FINAL REPORT PROGRAM LEFE

Program LEFE/ MANU	MoMu – Modélisation Multivariée par approche globale	Years 2015 – 2017

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Contribution to LMI *CEFIRSE (India)*
Other funding sources : PNTS (2016-2017 CNRS), InFiNiTi (2016-2017 CNRS)

Context: The projet MoMu is an extension of projects AMoGlo and SpatioGloMo (LEFE-Manu 2011-2014) which aim was to build a generic platform for the global modeling of the fluid envelopes and environment.

Objectives / scientific questions: The previous versions of the platform could only apply to ensembles of single time series. The objective of the present project was to investigate if the global modeling technique may be applied to multiple time series, for detecting couplings and for modeling.

Main results: The project enabled to produce a platform dedicated to hybrid (multiple/single) time series analysis. It has proven to be very efficient for the detection of couplings coupling between uncorrelated variables and to be powerful tool for retro-modeling (both under theoretical and real world conditions).

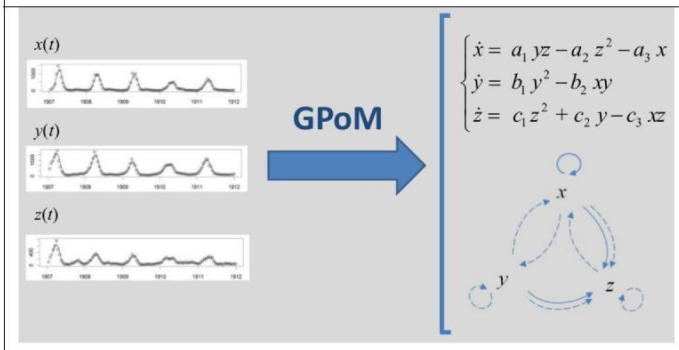

Fig. 1: Schematic presentation of the platform.

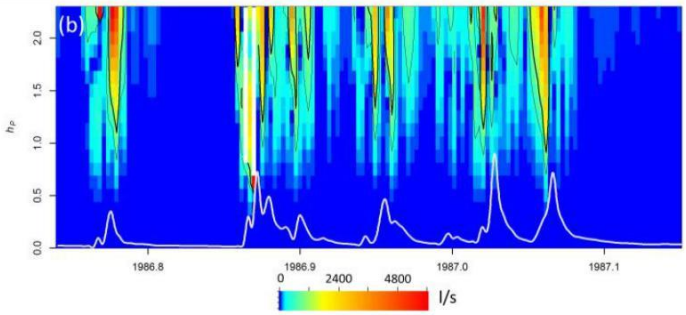

Fig. 2: Discharge forecasting error (color scale) of the Doubs spring. Horizontal axis: time at which forecast is performed; Vertical axis: horizon of prediction (in day)

The GPoM package (Mangiarotti et al. CRAN 2018) is a platform in R language that enables to obtain governing equations directly fom observed time series. This process is summarized in **Figure 1**. The three time series relate to a problem of eco-epidemiology: $x(t)$ the number of people died from bobonic plague, and $y(t)$ and $z(t)$ the number of black and brouwn rats contamitated by plague, all from 1907 to end of 1911. A three-variable model could be obtained from these time series. These model could be used to infer the links between the three populations and an interpretation could be proposed to each model term (Mangiarotti CSF2015). The tools could also be applied to the epidemic of Ebola virus disease (Mangiarotti et al. Chaos 2016) and to the discharge of three karstic springs, the Doubs, the Touvre and the Lez (Zhang et al. RNL 2016).

One way to estimate the performance of a model is to study its capacity to make good forecastings. The model obtained for the discharge of the Doubs Spring was used to perform forecasts. The model forecasting error of this model is presend in **Figure 2** (the original signal is given by the white line). The pattern shows that good forecasts can always be performed for horizons of half a day. Moderate levels of error can be reached for hozions of one day. Very large levels of error can be reached at larger horizons. Global modelling is an efficient approach for modelling the hydrodynamic of karstic spring (Mangiarotti et al. submitted).

The GPoM platform could also be applied to other domains (ecology, climatology). Results tend to show that this approach is a very powerful tool for modeling of environment.

Future of the project: The project could be extended in several directions. Two of these could be tried thanks to other projects which results appear promising. (I) The Crops'I Chaos project (funded by the PNTS program) aims to develop a new classification technique based on global modelling. It has several specific interests. It enables to establish an algebraic link between the observed signal and the governing equations of the observed system. It is also very general, being based on the identification of the dynamical behavior instead of signal similarity (Mangiarotti et al. CSF 2018). The approach could be tested on the Berambadi Basin (South India). (II) The main aim of the Musc & SlowFast project (InFiNiTi program) is to make the global modelling technique usable under nonstationary conditions (spatially or temporally). One present limitation of the approach is that it can only be

applied to few variables (up to six). A new path should be to make the technique applicable to larger ensembles of variables. A new kind of wavelet analysis based on the global modelling technique is another interesting path of investigation that could (/should!) be explored in another project. The approach being very generic it can be applied various domains and it can be particularly useful to model biotic-abiotic couplings or in biomedical context. The approach will be used in this sense for modelling the behavior of worms in Vietnam (Vinaworm project, EC2CO), and (if accepted) to model the dynamic of small neuronal networks (DALI project, H2020-ITN).

Publications :

2016 **Mangiarotti**, Peyre M., Huc M., 2016. A chaotic model for the epidemic of Ebola Virus Disease in West Africa. *Chaos*, **26**, 113112.

2016 **Mangiarotti**, Le Jean F., Huc M. & Letellier C., Global Modeling of aggregated and associated chaotic dynamics. *CSF*, **83**, 82–96.

2015 **Mangiarotti S.**, Low dimensional chaotic models for the plague epidemic in Bombay (1896-1911). *CSF*, **81**A, 184–196.

Packages :

2018 **Mangiarotti S.**, Le Jean F., Chassan M., Drapeau L., & Huc M., GPoM: Generalized Polynomial Modelling. V1.0 déposée le 18 février 2018 au *CRAN*. Sous licence CeCILL-2. https://cran.r-project.org/web/packages/GPoM

Actes (selection):

2016 Zhang Y., **Mangiarotti S.** & Leblanc M., Modélisation par technique globale du débit de trois sources karstiques (le Doubs, la Touvre et le Lez), *19e Rencontre du Non Linéaire*, **19**, Université Paris Diderot, *Paris*, *France*, 127-132.