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INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team clime

Couplage de la données environnementale et des modèles de simulation numérique pour une intégration logicielle

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THEME NUM

Activity Report

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2. Overall Objectives

The international political and scientific context is indicating the serious potential risks related to environmental problems, and is also pointing out the role that can be played by models and observation systems for the evaluation and forecasting of these risks. At a scientific level, initiatives like the European GMES program (Global Monitoring of Environment and Security) will give a long term structure to environmental research by insisting notably on the importance of observational data and satellite measures exploitation.

A typical example is met in atmospheric pollution, which is gaining a widening importance, either at small (air quality), regional (transboundary pollution) or global scale (greenhouse effect). The complexity of the phenomena taken into consideration and the operational objectives necessitate a growing interweaving between physical models, data processing, simulation and database tools.

It seems fundamental to couple all available data, these data being either of numerical origin (e.g. models outputs), or coming from raw observation (e.g. satellite data or spatial grids of acquired data), or obtained by processing and analysis of the observations (e.g. chemical concentrations retrieved by inversion of a radiative transfer model).

The Clime team has been created for that purpose by joining researchers in data assimilation and modelling from the CEREA laboratory (ENPC, Ecole Nationale des Ponts et Chausées) and INRIA researchers in environmental data processing from the former Air project. The Clime team carries out research in three directions:

- Environmental data processing, notably satellite data, by means of computer vision techniques and by accounting for the physical information on the acquisition process and on the dynamics of the observed phenomena.
- Data and model coupling, by means of data assimilation techniques and related issues (optimality problems, targetting observation, uncertainties propagation, ...).
- Integrated chains of data/models/outputs (databases, visualisation).

3. Scientific Foundations

3.1. Environmental images and data processing

Keywords: *matching, motion, segmentation, tracking*.

Visual processing

The goal is to find visual description modes of phenomena observed on satellite data.

This research includes:

- motion models,
- temporal structures' tracking and fragmentation-like approaches (e.g. clouds),
- deformation and matching problems.

Image processing and physical models

The goal in this activity is to perform image processing for the estimation of physical parameters (e.g. atmospheric models parameters), taking into account the whole set of physical information describing the image formation process (in the case of atmospheric remote sensing: description of the atmosphere and radiative transfer). Practically, one gets rapidly confronted with inverse problems, most of them being ill-posed. A first important research direction lies in the definition of regularization constraints coming from spatial neighbourhood relationships, instead of tackling the inverse problem separately for each pixel. Another promising approach lies in the consideration, during the process of analyzing an image sequence, of the physical model governing the temporal evolution of the observed phenomenon. In this manner, one seeks to establish conservation constraints based on the Navier-Stokes equations for example, or on the advection-diffusion equation etc. Lastly, a third direction aims at evaluating quantitatively the quality of image processing results. That latter direction will be contemplated within the framework of data assimilation. To this end, data obtained by image processing will be assimilated within models, and the quality of the data assimilation results will serve as criterion for evaluation.

3.2. Data assimilation and inverse modelling

Keywords: *Data assimilation*, *inverse modelling*.

This activity is one of the present major stakes in environmental sciences. It matches up the setting and the use of assimilation data methods, notably variational methods (4D-var). An emerging point lies in uncertainties propagation in models, notably through ensemble prevision methods.

Although modeling is not part of the scientific objectives of the Clime team, we have access to models developed by CEREA: POLAIR (photochemical pollution forecasting at continental and regional scales) and MERCURE (urban scale).

The research activities tackle scientific issues such as:

- Among a family of models (differing by their physical approximations or their discretization parameters) what is the optimal model for a given set of observations ?
- Which observation network to set up if the goal is to make forecasting with a fixed model and a given margin of error (taking into account observation costs) ?
- What is the optimal location of sensors ? And if these sensors are mobile, how to operate their trajectories in function of the situation's evolution ?
- How to perform estimation of uncertainties propagation ?

3.3. Software chains for environmental applications

Keywords: *Visualisation*, *databases*.

Building on the scientific capabilities developed in the previous directions, the ambition of the Clime project lies in the participation to the design and realization of software chain tools for impact assessment and environmental crisis management. Such software chains put together static or dynamic databases, data assimilation systems, forecast models, processing methods for images and environmental data, complex visualization tools, scientific workflows...

A privileged partner on that subject, inside INRIA, is the SMIS project.

4. Application Domains

4.1. Panorama

The priority application domain is atmospheric chemistry, since this is the central research topic of CEREA. We have at our disposal (thanks to the CEREA) the 3D Eulerian chemistry transport model POLAIR3D and its adjoint, thus capable of data assimilation. Atmospheric data processing will thus aim at providing POLAIR3D with relevant input data.

A second application domain is oceanography (supported by the former Thalweg ARC and the ASSIMAGE ACI). The methodology is comparable: providing relevant information, extracted from satellite images, in view of data assimilation within oceanic circulation models.

Finally, the Clime team carries out applied studies for getting informed of the needs of environmental experts and to have access to various data (satellite, ground truth, ...). These studies mainly concern dynamics of land cover (cooperation with Brazil, starting cooperation with India, cooperation with CESBIO).

4.2. Atmospheric chemistry

Atmospheric pollution is gaining a widening importance either at small (air quality), regional (transboundary pollution) or global scale (greenhouse effect). Atmospheric pollution problems motivate important needs for decision tools based on models and computer softwares. From a scientific viewpoint, the complexity of the phenomena taken into consideration and the operational objectives necessitate a growing interweaving between physical models, data processing, simulation and database tools.

In this context, the Clime team is interested in different problems:

- inverse modelling of emissions (passive tracers, radionuclides, active tracers),

- sensitivity analysis and uncertainty propagation,
- data assimilation,
- numerical platform for Air Quality modelling.

4.3. Oceanography

This application domain is supported by the ASSIMAGE ACI involving the INRIA teams IDOPT, CLIME and VISTA, the CNRS laboratories LGGE and LEGI, and CEMAGREF. Research works in the continuation of the Thalweg ARC also support this application.

The main motivation is to extract from satellite images structured information that can be related to the state variables of oceanic circulation models, hence allowing for data assimilation. We are currently investigating the following:

- surface motion from Sea Surface Temperature and ocean color measurements, directly related to a state variable (current),
- trajectories obtained by tracking specific structures in satellite sequences, requiring the use of Lagrangian data assimilation techniques,
- turbulence characterization.

4.4. Dynamics of land cover

This application domain concerns applied studies, with the objectives of cooperation with environmental experts and access to data (satellite, ground truth, validation) for specific case studies. Currently the Clime team is involved in three applications:

- Soil degradation: this study is a continuation of the INRIA-CNPq project ECOAIR (with UERJ and EMBRAPA, Brazil). We are interested in using image sequences of AVHRR and MODIS sensors to assess the soil degradation (erosion) in the Pantanal area (Brazil).
- Coal fires monitoring: this corresponds to a starting cooperation with the Indian Institute of Technology, Roorkee and BRGM. The objective is to design a monitoring system for characterizing coal fires in the Jharia mining district (India) and their impact on the environment (evapotranspiration, biomass, CO2 release). We plan to submit an international proposal on this topic.
- Land cover changes and early classification: this study is led in cooperation with CESBIO. It aims at assessing the potential of SPOT sequences for the detection of land use changes in agricultural areas, and for obtaining a land use classification as early as possible with respect to the vegetation cycle.

5. New Results

5.1. Quasi interpolation methods for estimating optical flow

Keywords: *fluid motion, optical flow, quasi-approximation, radial basis functions, reproducing kernels, turbulence, vector splines.*

Participants: Jean-Paul Berroir, Christine Graffigne, Isabelle Herlin, Till Isambert.

Turbulent fluid motion estimation from satellite image sequences is a difficult problem, that deserves adapted mathematic modelling and numerical approaches. This work is a continuation of a previous study, where a vector spline approach was used to assess apparent motion by solving for different conservation equations (luminance conservation, that corresponds to a divergence free transport; mass conservation; advection-diffusion) and by raising the aperture problem using 2nd order div-curl regularisation. We now have at our disposal a toolbox for fluid motion estimation, where one can choose the conservation equation to solve, the observed motion indices (e.g. observation of full velocity in some image locations, or observation of the normal velocity in locations with specific spatio-temporal gradient information). The method then computes the exact solution (the velocity field exactly interpolates the observed motion indices) that obeys 2nd order div-curl regularity. This solution is a thin-plate spline, which coefficients are obtained by solving a linear system as large as the number of points where an observation of the motion index is available.

The major drawback of this approach is that the change of one observed point implies solving again the full system: as the reproducing kernel of thin-plate splines $K(r) = r^4 \log r$ has no compact support, the a single observation point influences the solution on the whole image domain. It is therefore impossible to formulate this motion estimation method in a multiscale framework, although this is highly desirable for turbulent motion, which exhibits multiscale patterns in both space and time dimensions.

Current works address quasi-interpolation methods for that purpose. These methods approach the exact thin-splate solution by using a finite difference implementation of the PDE defining the solution. The solution is becoming a weighted sum of observed motion vectors with bell-shaped weighting functions, that makes it possible to establish a multiscale framework. We are currently studying the extension of this method to the observation of the normal component of the velocity field, and the design of a multiscale framework able to capture the different spatial and temporal scales.

5.2. Estimation of motion information in oceanographic images in view of data assimilation

Keywords: *data assimilation, motion estimation, oceanography, tracking.*

Participants: Jean-Paul Berroir, Alexandre Chariot, Isabelle Herlin, Etienne Huot.

This study addresses the estimation and validation of motion information from oceanographic image sequences with the objective of assimilating these data within ocean circulation models. We have carried out a preliminary feasibility study with synthetic data.

We consider here ocean satellite data acquired by passive sensors, measuring Sea Surface Temperature (SST) at high spatial resolution (km data acquired by AVHRR or MODIS), or ocean color (e.g. chlorophyll concentration), which is correlated to phytoplankton concentration. In order to perform data assimilation, the first issue is the observation operator: how to relate satellite measurements to the state variables of the model. Concerning motion estimation, we have two possibilities: surface velocities, and trajectories. Surface velocities are state variables of the models and can be directly assimilated, with the restriction that only 2D velocities can be estimated from satellite images. Trajectories can be assimilated in a Lagrangian framework.

For the purpose of the study, we have used data generated by the OPA circulation models, provided by LODYC. These data are comparable to satellite measurements, since we access with similar spatial and temporal resolutions to surface temperature and ocean color. The main advantages of using this sequence are that the data are not affected by atmospheric effects, and that the modelled motion field w_M is available, thus providing a powerful validation framework.

We have first assessed the validity of conservation equations in the image domain for the estimation of velocities. The considered conservation equations were (i) luminance conservation -classically used in computer vision- (ii) mass conservation -that accounts for the fluid divergence- and (iii) advection-diffusion, that additionally accounts for the diffusion of a scalar quantity like temperature which is transported by the fluid. Considering the Boussinesq approximation of quasi incompressible water, we found that luminance conservation is best adapted for oceanography. In all cases we face the problem that the images only provides 2D information, and that the source and sink terms involved in ocean models are not available from the images. Some structures, the ejection filaments, do not obey the conservation at all, owing to a specific configuration of the motion field, in this case perpendicular to the image gradient. These structures must therefore be discarded prior to the motion estimation, this is performed using morphological segmentation techniques. Reciprocally, points best observing the conservation equation are found (after discarding filaments) in the vicinity of image contours, in locations with sufficient amount of image information.

We then studied the spatial regularity of the motion field, to show that the 2nd order div-curl regularity is better adapted, as compared to L_1 or L_2 regularity. We thus applied a vector spline approach, that computes a motion field with 2nd order div-curl regularity, and that exactly interpolates the normal component of velocity on the selected pixels that best match the conservation equation.

Finally, trajectories estimation was performed for specific structures (vortices) which circular shape is well adapted to a modelling by active contours. A tracking process is applied on the contour of the vortices, and the centre of the structure can then be tracked.

5.3. Change detection in agricultural areas from SPOT sequences

Keywords: *SPOT sequences, agricultural practices, change detection, temporal profiles.*

Participants: Michel Auger, Jean-Paul Berroir, Isabelle Herlin.

This study is the continuation of a study led in 2003, where bio-physical models were used to characterise the temporal evolution of vegetation indices of agricultural parcels as measured by monthly SPOT images. These models were fitted to the satellite measurements on parcels with homogeneous temporal behaviour, thus making it possible to extract meaningful parameters (growth and senescence period and intensity) which in turn are used for image classification. This was applied on data provided by CESBIO in a test area close to the city of Toulouse: a full sequence of SPOT data for 2002 as well as the corresponding classification for validation purposes.

The objective here is to evaluate the use of this methodology for change detection and early classification: the SPOT images of 2003 are analysed, with the objective of detecting as soon as possible the changes in agricultural land use, and of designing a sequential classification process, where each SPOT images is processed as soon as it is available and the classification iteratively refined.

This application requires addressing the following two issues:

- Detection of parcels with homogeneous temporal behavior, since a parcel bearing one single type of plant during a given year can be shared into different cultivations the next year. This was performed by applying unsupervised clustering algorithms on the pixel data.
- Fit of the bio-physical model on partial sequences, that end before the end of the vegetation cycle. Some model parameters can be assessed from the beginning (e.g. minimum vegetation index) whereas other require observation of the growth (growth period and intensity), detection of maturation, or of the senescence (senescence period and intensity). The parameters are refined when new SPOT data is available.

The application to change detection and early classification is then a supervised process: learning samples were extracted from 2002 data, yielding the prior parameters for each agricultural land use. Statistical pattern recognition techniques are then used to classify the partial observation of parameters in 2003.

Results are promising despites of the difficulties related to the specific climate undergone in 2003 in this area: very warm temperatures all over the year with exceptional heat in summer, that has caused many of the cultivations to die before harvesting. Yet, we achieve a good recognition of winter cultivations, and of summer cultivations during the growth period.

This study is led in cooperation with CESBIO.

5.4. Large scale classification and change detection using MODIS data

Keywords: *change detection*, *land degradation*, *land use classification*.

Participants: Jean-Paul Berroir, Isabelle Herlin, Milton Jonathan, Bruno Sportisse.

This study is carried out in the continuation of the ECOAIR project (INRIA-CNPq project in cooperation with UERJ and EMBRAPA, Brazil) and is supported by a European Commission's Alβan master scholarship.

The objective is to assess the potential of MODIS visible data for the classification of large areas in order to study changes of land use and land degradation on potentially very large areas. We used as test area the Taquari basin, Mato Grosso, Brazil, which was already used during the ECOAIR project and for which many validation data are available.

We have at our disposal a classification of the test area at Landsat-TM resolution, valid for July 2001, and a full year of MODIS data starting in August 2001. This corresponds to daily data at 250m resolution, but because of cloud coverage and of two important viewing angle, only app. 60 images are usable.

The first step of the study consists in assessing how many different land covers can be discriminated from MODIS data. A cross examination of unsupervised classification of MODIS images and of the provided Landsat classification shows that the temporal information can be used to distinguish between different agricultural practices, and that the main natural land covers (forests, savannah, pasture) can be detected. It is however not possible to discriminate on the basis of temporal information only between different subtypes, such as open and dense savannah.

This study also shows that some land degradation patterns such as deforestation can be detected, since they induce a significant decrease of the vegetation indices to reach that of pastures or even bare soil.

This study is currently going on, addressing the automation of MODIS classification and its use for change detection. We are currently investigating optimal spaces for temporal profiles representation, and plan to perform classification and change detection in this space.

5.5. Localization of precipitation areas in infrared Meteosat image sequences

Keywords: *complex systems*, *fractals*, *precipitation determination*, *remote sensing*, *statistical physics*, *thermodynamics*, *turbulence*, *wavelets*.

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

We develop and explore the model for analyzing complex turbulent data with the help of the MSM (Most Singular Manifold". This model has been presented and used for convection detection in Meteosat Infrared images. It is based on the determination in a complex turbulent signal of areas which permit a reconstruction of the whole signal. These areas form the MSM, which correspond to the most informative areas in a signal, and also to the places where the energy is injected/depleted in the signal. The entropy is also extremal on the MSM. This year, we study more deeply the entropy and show that it enhances the determination of precipitation areas in Meteosat infrared meteorological image sequences.

We suppose that the multiscale entropy, a quantity easily computed on a signal image, is related to the physical entropy, that latter quantity being an expression of the heat transfer inside a thermic system. The gradient of the multiscale entropy combines the internal changes of a system with heat transfers across the thermal fronts detected by the MSM.

We identify the gradient of the multiscale entropy with a complex number and define a complex measure on the image plane whose density is the gradient of the multiscale entropy.

Then, we determine a source field by computing the Radon-Nykodim derivative of the measure defined above by another measure corresponding to a reconstruction of the signal using a normalized gradient perpendicular to the MSM: one observation is that the multiscale entropy varies more in a direction orthogonal to the MSM.

Our experimental results show that we obtain a better separation between the convective and advective areas in a complex fluid flow when the multiscale entropy is used. The singularities (in phase and modulus) of the source field derived from the entropy are in very good correspondance with rainfall areas localized on our complimentary validation dataset. Moreover, that source field is moving in the sequence to match the temporal evolution of the rainfall areas.

The gradient of the entropy and the gradient of the chromatically reduced signal are oriented in opposite ways in convective (precipitation) areas. Using such a characterization, the detemination of precipitation areas on Meteosat infrared meteorological sequences is performed accurately.

The combined used of the entropy, the chromatically reduced image, and the Radon-Nykodim derivative a complex measure represent a new set of tools for studying convection and advection in turbulent image data. We represent, on figure 1 the result of the source field computation with the entropy, ans how it relies to precipitation determination.

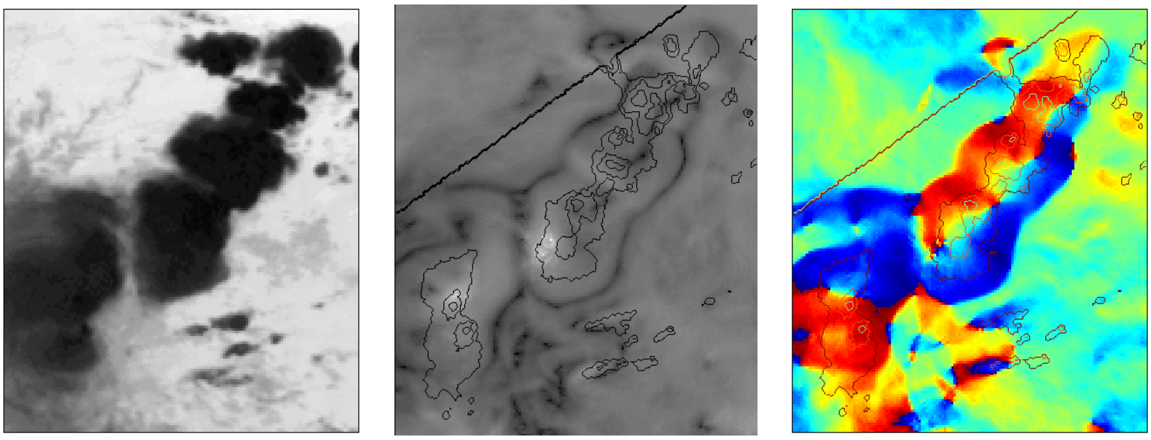

Figure 1. Source field computation on an image from a Meteosat ***IR*** *image sequence.* ***From left to right****:* ***IR****, norm and phase image source. Surimposed on the source images are temperature fronts coming from a validation dataset (micro-wave image). The norm and phase images (color) show how the source field is used to determine precipitation areas.*

This research took place in the context of the Thalweg ARC.

5.6. Turbulence in oceanographic data

Keywords: *complex systems, fractals, oceanography, turbulence.*

Participants: Antonio Turiel, Hussein Yahia.

We start a new research action dedicated to turbulent flows in oceanographic data. The model developped during the Thalweg ARC, which was applied on infrared meteorological image data, permitted the separation of convective and advective areas in the images.

Turbulent phenomena are always present in oceanographic data, and some of them are of particular importance in oceanography: for example seasonal phytoplankton blooms appear clear in color data. Moreover it is interesting to study the correlation between different kinds of image source, like ocean color and sea elevation.

First experiments show that the chromatically reduced image is an interesting starting point, as it is related to the study of the advective part in oceanographic fluid flows. Studying motion on oceanographic data with image processing techniques is not an easy task, because of the various artefacts that put some perturbation in the grey level values of the acquired data, henceforth complicating the application of models based on conservation hypothesis. The chromatically reduced image captures some information about the diffusion of temperature in oceanographic images of surface temperature. The discrepancies between the original signal and the chromatically reduced images give some information about the relative orientation of the temperature gradient w.r.t the temperature fronts. This information is important for the study of motion in oceanographic image sequences.

5.7. Surface reconstruction with amplitude SAR images

Keywords: *Hamilton-Jacobi equations*, *SAR (synthetic aperture radar) imagery*, *shape from shading*, *viscosity solutions*.

Participants: Hussein Yahia, Gowda Veerappa (on visiting Estime project).

Dr. G. Veerappa is on visiting Estime project in 2004. We worked on a surface reconstruction method using SAR imagery and shape from shading equation. The method consists in solving a shape from shading equation to restitute terrain elevation from SAR amplitude images. It consists in new numerical solution methods applied on a Hamilton-Jacobi partial differential equation. We tried the method on synthetic data, and also on natural images. The method give quite good results on synthetic data, and uses some hypothesis that may be perturbated in real acquisitions. We are working on enhancing the method in the case of natural images.

5.8. Mediation of environmental data

Keywords: *data and program wrappers*, *distributed systems*, *environmental management system*, *mediation sytem*, *relational database*.

Participants: Jean-Paul Berroir, Anne Marcadet, Jean-Pierre Matsumoto, Vincent Picavet, Hussein Yahia.

New developments are included in LeSelect: wrappers for geotiff and NOAHH-AVHRR image data have been written, and generic program wrappers allow an easier definition of programs that conform to an XML scheme for their input/output. LeSelect is a mediation system developped by the INRIA CARAVEL project (now SMIS) and MEDIENCE, used in the CLIME project for experimenting information technologies in advanced environmental management software. A NOAA-AVHRR processing chain has been included in LeSelect in the form of a Web application using the new developments.

5.9. Comparison of CTMs within a data assimilation framework

Keywords: *air quality*, *comparison of models*, *data assimilation*.

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

This is the continuation of a French-German project on the comparison of two Chemitry-Transport Models (CTMs) running on the same site (Berlin-Brandenburg area) for air quality forecast, and on implementation of sequential data assimilation procedures for these models, in order to assimilate data measured by the air quality monitoring network BLUME in Berlin.

The work of this year is mainly devoted to the implementation and testing of sequential data assimilation procedures adapted to regional air quality models. Two variants of Kalman data assimilation have been tested: rank reduced Kalman filtering, ensemble Kalman data assimilation. The latter has been selected because it explicitely handles the update of model error covariance matrices using Monte-Carlo methods.

This project, led in cooperation with the SAS laboratory of Fraunhofer FIRST, Berlin, is supported by a French-German 'Procope' project and wil be completed by the end of the year. The two considered CTMs (REGOZON, FhG and POLAIR3D, ENPC) can run in forecast mode over Berlin, and data assimilation is only considered for POLAIR3D. Data assimilation procedures have been implemented and tested on reference runs. The data assimilation experiments using actual BLUME data require a prior parallelisation of the ensemble Kalman filter, currently under progress.

5.10. Maximum entropy-based inverse modeling

Keywords: *atmospheric dispersion*, *grid resolution*, *inverse problems*, *maximum entropy*.

Participant: Marc Bocquet.

Over the past years, it turned out to be of considerable importance to trace back the source of chemical species dispersed through the atmosphere, with increasing precision in the source resolution. We have studied the high-resolution retrieval at continental scale of the source of an atmospheric passive tracer, given a set of concentration measurements. We have developed theoretical grounds for the reconstruction. Our approach is based on *the principle of maximum entropy on the mean*. It offers a general framework in which the information input prior to the inversion is used in a flexible and controlled way. The inversion is shown to be equivalent to the minimization of an optimal cost function, expressed in the dual space of observations. Examples of such cost functions are given for different priors of interest to the retrieval of an atmospheric tracer. In this respect, variational assimilation (4D-Var), as well as projection techniques, are obtained as off-springs of the method. Also this framework has been enlarged to incorporate noisy data in the inversion scheme.

Then, the method was tested on several examples, using the meteorological conditions of the European Joint Research Centre ETEX-I campaign. The retrieval of a temporal profile of emission from a source whose location is known has been studied before validating the method on a full reconstruction of the source (space-time profile).

Often, the retrieved source exhibits a very strong and unrealistic (therefore unwanted) influence by the observation sites. This problem was shown not to be an intrinsic flaw of the reconstruction methods, but is rather due to the specifics of the atmospheric dispersion of a tracer. It is more and more pronounced as the grid resolution for the source is improved and we show how this translates mathematically. The dependence of the reconstruction on the grid resolution is investigated both analytically and numerically, as well as the connection with the issue of the receptors influence. A generalization of the formalism is proposed to study the performance of reconstructions when observation errors are present.

5.11. Sensitivity analysis of mercury over Europe

Keywords: *inverse problems*, *mercury dispersion*, *sensitivity*.

Participants: Marc Bocquet, Yelva Roustan.

In this work, we have investigated the use of adjoint techniques on the dispersion of a heavy metal (namely mercury) over Europe. The first goal of this study was to calculate in full detail the sensitivity of concentration of elemental mercury measured at a particular station on the natural emission, anthropogenic emission, re-emission, incoming fluxes from boundaries, initial conditions, etc.

Since we have used an air-limited model (a priori a global or hemispherical model may have looked more appropriate for elemental mercury because of its long residence time), we also focussed (second objective) on qualifying this box-model for mercury studies as an open system.

Eventually, we have shown how the adjoint calculus developed could be applied to inverse modeling to improve the boundary conditions, using real measurements of mercury.

5.12. Retroplume methods

Keywords: *inverse modeling*, *passive tracers*, *retroplume methods*.

Participant: Jean-Pierre Issartel.

The year 2004 has been devoted to the development and publication of an original method for the identification of the widespread sources of tracers with a linear dispersion behaviour. The method emphasises the necessary smoothness of a reconstruction based on a limited number of pieces of information. The inversion is based on the use of adjoint concentrations but it goes through a geometric transformation of atmospheric and temporal domain under investigation. The inversion artefacts usually geopardising the inversions are much reduced. The method has been developped in the frame of the experiment ETEX1, thus leading to a publication in ACP. Discussions now under revision for ACP, and to two communications for the General Assembly of the EGU, Nice, April, and European Meteorological Society, Nice, september. The method has been proposed for a collaboration with the Centro de Modelamiento Matematico, Santiago, Chili. It was successfully validated by considerably improving the the retrieval of the copper smelters around Santiago from urban measurements of arsenic concentration. This collaborative work has been presented for the Atelier de Modelisation Atmospherique organised by Meteo-France, Toulouse, November, with a preliminary publication in the proceedings.

5.13. Inverse modeling of radionuclides

Keywords: *inverse modeling*, *radionuclides dispersion*.

Participants: Monika Krysta, Marc Bocquet, Bruno Sportisse.

We have built a variational inverse modeling tool coupled to the Gaussian puff model developed by IRSN (Institut de Radioprotection et de Sûreté Nucléaire). The tool has been tested on synthetic observations and successfully applied to the wind-tunnel measurements taken by École Centrale de Lyon. It simulate a local dispersion event around the Bugey nuclear power plant.

The program is a working version of a future operational system to be used in case of a nuclear accident. Hence, in the first place, we have focused our attention on source emission rate which has the strongest influence on the consequences of an accident. We have shown that inverse modeling results come very closely to the true values, provided that an appropriate observation network has been constructed and that Gaussian puff model is a good description of the wind-tunnel measurements. If however, measurements are shifted with respect to model outputs, one is forced to optimise the parameters that might be responsible for such a shift. Consequently, we have addressed ourselves to the problem of disagreement between measured and calculated concentration profiles and we have pointed out wind velocity as the crucial additional parameter to be optimised in these circumstances. Noticeable improvement on the profiles has resulted from optimisation of wind velocity along with source emission rate. Even further improvement has been achieved in case of extending optimisation process to parameters which appear in the Doury model of mean concentration standard deviations.

5.14. Uncertainty propagation

Keywords: *DEMM/SRSM*, *Monte Carlo*.

Participants: Jaouad Boutahar, Bruno Sportisse.

Chemistry-Transport Models (CTM) use several data and parameters which are some times known with a strong uncertainty (e.g. emissions, meteorological data,...). To neglect this uncertainty may affect the quality of these models and lead to poorly calibrated models. The importance of these parameters and their effect on the output model can be determined by sensitivity analysis or by uncertainty propagation study. The objective of uncertainty propagation is to quantify the uncertainty of the output model by taking into account the uncertainty of input parameters by the construction of probability density function (pdf) of the outputs from inputs pdf. Monte Carlo is one of the most largely method used, but for complex applications with complex 3D CTM, this method become very prohibitive due to the large number of simulations.

We have used a new approach of uncertainty propagation based on an efficient and reduced use of Monte Carlo method: DEMM (Deterministic Are equivalent Modeling Method) and Stochastic Response Surface

Method (SRSM). DEMM/SRSM is characterized by the representation of the probabilistic response of the uncertain model output as an expansion of orthogonal polynomials according to model inputs uncertainties. This method provides a reduced model based only on polynomial computing, then the classical Monte Carlo simulations can easily be used to compute the probability density function of the uncertain output. We have applied this method to POLAIR3D model with uncertainties on emissions over Europe, the comparison to the classical Monte Carlo has given good results and an important speed-up.

5.15. 4D-var inverse modeling of emissions for Chemistry- Transport Models

Keywords: *4D-var methods, inverse modeling of emissions*.

Participants: Vivien Mallet, Denis Quélo, Bruno Sportisse.

One of the major source of error for chemistry-transport models is the uncertainty of emissions. This uncertainty roughly ranges from 30depending on the polluants. Knowing that (1) chemistry-transport models are strongly sensitive to those emissions, and that (2) it is sometimes useful to accurately estimate the emission rates themselves (e.g. to assess the emission volume of a given country), retrieving the emission rates thanks to dedicated methods may be of high interest. A relevant technique to lead such studies is the four-dimensional variational analysis (4D-var). The 4D-var data assimilation enables to take into account measurements of pollutant concentrations to improve the emission rates.

This method has been applied with Polair3D at regional scale, over Lille (France), and is being applied at European scale. In practice, we start from satisfactory simulations using the complete system Polyphemus to ensure their reliability. We then assimilate measurements from the dedicated observation networks, e.g. observations from the EMEP network over Europe. The use of automatic differentiation makes the adjoint code (required by the 4D-var method) easily available. A key point is the choice of the parameters to be optimized (temporal evolution of emissions, spatial distribution, speciation, etc.).

As for the Lille experiment, the uncertainty was assumed to be on the temporal evolution of emissions and the sensitivity of output concentrations with respect to NOx emissions was found to be higher than the sensitivity with respect to other species. The temporal evolution of NOx emissions was therefore optimized over five days. Further experiments are currently in preparation at European scale. Detailed sensitivity analyses are led to choose the right parameters and the code for the experiments has been written.

5.16. Numerical Platform for Air Quality modeling

Keywords: *air pollution modeling, numerical platform, software*.

Participants: Vivien Mallet, Vincent Picavet, Denis Quélo, Bruno Sportisse.

Building a complete and reliable system is obviously a necessary step in order to study multiple and complex phenomena such as photochemistry or aerosols. The whole system must be well engineered to deal with the large amount of data involved, the miscellaneous physical parameterizations and the diversity of the applications. The reliability is ensured by up-to-date chemical mechanisms, numerical schemes, physical parameterizations and data.

The system was split into four parts: (1) the raw data, (2) libraries to manage the data and to implement physical parameterizations, (3) programs to call the libraries to pre-process the data, and (4) the chemistry-transport model to compute the output concentrations. The chemistry-tranport model Polair3D was suitable for part 4 but it has been improved, notably thanks to the inclusion of aerosol modules. The libraries (part 2) and the programs (part 3) have been developped and are now able to manage many simulations, e.g. daily forecasts based on MM5 input-files.

The whole system is called Polyphemus and mainly gathers AtmoData (C++ library for physical parameterizations – part 2), miscellaneous programs to pre-process the data (part 3) and the chemistry-transport model Polair3D (part 4). The system will grow to include post-treatment, data assimilation and other applications (e.g., Monte Carlo simulations).

A dedicated website promotes Polyphemus (http://www.enpc.fr/cerea/polyphemus/). The design of the next generation of the system has been proposed to the community. It should allow the teams of the community to share their work and to include, in a common structure, their own chemistry-transport models.

6. Other Grants and Activities

6.1. National initiatives.

- The ASSIMAGE project, dealing with image data assimilation, in collaboration with two other INRIA teams (IDOPT and VISTA), CEMAGREF and CNRS.

We have academic collaborations with the following laboratories:

- Medical Imaging team from ANP (Parallelism and Numerical Algorithmic) of the computer science laboratory of the University of Paris 6 (LIP6).
  The CHPV laboratory (University Paris 6), coordinated by Dominique Béréziat.
- Laboratory of Meteorological 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.

6.2. 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 Clime team has coordinated the redaction of a Marie Curie Research and Training Network, COFARE, on data and model coupling for environmental risk assessment. This submission was proposed under the supervision of ERCIM.

6.3. International initiatives.

Collaboration with the IRIS laboratory (University of Southern California). A research action on change detection in satellite imagery is funded in the framework of an INRIA-NSF collaboration.

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.

A cooperation has started with the Indian Institute of Technology, Roorkee, on coal fire monitoring. We plan to submit soon an international project on that topic.

A research project with Frauhofer, Berlin, was finded under the Procope programme as the comparaison of CTMS and data assimilation of monotoring dat within CTMS.

6.4. Visiting scientists

- Milton Jonathan - UERJ Brazil - from 09/06 to 02/28/05
- Gennady Korotaev - MHI Ukrain - from 10/27 to 11/6/04
- Francisca Munoz - University of Chile - from 12/02 to 12/09/04
- Dharmendra Singh - Institute of Technolgy, Roorkee, Inde - from 12/05 to 1/04/05
- Steffen Unger - Frauhofer-First - from 12/06 to 12/10/04

7. Dissemination

7.1. Leadership within scientific community.

- Isabelle Herlin is member of the commission of specialists for University Paris 12.

7.2. Conferences, meetings and tutorial organization.

- Organization in collaboration with IDOPT of ASSIMAGE kickoff meeting, January, 19th, Paris-La-Défense.
- Organization in collaboration with second ASSIMAGE meeting, June, 4th, Grenoble.

7.3. 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, Isabelle Herlin and Etienne Huot).
- C/C++ programming: courses and tutorial class: ISTM engineering school, 35 hrs (Jean-Paul Berroir and Till Isambert).
- Multimedia indexation: ISTM engineering school, 18 hrs (Isabelle Herlin).
- Algorithms: 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).

7.4. Conference and workshop committees, invited conferences.

- Isabelle Herlin: reviewer of the ICIP2004 conference, October, 24-27th, Singapore, and of ICASSP 2005 conference.

8. Bibliography

Major publications by the team in recent years

[1] J. BOUTAHAR, S. LACOUR, V. MALLET, D. QUÉLO, Y. ROUSTAN, B. SPORTISSE. *Development and validation of a fully modular platform for numerical modelling of air pollution: POLAIR*, in "International Journal of Environmental Pollution", vol. 22, n° 1-2, 2004.

[2] S. BOUZIDI, F. LAHOCHE, I. HERLIN, H. STAUDENRAUSCH, V. HOCHSCHILD. *The development of an innovative computer-based Integrated Water Resources Management System for water resources analyses*, in "Systems Analysis Modelling Simulation", 2000.

[3] E. DEBRY, B. SPORTISSE, B. JOURDAIN. *A stochastic approach for the numerical simulation of the general dynamics equation for aerosols*, in "J.Comp.Phys.", vol. 184, 2003, p. 649-689.

[4] J. GRAZZINI, A. TURIEL, H. YAHIA, I. HERLIN. *Edge-preserving smoothing of high-resolution images with a partial multifractal reconstruction scheme*, in "Int. Society for Photogrammetry and Remote Sensing, ISPRS'04, Istambul", July 2004.

[5] I. HERLIN, J.-P. BERROIR, T. DE SMIT. *Use of image regularity constraints for inverse modelling of solar irradiation*, in "International Geoscience and Remote Sensing Symposium IGARSS03, Toulouse, France", July 2003.

[6] I. HERLIN. *Spatial Environmental Data*, in "Encyclopedia of Life Support Systems, Eolss, Oxford", 2002.

[7] I. HERLIN, F. X. LE DIMET, E. HUOT, J. P. BERROIR. *Coupling models and data: which possibilities for remotely-sensed images?*, P. PRASTACOS, J. MURILLO, J. L. DÍAZ DE LEÓN, U. CORTÉS (editors)., chap. e-Environement: progress and challenges, Instituto Politécnico Nacional, México, 2004, p. 365–383.

[8] E. HUOT, H. YAHIA, I. COHEN, I. HERLIN. *Matching Structures by Computing Minimal Paths on a Manifold*, in "Special Issue on Partial Differential Equations in Image Processing, Computer Vision and Computer Graphics, Journal of Visual Communication and Image Representation", vol. 13, n° 1/2, March 2002, p. 302-312.

[9] J.-P. ISSARTEL. *Rebuilding sources of linear tracers after atmospheric concentration measurements*, in "Atmospheric Chemistry and Physics", vol. 3, 2003, p. 2111-2125.

[10] M. MEIRELLES, G. COSTA, D. SINGH, J.-P. BERROIR, I. HERLIN, E. SILVA, H. COUTINHO. *A methodology to support the analysis of environmental degradation using NOAA AVHRR data*, in "Int. Society for Photogrammetry and Remote Sensing, ISPRS'04, Istambul", July 2004.

[11] D. QUÉLO, B. SPORTISSE, J.-P. BERROIR, I. CHARPENTIER. *Some remarks concerning inverse modeling and data assimilation for slow-fast atmospheric chemical kinetics*, in "IMA Volume in Mathematics and its applications, APMS 2001", B. SPORTISSE (editor)., Springer, 2002, p. 499-513.

[12] B. SPORTISSE, D. QUÉLO. *Data assimilation and inverse modeling of atmospheric chemistry*, in "Proc. of Indian National Science Academy. Part A Physical Sciences", vol. 69, November 2003.

Articles in referred journals and book chapters

[13] M. BOCQUET. *Grid resolution dependence in the reconstruction of an atmospheric tracer source*, in "Nonlinear Process in Geophysics", Submitted, 2004.

[14] M. BOCQUET. *Reconstruction of an atmospheric tracer source using the principle of maximum entropy II : Applications*, in "Q.J.R. Meteorol. Soc.", Submitted, 2004.

[15] M. BOCQUET. *Reconstruction of an atmospheric tracer source using the principle of maximum entropy I : Theories*, in "Q.J.R. Meteorol. Soc.", Submitted, 2004.

[16] J. BOUTAHAR, S. LACOUR, V. MALLET, D. QUÉLO, Y. ROUSTAN, B. SPORTISSE. *Development and validation of a fully modular platform for numerical modelling of air pollution: POLAIR*, in "International Journal of Environmental Pollution", vol. 22, n° 1-2, 2004.

[17] J. GRAZZINI, A. TURIEL, H. YAHIA, I. HERLIN. *A multifractal approach for extracting relevant textural areas in satellite meteorological images*, in "Environmental Modeling and Software", 2004.

[18] I. HERLIN, F. X. LE DIMET, E. HUOT, J. P. BERROIR. *Coupling models and data: which possibilities for remotely-sensed images?*, P. PRASTACOS, J. MURILLO, J. L. DÍAZ DE LEÓN, U. CORTÉS (editors)., chap. e-Environement: progress and challenges, Instituto Politécnico Nacional, México, 2004, p. 365–383.

[19] J. ISSARTEL. *Emergence of a linear tracer source from air concentration measurements.*, in "Atmos.Chem.Phys.Disc.", vol. 4, n° 3, 2004, p. 2615-2670.

[20] J.-P. ISSARTEL. *Emergence of a linear tracer source from air concentration*, in "Atmospheric Chemistry and Physics Discussions", 2004.

[21] V. MALLET, B. SPORTISSE. *3-D chemistry-transport model Polair: numerical issues, validation and automatic-differentiation strategy*, in "Atmos. Chem. Phys. Disc.", 2004.

[22] D. SINGH, I. HERLIN, J.-P. BERROIR, E. SILVA, M. SIMOES MEIRELLES. *An approach to correlate NDVI with soil colour for erosion process using NOAA/AVHRR data*, in "Advances in Space Research", vol. 33, n° 3, 2004, p. 328-332.

Publications in Conferences and Workshops

[23] J. GRAZZINI, A. TURIEL, H. YAHIA, I. HERLIN. *Edge-preserving smoothing of high-resolution images with a partial multifractal reconstruction scheme*, in "Int. Society for Photogrammetry and Remote Sensing, ISPRS'04, Istambul", July 2004.

[24] M. KRYSTA, M. BOCQUET, J. ISSARTEL, B. SPORTISSE. *Data assimilation of radionuclides at short and regional scales.*, in "Proceedings of the Workshop on Environmental security", Kluiwer, NATO, 2004.

[25] M. MEIRELLES, G. COSTA, D. SINGH, J.-P. BERROIR, I. HERLIN, E. SILVA, H. COUTINHO. *A methodology to support the analysis of environmental degradation using NOAA AVHRR data*, in "Int. Society for Photogrammetry and Remote Sensing, ISPRS'04, Istambul", July 2004.

[26] A. TURIEL, J. GRAZZINI, H. YAHIA. *Approches multiéchelles pour l'extraction d'ensembles significatifs dans les images*, in "14ème Congrès Francophone AFRIF-AFIA de Reconnaissance des Formes et Intelligence Artificielle, RFIA'04, Toulouse, France", 28-30 Janvier 2004.

Miscellaneous

[27] M. AUGER. *Détection de changement du couvert végétal sur une séquence d'images satellitaires à haute résolution*, Technical report, Université Paris 6, 2004.

[28] A. CHARIOT. *Détection et suivi de fronts de température observés sur images satellites mesurant la température de surface de l'océan*, Rapport de stage ingénieur I4, ESIEE, 2004.

[29] A. MARCADET. *Publication de données et de programmes dans un environnement distribué sur le Web*, IUP-Génie Mathématique et Informatique, Université Paris-Dauphine, 2004.