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Spatial Aspects in the Alpilles-ReSeDA Project

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Abstract

The Alpilles-ReSeDA program has been initiated to develop and test methods for interpreting remote sensing data that could lead to a better evaluation of soil and vegetation functioning (biomass production, crop yield, energy balance and water budget). The proposed approach is based on the assimilation of remote sensing data into soil and vegetation functioning models. It emphasizes multispectral, multiangular and multitemporal properties of remotely sensed observations. This paper presents spatial and scaling issues that are addressed in this program.

1 INTRODUCTION

Remote sensing techniques have been mostly dedicated to the mapping and the inventory of crops and natural resources. Optical sensors such as Earth observation (TM, SPOT) and meteorological satellites (NOAA/AVHRR, METEOSAT) have provided almost all the data required. Future steps in using remote sensing data will focus on two main aspects:

- the assessment of vegetation and soil characteristics to get quantitative estimates of variables such as biomass production, crop yield or soil and vegetation energy and water budgets; these outputs are expected to increase our current understanding of the processes underlying environmental change, help agricultural planning and policy or water resources management;

- the concurrent use of multisensor data sources; at the beginning of the next century, Earth observation sensors aboard satellites will almost cover the whole electromagnetic spectrum, from the optical to the microwave domains (VEGETATION, MERIS, SPOT, MODIS, AATSR, RADARSAT, ERS, JERS, POLDER, MIMR, MISR, MSG, PRISM, ...); this situation is new and forces to investigate the combined use of these various data sources.

These two aspects led the French remote sensing community to initiate the Alpilles-ReSeDA project, which now federates many laboratories in France and Europe. Its main objective is to develop and test methods for interpreting remote sensing data that could lead to a better evaluation of soil and vegetation functioning (biomass production, crop yield, energy balance and water budget). The proposed approach is based on the assimilation of remote sensing data into soil and vegetation functioning models. It emphasizes multispectral, multiangular and multitemporal properties of remotely sensed observations. The combined use of several spectral domains may provide the maximum amount of informations on canopy and soil biophysical characteristics (canopy structure, biochemical composition and water content, energy balance, soil moisture and roughness, ...). Multidirectional data may be used to get more informations on the structural characteristics of the vegetation and soil. As the vegetation or the soil are dynamic targets, the time course of remotely sensed data brings a lot of informations that can be used to characterize soil and vegetation functioning.

1.1 Using vegetation and soil functioning models

Vegetation and soil functioning models have been developed to describe our current understanding of the physical and biophysical processes that occur between the atmosphere, vegetation and soil. These models describe energy and mass budgets and provide estimates of the time course of soil and vegetation state variables. Several types of models can be used and combined together:

- Crop Functioning models (CF models) describe the biophysical processes that govern crop canopy functioning and dynamics : plant phenological development, photosynthesis, respiration, evapotranspiration, carbon, nitrogen and water allocation between the various parts of the canopy (leaves, stems, roots, fruits, ...). They provide estimation of time courses of canopy structure, biomass, soil water and nitrogen budget. They have been mainly used for yield prediction, potentiality assessment and water resources management. They require informations on climate (incoming radiation, air temperature and humidity, wind speed), soil and vegetation types.
- Soil Vegetation Atmosphere Transfer models (SVAT models) describe the physical processes that control energy and mass transfers in the soil/vegetation/atmosphere continuum (radiative, turbulent and water transfers). They use a finer time step than CF models. As CF models, they require informations on climate, soil and vegetation types, but also on canopy structure since they are not usually designed to simulate long term vegetation processes. They have been mainly used for energy balance and water balance assessments in meteorological, climatological and hydrological studies. They may also be used to estimate the surface temperature that can be measured in the thermal infrared domain. SVAT models may be coupled with CF models to describe energy and mass transfers along a full growth cycle, or to make it possible the combination of thermal infrared data with CF models.

1.2 Combination of remote sensing observations with CF and SVAT models

The combination of remote sensing observations with models may be achieved using two approaches (Figure 1):

- **inverse methods:** radiative transfer models (RT models) describe the interaction between vegetation, soil or atmosphere and the electromagnetic radiation. The inversion of these models can provide estimates of canopy or soil biophysical characteristics from their spectral/directional/polarization signatures. The inversion process consists in tuning RT model input variables (canopy or soil biophysical characteristics) in such a way that the simulated remote sensing signals agree with the actual remote sensing observations (Baret *et al.* 1996). Then, the retrieved canopy or soil characteristics may be used as input in CF or SVAT models.
- **Assimilation methods:** SVAT and CF models contain a description of the biophysical characteristics such as canopy structure and optical/dielectric properties of the soil or vegetation elements that govern radiative transfers. They thus may be coupled to RT models to simulate what remote sensing systems actually observe. SVAT and/or CF models coupled with RT models simulate the time course of the spectral/directional/polarisation signature of soil and canopies. Then, they may be used to “assimilate” remote sensing data. The assimilation process consists in tuning SVAT or CF model parameters in such a way that model outputs (such as the time course of reflectance, emittance or backscattering) agree with actual remote sensing observations. Assimilation techniques can be used to set initial conditions or to correct time evolution of state variables in SVAT or CF models (Delécolle *et al.* 1992, Olioso *et al.* 1997).

1.3 The Alpilles-ReSeDA program and spatial aspects

The program has been decomposed into three main tasks:

- data acquisition, processing and data base; a year long experiment over a small agricultural region aimed at providing a consistent and comprehensive dataset allowing the calibration and the validation of inversion and assimilation procedures;
- inversion of RT models; several techniques will be evaluated and compared to retrieve canopy biophysical variables from multispectral/directional/polarisation remote sensing observations; they will include formal RT model inversion as well as empirically based techniques.
- assimilation of remote sensing data into SVAT or CF models; several approaches will be evaluated and compared using the multitemporal data acquired during the experiment.

The main emphasis of the program is its temporal and multispectral dimensions. However, scaling problems are also addressed. Inversion and assimilation procedures will be first implemented and tested at local scale (on experimental fields). Then, high resolution data (airborne and Earth observation satellite images) will be used to extend the results over the whole studied area, generating a spatialized distribution of soil and vegetation processes. The significance of mixed pixel will also be addressed. This is a key point since monitoring vegetation and soil processes often requires high temporal repititivity in data acquisition. Up to now, this can only be achieved by using coarse spatial resolution sensors, such as AVHRR, while most of the RT, CF and SVAT models are devoted to homogeneous surfaces.

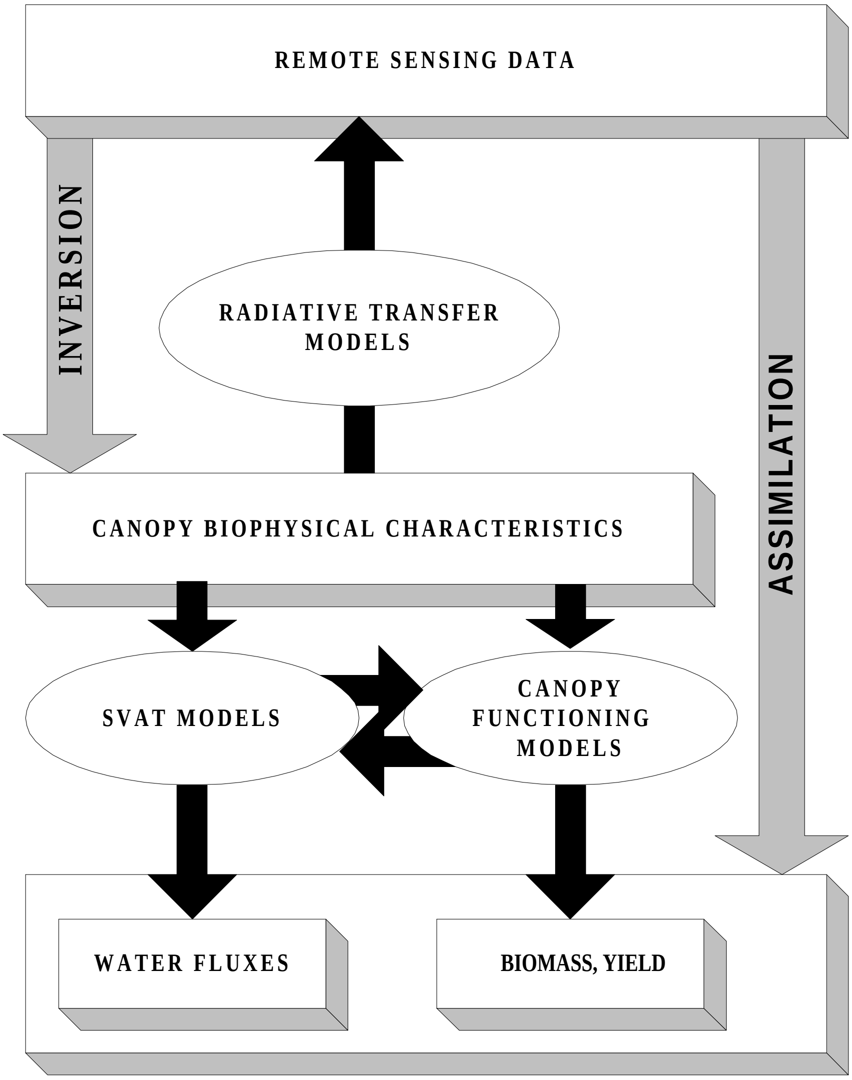

Figure 1: Flow chart diagram showing how to infer variables such as canopy biomass, yield or water fluxes from assimilation of remote sensing data into canopy and soil models. The black arrows indicate the way models work in the forward direction.

2 Data acquisition: the experiment

The experiment covered the whole growing season of winter and summer crops from October 1996 to November 1997. It included field measurements, airborne and satellite remote sensing measurements. The experimental site was located near Avignon (SE of France) in the Rhone valley (N43° 47' and E4° 45'). Its maximum dimension was approximately 4 km × 5 km. It was a very flat area with large enough fields (200 m × 200 m) to extract pure pixels from high spatial resolution satellites, as well as to implement atmospheric fluxes measurements. Main crops were wheat, corn, sunflower and forage. We chose to study 3 crops which have very different cultural cycles (wheat, sunflower and alfalfa). Some ground data were also collected on grassland and corn. A particular design of the experiment was chosen for addressing scaling problems (Figure 2). The spatial sampling strategy allowed a good characterization of the field scale, that revealed the variability within fields, and of a regional scale, as observed by coarse resolution sensors. Adjacent fields were chosen to study mixed pixel issues. In order to calibrate and validate CF and SVAT models we performed a continuous monitoring of surface energy balance components, surface temperature, albedo, soil water balance, standard meteorological data (wind speed, air humidity and temperature, rainfall, incident radiations), vegetation characteristics (height, biomass distribution, LAI), soil characteristics (temperature, moisture and water pressure profiles, surface soil moisture, surface roughness and surface dry bulk density). Additional measurements such as root density profiles, leaf water potential, stomatal conductance, leaf photosynthesis, plant and soil nitrogen content, leaf chlorophyll content, canopy CO_2 fluxes, soil hydraulic and thermal conductivities, dry bulk density profiles, soil texture were performed at critical periods. A detailed characterization was done on *"calibration"* fields (one wheat, one sunflower and one alfalfa fields). It will be used for the setup and the calibration of models and methods. A less detailed characterization was done on *"validation"* fields (two wheat and two sunflower fields) which will be used for validating models and methods. Additional measurements were done on *"remote sensing"* fields concurrently to aircraft campaigns and to some satellite image acquisitions (4 wheat, 1 sunflower, 1 grass and 3 corn fields). They will be used for further testing of inversion procedures (surface soil moisture, roughness, texture, dry bulk density, vegetation structure, biomass, height, water content, surface temperature, LAI, canopy cover fraction). A classical meteorological station was also settled in order to acquire climatic data consistent with the available data for an operational implementation of CF and SVAT models. Detailed measurements were done for characterizing incoming radiations and aerosols.

Specific measurements in relation with scaling issues were performed at some specific periods and located close to the center of the studied area:

- measurements with a small unmanned plane (Hobbs and Dyer 1994). They consisted in temperature, pressure and humidity transects at different heights over some heterogeneous areas.
- spatially integrated measurements of heat fluxes using large aperture scintillometers (McAneney *et al.* 1995). The measurements were performed along optical paths including several types of surfaces.
- radiosoundings to characterize vertical profiles of wind, humidity and temperature (in relation with atmospheric modeling).

Airborne remote sensing measurements were conducted to provide multispectral / multiangular remote sensing data with high temporal repetitivity (monthly or better). They are expected to be tools for extending the field measurements to the small region. Three main airborne sensors were operated : the Vis-NIR multiangular polarimeter POLDER and the thermal IR multiangular camera INFRAMETRICS, both on a Piper AZTEC, provided images with a 20 meter ground resolution every 15 or 30 days (16 POLDER and 21 INFRAMETRICS acquisitions); the microwave multiangular scatterometer ERASME (C and X bands, HH and VV polarizations), borne on a

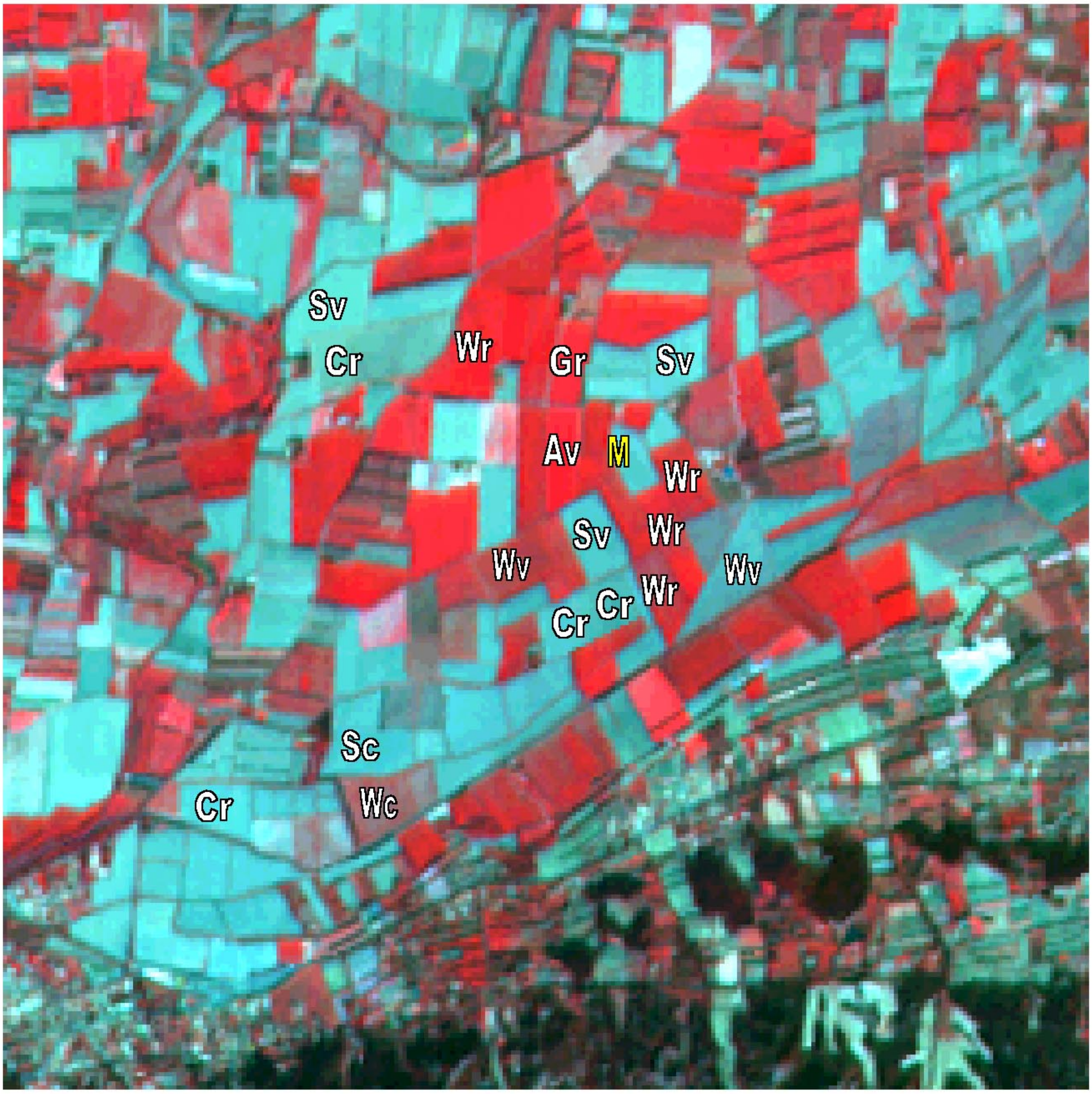

Figure 2: 5 km × 5 km SPOT image acquired on March 25, 1997;
M: meteorological site;
W: wheat fields; S: sunflower fields; A: Alfalfa field; C: corn fields; G: grass field;
c: *calibration* fields; v: *validation* fields; r: *remote sensing* fields.

helicopter, provided along track profiles with a 20 meter ground resolution. It was operated for 9 weeks chosen at specific periods in the crop cycles. Additional sensors were occasionally operated: RENÉ polarimetric radar (S, X bands), IROE passive radiometers (6.8, 10 and 37 GHz, H and V), DAIS German imaging spectrometer (Vis, NIR, MIR, thermal IR) and MAIS Chinese imaging spectrometer (Vis, NIR, MIR, thermal IR). As much as possible satellite data were acquired during the campaign : SPOT (7 images), ERS-2-SAR (15 images), RADARSAT 23° and 38° (7 images), NOAA-AVHRR (continuous from October 1996), ERS-2 AATSR (6/month) and Landsat-TM (1 image). All these data will be geometrically corrected, georeferenced, and calibrated to provide data equivalent to the ground level.

A detailed and exhaustive soil occupation map has been established using SPOT data, DAIS data, aerial photos and ground level enquiries. All the data will be integrated within the ARCINFO geographical information system.

3 Spatial extension

High spatial resolution images will be used for extrapolating inversion and assimilation procedures over the whole studied area. Inversions will produce maps of quantities such as soil moisture, soil hydrodynamic properties, LAI, albedo, canopy cover fraction, fresh biomass, fraction of absorbed PAR or chlorophyll content (see for example the work by Roujean *et al.* (1997) with POLDER data in the Hapex-Sahel program). Assimilation procedures will produce energy balance flux, biomass production and yield maps. Some methods, which exploit image spatial variability, will also be implemented to derive energy balance flux maps: the SEBAL model (Bastiaanssen 1995) and the NDVI/surface temperature method (Gillies *et al.* 1997).

An analysis of the spatial variability of meteorological data used for driving SVAT and CF models will be done. Procedures for extrapolating meteorological data from the meteorological site to other fields will be tested. They are based on a simplified description of the lower atmospheric boundary layer and on the assumption that surface has a very large influence on this layer, but that a regional equilibrium exists at some height in the atmosphere (Courault *et al.* 1996). These procedures may be directly coupled with SVAT models.

High resolution atmospheric modeling will also be used : Meso–NH, the French community non-hydrostatic mesoscale model (Lafore *et al.* 1998), will be implemented over a domain of some tens of km^2 using a horizontal resolution of the order of 100 m or 50 m, compatible with the field size over the experimental area. This model will provide a very detailed description of surface fluxes and atmospheric characteristics for some periods.

4 Heterogeneous pixel

Inversion of RT models and assimilation in SVAT and CF models may be directly implemented using informations obtained over coarse resolution pixels. As all these models have been designed to work on homogeneous surfaces, it is necessary to test whether these procedures are still valid for heterogeneous pixels. Retrieved quantities (parameters or variables) may be termed as *“equivalent”* quantities (Kreis and Raffy 1993). They are representative of a fictitious homogeneous media for which remote sensing data have the same behavior as the actual heterogeneous media. Such an approach will be taken to invert RT models against POLDER data and retrieve equivalent LAI, fraction of absorbed PAR and chlorophyll content. It will also be used to assimilate thermal infrared data into SVAT models and derive equivalent soil water content and energy balance fluxes. The signification of heterogeneous pixels in active and passive microwave domain, *e.g.* for retrieving surface soil moisture, will also be analyzed. We intend to investigate these approaches in building signals for heterogeneous pixels by aggregating high resolution signals from airborne or satellite sensors over an heterogeneous area. For validation purpose, heterogeneous pixels will be constructed either from area where most of the fields were ground sampled, or from the maps generated when processing inversion and assimilation procedures over high resolution images. The high number of data throughout the whole year will make it possible to assess very different situations.

The combination of fine and coarse resolution pixels will also be investigated. Works by Noilhan and Lacarrère (1995) or Chehbouni *et al.* (1995), among others, showed that simulations with SVAT models over heterogeneous area may be fed by *"effective"* parameters which are derived from specific averaging of homogeneous component parameters. This opens the way of combining high resolution data from Earth observation satellites (*e.g.* LAI, canopy cover fraction, ..) to thermal infrared measurements from meteorological satellite such as NOAA. High resolution data will also be used to evaluate the accuracy of surface temperature retrieval over heterogeneous pixels having internal variations of emissivity. Other works will implement the spatialization method proposed by Raffy (1992) and analyzed by Bouguerzaz (1997) in the case of energy balance flux retrieval. This method provide a range of possible values for the searched quantities, from global radiances. Spatialized models may then be proposed, which minimize the errors on the retrieved variables or parameters.

In the case of CF models, the possibility of using both low spatial resolution and high spatial resolution signals may be assessed in two ways (top–down and bottom–up approaches). In the *top-down approach*, the temporal profile at the regional scale, which is a mixed signal, is decomposed to estimate the individual behaviors of each crop category. Knowing the land use, two methods can be considered: a "spatial" one (Faivre and Fischer, 1996), or a "temporal" one (Fischer, 1994). Both provide the averaged signal of each crop and its standard-deviation. This signal is then used for the assimilation strategy defined at local scale. For each crop, the average results (yield, biomass production) and their incertitude ranges provided by the use of the coarse spatial resolution data will be compared to the statistics obtained, either from ground informations, or from assimilation of high spatial resolution data at the field scale. In the *bottom-up approach*, temporal reflectance profiles are simulated for each crop category and aggregated according to the land use, in order to reproduce the regional signal (Moulin *et al.*, 1995). Then, assimilation of low spatial resolution data attempts to adjust the key parameters of the production models for the different crops at the same time. Retrieved profiles and productions will be compared to the results obtained, for each crop, with the top-bottom approach. For some simple CF models it will be also possible to compare these two last approaches to a direct assimilation of coarse resolution data ("equivalent" variable approaches).

Other studies will be made in relation with heterogeneous pixels. Spatial analysis (textural analysis, FFT) on high resolution thermal infrared data will be undertaken in order to relate high resolution informations to low resolution informations and surface fluxes or near-surface atmospheric parameters. The measurements made by unmanned airplane and scintillometers, as well as the detailed atmospheric simulations with the Meso-NH model, will be used to investigate underlying processes: *e.g.* it will be possible to test some of the hypothesis required for applying effective or equivalent parameters in SVAT models.

5 Conclusion

The first phase of the Alpilles-ReSeDA program, the field campaign, was conducted with success. Remote sensing and ground truth data were collected over a wide range of situations representatives of various types of crops. A large variety of surface and atmospheric conditions were experienced. The large number of airborne and satellite data make it possible to investigate many aspects of RT model inversion and assimilation in SVAT and CF models. The detailed ground measurements provide a very useful database for the validation of inversion and assimilation procedures and the assessment of vegetation and soil characteristics in relation with biomass production, crop yield and soil+vegetation energy and water budget. Despite that the program is mainly focused on multitemporal and multisensor issues, the dataset is well suited for investigating many aspects of spatial extension and scaling. The processing of ground, airborne and satellite data is continuing. Additional informations on the program may be found at **http://www.synoptics.nl/reseda**.

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