FORUM

Joining Scientists and Stakeholders in Regional Earth System Modeling

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The 19th Conference of the Parties (COP19) to the United Nations Framework Committee on Climate Change concluded in November 2013 with limited progress toward reducing global emissions of greenhouse gases. However, while international negotiations on climate change have stalled, regional initiatives are quietly starting to play an important role in the fight to subvert catastrophic climate change. Examples include the Regional Greenhouse Gas Initiative to reduce emissions in the northeast United States and the ClimAct Regions Project, which aims to reduce greenhouse emissions in 60 regions and provinces of Europe.

Beyond climate, the regional scale has also emerged as critically important for a diverse range of environmental challenges for which Earth systems processes and thus management solutions extend beyond political geographic boundaries [*Murtugudde,* 2009]. Here we describe the challenges of engaging stakeholders in regional Earth system modeling and propose an alternative research framework.

While defining a "region" can be like a Rorschach test for modelers, we define it as any subcontinental domain that encompasses multiple political or administrative units that share biogeography, infrastructure, or socioeconomic features. Such domains range in area from thousands (i.e., New York Metropolitan Area) to millions (i.e., Amazon Basin) of square kilometers. The ideas proposed here apply to various regional modeling projects, including those on climate, atmospheric chemistry, water management, and agriculture and studies that integrate these sectors. Stakeholders for this work can be equally diverse and include policy makers, government agencies, industry representatives, and average citizens.

Recent advances in Earth system modeling allow for simulations at higher resolution that better represent physical processes, human infrastructure, and land cover changes while still providing spatial coverage that extends over large areas. This new generation of regional-scale models can thus provide "the best of both worlds," allowing for a holistic view of interacting biogeophysical and human systems but with sufficient resolution to consider the nuances of local-scale processes and actors. However, without designing studies to actively facilitate a workable engagement with stakeholders, we risk missing out on the potential for these models to support environmental decision making.

Data Versus Actionable Information

When regional modelers meet, for example, at AGU Fall Meeting union sessions (session AGU-U23A of the 2012 AGU Fall Meeting, San Francisco, Calif., 4 December 2012) or at international conferences on regional climate (Coordinated Regional Downscaling Experiment (CORDEX), 2013, available at http://wcrp-cordex.ipsl.jussieu.fr), major limitations with the current modeling paradigm are repeatedly voiced by scientists and stakeholders alike.

While quality science is being produced through these studies, stakeholders complain that scientists address academic questions yet ignore the needs of the user community. Even when data generated may be of value to regional stakeholders, in reality, relevant information often goes unused [*Dilling,* 2007]. Studies are ultimately published in the literature and add to the overall knowledge base but are rarely mainstreamed for use in regional policy making. In addition, modeling results can be misused by stakeholders who do not fully understand them [*Sarewitz and Pielke,* 2007].

Although complaints by stakeholders and scientists are not new [*McNie,* 2007], their persistence is surprising given the interest of funding agencies in supporting policy-relevant research [*Sarewitz and Pielke,* 2007]. Typical involvement of stakeholders in regional Earth system modeling studies is still largely peripheral, coming near the end of projects, when researchers endeavor to "advertise" their results to presumed users. Stakeholder engagement at this stage is too late, no matter how many resources are invested, and as a result, they may question the legitimacy of the findings [*Cash et al.,* 2003].

An Emerging Framework

Based on the experience of the authors and others, we recommend major changes to the research process for regional Earth system modeling, a new paradigm involving a functioning partnership of scientists and a diverse range of stakeholders. We propose six steps toward this end:

1. Develop the research questions, hypotheses, and expected products of the study. Engage stakeholders from the start of the project to ensure that the research questions are developed to meet their information needs as well as the interests of researchers. Scientists should take advantage of this early collaboration to assess stakeholder "demand" [*Sarewitz and Pielke,* 2007] for scientific information and ensure that stakeholders' expectations of the products from these studies are realistic.

2. Design modeling scenarios to address these questions and test hypotheses. Stakeholders should codesign regionally focused scenarios through participation in workshops, conference calls, and online forums.

3. Translate qualitative scenario narratives into the quantitative inputs for numerical modeling. In this translation, there is great opportunity for scientists to take advantage of local knowledge. Stakeholders involved in the early development of a modeling study may also be more likely to trust scientists with restricted data sets and information not typically available.

4. Conduct modeling and data analyses. While methods and software have been developed to directly involve stakeholders in conducting simulations and analyses [*Voinov and Bousquet,* 2010], given the complexity inherent in regional Earth system models, we advocate that this work be in the exclusive domain of the researcher. However, it is critical that a dialogue with scientists be maintained during this stage and that stakeholders understand the concepts and uncertainties embedded within the model. Scientists should consider the use of alternative media, such as fact sheets and animation, to help stakeholders understand the modeling process.

5. Interpret study results. Scientists and stakeholders should engage in coexploration of the findings, learning from each other's perspectives. The availability of new scientific information through this process may encourage stakeholders and scientists to reformulate their initial assumptions and research questions and repeat the process from step 1 [*Voinov et al.,* 2014].

6. Disseminate results. The ultimate products of the study should not be limited to journal articles and reports. Instead, a more active knowledge distribution process is required, tailored to the diverse needs of the user community. For example, the general public may benefit from videos summarizing key outcomes, while environmental managers would also desire access to an easily navigable online data portal.

Need for Novel Resources and Incentives

The recommended partnership of stakeholders with scientists at each step of the modeling process can be costly in terms of financial, technical, and human resources [*Lemos et al.,* 2012]. Thus, novel resources and incentives need to be developed to support stakeholder engagement in regional Earth system modeling. Examples may include the development of shared cyberinfrastructure, such as Web platforms for stakeholder review of modeling scenarios or posting of accessible output data. This approach has been successfully employed by the citizen science community [*Silvertown,* 2009] and could be adopted for regional Earth system modeling.

The proposed framework also requires training additional members of modeling teams, such as policy advisors or data translators, to serve as liaisons between scientists and regional decision makers. The U.S. National Research Council similarly recommended the accreditation of "climate interpreters" as a main component of the national strategy for advancing climate modeling [*National Research Council,* 2012]. Science writers and graphic designers may also be important in developing alternative media for communicating science to diverse stakeholders.

While these recommendations may seem expendable in light of strained research budgets and the hectic schedules of most investigators, they are essential to ensure that the resources invested in policy-focused regional Earth system modeling do not go to waste and that these models fulfill their mandate to provide the science needed to support society as it faces the complex environmental challenges of the 21st century.

Acknowledgments

This work was supported by NSF awards 1243106, 1049181, 1313897, AGS1243106, and BCS1114978 and DOE grant DESC000664.

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