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ORIGINAL ARTICLE

An integrated climate change assessment for the Northeast United States

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Abstract The papers in this Special Issue are the primary technical underpinnings for the Northeast Climate Impacts Assessment (NECIA), an integrated regional-scale assessment of projected climate change, impacts and options for mitigation and adaptation across the US Northeast. The consequences of future pathways of greenhouse gas emissions on projected climate and impacts across climate-sensitive sectors is assessed by using downscaled projections from three global climate models under both higher (Alfi) and lower (B1) emissions scenarios. The findings illustrate that near-term reductions in emissions can greatly reduce the extent and severity of regionally important impacts on natural and managed ecosystems and public health in the latter half of this century, and

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increase the feasibility that those impacts which are now unavoidable can be successfully managed through adaptation.

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Climate change is a global challenge, but the impacts are experienced locally. Many response strategies, both for adaptation and for mitigation, are best designed and implemented at local to regional scales. Regional-scale assessments of projected changes and impacts across multiple climate-sensitive sectors can provide critical input into the development of effective response strategies, provided that the underlying science is rigorous and the results are effectively communicated to public and policymaker audiences (Moser and Dilling 2007). Recent advances in the science of regional climate projections (Christensen et al. 2007; Hayhoe et al. 2007) allow for increasingly refined analyses to build upon the foundation laid by the first generation of integrated regional climate change assessments (e.g., National Assessment Synthesis Team 2001; ACIA 2005).

The Northeast Climate Impacts Assessment (NECIA) was designed to provide opinion-leaders, decision-makers and the public in the US Northeast – the nine-state region from New Jersey and Pennsylvania northward to Maine – with the best available science upon which to base informed choices about climate-change mitigation and adaptation. The result of this 3-year collaboration between the Union of Concerned Scientists (UCS) and more than 50 independent scientists and economists, the NECIA Synthesis Report (Frumhoff et al. 2007) was released to considerable media attention and is now serving as the basis for a robust climate-change dialogue among scientists, policymakers, private sector decision-makers and the public across the region (see www.climatechoices.org/ne). The papers in this Special Issue of *Mitigation and Adaptation Strategies for Global Change* are the primary technical underpinnings for the NECIA Synthesis Report.

Hayhoe et al. (this volume) set the stage for the assessment of regional impacts in the US Northeast by describing downscaled climate model outputs for annual and seasonal temperature and precipitation and other climate indices. Using the results of three global circulation models with different climate sensitivities (GFDL-CM2.1, HadCM3, and NCAR-PCM), Hayhoe et al. demonstrate the utility of their approach with respect to observed and modeled climate inter-comparisons among different downscaling approaches, and with regard to specific aspects of the region's climate. The average of these downscaled model outputs faithfully reproduces most aspects of the temperature trend and changes in precipitation patterns across the US Northeast over the past several decades. An exception is that the models consistently underestimate the rapid winter warming the US Northeast has experienced in recent decades, perhaps because they are not designed to incorporate the small-scale but important positive feedback effect of diminished surface snowpack.

Model projections forward to 2100 were derived using two greenhouse gas emissions scenarios – A1fi, a relatively high emissions scenario, and B1, a relatively low emissions scenario (Nakicenovic et al. 2000). While these two scenarios describe the outer envelope of emissions scenarios used by the United Nations Intergovernmental Panel on Climate Change (IPCC 2007), the A1fi scenario should not be considered a ceiling on possible emissions and climate futures, nor does the B1 scenario necessarily constitute a floor. The A1fi scenario assumes globally strong economic growth based largely on fossil fuels, with new and more efficient technologies emerging late in this century. Here, atmospheric concentrations of carbon dioxide (CO_2) rise to approximately 940 ppm by 2100. The B1

scenario assumes similarly strong economic growth, but involving less fossil fuel-intensive industries and increasingly driven by cleaner and more resource-efficient technologies, such that concentrations rise to approximately 550 ppm by 2100.

Estimates for annual warming over the next three decades (2010–2039) are similar under both the higher- and the lower-emissions scenarios, due to inertia in the climate system. For many features of the Northeast climate, interscenario differences emerge by mid-century. By 2070–2099, the higher-emissions scenario results in regional temperature increases that are roughly double those to be expected under the lower-emissions scenario (see also NECIA 2006).

These model projections for future climate provided the context for analyses of selected climate impacts on coastal regions, marine fisheries, forests, agriculture, winter recreation, and human health. Not surprisingly, for many of these systems the aforementioned divergence in higher and lower emissions and hence projected climate change lead to a widening range in the magnitude of impacts in the second half of the twenty-first century.

The impacts papers in this volume provide a broad survey of areas of concern for climate-sensitive sectors across the US Northeast region. Five of the papers address climate change in the context of marine and terrestrial ecology (Fogarty et al. – cod and lobster fisheries; Ollinger et al. and Iverson et al. – forests; Rodenhouse et al. birds; and Paradis et al. – habitat range of the hemlock woolly adelgid [*Adelges tsugae*]). The configuration of terrestrial and marine communities will be altered as climate changes unfold across the Northeast region. There is a wide range of species response times to local changes in climate, and across this spectrum there are cascading implications for ecosystem structure and function as communities of terrestrial and marine organisms are reconfigured by shifts in the geographic extent of species with different thermal limits of their ranges and hence species-species interactions (e.g., competition for space, predator – prey and host – pathogen relationships).

While the papers on forestry and fisheries contain important content with implications for the economy of the Northeast region, the paper by Wolfe et al. (this volume) examines potential climate change impacts in the region's most intensively managed ecosystems – those that produce crops and livestock, including dairy.

Marine fishing, commerce, and recreation have led to high population densities along the coasts of the Northeast states. The combined effect of future sea-level rise and storm surge raises many questions about the adequacy of infrastructure that protects coastal properties and provides transportation infrastructure and other essential societal services. The paper by Kirshen et al. (this volume) describes the shoreward incursion of the sea with rising sea level and projected storm surge elevations for several major cities in this region. The sea-level rise projections underlying this paper are conservative in that they do not account for the rapid rate of decay and melting of the major polar ice sheets already being observed nor the potential for further acceleration of this melting (Dowdesdell 2006; Rignot and Kanagaratnam 2006).

Two papers in this volume, Kunkel et al. and Ziska et al., address some of the implications of projected climate change on human health. It is already well established that more intense and/or persistent heat waves and storms in the future will put more people at risk. There are, however, many other aspects of the environment in the projected warmer world that can affect human health. Two that are explored here are the relationship between climate and tropospheric ozone concentrations in urban regions and the degree to which changes in carbon dioxide and temperature can affect the production of pollen and spores released by molds and fungi.

Finally, the substantial winter recreation industry in this region is dependent upon snow and ice. The paper by Scott et al. (this volume) considers how different aspects of this industry will be affected by the projected diminished snow cover and higher winter temperatures for this region. In the near term, snowmaking will allow adaptation within the

alpine skiing industry, but this is not a realistic prospect for snowmobiling, which is economically more important than skiing across much of the region. As is the case for this and the other sectors in this study, impact projections differ considerably between the climates driven by the lower- vs. higher-emissions scenarios.

This ensemble of impacts papers provides snapshots of a future that will in most respects tally with more losses than gains for the people and the economy of the US Northeast. Potential for mitigation is implicit in the comparisons of projected impacts arising from the higher- versus lower-emissions scenarios, and in some of the aforementioned papers adaptive strategies are specifically considered. One clear message is that adaptive strategies will be needed, some in the very near term and over the next few decades, in order to minimize impacts from climate change that is now inevitable. The paper by Moser et al. (this volume) presents a broad framework for evaluating technological, institutional and societal aspects of adaptation, and proposes a set of principles for prioritizing adaptation needs across the region.

A second overarching message focuses on opportunities to reduce greenhouse gas emissions. Moomaw and Johnston (this volume) review the regional sources of these emissions and provide examples of technology and policy measures that could steadily bend the curves of emission projections downward to meet a proposed mid-century goal of 80% below 2000 levels. Reductions of this magnitude by industrialized nations, together with substantial reductions by developing countries, would keep total emissions, and hence impacts, below those represented by lower emissions pathway used in this study (Luers et al. 2007; Meinshausen 2006). Although a concerted global effort will be required to achieve deep reductions in emissions, the authors argue that the US Northeast is well positioned to be a leader in these initiatives, many of which present substantial business opportunities. It is encouraging that a strategy for bending the emission curves downward does not require waiting for a vast array of yet to be developed technology, but is something that could literally begin today (IPCC 2007).

Importantly, we have passed the point where debate over whether to adapt or mitigate is meaningful. Inertia in the climate system ensures that regardless of near-term efforts to curb emissions of greenhouse gases some additional climate change is inevitable, thus making adaptation an essential complementary strategy to reducing emissions. As the systematic comparison of regional-scale impacts under higher- versus lower-emissions scenarios in the Northeast and elsewhere (e.g., Hayhoe et al. 2004; Cayan et al. 2006) illustrates, reducing emissions has enormous potential to reduce many impacts in the latter half of this century. Moreover, the greater the effort to mitigate climate change through concerted efforts in the next few decades, and the more constrained impacts will be, the more likely it is that impacts in the latter half of the century can be successfully managed through adaptation.

An integrated regional climate change assessment such as has been carried out under the auspices of the NECIA is a significant undertaking, involving the considerable investment of time and financial resources. Yet it is also an essential vehicle for providing decision-makers at all levels of society with the information and motivation needed to develop effective response strategies. It is our hope that such assessments, rare today, will quickly become a widespread, readily available, and regularly updated resource for confronting our changing climate.

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