H13-3

AN OPERATIONAL METEOROLOGICAL FORECAST SYSTEM AT MESOSCALE FOR RADIOLOGICAL AND CHEMICAL IMPACT ASSESSMENT

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Abstract: The Radiological and Chemical Impact Laboratory (LIRC) of the French Atomic Energy Commission (CEA) is in charge of the development of modelling tools to evaluate the consequences on human health of releases of radionuclides or toxic chemicals in the environment, for emergency planning and for safety evaluation. In this context, the laboratory has developed the operational meteorological forecast system MEDICIS (French acronym for “meteorology at mesoscale dedicated to human health impact assessment”) to provide, in case of emergency, meteorological input conditions to radiological and chemical impact assessment models developed by the laboratory.

Key words: *Mesoscale meteorology, automatic and operational forecast system, radiological and chemical impact assessment*

INTRODUCTION

The Radiological and Chemical Impact Laboratory (LIRC) of the French Atomic Energy Commission (CEA) is involved in many programs including, among others, the assessment of the health impact of releases of CEA centres within a regulatory framework and the struggle against CBRN threat (terrorism and malevolent actions). The laboratory is also in charge of the development of modelling tools to evaluate the consequences on human health of releases of radionuclides or toxic chemicals in the environment, for emergency planning and for safety evaluation. In this context, the need for an automatic mesoscale meteorological forecast system appeared following two observations:

1. Need to perform, in accidental situations, numerical simulations ranging from a few tens of km to the scale of a country. The problem could be related to these scales, or could be more local, but in this case, simulations at finer scale should be initiated by wind fields at a larger scale using a nesting method,
2. From an accidental situation, need to assess the atmospheric dispersion of the resultant plume during a few days following the event.

To meet this need, the laboratory has developed the operational meteorological forecast system MEDICIS (French acronym for “meteorology at mesoscale dedicated to human health impact assessment”).

THE MODELLING SYSTEM

The forecast system MEDICIS is designed to provide automatically meteorological forecasts at high resolution, over an area covering the French territory. The output data (local data at the location of CEA centres and 3D wind fields) are then input data for models such as the CERES platform (Monfort, M. *et al*., 2010) developed by the LIRC and devoted to the radiological and chemical impact assessment. These data are also input data for 3D urban models of wind fields and atmospheric dispersion such as MICRO-SWIFT-SPRAY (Harris, T. *et al.* 2007) and SIRANERISK (Cierco, F.-X. *et al.* 2010).

The meteorological modelling system is based on the PSU/NCAR Mesoscale Model (MM5). The well known MM5 system is a parallelized, limited area, nonhydrostatic, terrain following and sigma-coordinate model designed to simulate or predict mesoscale atmospheric circulation (Dudhia, J. *et al*., 2005). Pre-processors are used to define computing grids, to assimilate global scale hydrostatic models outputs (global analysis and forecasts), topography, land use data and thus prepare initialization and boundary conditions input files for MM5. In MEDICIS, NCEP/GFS global data with 6 hours and $0.5° \times 0.5°$ resolutions are used. The simulations are performed in a nested domains mode, which allows to consider, in a single run, both large calculation domains and high resolutions. The inner domains at high resolution are defined into a larger domain at lower resolution (coarse domain). Simulations are also performed in a two-way mode: calculations for all domains are carried out simultaneously, so that boundary conditions are provided at each time step to inner domains at high resolution. This method also allows feedback on the coarse domain. During forecast calculations, a weak relaxation towards the global model outputs is applied outside boundary layer for the coarse domain.

To perform forecast simulations over the French territory, the following domain setup has been defined for the current version of MEDICIS (Figure). The horizontal resolution for the coarser domain (D01) is 81 km, close to the GFS input data resolution. Inner domains D02 and D03 have respectively 27 km and 9 km resolutions. The geographical extent of the finer domain D03, centered on France, covers largely the country. In order to catch cyclonic structures coming from West, D01 domain covers a significant part of Northern Atlantic Ocean. D02 domain covers a large part of Western Europe and a small Eastern part of Atlantic Ocean. All domains have 37 vertical levels defined from soil to 10 000Pa (approximately 15 000m).

The following physical schemes have been used:

- Grell scheme (D01 and D02) for microphysics,
- RRTM scheme for radiation,
- MRF PBL scheme for planetary boundary layer (PBL),
- And Five-layer soil model.

Convection is explicitly solved for domain D03. With this configuration, wind fields are calculated with a 1hr resolution (24 outputs per simulated day) for a total period of 5 days. Runs are initialized for 24hr over a period corresponding to analysis input data (global model outputs with observations assimilation) and are then carried out in forecasting mode for 4 days.

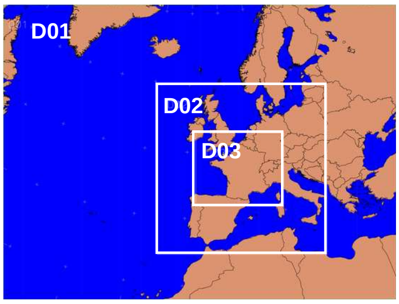

Figure 1. Domain setup

Once the mesoscale run has ended, calculated wind fields are automatically post-processed. Local data are extracted at the location of CEA centres and at the location of specific points defined by the user. 3D wind fields are converted to be used as input boundary conditions for Atmospheric Transport Modelling Systems (ATM) and for more refined urban wind field and dispersion models. Moreover, specific post processing treatments allow the automatic production of maps (wind, pressure, temperature, rainfall fields at ground level and geopotential at 850hPa), curves (local evolutions in time of wind direction and speed, rainfall, etc.) and statistical processing (wind roses over calculated period) that could be relevant for a quick description of the forecasted weather conditions.

Figure shows the MEDICIS flow chart. An automatic controller synchronizes the start of MEDICIS processes with the availability on FTP servers of updated GFS global input data. Thus, meteorological forecast calculations are started every 6 hours at 00:00, 06:00, 12:00 and 18:00 (Universal Time).

The entire process is achieved in 4h on an 8 CPU computer.

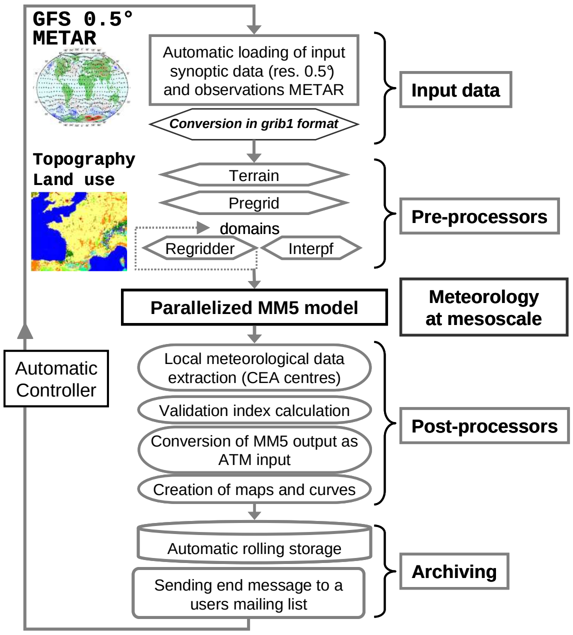

Figure 2. The MEDICIS Flow Chart

Finally, all processed data (local data and 2D maps) are made available for consultation at any moment to users through an interactive and ergonomic html bulletin (Figure). The bulletin is automatically updated every 6hr.

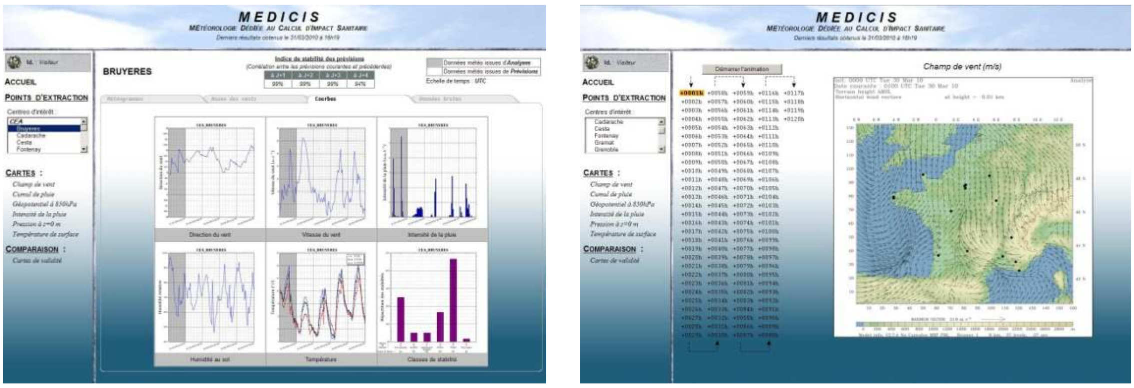

Figure 3 Examples of pages of the automatic html bulletin provided by MEDICIS

EXAMPLE OF COUPLING WITH IMPACT ASSESSMENT MODELS

In most cases, studies of radiological or chemical impact are carried out using average or simplified local weather conditions (wind roses, fixed atmospheric stability class, wind direction and wind speed). These methods are simple and conservative but well appropriate to estimate the health impact within a regulatory framework. However, these methods may be inadequate in case of crisis such as malevolent actions or real accidental atmospheric releases. In such situations, the objective is to determine as quickly as possible a potential danger zone. Taking into account average or too simplified weather conditions can lead to an underestimation of the consequences, especially when these conditions are specific (eg. rapid changes in wind direction and atmospheric turbulence) or unusual for the studied area. Emergency cases require having the most accurate possible weather forecast conditions.

Among the possible uses of MEDICIS outputs, we chose as an example the coupling between MEDICIS forecast outputs and the CERES platform devoted to the impact assessment. Each MEDICIS run produces at the location of every centre CEA, an extraction file containing local meteorological conditions during the 5 simulated days. Other specific locations (i.e. outside CEA centers) can also be defined as extraction point from the html interface. In all cases, results are provided to the puff Gaussian dispersion model included within the CERES platform as text files describing meteorological steps in terms of wind direction, wind speed, humidity, temperature on three levels, rainfall and atmospheric stability classes. The coupling between MEDICIS and CERES is illustrated by an example of hypothetical accidental release from the CEA reactor located at Saclay, France. In this example, a partial fusion of the reactor is assumed, causing a significant release of a few hours of radionuclides within the atmosphere. During the release, local meteorological forecasts provided by MEDICIS were a North West and North East wind with moderate wind speeds (Figure , wind rose produced by MEDICIS), mainly $2ms^{-1} <$ wind speed $\leq 5ms^{-1}$, occasionally $5ms^{-1} <$ wind speed $\leq 8ms^{-1}$ and rarely $0ms^{-1} \leq$ wind speed $\leq 2ms^{-1}$. The expected radiological consequences are then calculated from the air activity concentration and deposition fields at ground level.

Figure shows the result in terms of short term total dose (in mSv) provided by CERES.

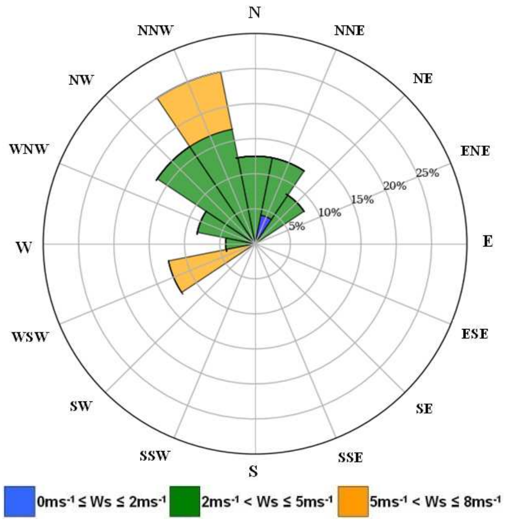

Figure 4. Wind rose expected on the day of fictitious release

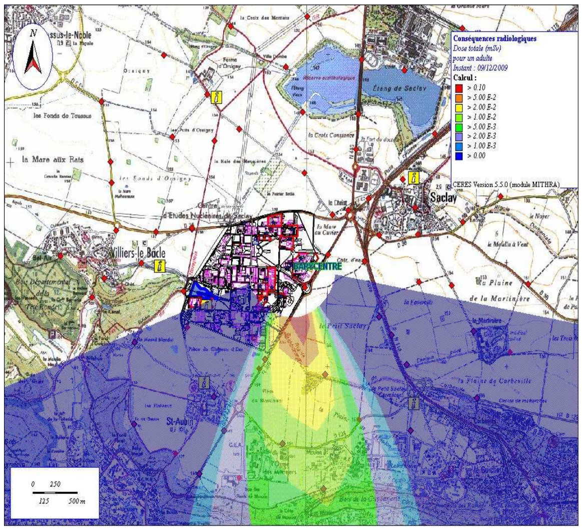

Figure 5. Radiological consequences: total dose (mSv)

VALIDATION CRITERIA

The most immediate way to assess the quality of simulation results is to compare, retrospectively and locally, calculated weather forecasts with observations from meteorological stations as METAR stations located at airports.

The comparison can be visual, for example by plotting the curves of the temporal evolutions of simulated and observed wind direction and wind speed. Figure shows the wind direction and wind speed calculated by MEDICIS and observed at the METAR station LFBG (Cognac, South-West of France) during the tempest *Xynthia* (February 27-28, 2010). MEDICIS results are presented for a "Reference run" and two forecasts initiated 12hr and 24hr before. The "reference run" is the last execution provided by MEDICIS and available when *Xynthia* took place. A quite good agreement is obtained between simulations and observations showing thus a good stability of forecasts. The increase in wind speed and change of wind direction during the morning of February 28 have been well reproduced by the mesoscale model. This visual comparison can be done at the location of 68 selected METAR stations located in France. These stations have been chosen with the condition that they have sent at least 8760 observations per year (one observation every hour).

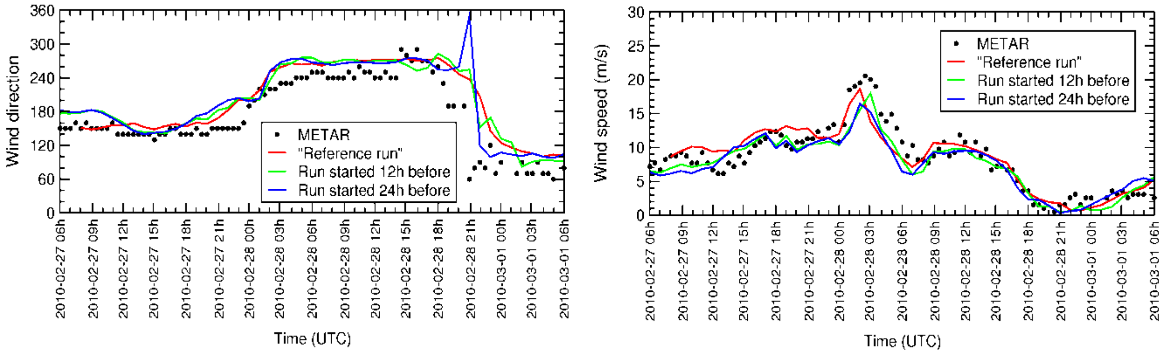

Figure 6. Wind direction and wind speed observed and modelled at LFBG station location from February 27 to March 03, 2010

Nevertheless, to characterize the agreement measurements / modelling at the scale of a country and to assess local discrepancies between modelling and observations, it may be more suitable to calculate some criteria at the location of a cluster of selected meteorological stations. In addition, other criteria must be introduced to characterize the current weather forecasts, for which the observations are not yet available. In this scope, two types of indexes are automatically calculated by MEDICIS.

Characterization of the quality of past forecasts

A first set of criteria is calculated to characterize the quality of past forecasts provided by MEDICIS, based on the comparison between past simulations and observations from the cluster of 68 selected METAR stations located in France. The methodology is based on the comparison of simulated and observed wind roses at a given point. The proposed criteria have values ranging from 0% to 100%, which is interpreted as follows: if the simulated wind-rose represents perfectly the observed wind-rose the score is 100%. If there is no common class, the score is 0%. At the location of each METAR station, three criteria, based on Météo-France ones (Soulan, I. and C. Lac, 2004), are calculated. They are defined as follow:

$$C_{\text{wind direction}} = 100 - \frac{1}{2}\left(\sum_{i=1}^{18}\left|Wd_i^{\text{METAR}} - Wd_i^{\text{MM5}}\right|\right) \qquad (1)$$

Equation (1) concerns wind direction (Wd_i). The simulated wind directions (MM5) and observations (METAR) are compared on 18 classes of 20 ° wide.

$$C_{\text{wind speed}} = 100 - \frac{1}{2}\left(\sum_{i=1}^{4}\left|Ws_i^{\text{METAR}} - Ws_i^{\text{MM5}}\right|\right) \qquad (2)$$

In equation (2) concerns wind speed (Ws_i). The simulated and observed wind speeds are compared on 4 classes: $0ms^{-1} \leq Ws_i \leq 2ms^{-1}$; $2ms^{-1} < Ws_i \leq 5ms^{-1}$; $5ms^{-1} < Ws_i \leq 8ms^{-1}$ and $Ws_i < 8$ ms^{-1}.

$$C_{\text{wind}} = 100 - \frac{1}{2}\left(\sum_{i=1}^{18\times 4}\left|(Wd_i, Ws_i)^{\text{METAR}} - (Wd_i, Ws_i)^{\text{MM5}}\right|\right) \qquad (3)$$

In equation (3) simulated and observed pairs (wind direction, wind speed) are compared on 72 classes consisting of 18 classes of direction and 4 classes of speed. This criterion C_{wind}, is quite restrictive, since there is agreement only if for a given class of direction, both simulated and observed wind speed classes are identical. It is also more comprehensive than the other ones criterion because it characterizes the wind vector (direction and speed).

All these criteria are cumulative and are updated at each new MEDICIS run. On an operating period of approximately one month, the calculated average criteria C_{wind} ranging from 70% for the "Analysis" part of runs to 66% for the 4-day forecasts part. These results are quite satisfactory and show that we can be confident in the forecasts produced by MEDICIS (the scores obtained for the analysis-part and 4-day forecasts are rather close).

Figure shows the criteria C_{wind} obtained for a 1 month period at the location of each selected METAR station for the analysis-part of runs, 2-day forecasts and 4-day forecasts. For each part of runs, lowest scores are obtained for some stations located in coastal regions (45% at LFMN, Nice, South East and 47% at LFMP, Perpignan, South) or in mountainous areas (49% at LFLS, Grenoble, French Alps). Highest scores are obtained from South West to North-central parts of France where the topography is quite smooth (example, 81% at LFPG, Paris Charles de Gaulle Airport).

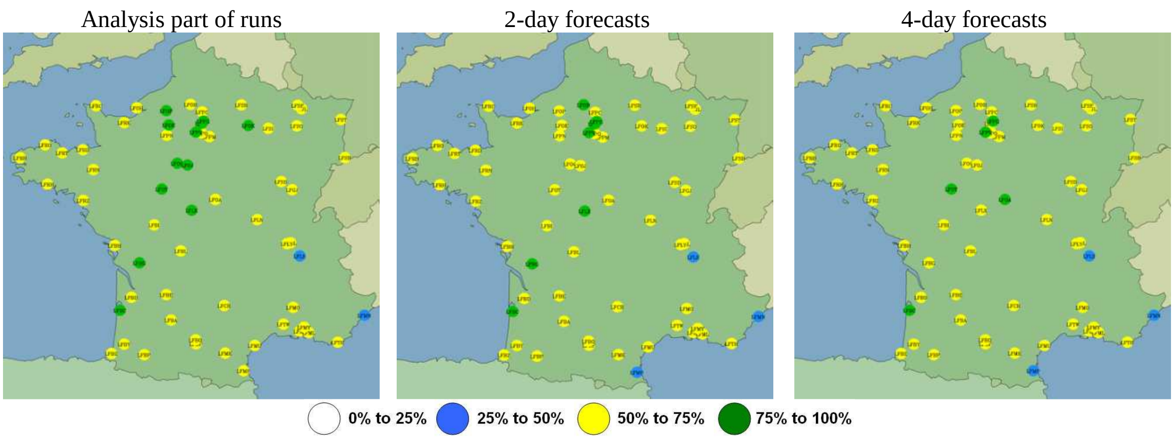

Figure 7: Cwind indexes automatically provided by MEDICIS and calculated for a 1 month period

Estimation of the quality of current forecasts

The quality of forecasts is assessed by calculating a correlation coefficient (Bravais-Pearson) between the current forecast (x_i data) and the previous one (y_i data). According to equation (4), indexes are calculated for the four days of forecasts (from N = 1 to N = 4) of the current run (n=number of available MM5 output in considered forecast day).

Indexes are calculated for the temperature on three altitude levels, humidity, wind speed and precipitation rate at ground level. Calculations are made at the location of CEA centres and specific extraction points. An average index R is then calculated. A score of R=100% is reached when the two consecutive forecasts are identical, showing thus the stability of simulations. When no linear correlation is observed R=0%.

$$R_N = \frac{\sum_{i=1}^{n}(x_i - \overline{x_N})(y_i - \overline{y_N})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x_N})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{y_N})^2}} \qquad (4)$$

Scores commonly observed up to now range from 50% (in coastal or mountainous regions) to almost 100%. Although this index allows to estimate the quality of the current forecasts, the method will however have to be improved to take into account the wind direction.

FUTURE WORK

The lowest scores obtained during the characterization of the quality of past forecasts (C_{wind}) may result from the used spatial resolution of the finer grid (9 km may be unsuitable in some areas) or from chosen physical parameterizations in MM5 that may not be optimal in coastal or mountainous regions. This may be also due to the fact that some stations METAR reflect local weather such as sea breezes and valley breezes or more local flow (not coupled to the mesoscale flow). Tests are underway using spatial resolutions of grids of 45 km, 15 km and 5 km for domains D01, D02 and D03 (the resolution of 45 km for the domain D01 is also in better agreement with the resolution of used input data 0.5° GFS). Preliminary tests seem to show an improvement of results in mountainous or coastal areas. Moreover, depending on time computing, an additional grid at a finer resolution (~1.5km) could be added on the south-eastern part of France. Eventually, MM5 may be replaced by the WRF mesoscale model.

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