Test-Sites in Remote Sensing Studies and Earth Observations

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The recognition and the spreading use of remote sensing as a tool in land cover/land use monitoring makes the question of data quality still more acute. In transferring remote sensing techniques to operative applications, data accuracy and information reliability are critical. Currently, the remote sensing community is recognizing, again and deeper, the indispensable necessity of ground-truth information in support of Earth observation missions. Supporting and raising the capacity of remote sensing investigations encompasses the implementation of a wide range of information sources, making full use of in-situ ground-based monitoring and airborne surveys along with space observations. In this context the paper presents a vision on the objectives of in-situ networks for data acquisition on target selected test-sites with the aim to enhance remote sensing scientific and modelling capacities and to meet the need for multidisciplinary research and multipurpose data application. The paper aims also at rising the interest in international collaboration.

Introduction

The challenges posed by the increasing natural and man-made pressures on the environment and its resources require efficient and coordinated research at different levels. Dealing with the consequences of the anthropogenic impact on the environment requires more informed policies. The same refers to geo-hazards such as floods, landslides, wildfires, pollution, etc. Improved assessment and forecasting are needed to mitigate risks. This implies a multidisciplinary and integrated approach to surveys and data analysis. Acknowledged and justified is the recognition of remote sensing as a powerful tool in land use/land cover monitoring for a large number of purposes ranging from agricultural practices to global ecology and environment protection. However, a better data provision is needed to fill existing gaps [1,2]. This is despite the fact that over the last years considerable progress has been made in space-borne devices and observation systems.

Ecosystem assessment is one of the most important areas in using remote sensing data. Land cover dynamics is strongly influenced by a great number of factors, generating the need for adequate monitoring tools. As a consequence, robust and sophisticated analysis methods are required for efficient data handling and accurate information extraction adapted to the rapid advances in sensor technologies. Besides, multi-temporal and multi-sensor approaches are becoming more and more important not only for change detection but also for the development of more detailed state assessment methods. In the study of land covers the information requirements can be effectively met by using conventional (terrestrial) and modern remote sensing techniques [3]. Often remote sensing data alone do only perform a part of the job since comprehensive end-user products are a result of the combination of remotely sensed data coupled with ground survey and modeling. Data accuracy, data processing, and the creation of customer specific and dedicated products are keys for a breakthrough of remote sensing applications.

The remote sensing community recognizes the indispensable necessity of ground-truth information in support of satellite Earth observation missions. In order the remote sensing techniques to be widely transferred to operative applications, data quality and retrieved information reliability are critical. Algorithms and quantitative models for estimating various land surface variables from remotely sensed observations need to be validated using ground-truth data [4-6]. Supporting and raising the capacity of remote sensing investigations encompasses the implementation of a wide range of information sources, making full use of in-situ surveys (ground-based and airborne) and space monitoring.

The paper presents a vision on the necessity and the objectives of an in-situ infrastructure for data acquisition on target selected and representative of different ecosystems and environmental conditions test-sites. The development of an integrated in-situ and remote sensing information system responds to the needs for coordinated multi-disciplinary data acquisition, integration and multi-use in monitoring the state of the environment, including air, water, soil, natural landscape and farmlands.

In-Situ Support - Closing the Gaps

Spatial information (any data with reference to a specific location or geographical area) plays a special role in environment monitoring because it allows information to be integrated from a variety of sources and disciplines for a variety of uses. However, the widespread use of spatial information is still not a routine. The main problems relate to data gaps and incompatible data sets due e.g. to varying data needs, standards, undefined quality and barriers to sharing, accessing and using of data. Remote sensing is an important source of information for a large number of Earth sciences and application fields. Data acquisition technologies and information extraction methods are pushed to give shift to user-oriented approaches where quantitative and reliable assessments, trend evaluations and forecasts are demanded. To achieve this, it is necessary to make full use of data collected from space-borne, airborne and field observation systems (the latter two composing the in-situ system). The way is to optimize the infrastructure for data acquisition, efficient processing, integration and use. The optimization includes adequate instrumentation and better timing and coordination in information collecting and management.

Validation of data processing and retrieval algorithms has an essential importance as well.

In this context, the in-situ support is indispensable because: ● Despite advances made in sensor technology, data evaluation techniques and information networks, the production of information remains often below its full potential to provide benefits for the users; ● Not all problems related to data acquisition, combining and integration from different sources have been addressed; ● Initiatives to share data between users and applications are not enough; ● Without a clearly designed and shared multi-use infrastructure that encompasses ground-based, airborne and space tools, the implementation of policies affecting the environment, natural resources and land use will be hampered by the barriers to gathering and exploiting cross-domain data; ● The synergy approach is a highlight of today's information technologies and responds to the need to integrate environmental considerations in view of sustainable development; ● Calibration of the implemented systems and validation of the operational tools (models, information extraction algorithms) through geo-referencing and ground-truth data gathering on test-sites are required to enhance data accuracy and reliability in order to provide the maximum added value. Thus, the provision of information products relies both on the space and in-situ components. Data sharing and integration from different levels (ground-based and remote sensing), sources and at different scales are needed to increase the potential of the observations and to ensure cross-level and cross-thematic consistency of the acquired data.

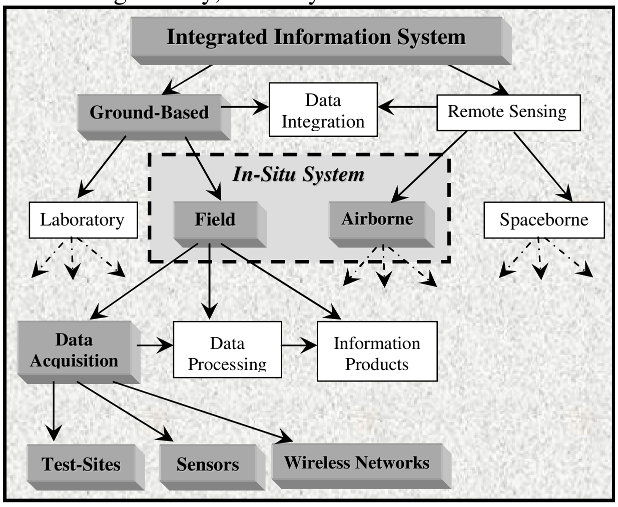
All these come to clarify that for the production of high-quality and timely information, an adequate in-situ support is required enabling data demand definition, acquisition, processing and use. Developing the in-situ component in environment and land cover monitoring is an essential step to the creation of an integrated space-terrestrial information system incorporating ground-based and remote sensing means for spatial data collection, handling and dissemination. In this way the overall continuity, comparability and integration of space and in-situ data, modeling activities and interoperability of the systems will be strengthened. Since much of the data is to be underpinned by "multi-purpose" information, special emphasis should be put on coordinated data acquisition, evaluation of different user data needs and access to information products.

Remote sensing information technologies have passed different stages in their development from sensor design to observation missions and data application. Views have changed during these stages on the importance of the various links of the information chain. Today it is unambiguously recognized that the in-situ component (encompassing field and airborne observations) is not only an integral part but the backbone of a spatial data information system and that in conjunction with the space component it forms a common environmental info-structure. To adequately obtain and deploy information, substantial improvement is required in in-situ surveys, observing systems and networks together with the development of GMES-oriented information services.

Integrated Ground-Based and Remote Sensing Information System

Because of its dispersed nature, it is more difficult to capture the full complexity of the in-situ information system than the space segment. The ground-based component relates to data collected by: (i) networks of sensors deployed on land, sea, water and in the atmosphere aimed at measuring and providing a complete description of the investigated object; (ii) surveys aimed at collecting socio-economic data, land cover and land-use data, geological, soil and bio-diversity information and other geographical data (such as for example elevation, administrative boundaries, etc). In-situ studies play a major role for the elaboration of information extraction methods and validation of algorithms and models. Geolocation of satellite imagery is needed because only if the navigation on ground does sufficiently coincide with the target parameters measured from space the data are useful. Remote sensing devices measure different spectral characteristics of land covers (reflectance, emittance, fluorescence) in a wide range of electromagnetic wavelengths (optical, thermal, radio). The spectral response of land covers is associated with and depends on the target type (vegetation, soils, rocks, water) and its biophysical and chemical properties, physiological and morphological state (biomass, leaf area index, chlorophyll, water content, mineral composition, organic matter, etc.). Ground-truth data allows quantitative relationships to be established and spectral-biophysical modeling to be performed which lies at the root of using remotely sensed data.

For instance, many of the applications of remote sensing rely on multispectral data in the visible and near infrared band where the radiometric sensitivity of the optical instruments is sufficient to measure small changes in target reflectance. Surface reflectance retrieval from imaging data is needed for quantitative information extraction. On the other hand, image data have to be expressed in reflectance values in order to allow comparisons with field or laboratory measurements and to be used in inversed models for target parameters retrieval. In order to calculate surface reflectance from remotely measured radiance, radiative transfer models are elaborated for removal of the scattering and gaseous absorption effects of the atmosphere. Comparison and verification of the retrieved land cover reflectance by ground-based reflectance measurements are essential for accurate information content extraction from remotely sensed data. In order reliable predictive equations of land cover parameters to be obtained from spectral data, the predictive ability of the established relationships has to be verified through ground-based measurements, the latter serving also for correction of the atmospheric effects on remotely sensed data. Besides, remote sensing multispectral and hyperspectral sensors have different spectral band-widths and wavelength position. Ground truthing by in-situ data from test-sites is essential for calibration purposes and analysis of remotely sensed data (ground-truth spectral characterization of reference targets, atmospheric corrections, data comparability and verification). In-situ field and airborne measurements are necessary to check the performance of remote sensing devices through evaluation of data quality (spectral sensitivity, accuracy, signal to noise ratio, signal variations, etc.), and for producing geometrically and radiometrically corrected datasets. Spectral data from field devices are needed to elaborate models and perform adequate image analyses and thematic interpretation of remotely sensed data. The in-situ obtained data are needed to develop land cover classification and state assessment tools basing on their spectral features as well as to perform feasibility studies on extrapolating the information over other similar objects. Some preliminary methodological issues are also essential, such as the timing of data collection, spatial and temporal scale of the measurement, viewing and illumination geometry, ancillary datasets and etc.



All this undoubtedly identifies the necessity of in-situ ground-based and airborne measurements which serve as reference datasets and support satellite data and imagery in terms of: ✓ Spectroradiometric calibration of remote sensing instruments; ✓ Radiometric data corrections for the atmospheric effects; ✓ Transferring image data to target spectral response; ✓ Referencing remotely sensed data to ground-truth spectral characteristics; ✓ Enhancement of data accuracy; ✓ Elaboration of data processing algorithms; ✓ Integration and fusion of data from different sources and levels (platforms); ✓ Development of models describing land cover state, trends, forecasts; ✓ Ground- truth feedbacks and methods for validation of spectral-biophysical models; ✓ Verification of information extraction techniques.

An integrated information infrastructure consists of distributed and interoperable facilities brought together into a coordinated system oriented towards multiple data use. Encompassing a wide range of information sources and making full use of space and in-situ monitoring capacities, it includes the following functionalities: data acquisition by a complex of terrestrial and remote sensing equipment; data processing; data verification and validation of algorithms for data analysis through terrestrial investigations on test-sites (ground-truthing); data integration from different sources and transformation into information products (maps, models, etc.). Data storage, cataloguing, access and sharing between users should be enabled as well. The following principles and cross topics contribute to optimizing the overall process in terms of effort and effectiveness: ✓ Develop synergies; ✓ Ensure compatibility between ground-based and remote sensing systems; ✓ Data fusion from multiple sources, data assimilation and data integrity; ✓ Validation of data acquisition technology and data processing algorithms; ✓ Verification of the existing and future research results.

In the Figure below, the basic infrastructural components of an integrated terrestrial and remote sensing information system are shown. They are distinguished according to their nature and the function they perform. The ground-based component includes laboratory and field studies, the in-situ component encompasses additionally airborne surveys. Data Acquisition, Data Processing and Information Production elements refer both to the ground-based and remote sensing systems. The in-situ component has the following data acquisition elements: ► test-sites used for geo- referencing, calibration and validation needs; ► spectroradiometric and other sensors for data acquisition; ► wireless networks for data collecting, storage and transfer; ► mobile station for the equipment; ► airborne platforms for remote sensing surveys.

Test-sites are thematically (target) selected territories to represent various ecosystems and landscapes (natural vegetation, forests, agricultural lands, soil types, geological objects) with different land-use, land management and degree of anthropogenic pressure. The test-sites are monitored at regular or requested intervals during the year using a mobile station equipped with a field data acquisition complex. Integral parts of this complex are devices for contact and remote sensing measurements of different physical and chemical land cover parameters such as spectral features (reflectance, absorption, transmittance, fluorescence, etc.), bioparameters (leaf areas index, chlorophyll content, etc,), soil humidity and organic matter, temperature, wind speed, solar irradiance, PAR and etc. Test-sites are thoroughly explored by means of conventional field measurements using both destructive and non-destructive methods, and by in-situ ground-based and airborne remote sensing techniques. Laboratory analyses are performed using dedicated methodologies and expertise.

The in-situ infrastructure more readily allows a 'build-as-you-need' approach retaining a modular open system that can easily accommodate new elements. Relevant to the latter is the special attention paid to the development and the implementation of field-based networks. Wireless sensor networks and wireless local aria networks are most advanced monitoring tools. The survey areas (environment, land covers) that are data intensive need high-performance networks that enable the gathering, aggregation and transfer of data from geographically distributed "autonomous" resources. The architecture progressively evolves from a set of unconnected networks to a fully integrated network, incorporating stand-alone data and information, the selection and aggregation of information from heterogeneous sources and the translation of data in real time. This, in turn, enhances the sharing of environmental information across sites and regions. To maintain coherence between various data sources is an essential emphasis in study activities on test-sites. Measuring environmental variables at appropriate temporal and spatial scales remains an important challenge in ecological research. New developments in wireless sensors and sensor networks will revolutionize the ability to study ecosystems at relevant scales. Sensor networks can analyze and manipulate the data they collect, thereby moving data processing from the end user to the sensor network itself. Such embedded processing will allow sensor networks to perform data analysis procedures, identify outlier data, alter sampling regimes, and ultimately control experimental infrastructure. A wireless sensor network is an integral element in the infrastructure of an end-to-end information system that transforms raw measurements to scientifically significant data and results. Wireless technology used to communicate information from one point to another, can be applied to various electronic devices. Although wireless technologies have been used in specific applications for decades, wireless networks have recently become much more widespread due to better technology and lower prices. Wireless networking offers various advantages over wired connections, including mobility, connectivity, adaptability, and ease of use in locations that prohibit wiring. The wireless technology covers various aspects but focuses on improving network performance (network speed, collecting and transmitting capacity), on examining mobility management, energy concerns, spatial diversity and multiuse. Specific applications include wireless sensor networks. A part of the instrumentation is a short range (up to 300 m) independent radio network to service up to 20 different devices from one central point. This central point works in two modes: autonomous (all devices are served at specified time interval and all data are stored) and user-oriented (only some of the devices provide data, but at shorter intervals).

These various instruments and systems need to be configured so that they can exchange information with one another and provide the integrated data and information products that decision makers need. The capacity of ground-based infrastructures to offer reference information and ground-truth data for calibration and validation purposes is critical in environment monitoring. The optimal combination of remote sensing airborne and space systems with terrestrial infrastructures, as well as the integration of multi-source data, creates further application perspectives. This combination comprises target and process dedicated surveys on test-sites, remote sensing and field data acquisition, data fusion from multiple sources, modelling and validation activities. The performance on test-sites of joint ground-based campaigns, airborne surveys and space observations addresses the following main issues: ✓ standards, sensor calibration and atmospheric correction; ✓ multi-platform sensing and sensor networking; ✓ system integration and interoperability; ✓ processing of multi-source and multi-temporal data; ✓ data fusion and information extraction; ✓ quality of spatio-temporal data and validation of models; ✓ remote sensing data verification. The provision of reliable multi-use information through a wide range of information sources and making full use of an appropriate ground-based and airborne in-situ monitoring infrastructure results in improved change detection tools and prediction capabilities.

Conclusions

It is by now well accepted that the proper monitoring of our planet will require the use of both in-situ and remote sensing techniques. While these approaches are operationally very different, they have each an essential role to play in any serious plan to monitor a site, region, country, or the Earth as a whole. Space and in-situ observing systems constitute significant contributions to environmental assessment, agriculture, water resources, risk mitigation and other domains. The way to strengthen the Earth observation capacity is linking space observations with ground-based monitoring. This results in reliable data acquisition and enhanced information products.

In integration and joint use of ground and remote sensing data, special attention is to be paid to the development, upgrading and expanding of the in-situ component. Aiming at optimal combination of terrestrial and space-based infrastructures, will create further interdisciplinary and multi-application perspectives. Putting emphasis on the integration of terrestrial and airborne data with space monitoring will increase the efficiency and the information value of research, will develop synergy and enable the validation of end-to-end information products. This will lead to: ✓ enhancement of monitoring technologies; ✓ improvement of interoperability and linkage between space observing systems and other data sources; ✓ ensuring the compatibility of different types of data; ✓ enhancement of modeling capacities; ✓ improvement of methods for information retrieval; ✓ strengthening the capacity for analysis, forecasting, planning and decision support. The establishment of an appropriate in-situ network for airborne and ground-truth data gathering, calibration and validation raises data quality and reliability. All these qualify the in-situ infrastructure as a pillar of remote sensing surveys and services.

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