EVOLUTION OF RESEARCH ORIENTATION IN THE DOMAIN OF SPECTRAL SIGNATURES

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ABSTRACT:

The series of international symposia on Physical Measurements and Signatures in Remote Sensing started in 1981 in Avignon (September 8-11) with the aim of understanding the remotely sensed spectra of surfaces at the point/local scale. Along the time, the scientific topics and spectral domains covered have progressively evolved and broaden in order to remain in the forefront of basic research in remote sensing. The aim of this paper is to briefly analyse this evolution and in conclusion to foresee the future developments.

1. INTRODUCTION

This series of symposia started in 1981 in Avignon (September 8-11) with the aim of understanding the remotely sensed spectra of surfaces at the point/local scale. Along the time, the objective of the symposia has broadened to encompass the application of our spectral understanding to problems of environmental understanding and environmental management from point/local and up to regional/global scales. The aim of this paper is to briefly analyse this evolution and in conclusion to foresee the future developments.

2. POSITION OF THE PROBLEM IN THE EIGHTIES

In the eighties, the main problem in remote sensing was the establishment of the basic knowledge for interpreting the first satellite data. The three topics selected for the sessions of the first symposium reflect this questioning:

- Determination of spectral properties of objects: equipment and methods;
- Relationships between the characteristics of an object and its spectral properties;
- Influence of the conditions of measurement.

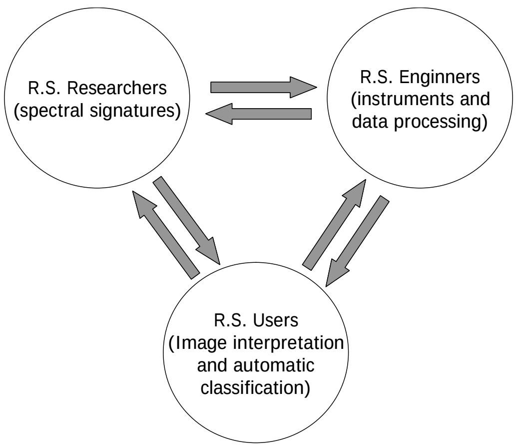

Figure 1. Relationships between remote sensing researchers, users and engineers.

In the relations between remote sensing researchers, engineers and users (Figure 1), the central question was to elucidate the role of spectral signatures research in relation to both the engineering design of satellite sensors and associated data processing and the community of users with resource management responsibility.

At that time, two series of satellite data was used: medium resolution from NOAA-AVHRR and high resolution from Landsat MSS. AVHRR data was used directly for a global characterisation of ground cover based on NDVI. MSS data was used mainly for classification of land occupation. In both cases the correction of the data was not an absolute necessity. The need of radiometric and atmospheric corrections has appeared with the preparation of the new generation of high resolution satellites: Thematic Mapper and SPOT for the comparison of data obtained at different dates and their quantitative interpretation. It was then necessary to solve two series of problems:

- How to perform ground-level radiometric measurements: The understanding of ground-based spectrometer measurements of plant canopies required a close attention to geometrical characteristics of plant and canopy. It was also necessary to take into account the effects of the field of view and polarisation of the sensors.
- How to extrapolate from these measurements to satellite level: This extrapolation showed the necessity to take into consideration the scale of spatial variability as well as the atmospheric effects in relation to view and sun angles.

3. THE FIRST EVOLUTION

During the period including the second, third and fourth symposium held respectively in Bordeaux (September-12-16, 1983), Les Arcs (December 16-20, 1985) and Aussois (January 18-22, 1988), we can schematically consider that the research activity has mainly evolved along two main directions:

- Development of rational approaches combining ground level experiments and modelling;
- Extension of investigations from short wavelengths to thermal infrared and microwaves.

3.1 Modelling in the solar spectrum

The first reflectance models were presented in Bordeaux, but it was necessary to wait for two supplementary years for having the first realistic and relatively accurate models for vegetation and snow in Les Arcs. This evolution has continued and in Aussois, modelling was the major topic of the symposium. Five orientations were defined for the research activity in this domain. They are still of interest at the present time:

- Search for new parameters accessible from space measurements for characterising in a simplified way, the different objects of interest.
- Development of simplified but realistic models delivering comparable results to those of sophisticated ones, but in a restricted domain of variation of the parameters, in order to facilitate the inversion.
- Assimilation of parameters measured by remote sensing in descriptive models in order to facilitate their inversion. This approach was discussed for the first time and will be the object of numerous studies in the nineties.
- Combination of phenomenological and basic approaches of the growth processes of plants, based on parameters measured by satellites.
- Adjustment and calibration of models working at different levels as shown on Figure 2.

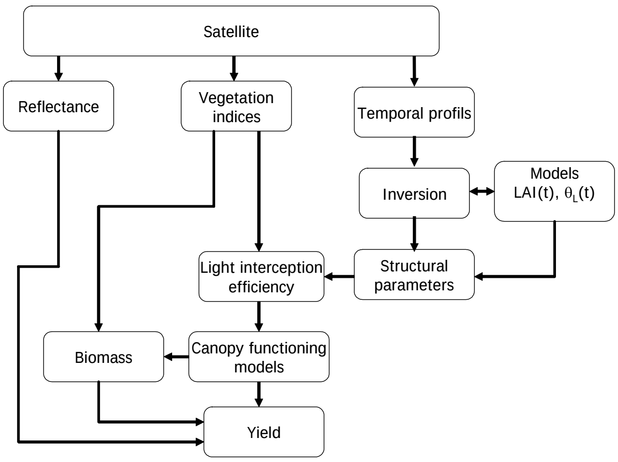

Figure 2. The different approaches used for crop yield forecasting.

3.2 High spectral resolution

Its interest was underlined in Bordeaux for monitoring vegetation and discriminating minerals, but the effective development of the research appeared in Les Arcs and was pursued in Aussois.

For vegetation the research was focussed on the detection of the red shift in the chlorophyll edge at 0.68 µm associated with various environmental stress factors. The interest of measurements in middle infrared was also shown with the use of airborne scanners over forests for mapping damages due to acid rains in Germany or determining the leaf content in starch and lignin in USA.

In geology, the utility of high spectral resolution in the 2.0 to 2.5 µm region was known from laboratory studies. Results of airborne measurements in visible and near infrared showed that complementary information was obtained for studying geomorphologic processes.

Over water, preliminary measurements were done on the chlorophyll fluorescence peak at 685 nm.

3.3 Thermal infrared

If the interest of these measurements was demonstrated in Bordeaux for analysing the thermal properties of natural surfaces, the decisive progress was done in Les Arcs. The significance of ground surface measurements was discussed, in particular over crop canopies for assessing their energy exchanges and a first modelling was proposed.

3.4 Active microwaves

The rapid development of the researches has appeared in les Arcs. One day of the symposium was jointly organised with ESA and devoted to the results of the simulation campaigns Promess and Toscane T for determining surface wind over ocean.

In 1988, the fourth symposium was jointly organised by two ISPRS working groups of commission VII: “Microwave Data” (Chairman N. Lannelongue) and “Spectral Signatures of Objects” because of the complementary scientific approaches in these two groups.

Significant progress was noted in the application of radar over ocean for determining both the wave and the wind fields. However, the models developed needed to be improved. For vegetation, soil and snow, the theoretical models presented in Les Arcs were useful for the understanding of the scattering mechanisms. In 1988 the presentation of water cloud models corresponded to a significant progress. These approaches enabled the introduction of the effects of plant geometry and canopy structure.

3.5 Laser active remote sensing

The new concept of active remote sensing in visible and thermal infrared was presented in Les Arcs. In short wavelengths, fluorescence and Raman scattering showed their potential for monitoring water quality (chlorophyll, organic matter, oil spills). In thermal infrared, some good results were presented on geological materials. These results were confirmed in Aussois and the research was extended towards the determination of the photosynthetic activity of plant canopies. The methods proposed were based on laser induced chlorophyll fluorescence.

3.6 Atmospheric corrections

The necessity of these corrections has appeared in the first symposia but not any practical method was available. The only possibility was the use of the empirical “split window” approach for correcting thermal infrared data. For the corrections in the solar spectrum the use of the atmospheric transfer codes such as 5S or Lowtran needed the measurement of atmospheric parameters and this problem was not solved in 1988.

3.7 Calibration of data and measuring equipment

In les Arcs, it was noted that studies involving the use of absolute radiometric calibration were rapidly developing and quantitative investigations involving energy-matter interactions have appeared.

4. TOWARDS OPERATIONAL METHODS IN THE NINETIES

At the end of the fourth symposium, the Scientific Committee considered that "Spectral Signatures" was too much restrictive. It proposed to combine the two groups "Spectral Signatures" and "Microwave Data" and change the title into "Physical Measurements and Signatures in Remote Sensing". This proposal was accepted at the General Assembly of ISPRS in Kyoto in July 1988.

In the nineties three symposia were organised in Courchevel (January 14-18, 1991 and April 7-11, 1997) and Val d'Isère (January 17-21, 1994). During this period the research activity has mainly followed four directions:

- Development of methods based on model inversion in different spectral domains;
- First steps of assimilation methods;
- Exploration of new techniques such as laser active remote sensing and directional and polarisation effects in optical domain;
- Synergistic use of measurements performed in different spectral domains.

4.1 Atmospheric corrections, modelling of measuring systems

A significant volume of researches has appeared in 1991 (25 papers over 163). Two atmospheric codes: Lowtran-7 and 5S were more particularly discussed. However, the application of these codes showed the necessity of atmospheric ground measurements. A decisive step has been crossed in 1994 with the presentation of a new scanning multiband sky and sun photometer which was installed in the AERONET network. In 1997 the first results of its sub-network PHOTONS in western Africa were presented. Atmospheric corrections entered thus into routine processing.

An alternative approach for atmospheric corrections presented also in 1991, was based on the use of high spectral resolution to derive atmospheric parameters. The combination of measurements under different view angles and the use of the light polarisation have induced the development of POLDER. The first results of its airborne version were presented in 1997.

In thermal infrared a few methods were proposed to overcome the emissivity problem that makes difficult to use traditional split-window techniques over land surfaces.

4.2 High spectral resolution

During this period, a large emphasis was given to high spectral measurements in three domains:

4.2.1 Vegetation: In the nineties a large emphasis was given to the analysis of main HRS features (in particular the red edge and its shifts) through modelling and experimentation, from the leaf to the canopy level. In 1994, model inversion demonstrated some potential for the retrieval of leaf canopy biochemical composition (chlorophyll, water, nitrogen and lignin). Several studies highlighted also the possibility to obtain the total amount of HRS information with a relatively small subset of spectral bands peculiar to specific vegetation parameter or constituent, opening the way for future space instruments (MODIS…)

4.2.2 Geology: The development of the research was to extend the studies to complex settings, and to utilise the information gained to study the geological processes that formed or modified the areas under study.

4.2.3 Water bodies: HRS data were applied to the study of snow, inland waters and ocean. HRS signatures of snow were shown to be useful for estimating the depth of thin snow and the water content. Studies of inland waters were aimed at understanding water quality, especially with respect to organic content. On ocean, HRS was used to study chlorophyll blooms and red tides associated to phytoplankton density. Whether the object studied was bright snow or dark water, the signal of interest was relatively small compared to the background. Hence good calibration and the ability to correct especially for atmospheric path radiance were critical and required some more efforts.

4.3 Thermal infrared

A decisive step was crossed in 1994 with the discussion of four points:

4.3.1 Physics of the measurement: The necessity of normalising the definitions of the temperature (surface temperature, aerodynamic temperature, brightness temperature…) and of the emissivity at the ground level has appeared.

4.3.2 Data correction and processing: A general agreement appeared on the necessity of decoupling temperature and emissivity (combination of day and night AVHRR data, combination of the two thermal channels of ATSR).

4.3.3 Use of thermal data: New promising applications appeared for estimating the energy fluxes (evapotranspiration) based on the combination of thermal and visible data into physical models.

4.3.4 Instrumentation: A new generation of space instruments was under preparation (ASTER, MODIS, AATSR) with better spatial, spectral and radiometric resolutions. It induced the development of new airborne equipments and also of a multi-band auto-calibrated radiometer for ground level measurements.

4.4 Active microwaves

In 1991, many new results were based on progress in calibration of radar sensors. Scattering models were used to derive quantitative information on soil roughness and moisture; vegetation types, density and water content; and on ocean waves and wind. Polarisation was also developing as an important tool in soil and vegetation studies. In 1994, two significant progresses were noted:

4.4.1 Development of practical applications: The use of multi-parameter measurements (multi-incidence angles, frequencies and polarisations) and of some new mathematical tools for classification, offered the possibility, at least for training sites, to retrieve numerous interesting parameters: tree species, soil water content…

4.4.2 Use of interferometry: It was a major step. The application of this technique to ERS-1 SAR data, showed the possibility to derive topographic maps and also to detect very small changes of the topography leading to a powerful tool for tectonic studies.

4.5 Passive microwaves

The concept of Microwave Polarisation Difference Temperature (MPDT) was introduced in 1991. MPDT was sensitive to vegetation water content and it was shown that the lower frequencies were more useful for vegetation sensing. The results from SMMR demonstrated long term stability, necessary for climate change studies. The coarse resolution of this sensor did not appear to be a limiting factor. The strong correlation of SSM/I and SMMR indicated the possibility of extending the applications into the future

In 1994, results from two new instruments were presented ESTAR and PORTOS. ESTAR was an airborne system developed to test the principle of a low frequency radiometer (L band) using the antenna synthesis technique. The test of the airborne version showed the validity of this concept and its potential for space measurements.

PORTOS was a conventional radiometer (5-90 GHz) able to be used either on an airplane or at ground level. It was operationally used in numerous experiments aimed at refining the understanding/modelling of surface characteristics.

The coupling of active and passive techniques was tested in the combined use of two instruments of ERS-1 (radar altimeter, microwave sounder) and ATSR for improving derived atmospheric and surface parameters. In addition, for the first time an innovative presentation showed the coupling of a microwave emission model to a vegetation growth model.

4.6 Laser active remote sensing

In 1991, the following salient points were noted:

- Development of different methodologies, for investigating the physiological status of plants by means of laser induced fluorescence. They were based on spectral and time-resolved detection. An effort was done to pass from qualitative to quantitative measurements and to develop reliable apparatus and processing techniques.
- Development of an approach using multidimensional laser induced spectral signatures for identification of oil pollutants and dissolved natural organic matter over ocean.
- Development of laboratory data bases for geological and ecological applications.
- Successful use of thermal infrared lasers for geological applications.

In 1994, significant progresses were noted on vegetation monitoring. The mechanism of plant fluorescence was better understood and it was possible to relate the physiological status of plants to three parameters: fluorescence life time, fluorescence spectrum from blue to red and photo-induced variable fluorescence. In addition, the analysis of the elastically reflected signal enabled a fast and accurate description of the architecture of a plant canopy. The comprehension of the fluorescence mechanisms offered also new perspectives for the development of passive measurements in the Fraunhofer lines or oxygen absorption band.

4.7 Polarisation and directional effects in the solar spectrum

This topic was discussed for the first time in 1991. The research was mainly focussed on the non-lambertian properties of vegetation canopies including the soil and was rapidly expanding. Progress was noted in the development of tractable models for inverting canopy reflectance properties to estimate physical parameters such as leaf area index and canopy water content. The use of both spectral and directional variables in an inversion model appeared especially promising.

The analysis of polarisation data delivered by airborne POLDER were essential for validating models and assessing the relative importance of competing light polarisation processes in the atmosphere and on the ground.

Significant progress had also appeared in both collection of calibrated, multi-spectral, multi-directional data sets supporting remote sensing research – and development of tools facilitating collection of such data (airborne simulators: POLDER, CASI, CAESAR, MODIS… and sensors for ground based measurements: PARABOLA for BRDF, sun photometer and radiometers for atmospheric properties).

4.8 Synergy between measurements performed in different wavelength domains:

This topic was discussed for the first time in 1991. The use of multi-source data needed a large effort in calibration and inter-calibration with specific problems due to the non simultaneity of the measurements and the data acquisition at different scales.

In modelling it was shown how the combination of some different types of data help to model surface processes such as: monitoring of soil surface status, bio-physical and -chemical characterisation of the vegetation, synergy between temporal and spectral signatures for estimating crop yield…

The combination of visible reflectance data, surface temperature and microwave polarisation difference temperature was successfully used for inter-annual monitoring of vegetation change due to water deficit. Another original approach was the Thermal Infrared Spectral Index (TISI). This index enabling the decoupling of surface temperature and emissivity appeared as a pertinent tool for discriminating bare soils and vegetated surfaces in combination with NDVI.

4.9 Remote sensing data assimilation in numerical models

The main contributions concerned crop yield prediction and determination of heat flux and evapotranspiration. A development appeared in 1994 with studies devoted to vegetation monitoring at a global scale in the framework of IGBP with a little contribution to hydrology.

In 1997, significant progresses have appeared. The most advanced techniques were shown for meteorological data, the main constraints being solved. For vegetation, the assimilation process was somewhat extended to the notion of multiple use of remotely sensed data obtained in different spectral domains and/or at different dates introducing the temporal dimension. However, in most cases, assimilation techniques were not applied to their full extent because of constraints not solved.

4.10 Spatial and temporal signatures

Two interesting steps were noted in 1991: the analysis of the relationship between crop growth models and multi-source remote sensing data for improving crop yield forecasting and the combination of temporal and spatial resolutions with AVHRR and SPOT data for land cover mapping. But problems due to both mixed pixels and heterogeneity at the scale of sub-pixels were not solved.

4.11 Impact assessment of environmental change by remote sensing

This question was discussed for the first time in 1997. Environmental change always implies a temporal dimension in data analysis, and therefore requires calibrated data sets. It must be noted that the changes are often in the same order of magnitude as instrumental drifts, calibration errors or atmospheric effects. It is therefore important to give particular attention to the quality and significance of datasets, especially if long term trends are to be deduced from them.

Some results were presented at the symposium: the evolution of global warming and the extension of the growing season in high latitudes, the TREES program for mapping and monitoring tropical forest from AVHRR imagery, and more limited studies on water cycle and quality monitoring, deforestation, forest dynamics and fires, desertification and salinity detection, soil erosion protection, air quality and aerosols, urbanisation…

5. THE LAST EVOLUTION AFTER 2000

Scientific topics	Aussois 2001	Beijing 2005	Davos 2007
Data correction and preprocessing	X	X	X
Remote sensing systems	X	X	X
Modelling			
• Physical modelling	X	X	X
• Model inversion	X	X	X
• Data assimilation in models	X	X	X
• Earth system models	–	–	X
Image classification methods	–	X	X
Land cover mapping and classification	X	X	X
Environmental change detection	–	X	X
Remote sensing applications	–	X	X
Calibration, validation RS products	–	X	X
RS data infrastructures	X	–	X

Table 1: Scientific topics covered in the three last symposia.

With the turn of the century, the volume and the quality of available data has considerably increased in the optical domain with the successful launch of VEGETATION, MODIS, MERIS, MISR and ASTER and the short lived POLDER. They were followed by AATSR, HYPERION, IKONOS Quickbird and CHRIS. In microwaves, the same phenomenon can be noted with ASAR on board ENVISAT in 2001, completing the series of data acquired by ERS 1 and 2 and RADARSAT. This data flow has induced two main orientations in the research:

- Development of application oriented works using multi-date and multi-sensor data;
- Development of advanced methods and techniques for acquiring more acute information in any spectral domain.

This period corresponds to the three last symposia organised in Aussois (January 8-12, 2001), Beijing (October 17-19, 2005) and Davos (March 12-14, 2007). The scientific topics covered are summarised in Table 1. It shows some differences and also the permanence of some problems on which research works are still in progress. The size of the symposia organised in Aussois and in Davos is similar (136 and 125 papers presented respectively) and correspond practically to the half of the Beijing Symposium (256 papers presented). This difference in the size explains the large place devoted to applications in Beijing, the volume of research papers being relatively stable in the three symposia.

5.1 Preprocessing and processing of remotely sensed data

In optical domain, the development of sophisticated correction models for instrumental transfer functions and atmospheric effects led to a continuous improvement of data preprocessing and processing techniques. The launch of POLDER and MODIS and the development of the ground level network of sun photometers AERONET, have strongly improved the accuracy of atmospheric corrections. In the context of long term trend studies the validation and intercalibration of archives of previous sensors is an absolute necessity.

In microwave domain, a similar evolution is observed. Besides the problems of calibration, the effective use of SAR data in many applications must include a strategy for coping with speckle. Different methods for speckle reduction were proposed in Aussois and in Beijing.

5.2 Remote sensing systems

A large emphasis to remote sensing systems was only given in Beijing.

In the microwave domain, the studies are mainly devoted to SAR data because of the large data set delivered by the satellites RADARSAT, ERS-1 and 2. For the passive microwaves, the development of research is slowed by technological constraints. As it has been seen in the nineties, this technique is well adapted for monitoring soil moisture, vegetation biomass and also ocean salinity. But for the moment, not any instrument is mounted aboard a satellite platform. However, three L-band sensor missions are now being prepared for launch: SMOS developed by ESA and Aquarius and Hydros developed by NASA as part of Earth System Pathfinder (ESSP). This new opportunity will probably stimulate the research.

The potential of lidar measurements was largely discussed in the nineties, but the development of this technique has also been limited by technological constraints. The application domain is limited to altimetry and structure of forest and crop canopies.

Hyperspectral studies are still expanding and are mainly oriented towards the determination of leaf nitrogen content and biochemistry using field and airborne data delivered by spectral imaging equipments. In addition, the instrument CHRIS developed by ESA delivering multi-angular and hyperspectral data has induced new studies on canopy structure and biomass.

In thermal infrared domain, the availability of data delivered by ASTER and MODIS of EOS platform and by SEVIRI on board METEOSAT-8 has stimulated research on methodologies for retrieving accurate land surface temperatures and developing the applications (energy balance, water balance, crop growth monitoring…).

5.3 Physical modelling

The research activity in this domain has followed the development of remote sensing techniques. The research was oriented towards the development of invertible models representing the bidirectional properties of plant canopies. They use the multidirectional and hyperspectral data delivered by MODIS or CHRIS for retrieving information about the canopy geometry (LAI) and also on it functioning (*f*APAR). In addition the global monitoring of the environment lead to the development of models adapted to coarse resolution satellites.

5.4 Land cover mapping and classification

The efforts are oriented towards the standardization of land occupation classes, leading to the use of criteria having a larger definition and to the introduction of the temporal dimension. For pixel classification it is also proposed to use a continuous classification in which each pixel is affected to different classes with probabilities depending on the temporal evolution of the corresponding signal.

5.5 Environmental change detection

With the availability of long series of medium resolution satellite data and the development of calibration, intercalibration and atmospheric correction methods, it is still possible to monitor environmental changes. Quasi-operational methods are then proposed for monitoring vegetation phenological evolution or seasonality.

In urban planning, the extension of urban zones or changes in use of urban area are easily monitored with high resolution satellites such as Thematic Mapper or SPOT and more recently with the very high resolution satellite Quickbird.

5.6 Remote sensing application

The practical applications of remote sensing concern two different scales. At the global scale it is now possible to derive the information necessary for monitoring the components of the carbon cycle. At the local or regional scale, remote sensing data are entered into operational systems for driving agricultural practices and determining crop production. High spatial and temporal resolution data delivered by satellites or aircrafts are used for drawing maps of LAI, chlorophyll content, ground cover… These maps are then used for driving the cultural practices at the field level.

Thermal infrared data sometimes combined with visible and near infrared or microwaves, are used for estimating the energy fluxes exchanged at the ground surface and more particularly the evapotranspiration of plant covers.

5.7 Calibration and validation of remote sensing products

This essential point has been deeply investigated in the nineties. Since 2000 the studies are oriented towards the practical correction and validation of data delivered by the new satellites and of archive data. A large effort has been done for delivering remote sensing products that can be used at different scales.

5.8 Remote sensing data infrastructures

The utilisation of the data by the research teams is conditioned by their availability and their cost. In the last five years, the large development of research works on medium resolution satellites has been simulated by the possibility of having easily free data of MODIS, SeaWifs and Vegetation.

6. CONCLUSION AND PERSPECTIVES

For concluding Figure 3 summarises the evolution in knowledge and in application domain of remote sensing data during the past 25 years. It represents schematically the evolution from the first inductive steps towards spectral understanding and environmental management. The bottom left to the top right show the increasing complexity of the problems, the extension of the scale from local to global and the development of applications. It shows also the transition of increasing uncertainty of the theory or data.

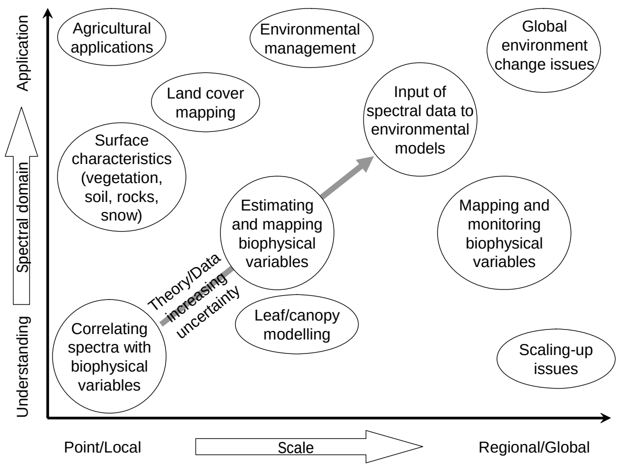

Figure 3. The relationship between the understanding to application of spectra and spatial scale.

The development of practical applications has followed the large amount of satellite data available since the years 2000. However, all the problems are not solved and new technological developments are appearing. That will induce new research activity:

- Global environmental monitoring based on medium resolution satellite data is starting to be operational. The application of models describing the functioning of plant canopies needs the use of decametric resolution data with a time interval of few days. It will then be necessary to use a constellation of satellites delivering compatible data (CYCLOPES, ESA mission project: Carbon cYcle and Change in Land Observational Products from an Ensemble of Satellites)
- One way for improving radiative transfer models is the integration of *in situ* data (“SensorWeb”) and remotely sensed data. This question has also to be validated.
- New spatial experiment are under study:
  - Lidar for altimetry and plant canopy geometry
  - Passive measurement of chlorophyll fluorescence in the oxygen absorption band (FLEX mission project)
  - Combination of hyperspectral measurements and thermal infrared measurements with a high spatial resolution.
  - Analysis of surface and atmospheric anisotropy.

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