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CEREA

Atmospheric Environment Center

Université Paris-Est

Laboratoire commun
- **École des Ponts ParisTech**
- **EDF R&D**

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3 technical staff
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Message from the director

The Atmospheric Environment Center (CEREA) was established in 2004 as a joint laboratory between École des Ponts ParisTech and the Research & Development Branch of the French Energy Group (EDF R&D). It also hosts a joint effort with the French National Computer Science Institute (INRIA, Institut National de Recherche en Informatique et en Automatique) since December 2005, the CLIME project-team.

CEREA has three locations in the Paris region (École des Ponts ParisTech at Champs-sur-Marne, EDF R&D at Chatou, and INRIA at Rocquencourt). The main research activities at CEREA focus on air quality and atmospheric dispersion modelling from short-range to long-range scales. Some research activities are also dedicated to studying the atmospheric boundary layer (for example, for applications related to wind power estimates and fog formation).

A particular emphasis is given to the assessment of the environmental impacts due to the transportation and energy production (both thermal and nuclear) sectors. These activities are related to the programs of EDF R&D and to the activities of the research and technical centers of the Ministry of Ecology, Energy, Sustainable Development and Regional Planning (MEEDDAT). Long-term relationships have also been developed with the French Agency for Nuclear Safety (IRSN, Institut de Radioprotection et de Sûreté Nucléaire) for impact studies related to radioactive releases and with the French Agency for the Industrial Environment and Risk Analysis (INERIS, Institut National de l'Environnement Industriel et des Risques) for air quality impact studies and forecasting.

Research activities are organized according to four major areas:
- Observation of the atmospheric boundary layer
- Atmospheric fluid mechanics and short-range dispersion
- Air quality modelling at regional and continental scales;
- CLIME Project-Team devoted mostly to data assimilation and inverse modelling.

Meteorological measurements are conducted to better understand the physical processes that govern the atmospheric flow, air pollutant dispersion and fog formation near the ground.
For modelling atmospheric processes, CEREA uses primarily two numerical models: an atmospheric Computational Fluid Dynamics (CFD) tool, Mercure_Saturne, for short-range applications (urban pollution, wind power estimates, fog formation), and an air quality modelling system, Polyphemus. Both models have been developed at CEREA and are open source. Polyphemus includes different models ranging from short-range dispersion (Gaussian plume and puff models) to long-range dispersion at regional and continental scales (for example, the Chemistry-Transport Model Polair3D).

These models are evaluated by comparison to available measurements (included those collected by CEREA) and used for impact studies or air quality forecasting. The research activities devoted to data assimilation (using measurements to improve model performance) aim at improving the ability of models to make reliable forecasts and identifying emission sources via inverse modelling.

Christian SEIGNEUR
Director of CEREA

QUALITATIVE RESULTS

Key facts in 2008

In 2008, one textbook on air pollution was published, 18 papers were published and 6 papers are in press in international peer-reviewed journals, and 3 Ph.D. theses were completed.

Real-world applications were conducted with the CEREA models to assess environmental impacts of planned roadway extensions and existing or new industrial sites. The atmospheric CFD model has been used to estimate wind and turbulence fields at a future wind power site.

The partnership with the observational group at SIRTA (Site Instrumental de Recherche par Télédétection Atmosphérique) has been renewed for four years. Some current activities include model evaluation for heat exchange, wind and turbulence, as well as data analysis of the Paris-Fog field campaign (which was conducted in collaboration with Météo-France).

Two new versions of the Polyphemus system have been released, and a training session, which included attendees from various transportation, energy and environmental agencies, was organized. Polyphemus was applied operationally for air quality forecasting during the Beijing Olympics and it is currently used for operational forecasts by the Chilean meteorological agency. It was also used for operational air quality forecasting in France.

Joint projects with IRSN have led to various practical applications including the development of new modelling tools for radionuclide dispersion in the atmosphere and the optimal design of monitoring network to detect radionuclides in case of accidental releases.

Teaching

CEREA staff participates in teaching activities at ParisTech, Université Paris-Est as well is at other schools and universities throughout France. The classes taught include air pollution, fluid mechanics, data assimilation and inverse modelling.

International Collaborations

CEREA fosters visits of foreign colleagues to receive training and collaborate on developing and applying its models.

CEREA has developed a long-term relationship (2003) with the CMM (Center for Mathematical Modelling) of Santiago de Chile, with topics devoted to air pollution modelling and inverse modelling of emissions. This work is supported by CONYCIT/INRIA and ECOSUD.

A new project for Southern America (AirPol) is also funded by STIC/AMSUD (Air Pollution Forecast and Data Assimilation with Polyphemus, 2006). Scientists from Argentina and Chile visited CEREA this past summer. The Polyphemus air quality system is now used operationally for ozone air quality forecasts in Chile.

CEREA participates in the European Integrated Projects HEIMTSA and EXIOPOL dedicated to impact studies and cost-benefit analysis of air pollution externalities. These projects provide the opportunity for collaborative efforts with IER Stuttgart around Polyphemus. This has been illustrated by the residency of Yelva Roustan at IER Stuttgart in spring and summer 2008.

CEREA has a joint project with the AGH University of Science and Technology (Krakow, Poland), funded by EDF Polska. The objective is to simulate with Polyphemus the air quality in Poland, and to assess the impact of the emissions of EDF Polska. As a result, several Polish students work at CEREA. For example, Janusz Zysk is conducting his Ph.D. thesis on air quality modelling in Poland (half time in Poland, half time at CEREA) and Justyna Rozmus completed an internship at CEREA in fall 2008.

A project with the Chinese Academy of Sciences (Institute of Applied Physics, Nansen-Zhu Research Center) was conducted. The numerical simulation of air quality was performed over Beijing for the Olympic Games with Polyphemus being one of the 8 models used by the Chinese team.

A collaboration was initiated with Dr. Talerko of the National Academy of Ukraine. The objective is to use measurements of wet deposition of radionuclides obtained after the 1986 Tchernobyl accident to estimate the emission of radioactive material released via inverse modelling.

CEREA is involved in the experimental part of the European project SAFEWIND, which addresses wind energy forecasting with emphasis on extreme weather conditions.

CEREA is also involved in the European project WAUDIT (ITN Marie Curie) whose objective is the generation of a pool of researchers in the field of wind resource assessment.

RESEARCH TOPICS

The following project examples are presented according to the four main research areas.

1. Meteorological Measurements of the Atmospheric Boundary Layer
Leader: Éric Dupont

2. Atmospheric Fluid Dynamics and Local Scale Dispersion
Leader: Bertrand Carissimo

3. Chemical Transport Modelling of Air Quality
Leader: Karine Sartelet

4. CLIME Project-Team
Leader: Isabelle Herlin

1. Meteorological Measurements of the Atmospheric Boundary Layer

(Research area leader: Éric Dupont)

1.1 Measurements at SIRTA

A formal agreement was signed between École des Ponts ParisTech and the other organizations involved at SIRTA (a permanent experimental site located at Palaiseau, about 20 miles southwest of Paris). The other organizations are coordinated by Institute Pierre-Simon Laplace (IPSL). This contract covers the period 2008-2011. The major part of the meteorological instruments of CEREA (UHF radar, sodars, sonic anemometers, radiative measurements) has been installed at SIRTA. SIRTA combines many *in-situ* and remote sensing instruments (lidars and radars) of several laboratories and is included in international networks of experimental sites devoted to research on aerosols and clouds. Up to 2008, two areas of the site had been instrumented by CEREA. In 2009, a third one located near buildings will be instrumented with sensors for temperature, humidity, radiative budget, and turbulence. One objective of this new instrumented location is to study the effect of wall surfaces on atmospheric physical parameters.

The SIRTA instruments provide both routine measurements and intensive data sets, which are later used to evaluate atmospheric models such as the Mercure_Saturne CFD model of CEREA (see examples below). To that end, it is of course essential that a good quality of the database be obtained via a careful follow-up of the instruments, a regular control of the data acquisition and a verification of data consistency.

1.2 Campaign for Wind Energy Resource Assessment in Complex Terrain

Wind energy resource is generally estimated with linearized models of the atmospheric flow. However, the limitations of this kind of models in complex terrain are well known, and CFD codes are more and more considered as valuable tools for sites characterized by complex orography and/or forest. However, it is essential to evaluate the accuracy of such models before they can be applied reliably and, to that end, meteorological data must be collected at typical wind energy production sites. A one year campaign of wind and turbulence measurements was performed at a future wind energy production site between June 2007 and June 2008. The selected site is located in southern France and is characterized both by strong slopes and forest. The main objective was to provide a well documented data set for the definition and the validation of a new methodology of wind resource estimates with the Mercure_Saturne code (Ph.D. thesis of Laurent Laporte). The horizontal and vertical heterogeneities of wind and turbulence were documented by means of 2 sodars and 4 instrumented masts among which one 80 m high mast equipped with cup and sonic anemometers, vanes, and temperature sensors. The first analyses indicate that the wind vertical profiles measured on the crest are quite well mixed and that the turbulent kinetic energy is often very high. The measurements have been used to correct the mesoscale information for the preparation of the lateral boundary conditions, and to compare the Mercure_Saturne simulations on some selected situations. One of the goals of the campaign was also to evaluate the behavior of a mini-sodar under very difficult conditions (complex terrain, strong ground clutters and strong winds). This mini-sodar provided measurements which were well correlated with the sonic anemometers, but with a tendency to underestimate wind speed. The detailed analysis is still in progress.

1.3 Evaluation of New Technologies

The Doppler lidar appeared on the market of wind instruments only some years ago but will probably play a major role in the next years both in applications related to wind energy and in pollutant dispersion studies.
CEREA is involved in the VMT (Virtual Meteorological Tower) project for lidar capabilities evaluation in collaboration with *EDF-Énergies Nouvelles*, the manufacturer Leosphere, and the renewable energy consultancy Garrad Hassan. Two campaigns have been performed in order to assess both the accuracy of the lidar measurements, and their possible contribution to the uncertainty reduction in the wind resource estimation. The analysis is on the way, and the

conclusions will be provided to ADEME before June 2009.

2. Atmospheric Fluid Dynamics and Local-Scale Dispersion

(Research area leader: Bertrand Carissimo)

This research area focuses mainly on the simulation of atmospheric processes within the boundary layer (roughly, the first kilometer of the atmosphere) using the CFD model Mercure_Saturne. This CFD model is part of the Code_Saturne project, which is open-source since the end of 2007 (http://www.code-saturne.org). Most research projects pertain to issues relevant to EDF (*e.g.,* wind power estimates, air pollutant dispersion from power plants) and the Ministry of Ecology (MEEDDAT; *e.g.*, atmospheric dispersion in the vicinity of roadways and tunnels).

2.1 Wind Potential Estimates

Most current operational studies of wind potential estimates use very simple linearized models, which fail in complex terrain and along the coast where local circulations induced by the thermal contrast can develop. Our goal was to develop a new methodology based on the use of an atmospheric CFD code. First, the classical case of the Asker vein hill was carried out to check the modelling results. Then, a programme including both measurements and simulations with Mercure_Saturne was conducted in 2007-2008 at a complex terrain site located in southern France. (see Section 1.2 for a description of the field campaign). Simulations were forced with hourly analyses and forecasts of a Météo-France meteorological model, ALADIN. In order to simulate long periods (at least one year), a clustering method was applied to the ALADIN outputs of the year 2007. The simulations were conducted using clusters representative of sets of atmospheric conditions. Thus, a first wind resource estimate was obtained with simulations conducted using Mercure_Saturne and modelling results were compared to the measurements and to the operational linear code WAsP. The results showed that Mercure_Saturne performed significantly better than the linearized model.

An additional objective of this work was to better quantify the effect of “mask” created by wind turbines, which can lead to a large uncertainty in the energy production estimate and an increase of the mechanical loads on the turbines, especially in very large offshore wind farms. The masking effect was treated in Mercure_Saturne by ways of a drag within the flow. This drag term was calculated according to the Blade Element Momentum theory using geometric and aerodynamic characteristics of the blades. A comparison with wind tunnel measurements was performed for a large multi-MW turbine in partnership with Polytech’Orléans. A globally good agreement was found although some differences in the magnitude of the speed deficit were identified.

2.2 Fog Modelling

Fogs are weather conditions with significant socio-economic impacts, associated with increased hazards in road, maritime and air traffic. The life cycle of fogs involves a complex composite of dynamic, microphysical and radiative processes that are not still fully understood. In this context, a field campaign involving several organizations (CEREA, IPSL and Météo-France) took place at SIRTA between November 2006 and April 2007. During this campaign, about 20 situations of fog or favorable to fog formation were documented, among which 15 IOPs (Intensive Observation Period) included additional measurements (radio soundings, tethered balloon, aerosol and droplet measurements). These IOPs correspond to different kinds of fog, in terms of physical processes, spatial heterogeneity, and temporal evolution. One-dimensional (1-D) simulations were conducted with Mercure_Saturne in order to test the physical schemes (radiation scheme, turbulence closure, surface processes, microphysical processes) and to identify the governing processes through sensitivity analysis. The mesoscale forcing is taken into account *via* meteorological simulations conducted with the MM5 model over a three month period (December 2006 to February 2007). Moreover, a detailed analysis was performed for two of the best documented IOPs to evaluate and improve the modelling of some microphysical processes: interactions between aerosols and fog droplets, deposition of fog droplets, interactions with solar and infrared radiation. Three-dimensional (3-D) simulations are now being conducted for selected radiation fog events (Ph.D. thesis of Xiaojing Zhang).

2.3 Flow Modelling in Complex Geometry

One of the main applications of Mercure_Saturne is the small-scale dispersion modelling in areas characterized by complex geometry (with possible applications to impact studies of power plants or road traffic). The SIRTA instrumental set-up offers the opportunity to compare Mercure_Saturne simulations with a long-term data set for a complex site in terms of land cover (buildings, trees, water) and nearby orography.
A detailed unstructured grid of the site has been prepared, with a mesh size ranging from a few meters in the building area to 25 m at the lateral boundaries. First, 3-D simulations were performed without including orography and with default neutral-stability boundary conditions, in

RANS mode using k-ε turbulence closure. These simulations show that Mercure_Saturne reproduces correctly the effects of the buildings on the wind and the turbulent kinetic energy. Next, the effect of thermal stratification and orography will be studied.

2.4 Particle Emissions, Dispersion and Deposition near Roadways

A model for atmospheric particles emissions, dispersion and deposition has been incorporated into Mercure_Saturne. This atmospheric particle model was developed at CEREA and uses log-normal functions to represent the particle size distribution. This advanced version of Mercure_Saturne has been applied to ultrafine particle formation in the exhaust plume of a vehicle and is currently being applied to the deposition of particulate cadmium near a roadway in eastern France. The model simulation results are being compared to measurements of cadmium deposition near the roadway. Comparison between a standard Gaussian approach and Mercure_Saturne will also be conducted.

3. Chemical Transport Modelling of Air Quality

Research area leader: Karine Sartelet

Air quality modelling at CEREA covers scales ranging from local impacts (from a roadway or an industrial plant) to urban and regional air pollution, and trans-boundary air pollutant transport at the continental scale. The applications are photochemistry, aerosols, heavy metals (such as mercury or lead), persistent organic pollutants and radionuclides. The activities range from process studies to air quality forecast and impact studies.

The backbone is the modelling system Polyphemus which hosts the dispersion models of CEREA, from local scales (Gaussian plume and puff models) to regional and continental scales (*e.g.* the Chemistry Transport Model Polair3D).

The Polyphemus modelling system is split into 4 distinct levels:
- Physical parameterizations and preprocessing with the object-oriented AtmoData library potentially shared with any team involved in atmospheric modelling, whatever the model is);
- High-level drivers of models viewed as black boxes (for data assimilation, for coupling, for Monte Carlo simulations, for ensemble runs);
- Numerical models (for instance Polair3D, Gaussian plume and puff models);
- Post-processing facilities, for instance for error statistics and model-to-data comparisons, through the Python library AtmoPy.

One advantage of this structure is the possibility to have a multi-model approach through the use of several available parameterizations.
Polyphemus is open source. Version 1.4 was released in October 2008 and a user workshop was held at CEREA in November 2008.

Polyphemus is also used in courses at ParisTech (École des Ponts and ENSTA: "Air Pollution'', "Data Assimilation and Inverse Modelling'').

3.1 Numerical Analysis for Chemistry-Transport Models

Solving the partial differential equations that describe the dispersion of atmospheric reactive species is still a challenging issue due to the wide range of timescales and the large dimension of the resulting systems. An improved numerical scheme that uses an adaptive time-step for the integration of the chemical kinetic equations was incorporated into Polair3D and the reactive puff model used in the plume-in-grid version (see below).

3.2 Integrated Modelling

Integrated assessment models address specific issues of interest for the public policies and are expected to serve the decision-making process. This kind of approach is strongly supported by the European Union. CEREA participates actively, jointly with the IER - University of Stuttgart (where the EcoSense model is currently developed), in two European projects:
- EXIOPOL (a new Environmental accounting framework using externality data and Input-Output tools for Policy analysis), mainly devoted to the valuation of externalities.
- HEIMTSA (Health and Environment Integrated Methodology and Toolbox for Scenario Assessment), turned towards exposure and health impact assessment.

In 2008, Yelva Roustan, who manages the CEREA components of those projects, spent four months at IER Stuttgart. One objective was the coupling of Polyphemus with the integrated model EcoSense. A second objective was to compare the externalities assessment derived through EcoSense from the comprehensive 3D Eulerian model Polair3D and from the simpler source-receptor matrices.

3.3 Plume-In-Grid Modelling

Polyphemus now hosts two Gaussian models (steady-state plume model and puff model), that are currently used for local-scale impact assessments. A Plume-In-Grid ability has also been developed in Polyphemus. It was recently implemented for chemically reactive air pollutants and applied to a large number of stacks in a 2001 simulation of air quality in the Paris region.

3.4 Modelling Secondary Organic Aerosols in Urban Areas

The modelling of secondary organic aerosols (SOA) is a challenging issue in particulate matter (PM) modelling because, to date, all models tend to significantly underestimate the organic mass in atmospheric PM. For example, in previous studies over Europe with Polyphemus and the organic module SORGAM, the concentrations of SOA were grossly under-estimated.

A new SOA model was developed and incorporated into Polair3D in 2007. This new model was applied to an air pollution episode in Paris (the LISAIR campaign) and compared to measurements of organic PM. In particular, the sensitivity of the modelling results to the treatment of semi-volatile organic compounds emitted from traffic was investigated. The model was shown to still underestimate measured organic PM concentrations (although not as much as the earlier version). Furthermore, taking into account semi-volatile traffic emissions was shown to improve model performance.

3.5 Sensitivity of Air Quality Models to Inputs and Formulation

The Polyphemus system hosts the coupling of the 3D Chemistry Transport Model Polair3D to aerosol and aqueous chemistry modules. A comprehensive sensitivity analysis of about thirty physical and numerical processes was performed over Europe in winter and summer, to assess the uncertainties of gas and aerosol concentrations to model input data, physical parameterizations of processes and numerical approximations used in Polyphemus (and in chemical transport models in general). Prior to the sensitivity analysis, improvements were made to the model. For example, different functionalities were added in the aerosol module SIREAM for the bulk redistribution amongst particle size sections after condensation and evaporation and after aqueous chemistry; for the diagnostics of clouds (the cloud cover was used rather than the liquid water content); for computing the pH in the aqueous phase module (calcium and iron were taken into account); for the heterogeneous reaction of N_20_5 (the reaction probability varies with the aerosol composition, humidity and temperature). Also, the nitrate heterogeneous formation on dust particles was added; a simple scheme can now be used for aqueous chemistry: and EQSAM can be used instead of ISORROPIA for inorganic thermodynamics of atmospheric particles.

3.6 Improved Radiative Transfer Treatment

The original version of Polair3D in the Polyphemus modelling system offers a simple treatment for the calculation of the solar radiation that drives the photochemical reactions. This treatment was improved to take into account the effect of clouds and particulate matter (PM) on solar radiation. First, several techniques available to calculate the influence of clouds on the radiative budget were reviewed and the most promising formulation was incorporated into Polair3D. Next, the effect of PM in terms of both light scattering and absorption was added into the model. Thus, Polair3D now accounts for the effect of clouds and PM on atmospheric photochemistry. Such a capability is essential to investigate the effect of climate change on future air quality.

3.7 Multi-Media Modelling

Impact of air quality pollutants on human health is an important field of application of the Polyphemus modelling system. In the Ph.D. thesis of Solen Queguiner, the outputs of Polyphemus for lead, cadmium and persistent organic pollutants (POPs) (air concentrations and ground deposition fluxes) were coupled to the land/water model OURSON developed at the National Hydraulics Laboratory (LNHE, a Department of EDF R&D). OURSON describes pollution in the ecosystems, soil and hydrological networks to estimate chemical doses to human beings.

3.8 Air Quality Impact Studies

Polyphemus is used by EDF Polska and by the consortium of associated Polish Universities (especially AGH University of Science and Technology, Krakow). The objective is to assess air quality in Poland and the related trans-boundary fluxes. In 2008, the model was applied to simulate ozone and particulate matter (PM). Ongoing work focuses on the incorporation of heavy metals (mercury, cadmium and lead) into the model and an assessment of the potential impacts of Polish fossil-fuel fired power plants on air quality in Poland and neighboring countries. In parallel, Polyphemus was applied to estimate the air quality impacts of a single power plant near Torun, Poland.

A specific version of Polyphemus devoted to impact studies and air quality forecast for power plants was developed. It has been applied extensively to assess the potential impacts of a fossil-fuel fired power plant in northern France as well as the potential impacts of nuclear power plants in the unlikely event of an accidental release of radioactive material.

3.9 Air Quality Impacts of Biofuels

Biofuels are being considered to replace gasoline and diesel to decrease the impact of greenhouse gas emissions from traffic. However, the impact of biofuels on urban and regional air quality is more complex as some air pollutants may increase while others will decrease. An air quality simulation was conducted with Polyphemus over Europe to investigate the effect of replacing gasoline and diesel by biofuels. The simulation results suggest that ozone concentrations would decrease in most urban areas but that they would increase overall in southern Europe.

3.10 Air Quality Forecasting

Polyphemus was used for operational air quality forecasting (for ozone, nitrogen dioxide and atmospheric particles) in France; model performance compared favorably to those of the other models of the French air quality forecasting system, Prév'air. For ozone concentrations, the model predictions were combined with measurements from the ground monitoring network using the optimal interpolation method to produce "re-analysis" maps of ozone concentrations over France.

4. CLIME Project-Team

Project-team leader: Isabelle Herlin

The CLIME Project-Team, which is a joint team between INRIA and École des Ponts ParisTech, is hosted by CEREA. Research activities cover mostly data assimilation and inverse modelling for geophysical flows, with a focus on air quality.

4.1 Solving Ill-posed Image Processing Problems with Missing Acquisitions

In this study, the framework of Data Assimilation is used as a generic tool to solve ill-posed Image Processing problems: the image data or related parameters constitute observations which are assimilated within a dynamic model. A data assimilation system has then to be defined with the evolution equation of the state vector (the quantity to be estimated), the observation equation linking this state vector and the image data, and an initial condition. These 3 components include error terms, quantified as error covariance matrices.

A specific effort has been done concerning the theoretical properties of these matrices and their relations with image processing. We first proved that modelling the evolution model error with a Gaussian covariance is equivalent to perform a Tikhonov regularization of the state vector at any order. Second, a generic formulation of the covariance matrix associated to the observation error has been proposed to consider the issue of missing or low quality observations based on a confidence measure (potentially included in metadata associated to the acquisition). On pixels with low confidence, the error value becomes high and the observation will not be taken into account in the computation.

We applied this approach to the problem of estimating optical flow on a sequence of image data. In a first attempt, simple dynamics assumptions have been considered: (i) the observation model is chosen as the transport of image brightness by velocity; (ii) the evolution model is written as the transport of velocity by itself. Experiments are conducted on image sequences displaying missing frames (the sensor has not acquired any data) or missing data. The resulting motion is then mainly obtained by the evolution model and is still correctly estimated on these pixels if the model accurately describes the dynamics of the state vector on the image sequence.

Moreover, if the dynamics of the sequence is known and represented by the evolution equation, it has been proven that the Data Assimilation framework allows to better estimate the motion field on the sequence, because avoiding the usual regularization which spatially smoothes the result.

4.2 3D+t Reconstruction from 2D+t Images Sequence using Data Assimilation

The objective is to reconstruct a 3D sequence from (1) an initial 3D image and (2) a temporal sequence of 2D images, each one being the projection of the 3D object of interest. This is in principle similar to tomography. The aim is to reduce the number of 2D projections, required for the 3D reconstruction at each time step, by introducing dynamical models.

The problem is formulated as finding a 3D warping that makes it possible to reconstruct the 3D sequence from the initial condition and the temporal 2D sequence. The warping is such that the discrepancy between one 2D image and the projection of the corresponding 3D warped image is minimized. As the projection from the 3D to 2D domain is not invertible, this problem is ill-posed. We use the framework of data assimilation by formulating the dynamics of the 3D sequence. The observations are constituted by the 2D images; the evolution model is the transport of 3D velocity by itself.

The method has been tested on an ideal experiment in which the parameters of the projection are exactly known: artificial spherical cells are observed by an actual biological imaging system. The objective is the reconstruction in time of the 3D spheres. The first results show that it is possible to recover the 3D sequence.

4.3 Ocean Surface Velocity Estimation using an Image Model

The objective of the study is to assess, from a sequence of images, a motion field which is coherent with the dynamics of the observed phenomenon. The application is the estimation of surface velocity from a sequence of oceanographic satellite images.

For that purpose, we define an Image Evolution Model describing the temporal evolution of image information and associated parameters. The state vector includes the measured temperature, the two components of velocity and the thickness of the surface layer. The evolution equations are: a simplified advection-diffusion scheme for temperature, the shallow-water equation for velocity and thickness. A data assimilation system is then defined by adding an observation equation describing the transport of temperature by the motion field. The initial conditions are chosen according to image processing software. Sea surface temperature data are then assimilated in the Image Model using a 4D-variational scheme for optimizing the initial conditions and deriving the flow field along the sequence. This field is further assimilated in an oceanic simulation model for validation.

4.4 Assimilation of Aerosol Ground Observations

Data assimilation of PM_{10} ground observations was carried out over Europe and for January 2001. The numerical model was a usual configuration of the aerosol variant of Polair3D, part of the Polyphemus modelling system whose implementation of the optimal interpolation method was applied here. The method was notably applied in operational-like conditions.

The assimilation is beneficial to forecasts, but it has a limited impact in time: after a few hours only, the effect of assimilation faints. Sensitivity tests investigated the spatial and temporal effects of data assimilation in order to better describe this limitation.

4.5 Assimilation of NO_2 Columns for Air Quality Forecast

This study concerns the data assimilation of satellite observations for improving the air quality forecast performed with the Polyphemus air quality system, jointly developed by École des Ponts ParisTech, EDF R&D and INRIA.

Nitrogen dioxide (NO_2) plays an important role in the tropospheric chemistry and has a direct impact on public health. A better knowledge and forecast of NO_2 concentrations are important to the air quality study. In this work, available satellite data are considered for that purpose : the Ozone Monitoring Instrument (OMI), aboard NASA Aura satellite, provides NO_2 column data with a good spatial resolution (13 by 24 km²) and daily global coverage.

First satellite data have been compared to Polyphemus simulations: the OMI column data and the Polyphemus simulations have both been averaged over November-December 2005 in Europe, demonstrating a good consistency in Spain, Italy and North Europe.

The satellite observations are then assimilated in Polyphemus. The forecast obtained with and without assimilation are compared with ground observations for validation. It is found that assimilation of these satellite data improves the NO_2 forecast, with the RMSE between model results and ground observations reduced after assimilation.

4.6 Ensemble Forecasting with Machine Learning Algorithms

Based on ensemble simulations, improved forecasts can be generated by means of linear combinations of the individual-model forecasts. A weight is associated to each model, depending on past observations and simulations. New machine learning algorithms (sequential aggregation) were developed and used for this purpose. Most of these methods provide theoretical bounds on the performance (relative to the optimal constant model combination) and deliver significantly improved forecasts in all configurations.

The practical performance of the methods is very satisfactory. The theoretical bounds are always reached: the potential of the ensemble is well exploited. This was checked for large ensembles (dozens of models) as well as for small ensembles (a few models). The methods were successfully applied to forecast ozone, nitrogen dioxide and aerosols in operational mode, on the Prév'air platform (test mode) managed by INERIS.

The new results focus on the calibration of the parameters used in the learning algorithms: automatic calibration, renormalization of processed data, adaptive penalization when relevant, and sparsity. First steps were also made to reduce the computational cost through *a priori* selection of the ensemble members.

4.7 Uncertainty Estimation based on Multimodel Ensembles

Air quality forecasts are limited by strong uncertainties especially in the input data and in the physical formulation of the models. There is a need to estimate these uncertainties for the evaluation of the forecasts, the production of probabilistic forecast and a more accurate estimation of the error statistics required by data assimilation.

Because a large part of the uncertainty in the forecast originates from uncertainties in the model formulation (primarily the physical parameterizations), multimodel ensemble seems to be the adequate tool for uncertainty estimation. A large ensemble with 100 members over year 2001 was generated and analyzed with criteria like the Brier score. Preliminary work on the calibration of the ensemble was carried out: the ensemble members were selected so as to optimize the evaluation criteria. This may be formulated as a combinatorial optimization problem where one searches for an optimal combination of models out of a huge space of acceptable models.

4.8. Design of a Monitoring Network over France in case of a Radiological Accidental Release

The Institute of Radiation Protection and Nuclear Safety (IRSN) is planning the set-up of an automatic nuclear aerosol monitoring network over the French territory (Descartes network), which complements the Teleray network. Each of the stations will be able to automatically sample the atmospheric aerosol content and to provide with radioactivity concentration measurements on several radionuclides. This will help monitor the French and neighboring countries nuclear power plants. It will help evaluate the impact of a radiological incident at a plant.

After the completion of the first phase (2006 and 2007), the second stage of the study started in March 2008. The resolution has increased from 0.36°× 0.36° to 0.25°× 0.25°, which doubles the number of potential sites, and hence the complexity of the optimization. Meteorological fields have been generated with
MM5 instead of using ECMWF fields. New considerations are taken into account: the inclusion of foreign nuclear power plants, the validation of the optimal network on new cost functions that have not been considered yet, or taking into account the population density as a weighting factor. Because the Descartes network might be deployed sequentially, we are also considering sub-optimal network design algorithms. The computational time which was an important issue in the first stage is now a decisive issue because of the resolution increase.
In order to accelerate optimization, we are considering and testing reduction of the accident database.

4.9. Reduction of an Air Quality Monitoring Network over France and the Île-de-France Region

Ozone is an important air pollutant and observational networks are designed for its monitoring at ground level. Due to the heterogeneous nature of the ozone field, the way ozone is observed does matter in the estimation of the concentrations. The evaluation of the network is thus of both theoretical and practical interests. In this study, we assess the efficiency of the air quality database (BDQA, *Base de Données sur la Qualité de l'Air*) network, by investigating a network reduction problem. We examine how well a subset of this network can represent the full network. The performance of a sub network is taken to be the root mean square error of the spatial estimations of ozone concentrations over the whole network based on the observations from that sub network. Spatial interpolations are conducted for the ozone estimation taking into account the spatial correlations. Several interpolation methods, namely ordinary kriging, simple kriging about means, kriging with means as external drifts, are compared for a reliable estimation. It is found that the statistical information about the means improves significantly the kriging results. We employ a translated exponential model for the spatial correlations. We show that it is necessary to consider the correlation model to be hourly-varying but daily stationary. The network reduction problem is solved using the simulated annealing algorithm. We obtain considerable improvements for the sub networks with different sizes. The redundant stations can thus be neglected to save maintenance costs.

4.10. Targeting of Observations in case of a Nuclear Accidental Release

In the event of an accidental atmospheric release from a nuclear power plant, high resolution and accurate information on the spread of the radioactive plume around the accident site constitute a major key point, acutely required by decision makers in order to evaluate early countermeasure actions and consequences. Therefore, deploying mobile measuring devices constitutes an adequate monitoring strategy that allows one to follow the real-time evolution of the radioactive plume. In fact, the collected measurements from the mobile network could be assimilated conjointly with data derived from the fixed monitoring network, so that to enhance knowledge on the state of the radioactive cloud. The targeting design consists in seeking the optimal spatial locations of the mobile stations at a certain time that satisfy some design criterion based on all available previous information. To illustrate how much a targeting strategy could improve the available information on the state of the radioactive plume, we considered a hypothetical accidental release occurring at the Bugey power plant and a sequential data assimilation scheme based on inverse modelling to reconstruct the accidental event. This assimilation scheme was coupled with a targeting strategy. Our initial results are promising and show that our approach is strongly sensitive to the errors in modelling, so that an important effort has to be made on this point in order to make the used data assimilation scheme more realistic.

4.11. Modelling Wildland Fire Propagation

Modelling wildland fires consists in simulating the propagation of a fire front idealized as a curve on a non-flat terrain. The curve may be closed or not. The front may also be split into several unrelated curves. Starting from an ignition location, the front expands with a velocity determined by the wind and the fuel load.

Based on an empirical physical model developed by Fendell and Wolff, simulations of idealized fires and of one real fire were carried out with the level set method implemented in the package Multivac. This method comes with a well-developed mathematical framework that may be missing in alternative approaches. The study demonstrated its practical value for fire spread simulations.

4.12. Automating the Learning Process of a Large Scale Classification Chain

This study concerns the automation of the learning process required for operating a large scale classification, from time-series of low resolution satellite data, and monitoring deforestation. The satellite sensor acquires temporal profiles (times-series of vegetation indices) which are represented in a specific feature space and classified. Each use of this large scale classification requires an adaptation to the sensor, the site, the observed classes, and hence a learning process must be performed. The objective is to automate as much as possible this learning phase, which includes:

- Determination of the low resolution classes
- Characterization of the profiles by high-level features;
- Selection of the relevant features allowing class discrimination;
- Selection and training of a statistical or fuzzy classifier.

The robustness of the processing chain and fuzzy classification schemes has been improved. An operational classification software, derived from this learning process and applied to deforestation monitoring in Brazil using MODIS images, is currently being registered commonly by INRIA and Embrapa (Brazilian agricultural research organization).

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Agrégation séquentielle pour la prévision de la qualité de l'air. *Journée MAS de la SMAI,* August 29th 2008, Rennes, France

MILLIEZ M., MUSSON-GENON L., CARISSIMO B. *CFD modelling of the urban* canopy with thermal effects : application to MUST container wall temperature evolution. *12*th *annual George Mason University conference on "Atmospheric Transport and Dispersion Modelling*", July 8-10th 2008, Fairfax, USA

REAL E.
Effects of clouds and aerosols on photolysis rates and regional air quality over Europe. *IGAC Conference*, September 7-12th 2008, Annecy, France

REAL E.
La campagne internationale ICARTT : quels enseignements pour le transport à longue distance des polluants au-dessus de l'Atlantique Nord*. Rencontres ADEME-INSU*, December 8-9th 2008, Nancy, France

SARTELET K, DEBRY E., TOMBETTE M., ROUSTAN Y., SPORTISSE B. Gas and PM Modelling at regional and continental scales. In Proceedings of MICS Asia, September 10th *Workshop, IIASA*, Laxenburg, Austria

SARTELET K., DEBRY E., TOMBETTE M., CHAZETTE P., SEIGNEUR C.
Impact of semi-volatile organic compounds from traffic on regional air quality. *IGAC conference*, September 2008, Annecy, France

TEINA R., BEREZIAT D., STOLL B., CHABRIER S.
Toward a global tuamotu archipelago trees sensing using high resolution optical data. *In IGARSS*, July 2008, Boston, USA

TEINA R., BEREZIAT D., STOLL B., CHABRIER S.
A spatial poisson process to classify coconut fields on Ikonos pansharpened images. *In: SPIE Asia Pacific Remote Sensing*, November 2008, Noumea, New Caledonia

TOMAI E., HERLIN I., BERROIR J.-P., PRASTACOS P.
Ontology-based land degradation assessment from satellite images. *In: International Society for Photogrammetry and Remote Sensing,* July 2008, Beijing, China

TOMBETTE M., CHAZETTE P., SPORTISSE B., SARTELET K., DEBRY E.
Evaluation of a mesoscale aerosol model over Europe and Greater Paris with chemical and optical data from AERONET and LISAIR campaign. *EGU General Assembly*, April 13-18*th 2008, Vienna, Austria*

WINIAREK V., MUSSON GENON L., SARTELET K., ROUSTAN Y.
Impact Studies of emission sources with the air-quality modelling system Polyphemus *GLOREAM workshop, October 29-31th 2008, Antwerpen, Belgium*

WU L., MALLET V., BOCQUET M., SPORTISSE B.
A Comparison Study of Dta Assimilation Algorithms for Ozone Forecasts at WWRP/THORPEX workshop on 4D-Var and ensemble Kalman filter inter comparisons, November 10-13th 2008, Buenos Aires, Argentina

WU L., MALLET V., BOCQUET M., SPORTISSE B.
On Data Assimilation Algorithms for ozone Forecasts. *EGU 2008*, April 13-18th 2008, Vienna, Austria

ZHANG X., CHALLET J., DUPONT É., MUSSON-GENON L.
Modélisation 1-D du brouillard avec le code Mercure_Saturne : application à la campagne ParisFog. *Atelier de Modélisation de l'Atmosphère*, *January 21-23th 2008,* Toulouse, France

ZHANG X., CHALLET J., DUPONT É., MUSSON-GENON L.
Modélisation 1-D du brouillard avec le code Mercure_Saturne : application à la campagne ParisFog et analyse de sensibilité. *Journée scientifique du SIRTA*, March 27th *2008,* Palaiseau, France

ZHANG X., MUSSON G., CARISSIMO B., DUPONT É.
Numerical Simulation of Radiation Fog: Sensitivity Analysis. *AGU Chapman Conference on Atmospheric Water Vapor and Its Role in Climate*, October 20-24th 2008, Kailua Kona, Hawaï, USA

ZHANG X.
ECMWF 2008 Annual Seminar on Parametrization of Subgrid Physical Processes, September 1-4th 2008, Reading, United Kingdom

Educational Activities

SUPERVISORY ACTIVITIES

Ongoing theses

ABDEL MEGUID A.
Assimilation of satellite acquisitions for air quality forecast. Université Paris-Est

ABIDA R.
Construction optimale d'un réseau de mesures pour la surveillance des radionucléides. Université Paris-Est

GARAUD D.
Estimation des incertitudes et prévision des risques en qualité de l'air. Université Paris-Est

KIM Y.
Modélisation de la qualité de l'air pour la prévision à l'échelle régionale. Université Paris-Est

KORSAKISSOK I.
Changements d'échelles en modélisation de la qualité de l'air et estimation des incertitudes associées. Université Paris-Est

LAGACHE R.
Couplage de modèles pour l'estimation des impacts de la pollution atmosphérique liée aux transports à l'échelle locale. Université Paris-Est

MALAKOOTI H.
Air pollution modelling on mega cities. Université Paris-Est

QU Y.
Modélisation fine des échanges énergétiques en milieu urbains. Université Paris-Est

ZHANG X.
Modélisation du brouillard à l'aide du code Mercure-Saturne. Université Paris-Est

ZYSK J.
Modelling of the atmospheric dispersion of heavy metals in Poland. Université Paris-Est

Theses completed

LAPORTE-DAUBE L .
Amélioration de l'estimation du productible éolien en terrain complexe, December 12th 2008, École des Ponts Paris-Est, Université Paris-Est

QUEGUINER S. Modélisation multi-milieux de la pollution atmosphérique. March 2008, École des Ponts Paris-Est, Université Paris-Est

TEACHING ACTIVITIES

Courses

École des Ponts ParisTech

Air Pollution
Christian Seigneur (3 hours)

École des Ponts ParisTech

Air Pollution and Transport, TRADD master
Karine Kata-Sartelet, Yelva Roustan (12 hours)

École des Ponts ParisTech

Fluid Mechanics
Bertrand CARISSIMO (30 hours)

ENSTA/École des Ponts ParisTech

Data Assimilation and Inverse Modelling
Marc BOCQUET, Vivien MALLET (36 hours)

ENTPE

Air Pollution
Yelva Roustan, Christian Seigneur (8 hours)

SGE Master, AQA Option

Atmospheric Modelling
Bertrand CARISSIMO, Édouard DEBRY, Vivien MALLET (6 hours)

Industrial Partnerships

CONTRACTS

Contracts with the Nuclear Engineering Department (EDF)
WINIAREK V., MUSSON-GENON L., Impact studies for nuclear power plants. 60 k€

Contract with EDF R&D (Joint Laboratory). 210 k€

CIFRE Ph.D. theses (Funded by Industrial Partners)

DEMAEL E.
Short-range dispersion and uncertainties, EDF

GARAUD D.
Impact studies and uncertainties, EDF

LAPORTE-DAUBE L.
Wind energy assessment, EDF

QU Y.
Modelling the urban heat budget, EDF

QUEGUINER S.
Multi-media modelling and POP, EDF

Technology Transfer

Software

Mercure_Saturne
CFD model for the atmospheric boundary layer
http://www.code-saturne.org
CARISSIMO B., DUPONT É., FOUDHIL H., MILLIEZ M., MUSSON-GENON L.

MAM
Modal Aerosol Model
SARTELET K., ABRIET B., SPORTISSE B.

SIREAM
Size Resolved Aerosol Model
DEBRY É., FAHEY K., SARTELET K., TOMBETTE M., SPORTISSE B.

Polyphemus
Air Quality Modelling system
http://cerea.enpc.fr/polyphemus
MALLET V., QUELO D., KORSAKISSOK I., MEYED DE BIASI M., ROUSTAN Y., SPORTISSE B.

Public Policy Support

Contract with SETRA
Roadway management agency
SARTELET K., TAGHAVI M.
Particular mater deposition near roadways
14 k€

Contract with ADEME (Energy Agency)
SARTELET K., ABRIET B.
Air quality impacts of aircraft
30 k€

Contract with IRSN (Institute for Nuclear Safety)
BOCQUET M., SAUNIER O.
Network design and data assimilation for accidental releases
60 k€

Contract with INERIS (Institute for Environmental and Risk Assesment)
MALLET V., SARTELET K.
Short-range dispersion and ensemble forecast
30 k€

Research Network devoted to Sustainable Development (R2DS, Île-de-France Region)
ROUSTAN Y.
Integrated modelling for air quality (with CIRED, École des Ponts ParisTech)
18 k€

Research Network devoted to Sustainable Development (R2DS, Île-de-France Region)
BOCQUET M., WU L.
Network design for air quality monitoring
96 k€

Grant from the Research Division of the Transportation Ministry MTETM /DRAST
SARTELET K. Air quality impacts of traffic
30 k€

List of acronyms

ADEME
Agence pour la Défense de l'Environnement et la Maîtrise de l'Énergie

CEA
Commissariat à l'Énergie Atomique

CEREA
Centre d'Enseignement et de Recherche en Environnement Atmosphérique

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

CNRS
Centre National de la Recherche Scientifique

DRAST
Direction de la Recherche et des Affaires Scientifiques et Techniques du METMLT

EDF R&D
Électricité de France Recherche et Développement

ENSTA
École Nationale Supérieure des Techniques Avancées

ENTPE
École Nationale des Travaux Publics de l'État

INRIA
Institut National de Recherche en Informatique et Automatique

INERIS
Institut National sur l'Environnement Industriel et les Risques

IPSL
Institut Pierre-Simon Laplace

IRSN
Institut de Radioprotection et de Sûreté Nucléaire

LEFE
Les Enveloppes Fluides et l'Environnement (CNRS Program)

MÉEDDAT
Ministère de l'Écologie, de l'Énergie, du Developpement Durable et de l'Aménagement du Territoire

PM
Particulate Matter

PREDIT
Programme pour la Recherche, le Développement et l'Innovation dans les Transports Terrestres

PRIMEQUAL
Programme Interministériel d'Étude de la Qualité de l'Air

R2DS
Réseau de Recherche sur le Développement Soutenable (Research Network of the Ile-de-France Region)

SIRTA
Site Instrumental de Recherche par Télédétection Atmosphérique