INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team Air2

Image processing and dynamic satellite data

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THEME 3B

Activity Report

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1. Team

Head of project-team
Isabelle Herlin [RD]

Vice-head of project team
Hussein Yahia [SR]

Administrative assistant
Christine Anocq [TR, partly in charge with M3N]

Staff member
Jean-Paul Berroir [SR]

Scientific advisor
Bruno Sportisse [CEREA, Ponts et Chaussées national High-School]

Civil servant (on partial secondment)
Etienne Huot [University of Versailles Saint-Quentin]

Research scientist (partner)
Dominique Béréziat [University of Paris 6]
Sonia Bouzidi [University of Evry]
Isaac Cohen [USC, Los Angeles, USA]
Antonio Turiel [University of Catalonia, Barcelona, Spain]

Visiting scientist
Mohamed Ben Ahmed [Professor, ENSI-RIADI, Tunisia]
Mohamed Saber Naceur [Professor, LTSIRS, Tunisia]

Post-doctoral researchers
Milan Jovovic [ARC Thalweg, since october 2002]
German Torres [University of Cordoba - Argentine]

Junior technical staff
Vincent Picavet [since 11-03-2003]

Ph.D. student
Jacopo Grazzini [INRIA grant co-funded by the Région Ile-de-France, University of Marne la Vallée]

Graduate student intern
Salem Belhaj [University of Versailles Saint-Quentin]
Till Isambert [University of Cachan]
Aymeric Pierre [University of Marne la Vallée]

Student intern
Michel Auger [University of Paris 6]
Christophe Couvreur [University of Paris 6]
Baptiste Guldner [University of Paris 6]
Mohamed Anis Loghmari [ENSI-RIADI - Tunisia]
Anne Marcadet [University of Paris 9]
Samya Sagar [ENSI-RIADI - Tunisia]
Heroor Shravan [IRIS - USC - USA]
Maher Trabelsi [ENSI-RIADI - Tunisia]

2. Overall Objectives

The AIR2 team is interested in the mathematical formalisation of image phenomena observed in satellite data. The selection of scientific subjects is conducted in collaboration with specialised scientists (agronomists, geologists, hydrologists, meteorologists, oceanographers, specialists in environmental pollution etc.) who wish to make use of earth-sea-atmosphere observations complementary or in place of others types of measures. Methodological research activities hinge on three main approaches:

1. Image analysis for structures' detection and temporal matching; physical quantities estimation by use of inverse modeling from acquisitions, ...
2. The interaction between satellite data and physical models, so as to apprehend the limit condition problems, parameter estimation and data assimilation problems. This research is conducted in strong collaboration with the CEREA laboratory (ENPC).
3. The integration of generic image processing processes, the publication of data and programs in a web-based distributed environment; this work is mainly done in collaboration with the SMIS project.

3. Scientific Foundations

3.1. Motion.

Key words: *vector fields*, *optical flow*, *variational method*, *statistical physics*, *spline functions*.

The project is examining dynamical phenomena present in satellite data. As a matter of fact, the nature of the data and the type of information the users are searching for are considered as constraints in the design of the solutions. A first step involves apparent motion estimation and interpretation from the data. These researches, which are nowadays considered as classic in the literature, are usually conducted around the problem of motion estimation using the optical flow hypothesis using a variational solution method. Adapting this technique to the special type of data and the particular structures the team is interested in, leads to the study of regularisation functions. First, we have been stuying non-quadratic functions for preserving physical discontinuities of the motion field. We now take up the case of the regularisation by incorporating information on the physical process of image formation (i.e. radiative transfer models), so as to derive regularity constraints applied on physical parameters rather than on image data. Other methodological works that take place in this context tackle the problem of generalising the optical flow equation by incorporating specific constraints such as the volumic conservation in the case of cloud structures. We have been working on coupled with/without a priori models to apprehend the hierarchical nature of movement components. Certain dynamical phenomena (ex: the temporal evolution of oceanographic structures) require a global modelisation on the structures in interaction (fronts, vortices). We have developped a solution method based on the theory of div-curl regularised spline vector fields and we study its generalisation to the problem of structures' matching. Lastly, the team is studying the contribution of methods coming from statistical physics to examine certain types of turbulent data present in satelitte image sequences (ex: the study of pluviometry in meteorology). For that matter, experimentation with a multifractal model of luminance diffusion inside specific subsets of pixels in an image is used to characterize convective regions in turbulent fluid flow data.

3.2. Deformation.

Key words: *differential characteristics*, *geodesic curve*, *fluid mechanics*, *interpolating surface*.

Dynamic structures present in satellite image generally undergo important temporal deformation. In addition, these structures interact each other. This makes the problem of temporal matching more complex than the one studied classically. Known techniques make use of small deformation hypothesis and conservation of differential characteristics. In this research domain, the team is conducting research on deformation modeling using an interpolating surface and the use of geodesic curves. Research is also performed in the 3D generalisation of level-set methods (for instance for digital elevation models).

3.3. Parameter estimation.

Key words: *data fusion*, *physical model*, *statistical model*.

Aiming at estimating certain input parameters in environmental models requires physical modeling of the measured signal. The problem is to model the parameter contribution to the different satellite measurements, then to perform the calibration and the validation of such a modelisation using ground data measures. To solve the estimation problem, the model must be inverted from sets of measures at various spatial and temporal resolutions. We use techniques coming from data fusion and statistical modeling (markov fields, bias-variance analysis). We make also use, in certain cases, of methods derived from image processing, adapted to allow the incorporation of knowledge about the physical process of signal formation and/or models of studied structures. Inverse problems are also considered using optimisation techniques, where the gradient of the cost function, that defines the agreement between the parameters and the measurements, is obtained by means adjoint modeling.

3.4. Data assimilation.

Key words: *data assimilation*, *radiance assimilation*, *atmospheric chemistry*.

Data coming from remote sensing put together a primary source of information for monitoring the chemical composition of the atmosphere, particularly in three important applications: the monitoring of stratospheric ozone depletion, of additional greenhouse effect, and of tropospheric pollution. Their modeling requires the use of sophisticated models, combining meteorological models (global or local circulation models), chemistry, and transport of chemical species under the action of meteorological fields. In this context, assimilation of satellite data is of highest importance to provide realistic modeling, and for the accurate estimation of initial conditions. The classical methodology consists in the assimilation of the principal product of atmospheric sensors: the *total column*, or the vertically integrated mass of chemical constituant(s) such as ozone. The main advantage lies in the ease of such an assimilation, since the total column is a linear function of the state variables of a chemistry-transport model. Nevertheless, obtaining the total column necessitates a preliminary step consisting in inverting the radiative measure. The approach undertaken by the AIR2 team, in collaboration with the CEREA team (ENPC), is the following: we proceed to the direct assimilation of the measure, i.e. the radiance. Such an approach discards important preprocessing and their associated errors. It necessitates the development of coupled chemistry/radiative transfer models. Contrary to pure radiative models, the stake consists in the development of numerical schemes compatible with the discretization of the chemistry model, efficient enough to be embedded in a variational assimilation procedure using automatic differentiation.

4. Application Domains

4.1. Panorama.

One main specificity of AIR2 team lies in the choice of a prioritary application : the study of environmental problems by use of remote sensing. This leads to the definition of image processing research problems from requests issued by scientists from different domains. Moreover, these specialists may also perform an evaluation process about the quality of the results. Hence, the AIR2 team has defined a wide network of collaborations on different thematics, some of these are introduced in this section.

4.1.1. Satellite-based input data for air quality modeling

These studies are first conducted in the framework of the ERCIM workgroup ”environmental modeling” -and more specifically with the SAS team (Fraunhofer FIRST, Berlin, Germany), then in the framework of the DECAIR european project (scientific coordinator: Dr. I. Herlin), lastly in the COMODE A.R.C. with ENPC, IDOPT project and CERFACS. Two research directions have been chosen:

- Input parameters estimation for prevision and simulation models of air quality in urban areas. The goal is:
  - to enhance forecast results by producing ”better quality” input data,

  - to enhance the models themselves by providing models with objective internal parameters values, that depend upon space and time. This typically concerns soil-surface related parameters,
  - to ease the automatic deployment of existing models on new sites.

- Radiative models inverse problems: satellite measures are physically explained by use of radiative transfer models. Inverting these models allows the estimation of the atmosphere's characteristics (optical, composition, temperature) along the optical path. Targeted applications are: first, estimating the chemical composition of the lower atmosphere, second, analyzing the radiative transfer through clouds. The first application displays an immediate interest for pollution modeling. The second application permits remote sensing studies under the clouds, for example exact sunshine computation at ground level. It also presents interest for the study on below cloud chemical mechanisms, such as scavenging, and hence has applications to the analysis of rain water quality.

4.1.2. Change detection.

Land cover and land use cartography is a necessary and fundamental step to study vegetation cover and its temporal evolution. At local scale, the characterization of the different types of land cover can be obtained from analysis of high resolution data (SPOT, LANDSAT) and/or ground measures. We have started studies (in particular in collaboation with CESBIO), on SPOT image sequences analysis to characterize the temporal evolution of vegetated land covers.

For larger scale studies, for instance at the scale of a whole catchment area, it is difficult to obtain such data on wide surfaces. One solution consists in using the spatio-temporal information given by broad swath sensors like NOAA-AVHRR and VEGETATION to make the cartography. In that case, one determines the pixels' composition at low spatial resolution (1.1km). This is used to generate percentages inside a pixel. Applications are for instance: assessment of erosion and flooding risks at the catchment area's in the framework of an INRIA/CNPq collaboration with Rio de Janeiro University (ECOAIR project).

4.1.3. Hydrology.

A study concerns hydrological parameters estimation (surface temperature, evapotranspiration) and the determination of their variability in function of ground occupation and/or the topography for some catchment areas in Austral Africa. These parameters are integrated in a hydrologycal modeling system used for decision support about water resources repartition, and to simulate the impact of ground occupations changes on hydrological responses.

A secound study in collaboration with CETP EMA team tackles the problems of front propagation and flow modeling on Digital Elevation Models (DEMs). The flows can be of different types (river flooding, mud flows on a mountain slope etc.) and the model must integrate terrain chacteristics, an information coming from other sources.

6. New Results

6.1. Multiscale Approaches for the Extraction of Meaningful Structures in Natural Images

Participants: Antonio Turiel, Jacopo Grazzini, Hussein Yahia, Isabelle Herlin.

Key words: *multiscale*, *multifractal*, *entropy measures*.

The objective of this work is the characterization and the extraction of meaningful structures in natural images. A natural way to measure their contribution to the image description consists in using the entropy defined by Shannon, which quantifies the information conveyed by subsets of the image. The local estimation of entropy provides a spatially localized, but redundant, measure of the information: we generalize it in a multiscale framework, in order to capture the scale-invariance property of natural images and to reduce this redundance. This new definition allows to decompose the image according to the local content of information. Similarily, in the context of image segmentation, the use of a multifractal model enables to decompose an image according to the local regularity of the signal. We show that both approaches are related: the entropy-based concepts and the geometrical approach of the multifractal formalism provide a similar characterization of local structures in images. Namely, the segmentation into fractal subsets is in good correspondance with the hierarchical decomposition obtained through the entropic description (see figure 1). In particular, the knowledge of one of the fractal subsets (the most singular), which is quite close to the maxima of the local entropy, allows to reconstruct the image.

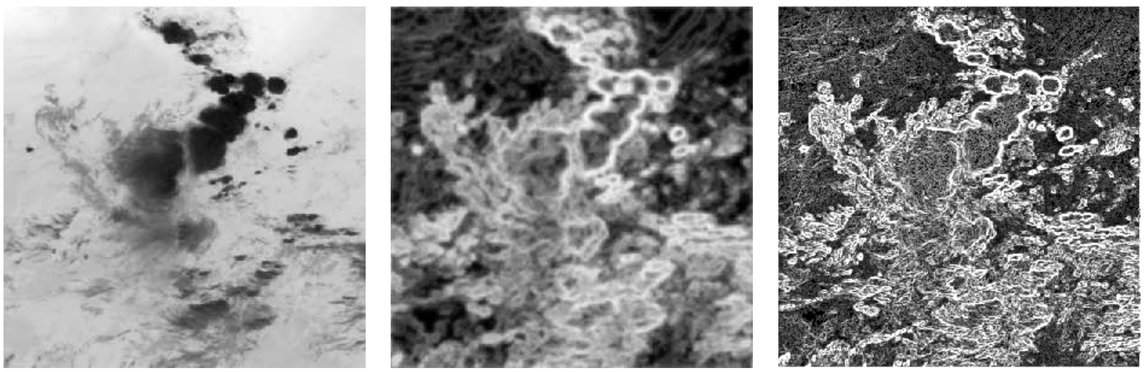


Figure 1. ***From left to right****: infrared image, multiscale entropy variable and singularity exponants (for the two last images, the brighter the pixel's value, the stronger the entropy - resp. the singularity - at this point).*

We make use of those techniques in order to clarify the role of different subsets of the image (edges, texture) according to the information they convey. The interest of our study lies in that it allows to identify the parts in the image which are relevant from the perspective of coding. Such a classification is useful for image compression purposes, but also for perceptual models (less informative parts of the image are more likely to be ignored by a subject). These considerations also show that the multifractal model enables to supply structures and objects in image with a multi-semantic interpretation (from geometrical, statistical and information theory points of wiew).

This research is undertaken in the context of the Thalweg ARC.

6.2. Multifractal Analysis of Infrared Meteorological Images: Application to the Detection of Convective Rainfall Areas

Participants: Jacopo Grazzini, Antonio Turiel, Hussein Yahia, Isabelle Herlin.

Key words: *infrared image*, *convective structures*, *vertical motion*, *precipitation*, *multifractal*, *sources*, *multiscale entropy*.

We address the problem of detecting the critical areas of meteorological structures mainly associated with convection. We are led to gain insight in the physical and geometrical properties of the observed complex structures as they are related with the turbulent character of the atmospheric fluid. We use a multifractal hierarchy to process infrared images, so that we are able to infer the mechanisms involving energy transfers in the atmospherical flow. Without any temporal information, we extract relevant information about the properties of the clouds, namely vertical movements in clouds.

We develop an approach for the characterization of the thermodynamic activity of meteorological systems from still infrared images. We propose a multifractal model that is derived from thermodynamic concepts, and that provides a geometrical and physical description of images. Indeed, the multifractal formalism allows to take into account both geometrical (spatial organization, structure) and physical (radiance, temperature) information conveyed by infrared images. The main underlying idea is that strong transitions in the signal are related with the dynamics of the flow. Namely, the model enables to extract, at different scales, a subset in the image which is essentially composed with the boundaries of the meteorological structures and correspond to the thermal fronts of the flow. It is also observed that the uniform propagation of the temperature from this front to the other parts of the image can be assimilated to an advective motion. We measure how the observed transport across the main thermal fronts differs from this uniform propagation. We express this relation with a suitable transformation that quantifies this deviation: technically, this is done through the Radon-Nykodin derivative of a measure related to the original signal with respect to a measure associated to advective motion. This formalism enables to identify the hidden sources for the process, *i.e.* areas where the motion is non advective, or, similarily, where energy and matter are injected in the system. These sources provides critical information about the nature of the underlying motion as they can be used for the detection of convective structures associated with vertical transport. Inside the clouds, the poles and zeros of the sources are in good correspondance with the divergent areas of the motion fields (see figure 2). We identify foci of rainfall in clouds with strong deviations areas surrounded by smooth phase transitions.

This research, which takes place in the context of the Thalweg ARC, is currently engaged in order to provide further validation and accurate characterization of the different processes involved.

6.3. Edge-Preserving Smoothing of Very High-Resolution Satellite Images

Participants: Jacopo Grazzini, Antonio Turiel, Hussein Yahia, Isabelle Herlin.

Key words: *segmentation*, *edges*, *textures*, *multiscale*, *multifractal*, *very high-resolution*.

We introduce a novel approach to edge-preserving smoothing of high-resolution images as a preprocessing step for feature extraction and/or image segmentation. Due to the fact that very high-resolution images (acquired by the new generation of satellites, such as Ikonos or QuickBird) show great heterogeneity, classical approaches cannot produce satisfactory results: they may induce simultaneously under and over-segmentation within a single scene, depending on the heterogeneity of the considered objects, that confuse the global information and prevent further analysis. This problem can be related with the idea of resolution reduction: the retained technique should enable to preserve the features of the original image corresponding to the boundaries of the objects while homogeneizing the other parts of the image. The method we propose is derived from the multifractal formalism introduced for image compression. It is performed in 2 steps:

- First, meaningful subsets of the original image, which mainly consists in its boundaries, are extracted using a multifractal decomposition scheme.
- Second, an universal propagation kernel is used to partially reconstruct typical object shapes from the values of the gradient of the original image over the previous subset.

Such an approach is efficient, as it assumes that objects can be reconstructed from their boundary information. This strategy results in very nicely smoothed homogeneous areas while it preserves the main information contained in the boundaries of objects. Examples of results are depicted on figure 3.

Current research is geared toward image restoration. Namely, we propose a similar approach to restore noisy satellite images. The main problems regard the selection of the reconstructing manifold and the propagation technique, which should be modified to reduce the noise when reconstructing the image.

6.4. Clusterized multispectral segmentation in complex signals

Participant: Milan Jovovic.

Key words: *multi-scale*, *simulated annealing*, *segmentation*, *turbulence*.

We propose a method for image analysis, processing and coding, based on physical computation of signal distortion. We assess the scale invariance, in the method, by hierarchically clustering data. The model

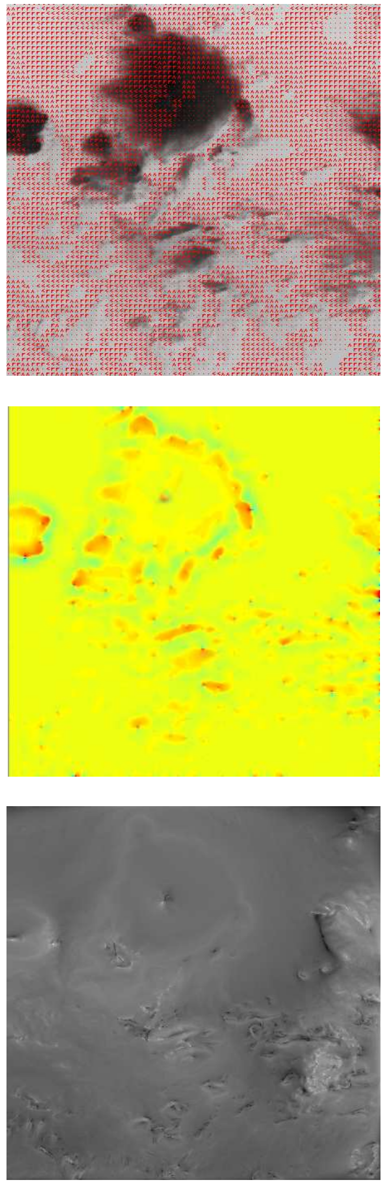


Figure 2. Comparison of dense velocity fields estimated with an Optical Flow based constraint and the sources on two cloudy systems extracted from the same sequence of infrared images. ***Left****: Representation of velocity fields; arrows indicate the intensity and the direction of the field.* ***Middle****: Divergence of the estimated velocity fields. The values of divergence stand from blue (low) to red (high).* ***Right****: Norm of the sources (*log*-representation).*

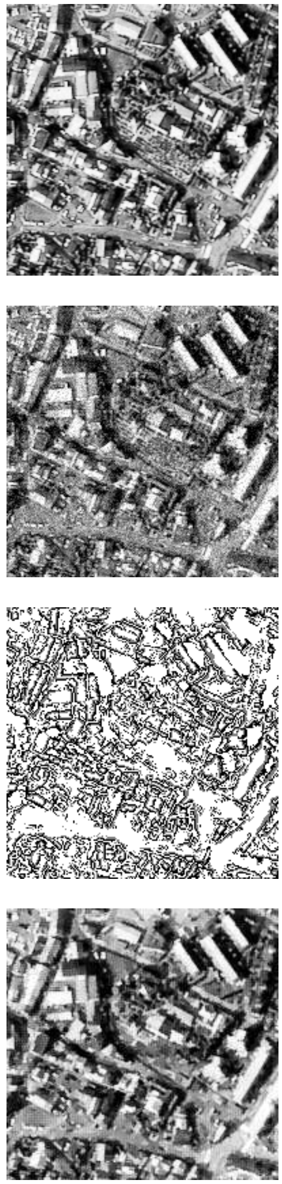


Figure 3. Segmentation of an ***Ikonos*** *high-resolution image.* ***From left to right****:* ***Ikonos*** *exercpt* ($2.5x2.5m$)*, noisy excerpt, set of pixels (black) used as a reconstructing manifold and reconstructed excerpt using this set.*

comes from information theory approach in statistical mechanics, and a partition function, that describes the probabilistic model of data clusters, is analyzed as a multifractal measure. We show that the propagation of information in image sequences is governed by the scale-space wave equation, therefore enabling us to treat singular frequencies of data clusters in an unified way, both in space and in time.

We define a cluster with its computed vector representative $\mathbf{y}$, and the selected cluster window of computation, W. Let $d(\mathbf{x}, \mathbf{y})$ denotes a distortion measure introduced to a data point $\mathbf{x}$ by the representation $\mathbf{y}$. The distortion energy, or variance V of a cluster is defined by:

$$V = \int_W d(\mathbf{x}, \mathbf{y}) P(\mathbf{x})$$

We consider the Gibbs distribution that maximizes the entropy:

$$P(\mathbf{x}) = \frac{e^{-\beta d(\mathbf{x},\mathbf{y})}}{Z} = \frac{e^{-\beta d(\mathbf{x},\mathbf{y})}}{\int_W e^{-\beta d(\mathbf{x},\mathbf{y})}}$$

where Z is the partition function, and β is a Lagrange multiplier. The nonlinear dynamics of clustering, in this work is derived from the model of "free energy", originally used in statistical physics to model different complex systems. The distortion measure is chosen to be the constraint equation on the motion vector $\overrightarrow{v}$, also known as the extended optical flow constraint equation:

$$d = z^2 = (I_t + \nabla I \overrightarrow{v} + I div(\overrightarrow{v}))^2,$$

which provides the mass conservation principle, as studied in the AIR2 team. The partition function induces a multifractal measure, giving a way of decomposing the signal into feature vector clusters ordered by the singularity exponents. For temporal aspects we propose an alternative scheme, by considering the splitted clusters with constrained equations of motion whith respective parts corresponding to "cooling" and "melting".

This work takes place in the context of the Thalweg ARC.

6.5. Div-curl approximation reproducing kernels and optical flow

Participants: Till Isambert, Jean-Paul Berroir, Isabelle Herlin, Hussein Yahia.

Key words: *Optical flow*, *fluid motion*, *turbulence*, *vector splines*.

This study is focused on the estimation of turbulent fluid motion field from image sequences, such as those provided by geostationary satellites. This work is a continuation of a previous study dealing with the establishment of appropriate conservation hypothesis, whereas we are interested here in the regularisation techniques for solving the aperture problem, adapted to the case of turbulent fluid motion.

The approach consists in applying second-order 'div-curl' regularisation, instead of the classical L_2 regularisation usually applied. This corresponds to the minimisation of the following cost function, depending upon the motion field v:

$$J(v) = \int |\nabla \text{div} v|^2 + |\nabla \text{curl} v|^2$$

We use this regularising term, in conjunction with an extended optical flow equation, based on the mass conservation hypothesis (adapted to fluid motion):

$$\frac{\partial I}{\partial t} + v.\nabla I + I \text{div} v = 0$$

Using the theory of reproducing kernels in Hilbert spaces, we generalise the work of Suter , and compute the exact solution in the space of spline vector fields. The computed solution is regular enough to simplify the introduction of a diffusion term in the optical flow formulation.

The obtained results are much better than those obtained using L_2 regularisation, especially in areas of strong turbulence, where the motion field can be divergent and have strong curl. A validation based on reanalyses of meteorological fields is planned.

6.6. Estimation of trajectories within fluid turbulent flow

Participants: Aymeric Pierre, Jean-Paul Berroir, Isabelle Herlin.

Key words: *Turbulent motion*, *tensor voting*, *motion segmentation*, *trajectory estimation*.

We are concerned here with the analysis of image sequences of a turbulent fluid. The applicative objective of the study is, given any initial location in the image sequence, to assess a beam of probable trajectories. This beam provides information on the most probable trajectories starting from the initial condition, and the uncertainty should be related to turbulent parameters, such as eddy diffusivity.

From the methodological point of view, the focus is on robust motion representation techniques, where the motion is locally approximated by an affine field. As motion estimation is essentially a local (in time) process, the difficulty when assessing trajectories is to obtain a motion representation consistent over the whole image sequence. The adopted methodology builds on four successive steps:

1. Cleaning of the initial motion field to discard mismatches: the motion field is analysed in two spaces, (x, y, u) and (x, y, v), where u and v are the two components of the motion vector: in these spaces, the motion field should correspond to smooth surfaces. Tensor voting techniques, developed by the IRIS lab of the University of Southern California , have been used to generate the surfaces, that correspond to the corrected motion field.
2. Local motion representation by an affine field, obtained as the tangent plane to the aforementioned surfaces. The saliency, provided by the tensor voting process, informs about the quality of this representation.
3. Segmentation of the motion field on the basis of the affine representation. This can be done independently in each sequence frame, or directly in the 2D+T space, but at the expense of a less accurate segmentation.
4. Integration of motion field during the image sequence, starting from an arbitrary initial point. Runge-Kutta integration techniques are used to integrate the locally affine motion. The beam of trajectories is obtained by perturbating the initial condition. It can be shown that the sensitivity of the trajectory to the initial condition is related to the divergence of the motion field.

The obtained trajectories are consistent with a visual interpretation of the image sequences, even in presence of highly turbulent motion. A numerical validation is planned in the near future within the framework of the ASSIMAGE project. The validation will be performed on oceanographic image sequences, by comparison with buoy trajectories.

6.7. Change detection on Noaa data

Participants: Christophe Couvreur, Salem Belhaj, Sonia Bouzidi, Jean-Paul Berroir, Isabelle Herlin.

Key words: *Change detection*, *land degradation*.

The objective of this work is to assess the potential of NOAA data for detection of land cover changes over large areas. The application concerns the monitoring of land degradation processes, such as erosion, deforestation or desertification.

This study has been undertaken from two different perspectives:

- Analysis of temporal profiles: assuming the availability of NOAA sequences (daily images) over several years on the site of interest, the approach consists in establishing a feature space where temporal signals are analysed. This feature space should be robust to atmospheric conditions and sensor noise, and should be small enough to allow for an easy comparison between two temporal profiles. The feature space, currently tested, captures the main features of a vegetative cycle: date of growth start, speed of growth, date and duration of maturation, date of senescence start, speed of senescence. Results show that the occurrence of a land cover change corresponds to a significant change of the temporal profile representation in this feature space.
- Analysis of key dates: the idea is to analyse NOAA data only at dates where major land cover patterns (e.g. natural vegetation, summer and winter agriculture, bare soil) exhibit very different spectral responses. A set of indices (vegetation indices, reflectances in each NOAA-AVHRR channel) at these dates are analysed for detecting land cover changes.

This study is currently under process, and preliminary results have been obtained on agricultural areas, for which the selected feature space representation is well adapted. The continuation of this study concerns the establishment of adapted feature spaces capturing all land cover patterns, and validation.

This study is undertaken in collaboration with CESBIO for agricultural areas, and EMBRAPA (Brazil) for the analysis of land degradation.

6.8. Characterisation of the temporal behavior of agricultural parcels on SPOT sequences

Participants: Baptiste Guldner, Jean-Paul Berroir, Isabelle Herlin.

Key words: *SPOT sequences*, *temporal profiles*, *agricultural practices*.

The objective of this study is to assess the potential of SPOT sequences for the analysis of the temporal behavior of agricultural parcels. Applications concern the comparison of agricultural practices on a given area, the detection of hydric stress for monitoring irrigation.

The data available for this study consist of a land cover/land use classification provided by CESBIO in the vicinity of the city of Toulouse, and monthly SPOT-3 and SPOT-4 images of the same site. The methodology relies on the following steps:

- Subdivision of the land use classification: the temporal profile of each individual pixel is compared to the mean profile of the parcel -provided by the classification- to which the pixel belongs. At the end of this process, parcels that exhibit different types of temporal profiles are subdivided, yielding smaller parcels with homogeneous temporal behaviour.
- Labelling of the parcels: each parcel is then given a label that tells about the type of temporal behaviour. At the end of this process, each parcels bears two different labels: the land use, given by the classification, and the type of temporal behaviour.

These two steps can be applied to the entire SPOT sequence, for cartography purposes (comparison of practices). Another alternative is to repeat these two steps iteratively whenever a new SPOT image is available, in this case the application is early detection of abnormal temporal behaviour, such as related to hydric stress.

This study is under process, and will be continued next year on the same site using a second year of SPOT-5 data.

This study is led in cooperation with CESBIO.

6.9. Comparison of CTMs within a data assimilation framework

Participants: German Torres, Bruno Sportisse, Jean-Paul Berroir, Isabelle Herlin.

Key words: *Data assimilation*, *comparison of CTMs*, *air quality*.

The objective of this study is twofold: firstly, to run two Chemistry-Transport Models (CTMs) on the same site (the Berlin-Brandeburg area), and with the same data for model comparison purposes. Secondly, to implement a Kalman data assimilation system that will be applied to both models in order to assimilate the pollution measurements provided by the Berlin monitoring network. On a longer term, it is planned to assimilate satellite-based total column of trace gases.

The two models under consideration are:

- REGOZON, developed by the SAS laboratory of Fraunhofer FIRST, Berlin. This Eulerian model is not a 3D model, since it only considers three vertical layers. REGOZON includes a built-in mesoscale meteorological model, that computes the local meteorological fields from synoptic fields, provided by the national weather office.
- POLAIR, developed by the CEREA team of ENPC, is a 3D Eulerian model. POLAIR is fully modular, and can be adapted to different chemical schemes, different spatial resolutions (e.g. regional or continental studies). The adjoint model of POLAIR is available, making it particularly adapted to variational data assimilation (4DVAR). POLAIR considers meteorological fields as an external input, thus it was required to run a mesoscale meteorological model (MM5) for the provision of meteorological fields.

This study is currently under process. Most of this year's work concern the adaptation of models' inputs for running with the same initial dataset, and the preparation of mesoscale meteorological fields from MM5. Preliminary results of model comparison have been obtained, and data assimilation experiments are starting.

This study is led in cooperation with the SAS laboratory of Fraunhofer FIRST, Berlin, and is supported by a French-German 'Procope' project.

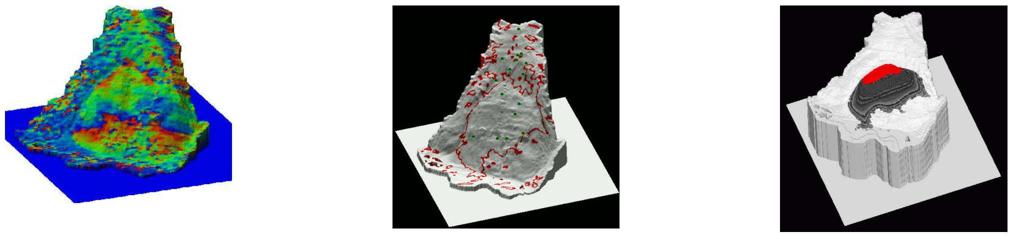
6.10. Landslide tracking with a curve evolution model driven by interferometric data

Participants: Etienne Huot, Hussein Yahia, Isabelle Herlin.

Key words: *Landslide*, *geodesic distance*, *curve propagation*, *interferometry*.

In this study we are interested in the problem of modelling the propagation of landslides in the context of environmental risk management. This work hinges on a global study of ground evolution using remote sensing data. According to different fields of research, several kinds of approaches can be found to solve the problem of tracking a 2D front on a 3D surface representing the elevation of the ground. We propose an approach based on the computation of a geodesic distance map weighted by SAR interferometric data. SAR interferograms are built using the phase difference of two backscattered radar signals. The phase difference is directly linked to the antenna-target distance. If the two acquisitions are separated by few days, it is possible to interpret a differential interferogram as a geometric modification map between the two acquisitions. We use SAR interferometry data to segment regions corresponding to an evolution of the ground along time and quantify the displacement field by using an *unwrapping* method. In previous studies we generalized the computation of a geodesic distance map incorporating constraints. We consider that constraints can be formulated by a variation of some "density", that captures the slope of the terrain (obtained from the DEM) and the displacement provided by the unwrapped interferogram. The density drives the speed of the front evolution.

Figure 4 represents a well known landslide in an alpine region: (a) corresponds to the differential interferogram mapped to the DEM; (b) is the segmented region taken to be the landslide (in red); (c) displays the evolution of an initial contour (upper red blob) driven by the evolution equation. It appears that the landslide



(a) (b) (c)

Figure 4. Landslide contours evolution.

evolves in time until it reaches the river downhill. This way, we are able to determine the instant when the landslide is expected to reach this critical point.

Future work concerns the assimilation of the information on front evolution within geophysical models. It will be performed within the context of the ASSIMAGE project.

This work is performed in collaboration with the EMA team of CETP (CNRS/University of Versailles Saint-Quentin).

8. Other Grants and Activities

8.1. National initiatives.

The AIR2 team is building collaborations at different levels: with image processing research teams, with specialists in different environmental application domains, with researchers specializing in databases or distributed information systems. The latter type of collaboration is directed towards the integration in environmental management systems.

About research in image processing and in parameter estimation, we cite:

- The A.R.C. THALWEG, coordinated by H. Yahia. Participating research teams are : the Laboratory of Meteorologial Dynamics of Ecole Polytechnique (LMD), the Laboratory of Physical Statistics (Complex Networks and Cognitive Systems group, ENS Paris), the ANED team of the Paris-13-Villetaneuse University.
- The CHPV laboratory (University Paris 6), coordinated by Dominique Béréziat.
- The ASSIMAGE project, just started, dealing with image data assimilation, in collaboration with two other INRIA teams (IDOPT and TEMICS), CEMAGREF and CNRS.

Important collaborations take place with the following laboratories:

- Laboratory of Meteorologial Dynamics of Ecole Polytechnique (LMD): temporal evolution of convective systems, microwave and infrared data fusion.
- Laboratory of Physical Statistics (Complex Networks and Cognitive Systems group, ENS Paris, team directed by J.P. Nadal): turbulence, statistical physics.
- CETP: data fusion, flows and front propagation.
- CESBIO: vegetation evolution.

About system integration, a fundamental contribution comes from the collaboration with MEDIENCE company.

8.2. European initiatives.

The study about the input data estimation for air quality models is mentionned in the framework of the ERCIM working group ”*Environmental Modelling*” in collaboration with SAS team of Fraunhofer-FIRST, Berlin.

The team has coordinated the redaction of one Network of Excellence, one STREP, submitted to the second IST FP6 call, and one Marie Curie RTN network, submitted to the second RTN call. These submissions were proposed under the supervision of ERCIM.

8.3. International initiatives.

Collaboration with the IRIS laboratory (University of Southern California). Dr. I. Cohen, former member of the AIR2 team, is now Research Professor at IRIS. A research action on change detection in satellite imagery is funded in the framework of an INRIA-NSF collaboration.

A research project, named ECOAIR, which was risen in the INRIA-CNPq collaboration, is established with different Rio de Janeiro universities, Brazil. The goal is to obtain information on soil erosion from satellite data, then create a specific information system adapted to the case of Pantanal area, Brazil.

A research project, aiming at building an information system for assessing desertification, was initiated with two tunisian laboratories, belonging to ENSI and LTSIRS.

A research project, named AIRPOL, which was risen in the INRIA/CONICYT collaboration (Chile), is established with the Santiago University and the CEREA laboratory (ENPC). This project aims at studying data assimilation methodologies (ground measures and satellite data) for inverse modelling of static sources of arsenic.

8.4. Visiting scientists

In the framework of a INRIA-STIC Tunisie project, Prof. Mohamed Ben Ahmed from ENSI and Prof. Naceur Saber from LTSIRS visited the AIR2 team.

Prof. Laura Gallardo, from CMM, Santiago, Chile, visited the AIR2 team in April, 2003, within the framework of the INRIA-CONYCIT “AIRPOL” project.

9. Dissemination

9.1. Leadership within scientific community.

The AIR2 team is running an ERCIM working group on the theme ”Environmental Modelling” (in collaboration with Fraunhofer-FIRST). Workshops take place on a regular basis twice a year.

Isabelle Herlin was member of the programme committee of the RFIA’2004 conference.

9.2. Conferences, meetings and tutorial organization.

In the framework of the A.R.C. THALWEG, a workshop on complex systems in image processing has been organized, and took place on 9th and 10th of December, at INRIA-ROCQUENCOURT. The workshop is organized by H. Yahia.

9.3. Teaching.

- Image processing: Paris-12 University, master of biomedical engineering, 8 hrs (Jean-Paul Berroir).
- Image processing: ISTM engineering school, 27 hrs (Jean-Paul Berroir).
- Operating systems and Unix: ISTM engineering school, 21 hrs (Jean-Paul Berroir).
- C/C++ programming: courses and tutorial class: ISTM engineering school, 35 hrs (Jacopo Grazzini).
- Statistical methods in shape recognition: ISTM engineering school, 18 hrs (Isabelle Herlin).
- Image processing: ISTM engineering school, 8 hrs (Isabelle Herlin).
- Algorithms and data structures: Leonard De Vinci University, 20 hrs (Isabelle Herlin).
- 2D Infography and Java: Leonard De Vinci University, 20 hrs (Hussein Yahia and Isabelle Herlin).
- OpenGL: ISTM engineering school, 36 hrs (Hussein Yahia).
- Man-Machine interfaces: Leonard De Vinci University, 20 hrs (Hussein Yahia).

9.4. Conference and workshop committees, invited conferences.

Besides the participation to conferences already mentioned in the reference list, staff of the AIR2 team participated to the following seminars:

- Jean-Paul Berroir, Isabelle Herlin: Characterisation of the temporal behavior of agricultural parcels. CESBIO, Toulouse, France, May 2003.
- Jean-Paul Berroir, Isabelle Herlin, Sonia Bouzidi: Use of high resolution and low resolution satellite data for land evolution assessment, ENSI, Tunisia, April 2003.
- Jean-Paul Berroir, Hussein Yahia, Bruno Sportisse, Isabelle Herlin: 10th ERCIM Environmental Modelling Group Workshop, Sophia-Antipolis, France, February 2003.
- Jean-Paul Berroir: Some results of physical image processing for meteorological applications. Weather Office, Santiago, Chile, July 2003.
- Jean-Paul Berroir: Assimilation of total ozone columns for estimating background concentrations. CMM, Santiago, Chile, July 2003.
- Isabelle Herlin, Jean-Paul Berroir: Detection of land cover changes on low resolution satellite data. Embrapa, Rio de Janeiro, Brasil, November 2003.
- Hussein Yahia: Entropy estimation and multiscale processing in meteorological satellite images. Application to the study of pluviometry in cloud structures. 11th ERCIM Environmental Modelling Group Workshop, Smolenice, Slovakia, October 2003.
- Germán Torres: A meteorological preprocessor for a chemistry transport model, and comparisons. 11th ERCIM Environmental Modelling Group Workshop, Smolenice, Slovakia, October 2003.
- Jacopo Grazzini: Study of the distribution of the entropy over the MSM for the detection of precipitation areas in meteorological infrared images. Thalweg Workshop, INRIA Rocquencourt, France, March 2003.
- Jacopo Grazzini: Multiscale tools for processing meteorological images: application to the detection of precipitation areas in infrared data. Institut de Ciències del Mar (ICM), Barcelona, Spain, October 2003.

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[11] A. TURIEL, C. PÉREZ-VICENTE. *Multifractal geometry in stock market time series.* in « Physica A », volume 322, 2003, pages 629–649.

[12] A. TURIEL. *Relevance of multifractal textures in static images.* in « Electronic Letters on Computer Vision and Image Analysis », number 1, volume 1, 2003, pages 35–49.

Publications in Conferences and Workshops

[13] S. BOUZIDI, S. BELHAJ, I. HERLIN, J.-P. BERROIR. *An approach for land cover change detection using low spatial resolution data.* in « IGARSS03 », 2003.

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