Available online at www.sciencedirect.com
ScienceDirect
Journal of Marine Systems 74 (2008) 259–294
JOURNAL OF MARINE SYSTEMS
www.elsevier.com/locate/jmarsys

A 3-dimensional primary production model (BLOOM/GEM) and its applications to the (southern) North Sea (coupled physical–chemical–ecological model)

F.J. Los [a,*], M.T. Villars [a], M.W.M. Van der Tol [b]

[a] *WL | Delft Hydraulics, P.O Box 177, 2600 MH Delft, The Netherlands*
[b] *National Institute for Coastal and Marine Management/RIKZ, Kortenaerkade 1, 2518 AX Den Haag, The Netherlands*

Received 21 April 2006; received in revised form 21 November 2007; accepted 11 January 2008
Available online 1 February 2008

Abstract

This paper presents the ecological modelling instrument BLOOM/GEM and several applications to the southern North Sea, including a 3-dimensional model validation. The current instrument and its predecessors have been used since the 1980s for evaluating the ecological status of the North Sea and potential effect of management strategies. The main modelled processes of nutrient cycling, oxygen dynamics and primary production are described, as well as the external forcings required for the ecological model (hydrodynamics, suspended sediments and river loads). In the development of the BLOOM/GEM modelling instrument, the explicit choice of processes to include (the '*ecological*' resolution) has been balanced with the need for high *spatial* resolution in the model applications for the Dutch coastal zone. The calibration and validation of the BLOOM/GEM modelling instrument as well as the model applications have mainly drawn on the extensive dataset available for the Dutch coastal waters (http://www.waterbase.nl). A specific 3-dimensional model application to the North Sea is described including the model validation results based on the use of an objective cost function for a number of different substances. Plotted model results showing seasonal as well as regional variations and spatial gradients for many substances at several stations give additional support to the validation. As such, the model is well suited to support many management decisions, related to e.g. the OSPAR convention and the European Water Framework Directive and the construction of infrastructural works.

Keywords: Ecological modeling; Primary production; North Sea; Model validation

1. Introduction

In the Netherlands, the generic modelling instrument BLOOM/GEM (Generic Ecological Model) is regularly applied to assess ecological quality of the Dutch coastal waters and the southern North Sea, as well as to evaluate potential effects of e.g. new coastal infrastructure projects, and new national and international policies (OSPAR, Water Framework Directive). A model application requires a hydrodynamics calculation, which is then coupled (off-line) to the water quality–ecological modelling instrument BLOOM/GEM.

The generic modelling instrument, originally developed at WL | Delft Hydraulics, has evolved over the past 20 years. In the early stages of the development of GEM,

* Corresponding author. Tel.: +31 15 285 8549; fax: +31 15 285 8582.
E-mail address: hans.los@deltares.nl (F.J. Los).

0924-7963/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmarsys.2008.01.002

WL | Delft Hydraulics has been advised by other Dutch institutes with respect to the general model set-up (National Institute for Coastal and Marine Management/RIKZ, National Institute for Ocean Research/NIOZ, and National Institute for Ecologic Research/NIOO, Alterra). Some specific formulations provided by these institutes are available in GEM (see also Section 3.2). This paper gives a general description of BLOOM/GEM and specific applications to the Dutch coastal zone and southern North Sea, focusing on the extensive validation conducted using available data from project-related and regular monitoring.

The BLOOM/GEM North Sea application is one example of several existing European large-scale 3D ecosystem models applied to the North Sea and parts of the Northwest European Continental Shelf. Others include ERSEM (Baretta et al., 1995), NORWECOM (Skogen and Soiland, 1998), POL3dERSEM (Allen et al., 2001), COHERENS (Luyten et al., 1999), ECOHAM (Moll, 1997, 1998), Elise (Ménesguen et al., 1995), MIRO (Lancelot et al., 1995, 2000, 2005; Lacroix et al., 2007) and ECOSMO (Schrum et al., 2006a,b). Moll and Radach (2003) and Radach and Moll (2006) have written two extensive papers on the description and comparison of a number of these existing eco-hydrodynamical models, in which they also provide many additional references. They deal both with the model structure and with the validation, and include a review of model inter-comparisons which have been performed during the last decade. Lacroix et al. (2007) in their description of the MIRO model give a more comprehensive, but also more recent description of some of the North Sea models.

There are several reasons for the existence of so many different models. A somewhat trivial explanation is that authorities in different countries want to have national modelling systems. From a scientific point of view it is obvious that the driving physical and ecological forces vary considerably across the North Sea. These differences are reflected by the models which are being developed with respect to the area included, the size of the computational elements (grid cells), the level of detail of the water quality and ecological processes and the amount of data used for the validation of these models.

Models covering the entire North Sea area while using computational elements small enough to describe coastal gradients which also include a large number of potentially relevant ecological functional groups and processes, would require simulation times in the order of several weeks for a one year period. To keep models manageable, modelers make specific choices. Thus the models developed in countries with a long shoreline generally cover a large area but use a coarse grid. Among these are NORWECON and POL3dERSEM. Other models with a similar physical schematization are ECOHAM and CSM-NZB (Los and Bokhorst, 1997). In contrast, models developed for regions with a short shoreline characterized by strong physical gradients tend to cover a much smaller area but also use a more refined grid. Elise, MIRO and DCM-NZB (Los and Bokhorst, 1997) are typical representatives of these kinds of models. There is a tendency for the regional models to also describe the ecology in greater detail but obvious exceptions are POL3dERSEM and CSM-NZB, both of which describe a number of processes at a similar level of detail as the aforementioned regional models.

In the Dutch coastal zone, observed gradients of nutrients, algal biomass and suspended matter are very steep; even a concentration difference by a factor of 10 over a distance of only 10 km is not uncommon (http://www.waterbase.nl). In addition, the Rhine-Meuse river system is the major fresh water source of the North Sea. Its impact is not confined to the Dutch coastal zone, but extends much further i.e. to the German Bight. The Dutch continental waters stretch as far as 400 km north of the Wadden Islands and include important regions such as the Oystergrounds and Dogger Bank. Observed horizontal gradients in these waters are less pronounced compared to the coastal zone. In order to consider both the coastal waters and off shore regions, previously two different schematizations were developed: CSM-NZB covering a wide area including the Dutch coastal zone with a coarse 18 × 18 km grid and DCM-NZB including only the coastal zone up till 70 km using a grid size in the order of 1 × 1 km. In both cases the same ecological modules were applied (North Sea BLOOM; see also Table 1). In recent years, these two model applications have been merged into a single one using a variable grid size with a minimum of about 1 × 1 km in the coastal zone and a maximum of about 20 × 20 km in the most north westerly part of the model domain. In order to match the rounded shape of the Dutch coastline the model uses curve-linear elements. The ecological processes are based on those of its predecessors.

Comparing the present North Sea application of BLOOM/GEM to these other models, it should be noted that the modelled area is intermediate: for instance NORWECON and POL3dERSEM consider a larger area, but Elise and MIRO consider a much smaller area. All other models use rectangular grids; no other model uses a curve-linear grid. The obvious advantage is that the grid can be better adapted to spatial gradients using a fine resolution where necessary and a much coarser resolution elsewhere. Hence the spatial resolution in the coastal zone of BLOOM/GEM is considerably more refined than in any other model (approximately 1 × 1 km)