Application of Model Reduced 4D-Var to a 2D North Sea Ecosystem Model

Joanna S. Pelc[a,b], Ghada Y. El Serafy[b,a], Hans F. Los [c], and Arnold W. Heemink[a]

[a] *Applied mathematics, Delft University of Technology, The Netherlands, joanna.pelc@gmail.com,* [b] *Marine and Coastal Systems, Deltares, The Netherlands,* [c] *Water Quality and Ecosystems, Deltares, The Netherlands.*

Model reduced 4D-Var method [1] is investigated in the 2D North Sea physical-ecological model (BLOOM/GEM) [2]. Ecological models are characterized by strong nonlinearities and difficulties with their differentiability. For such systems the implementation of the adjoint of the tangent linear approximation of the original model is commonly a challenge. The model reduced 4D-Var method is designed in such a way that the adjoint for the original model is not required. Instead, it is approximated by the adjoint of the tangent linear approximation of the reduced model. Moreover, the technique tackles the initial condition in the reduced space, where it is estimated as a linear combination of principal components of the original model dynamics [3]. Adapting this approach results in a decrease of the model state size by a couple of orders of magnitude, maintaining a relatively good accuracy.

Followed by sensitivity analysis supported by experts opinion, a number of parameters was selected as the most significant in the BLOOM/GEM model [4]. The method was first carried out in a twin experiment framework, where the parameters were calibrated in a combination with the initial condition estimation. Parameter relative error was successfully decreased down to 10%-20% (with respect to the prior error). Moreover, the initial condition size was reduced from 108750 down to 40. Despite this drastic reduction of the control vector size, the method maintained a relatively good accuracy of the initial condition estimates obtaining 75%-90% of the relative error. Additionally, the resulting chlorophyll-a prediction reached up to 35% of a total improvement as calculated for a two year period. Furthermore, the model reduced 4D-Var method was used to calibrate the 2D North Sea BLOOM/GEM model using the chlorophyll-a measurements derived from remotely sensed MERIS data. The predictions of chlorophyll-a concentration resulting from assimilated model were validated using remotely sensed MERIS measurements from a two years period following the assimilation window. The performance of assimilated model was enhanced with respect to the original model, showing for some control strategies even up to 10% of the overall chlorophyll-a prediction improvement in the validation period.

The study highlights the model reduced approach to be an effective tool for approximating the adjoint model in a reduced space for ecosystem applications. It also shows to be proficient in biological parameter calibration. Moreover, it substantially decreased the size of the model initial condition, sustaining its relatively good estimations.

References

[1] P. T. M. Vermeulen and A. W. Heemink. "Model-Reduced Variational Data Assimilation", *Monthly Weather Review,* vol. 134, no. 10, pp. 2888-2899, October 2006

[2] A. N. Blauw, F. J. Los, M. Bokhorst, and P. L. A. Erftemeijer. "GEM: a generic ecological model for estuaries and coastal waters", *Hydrobiologia,* vol. 618, pp. 175-198, 2009

[3] J. S. Pelc, E. Simon, L. Bertino, G. El Serafy, and A. W. Heemink. "Application of model reduced 4D-Var to a 1D ecosystem model", *Ocean Modelling,* vol. 57-58, pp. 43-58, September 2012

[4] K. Salacinska, G. Y. El Serafy, F. Los, A. Blauw. "Sensitivity analysis of the two dimensional application of the Generic Ecological Model (GEM) to algal bloom prediction in the North Sea", *Ecological Modeling,* vol. 221, no. 2, pp. 178-190, January 2010