Activity Report 2014

Project-Team CLIME

Coupling environmental data and simulation models for software integration

RESEARCH CENTER
Paris - Rocquencourt

THEME
Earth, Environmental and Energy Sciences

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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 created 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 through collaborations with CEREA (Centre d'Enseignement et de Recherche en Environnement Atmosphérique, École des Ponts ParisTech): 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 with LOCEAN (Laboratoire d'OCEANographie et du climat, UPMC).

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 pixel 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 Météo-France, 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 first 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 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. The ensemble methods allow 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 acquisitions are assimilated into these 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. New Software and Platforms

5.1. Data assimilation library: Verdandi

Participants: Nicolas Claude, Vivien Mallet, Dominique Chapelle [M3DISIM], Philippe Moireau [M3DISIM].

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 2014, version 1.6 was released with a lot of new unit tests, within the Google Test framework. The extended Kalman filter now supports model error. For users of C++11, a native random perturbation manager has been added and allows to circumvent the use of Newran. The overall compatibility with Clang has been reinforced. The documentation was significantly improved, especially about the installation under Windows and Linux.

5.2. Image processing library: Heimdali

Participants: David Froger [SED], Dominique Béréziat, Isabelle Herlin.

The initial aim of the image processing library Heimdali was to replace an internal Inria library (named Inrimage) by a library based on standard and open source tools, and mostly dedicated to satellite acquisitions.

The leading idea of the library is to allow the following issues:

- making easier the sharing and development of image assimilation softwares. For that purpose, the installation is easily achieved with the package manager Conda.
- developing generic tools for image processing and assimilation based on ITK (Insight Segmentation and Registration Toolkit http://www.itk.org). In reverse providing tools to ITK and contribute to the ITK community. Our software corresponds to issues related to satellite acquisitions but could be of interest for processing medical image sequences.

The main components of Heimdali concern:

- the pre/post processing of image sequences,
- the image assimilation with numerical models,
- the visualization of image sequences.

In 2014, prototypes of the two first items have been defined. The development of the whole library should be available in 2015.

5.3. Polyphemus

Participants: Sylvain Doré, Vivien Mallet, 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 post-processing abilities (AtmoPy);
- programs for physical pre-processing 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.

Fig. 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 2014, Polyphemus was developed to better handle in-cloud and below-cloud scavenging. The interface of its Eulerian model, Polair3D, was extended to allow for detailed sensitivity analysis.

6. New Results

6.1. Highlights of the Year

BEST PAPER AWARD :

[20] **Image-based modelling of ocean surface circulation from satellite acquisitions in VISAPP - International Conference on Computer Vision Theory and Applications**. D. BÉRÉZIAT, I. HERLIN.

6.2. State estimation: analysis and forecast

One major objective of Clime is the conception of new methods of data assimilation in geophysical sciences. Clime is active on several challenging aspects: non-Gaussian assumptions, multiscale assimilation, minimax filtering, etc.

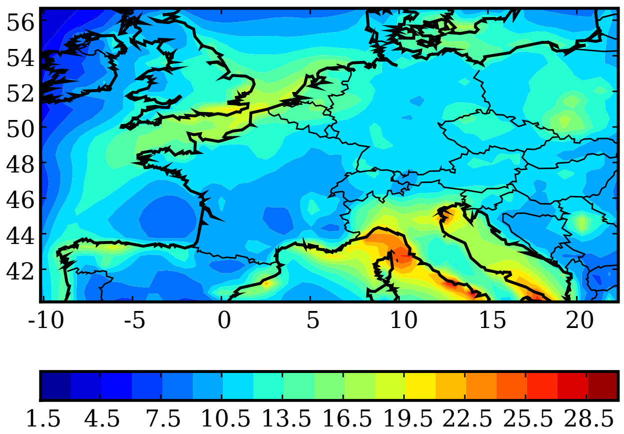


Figure 1. Map of the relative standard deviation (or spread, %) of an ensemble built with Polyphemus (ozone simulations, $\mu g\ m^{-3}$). The standard deviations are averaged over the summer of 2001. They provide an estimation of the simulation uncertainties.

6.2.1. An iterative ensemble Kalman smoother

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

The iterative ensemble Kalman filter (IEnKF) was proposed for improving the performance of the ensemble Kalman filter on 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). IEnKS is an ensemble variational method. It does not require the use of the tangent of the evolution and observation models, nor the adjoint of these models: the required sensitivities (gradient and Hessian) are computed from the ensemble. Looking for the optimal performance, we consider a quasi-static algorithm, out of the many possible extensions. IEnKS was explored on the Lorenz'95 model and on a 2D turbulence model. As a logical extension of IEnKF, IEnKS significantly outperforms the 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.

6.2.2. Modeling and assimilation of lidar signals

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

In this study, we investigate the ability of the chemistry transport model (CTM) Polair3D of the air quality platform Polyphemus to simulate lidar backscattered profiles from model aerosol concentration outputs. This investigation is an important pre-processing stage of data assimilation (validation of the observation operator). To do so, simulated lidar signals are compared to hourly lidar observations performed during the MEGAPOLI (Megacities: Emissions, urban, regional and Global Atmospheric POLlution and climate effects, and Integrated tools for assessment and mitigation) summer experiment in July 2009, when a ground-based mobile lidar was deployed around Paris on-board a van. The comparison is performed for six days (1, 4, 16, 21, 26 and 29 July 2009), corresponding to different levels of pollution and different atmospheric conditions. Overall, Polyphemus reproduces well the vertical distribution of lidar signals and their temporal variability, especially for 1, 16, 26 and 29 July 2009. Discrepancies on 4 and 21 July 2009 are due to high-altitude aerosol layers, which are not well modeled. In the second part of this study, two new algorithms for assimilating lidar observations based on the optimal interpolation method are presented. One algorithm analyses PM_{10} (particulate matter with diameter less than 10 μm) concentrations. Another analyses $PM_{2.5}$ (particulate matter with diameter less than 2.5 μm) and $PM_{2.5-10}$ (particulate matter with a diameter higher than 2.5 μm and lower than 10 μm) concentrations separately. The aerosol simulations without and with lidar Data Assimilation (DA) are evaluated using the Airparif (a regional operational network in charge of air quality survey around the Paris area) database to demonstrate the feasibility and usefulness of assimilating lidar profiles for aerosol forecasts. The evaluation shows that lidar DA is more efficient at correcting PM_{10} than $PM_{2.5}$, probably because $PM_{2.5}$ is better modeled than PM_{10}. Furthermore, the algorithm which analyzes both $PM_{2.5}$ and $PM_{2.5-10}$ provides the best scores for PM_{10}. The averaged root-mean-square error (RMSE) of PM_{10} is 11.63 $\mu g\, m^{-3}$ with DA ($PM_{2.5}$ and $PM_{2.5-10}$), compared to 13.69 $\mu g\, m^{-3}$ with DA (PM_{10}) and 17.74 $\mu g\, m^{-3}$ without DA on 1 July 2009. The averaged RMSE of PM_{10} is 4.73 $\mu g\, m^{-3}$ with DA ($PM_{2.5}$ and $PM_{2.5-10}$), against 6.08 $\mu g\, m^{-3}$ with DA (PM_{10}) and 6.67 $\mu g\, m^{-3}$ without DA on 26 July 2009.

6.2.3. Assimilation of lidar signals: application to aerosol forecasting

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

This study represents a new application of assimilating lidar signals to aerosol forecasting. It aims at investigating the impact of a ground-based lidar network on the analysis and short-term forecasts of aerosols through a case study in the Mediterranean basin. To do so, we employ a Data Assimilation (DA) algorithm based on the optimal interpolation method developed in the Polair3D chemistry transport model (CTM) of the Polyphemus air quality modeling platform. We assimilate hourly averaged normalized range-corrected lidar signals retrieved from a 72 h period of intensive and continuous measurements performed in July 2012 by ground-based lidar systems of the European Aerosol Research Lidar Network (EARLINET). Particles with an aerodynamic diameter lower than 2.5 μm ($PM_{2.5}$) and those with an aerodynamic diameter higher than 2.5 μm but lower than 10 ($PM_{10-2.5}$) are analyzed separately using the lidar observations at each DA step. First, we study the spatial and temporal influences of the assimilation of lidar signals on aerosol forecasting. We conduct sensitivity studies on algorithmic parameters, e.g. the horizontal correlation length ($L_{\rm h}$) used in the background error covariance matrix (50 km, 100 km or 200 km), the altitudes at which DA is performed (0.75–3.5 km, 1.0–3.5 km or 1.5–3.5 km) and the assimilation period length (12 h or 24 h). We find that DA with $L_{\rm h} = 100$ km and assimilation from 1.0 to 3.5 km during a 12 h assimilation period length leads to the best scores for PM_{10} and $PM_{2.5}$ during the forecast period with reference to available measurements from surface networks. Secondly, the aerosol simulation results without and with lidar DA using the optimal parameters ($L_{\rm h}$ = 100 km, an assimilation altitude range from 1.0 to 3.5 km and a 12 h DA period) are evaluated using the level 2.0 (cloud-screened and quality-assured) aerosol optical depth data from AERONET, and mass concentration measurements (PM_{10} or $PM_{2.5}$) from the French air quality (BDQA) network and the EMEP-Spain/Portugal network. The results show that the simulation with DA leads to better scores than the one without DA for $PM_{2.5}$, PM_{10} and aerosol optical depth. Additionally, the comparison of model results to evaluation data indicates that the temporal impact of assimilating lidar signals is longer than 36 h after the assimilation period.

Fig. 2 shows the performance of assimilating real lidar data over the Mediterranean sea with a view to forecast particulate matter over France.

6.2.4. Local ensemble transform Kalman filter for adaptive optics on extremely large telescopes

Participants: Morgan Gray [LAM, France], Cyril Petit [ONERA, France], Sergei Rodionov [LAM, France], Marc Bocquet, Laurent Bertino [NERSC, Norway], Marc Ferrari [LAM, France], Thierry Fusco [LAM and ONERA, France].

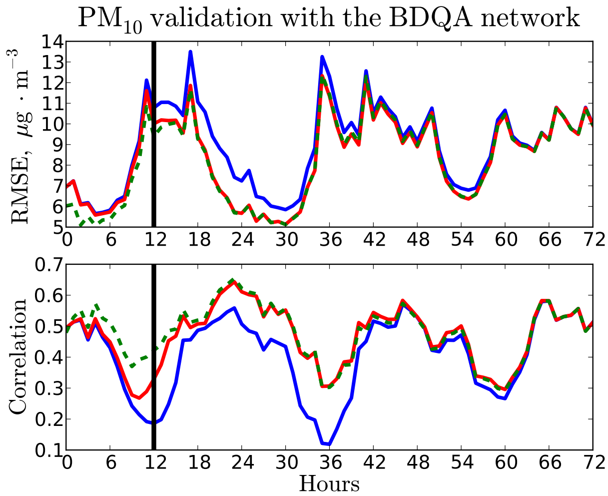


Figure 2. Validation of forecasts of particulate matter PM_{10} using ground stations over France when lidar data have been assimilated over the Mediterranean sea. These forecasts (red line: 12-hour assimilation period and dashed green line: 24-hour assimilation period) are compared to a free run (blue line).

We proposed a new algorithm for an adaptive optics system control law, based on the Linear Quadratic Gaussian approach and a Kalman Filter adaptation with localizations. It allows to handle non-stationary behaviors, to obtain performance close to the optimality defined with the residual phase variance minimization criterion, and to reduce the computational burden with an intrinsically parallel implementation on the Extremely Large Telescopes.

6.3. Inverse modeling

Research on inverse modeling techniques is a major component of Clime, with a focus, in 2014, on hyperparameter estimation when the statistics are non-Gaussian.

6.3.1. Estimation of the caesium-137 source term from the Fukushima Daiichi plant

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 emphasized 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. 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.

6.4. 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, the 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.

6.4.1. 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 depends simultaneously on the initial motion field, at the beginning 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 is used to estimate geophysical forces (gravity, Coriolis, diffusion) from images in order to better assess the surface dynamics [20] and forecast the displacement of structures like oilspill.

6.4.2. 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.

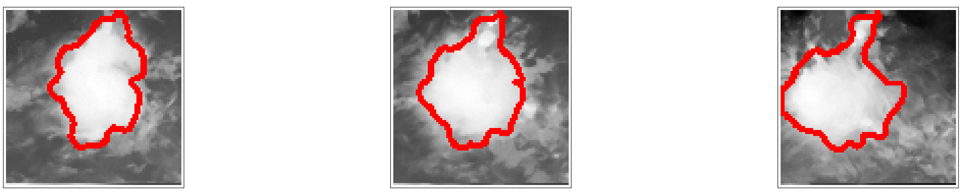


Figure 3. Tracking a tropical cloud. Frames 3, 9, 18 of the sequence.

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.

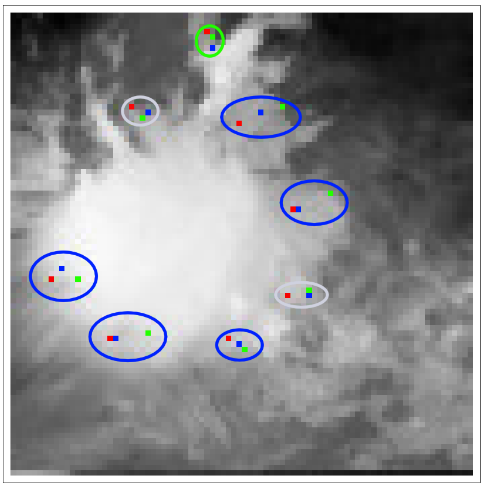


Figure 4. Red point: ground truth. Blue point: our method. Green point: Sun's optical flow. Blue ellipse: our method is the best. Green ellipse: Sun's result is the best. Grey ellipse : results are equivalent.

Data assimilation is performed either with a 4D-Var variational approach or with a Kalman ensemble method [22]. In the last case, the initial ensemble is obtained from a set of optical flow methods of the literature with various parameters values.

6.4.3. Motion estimation from images with a waveforms reduced model

Participants: Etienne Huot, Isabelle Herlin, Giuseppe Papari [CFLIR, Belgium].

Dimension reduction is applied to a model of image evolution, composed of transport of velocity and image brightness. Waveform bases are obtained on the image domain for subspaces of images and motion fields, as eigenvectors of previously defined quadratic functions. Image assimilation with the reduced model allows to estimate velocity fields satisfying the space-time properties chosen defined by the user for designing the quadratic function. This approach allows complex geographical domains and suppresses the difficulty of boundary conditions on such domains: these boundary conditions are automatically applied on the bases elements. Motion estimation is then obtained with a reduced model whose state vector is composed of a few components for motion and images. This has to be compared with the initial motion estimation problem that involves a state vector that has a size proportional to the image domain. Current research concern the definition of new quadratic functions from image properties.

6.4.4. Applying POD on a model output dabase for defining a reduced motion model

Participants: Etienne Huot, Isabelle Herlin.

Dimension reduction may also be studied by determining a small size reduced basis obtained by Proper Orthogonal Decomposition (POD) of a motion fields database. This database is constructed for characterizing accurately the surface circulation of the studied area, so that linear combinations of the basis elements obtained by POD accurately describe the motion function observed on satellite image sequences. The database includes the geostrophic motion fields obtained from Sea Level Anomaly reanalysis maps that are available from the MyOcean European project website (http://www.myocean.eu/). Fig. 5 displays such SLA maps and the associated motion fields.

Image assimilation with the POD reduced model allows estimating motion as displayed on Fig. 6.

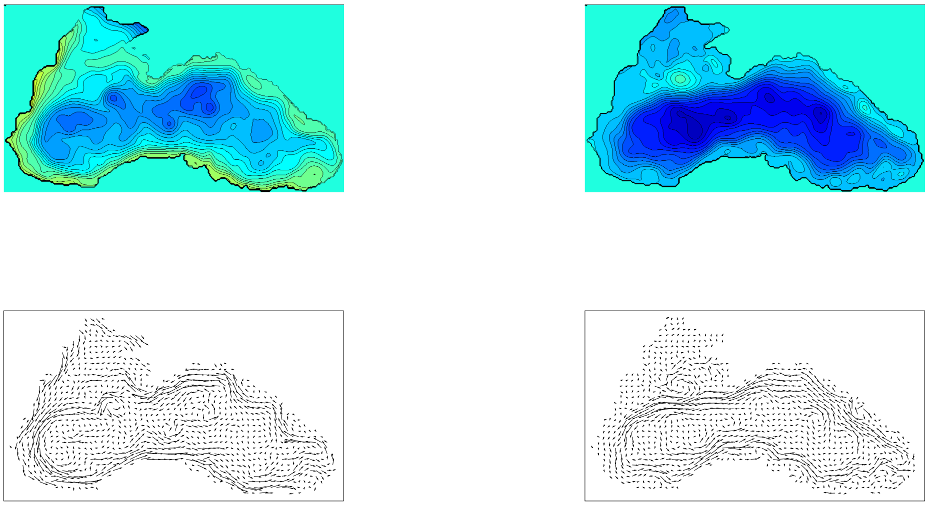


Figure 5. Top: reanalysis of SLA. Bottom: geostrophic motion.

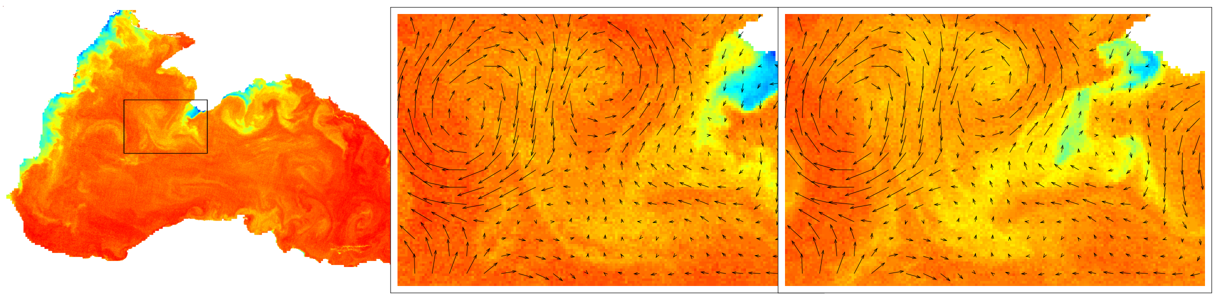


Figure 6. Zoom on a region of interest and motion estimation superposed on two consecutive images.

6.4.5. Rain nowcasting from radar image acquisitions

Participants: Yann Lepoittevin, Isabelle Herlin.

This research concerns the design of an operational method for rainfall nowcasting that aims at prevention of flash floods. The nowcasting method is based on two main components:

- a data assimilation method, based on radar images, estimates the state of the atmosphere: this is the estimation phase.
- a forecast method uses this estimation to extrapolate the state of the atmosphere in the future: this is the forecast phase.

Results were analyzed by Numtech (partner of a joint I-lab) on space-time neighborhood in order to prevent consequences of flash floods on previously defined zone.

Current research concerns the use of object components in the state vector in order to get an improved motion estimation and a better localization of endangered regions.

6.5. Uncertainty quantification and risk assessment

The uncertainty quantification of environmental models raises 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 required when integrating the model in time.

While uncertainty quantification is a very active field in general, its implementation and development for geosciences requires specific approaches that are investigated by Clime. The project-team tries to determine the best strategies for the generation of ensembles of simulations. In particular, this requires addressing the generation of large multimodel ensembles and the issue of dimension reduction and cost reduction. The dimension reduction consists in projecting the inputs and the state vector to low-dimensional subspaces. The cost reduction is carried out by emulation, i.e., the replacement of costly components with fast surrogates.

6.5.1. Application of sequential aggregation to meteorology

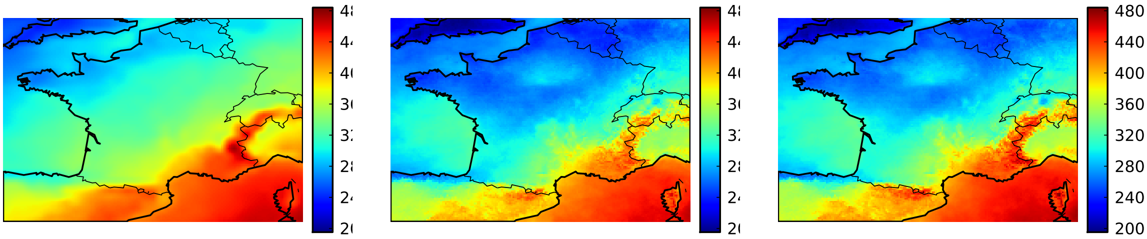
Participants: Jean Thorey, Paul Baudin, Vivien Mallet, Stéphanie Dubost [EDF R&D], Christophe Chaussin [EDF R&D], Laurent Dubus [EDF R&D], Luc Musson-Genon [CEREA, EDF R&D], Laurent Descamps [Météo France], Philippe Blanc [Armines], Gilles Stoltz [CNRS].

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 mean sea level pressure, from the THORPEX Interactive Grand Global Ensemble, were aggregated with a forecast error decrease by 20% compared to the ensemble mean.

We studied the aggregation of ensembles of solar radiations in the context of photovoltaic production. The observations are based on MeteoSat Second Generation (MSG) and provided by the HelioClim-3 database as gridded fields. The ensembles of forecasts are from the THORPEX Interactive Grand Global Ensemble. The aggregated forecasts show a 20% error decrease compared to the individual forecasts. They are also able to retrieve finer spatial patterns than the ones found in the individual forecasts (see Figure 7).

6.5.2. Sequential aggregation with uncertainty estimation

Participants: Vivien Mallet, Jean Thorey, Paul Baudin, Gilles Stoltz [CNRS].



(a) (b) (c)

Figure 7. Yearly average of the map of downward shortwave solar radiation in $\mathrm{W m^{-2}}$*, for an ensemble mean (a), for our aggregated forecasts (b) and observed (c).*

An important issue is the estimation of the uncertainties associated with the aggregated forecasts. We devised a new approach to predict a probability density function or cumulative distribution function instead of a single aggregated forecast. In practice, the aggregation procedure aims at forecasting the cumulative distribution function of the observations which is simply a Heaviside function centered at the observed value. Our forecast is the weighted empirical cumulative distribution function based on the ensemble of forecasts. The method guarantees that, in the long run, the forecast cumulative distribution function has a continuous ranked probability score at least as good as the best weighted empirical cumulative function with weights constant in time.

6.5.3. Sensitivity analysis in the dispersion of radionuclides

Participants: Sylvain Girard, 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. The sensitivity analysis was carried out with the Morris method and by computing Sobol' indices. Both approaches were found to be consistent. Computing the Sobol' indices required the use of Gaussian process emulation, which proved to be successful at least on targets averaged in time and space.

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 in time and space (see Figure 8). 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.

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.

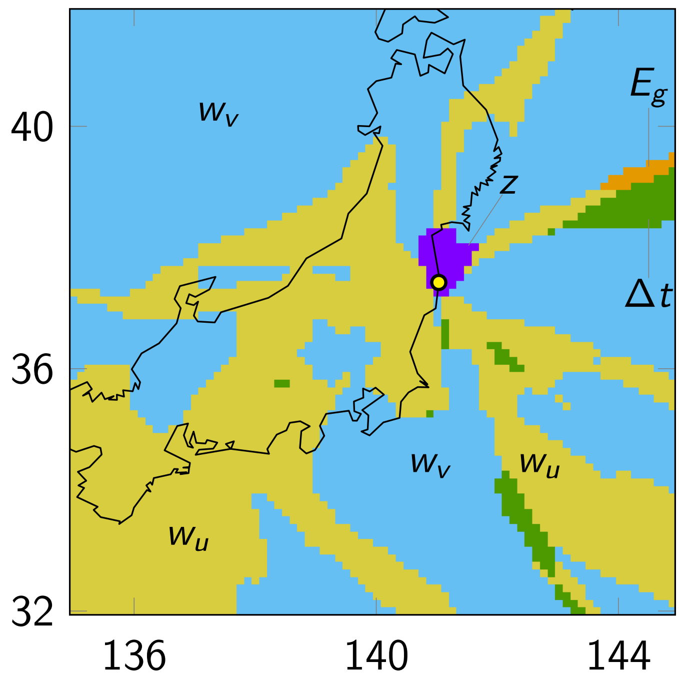


Figure 8. Variables that influence the most the atmospheric radioactivity after Fukushima disaster. z is the emissions altitude; Δt is the time shift on emissions; E_g stands for the emissions of noble gas; w_u and w_v are for zonal and meridional winds, respectively.

- 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, (3) carry out nowcasting rain events from radar images.

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.

8.2. European Initiatives

8.2.1. Collaborations in European Programs, except FP7 & H2020

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/en/index.html, 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.

9. Dissemination

9.1. Promoting Scientific Activities

- Marc Bocquet is a member of the INSU/LEFE MANU scientific committee.
- Marc Bocquet is a member of the Scientific Council of the CERFACS institute in Toulouse, France.
- Marc Bocquet is a member of the selection comittee of the Prix André Prud'homme of Météo et Climat (Société Météorologique de France).
- 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 the Evaluation Committee at Inria.
- Isabelle Herlin is a member of the AERES Evaluation Committee of LISTIC.

9.1.1. Scientific events organisation

9.1.1.1. general chair, scientific chair

- Marc Bocquet: Ensemble session, Colloque national sur l'assimilation de données LEFE-MANU, Toulouse, 1-3 December 2014.

9.1.1.2. member of the organizing committee

- Vivien Mallet: seminar on "Uncertainty quantification and ensemble-based methods for geo-sciences", École normale supérieure, Paris, January 2014.

9.1.2. Scientific events selection

9.1.2.1. reviewer

- Isabelle Herlin: European Conference on Computer Vision (ECCV)

- Isabelle Herlin: International Conference on Image Processing (ICIP).

9.1.3. Journal

9.1.3.1. member of the editorial board

- Marc Bocquet is Associate Editor of the Quaterly Journal of the Royal Meteorological Society.

9.1.3.2. reviewer

- Vivien Mallet: Atmospheric Chemistry and Physics.
- Vivien Mallet: Environmental Modeling & Software.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Master OACOS/WAPE: Marc Bocquet, Vivien Mallet, Jean-Matthieu Haussaire; 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, Jean-Matthieu Haussaire; 12 hours; M2; École des Ponts ParisTech, Centrale Paris, INSTN; France.

Master SGE and 3rd-year class at École des Ponts ParisTech: Vivien Mallet; Air quality modeling; 9h; M2; Universities Paris Diderot- Paris 7, Paris 12 and École des Ponts ParisTech, 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 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: Ruiwei Chen, "Quantification d'incertitude en simulation des émissions du trafic routier", November 2014, Vivien Mallet.

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: Raphaël Ventura, "Simulation numérique de la ville par couplage entre la modélisation et l'observation", September 2014, Vivien Mallet.

9.2.3. Juries

- Marc Bocquet, member, PhD thesis, Victor Winiarek, "Dispersion atmosphérique et modélisation inverse pour la reconstruction de sources accidentelles de polluants", 4 March 2014, University Paris-Est, Champs-sur-Marne, France.
- Marc Bocquet, reviewer, PhD thesis, Benjamin Ménétrier "Utilisation d'une assimilation d'ensemble pour modéliser des covariances d'erreur d'ébauche dépendantes de la situation météorologique à l'échelle convective", University Toulouse, 3 July 2014, Toulouse, France.
- Marc Bocquet, reviewer and chair, PhD thesis, Nabil BenSalem, "Modélisation directe et inverse de la dispersion atmosphérique en milieux complexes", École centrale de Lyon, 17 septembre 2014, Lyon, France.

- Marc Bocquet, member, PhD thesis, Vincent Loizeau, “La prise en compte d’un modèle de sol multi-couches pour la modélisation multi-milieux à l’échelle européenne des polluants organiques persistants”, 20 November 2014, University Paris-Est, Champs-sur-Marne, France.
- Marc Bocquet, member, PhD thesis, Yin Yang, “Study of Variational Ensemble Methods for Image Assimilation”, University Rennes 1, 16 December 2014, Rennes, France.
- Marc Bocquet, reviewer, PhD thesis, Antoine Berchet, “Quantification des émissions de méthane en sibérie par inversion atmosphérique à la méso-échelle”, University Versailles Saint-Quentin-en-Yvelines, 19 December 2014, Paris, France.
- Isabelle Herlin, reviewer, Hector Simon Benavides Pinjosovsky, PhD thesis, “Assimilation variationnelle des données dans le modèle de surface continentale ORCHIDEE grâce au logiciel YAO”, University Pierre and Marie Curie, 27 March 2014, Paris, France.

9.3. Popularization

- Marc Bocquet wrote a paper on “La prévision numérique du temps” in the journal “Revue de Technologie” meant for the teachers of vocational technical education.
- Victor Winiarek and Marc Bocquet wrote an internet contribution “de la radioactivité dans l’air”, which was published in the general audience book “Brève de maths”, Nouveau Monde éditions, Paris, 2014.
- Marc Bocquet and Mohammad Reza Koohkan wrote an internet contribution “Quand modèles numériques et mesures ne sont pas sur la même longueur d’onde”, which was also published in “Brève de maths”.
- Vivien Mallet took part to a one-day introduction to Inria research at Assemblée Nationale, as organized by the group “ Internet et société numérique”.
- Vivien Mallet introduced data assimilation at urban scale during the “rencontre Inria-industry” organized during the Futur-en-Seine digital festival.

10. Bibliography

Major publications by the team in recent years

[1] M. Bocquet, P. Sakov. *An iterative ensemble Kalman smoother*, in "Quarterly Journal of the Royal Meteorological Society", October 2013 [*DOI :* 10.1002/qj.2236], http://hal.inria.fr/hal-00918488

[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

[3] D. Garaud, V. Mallet. *Automatic calibration of an ensemble for uncertainty estimation and probabilistic forecast: Application to air quality*, in "Journal of Geophysical Research", October 2011, vol. 116 [*DOI :* 10.1029/2011JD015780], http://hal.inria.fr/hal-00655771

[4] I. Herlin, D. Béréziat, N. Mercier, S. Zhuk. *Divergence-Free Motion Estimation*, in "ECCV 2012 - European Conference on Computer Vision", Florence, Italie, A. Fitzgibbon, S. Lazebnik, P. Perona, Y. Sato, C. Schmid (editors), Lecture Notes in Computer Science, Springer, October 2012, vol. 7575, pp. 15-27 [*DOI :* 10.1007/978-3-642-33765-9_2], http://hal.inria.fr/hal-00742021

[5] M. R. KOOHKAN, M. BOCQUET. *Accounting for representativeness errors in the inversion of atmospheric constituent emissions: application to the retrieval of regional carbon monoxide fluxes*, in "Tellus B", July 2012, vol. 64, n° 19047 [*DOI :* 10.3402/TELLUSB.V64I0.19047], http://hal.inria.fr/hal-00741930

[6] G. K. KOROTAEV, E. HUOT, F.-X. LE DIMET, I. HERLIN, S. STANICHNY, D. SOLOVYEV, L. WU. *Retrieving ocean surface current by 4-D variational assimilation of sea surface temperature images*, in "Remote Sensing of Environment", April 2008, vol. 112, n° 4, pp. 1464-1475, Remote Sensing Data Assimilation Special Issue [*DOI :* 10.1016/J.RSE.2007.04.020], http://hal.inria.fr/hal-00283896

[7] V. MALLET. *Ensemble forecast of analyses: Coupling data assimilation and sequential aggregation*, in "Journal of Geophysical Research", December 2010, vol. 115 [*DOI :* 10.1029/2010JD014259], http://hal.inria.fr/inria-00547903

[8] B. SPORTISSE. *Pollution atmosphérique. Des processus à la modélisation*, Ingénierie et développement durable, Springer-Verlag France, 2008, 350 p. , http://hal.inria.fr/inria-00581172

[9] V. WINIAREK, M. BOCQUET, O. SAUNIER, A. MATHIEU. *Estimation of errors in the inverse modeling of accidental release of atmospheric pollutant: Application to the reconstruction of the cesium-137 and iodine-131 source terms from the Fukushima Daiichi power plant*, in "Journal of Geophysical Research Atmospheres", March 2012, vol. 117 [*DOI :* 10.1029/2011JD016932], http://hal.inria.fr/hal-00704999

[10] L. WU, V. MALLET, M. BOCQUET, B. SPORTISSE. *A comparison study of data assimilation algorithms for ozone forecasts*, in "Journal of Geophysical Research", October 2008, vol. 113 [*DOI :* 10.1029/2008JD009991], http://hal.inria.fr/inria-00582376

Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] V. WINIAREK. *Atmospheric dispersion and inverse modeling for the reconstruction of accidental sources of pollutant*, Université Paris-Est, March 2014, https://tel.archives-ouvertes.fr/tel-01004505

Articles in International Peer-Reviewed Journals

[12] M. BOCQUET, P. SAKOV. *An iterative ensemble Kalman smoother*, in "Quarterly Journal of the Royal Meteorological Society", July 2014, vol. 140, n° 682, pp. 1521-1535 [*DOI :* 10.1002/QJ.2236], https://hal.inria.fr/hal-00918488

[13] E. DEBRY, V. MALLET. *Ensemble forecasting with machine learning algorithms for ozone, nitrogen dioxide and PM10 on the Prev'Air platform*, in "Atmospheric Environment", July 2014, vol. 91, pp. 71-84 [*DOI :* 10.1016/J.ATMOSENV.2014.03.049], https://hal.inria.fr/hal-01066960

[14] J.-B. FILIPPI, V. MALLET, B. NADER. *Evaluation of forest fire models on a large observation database*, in "Natural Hazards and Earth System Sciences", May 2014, vol. 14, pp. 3077 - 3091 [*DOI :* 10.5194/NHESS-14-3077-2014], https://hal.archives-ouvertes.fr/hal-01108597

[15] J.-B. FILIPPI, V. MALLET, B. NADER. *Representation and evaluation of wildfire propagation simulations*, in "International Journal of Wildland Fire", February 2014, vol. 23, n° 1, pp. 46-57 [*DOI :* 10.1071/WF12202], https://hal.inria.fr/hal-00903862

[16] M. GRAY, C. PETIT, S. RODIONOV, M. BOCQUET, L. BERTINO, M. FERRARI, T. FUSCO. *Local ensemble transform Kalman filter, a fast non-stationary control law for adaptive optics on ELTs: theoretical aspects and first simulation results*, in "Optics Express", August 2014, vol. 22, n^{o} 17, pp. 20894-20913 [*DOI :* 10.1364/OE.22.020894], https://hal.inria.fr/hal-01066951

[17] Y. WANG, K. SARTELET, M. BOCQUET, P. CHAZETTE, M. SICARD, G. D'AMICO, J. LÉON, L. ALADOS ARBOLEDAS, A. AMODEO, P. AUGUSTIN, J. BACH, L. BELEGANTE, I. BINIETOGLOU, X. BUSH, A. COMÉRON, H. DELBARRE, D. GARCIA-VIZCAINO, J. L. GUERRERO-RASCADO, M. HERVO, M. IARLORI, P. KOKKALIS, D. LANGE, F. MOLERO, N. MONTOUX, A. MUNOZ, C. MUNOZ, D. NICOLAE, A. PAPAYANNIS, G. PAPPALARDO, J. PREISSLER, V. RIZI, F. ROCADENBOSCH, K. SELLEGRI, F. WAGNER, F. DULAC. *Assimilation of lidar signals: application to aerosol forecasting in the western Mediterranean basin*, in "Atmospheric Chemistry and Physics Discussions", November 2014, vol. 14, n^{o} 22, pp. 12031 - 12053 [*DOI :* 10.5194/ACP-14-12031-2014], https://hal.inria.fr/hal-01094647

[18] Y. WANG, K. SARTELET, M. BOCQUET, P. CHAZETTE. *Modelling and assimilation of lidar signals over Greater Paris during the MEGAPOLI summer campaign*, in "Atmospheric Chemistry and Physics", April 2014, vol. 14, n^{o} 7, pp. 3511-3532 [*DOI :* 10.5194/ACP-14-3511-2014], https://hal.inria.fr/hal-01066822

[19] V. WINIAREK, M. BOCQUET, N. DUHANYAN, Y. ROUSTAN, O. SAUNIER, A. MATHIEU. *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*, in "Atmospheric Environment", January 2014, vol. 82, pp. 268-279 [*DOI :* 10.1016/J.ATMOSENV.2013.10.017], https://hal.inria.fr/hal-00907484

International Conferences with Proceedings

[20] *Best Paper*
D. BÉRÉZIAT, I. HERLIN. *Image-based modelling of ocean surface circulation from satellite acquisitions*, in "VISAPP - International Conference on Computer Vision Theory and Applications", Lisbon, Portugal, January 2014, https://hal.inria.fr/hal-00908791.

[21] S. HACHEM, V. MALLET, V. RAPHAËL, P.-G. RAVERDY, A. PATHAK, V. ISSARNY, R. BHATIA. *Monitoring Noise Pollution Using The Urban Civics Middleware*, in "IEEE BigDataService 2015", San Francisco, United States, March 2015, https://hal.inria.fr/hal-01109321

[22] Y. LEPOITTEVIN, I. HERLIN, D. BÉRÉZIAT. *An Image-Based Ensemble Kalman Filter for Motion Estimation*, in "VISAPP - International Conference on Computer Vision Theory and Applications", Berlin, Germany, March 2015, https://hal.inria.fr/hal-01095360

Other Publications

[23] M. BOCQUET. *La prévision numérique du temps*, June 2014, pp. 48-51, Technologie, https://hal.inria.fr/hal-01092941

[24] M. BOCQUET, M. R. KOOHKAN. *Quand modèles numériques et mesures ne sont pas sur la même longueur d'onde*, January 2014, Brève publiée dans "Mathématiques de la planète Terre 2013". Blog français de l'initiative internationale "Mathematics of Planet Earth - MPE", https://hal.inria.fr/hal-00934527

[25] P. GAILLARD, P. BAUDIN. *A consistent deterministic regression tree for non-parametric prediction of time series*, May 2014, https://hal.archives-ouvertes.fr/hal-00987803

[26] V. WINIAREK, M. BOCQUET. *Fukushima : de la radioactivité dans l'air*, January 2014, Brève publiée dans "Mathématiques de la planète Terre 2013". Blog français de l'initiative internationale "Mathematics of Planet Earth - MPE", https://hal.inria.fr/hal-00934520