Validation and calibration of remote sensing data products on test site DEMMIN.

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ABSTRACT

One of the main research objectives of the working group Thematic Processors and Validation (TPV) of the Remote Sensing Data Centre (DLR-DFD) is the automation of remote sensing data processing. Whereby, the focal point of research is the derivation of value-added products for agriculture and forestry objectives. Three examples are given to outline past and present research of working group. These are: (1) a standard processor for automated data usability assessment based on multispectral quicklook data; (2) a thematic processor for retrieval of actual evapotranspiration from multispectral image data; and (3) an ongoing research work for the conception of a thematic processor for derivation of soil parameters from hyperspectral image data.
Since 1999 DLR Neustrelitz operates the test site DEMMIN (Durable Environmental Multidisciplinary Monitoring Information Network) to assure validation and calibration of data products and algorithms. DEMMIN is an intensively used agricultural ecosystem located in the northeast of Germany and is based on a cooperation between local farmers (IG Demmin) and DLR. It provides a manifold of instrumentation for the measurement of environmental parameters which are stored in the DEMMIN database.

1 Introduction

Sustainability is by now generally accepted as the paramount objective of human activities. An essential precondition for the analysis and the sustainable management of environmental resources is the knowledge of biophysical or physicochemical parameters and their spatial distribution. With respect to the growing demand for reliable information on the status of our environment, conventional methods of in-situ data collection alone can no longer satisfy our needs. Earth observation from space has become an outstanding tool for the retrieval of environmental parameters, especially with regard to their spatial and temporal dynamics. The set off of the European GMES (Global Monitoring for Environment and Security) initiative has confirmed and pushed the application of earth observation for environmental assessment and human security. To meet the increasing demand of information and data products, automation of data processing is of vital importance. Automation facilitates the processing of large data quantities as required in monitoring tasks. It allows fast data processing needed for near real-time applications such as precision farming or emergency mapping and disaster monitoring. Automation furthermore implies the standardization of the production process and products to provide reproducible and objective deliverables. To assure and to quantify the reliability of satellite products that were generated by this means and to approve new algorithms and methods, validation is mandatory. The establishment and long-term operation of test sites therefore is a central issue for the successful application of earth observation data.
This contribution first outlines the concept of the CATENA processing chain from DLR-DFD-TPV, presenting three examples from research on automatic data processing. In the second part of the paper, the DLR's test site DEMMIN (Durable Environmental Multidisciplinary Monitoring Information Network) in north-eastern Germany is introduced. Characteristics of the test site, its objectives and existing data base are summarized.

2 CATENA

Figure 1 illustrates the design of the automatic processing chain CATENA for the derivation of value-added products from remote sensing data and its close interaction with the test site DEMMIN. This processing chain consists of standard processors for data pre-processing such as data calibration and data usability assessment (DUA), atmospheric correction, geometric correction, and a thematic processor. The thematic processor subsequently supplies value-added products which undergo a cartographic production before final output. Due to the modular concept of CATENA, all components are interchangeable permitting the integration of a variety of thematic processors. It also allows the test of new algorithms for standard and for thematic processing within the CATENA environment. The validation of data products on the other hand is assured by on-site measurements of diverse environmental parameters at the test site DEMMIN (see chapter 3).

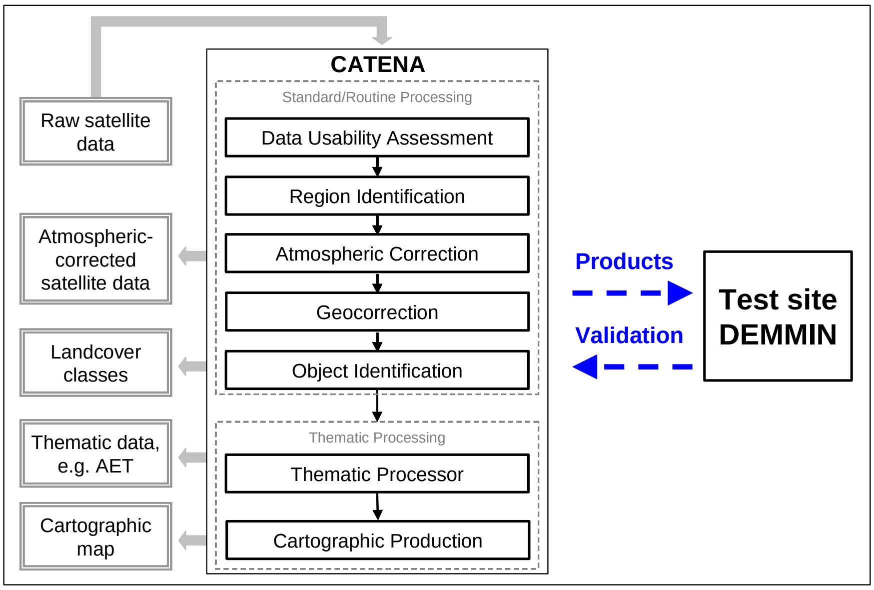

Fig. 1: Derivation of value-added products based on Remote Sensing data by the automated processing chain CATENA and validation with long- and short-term measurements of environmental parameters on test site DEMMIN.

In the following, three examples from research are briefly outlined: a standard processor for data usability assessment including cloud cover detection and structural analysis, a thematic processor for the retrieval of actual evapotranspiration and an ongoing research work on the derivation of soil parameters.

2.1 Automated Data Usability Assessment (DUA)

The increased availability of remote sensing data is accompanied by an increasing user demand for additional information, e.g. metadata to facilitate searches within remote sensing databases of providers (e.g. ESA). The information desired may typically concern the geographical position of the scene, acquisition time, but also data quality. Particularly information on data quality gives clues about the usefulness of remote sensing images. One quantitative indicator is the number of cloud-contaminated pixels compared with the total number of pixels for the data unit being assessed (scene/quadrant) (Hollingsworth et al., 1996; Irish, 1998; Irish, 2000; Xu & Wu, 2003).
However, the simple criterion of number of cloud contaminated pixels is an insufficient measure of data quality since the usefulness of a remote sensing image is influenced not only by the number of cloud-contaminated pixels but also by their distribution (Biasutti, 2000). Taking this into account, data quality assessment, e.g. at the ESA LANDSAT 7 ground segment, is at the moment accomplished by an operator's interactive visual interpretation (considering the amount of cloud contaminated pixels and the cloud distribution in a data usability scale of 0 = optimally usable, 90 = not usable, no unit). This makes data quality assessment not only labor-intensive; it is also influenced by subjective interpretation. In view of the increasing number of satellite missions and data, it is obvious that this processing step must become more efficient and operational.

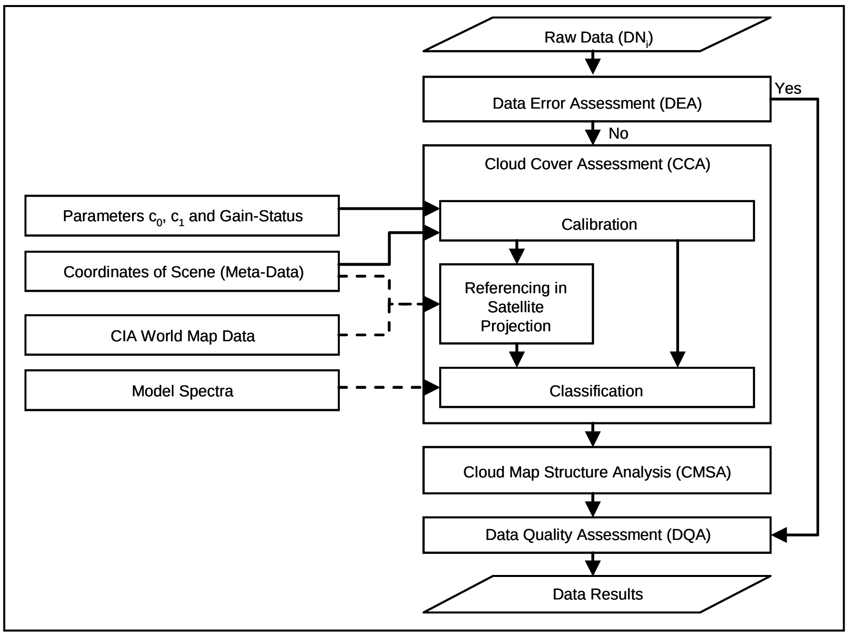

Fig. 2: Near-real-time processing algorithm for deriving the data usability on quicklook data of remote sensing data. Borg, Fichtelmann (2004).

We suggest that the interactive interpretation step in the otherwise fully automatic processing of e.g. LANDSAT 7/ETM+ data can be replaced by automatic evaluation. The DUA is an example of a standard processor which automatically assesses the usability of a scene from optical remote sensed data in terms of its potential for consecutive image interpretation.

Besides detection of existing data errors (an essential quality criterion of remote sensing data), and detection of haze and clouds, special attention is directed to the recording and assessing of cloud distribution and its influence on the usefulness of a scene. In order to take into account not only the number but also the distribution of cloud pixels, a structure analysis procedure was developed for the quantitative assessment of cloud distribution.

Only by combining cloud detection and structure analysis an adequate automatic assessment of the quadrants can be derived comparable to the operator's voting. The processor procedure is shown in Figure 2. Finally, the results of cloud detection and structure analysis were combined to a quantitative quality parameter with the help of two independent assessment algorithms. Until now, data usability analysis which meets ESA requirements had to be interactively executed by operators.

The processor is fed with image quicklook data. It should be noted that the examinations were based on data-reduced and jpeg-compressed quicklook LANDSAT 7/ETM+ products. It is well known that this restricts classification accuracy (Lam et al., 1999; Lau et al., 2003). Processing time is an essential criterion for evaluating any operational processor. Within the operational receiving environment in Neustrelitz, between 90 and 120 seconds are available for the trouble-free processing of a single scene. Tests were run with about 3000 Landsat quicklook scenes (completely covering Europe). Each quicklook data set comprises 7 spectral bands, each with a size of 1000x1000 pixel. The processing time per scene is about 40s.

The algorithm is easily adaptable to other geographical regions and other remote sensing data (e.g. ALOS). Additional to these, topographic information can be used for differentiation land and water in the frame of assessing data usability. In Figure 3 an example of a resulting value added quality product is shown.

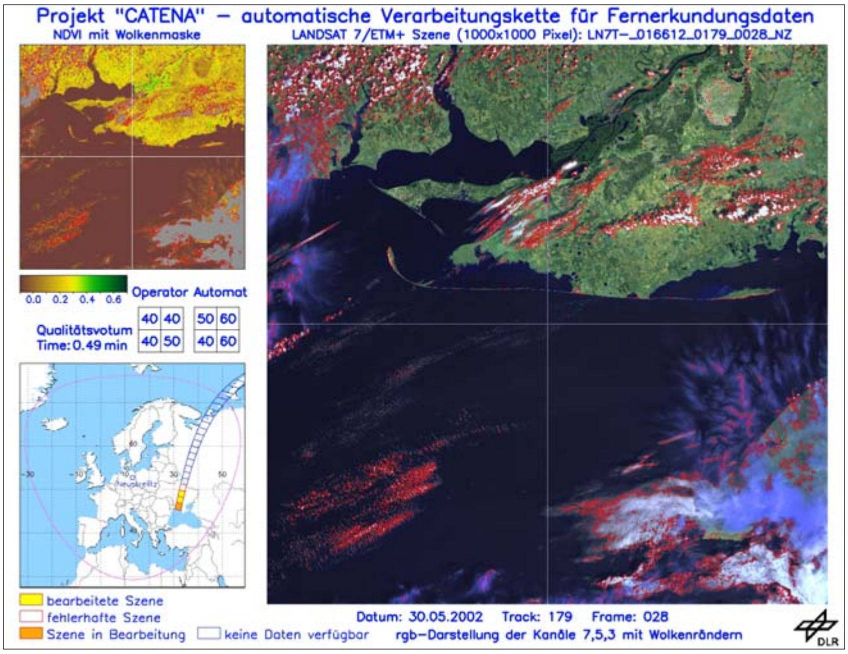

Fig. 3: Graphic output of the Automatic Data Usability Assessment (Borg, 2007).
Upper left: NDVI with cloud mask. Lower left: Progress of scene processing (yellow: processed scene, orange: scene in process, white: erroneous scene). Middle left: Operator's versus Automat votum. Right: RGB display of image scene with cloud mask and vector boundary layer (red).

2.2 Retrieval of Actual Evapotranspiration (AET)

Actual evapotranspiration (AET) is the connecting element between water and energy cycle. Its area-wide determination is necessary for manifold applications, e.g., modelling climate change, water supply and irrigation demand. Because AET is highly variable in time and space, its accurate determination is especially demanding.

Wloczyk (2007) suggests an automated thematic processor for retrieval of AET within the CATENA processing chain. This processor calculates AET for land surfaces (soil and vegetation, no water, no urban areas) based on the equation of energy balance at earth surface. As input multispectral satellite data consisting of bands in the following spectral regions are needed: Green, Red, Near Infrared and Thermal Infrared. No additional (in-situ) data are required.

Validation of the AET processor has been partly accomplished for Mecklenburg-Western Pomerania, including the DEMMIN test site (Fig. 4). For nine LANDSAT scenes covering all seasons, AET was calculated with an accuracy of approximately 50 % (Wloczyk, 2007). At the same time surface temperature, air temperature and incident solar radiation were calculated with accuracies of ca. +/-2 K, +/-3 K and +/-20 Wm-2, respectively (Wloczyk and Richter, 2006, Wloczyk et al. 2006).
However, further validation based on more satellite data as well as in-situ data is needed. The mostly physically based algorithms are transferable to other humid regions.

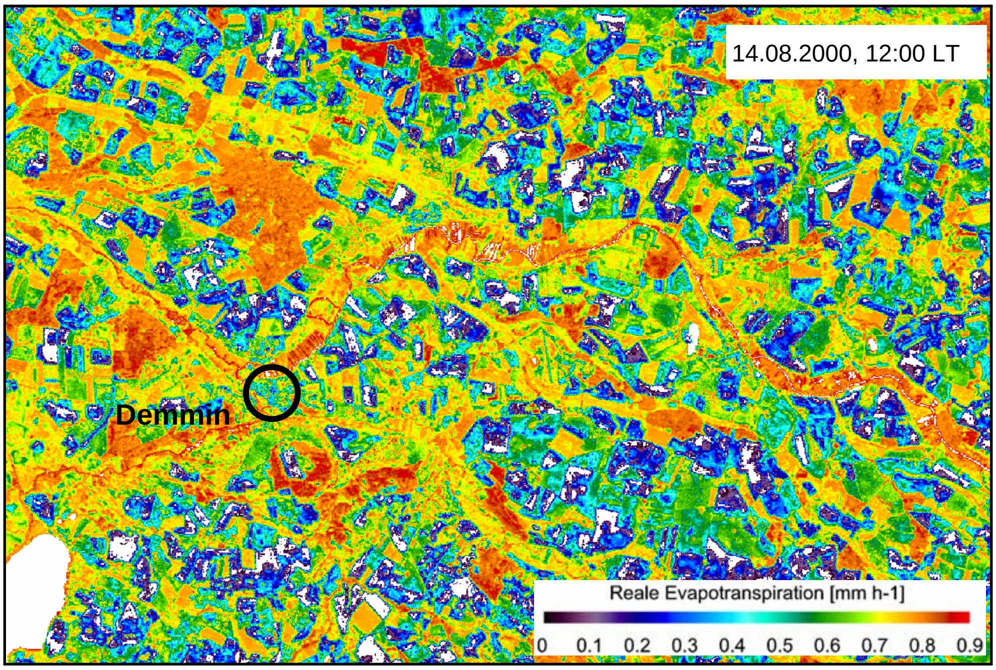

Fig. 4: Map of AET for the test site DEMMIN. Evaporation was estimated for the 14th August 2000, 12 am local time. Hourly evapotranspiration is estimated based on one instantaneous value. Water surfaces are

2.3 Derivation of soil parameters

Information on the current status of soil is of vital importance for a variety of applications in agriculture such as precision farming or soil erosion assessment. But the provision of area-wide soil data poses a problem, in particular on a regional to local scale. The following example aims at the retrieval of physico-chemical soil characteristics from remote sensing data focusing on clay and organic carbon content. By now, no automation in terms of a thematic processor has been attempted due to the present state of research.

The study is carried out on the base of airborne hyperspectral image data from the Australian sensor HyMAP. HyMAP image data has an average spectral band width of 16 nm in the range of 450-2500 nm that is in total 128 bands. The ground sampling distance (GSD) is about 4 m. The GSD of HyMAP varies between 3-10 m depending on the flight altitude during data acquisition (Cocks et al. 1998). Within the scope of the study, two models have been successfully set up by means of multiple linear regression analysis. Models have been established and evaluated using a soil reference data base of the test site DEMMIN and laboratory and field spectrometer measurements. Predictor variables selected for regression modelling exclusively base on material inherent absorption bands. As a result, percentage of clay and organic carbon could be estimated for bare soils on agricultural fields of test site DEMMIN with an accuracy of ±3% for clay and ±0.25% for organic carbon.

The principle workflow for soil parameter derivation is displayed in figure 5. Model input is atmospheric and geometric corrected hyperspectral image data. First image data is pre-classified adopting indices thresholds. Area covered with fresh vegetation or crop residuals and dry vegetation is masked by computing the Normalised Difference Vegetation Index (NDVI) (Rouse et al., 1973) and the Chlorophyll Absorption Index (CAI) respectively (Nagler et al., 2003). In a next step, models are run on the pre-classified data to derive maps of clay and organic carbon content. Because of very tight management plans, time slots for bare soil on agricultural fields are short. Therefore, soil parameter maps must be complemented consecutively for different fields adopting a multi-temporal approach. Final soil parameter maps are then generated by map stacking of several years. Next steps will be a thorough validation of the models and a substantial extension of the data base. However, reasonable care has to be taken if models shall be applied to other study sites because of their empirical nature.

At the moment, there is a lack of multitemporal hyperspectral data. But with the start of the operational hyperspectral satellite mission EnMAP, anticipated for 2012, the availability of multitemporal hyperspectral data will considerably improve.

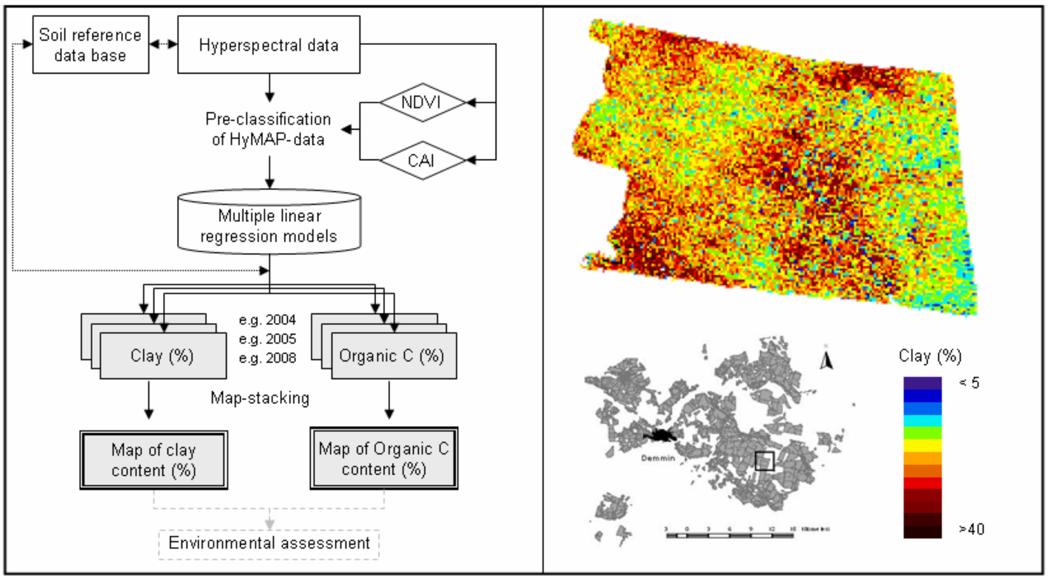

Fig. 5: Principle workflow for the derivation of soil parameters from hyperspectral image data and estimated clay content for a field in the southeast area of DEMMIN.

3 Test Site DEMMIN - Durable Environmental Monitoring Information Network

3.1 General characteristics

The DEMMIN test site is located in Mecklenburg-Western Pomerania in North-East Germany, approximately north of the capital Berlin (Fig. 6). It is an intensively used agricultural ecosystem which extends from 54°2′54.29″ N, 12°52′17.98″ E to 53°45′40.42″ N, 13°27′49.45″ E. The test site has been established in 1999 based on a cooperation of the DLR with the Interest Group Demmin (IG Demmin). The IG Demmin is an association of local farmers and consists of 5 limited and joint stock agricultural companies covering approximately 25.000 ha of agricultural fields. Field sizes in this area are very large with an average of about 80 - 100 ha. The main crops grown in the area are winter crops (winter wheat, winter barley, winter rape, winter rye) covering almost 60 % of the fields. Root crops such as maize, sugar beet and potatoes make up about 13 %.

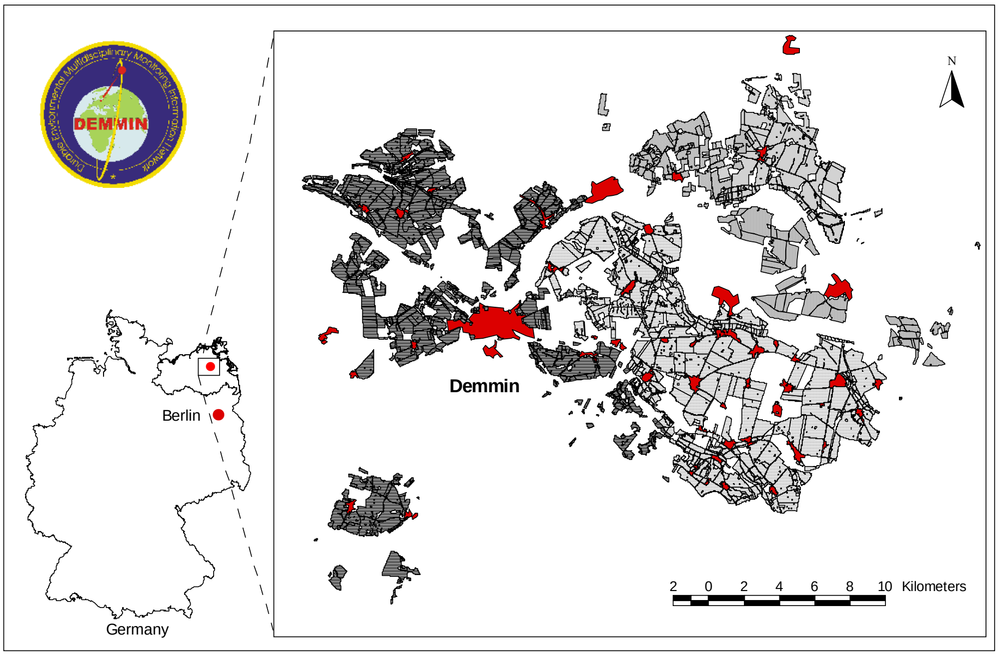

Fig. 6: Location of the DEMMIN test site in the northeast Germany and agricultural fields of IG Demmin.

The landscape belongs to the north german lowlands formed during the last Pleistocene period. It is characterized by glaci-fluvial and glaci-limnic deposits, and moraines which are reflected in a slightly undulating relief. Soil substrates are dominated by loamy sands and sandy loams alternating with pure sand patches or clayey areas.
The altitudinal range within the test site is around 50 m with some slopes of considerable gradients (12 °) along the Tollense River in the southeastern part of the test site. Mean annual temperatures vary from 7.6 to 8.2 °C. Precipitation ranges from about 650 to 500 mm (Hurtig et al., 1957). Due to micro-relief, climate conditions may vary significantly on a local scale.

3.2 Data base

Since the kick-off of DEMMIN in 1999, the data base successively expanded over the years. On the one hand, farmers annually provide new precision farming information such as yield and nutrient maps. On the other hand, the data base broadens during various research activities accompanied by airborne image acquisition and ground measurements as for example during AgriSAR campaign 2006 (Gerighausen et al., 2007). Therefore, a large number of data are now available. The data base can be subdivided in digital quasi-static-data, data derived from precision farming (digital dynamic data) and data from previous campaigns and monitoring activities. Table 1 gives an overview of the current state of the DEMMIN data base.

Table 1. Overview of DEMMIN data base

Category	Data
Digital quasi-static data	- Geological maps - Soil maps - Hydrological maps - Agricultural field maps - Digital Elevation Model
Digital dynamic data	- Annual yield maps (Combine measurements) - Annual nitrogen-sensor measurements (Track measurements) - Annual application maps - Macro and micro nutrients - Measurements of vegetation stages
Campaign data I (In-situ data or equivalent data)	- Destructive measurements for determination of leaf area index (since 2004) - Biomass measures (dry and wet), - Nitrogen measures, - Photographical documentation for measuring crop height and crop density, - Measurement of soil parameters (e.g. bulk density, texture) - Spectrometric measures on ground
Campaign data II (airborne data)	- Annual hyperspectral airborne campaigns (e.g. HyMap) - Simultaneous ground measurement program for data validation, e.g. spectrometer measurements, vegetation parameters, soil parameters

3.3 Automated Agrometeorological Measurement Network

Since 2004, a network of 15 agrometeorological stations is operated on the test site. It comprises the following atmospheric and soil science instruments (Fig. 7): two pyranometers to measure up- and downwelling short-wave radiation, two pyrgeometers for up- and downwelling long-wave radiation measurements, devices for the measurements of relative air moisture, air temperature, leaf moisture, wind direction and speed in 2 m height, an electronic rain sensor, soil moisture C-Probes at 0, 5, 15, 20 and 50 cm depth and soil temperature sensors at 10, 30 and 90 cm depths. Stations are uniformly distributed on the test site that guarantees access to local weather conditions and variability.

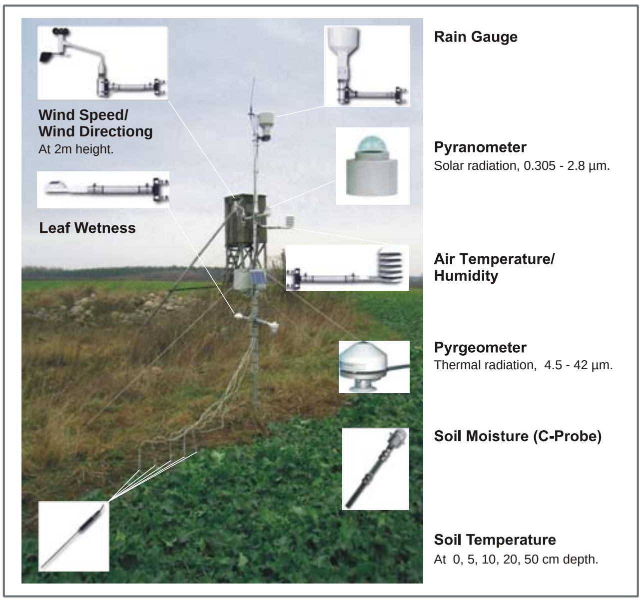

Fig. 7: Agrometeorological measurement station and instrumentation.

Measurements are usually taken every 15 minutes, though the sampling rate of the precipitation device is programmable. It can be adjusted for example to heavy rainfall intensities if a high temporal resolution is required. All measurements, agrometeorological and soil data are transmitted automatically to a receiving station and a data server.

4 Summary

One of main research objectives of the working group TPV, Thematic Processors and Validation at the German Remote Sensing Data Centre, German Aerospace Centre is the automation of remote sensing data processing. Three examples of past and present research activities have been outlined: a standard processor for Data Usability Assessment, a thematic processor for the retrieval of actual evaptranspiration and a potential thematic processor for the derivation of soil parameters.
To assure validation of satellite and airborne derived data products, DLR DFD operates the test site DEMMIN. DEMMIN is an intensively used agricultural area in a middle-European environment and is therefore dedicated to the development of remote sensing based agricultural land applications. It addresses a wide range of sensors, from high to low ground resolution due to its overall area and size of single fields. At the same time, on-site instrumentation and a comprehensive data base on quasi-static and quasi-dynamic data provides detailed ground truth information. The existing data base is steadily extended owing to a very close cooperation with local farmers.

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