Report of the Online CEEDS workshop on Model Coupling

18 September 2020

INTRODUCTION

CEEDS organised an online workshop on 18 September 2020 on the important topic of **model coupling**. This followed up the successful seminar "*Model Coupling for Evaluating Complex Systems*" held in June 2020, which discussed model coupling as a means to address interdependencies between different aspects of the environment. The seminar considered the extent to which complicated environmental questions can be better assessed by integrating models, and discussed the advantages, challenges and limitations of joined-up modelling for complex systems. Four invited speakers discussed this grand challenge for 10 minutes each followed by a panel discussion:

- Rob Dunford-Brown (UK Centre for Ecology & Hydrology): "Integrating models: why and how?"
- Simon Dadson (UK Centre for Ecology & Hydrology): "Hydro-JULES: Next Generation Land-surface and Hydrological Predictions"
- Gordon Blair (Lancaster University): "Model coupling: looking beyond interoperability?"
- Andrew Jarvis (Lancaster University): "Is model coupling a case of cut and shunt?"

The **model coupling workshop** enabled more detailed discussions of key questions raised at the seminar around the role of model coupling in integrated environmental modelling, including questions around how we deal with issues around uncertainty, scaling and complex feedbacks, and how to provide a modular toolkit to ease the development of coupled models. The workshop was facilitated by Countryscape.

KEY MESSAGES

- Coupling of disciplines is a prerequisite to model coupling. There is a need to really take time to communicate and understand someone's disciplinary perspective/philosophy through an open and reflexive process that builds trust around common goals.

- This is particularly important in teasing out all the complexities in integrated modelling, the relationships, feedbacks and rebound effects that exist between models and that should all be captured in the resultant model coupling framework. This recognises that in integrated modelling the coupling can sometimes be as complex as the models themselves particularly in really representing emergent behaviour of complex systems and tier interactions.
- Model coupling can be supported by collaborative environments (cf. virtual labs) that are open to users with different levels of expertise. Various building blocks for facilitating the coupling of models could be offered within such environments: shared vocabularies and ontologies, interoperability across programme languages, functions for transferring between temporal and spatial scales, Bayesian backbones for reasoning about uncertainty, and services for creating model emulators, supporting data assimilation, or enabling plug and play of models within coupled model frameworks to analyse structural uncertainty.
- The above needs certain barriers to be overcome (disciplinary interests, single model interests, the way science is done, language, the considerable time and effort it takes to do it properly). But, these can be overcome through communication to develop shared understanding and collaborative environments (such as Data Labs) that can facilitate long-

term interdisciplinary training and learning. This requires long-term funding that explicitly recognises innovation across different fields -> leads to new discoveries.
- Above all there is real excitement to tackle this head on now as it is potentially very powerful for addressing today's complex real-world problems. There is a huge amount of expertise to be shared and combined through coupling models, revealing unexpected feedbacks, exposing new realities about the world and casting new light on areas of science to which we are currently blind.

ISSUES RAISED IN WORKSHOP SESSIONS

How can we improve/support the coupling of disciplines to facilitate the coupling of models?

- Communication and collaboration within disciplines as well as between them
- Communication/collaboration needed to get common understanding of the discipline jargon and get a common understanding of words
- Take time to communicate and really understand someone's disciplinary perspective/philosophy
- Bring in understanding of socio-economics and politics into environmental models
- Openness, reflexivity and transparency over disciplinary capabilities, biases and limitations
- Proximity of minds is key and needs to be enabled as far as possible through multiple means, with time for random 'collisions' that spark ideas in one individual or mutually
- Build clarity and understanding of all parties on end goal
- What are you trying to communicate, needs an overview of all the models in the framework and how they behave as one
- Goal oriented meetings or workshops based around existing models
- Good model documentation
- Using common language in model specification
- Open discussion of ontologies and language
- A shared, agreed vocabulary
- Improve the understanding of the different areas -> dictionaries
- Collaborative environments
- Openness about models – not widely available and not explained thoroughly
- Open models that are understandable outside the model development team
- Clean separation of science and basic modelling functionalities (I/O, time management, etc.)
- Need typology of models – operate on different scales and spatial associations
- Can the linked model answer questions from all angles. Can the model be inverted model to answer a hydrological question - or conversely answer a land use/ energy question?
- Collaboration on examples/case studies
- Making your science have an impact in the real world, solving problems, and influencing society
- Coupling/co-design with end-users/stakeholders is as important
- Adaptive modelling for policy support
- Long-term interdisciplinary training
- Long-term funding to allow for learning

What components would be useful to support model coupling?

- Glossary that all models understand and draw from. Glossary that is explicit about what is being transferred between components
- Create flexible interfaces to translate the language rather than impose an overall dictionary
- Language translation both scientific and programming
- Open source, interoperability across programme languages
- Wrappers to enable models worn in different code to be coupled

- Code translators
- Define interfaces and have translators within the modelling framework. Interface to translate people's terminology
- Tools to support different types of integration, dependant on if it is tight or loose
- Guidelines/standards for defining data passes between models
- Modularise components of models to build understanding of the importance of the bits, figure out what drives what, what are the structural relationships between models
- Transfer functions
- Functions for transferring between temporal and spatial scales, and how they fit together in the integrated model architecture
- Upscaling and downscaling tools, both spatial and temporal
- Model and data interface – spatial support as sampling element
- Wrapper to link temporal and spatial scales
- Regrinding interpolation translator
- Modelling frameworks have to incorporate statistics
- Bayesian backbone for uncertainty reasoning end-to-end
- Model agnostic translation tools
- Micro-services software architecture to put pieces together – small services to plug-and-play to build the model
- GP emulators to speed up models or sub models
- Plug and play collaborative environments that enable exploration of structural uncertainty
- Data assimilation
- Sensitivity analyses
- Take into account the 3-D aspects to enhance the model
- Tools that provide anonymised data
- Data sets that drive the model

<u>How do we weave these components together?</u>

- Collaborative environments that are open to users with different levels of expertise
- Approaches that link different kinds of models - data, process-based, agent-based, ...
- Integrating process and statistical based approaches
- Data linkage – outputs from one model become the input to another model
- With tools designed to link, convert between and analyse the different components of the system
- Carefully! With lots of testing of outputs with different configurations to check no weird effects
- A "links table" listing name, type, units and dimensionality of each variable passed, in both the source and the receptor model / database / analysis /visualisation tool. Defining the arrow as a flat format table
- Look at the model linkage space from alternative perspectives, e.g. from a temporal or a spatial view
- In a dream world, can you generate coupling structures from system diagrams and make sure all these feedbacks are represented
- Modularisation
- Couple things through data – have to characterise uncertainty in an appropriate way
- Important to characterise uncertainty

<u>What are the barriers to coupling models/disciplines and how can we overcome them?</u>

- Barrier = disciplinary interests and the way science is done. Solution = recognising innovation in different fields -> leads to new discoveries
- Solution = build trust and understanding of different disciplines

- Barrier = urgency to do the science and not take time to do the coupling properly
- Barrier = time! interrupted flows of time
- Barrier = extra effort required to make existing models explicit about what they can do
- Barrier = language and understanding. Solutions = communication; shared understanding of terms; translation of terminology
- Barrier = people only interested in development of own models/interests. Solution = shared goals
- Barrier = coding language and difficulties in switching or learning a new language
- Solution = when dynamically linking one discipline to another there is a need to understand the terminology; the link itself could contain/display information about the ontology/metadata/glossary
- Solution = better documentation of process of coupling models
- Barrier = spatial and temporal differences between models. Solutions = transfer functions for upscaling and downscaling
- Solution = graphical visualizations rather than language
- Solution = collaborative environments for working together across disciplines
- Solution = virtual labs
- Solution = training
- Solution = standards?
- Solution = legacy - not starting from scratch again at the beginning of each project

<u>What do you find most exciting about model coupling?</u>

- Collaboration with other disciplines
- Broadening our understanding across disciplines
- Learning from others
- Building on what's already been done
- Learning new stuff!
- Pulling together the learning done so far with scientific and stakeholder needs
- Being able to deal with the messiness of the real world!
- Working with end users whilst trying to couple models – changing continuously to address real world policy issues
- Being more holistic
- Potential to get answers from coupled models you can't get from individual ones
- There is a huge amount of expertise to be shared and combined through coupling models - this is a really tricky task but potentially very powerful!
- Finding unexpected feedbacks
- It has the prospect of exposing new realities about the world - peels back the layers of the onion - new visualisations
- Casts new light on areas of science to which we are currently blind
- Timely to be doing this – has to be done collaboratively
- This area is really compelling - it is timely NOW to do something about this collaboratively within CEEDS