive Space-time variety of data, therefore the network is an excellent starting point to support environmental protection and management initiatives. Successful results have been reached at local level by implementing specific monitoring-forecasting systems as well as Decision Supporting Systems (DSS) to help developing and implementing of environmental planning strategies.
A strong effort to promote a more fruitful cooperation between science and policy, not only at local level but also at national and international level, is the main challenge of the LTER network. A first step in this sense has been provided by the *EnvEurope* Life+ Project (cf. box). By building SEIS (Shared Environmental Information System) and supporting the implementation of GMES, the "Environmental Policy and Governance" Life+ priority area strengthens the knowledge base for policy making and implementation. The *EnvEurope* Life+ project, which was selected under this priority area, promotes the participation of representatives of selected LTER sites located in different European countries. The national LTER Italy network is part of this project through the participation of several national sites.
LTER Italy (www.lteritalia.it) comprises 20 sites, which include freshwater, marine and terrestrial environments representing the main ecosystem typologies of the country. This is completed with two international sites (Himalayan Lakes and Antarctic). All sites have been selected according to LTER-International criteria. Many Italian institutions participate to LTER-Italy, notably through site management and network coordination: the National Research Council, the National Forest Service, Universities, the Zoological Station of Napoli and Regional Environmental Agencies.

"The collection of an extensive Space-time variety of data is an excellent starting point to support environmental protection and management initiatives"

LTER-Italy sites are potential providers of *in situ* data for GMES services. This article presents three examples from terrestrial, lacustrine and marine habitats. The LTER North-Western Adriatic Sea site already provides data for the GMES Marine Service through its involvement in *MyOcean* and *MyWaves* projects. In the two other sites, Lake Garda and North-Western Alps, the existing automatically recorded medium-to-long term field data provides the opportunity for comparison with remote sensing data. This spatially extensive remote sensing data may be useful to spatially interpolate point data taken in the field.

A joint coastal oceanographic observatory network in the Adriatic Sea (LTER-Italy site: North-Western Adriatic Sea)

Fixed measuring stations and oceanographic buoys are fundamental to understand and manage the marine environment. This is particularly important in dynamic coastal areas, given the delicate balance between



The geoportal, which presents the Italian sites involved in the LTER network. Green markers: terrestrial sites; light blue markers: freshwater sites; blue markers: marine sites (Credits: LTER Italia).

* *Article written in collaboration with:*
Paolo Colangelo, Sapienza University of Rome IT - Dept. Biology and Biotecnology "Charles Darwin";
Mauro Bastianini, National Research Council of Italy - Institute of Marine Science;
Claudia Giardino, National Research Council of Italy - Institute for Electromagnetic Sensing of the Environment;
Paola Focaccia, National Research Council of Italy - Institute of Marine Science;
Michele Freppaz, University of Torino - DIVAPRA Agricultural Chemistry and Pedology - LNSA, NatRisk;
Mariangela Ravaioli, National Research Council of Italy - Institute of Marine Sciences.

The LTER network

The Long-Term Ecosystem Research-network (LTER) is a network of sites where a series of ecological data is gathered over several decades, at regional, national and continental scales. LTER sites consist of various reference ecosystems, research and monitoring facilities that form part of a global network. The long-term ecological research gives a scientific background for the study and interpretation of global environment modifications caused by human activities (e.g. the increase in the rate of supply of organic matter in an ecosystem –eutrophication- or introduction of alien species). It can also be used for identifying trends, planning solutions and assessing the success of environmental management projects.
The research network can also deal with the socio-economic effects of the modification of the natural environment, which can result in misleading interpretations. LTER benefits from a solid interdisciplinary approach to the study of environmental problems, which in recent years has involved the socio-ecological aspects.
Following the start of the first LTER programme in the USA in the 1980s, a number of national LTER networks have been established. These have been at the global and European level, giving rise to LTER-International and LTER-Europe.
The European LTER networks are associated with a number of relevant initiatives or programmes at European (e.g. Natura*2000*, GMES and SEIS - Shared Environmental Information System) or international level.

environmental and socio-economic factors. At European level, technological progress now makes it possible to automatically measure many sea state variables, particularly applicable to water quality monitoring (for swimming, public health, food safety and environmental protection) and for the understanding of environmental change. Measuring physiochemical and biological sea states through automatic data gathering systems is the new frontier of modern oceanography; to this purpose the use of a joint observatory is crucial. These instruments are able to provide real-time monitoring with high temporal resolution sampling for:

- The principal parameters describing the physiochemical and biological conditions of a marine environment, such as: temperature, salinity, current speed and direction, pH, oxygen saturation, chlorophyll, transparency and backscattering;
- Meteorological parameters near the surface, where the dynamics of energy exchange between atmosphere and the sea represent a noteworthy source of criticality for numerical forecasting.

"LTER-Italy sites are potential providers of *in situ* data for GMES services"

In Italy various research institutes, gathered in the National Operational Oceanography Group (GNOO), are responsible for the upkeep and management of the instrumentation used on buoys. There are six principal long-standing stations dedicated to observing the sea's status in the Northern Adriatic Sea (Figure 2): the Gulf of Trieste near the Miramare reserve where the MAMBO (run by the Trieste Institute of Oceanography and Experimental Geophysics OGS) and Paloma (run by CNR-ISMAR in Trieste) buoys are moored; the Gulf of Venice with the Acqua Alta Oceanographic Tower (run by CNR-ISMAR in Venice); and sites S1 south of the Po Delta and E1 off Rimini (both run by CNR-ISMAR in Bologna); the Telesenigallia mast (run by CNR-ISMAR in Ancona) at the southern limit of the North-Adriatic Sea.

The *MyOcean and MyWave* GMES projects use the data supplied by the platforms and buoys listed below to validate forecast models:

- The MAMBO buoy is moored to a 20 m seabed in the Gulf of Trieste by the edge of the Miramare marine park. It collects and transmits real-time meteorological and marine data: temperature and salinity are recorded continuously. The buoy is an ideal laboratory for using advanced instrumentation to measure marine currents or monitor dissolved carbon dioxide concentration;
- The Paloma mast is located 12 km offshore in the Gulf of Trieste, at a depth of 25 m. It records data of sea temperature, wind speed and direction, air temperature, relative humidity, precipitation, solar radiation, and air pressure. The data acquisition and elaboration occurs every 5 minutes and transmission is in near real-time (every 3 hours);
- The Acqua Alta research tower was installed in January 1970 and is located 15 km from the city of Venice. A broadband wireless communication system between the tower and the operating institute allows real time data availability. Measurements routinely acquired with periodic samplings relate to biology, chemistry and physical oceanography. Autonomous instruments cover atmospheric (wind, air and water temperature, atmospheric pressure, humidity, precipitation) and hydrological parameters (waves, currents along the column with ADCP, temperature at surface and bottom, salinity, turbidity, oxygen, chlorophyll-a and sea level) with a series of meteorological stations and oceanographic instruments. A direct view of the sea's condition around the tower is available continuously thanks to three high-resolution webcams installed on the roof. Two underwater webcams are installed at -3 m and -12 m to observe biological populations and to monitor potentially critical phenomena such as jellyfish swarms etc.;
- The S1 buoy is located at 7,5 km to the southeast of the Po di Goro mouth in the Po Delta. It is moored at a depth of 22,5 m in a coastal area dominated by the sea-river energy exchange, which is sensitive even to the smallest variations in any given environmental component. The site is optimal for studying climate variability in the upper Adriatic, the role of the seabed in local dystrophic[1] and sedimentation

Map of the buoys and fixed platforms in the NW Adriatic Sea (Credits: CNR-ISMAR).

[1] Distrophic refers to basins with brown coloured waters, which results from high concentrations of humic substances and organic acids suspended in the water.

ENVEUROPE (LIFE+ PROJECT ENV/IT/000399)

EnvEurope began and is being developed within the LTER-Europe network, which represents more than 400 sites across Europe and the Near East. The project contributes to the integration and coordination of long-term ecosystem research and monitoring initiatives in Europe. It focuses on understanding the current status of ecosystems and how they are changing, and is characterised by a broad-scale and cross-domain approach (terrestrial, freshwater and marine ecosystems), combining the efforts of over 65 LTER sites in 11 countries.
EnvEurope was conceived and organised to play a role in the conceptual and operational context of SEIS, promoted by the European Commission. The permanent long-term site network on which the *EnvEurope* project focuses will represent a valuable system for *in situ* validation of satellite data, thus also supporting the implementation of the GMES programme. *EnvEurope* will supply ecological data and information on the status and long-term trends of terrestrial, freshwater and marine ecosystems at the European level, based on field data gathered at different scales. It will thus contribute to bridging the gap between science and policy and improve scientific support to the EU's environmental policy and conservation plans. The National Research Council of Italy, through the Institute of Marine Sciences, coordinates the project, which runs from 2010 to 2013.

processes and sediment re-suspension in pro-delta areas;
- The E1 buoy is located 5.5 km north of the city of Rimini. It is moored at a depth of 10.5 m and is representative for a wide stretch of the coast between Rimini and Ancona. Its monitoring is mainly used for forecasting hypoxic[2] and anoxic[3] episodes that in the past have often characterised this part of the coast;
- **The TeleSenigallia** mast, which is two kilometres offshore of the city of Senigallia, at the bottom depth of 10.5 m, provides meteorological data (wind speed and direction and air temperature) and oceanographic data (sea temperature, current speed and direction and sea level) and near real-time data transmission at present (manual data recovery via GSM every 2-7 days).

The buoys acquire meteorological and oceanographic data. As far as the atmosphere is concerned, they measure temperature, pressure, wind speed and direction, relative humidity and net radiation. For oceanography they measure current direction and intensity, temperature, salinity, oxygen saturation, pH, turbidity and fluorescence.

All these buoys and platforms are supported by the governments of the regions involved (Friuli-Venezia Giulia, Veneto, Emilia-Romagna and Marche) and by their respective environmental agencies.

[2] Hypoxia is a phenomenon that occurs in aquatic environments as dissolved oxygen becomes so reduced in concentration that it endangers aquatic organisms living in the system.

[3] Anoxic events or anoxic events occur when the oceans become completely depleted of oxygen

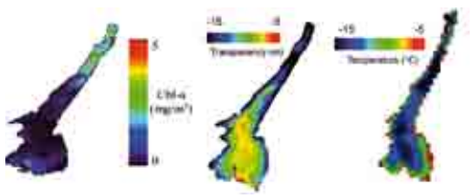
"The *in situ* long time series of data acquired in the Northern Adriatic Sea have, for instance, led to the development of a decision support system helping local authorities in the management of events affecting ecosystem integrity"

In situ long time series of data acquired in the Northern Adriatic Sea have been fundamental for the development of applied research initiatives involving regional and local policy authorities, environmental protection agencies and socio-economic actors.
One example is an observation and 3-D forecasting system and a decision support system aiming to help local authorities in the management of hypoxic and anoxic events. This system, with special focus on the Rimini coastal area, is based on an early-warning system, which predicts spatial and temporal evolution of the marine oxygen concentration, thus supporting the administrative and socio-economic actors (Municipality of Rimini, Emilia-Romagna Region, Agency for protection and environment of the Emilia-Romagna Region - ARPA) in adopting short-term and long-term strategies to reduce the impacts that these marine risks can have on tourism, fishing and the environment. Widely speaking, implementations and progresses in the field of oceanographic and meteorological predictions are supported by long-term intense cooperation with national and regional environmental protection agencies (ISPRA– the National Institute for Environmental Protection and Research-, ARPA– the Regional Agency for Prevention and Environment of Emilia-Romagna- and National Civil Protection) and groups (GNOO -Gruppo Nazionale di Oceanografia Operativa- supported by the Italian Environment Ministry). The data from buoys, included both in the setting-up and validation phases of the forecasting models, assure the high quality level of the meteo-oceanographic Adriatic Sea previsions.

Combining *in situ* and satellite data for lake management (LTER-Italy site: Lake Garda)

Lake Garda is one of the most important touristic areas in Italy, but also a very valuable one as far as hydrological resources are concerned. Together with the other Italian Subalpine lakes (Maggiore, Lugano, Como and Iseo), it plays a central role in the overall water balance of the Po River Valley, representing together more than 20% of the entire basin of the Po River.
The possibility to monitor these lacustrine ecosystems permanently, through Space-based services and *in situ* observations, can provide many answers about the impact of human and natural modifications, biodiversity loss, global warming and the increasing occurrence of natural hazards.

Lake Garda, the largest in Italy, is surrounded by mountains and represents a major environmental as well as an important tourism area. Monitoring activities help protecting the ecological status of the area despite the multiple leisure activities (Credits: Fabio Alessandro Locati).



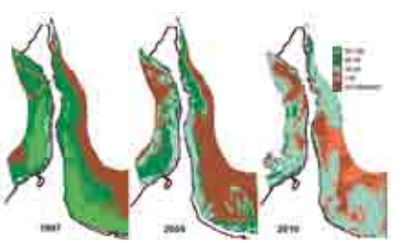
Maps of surface chlorophyll-a concentration, transparency and water temperature in Lake Garda (Credits: CNR-IREA).

Studies on Lake Garda with remote sensing techniques, made at the CNR's (Italian National Research Council) Eugenio Zilioli Experimental Station, started in the early 1990s. These studies were consolidated after 1996 with the participation in the *Satellite Remote Sensing for Lake Monitoring (SALMON)* FP4 project. In 2000 the station was established as a permanent point of reference for the collection of *in situ* measurements, in support of remote sensing. This station collected specific parameters for the validation and analysis of satellite images of the entire basin of Lake Garda.

"Permanent monitoring of lacustrine ecosystems provides answers about the impact of human and natural modifications, biodiversity loss, etc."

Through the integration of *in situ* measurements and the regular acquisition of satellite images, two types of distribution maps are produced. The first provides water quality parameters (such as chlorophyll, total suspended solids, yellow substances and transparency) on a monthly or bimonthly basis, using MERIS ESA satellite images. The second is produced using a sensor mounted on the NASA satellite AQUA MODIS 11A, which returns maps of the temperature of the lake.

Only on one occasion were specific *in situ* measurements acquired for the production of thematic maps, relating to the distribution of aquatic macrophytes[4]. These observations give meaningful information for lakeshore management and are useful for the evaluation of the long-term evolution of macrophyte populations.
All these activities, following the GMES philosophy of integration of Earth Observation with *in situ* data, allow the provision of constant monitoring services and infrastructure not only for Lake Garda but also for the entire subalpine lakes district. The main end-users benefiting from this are the local agencies and communities in charge of monitoring and assessing the status of the lake. An example of this use can be the Centro di Rilevamento Ambientale of the Municipality of Sirmione (Garda Lake), which used remote sensing images of the lake to monitor water quality and obtain the 'blue flag' certification by the Foundation for Environmental Education (FEE).



Developments in areas colonised by submerged macrophytes in the shoreline of the Sirmione peninsula (the percentages of coverage in the legend). Data purchased by hyperspectral sensors mounted on aircrafts (Credits: CNR-IREA).

[4] A macroscopic plant, commonly used to describe aquatic plant, that is large enough to be visible to the naked eye.

Monitoring the alpine environment using satellite and *in situ* data (LTER-Italy site: North-Western Alps)

The Alps represent one of the most sensitive terrestrial ecosystems in Europe, due to natural and human factors. The Alpine Convention states that the Alpine environment is under imminent threat and demands comprehensive countermeasures. The planning and success of every preventative measure strictly depends on the availability of knowledge and information about the state and evolution of the ecological conditions of the Alpine environment. In particular, the maintenance of long-term observations is essential when dealing with such a sensitive ecosystem. The synergies between conventional terrestrial investigations and satellite remote sensing represent an ideal and cost efficient tool for this purpose. Satellite images can synoptically record wide areas, and remote sensing may provide repeated observations of the same areas, which allows detailed long-term monitoring .
The LTER-Italy network includes several high elevation sites in the north-western Alps, which represent the main high altitude environments of this area falling within the Piemonte and Valle d'Aosta regions. They include six research sites located along an altitudinal gradient, ranging from 2100 m to 3100 m Above Sea Level (ASL), where soils are seasonally snow covered. Vegetation cover ranges from larch and spruce stands to alpine grasslands, and overlying soils at various degrees of evolution. One of these six sites belongs to the *GLORIA* (*GLobal Observation Research Initiative in Alpine Environments*) network while another, at a higher elevation (3100 m ASL), is a permanent area for monitoring permafrost and the active soil layer. The main organisation managing both sites is the Regional Agency for Environmental Protection of the Valle d'Aosta region (ARPA Valle d'Aosta).

The Angelo Mosso mountain research station (2901 m ASL - Monte Rosa Massif, Italy) (Credits: Università degli Studi di Torino-NatRisk-LNSA).

"The information collected contributes to the monitoring of avalanche risk and the construction and maintenance of ski slopes in the Monterosa Ski Resort"

The Istituto Scientifico Angelo Mosso (Mosso) research site, close to the Monte Rosa Massif (Alagna Valsesia – Gressoney La Trinité municipalities), belongs to the University of Torino. It is located at a high altitude (2901 m ASL) and hosts the NatRisk-LNSA research centre (www.natrisk.org). Climatic data has been collected there since 1926 thanks to the close presence of a monitoring station belonging to the *Regii Osservatori Meteorologici e Geofisici del Monte Rosa*. An automatic weather station has been in operation since 2005, managed by the Italian army. The automatic weather station has specific sensors for the measurement of temperature at the snow/soil interface and at 10 cm depth. The information collected contributes to the monitoring of avalanche risk and the construction and maintenance of ski slopes in the

Monterosa Ski Resort, where the Mosso research site is located. Moreover, thanks to specific agreements with local governments, the Mosso Institute hosts specific educational and communication activities addressed to local schools and the general public. Among these activities the International Programme for Mountains (IPROMO) organised by the FAO-Mountain Partnership Secretariat and the Turin University-NatRisk, is particularly relevant.

Final remarks

Environmental managers are recognising that a successful environmental management strategy depends on an integrated approach to the maintenance of ecosystem structure and functioning, and that this will optimise the ecosystem services for the benefit of humans and nature. The key question is whether there is sufficient ecological knowledge to provide the necessary information about ecosystem structure, function and response to disturbance. Within this context, the synergies among long-term *in situ* observations (LTER networks), technological innovations, remote sensing (GMES) and ecological modelling are crucial in order to improve our understanding of the environment and our attempts to properly manage and protect it. The activities described, from the three LTER-Italy sites, are examples of *in situ* assessment of the usability and applicability of remote sensing products for long-term ecosystem monitoring.

Alessandro CAMPANARO (biologist, PhD in Animal Biology) is a PostDoc at the University of Rome "La Sapienza" (IT) in agreement with the National Centre for Forest Biodiversity "Bosco Fontana" of Verona (IT). His main research interest focuses on the ecology and monitoring of saproxylic insects. He is involved in the LTER-Italy network since 2009 and in the Life+ Project *EnvEurope* for the "Network design" action.

Alessandro OGGIONI (natural scientist, PhD in Ecology) is a PostDoc at the National Research Council of Italy. His main research interest focuses on GIS, Data Management and phytoplankton and aquatic plants ecology in lacustrine. He is involved LTER-Italy network since 2010 and in the Life+ Project *EnvEurope* for the action about Data Management and Infrastructure development.

Alessandra PUGNETTI (biologist, PhD in Environmental Sciences) is a scientist at the National Research Council of Italy. Her main research interest focuses on phytoplankton ecology in lacustrine, transitional and marine environments. She is involved in the coordination of the LTER-Italy network since 2004 and she is the Coordinator of the Life+ Project "EnvEurope".

Interview

GMES IS NOT ONLY BRINGING VALUABLE PRODUCTS AND SERVICES TO VARIOUS LEVELS OF LOCAL GOVERNMENT; IT IS ALSO A CORNERSTONE OF THE EUROPE 2020 STRATEGY AS THE PROGRAMME WILL FOSTER GROWTH AND JOBS IN THE EUROPEAN ECONOMIC AREA. THE INNOVATIVE DIMENSION TO THE FORMULATION OF GMES SERVICES IMPLIES THAT ENTREPRENEURSHIP WILL PLAY A MAJOR ROLE IN THEIR DEVELOPMENT. TO ILLUSTRATE THE POTENTIAL BUSINESS DEVELOPMENT POTENTIAL OF GMES, *WINDOW ON GMES* HAS SOLICITED THE CEOs AND FOUNDERS OF FOUR SUCCESSFUL SMES TO SHARE THEIR STORY, THEIR EXPERIENCE AS WELL AS THEIR ADVICE.

Can you tell our readers when you created your company and what the trigger was?

Jan Kolar: I created GISAT in October 1990. The main direct driver was my professional interest in satellite remote sensing – the discipline to which I had devoted more than ten years of university research. However, the company could only become reality thanks to revolutionary changes in our society making private business possible.

Giovanni Sylos-Labini: Planetek Italia was founded in 1994. At this time in Italy, all players in Earth Observation were technology-oriented companies and a true application-oriented company was missing from the market place.

Giulio Ruffini: When I founded Starlab I thought that there was room for goal oriented scientific people wanting to make a difference outside classical academia. The science and technology were evolving rapidly, and the cycle from idea to product/service was accelerating. Since we wanted to create an interdisciplinary environment, we focused on Earth Observation and Applied Neuroscience as our target development fields. The nexus is technological: data processing and Maxwell's equations.

Christian Hoffmann: I founded GeoVille in 1998 as a one-person company. At the time I was convinced of the added value of satellite remote sensing for activities related to land management and, so far, I have not been proven wrong.

The creation of a company must build on a sound business plan. Would you advise a young entrepreneur to elaborate his business plan on his own or to get support from third parties (e.g. specialised consultancy)?

CH: The ingredients for success are a sound and realistic business plan, a unique selling proposition, an excellent accounting company and enough cash to survive year one.

JK: My recommendation is to have your own idea and also necessary the understanding of business activities in your chosen sector. Consultancy services are useful