The role of mesoscale dynamics in the prediction of background noise of xenon-133

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Abstract

The average activity of ambient xenon-133 released by the french nuclear power plants is examined in terms of background noise. Regional phenomena due to strong topography are taken into account by carrying out mesoscale meteorological simulations with MM5 in order to drive a Lagrangian dispersion model. Assimilation of NCEP global analysis is found to have a significant impact on the simulated lower atmospheric concentrations by better resolving low-level structures of the system. Depending on the grid resolution of NCEP analysis, the nesting configuration of computational domains has to be chosen in order to reproduce the most important coherent flow structures. These structures often control the space and time behaviour of plumes downstream the sources. The role of random turbulent motions is shown to be only of second order and may be estimated by using a suitable planetary boundary layer model. Atmospheric concentrations of xenon-133 are compared with that measured in February 2003, at Marseille, during a test phase of an automatic station. These background levels are of interest in monitoring for atmospheric radioxenon to assure compliance with a Comprehensive nuclear Test Ban Treaty (CTBT).

1. Introduction

To support the Comprehensive Test Ban Treaty (CTBT) objectives, an international effort to establish a global monitoring network is currently underway. This comprehensive network incorporates seismic, hydroacoustic, infrasonic and radionuclide monitoring technologies, with detection limits depending strongly on space and time (see for instance Currie[1]). Indeed, it turns out that atmospheric conditions and human activities may have an impact on the ability to measure CTBT relevant radionuclides.

Recently, the xenon isotopes in the mass range 131-135 were measured at Marseille, in France, during a test phase of an automated sampler-analyzer. Atmospheric concentrations were found to be highly variable and depending on a large extent on the regional meteorology. When winds from the Rhone valley were dominant, measurements showed that the one-day average activity of ambient xenon-133 was higher than most of other meteorological configurations, up to ten or so mBq.m^{-3}. In the past 20 years, other measurements have still been published about "low level" radioactivity (see for instance Bowyer *et al.*[8,9] and Kunz[3]). But most of works did not quantify the role of regional and siting effects.

In this study, the xenon-133 nuclear power plant contribution is examined through a numerical approach, by using the MM5 mesoscale model. An extended version of the lagrangian dispersion model HYSPLIT developed by NOAA and Australia's Bureau of Meteorology, is used to estimate the short-range transport from french nuclear sites.

Since it is widely accepted that the primary source of atmospheric xenon-133 is routine releases from nuclear reactors, as a fission product, other sources such as hospital and laboratory use, and cosmic-ray production are considered to be orders of magnitude lower than the reactor releases and are not taken into account.

2. A brief description of models

Presently a consensus seems to have emerged that dispersion model simulations must be performed with mesoscale meteorological fields. Small scale terrain features may be of first importance in situations involving strong or weak forcing.

Actually, models as MM5 or WRF are computationally too expensive to be directly coupled with a transport model. Thus, the model simulations of this paper were performed independently. In that way, it was possible to use sensitivity analysis in order to determine the role of mesoscale dynamics as modeled by MM5. Indeed, parameters governing horizontal and vertical turbulence in the dispersion model were found to be only plume boundary corrections of second order.

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Extensive calculations were performed to investigate the role of model physics and nesting in the prediction of background noise of xenon-133. Depending on the grid resolution of NCEP global analysis, the nesting configuration may be a deciding factor in pursuing source-receptor matrix calculations.

Nudging technique in MM5

The four-dimensional data assimilation (FDDA) scheme included in MM5 is based on Newtonian relaxation or "nudging". Nudging is a continuous form of FDDA where artificial (non-physical) forcing functions are added to the model's prognostic equations to nudge the solutions toward either a verifying analysis or toward observations. Nudging in MM5 is extensively discussed in Stauffer *et al.*[6,7] and is not necessary to review here.

The grid dimensions of computational domains are chosen in accordance with the data resolution of NCEP Global analysis, such that the coarse mesh is large enough to contain at least 100 or so NCEP grid points. For simulations of this paper, it covers France and a small part of the Mediterranean Sea. The other domains are completely interacting through *two-way interactions.*

In order to analyse the role of nudging, several cases were considered. No significant changes were observed when including or not the boundary layer from FDDA and when varying coefficients of observation nudging in the range of 10^{-4} to 10^{-2}. Indeed, in typical applications involving a strong topography, it was found that analysis nudging on 1.0 degree grids must be performed on fine scale nests to restrict the variability in three dimensional wind fields. Observational nudging with Météo-France data was found to be unsuitable for small flow structures simulation.

Physics and numerics in MM5

The essential model physics and parameters used in this paper are summarized in Table 1. Figure 1 shows a typical grid configuration used in our simulations. Each domain covers the Rhone valley and includes both Marseille and a part of the french nuclear power plant which may be seen as a xenon source network. The finest domain was defined as being able to reproduce the coherent structures which may appear when dominant winds are from the Rhone valley. Other configurations were considered for sensitivity runs. But it was not possible to find a generic nest configuration for the whole period considered. In situations involving weak forcing, the effect of smaller scales may be critical to simulations of pollutant transport and ultimately to the prediction of ground level concentrations of chemical species.

Physics :
Simple ice explicit moisture scheme
Grell-type cumulus parameterization
Cloud radiation scheme
Pleim-Xiu PBL formulation
Numerics :
2 or 3 domains in tfinest wo-way interactions
5 km or 3 km finest grid resolution
42 vertical layers in sigma coordinate

Table 1 Physics and parameters used in MM5.

It is known that parameterization of land surface processes and consideration of surface inhomogeneities are crucial to mesoscale meteorological modeling applications, especially those that provide information for transport modeling. In order to examine the role of the planetary boundary layer (PBL) on radioxenon transport, several models were used. One of them belongs to the so called Land-Surface Models (LSM) that have long been important components in global-scale climate models. This model is described by Xiu and Pleim,[2,4] as implemented in MM5. The number of vertical layers, defined at sigma values obeying a geometrical law, was determined from a mesh convergence study for all physics options.

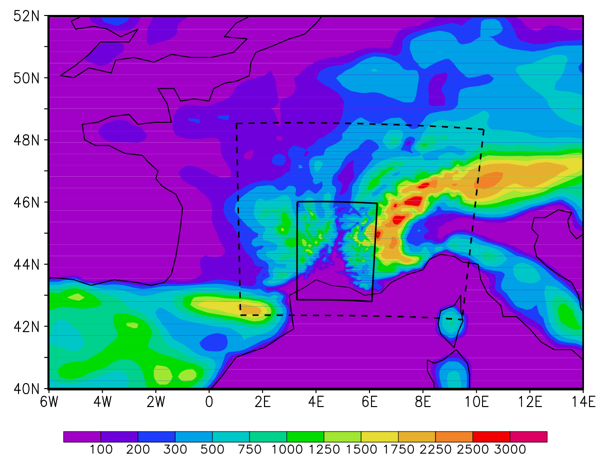

Fig. 1 Typical grid configuration with resolutions of 27, 9 and 3 km for largest to smallest domain, respectively.

Dispersion calculation with HYSPLIT

The dispersion of xenon-133 was calculated by assuming a particle dispersion with an extended version of the HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model. The distribution of ver-

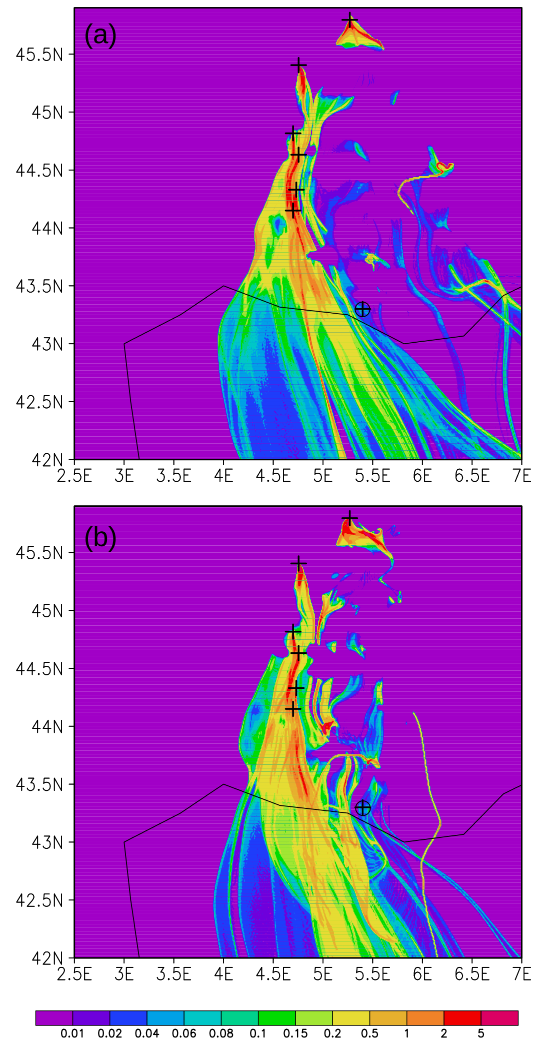

Fig. 2 Concentrations (in Bq.m^{-3}) of xenon-133. (a) : 05-06 feb. 2003 ; (b) : 06-07 feb. 2003. Observation nudging. + : sources ; ⊕ : Marseille.

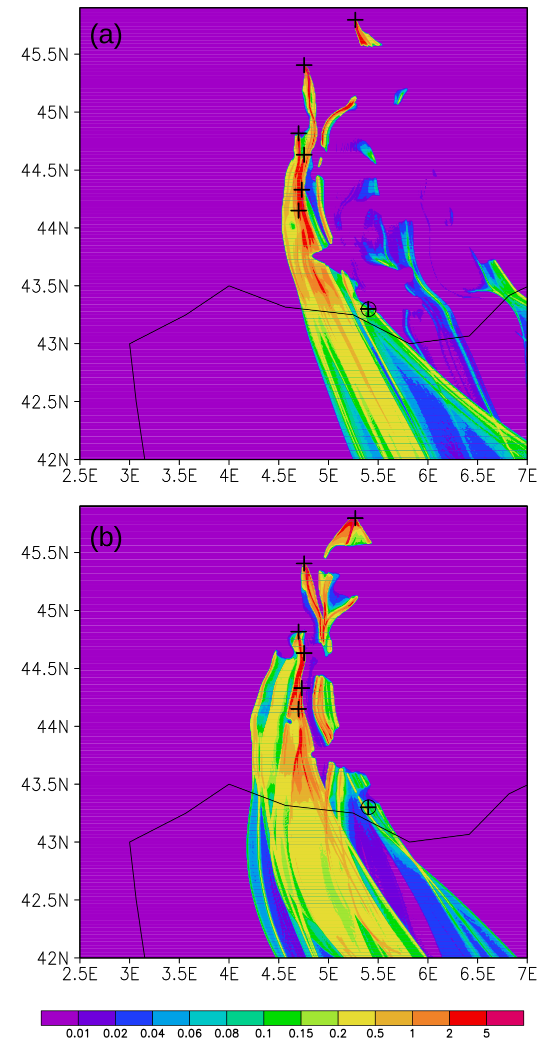

Fig. 3 Concentrations (in Bq.m^{-3}) of xenon-133. (a) : 05-06 feb. 2003 ; (b) : 06-07 feb. 2003. Analysis and observation nudging.

tical levels is identical with that used in MM5. For simulations of figure 4, the vertical mixing coefficient profile is computed from classical relations (see Draxler and Hess[5]). Note that in older versions, a single average value was computed from the profile and replaced all the values within the boundary layer. Such approximation is well-suited to global atmospheric transport but obviously fails in mesoscale studies.

Since no information was available about sources in the area under consideration, continuous emissions were specified by cycling the emissions over the duration of the simulation, that is, 250 particles were emitted for the first time step of each hour. Those particles would contain the total mass, here 10 GBq, for a one-hour release. In addition, emissions were assumed to be defined by point sources, all located at 50 meters above the ground.

3. The mesoscale Rhone valley

When on 7 February 2003 a xenon-133 peak of about 20 mBq.m^{-3} was detected at Marseille, the question of its origin immediately arose. Such a question is generally answered in terms of lagrangian back-trajectories. However, in this study the purpose is somewhat different since one is interested in the background noise of french nuclear power plants.

Figures 2 and 3 give the 24 hour average concentrations of xenon-133 up to 50 meters above the ground. During the initial stage of mixing by the atmospheric flow, the tracer form an elongated set of filaments which meanders in the Rhone valley direction, from nuclear power plants, identified by crosses. Following subsequent stretching and folding by vortex flows due to small scales of the topography, the filaments become progressively more complex. In figure 2 only observation nudging is used in the finest scale domain whereas in figures 3 and 4, the use of analysis nudging gives rise to major changes. Some of these changes may be of first importance when calculating source receptor relationships.

There are two main factors limiting the range of scales in filamentary structures. The first factor is related to the eroding influence of diffusion that is generally supposed to be dominant. Figure 4 shows that when diffusion is taken into account, concentrations are one order of magnitude less, but plume boundary corrections are not significant. Indeed, the feature is governed by the second factor which is of a purely kinematic nature and is associated with the resolution of the mesoscale model used to calculate the wind field. We may formulate the hypothesis that although filamentary structures are not drastically affected by the injection of small-scale information, smaller scales act as a strong perturbing factor of the coherent structures of the flow and so to the prediction of ground level concentrations.

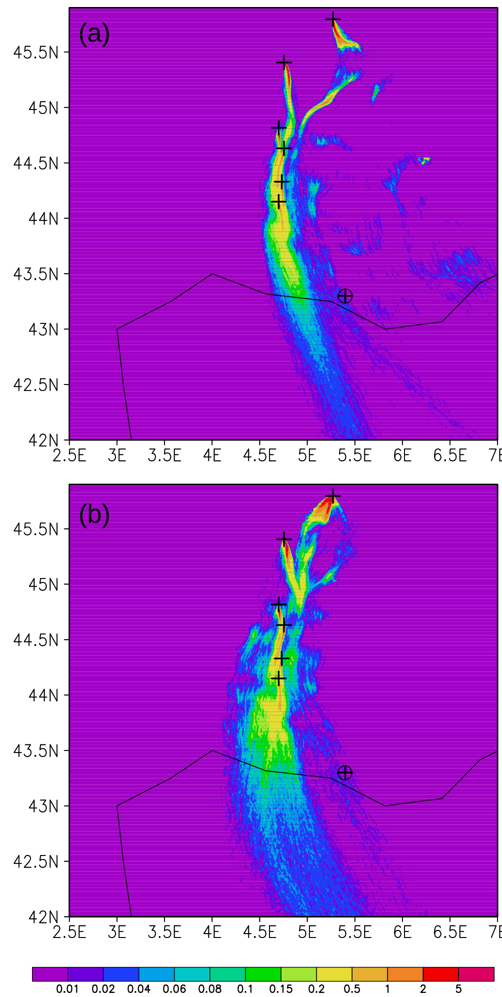

Fig. 4 Concentrations (in Bq.m^{-3}) of xenon-133. (a) : 05-06 feb. 2003 ; (b) : 06-07 feb. 2003. Analysis and observation nudging + turbulent dispersion.

4. Conclusion

In this study, the MM5 mesoscale model was used and developed to estimate the background noise of xenon-133. It was found that the nesting configuration and assimilation must be chosen carefully to reproduce flow structures that are important for atmospheric transport.

Further simulations are planed to find the best nesting configuration in a more general case, by using the optimization theory and the distributed memory extension of MM5.

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