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Ecole des Ponts ParisTech

Activity Report 2013

Project-Team CLIME

Coupling environmental data and simulation models for software integration

IN COLLABORATION WITH: Centre d'Enseignement et de Recherche en Environnement Atmosphérique

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THEME
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Project-Team CLIME

Keywords: Data Assimilation, Geophysics, Image Processing, Inverse Problem, Stochastic Methods

Creation of the Project-Team: 2005 September 01.

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2. Overall Objectives

2.1. Clime in short

The international politic, economic and scientific contexts are pointing out the role that is played by models and observation systems for forecasting and evaluating environmental risks.

The complexity of environmental phenomena as well as the operational objectives of risk mitigation necessitate an intensive interweaving between geophysical models, data processing, simulation, visualization and database tools.

For illustration purpose, we observe that this situation is met in the domain of atmospheric pollution, whose modeling is gaining an ever-increasing significance and impact, either at local (air quality), regional (transboundary pollution) or global scale (greenhouse effect). In this domain, numerical modeling systems are used for operational forecasts (short or long term), detailed case studies, impact studies for industrial sites, as well as coupled modeling, such as pollution and health or pollution and economy. These scientific subjects strongly require linking/coupling the models with all available data either of physical origin (e.g., models outputs), coming from raw observations (satellite acquisitions and/or information measured in situ by an observation network) or obtained by processing and analysis of these observations (e.g., chemical concentrations retrieved by inversion of a radiative transfer model).

Clime has been jointly created, by Inria and École des Ponts ParisTech, for studying these questions with researchers in data assimilation, image processing, and modeling.

Clime carries out research activities in three main areas:

- Data assimilation methods: inverse modeling, network design, ensemble methods, uncertainties estimation, uncertainties propagation.
- Image assimilation: assimilation of structures in environmental forecasting models, study of ill-posed image processing problems with data assimilation technics, definition of dynamic models from images, reduction of models.
- Development of integrated chains for data/models/outputs (system architecture, workflow, database, visualization).

3. Research Program

3.1. Data assimilation and inverse modeling

This activity is one major concern of environmental sciences. It matches up the setting and the use of data assimilation methods, for instance variational methods (such as the 4D-Var method). An emerging issue lies in the propagation of uncertainties by models, notably through ensemble forecasting methods.

Although modeling is not part of the scientific objectives of Clime, the project-team has complete access to models developed by CEREA: the models from Polyphemus (pollution forecasting from local to regional scales) and Code_Saturne (urban scale). In regard to other modeling domains, such as meteorology and oceanography, Clime accesses models through co-operation initiatives.

The research activities of Clime tackle scientific issues such as:

- Within a family of models (differing by their physical formulations and numerical approximations), which is the optimal model for a given set of observations?
- How to reduce dimensionality of problems by Galerkin projection of equations on subspaces? How to define these subspaces in order to keep the main properties of systems?
- How to assess the quality of a forecast and its uncertainty? How do data quality, missing data, data obtained from sub-optimal locations, affect the forecast? How to better include information on uncertainties (of data, of models) within the data assimilation system?
- How to make a forecast (and a better forecast!) by using several models corresponding to different physical formulations? It also raises the question: how should data be assimilated in this context?
- Which observational network should be set up to perform a better forecast, while taking into account additional criteria such as observation cost? What are the optimal location, type and mode of deployment of sensors? How should trajectories of mobile sensors be operated, while the studied phenomenon is evolving in time? This issue is usually referred as “network design”.

3.2. Satellite acquisitions and image assimilation

In geosciences, the issue of coupling data, in particular satellite acquisitions, and models is extensively studied for meteorology, oceanography, chemistry-transport and land surface models. However, satellite images are mostly assimilated on a point-wise basis. Three major approaches arise if taking into account the spatial structures, whose displacement is visualized on image sequences:

- Image approach. Image assimilation allows the extraction of features from image sequences, for instance motion field or structures' trajectory. A model of the dynamics is considered (obtained by simplification of a geophysical model such as Navier-Stokes equations). An observation operator is defined to express the links between the model state and the pixels values. In the simplest case, the pixel value corresponds to one coordinate of the model state and the observation operator is reduced to a projection. However, in most cases, this operator is highly complex, implicit and non-linear. Data assimilation techniques are developed to control the initial state or the whole assimilation window. Image assimilation is also applied to learn reduced models from image data and estimate a reliable and small-size reconstruction of the dynamics, which is observed on the sequence.
- Model approach. Image assimilation is used to control an environmental model and obtain improved forecasts. In order to take into account the spatial and temporal coherency of structures, specific image characteristics are considered and dedicated norms and observation error covariances are defined.
- Correcting a model. Another topic, mainly described for meteorology in the literature, concerns the location of structures. How to force the existence and to correct the location of structures in the model state using image information? Most of the operational meteorological forecasting institutes, such as MétéoFrance, UK-met, KNMI (in Netherlands), ZAMG (in Austria) and Met-No (in Norway), study this issue because operational forecasters often modify their forecasts based on visual comparisons between the model outputs and the structures displayed on satellite images.

3.3. Software chains for environmental applications

An objective of Clime is to participate in the design and creation of software chains for impact assessment and environmental crisis management. Such software chains bring together static or dynamic databases, data assimilation systems, forecast models, processing methods for environmental data and images, complex visualization tools, scientific workflows, ...

Clime is currently building, in partnership with École des Ponts ParisTech and EDF R&D, such a system for air pollution modeling: Polyphemus (see the web site http://cerea.enpc.fr/polyphemus/), whose architecture is specified to satisfy data requirements (e.g., various raw data natures and sources, data preprocessing) and to support different uses of an air quality model (e.g., forecasting, data assimilation, ensemble runs).

4. Application Domains

4.1. Introduction

The central application domain of the project-team is atmospheric chemistry. We develop and maintain the air quality modeling system Polyphemus, which includes several numerical models (Gaussian models, Lagrangian model, two 3D Eulerian models including Polair3D) and their adjoints, and different high level methods: ensemble forecast, sequential and variational data assimilation algorithms. Advanced data assimilation methods, network design, inverse modeling, ensemble forecast are studied in the context of air chemistry. Note that addressing these high level issues requires controlling the full software chain (models and data assimilation algorithms).

The activity on assimilation of satellite data is mainly carried out for meteorology and oceanography. This is addressed in cooperation with external partners who provide numerical models. Concerning oceanography, the aim is to assess ocean surface circulation, by assimilating fronts and vortices displayed on image acquisitions. Concerning meteorology, the focus is on correcting the model location of structures related to high-impact weather events (cyclones, convective storms, etc.) by assimilating images.

4.2. Air quality

Air quality modeling implies studying the interactions between meteorology and atmospheric chemistry in the various phases of matter, which leads to the development of highly complex models. The different usages of these models comprise operational forecasting, case studies, impact studies, etc., with both societal (e.g., public information on pollution forecast) and economical impacts (e.g., impact studies for dangerous industrial sites). Models lack some appropriate data, for instance better emissions, to perform an accurate forecast and data assimilation techniques are recognized as a major key point for improving forecast's quality.

In this context, Clime is interested in various problems, the following being the crucial ones:

- The development of ensemble forecast methods for estimating the quality of the prediction, in relation with the quality of the model and the observations. This allows sensitivity analysis with respect to the model's parameters so as to identify physical and chemical processes, whose modeling must be improved.
- The development of methodologies for sequential aggregation of ensemble simulations. What ensembles should be generated for that purpose, how spatialized forecasts can be generated with aggregation, how can the different approaches be coupled with data assimilation?
- The definition of second-order data assimilation methods for the design of optimal observation networks. The two main objectives are: management of combinations of sensor types and deployment modes and dynamic management of mobile sensors' trajectories.
- How to estimate the emission rate of an accidental release of a pollutant, using observations and a dispersion model (from the near-field to the continental scale)? How to optimally predict the evolution of a plume? Hence, how to help people in charge of risk evaluation for the population?
- The definition of non-Gaussian approaches for data assimilation.
- The assimilation of satellite measurements of troposphere chemistry.

The activities of Clime in air quality are supported by the development of the Polyphemus air quality modeling system. This system has a modular design, which makes it easier to manage high level applications such as inverse modeling, data assimilation and ensemble forecast.

4.3. Oceanography

The capacity of performing a high quality forecast of the state of the ocean, from the regional to the global scales, is of major interest. Such a forecast can only be obtained by systematically coupling numerical models and observations (in situ and satellite data). In this context, being able to assimilate image structures becomes a key point. Examples of such image structures are:

- apparent motion that represents surface velocity;
- trajectories, obtained either from tracking of features or from integration of the velocity field;
- spatial objects, such as fronts, eddies or filaments.

Image models of these structures are developed and take into account the underlying physical processes. Image data are assimilated in these image models to derive pseudo-observations of state variables, which are further assimilated in numerical ocean forecast models.

4.4. Meteorology

Meteorological forecasting constitutes a major applicative challenge for image assimilation. Although satellite data are operationally assimilated within models, this is mainly done on an independent pixel basis: the observed radiance is linked to the state variables via a radiative transfer model, that plays the role of an observation operator. Indeed, because of their limited spatial and temporal resolutions, numerical weather forecast models fail to exploit image structures, such as precursors of high impact weather:

- cyclogenesis related to the intrusion of dry stratospheric air in the troposphere (a precursor of cyclones),
- convective systems (supercells) leading to heavy winter time storms,
- low-level temperature inversion leading to fog and ice formation, etc.

To date, there is no available method for assimilating such data, which are characterized by a strong coherence in space and time. Meteorologists have developed qualitative Conceptual Models (CMs), for describing the high impact weathers and their signature on images, and tools to detect CMs on image data. The result of this detection is used for correcting the numerical models, for instance by modifying the initialization. The aim is therefore to develop a methodological framework allowing to assimilate the detected CMs within numerical forecast models. This is a challenging issue given the considerable impact of the related meteorological events.

5. Software and Platforms

5.1. Polyphemus

Participants: Sylvain Doré, Vivien Mallet, Florian Couvidat [CEREA], Yiguo Wang [CEREA], Nora Duhanyan [CEREA], Yelva Roustan [CEREA].

Polyphemus (see the web site http://cerea.enpc.fr/polyphemus/) is a modeling system for air quality. As such, it is designed to yield up-to-date simulations in a reliable framework: data assimilation, ensemble forecast and daily forecasts. Its completeness makes it suitable for use in many applications: photochemistry, aerosols, radionuclides, etc. It is able to handle simulations from local to continental scales, with several physical models. It is divided into three main parts:

- libraries that gather data processing tools (SeldonData), physical parameterizations (AtmoData) and postprocessing abilities (AtmoPy);
- programs for physical preprocessing and chemistry-transport models (Polair3D, Castor, two Gaussian models, a Lagrangian model);
- model drivers and observation modules for model coupling, ensemble forecasting and data assimilation.

Figure 1 depicts a typical result produced by Polyphemus.

Clime is involved in the overall design of the system and in the development of advanced methods in model coupling, data assimilation and uncertainty quantification (through model drivers and post-processing).

In 2013, Polyphemus has received numerous improvements on aerosol modeling, including better dynamics for organic aerosol formation and interactions between organic and inorganic aerosols. The data assimilation part of Polyphemus can now perform 3D data assimilation, taking advantage of Lidar data. Further integration of the data assimilation library Verdandi was also carried out.

5.2. Data assimilation library: Verdandi

Participants: Vivien Mallet, Dominique Chapelle [M3DISIM], Philippe Moireau [M3DISIM], Anne Tilloy, Paul Baudin, Tristan Perotin.

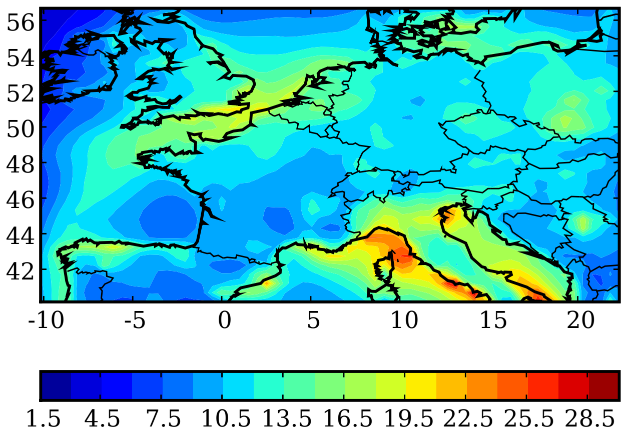

Figure 1. Map of the relative standard deviation (or spread, %) of an ensemble built with Polyphemus (ozone simulations, $\mu g\ m^{-3}$). The standard deviations are averaged over the summer of 2001. They provide an estimation of the simulation uncertainties.

The leading idea is to develop a data assimilation library intended to be generic, at least for high-dimensional systems. Data assimilation methods, developed and used by several teams at Inria, are generic enough to be coded independently of the system to which they are applied. Therefore these methods can be put together in a library aiming at:

- making easier the application of methods to a great number of problems,
- making the developments perennial and sharing them,
- improving the broadcast of data assimilation works.

An object-oriented language (C++) has been chosen for the core of the library. A high-level interface to Python is automatically built. The design study raised many questions, related to high dimensional scientific computing, the limits of the object contents and their interfaces. The chosen object-oriented design is mainly based on three class hierarchies: the methods, the observation managers and the models. Several base facilities have also been included, for message exchanges between the objects, output saves, logging capabilities, computing with sparse matrices.

In 2013, version 1.5 was released with better consistency between the methods. Verdandi received improvements in its test cases. Increased flexibility was introduced in error descriptions, especially for uncertainty quantification.

A C++ interface to the Nucleus for European Modelling of the Ocean (see the web site NEMO http://www.nemo-ocean.eu/) has been developed so that it can be plugged to Verdandi. The interface currently enables the application of Monte Carlo simulations and the ensemble Kalman filter.

5.3. Urban air quality analysis

Participants: Anne Tilloy, Vivien Mallet, Raphaël Périllat.

"Urban Air Quality Analysis" carries out data assimilation at urban scale. It merges the outputs of a numerical model (maps of pollutant concentrations) with observations from an air quality monitoring network, in order to produce the so-called analyses, that is, corrected concentration maps. The data assimilation computes the Best Linear Unbiased Estimator (BLUE), with a call to the data assimilation library Verdandi. The error covariance matrices are parameterized for both model simulations and observations. For the model state error covariances, the parameterization primarily relies on the road network. The software handles ADMS Urban output files, for a posteriori analyses or in an operational context.

In 2013, the software introduced new models for error covariances. It may now take into account tunnels. New options were added to filter out certain observations. The software was extended to handle new file formats.

6. New Results

6.1. New methods for data assimilation

One major objective of Clime is the conception of new techniques for data assimilation in geophysical sciences. Clime is active on several of the most challenging theoretical aspects of data assimilation: data assimilation methods based on non-Gaussian assumptions, methods for estimating errors, ensemble filtering techniques, 4D variational assimilation approaches, ensemble-variational methods, etc.

This year, focus was on ensemble-variational methods. We introduced a new method known as the iterative ensemble Kalman smoother. It is an ensemble method with an underlying cost function; it does not require the use of the adjoint; and it is flow-dependent. Because of these propreties, the IEnKS outperforms other data assimilation methods when tested with perfect meteorological toy-models. Its potential for parameter estimation has also been demonstrated.

6.1.1. An iterative ensemble Kalman smoother

Participants: Marc Bocquet, Pavel Sakov [BOM, Australia].

The iterative ensemble Kalman filter (IEnKF) was recently proposed to improve the performance of ensemble Kalman filtering with strongly nonlinear geophysical models. IEnKF can be used as a lag-one smoother and extended to a fixed-lag smoother: the iterative ensemble Kalman smoother (IEnKS [12]). IEnKS is an ensemble variational method. It does not require the use of the tangent linear of the evolution and observation models, nor the adjoint of these models: the required sensitivities (gradient and Hessian) are obtained from the ensemble. Looking for the optimal performance, we consider a quasi-static algorithm, out of the many possible extensions. IEnKS is explored on the Lorenz'95 model and on a 2D turbulence model. As a logical extension of IEnKF, IEnKS significantly outperforms standard Kalman filters and smoothers in strongly nonlinear regimes. In mildly nonlinear regimes (typically synoptic scale meteorology), its filtering performance is marginally but clearly better than the standard ensemble Kalman filter, and it keeps improving as the length of the temporal data assimilation window is increased. For long windows, its smoothing performance very significantly outranks the standard smoothers, which is believed to stem from the variational but flow-dependent nature of the algorithm. For very long windows, the use of a multiple data assimilation variant of the scheme, where observations are assimilated several times, is advocated. This paves the way for finer re-analysis freed from the static prior assumption of 4D-Var, but also partially freed from the Gaussian assumptions that usually impede standard ensemble Kalman filtering and smoothing.

6.1.2. Joint state and parameter estimation with an iterative ensemble Kalman smoother

Participants: Marc Bocquet, Pavel Sakov [BOM, Australia].

Both ensemble filtering and variational data assimilation methods have proven being useful in the joint estimation of state variables and parameters of geophysical models. Yet, their respective benefits and drawbacks in this task are distinct. An ensemble variational method, known as the iterative ensemble Kalman smoother (IEnKS), has recently been introduced. It is based on an adjoint-free variational but flow-dependent scheme. As such, IEnKS is a candidate tool for joint state and parameter estimation that may inherit the benefits from both the ensemble filtering and variational approaches.

In this study [13], an augmented state IEnKS is tested on the estimation of the forcing parameter of the Lorenz'95 model. Since joint state and parameter estimation is especially useful in applications where the forcings are uncertain but nevertheless determining, typically in atmospheric chemistry, the augmented state IEnKS is tested on a new low-order model that combines the Lorenz'95 model, representing its meteorological part, and the advection diffusion of a tracer for its chemical part. In these experiments, IEnKS is compared to the ensemble Kalman filter, the ensemble Kalman smoother and a 4D-Var method, that are considered choices to solve these joint estimation problems. In this low-order model context, IEnKS is shown to significantly outperform those methods, for any length of the data assimilation window, and for present time analysis as well as retrospective analysis. Besides, the performance of IEnKS is even more striking on parameter estimation, whereas getting close to the same performance with 4D-Var is likely to require both a long data assimilation window and a complex modeling of the background statistics.

6.1.3. Data assimilation applied to air quality at urban scale

Participants: Vivien Mallet, Raphaël Périllat, Anne Tilloy, Fabien Brocheton [Numtech], David Poulet [Numtech], Frédéric Mahé [Airparif], Pierre Pernot [Airparif], Fabrice Joly [Airparif].

Based on Verdandi [14], Polyphemus and the "Urban Air Quality Analysis" software, data assimilation was further developed at urban scale. The Best Linear Unbiased Estimator (BLUE) is computed to merge the outputs of the ADMS Urban model and the observations of a sparse monitoring network [19]. We improved the modeling of the covariance of the model state error. The assimilation was applied for part of Paris (see Fig. 2) and for Paris region, in the context of the PRIMEQUAL project PREQUALIF ("Multidisciplinary Program on Air Quality Research in Île-de-France").

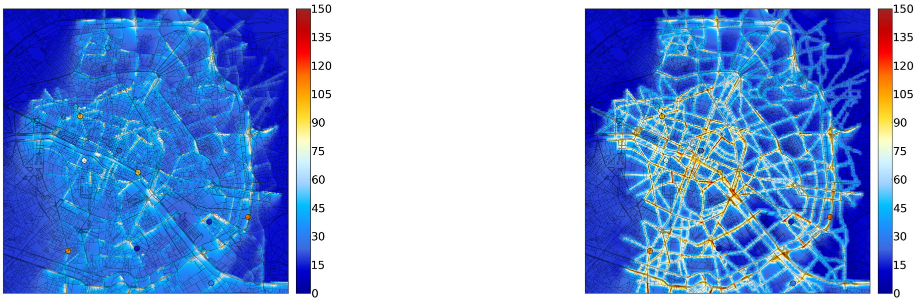

Figure 2. Left: Map of [NO_2] ($\mu g\ m^{-3}$), before assimilation, at a given date in September 2012. Right: Map of [NO_2] ($\mu g\ m^{-3}$), after assimilation of the observations (disks).

It was applied to nitrogen dioxide, particulate matter and black carbon. Specific investigations were carried out to estimate the variance of the a posteriori error and to determine the impact of each monitoring station on the final results.

6.2. Inverse modeling

We continued research on inverse modelling techniques, with a focus on hyperparameter estimation when the statistics are non-Gaussian. We applied these methods to the estimation of the caesium-137 Fukushima source term using heterogenous datasets. We applied similar methods to the estimation of Volatile Organic Compounds (VOC) at the European scale by assimilation of the EMEP VOC observations over one year. We also studied the estimation of several hyperparameters in the context of CO_2 flux inversions.

6.2.1. Estimation of the caesium-137 source term from the Fukushima Daiichi nuclear power plant using a consistent joint assimilation of air concentration and deposition observations

Participants: Victor Winiarek, Marc Bocquet, Nora Duhanyan [CEREA], Yelva Roustan [CEREA], Olivier Saunier [IRSN], Anne Mathieu [IRSN].

To estimate the amount of radionuclides and the temporal profile of the source term released in the atmosphere during the accident of the Fukushima Daiichi nuclear power plant in March 2011, inverse modeling techniques have been used and have proven their ability in this context. In a previous study, the lower bounds of the caesium-137 and iodine-131 source terms were estimated with such techniques, using activity concentration observations. The importance of an objective assessment of prior errors (the observation errors and the background errors) was emphasised for a reliable inversion. In such critical context where the meteorological conditions can make the source term partly unobservable and where only a few observations are available, such prior estimation techniques are mandatory, the retrieved source term being very sensitive to this estimation.

We propose to extend the use of these techniques to the estimation of prior errors when assimilating observations from several data sets [21]. The aim is to compute an estimate of the caesium-137 source term jointly using all available data about this radionuclide, such as activity concentrations in the air, but also daily fallout measurements and total cumulated fallout measurements. It is crucial to properly and simultaneously estimate the background errors and the prior errors relative to each data set. A proper estimation of prior errors is also a necessary condition to reliably estimate the a posteriori uncertainty of the estimated source term. Using such techniques, we retrieve a total released quantity of caesium-137 in the interval $11.6 - 19.3$ PBq with an estimated standard deviation range of $15 - 20\%$ depending on the method and the data sets. The "blind" time intervals of the source term have also been strongly mitigated compared to the first estimations with only activity concentration data.

6.2.2. An inverse modeling method to assess the source term of the Fukushima Nuclear Power Plant accident using gamma dose rate observations

Participants: Olivier Saunier [IRSN], Anne Mathieu [IRSN], Damien Didier [IRSN], Maryline Tombette [IRSN], Denis Quélo [IRSN], Victor Winiarek, Marc Bocquet.

The Chernobyl nuclear accident, and more recently the Fukushima accident, highlighted that the largest source of error on consequences assessment is the source term, including the time evolution of the release rate and its distribution between radioisotopes. Inverse modeling methods, which combine environmental measurements and atmospheric dispersion models, have proven being efficient in assessing source term due to an accidental situation. Most existing approaches are designed to use air sampling measurements and some of them also use deposition measurements [21]. Some studies have been conceived to use dose rate measurements, but none of the developed methods were carried out to assess the complex source term of a real accident situation like the Fukushima accident. However, dose rate measurements are generated by the most widespread measurement system and, in the event of a nuclear accident, these data constitute the main source of measurements of the plume and radioactive fallout during releases. This study [18], [23] proposes a method to use dose rate measurements as part of an inverse modeling approach to assess source terms. The method is proven efficient and reliable when applied to the accident at the Fukushima Daiichi Nuclear Power Plant (FD-NPP). The emissions for the eight main isotopes have been assessed. Accordingly, 105.9 PBq of ^{131}I, 35.8 PBq of ^{132}I, 15.5 PBq of ^{137}Cs and 12,134 PBq of noble gases were released. The events at FD-NPP (such as venting, explosions, etc.) known to have caused atmospheric releases are well identified in the retrieved source term. The estimated source term is validated by comparing simulations of atmospheric dispersion and deposition with environmental observations. In total, it was found that for 80 % of the measurements, simulated and observed dose rates agreed within a factor of 2. Changes in dose rates over time have been overall properly reconstructed, especially in the most contaminated areas to the northwest and south of the FD-NPP. A comparison with observed atmospheric activity concentration and surface deposition shows that the emissions of caesiums and ^{131}I are realistic but that ^{132}I and ^{132}Te are probably underestimated and noble gases are likely overestimated. Finally, an important outcome of this study is that the method proved to be perfectly suited to emergency management and could contribute to improve emergency response in the event of a nuclear accident.

6.2.3. *Estimation of volatile organic compound emissions for Europe using data assimilation*

Participants: Mohammad Reza Koohkan, Marc Bocquet, Yelva Roustan [CEREA], Yougseob Kim [CEREA], Christian Seigneur [CEREA].

The emissions of non-methane volatile organic compounds (VOCs) over western Europe for the year 2005 are estimated via inverse modeling by assimilation of in situ observations of concentration and they are subsequently compared to a standard emission inventory. The study [16] focuses on fifteen VOC species: five aromatics, six alkanes, two alkenes, one alkyne and one biogenic diene. The inversion relies on a validated fast adjoint of the chemical transport model used to simulate the fate and transport of these VOCs. The assimilated ground-based measurements over Europe are provided by the European Monitoring and Evaluation Programme (EMEP) network. The background emissions errors and the prior observational errors are estimated by maximum likelihood approaches. The positivity assumption on the VOC emission fluxes is pivotal for a successful inversion and this maximum likelihood approach consistently accounts for the positivity of the fluxes. For most species, the retrieved emissions lead to a significant reduction of the bias, which underlines the misfit between the standard inventories and the observed concentrations. The results are validated through a forecast test and a cross-validation test. An estimation of the posterior uncertainty is also provided. It is shown that the statistically consistent non-Gaussian approach, based on a reliable estimation of the errors, offers the best performance. The efficiency in correcting the inventory depends on the lifetime of the VOCs and the accuracy of the boundary conditions. In particular, it is shown that the use of in situ observations using a sparse monitoring network to estimate emissions of isoprene is inadequate because its short chemical lifetime significantly limits the spatial radius of influence of the monitoring data. For species with longer lifetime (a few days), successful, albeit partial, emission corrections can reach regions hundreds of kilometres away from the stations. Domainwide corrections of the emissions inventories of some VOCs are significant, with underestimations on the order of a factor of two for propane, ethane, ethylene and acetylene.

6.2.4. *Hyperparameter estimation for uncertainty quantification in mesoscale carbon dioxide inversions*

Participants: Lin Wu [LSCE, France], Marc Bocquet, Frédéric Chevallier [LSCE, France], Thomas Lauvaux [Department of Meteorology, Pennsylvania State University, USA], Kenneth Davies [Department of Meteorology, Pennsylvania State University, USA].

Uncertainty quantification is critical in the inversion of CO_2 surface fluxes from atmospheric concentration measurements. We estimate the main hyperparameters of the error covariance matrices for a priori fluxes and CO_2 concentrations, that is, the variances and the correlation lengths, using real, continuous hourly CO_2 concentration data in the context of the Ring 2 experiment of the North American Carbon Program Mid Continent Intensive. Several criteria, namely maximum likelihood (ML), general cross-validation (GCV) and χ^2 test are compared for the first time under a realistic setting in a mesoscale CO_2 inversion. It is shown [22] that the optimal hyperparameters under the ML criterion assure perfect χ^2 consistency of the inverted fluxes. Inversions using the ML error variances estimates rather than the prescribed default values are less weighted by the observations, because the default values underestimate the model-data mismatch error, which is assumed to be dominated by the atmospheric transport error. As for the spatial correlation length in prior flux errors, the Ring 2 network is sparse for GCV and this method fails to reach an optimum. In contrast, the ML estimate (e.g. an optimum of 20 km for the first week of June 2007) does not support long spatial correlations that are usually assumed in the default values.

6.3. Monitoring network design

In this section, we report studies that are related to the evaluation of monitoring networks and to new monitoring strategies. This year, we studied the impact of using lidar observation for particulate matter forecasting.

6.3.1. Assimilation of ground versus lidar observations for PM_{10} forecasting

Participants: Yiguo Wang [CEREA], Karine Sartelet [CEREA], Marc Bocquet, Patrick Chazette [LSCE, France].

This study [20] investigates the potential impact of future ground-based lidar networks on analysis and short-term forecasts of PM_{10}. To do so, an Observing System Simulation Experiment (OSSE) is built for PM_{10} data assimilation using optimal interpolation over Europe for one month in 2001. First, we estimate the efficiency of the assimilation of lidar network measurements in improving PM_{10} concentration analysis and forecast. It is compared to the efficiency of assimilating concentration measurements from the AirBase ground network, which includes about 500 stations in western Europe. It is found that the assimilation of lidar observations is more efficient at improving PM_{10} concentrations in terms of root mean square error and correlation after 12 hours of assimilation than the assimilation of AirBase measurements. Moreover, the spatial and temporal influence of the assimilation of lidar observations is larger and longer. In our experiments, the assimilation of lidar products improves PM_{10} forecast for 108 hours against 60 hours for AirBase assimilation. The results show a potentially powerful impact of the future lidar networks. Secondly, since a lidar is a very costly instrument, a sensitivity study on the number of required lidars is performed to help defining an optimal lidar network for PM_{10} forecast. The results suggest 12 lidar stations over western Europe, because a network with 26 lidar stations is more expensive and offers a limited improvement (less than $1\ \mu g\ m^{-3}$ of root mean square error on average) over the lidar network. A comparison of two networks with 12 lidar stations at different locations does not lead to substantial differences.

6.4. Reduction and emulation

The use of environmental models raise a number of problems due to:

- the dimension of the inputs, which can easily be $10^5 - -10^8$ at every time step;
- the dimension of the state vector, which is usually $10^5 - -10^7$;
- the high computational cost.

In particular, the application of data assimilation methods and uncertainty quantification techniques may require dimension reduction and cost reduction. The dimension reduction consists in projecting the inputs and the state vector to low-dimensional subspaces. The cost reduction can be carried out by emulation, i.e., the replacement of costly components with fast surrogates.

6.4.1. Reduction and emulation of a chemistry-transport model

Participants: Vivien Mallet, Serge Guillas [University College London].

Both reduction and emulation were applied to the dynamic air quality model Polair3D from Polyphemus. The reduction relied on proper orthogonal decomposition (POD) on the input data and on the state vector. The dimension of the reduced subspace for the input data is about 80, while the dimension of the reduced state vector is less than 10. The projection of the state vector on its reduced subspace can be carried out before every integration time step, so that one can reproduce a full state trajectory (in time) using the reduced model.

Significant advances were made to emulate the reduced model, which requires about 90 inputs (reduced input data and reduced state vector) and computes about 10 outputs (reduced state vector). 90 inputs is however a large number to build an emulator using a classical approaches. Promising results were however obtained with radial basis functions and an adapted kriging-based method.

6.4.2. Reduction and emulation of a static air quality model

Participants: Vivien Mallet, Anne Tilloy, Fabien Brocheton [Numtech], David Poulet [Numtech].

The dimension reduction was applied to the outputs of the urban air quality model ADMS Urban, which is a static model with low-dimensional inputs and high-dimensional outputs. A proper orthogonal decomposition (POD) on the outputs allowed us to drastically reduce their dimension, from 10^4 to just a few scalars. The emulation of the reduced model itself was successfully carried out with radial basis functions or an adapted kriging-based method. The resulting reduced/emulated model exhibited meaningful response to all variables. Its performance compared to observations was the same as the original model. The computational cost of the full model is about 8 minutes on 16 cores (for a single time step), while the reduced/emulated model requires only 50 ms on one core [29].

6.4.3. Motion estimation from images with a waveforms reduced model

Participants: Etienne Huot, Isabelle Herlin, Giuseppe Papari [Lithicon, Norway], Karim Drifi.

Dimension reduction is applied to an image model, composed of Lagrangian constancy of velocity and transport of image brightness. Waveforms basis are obtained on the image domain for subspaces of images, motion fields and divergence-free motion fields, as eigenvectors of quadratic functions. Image assimilation with th reduced model allows to estimate velocity fields satisfying space-time properties defined by user and traduced as a quadratic function. This approach also solves the issue of complex geographical domains and the difficulty of applying boundary conditions on these domains. Results are obtained with a reduced dimension of motion to a few scalars, to be compared with the original problem that has the size of image domain [31], [26], [25].

6.5. Ensemble forecasting with sequential aggregation

The aggregation of an ensemble of forecasts is an approach where the members of an ensemble are given a weight before every forecast time, and where the corresponding weighted linear combination of the forecasts provides an improved forecast. A robust aggregation can be carried out so as to guarantee that the aggregated forecast performs better, in the long run, than any linear combination of the ensemble members with time-independent weights. The approaches are then based on machine learning. The aggregation algorithms can be applied to forecast analyses (generated from a data assimilation system), so that the aggregated forecasts are naturally multivariate fields.

6.5.1. Application of sequential aggregation to meteorology

Participants: Paul Baudin, Vivien Mallet, Gilles Stoltz [CNRS], Laurent Descamps [Météo France].

Nowadays, it is standard procedure to generate an ensemble of simulations for a meteorological forecast. Usually, meteorological centers produce a single forecast, out of the ensemble forecasts, computing the ensemble mean (where every model receives an equal weight). It is however possible to apply aggregation methods. When new observations are available, the meteorological centers also compute analyses. Therefore, we can apply the ensemble forecast of analyses. Ensembles of forecasts for wind velocity and mean sea level pressure, from Météo France, were aggregated. Preliminary results show significant improvements for mean sea level pressure.

6.5.2. Sequential aggregation with uncertainty estimation

Participants: Vivien Mallet, Sergiy Zhuk [IBM research, Ireland], Paul Baudin, Gilles Stoltz [CNRS].

An important issue is the estimation of the uncertainties associated with the aggregated forecasts. One investigated direction relies on the framework of machine learning, with the aggregation of an ensemble of probability density functions instead of the point forecasts of the ensemble.

Another direction is to reformulate the aggregation problem in a filtering problem for the weights. The weights are supposed to satisfy some dynamics with unknown model error, which defines the state equation of a filter. An observation equation compares the aggregated forecast with the observations (or analyses) with known observational error variance. The filter finally computes estimates for the weights and quantifies their uncertainties. We applied a Kalman filter and a minimax filter for air quality forecasting. We also introduced a criterion that the filter results should satisfy if they are representative of the uncertainties [17].

6.6. Uncertainty quantification

Many uncertainties limit the forecast skills of geophysical simulations: limited understanding of physical phenomena, simplified representation of a system state and of the physical processes, inaccurate data and approximate numerical solutions. In many applications, a deterministic forecast or analysis is not enough a result since its uncertainties may be very large. It is of high interest to evaluate the quality of a forecast, before observations are available, and the quality of an analysis at any location, observed or not. An even more desirable result is the full probability density of system state, which can only be derived from a fully stochastic approach.

6.6.1. Sensitivity analysis in the dispersion of radionuclides

Participants: Sylvain Girard [IRSN], Vivien Mallet, Irène Korsakissok [IRSN].

We carried out a sensitivity analysis of the dispersion of radionuclides during Fukushima disaster. We considered the dispersion at regional scale, with the Eulerian transport model Polair3D from Polyphemus. The sensitivities to most input parameters were computed using the Morris method (with 8 levels and 100 trajectories). The influences of 19 scalar parameters were quantified. The scalar parameters were additive terms or multiplicative factors applied to 1D, 2D or 3D fields such as emission rates, precipitations, cloud height, wind velocity. It was shown that, depending on the output quantities of interest (various aggregated atmospheric and ground dose rates), the sensitivity to the inputs may greatly vary. Very few parameters show low sensitivity in any case. The vertical diffusion coefficient, the scavenging factors, the winds and precipitation intensity were found to be the most influential inputs. Most input variables related to the source term (emission rates, emission dates) also had a strong influence.

6.7. Image assimilation

Sequences of images, such as satellite acquisitions, display structures evolving in time. This information is recognized of major interest by forecasters (meteorologists, oceanographers, etc.) in order to improve the information provided by numerical models. However, these satellite images are mostly assimilated in geophysical models on a point-wise basis, discarding the space-time coherence visualized by the evolution of structures such as clouds. Assimilating in an optimal way image data is of major interest and this issue should be considered in two ways:

- from the model's viewpoint, the location of structures on the observations is used to control the state vector.
- from the image's viewpoint, a model of the dynamics and structures is built from the observations.

6.7.1. Divergence-free motion estimation

Participants: Dominique Béréziat [UPMC], Isabelle Herlin, Sergiy Zhuk [IBM Research, Ireland].

This research addresses the issue of divergence-free motion estimation on an image sequence, acquired over a given temporal window. Unlike most state-of-the-art technics, which constrain the divergence to be small thanks to Tikhonov regularization terms, a method that imposes a null value of divergence of the estimated motion is defined.

Motion is either characterized by its vorticity value or by its coefficients on a divergence-free basis and assumed to satisfy the Lagragian constancy hypothesis. An image assimilation method, based on the 4D-Var technic, is defined that estimates motion as a compromise between the evolution equations of vorticity or projection coefficients and the observed sequence of images.

The method is applied on Sea Surface Temperature (SST) images acquired over Black Sea by NOAA-AVHRR sensors. The divergence-free assumption is roughly valid on these acquisitions, due to the small values of vertical velocity at the surface.

6.7.2. Model error and motion estimation

Participants: Dominique Béréziat [UPMC], Isabelle Herlin.

Data assimilation technics are used to retrieve motion from image sequences. These methods require a model of the underlying dynamics, displayed by the evolution of image data. In order to quantify the approximation linked to the chosen dynamic model, an error term is included in the evolution equation of motion and a weak formulation of 4D-Var data assimilation is designed. The cost function to be minimized simultaneously depends on the initial motion field, at the begining of the studied temporal window, and on the error value at each time step. The result allows to assess the model error and analyze its impact on motion estimation.

The approach has been used to estimate the impact of geophysical forces (gravity, Coriolis, diffusion) and better assess the surface dynamics [24].

6.7.3. Tracking of structures from an image sequence

Participants: Yann Lepoittevin, Isabelle Herlin, Dominique Béréziat [UPMC].

The research concerns an approach to estimate velocity on an image sequence and simultaneously segment and track a given structure. It relies on the underlying dynamics' equations of the studied physical system. A data assimilation method is designed to solve evolution equations of image brightness, those of motion's dynamics, and those of the distance map modeling the tracked structures. The method is applied on meteorological satellite data, in order to track tropical clouds on image sequences and estimate their motion, as seen on Fig. 3.

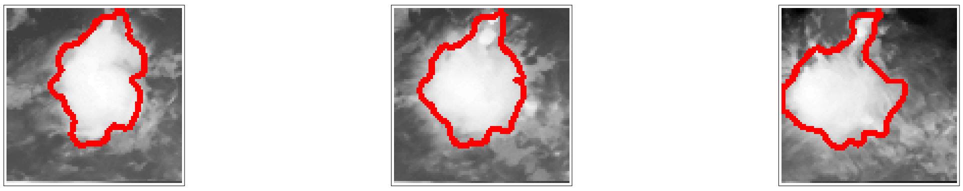

Figure 3. Tracking a tropical cloud. Frames 3, 9, 18 of the sequence.

Quantification is obtained on synthetic experiments by comparing trajectories of characteristic points. The respective position of these points on the last image of the sequence for different methods may be compared to that obtained with ground truth as seen on Fig. 4.

Data assimilation is performed either with a 4D-Var variational approach [27], [30], [28] or with an ensemble approach. In the last case, computation of the ensemble from optical flow methods of the literature is currently studied.

6.8. Minimax filtering

In minimax filtering for state estimation, the initial state error, the model error and the observation errors are supposed to belong to one joint ellipsoid. It is only assumed that the errors, stochastic or deterministic, are bounded. During the assimilation process, the filter computes an ellipsoid where one will find at least all states compatible with observations and errors description. The state estimate is taken as the center of the ellipsoid. No assumption on the actual distribution of the errors in needed and the state estimate minimizes the worst-case error, which makes the filter robust.

6.8.1. Retrieval of a continuous image function and a posteriori minimax motion estimation

Participants: Sergiy Zhuk [IBM Research, Ireland], Isabelle Herlin, Olexander Nakonechnyi [Taras Shevchenko National University of Kyiv], Jason Frank [CWI, the Netherlands].

An iterative minimax method is developed for the problem of motion estimation from an image sequence. The main idea of the algorithm is to use the "bi-linear" structure of the Navier-Stokes equations and optical flow constraint in order to iteratively estimate the velocity. The algorithm consists of the following parts:

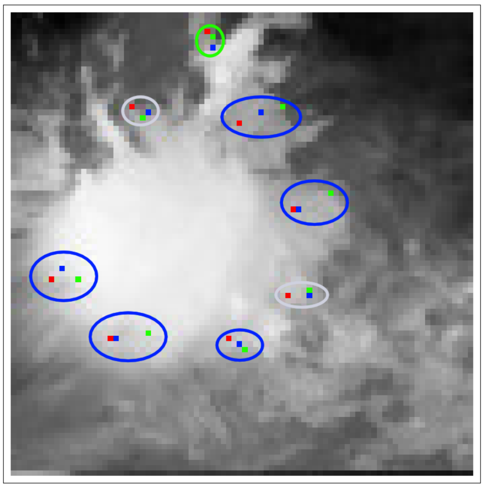

Figure 4. Red point: ground truth. Blue point: our method. Green point: Sun's optical flow. Blue ellipse: our method is the best. Green ellipse: Sun's result is the best. Grey ellipse : results are equivalent.

1) we construct a continuous image function $\widehat{I}$, solving the optical flow constraint, such that $\widehat{I}$ fits (in the sense of least-squares) the observed sequence of images. To do so, we set the velocity field in the optical flow constraint to be the current minimax estimate of the velocity field $\mathbf{w}$, obtained at the previous iteration of the algorithm, and construct the minimax estimate $\widehat{I}$ of the resulting linear advection equation using the observed image sequence as discrete measurements of the brightness function;

2) we plug the estimate of the image gradient, obtained out of pseudo-observations $\widehat{I}$ in 1), into the optical flow constraint and the current minimax estimate $\mathbf{w}$ of the velocity field into the non linear part of Navier-Stokes equations so that we end up with a system of linear PDEs, which represents an extended state equation: it contains a linear parabolic equation for the velocity field and linear advection equation for the image brightness function. We construct the minimax estimate of the velocity field from the extended state equation using again the observed image sequence as discrete measurements of the brightness function;

3) we use the minimax estimate of the velocity field obtained in 2) in order to start 1) again.

Alternatively, point 1) may be used to retrieve a continuous image function from sparse and noisy image snapshots, based on previous motion estimation with a 4D-Var technic as seen on Fig. 5, that displays ground truth, noisy image observation, image estimation at the end of the studied intervall.

6.9. Fire application

6.9.1. Model evaluation for fire propagation

Participants: Vivien Mallet, Jean-Baptiste Fillipi [CNRS], Bahaa Nader [University of Corsica].

In the field of forest fires risk management, important challenges exist in terms of people and goods preservation. Answering to strong needs from different actors (firefighters, foresters), researchers focus their efforts to develop operational decision support system tools that may forecast wildfire behavior. This requires the evaluation of model performance, but currently, simulation errors are not sufficiently qualified and quantified.

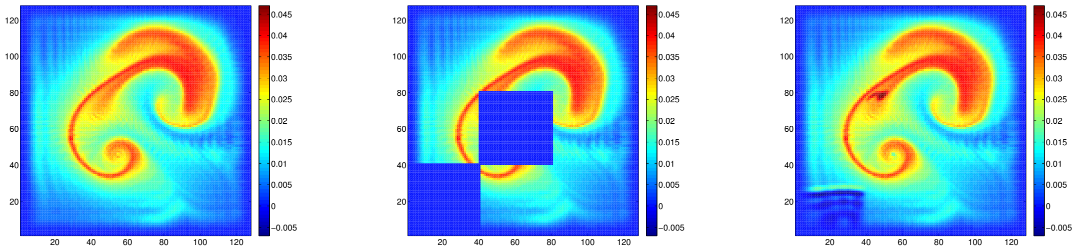

Figure 5. From left to right: Ground truth, image observation, result.

We consider that the proper evaluation of a model requires to apply it to a large number of fires – instead of carrying out a fine tuning on just one fire. We implemented a software to simulate a large number of fires (from the Prométhée database, http://www.promethee.com/) with the simulation model ForeFire (CNRS/University of Corsica) and evaluate the results with error measures [15]. One simulation requires mainly the following data: the ignition point, the ground elevation, the vegetation cover and the wind field. See illustration in Fig. 6. We simulated 80 fires with four physical models, which proved that the most advanced models performed better overall, even though the input data is often inaccurate. We also carried out Monte Carlo simulations to evaluate the impact of the uncertainty in input data. We showed that the Monte Carlo approach led to a reliable forecasting system, which suggests that the probability densities derived from the simulations (see Fig. 6) may be useful information for preventive actions in an operational context.

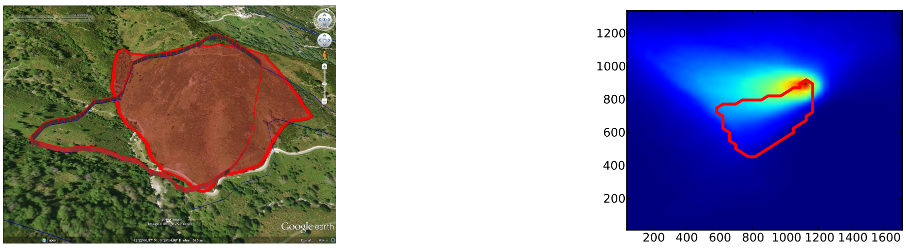

Figure 6. Left: Fire simulation (using ForeFire) in red elevated contour, and observation (from Prométhée) of the burned area in filled red contour, for a 2003 fire near San-Giovanni-di-Moriani (Corsica). Right: Burn probability as computed by a Monte Carlo simulation for a wildfire that was observed (red contour) in Corsica in 2003.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

- Clime is partner with INERIS (National Institute for Environmental and Industrial Risks http://www.ineris.com/en) in a joint cooperation devoted to air quality forecast. This includes research topics in uncertainty estimation, data assimilation and ensemble modeling.

  Clime also provides support to INERIS in order to operate the Polyphemus system for ensemble forecasting, uncertainty estimations and operational data assimilation at continental scale.

- Clime is partner with IRSN http://www.irsn.fr/, the French national institute for radioprotection and nuclear safety, for inverse modeling of emission sources and uncertainty estimation of dispersion simulations. The collaboration aims at better estimating emission sources, at improving operational forecasts for crisis situations and at estimating the reliability of forecasts. The work is derived at large scale (continental scale) and small scale (a few kilometers around a nuclear power plant).
- Clime takes part to a joint Ilab with the group SETH (Numtech http://www.numtech.fr/). The objective is to (1) transfer Clime work in data assimilation, ensemble forecasting and uncertainty estimation, with application to urban air quality, (2) identify the specific problems encountered at urban scale in order to determine new research directions.

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. ANR

- The ANR project Estimair aims at quantifying the uncertainties of air quality simulations at urban scale. The propagation of uncertainties requires the use of model reduction and emulation. A key uncertainty source lies in the traffic emissions, which will be generated using a dynamic trafic assignment model. Ensembles of traffic assignments will be calibrated and used in the uncertainty quantification. Estimair is led by Clime.
- Clime is one partner of the ANR project GeoFluids. It focuses on the specification of tools to analyse geophysical fluid flows from image sequences. Clime objectives concern the definition of reduced models from image data.
- Clime takes part to the ANR project IDEA that addresses the propagation of wildland fires. Clime is in charge of the estimation of the uncertainties, based on sensitivity studies and ensemble simulations.

8.1.2. PRIMEQUAL (ADEME)

- Clime takes part to the PRIMEQUAL project PREQUALIF, "Programme Pluridisciplinaire de REcherche sur la QUALité de l'air en Île-de-France" (i.e., "Multidisciplinary Program on Air quality research in Île-de-France"). The objective is to investigate the impact of low emission zones. The project aims at designing a new generation of diagnostic tools for assessment of health and analysis of economic benefits attributed to traffic restrictions. Clime brings data assimilation expertise which allows to compute the most accurate air pollution maps.

8.2. European Initiatives

8.2.1. Collaborations in European Programs, except FP7

Program: COST Action ES104.

Project acronym: EuMetChem.

Project title: European framework for online integrated air quality and meteorology modeling.

Duration: January 2011 - December 2014.

Coordinator: Alexander Baklanov, Danish Meteorological Institute (DMI) Danemark.

Other partners: around 14 european laboratories, experts from United States, ECMWF.

Abstract: European framework for online integrated air quality and meteorology modeling (EuMetChem) focuses on a new generation of online integrated Atmospheric Chemical Transport (ACT) and Meteorology (Numerical Weather Prediction and Climate) modeling with two-way interactions between different atmospheric processes including chemistry (both gases and aerosols), clouds, radiation, boundary layer, emissions, meteorology and climate. Two application areas of the integrated modeling are considered: (i) improved numerical weather prediction (NWP) and chemical weather forecasting (CWF) with short-term feedbacks of aerosols and chemistry on meteorological variables, and (ii) two-way interactions between atmospheric pollution/ composition and climate variability/change. The framework consists of four working groups namely: 1) Strategy and framework for online integrated modeling; 2) Interactions, parameterizations and feedback mechanisms; 3) Chemical data assimilation in integrated models; and finally 4) Evaluation, validation, and applications. Establishment of such a European framework (involving also key American experts) enables the EU to develop world class capabilities in integrated ACT/NWP-Climate modeling systems, including research, forecasting and education.

8.2.2. Collaborations with Major European Organizations

Partner: ERCIM working group “Environmental Modeling”.

The working group gathers laboratories working on developing models, processing environmental data or data assimilation.

8.3. International Initiatives

8.3.1. Inria International Partners

8.3.1.1. Informal International Partners

Partner: Chilean meteorological office (Dirección Meteorológica de Chile)

The partner produces its operational air quality forecasts with Polyphemus. The 3-day forecasts essentially cover Santiago. The forecasts are accessible online in the form of maps, time series and video (http://www.meteochile.gob.cl/modeloPOLYPHEMUS.php).

Partner: Marine Hydrophysical Institute http://mhi.nas.gov.ua/eng/, Ukraine.

The collaboration concerns the study of the Black Sea surface circulation and the issue of image assimilation in forecasting models.

Partner: IBM Research, Dublin, Ireland

The collaboration addresses the assimilation of classical observations as well as images, with application to geophysics. New assimilation methods are developed, mainly based on minimax filtering.

8.4. International Research Visitors

8.4.1. Visits of International Scientists

- Sergiy Zhuk, IBM, Dublin Research Lab, Ireland, September 2013.

9. Dissemination

9.1. Scientific Animation

- Marc Bocquet is a member of the INSU/LEFE MANU scientific commitee.
- Marc Bocquet is a member of the Scientific Council of the CERFACS institute in Toulouse, France.
- Marc Bocquet is Associate Editor of the Quaterly Journal of the Royal Meteorological Society.

- Marc Bocquet co-organised the LEFE-MANU workshop “Que peuvent attendre les modélisateurs de l’assimilation de données ?” with Frédéric Chevallier and Jacques Verron,12 February 2013, Inria, Paris, France.
- Marc Bocquet co-organised the symposium “Open session on Data Assimilation” with Jacques Blum, and Olivier Talagrand. MCPIT 2013, GDRE ConEDP, Insitut Henri Poincaré, Paris, France, 19 November 2013.
- Isabelle Herlin is a member of the Scientific Council of CSFRS (High Council for Strategic Education and Research in France).
- Isabelle Herlin is a member of the program committee of DIGITEO, french research cluster in science and technology of information.
- Isabelle Herlin is a member of the Scientific Council of OSU-EFLUVE.
- Isabelle Herlin is a member of Evaluation Committee at Inria.
- Isabelle Herlin co-organised a session on operational oceanography in the European Geosciences Union General Assembly 2013 (EGU2013), 07-12 April 2013, Vienna, Austria.
- Isabelle Herlin is a member of the scientific committee of the conference “Image Sequence Analysis for Object and Change Detection”, organized by the International Society for Photogrammetry and Remote Sensing (ISPRS).

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Master OACOS/WAPE: Marc Bocquet, Vivien Mallet; Introduction to Data Assimilation for Geophysics; 30 hours; M2; UPMC, X, ENS, ENSTA ParisTech, École des Ponts ParisTech; France.

Master "Nuclear Energy": Marc Bocquet, Vivien Mallet; 12 hours; M2; École des Ponts ParisTech; France.

Master SGE and École des Ponts ParisTech: Vivien Mallet; Air Pollution; 6 hours; M2; École des Ponts ParisTech , Paris 7-Diderot, Paris Est; France.

Master in applied mathematics and scientific computing: Vivien Mallet; Introduction to Data Assimilation and Uncertainty Quantification in Geosciences; 11 hours; M2; Sup’Galilée, University Paris 13, École centrale Marseille; France.

Training: Vivien Mallet; Uncertainty Quantification: Ensembles and Data Assimilation – Application to Climate and Geosciences; 5.25 hours; CERFACS; France.

9.2.2. Supervision

PhD : Karim Drifi, “Reduced models for image assimilation”, University Paris Centre, July 1st, 2012, Isabelle Herlin.

PhD : Yiguo Wang, "Une nouvelle approche de modélisation de la qualité de l’air à l’échelle régionale par assimilation de mesures lidar", École Polytechnique, 20 December 2013, Marc Bocquet, Karine Sartelet, Patrick Chazette.

PhD in progress : Paul Baudin, “Agrégation séquentielle de prédicteurs appliquée à la prévision de la qualité de l’air”, September 2012, Vivien Mallet and Gilles Stoltz.

PhD in progress : Jean-Matthieu Haussaire, “Méthodes variationnelles d’ensemble pour la modélisation inverse en géosciences. Application au transport et la chimie atmosphérique”, University Paris-Est, October 2013, Marc Bocquet.

PhD in progress : Yann Lepoittevin, “Tracking of image structures”, University Paris Centre, October 2012, Isabelle Herlin.

PhD in progress : Jean Thorey, “Prévision d’ensemble du rayonnement solaire pour la production photovoltaïque du parc EDF”, November 2013, Vivien Mallet.

PhD in progress : Victor Winiarek, “Dispersion atmosphérique en milieu urbain et modélisation inverse pour la reconstruction de sources”, University Paris Est, October 2009, Marc Bocquet.

9.2.3. Juries

- Bocquet, M., member, PhD thesis, Benjamin Gaubert, “Assimilation des observations pour la modélisation de la qualité de l’air”, Paris Diderot University , 8 July 2013, Créteil, France.
- Bocquet, M., member, PhD thesis, Bertrand Bonan, “Assimilation de données pour l’initialisation et l’estimation de paramètres d’un modèle d’évolution de calotte polaire”, 15 November 2013, Grenoble University, Grenoble, France.
- Bocquet, M., member, PhD thesis, Yiguo Wang, “Une nouvelle approche de modélisation de la qualité de l’air à l’échelle régionale par assimilation de mesures lidar”, 20 December 2013, University Paris-Est, Champs-sur-Marne, France.
- Herlin, I., reviewer, PhD thesis, Anastase Charantonis, “Méthodologie d’inversion de données océaniques de surface pour la reconstitution de profils verticaux en utilisant des chaînes de Markov cachées et des cartes auto-organisatrices”, January 24th 2013, Paris, France.

9.3. Popularization

- Marc Bocquet made a presentation on employment in the environment sector at the second “Forum Maths Emploi”, January 2013, Paris.
- Marc Bocquet wrote a paper [32] on “Modélisation numérique de la dispersion atmosphérique accidentelle des radionucléides : l’état de l’art de la recherche” in the journal “Revue du Centre de Défense NBC”.
- Isabelle Herlin and Vivien Mallet wrote an introduction to air quality simulation [33] for a special issue on Mathematics for Planet Earth dedicated to teachers in french “collèges” and “lycées” and an internet contribution [35] “Votre air, votre santé”: http://mpt2013.fr/votre-air-votre-sante/
- Vivien Mallet introduced numerical simulation of air pollution at the 2013 edition of “Mathématiques en mouvement”.
- Vivien Mallet and Anne Tilloy took part to the festival “Futur en Seine” and presented, during four days, research advances in air quality simulation at urban scale.

10. Bibliography

Major publications by the team in recent years

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[2] D. Béréziat, I. Herlin. *Solving ill-posed Image Processing problems using Data Assimilation*, in "Numerical Algorithms", February 2011, vol. 56, n^{o} 2, pp. 219-252 [*DOI :* 10.1007/s11075-010-9383-z], http://hal.inria.fr/inria-00538510

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