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Hydrology and Earth System Sciences Discussions

# *Interactive comment on* "Accessible integration of agriculture, groundwater, and economic models using the Open Modeling Interface (OpenMI): methodology and initial results" *by* T. Bulatewicz et al.

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**Reviewer Comment**
"The paper is about linking models; the specific set of models integrated serves as an example. The paper presents a literature review of integrated modeling, but no mention of past literature is made on the disciplinary topic, i.e. combined water and economic models. It would be useful to provide the context for the integrated modeling described here, i.e. what forms of component integration have other hydro-economic



models used in the past and how is the 'black box' integration used here different? A recent literature review of this field [Harou, et al., 2009] adopts the terminology of Braat and others [Braat and Lierop, 1987; Cai, et al., 2003] in differentiating between holistic (endogenous, fully integrated) or compartmental (modular) modeling approaches. Interestingly, the current paper presents a hybrid between these 2 model types. The 'wrapper' program does the integration so that the individual disciplinary models can stay independent (and easier to manage). The disciplinary context of this paper's integration innovation should be addressed (e.g. in section 2.2)."

**Author Response**
You are correct that combined water and economic models have a long history and were among the first attempts at integrating models across disciplines. This literature is reviewed by Harou et al. (2009), Kondouri (2004), and Brouwer and Hofkes (2008). As Harou et al. point out, one of the criticisms of previous integrated models is that they have drastically simplified certain model components and spatially aggregated the base data. For instance, the hydrologic relationships are often reduced to simple mass balance equations that update the water stock between periods over a large region. This is particularly true when models are integrated in a holistic manner. Explicit hydrologic models can predict spatially detailed water level changes that are often relevant for management decisions at a regional scale. Such models are better accommodated by modular integration. We view our contribution as one of the first studies to utilize a standardized, modular linking interface that provides automated execution and data exchange between multidisciplinary models without requiring them to be modified. We have added a discussion of this as a new section 2.2.4 titled "Related Work".

**Changes to the Manuscript**
*Add to page 7221, line 27, with new section heading "2.2.4 Related Work":*
"Within the disciplinary context of integrating agricultural, groundwater, and economics

models, there has been considerable research dating back to the 1960's (Burt, 1964, 1966). This literature is reviewed by Harou et al. (2009), Kondouri (2004), and Brouwer and Hofkes (2008). As Harou et al. point out, one of the criticisms of previous integrated models is that they have drastically simplified certain model components and spatially aggregated the base data. For instance, the hydrologic relationships are often reduced to simple mass balance equations that update the water stock between periods over a large region. This is particularly true when models are integrated in a holistic (Braat and Lierop 1987) manner in which a single model simulates all disciplinary processes endogenously (i.e. economic and hydrologic equations are solved simultaneously). Explicit hydrologic models can predict spatially detailed water level changes that are often relevant for management decisions at a regional scale. Such models are better accommodated by modular (or compartmental) integration (Braat and Lierop 1987) in which independent models transfer data. Data is either transferred in one direction from one model to another, or there is a bidirectional exchange.

Data transfer between models has been realized in different ways with varying levels of automation. Draper (2003) used an economic model to estimate economic benefit and loss functions that were then used as input to a water resource optimization model. In Volk et al. (2008), ecological and economic models exchanged data through an intermediary GIS that stored model inputs and outputs. Ahrends (2008) coupled a groundwater model to an economic model employing a custom program that executed the models and translated input/output files in an automated fashion. The IWRAM DSS (Jakeman and Letcher 2003) employed a variety of modular approaches, from creating component models in a common programming language or software tool allowing them to be executed together, to creating an integrating engine that executed customized models written in different languages (Cuddy et al. 2005).

Two of the fundamental challenges of the modular approach are (1) identifying



the appropriate data exchanges and (2) enabling the models to transfer data (Brouwer and Hofkes 2008; Cai 2003). Our work is one of the first studies to utilize a standardized, modular linking interface that provides automated execution and data exchange between multidisciplinary models without requiring them to be modified.

*New References:*

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Volk, M., J. Hirschfeld, A. Dehnhardt, G. Schmidt, C. Bohn, S. Liersch, P. W. Gassman. 2008. Integrated ecological-economic modelling of water pollution abatement management options in the Upper Ems River Basin. Ecological Economics. 66(1). 66-76.

**Reviewer Comment**

"In the example provided, integrated modeling using openMI is relatively straightforward because 'full model reuse' (connecting the different models as black boxes) was chosen. This may leave the reader with the impression that most agricultural-groundwater- economic models can be connected in this way.



This is not true in light of the following:

1. Many hydro-economic models use multi-period optimisation for the water resource and/or economic submodels. In such cases using OpenMI may be either impractical or impossible.

2. The individual models in this study have the same spatial scale (parcel) and time scale (annual). However in irrigated agriculture surface water is often also used. Groundwater and surface water may have significant interactions. This complicates integrated modeling considerably as surface water storage and flow have spatial and temporal scales different from those of groundwater. OpenMI can address surface water – groundwater interaction but likely not by using 'full model reuse'. Connecting such models using OpenMI becomes an advanced modeling and software engineering project.

The authors should make clear what specific attributes of the models they connected in this paper made the relatively easy OpenMI 'full model reuse' possible and in what other cases linking 'black boxes' may not be possible."

**Author Response**

We agree that it would be beneficial to the reader to describe the specific attributes of the models that made them good candidates for the integration approach described in this paper.

In response to point 1, OpenMI does support linked model optimization through its ManageState interface (for an example: http://public.deltares.nl/display/OPENMI/Optimization+and+calibration) and improvements have been made to OpenMI's optimization capabilities in the 2.0 version of the standard. Even so, the reviewer's point is well taken that it may be possible that some linked-model configurations cannot be represented using OpenMI (optimization-related or not), which would preclude the use of our approach. We've highlighted this point in the text's discussion of the trade-offs between using customized linking software vs. standard interfaces.

A clarification in point 2: the models in this study do not use the same time step (the agricultural model uses a daily time step, the economic model uses an annual time step, and the groundwater model is analytical, using mathematical equations that vary continuously in both space and time, and does not have a time step); the linkable components execute the models for a period of one year each time the component is asked to advance its simulation.

In response to point 2, the reviewer is correct that integrated modeling using 'full model reuse' would not be possible when model calculations require an exchange of information at intervals that are shorter than the simulation period of a single model run. In such cases model code must be modified to enable such information flows. Although this is stated in the text (page 7219, line 6) it may not be clear to the reader, so we've added an example to help illustrate this point.

As an additional third point, 'full model reuse' is best suited to models that do not rely on an interactive graphical user interface for input and/or output (for example, a model that displays its output as a graph on the screen) since this would prevent a wrapper program from accessing the model's input and/or output.

**Changes to the Manuscript**
*In response to point 1, add to page 7217, line 26:*
"or when general-purpose tools prove too restrictive or impractical".



*In response to point 2, add to page 7219, line 9:*
For example, consider a groundwater model and surface water model that are to be linked at time scales appropriate for each model (hours to seasons for surface water and hours to decades for groundwater). If linkable components are created for these models using the black-box approach, then the models would not be able to exchange information at intervals that are shorter than the simulation period of a single run of either model. So if a single run of the groundwater model simulates a time period on the order of months or years, then data could not be exchanged at a sufficient rate to capture daily interactions between the groundwater and surface water. In such a case, the models would require modification to enable them to exchange data after each internal time step.

*In response to point 3, add to page 7219, line 9:*
"In addition, a model must not rely on an interactive graphical user interface for input and/or output, since this would prevent a wrapper program from accessing the input and/or output.

**Reviewer Comment**
"I agree with Peter Gijsbers' comment that the problem that occurred when linking the models (error compounding) should be mentioned in the conclusions, both its impact on the case study and the general challenge it poses in integrated modeling."

**Author Response**
We agree that the conclusion should mention the problem of compounded error in the linked model.

**Changes to the Manuscript**
*Add to page 7231, line 5:*

“The initial parameter set selected for the agricultural model was found to induce error in the groundwater model that compounded on each year of simulation. Through the use of an alternative parameter set, the error was reduced and the overall consistency of the linked model was maintained. This highlights the challenge of ensuring that the quantities provided by a model meet the specific accuracy requirements of the model that consumes them, and that the error is not accumulated or amplified beyond acceptable limits on successive iterations of the linked model.”

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 6, 7213, 2009.