LEVEL II PRE-PROCESSING CONCEPT FOR THE AIRBORNE PRISM EXPERIMENT (APEX)

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ABSTRACT

A concept for the processing and archiving facility for APEX (Airborne Prism Experiment) is defined. A special emphasize is put on the level 2 processing steps which include geometric, radiometric and atmospheric correction of the image data. The presented concept combines these processing steps in a radiometrically logical manner and allows the online production of user required products. The full knowledge about the scanning geometry is used for both radiometric and atmospheric correction. Additionally, the design also foresees possiblities to produce atmospherically corrected images directly from calibrated raw data. The presented concept will allow a fast delivery of high quality data products for the various specific requirements of the APEX data users.

KEYWORDS:

Preprocessing, atmospheric correction, parametric geocoding

1 - INTRODUCTION

In 1998 the Airborne Prism Experiment (APEX; [3]) was initiated by the European Space Agency ESA. The instrument will be built as an airborne simulator for the planned PRISM instrument [5] on the Land Surface Processes Interactions Mission (LSPIM). APEX will scan the earth's surface using a 'pushbroom' -system in spectral bands between 400 and 2500 nm at a flight altitude of 6 to 10 km. The ground pixel size will be 3-5 m at about 1000 pixels per scan line. The sensor will be completed by the year 2001. During the development period, the processing and archiving facility (PAF) will be implemented and tested simultaneously to the hardware construction and the calibration of the sensor.

The level 2 processing is a crucial part of the whole processing chain for imaging spectroscopy data, and therefore has to be evaluated carefully. There exist a variety of possibilities to perform radiometric, atmospheric and geometric correction and rectification steps. The required software will be partly implemented from scratch while other parts will be included from (semi-)commercial applications. The geometric correction is performed based on a parametric approach, using a digital elevation model. This approach offers information on the scan angle for each image pixel as well as on the full optical path through the atmosphere. The knowledge about the geometry of each image pixel can then be used for a sophisticated atmospheric and radiometric correction. The description and delimitation of the various processing steps and the definition of the links between the various modules are the main tasks. Additionally, a sophisticated web-user interface will help to provide the variety of processed data in an efficient manner to the user community.

2 - THE APEX PROCESSING AND ARCHIVING FACILITY PLAN

A complete processing and archiving facility is built within the framework of the APEX project. After recording, the data is piped to an automatic processing and calibration procedure. This chain combines the production of quicklooks, the storage and synchronization of auxiliary data, as well as geometric, spectral and radiometric calibration (see Table 1). The human interaction during the level 1 processing phase will be minimal to increase the repeatability and speed of the process. Quicklooks and raw data products thus will be available within short time after data take. All parameters used for this first processing are stored such that each intermediate level may be reconstructed from the stored level 1D calibrated data product.

The second level processing is based on a modular system. The single processing steps can be performed at various quality levels and in changing priority. This structure allows the production of specific level 2 data products, using the level 1D data and auxiliary information provided by the user. Table 1 lists all the steps and products in their (foreseen) processing order.

TABLE 1. Processing Levels and Product Generation

Processing Step	Product	Description
Downloading of the flight recording media and/ or data and transfer of the media/data from the aircraft to the processing facilities	Level 0	Raw data, not distributed
Assessment of raw data quality / Determination of scene related effects (cloud cover, missed flight lines) / Generation of quick–look product	Quicklooks	Distributed over the internet (on demand of the investigator)
Reformatting and archiving of the data	Level 1	Scenes level
Geolocating and archiving of scene attribute data	Level 1+	Scenes level with attributes list
Instrument performance determination and calibration strategy definition	Level 1A	Sensor specific calibration
Calibration processing	Level 1B	1A & geometric response calibration
	Level 1C	1A & spectral response calibration
	Level 1D	1B & 1C
Instrument performance trend monitoring		Definition of data quality and distribution philosophy
Value added product generation	Level 2A	1D & geometric correction
	Level 2B	1D & atmospheric correction
	Level 2C	2A & 2B
Application of special analysis methods	Level 3	User defined processing requests

2.1 Processing Software

The choice of software used for the PAF is dependent on the modules and the type of integration and customization. Parts of the PAF are time–critical applications and must be optimized for speed and throughput. Other parts of the PAF are highly customizable and must be designed for maximal flexibility and user friendliness. Table 2 lists the customization requirements and the software packages to realize the processing and archiving facility. It is suggested that only the level 0 processing and the data base interfaces are implemented in C or C++, because these are time critical core parts of the whole system.

The database for systematic storage and retrieval of the data and attributes is a combination of relational and object type of database. Because relational databases handle rich data types as binary large objects, no content–based queries can be performed on these uninterpreted bit patterns. Since there are no comparison operators, the user cannot build an intelligent query plan and the work is relegated to the application programmer. The access to the database is controlled by a relational data base management system (RDBMS). The database is capable of handling all the necessary functions associated with backup and recovery features. In addition a Web interface that converts HTML pages into SQL queries reduces the implementation effort of developing a specific user interface.

A very efficient way of realizing applications in imaging spectroscopy is using a programming environment that supports the easy treatment of arrays, numerous mathematical and statistical functions as well as graphical display techniques. The chosen programming language is IDL [6] and is considered as a defacto standard in hyperspectral image processing. A stand-alone application developed on top of IDL is called ENVI (Environment for Visualizing Images, [7]). ENVI implements a large number of very advanced techniques for hyperspectral data analysis and image visualization and will be used for standard processing steps.

Two specialized additional applications will be partly included for geocoding (PARGE, [13]) and atmospheric correction (ATCOR, [8]).They both are also based on IDL and use the ENVI data formats in their processing structure. This common standard (i.e. ENVI and IDL) helps to minimize the number and complexity of interface routines between the single modules of the level 2 processor.

TABLE 2. Processing Data Flow and Product Generation

Software Package / Language	Level Product	Customization level
C / C++	Level 0	+++
ENVI and IDL / RDBMS	Quicklooks	–
IDL	Level 1	+
IDL / ENVI / SQL	Level 1+	++
	Level 1A	+++
SQL / RDBMS	Level 1B	+++
	Level 1C	+++
	Level 1D	–
IDL and PARGE	Level 2A	+
IDL and ENVI/ATCOR	Level 2B	++
	Level 2C	–
IDL and ENVI	Level 3	+++
RDBMS / SQL	Enduser products	++

3 - APEX LEVEL 2 PROCESSING MODULES

The level 2 processing consists usually of geometric, atmospheric, and radiometric corrections. Since each of them depends on each other, the concept for level 2 processing must consider these relationships. Pragmatic substitutes have to be provided if some auxiliary data is missing or a faster low level processing is required.

A number of modules is defined for the flexible level 2 processing of the data. The complete list includes advanced program modules as well as basic processing algorithms:

- Geometric correction: Simple roll compensation,
- Geometric correction: Image wrapping,
- Geocoding: Parametric geocoding (PARGE),
- Empirical atmospheric correction (flat field/empirical line),

- Full atmospheric and radiometric correction (ATCOR),
- Adjacency effect correction,
- Correction of bidirectional effects.

3.1 Geometric Processing

Various imaging spectroscopy applications require either an exact localization of ground truth measurements, or need the information from a digital elevation model (DEM) in relation to the scanner data. Single pixels have to be geometrically located to relate their spectra to ground measurements (e. g. for inter-calibration studies). The relation to the DEM is furthermore used to perform modellations with the terrain height, slope, and aspect.

3.1.1 ***Roll Compensation and Image Wrapping.*** Two simple methods will be implemented for the easy correction of geometrical distortions. They both do not consider the height of the terrain accurately. Roll compensation will correct the movements of the airplane with respect to a stable horizontal flight it produces an optically enhanced image, especially if the platform stabilization fails. The image wrapping procedure will use standard polynomial transformation functions to correct the image based on known ground control points.

3.1.2 ***Parametric Geocoding.*** The main geocoding procedure used in this processor is based on a parametric approach and was already successfully tested on DAIS data. Single modules of the parametric geocoding application PARGE [13] are transformed to be used with the APEX data formats and processing philosophy. The modules require exact information on the position of the airplane as well exact measurements on the flight attitude. Most probably the APEX system will be mounted on a stabilized platform. Thus, lower level processing may deliver sufficiently accurate results without taking full advantage of the parametric approach and the given auxiliary data. Such levels will be defined for fast processing or for cases, where parts of the auxiliary data are not available.

3.2 Atmospheric and Radiometric Correction

Radiative transfer code based simulations of the at sensor radiance are used for atmospheric correction. The standard simulation code used is MODTRAN [4], while some comparison simulations and the correction of bidirectional effects will be done using the 6S code [16]. When using such a code, the forward runs of the model have to be done with special respect to the geometric and atmospheric situation for one specific scene. The external parameters used for such a correction are the geometry of the sun (sun zenith and azimuth angle), the geometry of the sensor (sensor view angle), and an approximation of aeorosol type and visibility. The atmospheric profile usually is taken from standard meteorological measurements.

The atmospheric correction process derives the ground reflectance ρ_g from the radiance at the sensor L_s principally by subtracting atmospherically scattered light and correcting for the optical thickness. A simplified atmospheric correction equation then can be written as [13]:

$$\rho_g = \frac{\pi(L_s - L_{atm})}{\tau_{tot}E_0(\cos\varphi + c)}. \qquad \text{(EQ 1)}$$

The relative sun view angle (φ) and the distance for optical thickness definition are derived directly from the geometrical conditions of the image. Other correction parameters have to be simulated with the radiative transfer code. The apparent total transmittance τ_{tot} and the atmospheric radiance L_{atm} vary for each pixel location and have to be interpolated over view angle and height.

The irradiance term E_0 is corrected for the diffuse components. The introduced constant *c* can be derived semi-empirically or calculated from the effective skyview factors and diffuse transmittance values. The simplification for the irradiance term $E_0(\cos\varphi + c)$ only can be made if the angles between the sun and the slope of the terrain are less than 40 degrees for most of the area [13]. For high zenith angles and steep terrain the more accurate radiance simulation for all potential geometrical situations within an image has to be related to the image data.

Equation 1 already includes a correction factor for a lambertian radiometry distortion. However, bidirectional effects should be treated seperately. Appropriate models first will have to be tested and implemented. They are therefore planned to be introduced into the processing facility of the APEX instrument in a separate module.

3.2.1 ***Empirical Correction:*** Empirical corrections fully rely on the knowledge about the spectrum of a group of pixels within the image. They are fast and allow a pragmatic processing of the image at low costs. Their disadvantage is a low reliability in mountaineous terrain and for changing meteorologic conditions within one image. The empirical atmospheric correction module will contain the basic algorithms such as black targets, flat field or empirical line approaches [9].

3.2.2 ***Image Based Correction.*** More accurate results can be achieved if some of the data is extracted from the image data itself, e.g. water vapor and the aerosol content [2]. The retrieval of the humidity is described extensively in [13]. Its spatial distribution allows calculation of the exact value of the water vapor transmittance for all pixels and wavelengths.

The estimation of the aerosol content is not yet operational. Statistical approaches use the contrast reducing effect of strong scattering to estimate the aerosol content. Histogram matching allows one to even obtain the spatial distribution of the haze in the image [8] - as long as the image data is statistically homogeneous. Simpler approaches use dark targets or a series of known spectrally homogeneous areas for an estimate of the atmospherically scattered radiance within the image.

3.2.3 ***Adjacency Correction.*** The correction of the atmospheric adjacency effect is vital, especially for limnological applications of APEX data. Tests with a helicopter mounted spectroradiometer have proven that the effect is relevant for flight heights of 1000 m above ground and higher [11]. The effect was significant on a horizontal range of 100–200 m for flight altitudes below 3 km.

Standard atmospheric correction methods usually do not include an adaptive compensation for the adjacency radiance (often an average adjacency is considered), although this effect can easily override the information over dark targets. Each pixel has to be corrected with respect to the average reflectance of the adjacent areas. This can be done by the definition of a spatial convolution function which takes a distance-weighted average of the adjacent area in the image to calculate an adjacency weighting factor. The corresponding radiance has to be simulated in the radiative transfer code as indirect ground reflected radiance [1]. Its correct modellation is not yet solved and remains a very challenging task.

3.3 Ideal Implementation Scheme

The scheme shown in Figure 1 presents the concept of a ideal, high level standard procedure which includes the combined geometric and atmospheric processing. Geometric and atmospheric corrections are no independent processing steps in methodological terms, and thus have to be treated together in the chain. It is possible to use parameters from the georeferencing procedure for an improved atmospheric correction. Possible linking parameters are the viewing angle per pixel, the absolute distance from the aircraft to each pixel location, or the

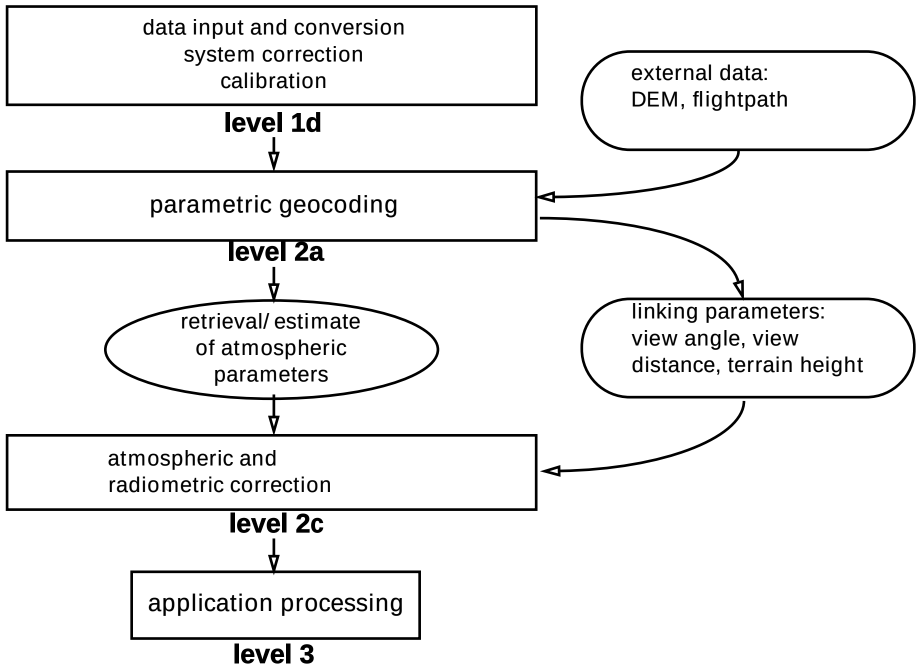

FIGURE 1: A complete processing chain, including parametric geocoding algorithm and terrain dependent atmospheric correction.

relative airmass between sensor and pixel. Furthermore, other DEM related parameters, such as height, slope or aspect are required for radiometric correction algorithms and can only be used if the image is brought to the same geometry as the DEM. Not all modules are fully functional independent of each other. A hierarchical view of the modules and the planned interfaces is shown in Figure 2.

4 - INTERFACE DEFINITIONS

Two types of interfaces have to be defined for the implementation of the processing unit. First, the access to a global database and the processor has to be specified and second the user interface is designed. All interfaces have to be on a highly standardized level and base on a common data format. The design of the dataflow is depicted in Figure 2

4.1 Level 2 Processor Data Structure

The single modules of the Level 2 Processor will communicate with each other using a proprietary data format. It will be common to geometric and atmospheric correction steps, what makes special interfaces between the modules mostly obsolete. A special data flow only has to be defined between the parametric geocoding module and the complete atmospheric processing since outputs of the geocoding will be used for the atmospheric correction step. The updates to this structure will be done from the database whenever a new processing step is launched by the end user.

4.2 Data Base Interface

The whole data acquired during campaigns and used during the processing will be stored in a central ORACLE™ database system. All relevant items to a scene are permanently stored for later processing up to higher levels. The design and the stored parameters allow the reconstruc-

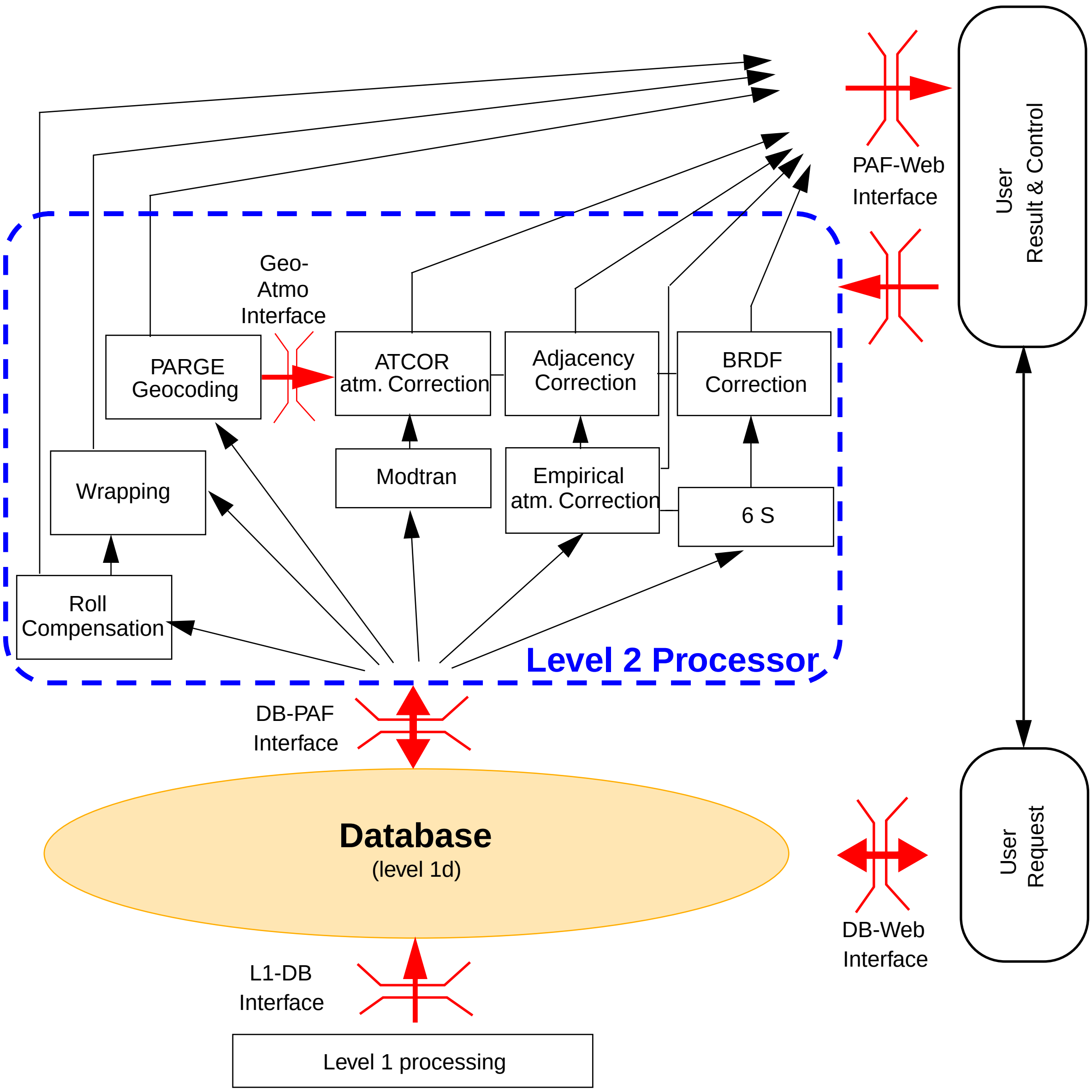

FIGURE 2: The interface design between the single modules for the APEX level 2 processor.

tion of any intermediate processing level. The access to the database will be done by a Web-savy interface. Each user will be able to store and access the relevant data for his scene(s) (see next Section).

The first interface to the database will be trespassed by any data acquired by the sensor. It defines the raw engineering data acquisition and the storage of all parameters for the calibration and processing up to level 1D. The level 2 processing modules will draw all their input over the DB-PAF interface from the data base, while their control will be done directly by the WEB-PAF interface. If any data is missing for a certain processing step the data input section of the user interface will be activated for updating of the data base.

4.3 User Interface Specifications

The third and most challenging task will be the creation of a consistent user interface on HTML basis. It has to manage three major tasks: i) the access and query to the data base; ii) the input of new data to the data base; and iii) the control of the PAF modules execution. The interface furthermore will provide online help for all systems and should make 'intelligent' suggestions if any data is missing or a processing chain has to initiated.

5 - CONCLUSIONS AND OUTLOOK

A concept has been presented for data flow, interface and modules definitions of the APEX level 2 processing. The whole processing is based on a central data base where all scene relevant data are managed. Well defined interfaces allow the interactions between database and user, database and modules, module to module, and module to user.
This concept is implemented during the development of the APEX system in Phase B and C/D until the year 2001. Its performance has to be tested on simulated at sensor data derived from data of current imaging spectrometers as well as modelled data. The whole system will be able to handle any kind of airborne remote sensing data and thus could also be interesting for other sensor developments.

6 - REFERENCES

[1] Bach H., and Mauser W., 1994: Atmospheric Correction of Hyperspectral Data in Terms of the Determination of Plant Parameters. In *EOS / SPIE Symposium ROM*, Munich, 10 pp.

[2] Gao B.–C., Heidebrecht K.B., and Goetz A.F.H., 1993: Derivation of Scaled Surface Reflectance from AVIRIS Data. *Remote Sens. Environ.*, 44:165–178.

[3] Itten K.I., Schaepman M., De Vos L., Hermans L., Schlaepfer H., and Droz F., 1997: APEX-Airborne Prism Experiment: A New Concept for an Airborne Imaging Spectrometer. Proc. 3rd Intl. Airborne Remote Sensing Con. and Exh.n, ERIM, Copenhagen (DK), I:181-188.

[4] Kneisys F.X., Abreu L.W., Anderson G.P., Chetwynd J.H, et al., 1995: The MODTRAN 2/3 and LOWTRAN 7 Model. Philips Laboratory, prepared by Ontar Corporation, North Andover (MA), 267 pp.

[5] Posselt W., Kunkel P., Schmidt E., Del Bello U., and Meynart R., 1996: Processes Research by an Imaging Space Mission . H. Fujisada, G. Calamai, and M. Sweeting, Proc. of Advanced and Next-Generation Satellites, Vol. 2957, SPIE, Taormina

[6] Research Systems Inc., 1993-1997: *Interactive Data Language (IDL)*, Boulder, Colorado, http://www.rsinc.com

[7] Research Systems Inc., 1993-1997:*The Environment for Visualizing Images (ENVI)*, , Boulder, Colorado, http://www.rsinc.com

[8] Richter R., 1996: A Spatially Adaptive Fast Atmospheric Correction Algorithm. *Int. J. of Remote Sensing*, 17(6):1201–1214.

[9] Roberts D.A., Yamaguchi Y., and Lyon R.J.P., 1986: Comparison of Various Techniques for Calibration of AIS data. In *2nd AIS workshop, JPL Publication 86-35*, JPL, Pasadena (CA), pp. 21–30.

[10] Sandmeier S., and Itten K.I., 1997: A Physically–Based Model to Correct Atmospheric and Illumination Effects in Optical Satellite Data of Rugged Terrain. *IEEE Trans. on Geosc. and R. S.*, 35(3):708–717.

[11] Schaepman M., Keller P., Schläpfer D., Cathomen C., and Itten K.I., 1997: Experimental Determination of Adjacency Effects over an Eutrophic Lake using a Helicopter mounted Spectroradiometer for the Correction of Imaging Spectrometer Data. In *3rd Int. Airb. R. S. Conference and Exh.*, ERIM, Copenhagen (D), II:497–504.

[12] Schläpfer D., Schaepman M., and Itten K.I., 1998: PARGE: Parametric Geocoding Based on GCP-Calibrated Auxiliary Data, SPIE, San Diego, 6 pp. (in press)

[13] Schläpfer D., 1998: Differential Absorption Methodology for Imaging Spectroscopy of Atmospheric Water Vapor. Remote Sensing Series, RSL, Zuerich, 131 pp.

[14] Schowengerdt R.A., 1997: *Remote Sensing: Models and Methods for Image Processing.* 2nd Ed., Academic Press, 522 pp.

[15] Tanré D., Deschamps P.Y., Duhaut P., and Herman M., 1987: Adjacency Effect Produced by the Atmospheric Scattering in Thematic Mapper Data. *J. of Geophysical Research*, 92(D10)12.000–12.006.

[16] Tanré D., Deroo C., Duhaut P., Herman M., Morcrette J.J., Perbos J., and Deschamps P.Y, 1990: Description of a Computer Code to Simulate the Satellite Signal in the Solar Spectrum: The 5S Code. *Int. J. of Remote Sensing*, 11(4):659–668.