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Integrated climate change risk assessment: A practical application for urban flooding during extreme precipitation

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ABSTRACT

Risk assessments of flooding in urban areas during extreme precipitation for use in, for example, decision-making regarding climate adaptation, are surrounded by great uncertainties stemming from climate model projections, methods of downscaling and the assumptions of socioeconomic impact models. The multidisciplinary character of such risk assessments also requires that research groups and experts from different scientific disciplines combine knowledge and share model outputs. This paper describes an integrated framework and tool, the Danish Integrated Assessment System (DIAS), which has been designed to address the complex linkages between the different kinds of data required in assessing climate adaptation. It emphasizes that the availability of spatially explicit data can reduce the overall uncertainty of the risk assessment and assist in identifying key vulnerable assets. The usefulness of such a framework is demonstrated by means of a risk assessment of flooding from extreme precipitation for the city of Odense, Denmark. A sensitivity analysis shows how the presence of particularly important assets, such as cultural and historical heritage, may be addressed in assessing such risks. The output of the risk assessment for Odense indicates that highly detailed geographical data reduce the overall uncertainty and assist climate adaptation decision-makers in focusing on protecting those assets that are considered to be relevant in the given context. Also, using an integrated framework such as DIAS enables the relative importance of the different factors (i.e. degree of climate change, assets value, discount rate etc.) to be determined, thus influencing the overall output of the assessment.

Practical Implications

Cities are facing increasing risks from flooding caused by extreme precipitation events, making housing, traffic, health, ecosystems and cultural and historical heritage vulnerable. Accordingly, planning adaptation measures has become a high priority for local government authorities and property owners in cities. However, the cost-effective planning of adaptation strategies is very complicated. The integrated assessment of climate events, associated flooding, damage costs and adaptation measures requires multidisciplinary work and close interaction between professionals and decision-makers. Damage cost assessments and adaptation planning also require context-specific data and modelling, which, taken together, can be very demanding in seeking to develop a basis for solid local decision-making. This paper presents an integrated framework and tool, the Danish Integrated Assessment System (DIAS) for localized risk assessments, which can support context-specific assessments of how cities may adapt to climate change. We exemplify the usefulness of such a framework though a case study of cost assessments of damage caused by urban flooding during high-intensity precipitation for the city of Odense, Denmark. DIAS contains a very rich database on climate, land cover and socioeconomic activities for Denmark, which provides a basis for spatially detailed assessments of the climate risks for various assets and for society as a whole. It may serve as an inspiration for the development of similar open-access databases both regionally and globally.

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1. Introduction

Risk analysis for current and future extreme precipitation in urban areas is surrounded by great uncertainties originating from complex linkages of climate models, methods of downscaling, impact assessments and socioeconomic impact models (Schneider, 1983; Moss and Schneider, 2000; Heal and Kristrom, 2002; Wilby and Dessai, 2010; Weitzman, 2011). The uncertainties related to the different steps in an integrated risk assessment have different characteristics. Structural uncertainties reflect incomplete understandings of the processes and components of the earth system in climate and impact models, while other uncertainties are related to economic models, where valuation issues, risk attitudes and discounting approaches can play a major role (Mastrandrea et al., 2010; Halsnæs et al., 2015). As Hawkins and Sutton (2011) and Wilby et al. (2014) argue, some climate change impacts, like extreme precipitation in local areas, are surrounded by particularly large uncertainties. Precipitation projections are in general very uncertain and predominantly short term, as there is a lot of noise from natural fluctuations (Field et al., 2012). The downscaling of the frequencies and intensities of extreme precipitation events to relevant geographical scales – here specific urban areas – adds yet another large element of uncertainty (Schneider, 1983; Sunyer et al., 2015a). Against this background, it can be argued that risk assessments of flooding in cities during extreme precipitation face these uncertainties simply because it is very difficult to estimate the probability of low-frequency, high-intensity events for specific locations. When assessing the risks of extreme events, it is therefore important to recognize that, although probabilities are very uncertain, large-scale consequences might occur, and that the willingness to pay (WTP) for avoiding them will then be very dependent on the general risk-averse attitudes of decision-makers and of society as a whole (Weitzman, 2011; Halsnæs et al., 2015). Recognizing these limitations, an analysis based on extreme rainfall simulations using flood models, combined with damage cost assessments and economic valuations, can still provide important insights into the specific consequences of flooding from extreme rainfall both today and in the future. Additionally, studies can also be supported by available data on insurance claims from past events that provide evidence for the physical and economic consequences of similar extreme rainfall events.

This paper presents an integrated framework and tool, the Danish Integrated Assessment System (DIAS), for localized risk assessments, and highlights key uncertainties related to modelling tools, data and assumptions. The usefulness of such a framework is demonstrated by a case study of urban flooding during high-intensity rainfall for the city of Odense, Denmark. We selected Odense as a case study for this paper due to the availability of most of the relevant information and of the data needed to conduct an integrated risk assessment successfully. However, as the integrated risk assessment method presented here is highly generic, we consider the approach appropriate for use in urban areas elsewhere, both regionally and globally. DIAS has been developed as a tool for facilitating short- to medium-term climate change risk analysis covering a time frame of ten to fifty years and beyond, the aim being to support decision-making in respect of local climate change adaptation, for example, for urban areas (Skougaard Kaspersen et al., 2012). It includes a very rich database on climate, land cover and socioeconomic activities for Denmark, which provides a basis for spatially detailed assessments of the climate risks to various assets and to society as a whole. In terms of the planning perspectives of governments and stakeholders, DIAS facilitates a broad cross-cutting assessment of climate risks associated with infrastructure, buildings, public services, nature, health and historical and cultural heritage. Also, it is shown how the uncertainties of a risk assessment can be reduced by using a detailed context-specific approach, where it is possible to identify particularly vulnerable areas. This enables the risk assessment to focus on more detailed climate data and impacts for specific areas, rather than on risk assessments, where uncertainties related to different modelling components are concealed by aggregation. Detailed assessments are made possible by open access to spatial data on land use, drainage systems, buildings, ecosystems and socioeconomic factors, on which basis critical flood risk areas and damage thresholds can be identified.

2. Methods and materials

2.1. Risk assessment

For the purposes of this paper, climate change risks are defined as the probability of a specific climate event multiplied by the consequences of that particular event. The risk of an event is thus based on a combination of information, from downscaled climate model outputs and spatially explicit impact assessments. Subsequently, the consequences can be assessed in the form of costs by assessing the value of those assets that are affected by the extra risk caused by climate change using methods of economic valuation. A generic structure for climate impact and risk assessment is presented in Fig. 1. It shows how information about the climate system, impacts, damage and related costs can support risk assessments.

Several linked modelling steps are included in risk assessments. Depending on the specific focus of the individual assessment, each step will include their own uncertainties, data limitations and/or the structural weaknesses of models and methodological frameworks. In discussing the case study of urban flooding in the city of Odense, we will highlight key uncertainties and suggest approaches for reducing them. Rather than going into all the subcomponents of the assessment in depth, we will select focal flood-prone areas to demonstrate how the risk of particularly valuable assets can be assessed based on detailed context-specific data.

In our risk assessment framework, consequences are measured in terms of society's WTP for avoiding a given hazard. The perspective of the damage cost assessment is thus that of social welfare,[1] where the total damage cost is an aggregate measure of the costs to all individuals of damage to given assets. Total damage costs are estimated using a bottom-up approach, with cost parameters being assigned to different assets, including buildings, health, infrastructure, historical and cultural heritage, and ecosystems. Total damage is calculated as the sum of all damage in all the sub-categories.

2.2. Analytical tool for integrated risk assessment

The risk assessment for the case study of urban flooding is conducted using DIAS, which has been developed in order to support risk assessments as part of decision-making regarding climate change adaptation (Skougaard Kaspersen et al., 2012) (Fig. 2). DIAS aims at facilitating modelling groups and experts sharing outputs and data, given the understanding that the multidisciplinary character of risk and adaptation studies demands such a structured approach to collaboration. The system is based on open-source information for research groups made available by universities and public institutions. It includes geographical data on current and future climate patterns, land use, groundwater resources, soil types, specific ecosystems, population, income, buildings, historical and cultural heritage, infrastructure, traffic, industry and social institutions (hospitals, schools etc.), which are all represented in

[1] Social welfare reflects society's own perspectives in relation to, for example, climate change impacts.