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REFLECTANCE SPECTRORADIOMETRY – A NEW TOOL FOR ENVIRONMENTAL MAPPING

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Abstract. Imaging spectroradiometry or hyperspectral imaging is a new technique for investigating natural resources as a tool for environmental mapping. The increased interest among scientists for the application of this technique is accompanied by an interchangeably usage of several technical terms having originally well established, different meaning, what calls for clarification of the definitions and the terminology. This paper provides an overview of the disturbing word usage, the history of the development of the technical terms and their explanation based on the corresponding physical measuring instruments.

Keywords: imaging spectroscopy, imaging spectrometry, reflectance field spectroradiometry, hyperspectral imaging, environmental mapping, applied environmental sciences, optical remote sensing

1. INTRODUCTION

The gaining importance of environmental protection, climatic change, and nature preservation called for an intensive research of vegetation cover on global and regional scale by spectral methods of optical remote sensing. The term “reflectance spectroradiometry” stands for a rapidly developing new branch of remote sensing and field technologies covering the acquisition of the reflectance spectra in the optical wavelength range of 0.4-2.4 μ, their processing and interpretation, which are, thus, suitable for the investigation of the spectral behaviour of natural resources, such as soil, natural vegetation cover, waters (snow), etc., and also agricultural objects such as industrial crops, forests, etc. Its applications in connection with remote sensing are referred commonly as “hyperspectral imaging” or “imaging spectroscopy”, or “imaging spectrometry”.

Even the present-day loose terminology, the interchangeably usage of the terms “spectroscopy”, “spectrometry” and spectroradiometry in the remote sensing community contributes seemingly to obscuring the unique, meaningful wording.

The currently used terminology reflects a very strong influence of the historical development of the hyperspectral remote sensing technology, including the change of theoretical hypoteses and the practical expectations and it is strongly rooted in traditions.

When studying, namely, the current word usage as found in the technical literature, we can observe a definite systematic change in it from the 70s-80s to the 90s. The dualty of using the terms “spectroscopy” and “spectrometry” simultaneously in a mutually repleacable manner has shown up only in the hyperspectral era, when the term “hyperspectral” tended to be used for any high spectral resolution data by the optical remote sensing community. Indeed, at the beginning of spectral data applications (approximately in the 80s, as appearing in Dozier & Strahler, 1989), the measuring intruments of the spectral reflectance remote sensing in the optical range were referred exclusively to as “spectral radiometers” or “spectroradiometers” e.g Collins et al., (1981). The analysis and interpretation of the data measured by spectroradiometers were referred to as “spectroradiometry” as “…those involved in remote sensing are concerned with determining surface radiance by measuring the radiant flux **Φ** emerging from a given portion of a surface…” as formulated by Slater et al, 1989. The involvement of extended surfaces of changing geometry in the remote sensing measurements radiation fluxes (and not intensities) explains the obligatory application of the terminology of radiometry in optical remote sensing.

The scope of applications became even wider inasmuch as remote sensing techniques does not mean necessarily the use of airborne or satellite platforms, but also field spectroradiometers can be deployed as a kind of surface geophysical technique used as hand-held, back-pack or other ragged versions of spectroradiometers mounted on mobile platforms such as the machines of precision agriculture.

Hyperspectral imaging of optical remote sensing though being a well delineated, rather narrow specialisation, is still covering very diverse disciplines that can be grouped in two basic classes. One of them comprises those science branches describing the principles of operation of the technical components of hyperspectral data acquisition systems, e.g. physics, geophysics, geodesy, astronomy, and engineering application fields of theses sciences not to forget about mathematics and this group is designated now as the “technological side” of remote sensing. The diversity of science branches comprising remote sensing is even enhanced by the multitude of application fields, naming here only geology, pedology, geography (physiography) dealing mainly with the a biotic environment, moreover wetland hydrology, limnology, plant biological sciences, ecology, agricultural sciences dealing with the biotic environment of the biosphere. All these application fields referred here to as “application side” of remote sensing and constituting the above mentioned second class of grouping are based commonly on university curricula with less emphasis on the science branches of the technology side. The remoteness of concepts of the application and the technology side and the usually unbalanced treatment in the university training of the science branches they are based on is one of the main causes of the slow penetration of image interpretation skill and knowledge of remote sensing in the applied sciences and the long-ago realised bottle-neck in data interpretation in relation to the huge amount of remote sensing data. The development of remote sensing application fields is partly hindered by the inaccurate transfer of definitions and concepts from the technology side in the application fields.

The modelling of complex ecological systems having biotic and a biotic components coupled with each other and the modelling of radiative transfer in such complex media require the consistent application of uniquely defined measurement concepts of the technology side. Otherwise, several measurement platforms provide inconsistent data, being useless for the purposes of model parameterisation, and for comparison. Especially, in the application side of remote sensing, applied scientists and engineers dealing with botanical, ecological or agricultural, pedological, geological sciences rely on the availability of updated versions of technological reviews of data acquisitions or measurement principles, although sometimes incongruities of concepts within the technology side can also be found: e.g. intensity in astronomy and radiance in radiometry are terms designating the same physical quantity.

This paper is designed to give a precise-as-possible definition of reflectance spectroradiometry alleviating thus the recognition and appreciation of the usefulness of the deployment of hyperspectral imaging technique of optical remote sensing in applied sciences dealing with environmental, ecological or climatic problems.

2. DEFINITION OF REFLECTANCE SPECTROSCOPY

The precise definition of the term “reflectance spectroscopy” appearing in connection with remote sensing data acquisitions or field campaigns described in technical and scientific papers seems throughout necessary in seeing the wealth of various spectroscopic analytical methods applied in a number of disciplines, mainly in chemical, geological or material sciences for the purpose of materials testing.

Spectroscopy - relevant to our subject - is a very broad range of laboratory techniques, which are all based on the investigation of interactions of light with material, more specifically the ones of photons of electromagnetic waves with the atoms or molecules of material. These types of spectroscopy provide the so-called electromagnetic spectra. Other types including particle radiations are ignored in this discussion. Spectroscopy is carried out for the identification atomic or molecular species, the investigation of molecular structures or molecular environment of atoms.

The wide range of the spectral analysis techniques arises form the multitude of different physical processes underlying the interactions. These are determined basically by the kinetic energy levels of the interacting photons, the nature of the energetic transitions between photon and material (electronic, vibrational, rotational, translational, nuclear), and the atomic and molecular structure of the material.

In addition to these factors, the kinds of radiative process (emission, absorption, fluorescence) sets the kinds of measurement, and the geometrical arrangement of the spectral measurements sets the modes of measurements and spectra (reflection, transmission, emission).

In optical remote sensing (in the above mentioned reflective wavelength range) the absorption spectra are used for interpretation. Laboratory versions of spectroscopy working with spectroscopes or spectrographs usually measure directly the relative absorption spectra in transmission mode, using collimated light beams passing through the sample perpendicularly, and controlled light sources of known radiation intensity. Reflectance spectroscopy, however, works with spectroradiometers (formerly referred to spectrophotometers, or simply photometers, nowadays these are replaced by the term spectrometer), which measure radiometric quantities of light beams scattered from the surface of the sample. In laboratory circumstances the light source is also well controlled, and ensures the homogene illumination of the sample surface. Scattering and absorption, two independent and different processes are superimposed on each others: the scattered light spectra modified by the absorption features of the sample material will carry the information on absorption. In this case, however, the collimated light beam incident on the surface of the sample is not scattered back in a collimated fashion, but in all possible direction, and in general anisotropically. Therefore, radiometric characterisation of reflected (remitted) light is necessary.

3. SPECTROSCOPY, SPECTROMETRY OR SPECTRORADIO-METRY?

It should be noted, that this discussion focuses only on the terminology of the optical remote sensing. In other fields of sciences, the common usage may differ from that recommended in this paper: e.g. in chemical sciences, spectrometry refers to mass-spectrometric measurements, while spectroscopy comprises all kinds of light-material interactions [8] or even extended to particle-material interactions too.

Even the present-day loose terminology, the interchangeably usage of the terms “spectroscopy”, “spectrometry” and spectroradiometry in the remote sensing community contributes seemingly to obscuring the unique, meaningful wording.

The current usage seems to suggest, that the choice of one or the other term is governed by traditions only, or perhaps by newly formed claims of establishing the special terminology for remote sensing, as do all self-contained disciplines.

Some authors simply observe the duality of terminology, van der Meer and de Jong (2001), Curran (1995) and seem to accept it, but van der Meer, and de Jong (2001) uses consequently the term „spectrometry”, while Clark (1999) refers consequently to “imaging spectroscopy”. and opts definitely for using this term. All mention that both terms are synonyms of the corresponding new technique, the hyperspectral imaging.

This ambiguity in the usage shows itself as e.g. Clark (1999) refers in connection with “imaging spectroscopy” to a paper of Goetz (1985) in the title of which the term “imaging spectrometry” appears. The less conscious use of the terms under discussion can be observed, at least partly, in the research community of the hyperspectral project MINEO as well, when Chevrel. (2005) refers to the project as “imaging spectroscopy” and Kuosmanen (2005) refers to the same project as “imaging spectrometry”. Or, Keller et al. (1986) refers to the first EARSEL Conference as “Conference on imaging spectrometry”, while other contributors refer to the same conference as “Conference on imaging spectroscopy”. The above few and rather ad hoc examples of ambiguous usage will only highlight anomalies of this duality. This kind of loos terminology is not beneficial to the development of applied remote sensing sciences, and is not justified at all, as the terms under discussion have firmly established and different meanings and definitions in physics, which are used – even when not fully explained - by many theoreticians and practicians of remote sensing correctly.

A straight explanation of the differences in usage is offered simply by the different etymological meaning of the original Greek words they are based on: σκοπειν (transliterated: scopein) means to see, μετρον (metron) means to measure, what may not be sufficient to found a firm basis of terminology.

Curran (1994) refers to „spectrometry" as well in connection with remote sensing discriminating it from „spectroscopy" by designating this latter as a standard technique for chemical essay. Indeed, pioneering works of spectral remote sensing, and theoretical foundations of measurements, e.g. Hapke (1995) nearly exclusively refer to "spectroscopy".

The term "spectroscopy" as used in remote sensing e.g. Curran (1995) belongs certainly to the traditional usage, taken over from the chemical sciences meaning simply the techniques of displaying spectra of different kinds for the identification of several materials. It comprises namely only laboratory measurements carried out by spectroscopes or spectrometers on minerals at the beginning phase of the development of spectral remote sensing techniques in the 70^s and 80^s. During such measurements, the illumination sources used are well controlled and the intensity of radiation is held constant. Confining ourselves now only to reflectance spectroscopy, the information is held in the case of such spectra in the positions of absorption minima in the wavelength or frequency axis and their relative depths and width, which are, thus, relative quantities. The absolute radiation quantities are playing a secondary role, they do not need to be quantitatively measured.

The whole set of the absorption features in the wavelength range constitutes a spectral pattern specific to the material investigated. This pattern is called "spectral signature" and it constitutes the spectral characterization of the targets (or classification end members) in connection with hyperspectral imaging. This characterization does not require, however, the knowledge of the absolute intensity of radiation, either measured in laboratory or in the field (see Fig. 1.). Many simple forms of data processing techniques of hyperspectral data are confined to the investigation of the relative shape of spectra.

What is then spectrometry? Some authors stick at deriving the term spectrometry historically from spectrophotometry (Curran 1995; Kumar et al., 1995), which is itself a group of technologies, and therefore no explicit explanation is usually available in remote sensing text books. Curran (1995) thoroughly explains the difference between spectrometry and field measurements, but does not mention the term spectrometry or even spectroradiometry.

Indeed, the main difference between spectroscopic and spectrometric or spectroradiometric measurements that in the latter case illumination sources are uncontrolled, changing with time (Curran, 1995; Kumar et al., 1995), and having multiple components (directional beam of the sun, hemispherical diffuse irradiation, etc.). Therefore, the radiant fluxes of the spectral radiation components including the incoming and reflected radiations must be measured, if we intend to characterize the targets with spectral signatures being independent of timely variation of the irradiation and whether conditions. The ratio of the incoming and reflected fluxes is considered then characteristical to the target only. This is true without further considerations, however, only in the case of perfect, isotropic, diffuse surfaces (Lambertian-surfaces).

In the case of real materials, usually a strong angular dependence can be observed depending on the geometry of incoming and reflected radiation fluxes. An adequate description of this directional phenomenon is possible with the Bi-directional Reflectance Distribution Function (BRDF), (Nicodemus et al., 1997), which appears in various forms depending on the radiation flux geometries used in the course of measurements (directional, conical, hemispherical referring both the illumination and viewing geometries).

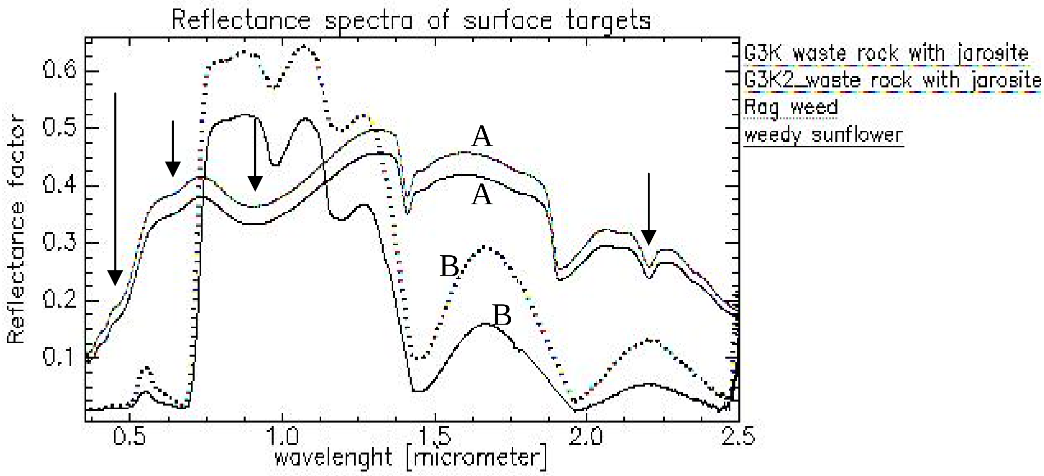

Fig. 1. A - Reflectance spectra of waste rock samples taken from the waste rock dump site in Recsk measured in the field in the function of wavelengths in micrometer, JRC, 2002 in cooperation with the Geological Institute of Hungary in the framework of the HYSENS 2002 project (Kardeván et al., 2003). The series of absorption minima (spectral signature) are indicated by the arrows. B – Reflectance spectra of vegetation (rag weed and weedy sunflower)

The ignorance of these geometric concepts of radiometry leads usually to statements – even nowadays Mustard and Sunshine (1999) - that “in general reflectance is defined as the ratio of the intensity of the electromagnetic radiation scattered from a surface to the intensity of radiation incident upon it.” This gives the deceitful impression that the same reflectance will be obtained whatever the illumination and viewing geometry of measurements would be. This loos terminology leads to misunderstandings of the scientists dealing with in the remote sensing applications. A series of excellent papers repeatedly drew attention of the scientific community to the right application of radiometric concepts, and for the incompatibilities of reflectance and albedo products of several remote sensing systems, including laboratory and field measurements with different radiant flux geometries (Martonchik et al., 2000; Schaepman-Strub et al., 2003, 2004, 2006).

The historical reference to spectrophotometry means implicitly a reference to the application of photometry. In hyperspectral remote sensing data acquisition, however, the inclusion of radiometry, and combination with spectroscopy is necessary, when measuring and interpreting calibrated radiance spectra.

The term “spectroradiometry” expresses the combination of spectroscopic techniques with radiometric measurements, and is also widely referred shortly and less precisely to as spectrometry.

Even so, the duality of terminology seems to be encouraged by certain international organizations as well. The European Association of Remote Sensing Laboratories EARSEL is, for instance, organising "Conferences on Spectroscopy", e.g. Kuosmanen et al., (2005); Cocks et al., (1998); Riaza et al., (2003); Gege et al., (1998) covering obviously topics of both spectroscopy and spectrometry. Nevertheless, "spectrometry" is used e.g. in connection with SPIE conferences that focus on research with hyperspectral equipment, just as EARSEL conferences do.

The precise word usage can be found e.g. in papers of Goetz, (1989), who speaks about a renewed interest in field and laboratory spectroradiometric measurements, and, thus, divides historical times from current days, and names the new remote measurements spectroradiometry (Goetz, 1989). In papers, theses dealing with instruments, only the terms "spectrometry" or "spectroradiometry" appear e.g. Schaepman, (1998). Indeed, a clear-cut distinction regarding the measuring instruments of spectrometry and spectroscopy has relatively long been precisely elaborated (Elachi, 1987), and this information is available in the Internet as well (Clarck, 1998). Accordingly, spectrometers refer to measurements of spectral information, radiometers refer to measurements of radiometric quantities, spectroradiometers designate instruments that measure both kinds of data, see Fig.2.

As could be inferred from the afore mentioned, however, the term spectroradiometry should not necessarily be linked with spectral field measurements, or hyperspectral data acquisition. In remote sensing, the application of reflectance factor has proven successful in spectrally characterising the surface objects. Its use, however, does not need the knowledge of the absolute radiance although measurements are carried out with spectroradiometers.

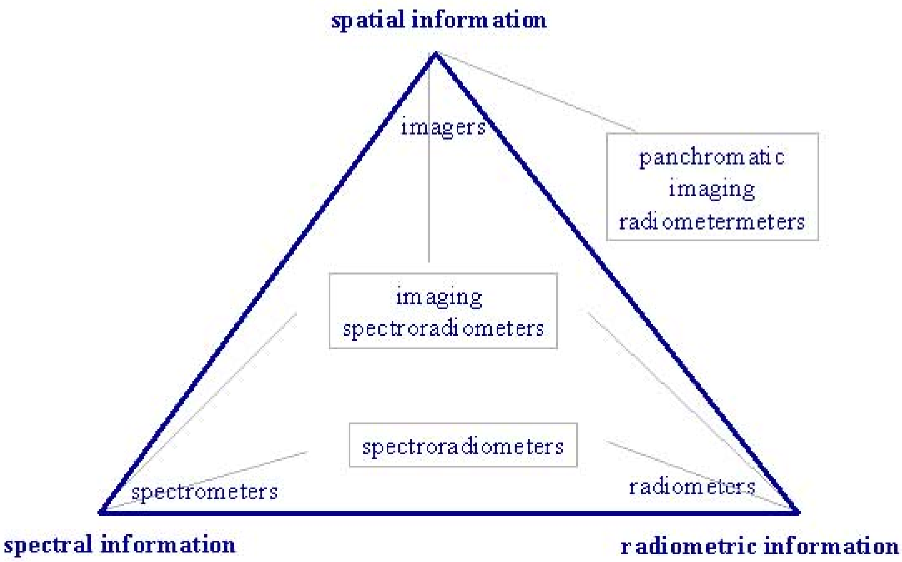

Fig 2. Classification of spectrometers. Re-drawn after Elachi 1987, (modified)

The direct transfer of spectroscopic information to such relative field spectra can well be referred to as field reflectance spectroscopy, as nothing more then the relative spectral signatures are used to the target identifications (Clarck, 1998). One can say: spectroscopic results were applied to spectroradiometric measurements.

The research of the delicate radiation balance of the Earth atmosphere and an accurate atmospheric correction for at-sensor calibrated radiance spectra call for the application of the concepts and precise definitions of radiometry, and then we pursue spectroradiometry.

But not only in such cases: as discussed, the flux geometry, the angular resolution, i.e. the FOV of the spectroradiometer is playing important role in defining reflectance quantities. Thus, even when relative reflectance spectra are measured, radiometric definitions are to be taken into account whenever we are concerned with illumination or viewing geometry. This is always the case, when field spectroradiometry is carried out for the calibration of remote sensing data.

BIBLIOGRAPHY

Chevrel, S., 2005. *MINEO two years later - did the project impulse a new era in imaging spectroscopy applied to mining environments?* In: Proceedings of the 4th Workshop on Imaging Spectroscopy, Imaging Spectroscopy. New quality in environmental studies. 26-29 April 2005,Warsawa, pp. 389-395.

Clark, R.N. 1999: *Spectroscopy of rocks and minerals, and principles of spectroscopy.* In: Remote Sensing for the Earth Sciences, edited by A.N.Rencz, pp.7.,

Clark, R.N., 1998. *About reflectance spectroscopy*. USGS Spectroscopy Laboratory.

Cocks T, R Jenssen, A Stewart, I Wilson, T Shields, 1998. *The HyMapTM airborne hyperspectral sensor: the system, calibration and performance.* In: 1stst EARSeL Workshop on Imaging Spectroscopy, edited by M Schaepman, D Schläpfer & K Itten (EARSeL, Paris), 37-42.

Collins, W.S., Chang, H., Kuo, J.T., 1981. *Remote mineralogical analysis using a high resolution airborne spectroradiometer: preliminary results of the Mark II System.* Digest, Intl. Geosc.Rem Sens. Symp., 1, 337-344.

Curran, P. J. 1995 *Imaging spectrometry – its present and future role in environmental research.* In: Imaging Spectrometry – a Tool for environmental Observations, edited by Joachim Hill. 27-59.

Curran, P. J., 1994. *Imaging Spectrometry*. Progress in Physical Geography, 18(2):247-266

Dozier,J., Strahler, A.H, 1989. *Ground Invetigations in Support of Remote Sensing*. In: **Colwell, R.N.** (ed.): Manual of Remote Sensing, II^{d} Edition, I., edited by American Society of Photogammetry, The Sheridan Press, 973.

Elachi, C. 1987. *Introduction to the Physics and Techniques of Remote Sensing*. Wiley Interscience

Gege, P., et al. 1998. *System analysis and performance of the new version of the imaging spectrometer ROSIS.* In: 1st EARSeL Workshop on Imaging Spectroscopy. Remote Sensing Laboratories, University of Zurich, Switzerland.

Goetz, A.F.H., Vane, G., Solomon, J.E., Rock, B.N. 1985. *Imaging spectrometry for earth remote sensing*, Science, 228:1147-1153.

Goetz, A.F.H.,1989. *Spectral remote sensing in geology*. In: theory and applications of optical remote sensing edited by Ghassem Asrar, pp. 491-547, Wiley Series of Remote Sensing, John Wile & Sons, Inc.

Hapke, B., 1993. *Theory of Reflectance and Emittance Spectroscopy*. Cambridge University Press.

Kardeván P., Vekerdy Z., Róth L., Sommer St., Kemper Th., Jordan Gy., Tamás, J. Pechmann I., Kovács E., Hargitai H., László F. 2003: *Outline of scientific aims and data processing status of the first Hungarian hyperspectral data acquisition flight campaign*, 3rd EARSeL Workshop on Imaging Spectroscopy in Oberpfaffenhofen, 2003. may 13-16.

Keller, P.A., Keller, I., and Itten, K.I. 1998. *Combined hyperspectral data analysis of an Alpine Lake using CASI and DAIS-7915 imagery*, In: Ist EARSEL Workshop on Imaging Spectrometry, Remote Sensing Laboratory, University of Zurich, Switzerland..

Kumar, L., Schmidt, K., Dury, S., Skidmore,A., 1995. *Imaging spectrometry and vegetation science.* In: Imaging Spectrometry. Basic Principles and Prospective Applications, Kluwer Academic Publishers. pp. 113.

Kuosmanen,V., Laitinen, J. and Arkimaa, H. 2005. *A comparison of hyperspectral airborne HyMap and spaceborne HYPERION data as tools for studying the environmental impact of talc mining in Lahnaslampi, NE Finland.* In: Proceedings of the 4th Workshop on Imaging Spectroscopy, Imaging Spectroscopy. New quality in environmental studies. 26-29 April Warsawa, pp. 397-407

Martonchik, J., C. Bruegge, A. Strahler, 2000. *A review of reflectance nomenclature used in remote sensing.* Remote Sensing Reviews, 19, 9-20,

Mustard, J.F., Sunshine J.M., 1999. *Spectral Analysis of Earth Science: Investigation using remote sensing data.* In: Remote sensing for Earth Sciences: Manual of Remote Sensing. 3rd. Edition, Vol. 3, edited by A.N. Rencz. John Wiley & Sons, Inc. pp. 252.

Nicodemus F.E., J.C. Richmond and J.J. Hsia, I.W. Ginsberg, T. L, Imperis, 1977. *Geometrical Considerations and nomenclature for reflectance*. National Bureau of Standards Monograph 160.

Riaza, A., Garcia Melendez E., Suarez M., Hausold A., Beisl U., van der Werff H., 2003. Mapping Paleoflooded And Emerged Areas Around Lake Marshes (Tablas De Daimiel, Spain) Using Hyperspectral DAIS 7915 and ROSIS Spectrometer Data, Proceedings 3rd EARSeL Workshop on Imaging Spectroscopy, Oberpfaffenhofen, 257-269.

Schaepman, M.E. 1998. Calibration of field Spectroradiometer. PhD. Thesis. Remote Sensing series Vol. 31. Remote Sensing Laboratories, Dept. of Geography, University of Zurich,

Schaepman-Strub, G., M.E. Schapman, S. Dangel,T. Painter, J. Martonchik, F., 2004. *The importance of reflectance terminology in imaging spectroscopy.* Proceedings of the 4th EARSEL Conference on Imaging Spectroscopy. pp. 39-52.

Schaepman-Strub, G., M.E.Schapman, ,T. Painter, S. Dangel J. Martonchik, F. 2006. *Reflectance quantities in optical remote sensing – definitions and case studies*. Remote Sensing of environment 1003, 27-42.

Schaepman-Strub, G., T. Painter, S. Huber, S. Dangel, M.E. Schapman, J. Martonchik, F. Berendse, 2003. *About the importance of the definition of reflectance quantities – results of case studies*. Proceedings of the 4th EARSEL Conference on Imaging Spectroscopy. pp. 31-39.

Slater, Ph.N., Doyle, F.J., Fritz, N.L., Welch, R. 1989. *Photographic Systems for remote sensing.* In: **Colwell, R.N.** (ed.): Manual of Remote Sensing, IId Edition, I., edited by American Society of Photogammetry, The Sheridan Press, 232-234.

van der Meer F. & de Jong S.M., (Editors), 2001. *Introduction. In: Imaging Spectrometry.* Basic Principles and Prospective Applications, pp. XXI. Kluwer Academic Publishers

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