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ARTICLE

Adaptation to Five Metres of Sea Level Rise

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ABSTRACT There is an unknown but probably small probability that the West-Antarctic Ice Sheet (WAIS) will collapse because of anthropogenic climate change. A WAIS collapse could cause a 5–6 metre global sea level rise within centuries. In three case studies, we investigate the response of society to the most extreme yet not implausible scenario, a five-metre sea level rise within a century, starting in 2030. The case studies combine a series of interviews with experts and stakeholders with a gaming workshop. In the Rhone delta, the most likely option would be retreat, with economic losses, perhaps social losses, and maybe ecological gains. In the Thames estuary, the probable outcome is less clear, but would probably be a mix of protection, accommodation and retreat, with parts of the city centre turned into a Venice of London. A massive downstream barrier is an alternative response. In the Rhine delta (the Netherlands), the initial response would be protection, followed by retreat from

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the economically less important parts of the country and, probably, from Amsterdam–Rotterdam metropolitan region as well. These impacts are large compared to other climate change impacts, but probably small compared to the impacts of the same scenario in other parts of the world. This suggests that the possibility of a anthropogenic-climate-change-induced WAIS collapse would strengthen the case for greenhouse gas emission reduction.

KEY WORDS: Sea level rise, West-Antarctic Ice Sheet, adaptation

Introduction

Climate change policy has always been driven by fear of the "big impact" that, although not fully understood let alone quantified, would justify stringent cuts of greenhouse gas emissions. In the 1980s, impacts on agriculture (e.g., Parry, 1990) and coastal zones (e.g., Schneider and Chen, 1980) were deemed catastrophic. In the early 1990s, it was argued that tropical diseases would spread and kill many millions (e.g., Haines and Fuchs, 1991). Since then, extreme weather events (e.g., Berz, 2001) and the possibility of abrupt climate change (e.g., Alley *et al.*, 2003) have received most attention (see, for instance, Smith *et al.*, 2001). These assessments have been all speculative, being based largely on qualitative reasoning with little empirical constraints. On closer inspection, the earlier "big impacts" were shown to be much smaller[1] (although by no means negligible). Extreme weather events remain speculative, particularly because the natural science of tropical storms and river floods is still incomplete (Arnell *et al.*, 2001; Cubasch *et al.*, 2001). For extreme climate scenarios, progress is now rapid. This is particularly the case for the thermohaline circulation, where there is now a body of model-based literature on the probability of collapse, the impacts, and the policy implications (see below). This paper looks at a different extreme scenario, namely the collapse of the West-Antarctic Ice Sheet (WAIS).

Extreme climate scenarios are also characterised by their low probability,[2] high impact scenarios. They are a reason for concern for climate change because both the probability of occurrence and the scale of impacts are unknown. Although the former is believed to be low, the latter could be extremely high. The high uncertainty adds to the level of concern

[1] To see this, compare the studies mentioned above to the ones reviewed by McCarthy *et al.* (2001).

[2] Note that the word "probability" is used here to express a "degree of belief", rather than a "frequency". As such things as a shutdown of the thermohaline circulation and a collapse of the West-Antarctic Ice Sheet do not happen very often, and because modelling them is hard, it is extremely difficult to objectively estimate such a probability. Most people who know these systems nonetheless argue that the chance is small. However, the uncertainty regarding just how small is large.

experienced (Alley *et al.*, 2003; Smith *et al.*, 2001). A collapse of the North Atlantic thermohaline circulation (THC) has attracted much attention (Link and Tol, 2004; Rahmstorff, 2000; Schiller *et al.*, 1997; Stocker and Schmittner, 1997; Vellinga and Wood, 2002). This could lead to rapid cooling of Northern and Western Europe. The literature now comprises many studies on the physics of the THC (Rahmstorff, 2000; Schiller *et al.*, 1997; Stocker and Schmittner, 1997; Vellinga and Wood, 2002), a few impact studies (Link and Tol, 2004) and a handful of policy analyses (Keller *et al.*, 2000, 2004). The impact studies, in particular, can be criticised for extrapolating from standard climate change impact studies, which look at more gradual change, a different sign of change, and are placed in a nearer future.

The literature on a WAIS collapse is less extensive than that on the THC, with the physical aspect of the problem better represented in the literature (Alley and Whillians, 1991; Bentley, 1997; Kerr, 1998; MacAyeal, 1992; Mercer, 1978; Oppenheimer, 1998; Thomas *et al.*, 1979) although even this is far from complete (Vaughan and Spouge, 2002)). Impact studies are few and dated (Schneider and Chen, 1980), while policy analyses are scarce and qualitative (Oppenheimer and Alley, 2004). Kasperson *et al.* (2005) provide a recent survey. This paper makes a first attempt to fill some of these gaps, especially with regard to adaptation and policy.

The implications of a 5–6-m rise in sea level are significant as there are important coastal lowlands within this elevation of present sea level. For instance, large parts of Florida might disappear, as would large areas around the southern North Sea, especially the Netherlands, and the major deltas, including the densely-populated Nile and Asian "mega-deltas". The world's coastal zones are home to a significant part of humanity, living at average densities three times the global mean density (Small and Nicholls, 2003). Population and economic density also increase seawards across the coastal zone, with the highest densities being below 20-m elevation. This includes significant numbers of the world's major cities. Based on 1990 data by CIESIN and CIAT (2004), at least 410 million lived within 5 m of present high tide, although the uncertainties are large (Nicholls *et al.*, 2005). Allowing for population growth of the coastal zone and likelihood of a continued coastward migration, this threatened population will likely at least double through the twenty-first century and possibly increase much more. There has been limited detailed assessment of extreme sea-level rise, but shortly after Mercer (1978) published his paper there were national assessments by Schneider and Chen (1980) for the USA and by Rijkswaterstaat (1986) for the Netherlands. These reinforced how much is threatened, although the Dutch case study did think that adaptation might be feasible.

In the next section, we describe the mechanisms that may lead to a WAIS collapse under global warming, discuss the probability that this would occur, and make a rough assessment of the implications. The following section discusses the methodology used to assess the likely impacts. In the next section, we deviate from the typical climate change impact study. Rather than focussing on the impacts, we place adaptation at the heart of the analysis. For impacts in general and for a five-metre sea level rise in particular. We find that the responses of people, companies and governments have at least as large an influence on the results as does the magnitude of climate change and sea level rise. In the penultimate section, we speculate on the policy implications of our results, while the final section concludes.

The Problem

The WAIS comprises about 10% by volume of the entire Antarctic ice sheet, and in volume is equivalent to a 5–6 m rise in sea level (Lythe *et al.*, 2001; Vaughan and Spouge, 2002; Oppenheimer and Alley, 2004). The volume of ice it contains is controlled by the balance of precipitation across the sheet, and seaward flow of ice through the ice sheet, to the floating ice shelves. Here there is melting on the underside of the ice shelf, or iceberg calving at the periphery. Mercer (1978) caught the attention of policymakers when he speculated that human-induced global warming could cause the ice shelves of West Antarctica to disintegrate during the twenty-first century, allowing the ice sheet to be catastrophically released into the ocean by a progressive inland retreat of the ice sheet grounding line. This dynamic retreat through increased rates of ice flow could happen much faster than could be achieved by melting of the ice in situ. Thus, the resulting rise in sea level could be much faster than for example the loss of the Greenland ice sheet, which would require melting of the ice, taking many hundreds or even thousands of years (Gregory *et al.*, 2004; Lowe *et al.*, 2005). Although people often speak about a "WAIS collapse", meaning the loss of most or all of the WAIS land-based ice, this process would in fact be slower that collapse might imply. It is difficult to postulate significant loss occurring in less than a few hundred years (Vaughan and Spouge, 2002).

Having established this risk, there was widespread concern about the likelihood of extreme sea-level rise, and the maximum rate of rise that might be possible. There are widely divergent views ranging from a position that the mechanism is almost impossible, to expectations that WAIS collapse may begin in the twenty-first century. Vaughan and Spouge (2002) recently conducted a formal risk assessment of the WAIS collapse, including using a Delphi technique with a panel of experts to explore these uncertainties and estimate the resulting risk. The complexity of the collapse mechanism is captured in their Figure 2, illustrating the range of processes of interest when trying to understand WAIS collapse. They concluded that the scientific opinion allows for a 5% probability of the WAIS causing a sea-level rise of at least 10 mm/yr (or 1 m/century) within 200 years. In terms of total rise due to the WAIS contribution, they estimated a 5% probability of a 0.5 m rise by 2100, about 2.3 m by 2500, and about 3.2 m rise by 4000. Hence, none of these estimates equate to a total WAIS collapse.

The goal of the Atlantis Project was to look at an extreme scenario, and especially to understand the societal response to such an extreme change. Given the current status of scientific knowledge, the total collapse of the WAIS in relatively short timescales of 100–200 years cannot presently be stated as completely impossible. This is supported by discussions with several glaciologists who all thought such rapid collapse highly unlikely, but felt the system was not well enough understood to totally discount such a rapid change. Given the limited resources of the project, it was felt that we would learn most about the response by considering the most extreme scenario possible, and the Atlantis Project decided to use a scenario of a 5-m rise in 100 years due to the WAIS collapse. This was kept deliberately simple and was applied linearly from 2030 for all the three case studies discussed below. In 2130, the rise ceases, as abruptly as it began. (The global analysis was able to explore a wider range of scenarios from a 1 m/century up to a 5 m/century scenario.) Even if the Atlantis scenario is later demonstrated to be impossible, which we recognise may be the conclusion of future glaciological assessments, the intellectual exercise of thinking through an extreme scenario to impacts and especially responses has been very valuable and informative, both for coastal issues and more generally to understanding extreme climate change.

As stated in the introduction, the impacts of a 5–6 metre sea level rise may be substantial. Nicholls *et al.* (2005) conducted a global assessment of extreme sea-level rise using a benefit–cost methodology implemented within the FUND model (Tol, 2004). For sea-level rise at rates of <1 m/century, protection is the normal response around the world's coasts, especially allowing for typical economic growth scenarios. As the rate of sea-level rise increases up to a 5 m/century scenario, so larger and larger lengths of shoreline are not defended. This result is, however, also sensitive to assumptions of adaptation costs: as these costs rise, so more coast is abandoned. While more analysis is required, these results are consistent with the three case studies, which show that a widespread retreat may occur in the face of an extreme rise in sea level, such as the WAIS collapse.

Methodology

While methods to analyse the physical implications of such rapid sea-level rise (RSLR) (inundated areas, and increased flood risks) using both simple "bath-tub" methods and more sophisticated methods which consider hydraulics and defences (e.g., Dawson *et al.*, 2005), it is a much greater challenge to investigate the social perceptions of and the possible reactions to this risk by engaging key stakeholders. The reasons are diverse and numerous: the very low probability and the very long time horizon of the event, the preoccupation of policy-makers with near-term problems, and so on.

Participatory techniques were adopted to provide a structured interaction among representatives of main stakeholder groups in three European regions. An extensive literature review identified three participatory methods that were worth considering for use to explore the implications of and management responses to a RSLR: Simulation-Gaming techniques (Greenblat and Duke, 1981), the Policy Exercise method (Toth, 1988a, 1988b), and the Focus Group technique (Krueger, 1988). Based on lessons learned from the application of these methods to problems with characteristics resembling those of the RSLR, several elements of the procedural design were sketched out in order to simulate a regional management board responsible for preparing plans and undertaking actions to cope with the RSLR problem. Two such elements are elaborated in detail:

- The "Classic" design resembles the most widely used procedure in Policy Exercises. Participants are given the original scenario outlining the information about socio-economic development and the regional specifics for the year 2030 together with projections about the magnitude and timing of RSLR. In a series of moves, participants develop strategies and put in place the necessary actions for the subsequent decades. The Control team evaluates these strategies and provides new information about improved scientific knowledge and other features of the original sea-level-rise scenario. At the end of the time horizon, the Control team produces the full scenario including the final state of the world.
- The "Backcasting" design starts with a scenario presenting the impacts of RSLR in 2130 when the process will have been completed. Participants imagine themselves to be in 2030 when the first reports about the plausibility of RSLR become available and agree on the basic strategy: total/partial retreat or full protection. The implications of this strategy are projected to the year 2130. The backcasting process regresses from this endpoint to 2030 in 30-year time steps and involves in-depth clarification of actions and preconditions required to ensure the successful implementation and completion of the strategy.

The ATLANTIS regional exercises adapted procedural elements of the two detailed workshop designs and ideas from the other sketches. They reformulated the designs according to the biophysical and socio-political/cultural characteristics of the regions. Propositions in the original designs and their creative adoption in the regional case studies resulted in effective and inspiring albeit different procedures involving about 20 participants in each case; see Toth and Hizsnyik (2005) for a more detailed discussion. The Dutch workshop implemented a simplified Policy Exercise with elements of a structured group interview. The Rhone/Camargue exercise resembled a flexible Policy Exercise arrangement without a Control team and assisted by carefully prepared information packages that were used according to the evolution and branching points in the scenario progression. The Thames exercise involved a free-form gaming session in which participants played the future equivalent of their current positions and the proposed strategies were evaluated by a self-selected Control team. As a result, the information flows, the group dynamics, and the main foci of the group elaborations differed, but each provided an effective and inspiring analytical-discursive procedure.

Three Case Studies of Possible Adaptation

The Rhine Delta[3]

Like many other deltas, the Rhine delta is vulnerable to sea level rise and densely populated. The Rhine delta is the historic and economic heart of the Netherlands, and home to Europe's largest harbour: Rotterdam. Centuries of subsidence have put most of the country below mean sea level. Flood safety is a national issue. A sophisticated and ancient system of high dikes, dunes and sluices protect against sea floods, while an elaborate system of canals and pumps prevents the land behind the dikes from flooding from rivers and rainfall. Flood safety management is ruled by a series of national laws and carried out by national governmental organisations. Policy strategy design within these organisations considers a sea level rise of about 0.8 m—from climate change and tectonic subsidence—during the coming century as a fact.

In order to assess the consequences of a 5–6 metre sea level rise, the literature was surveyed (and it turned out that a technical report on this scenario had already been published: Rijkswaterstaat, 1986), 20 specialists were consulted in semi-structured interviews, and 12 specialists were convened in a scenario/brainstorm workshop. The specialists included academics from the social and engineering sciences, and representatives from government and business.

There are three adaptation options, in order of increasing likelihood according to the workshop participants: (1) raising the dikes by 6–7 metres everywhere; (2) raising the dikes of Amsterdam/The Hague/Rotterdam/Utrecht metropolitan area, abandoning other low-lying areas; (3) abandoning all low-lying areas (some two-thirds of the country). The first two options also imply that the entire flow of the Rhine would have to be *pumped* to the sea. The scale of the dike raising that is required is such that the entire operation will take many decades. Nonetheless, according to various experts, it would be technically possible to have flood defences in place that more or less would preserve Dutch territorial integrity in a situation with a 5 m higher sea level. Reinforcing and constructing flood defences, rather than abandoning land, would be the default response of the Dutch society, in line with a tradition that started in the sixteenth century. This tradition, however, emerged during a period of sea level movement that was very slow compared to a 5 m SLR in one century.

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[3] This section is based on Olsthoorn *et al.* (2005).

We developed two scenarios from two different assumptions about basic societal trends. One scenario assumes ongoing liberalisation, globalisation and associated high economic growth of GDP and an unequal income distribution. The other scenario assumes a greater role of governmental coordination of economies, solidarity, a more equal income distribution, but less growth of GDP.

In both scenarios, the initial signs of a WAIS collapse would be ignored. Only after the occurrence of chance events such as (near) floods, public belief and a sense of urgency would develop. Government action would be taken after such events, when flood safety has become a societal problem, but only if politicians deem proposed solutions important in relation to other items on their agendas. Meanwhile, peripheral actors can decide to react on their own. Strategic planning is more likely in large companies than in government. Headquarters, plants and infrastructure may be relocated to the east of the country, or abroad, probably in response to a flood. Domino effects to other companies, big and small, are likely. Terrorists may target dikes, and this would add to the feeling of insecurity. People would follow the companies. The (international) mobility of particularly higher-educated people has increased tremendously, and this trend is likely to continue to increase in the future. This would erode the willingness to defend Holland at all costs. At first, the areas of relatively low economic value—the southwestern and northern parts of the Netherlands—would be abandoned, but later, the western parts containing Rotterdam and Amsterdam would be allowed to disappear as well.

Interestingly, the participants of the workshop believed that this is also the likely outcome in the other scenario, albeit at a later date. This outcome, however, was met after a different course of events. Politics, in a society in which much value is attached to solidarity and where flood safety issues may give rise to new political divides, will tend to prefer flood safety policies that do not consider abandoning areas of less economic value. The government would then favour protection of the entire country. It has become increasingly hard to favour the special interests of the low-lying west at the expense of other parts of the country. But decision-making would be slow, probably too slow to preserve flood safety vis-à-vis the rate of SLR, since the design and construction of flood defence works takes years and works cannot be constructed everywhere simultaneously. Eventually, it was thought, peripheral actors would start a process of abandoning areas. Again, the occurrence of a chance event such as a flood would catalyse developments.

In general, the interviewees and workshop participants expect little action from the government, and even less *timely* action. The reasons include lack of prioritisation and short-term interests. The government would also provide insufficient support for relocation. The wildcard in both scenarios is the position of ethnic minorities. They are a growing political and economic force, particularly in the big cities in the west, but their attitude towards flood risks is unknown.

The Thames Estuary[4]

As an estuary, the mouth of the river Thames is not as vulnerable to sea level rise as the Rhine delta. However, this area does contain London, one of the world's great cities, which is expanding seawards, particularly with 120,000 new houses in the Thames Gateway by 2016. But the historic heart of London is also vulnerable to flooding and sea-level rise, particularly Westminster and the South Bank.

Interviews were conducted with 25 individuals from 21 different organisations. The interviewees came from a range of government departments and associated bodies, the NGO and private sector. In large organisations such as government departments or public bodies such as the Environment Agency individuals from different parts of the organisation were interviewed to get, for example, a strategic and a more operational perspective. The strategy game consisted of a day-long role playing exercise. The game had a minimal set of rules (to stay in role, to keep to time, to be plausible, and not to identify speakers by name or affiliation outside the room). The roles were tailored to fit the existing roles of the participants but adapted for 2030. Roles were developed for 24 participants but as five dropped out in the last couple of days, the game was played with 19 participants from 16 different organisations or departments.

The main issues in the Thames case study were uncertainty regarding the forecast of extreme sea level rise and lack of experience with the phenomenon. It was thought that this could well result in paralysis and thus a delay in decision making. The ability to cope with extreme sea level rise was thought to depend on the speed at which it is manifest. Signs of increasing flood risk—including escalation of backwater ponding or sewer flooding—were identified as important catalysts for action. Through the discussion it was apparent that there are no easy options, and agreement on an option between the various actors would be hard to achieve. The more popular options include:[5] (1) building a new and larger Thames Barrier further downstream (near Canvey Island); (2) abandoning the flood plain and relocating to higher ground; and (3) reshaping the city to a Venice of London, with stilts, floats, abandonment and sea walls. All these options have very large financial implications, questions of technical feasibility and would be disruptive to implement. Under each option it is possible to identify winners and losers. To try and limit the negative implications of this public engagement is key to a planned response, even if it slows down the process of decision making. Such engagement requires clear communication of the risks and options. Without this, denial or panic may well result. It was considered important that London should be seen in the national, European and global context. The availability of finance, the balance of bearing the costs, fairness among the regions affected, the role of democracy and public

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[4] This section is based on Lonsdale *et al.* (2005).
[5] In order of increasing preference among the workshop participants.

support for action would all be decided at least in UK and EU political debates. At same time, London was considered to be unique because of its heritage, as a financial centre and in attracting tourists. The economic success of the UK depends on the maintenance of London as a World City and flood defences are being upgraded for a 1-m sea-level rise (Lavery and Donovan, 2005). This may not hold when faced with the scale of the threat of a 5–6 metre sea level rise.

The Rhone Delta[6]

The Rhone Delta or Camargue in southeast France resembles a 750 km^2 island embraced by the two branches of the Rhone and the Mediterranean Sea. Protected since 1859 by a sea dike and much later embankments, the present shape of the delta, its rice farming and exceptionally rich wildlife reserves depend upon irrigation and draining. The Camargue is a popular nature-oriented tourist destination and important pilgrimage site; 8000 gypsies fete their patron saint there each May.

The policy workshop "convened" at three points in time. At the opening (2004), the risk of a WAIS collapse is announced but not quantified. In 2030, this risk is assessed at 20%, potentially producing linear SLR totalling 5–6 m over one century. In 2050, the actual collapse has indeed occurred and the Rhone Delta has already experienced a 1-m SLR. Socio-economic scenarios were in reserve showing alternative pathways of local/regional development. They were informed by 30 individual interviews with experts (geology, hydrology, geography, sociology), professionals (land use planning, risk analysis, public health, insurance), and local stakeholders (industry, elected bodies and management support, farmers, hunters, clergy). A similarly representative subset of 12 participated in the workshop as a Camargue Consultative Committee mandated by the European Commission to examine SLR risk and make action recommendations. Scenarios and maps as appropriate provided a basis for group discussion and decision.[7]

In 2030, the Committee chose to *"wait and see/prepare strategic retreat"* and recommended:

1. Land use planning policy to reflect a "hold off, wait and see" attitude; moratorium on development.
2. Create a margin of liberty for the sea (review and alter or condemn building zones).
3. Engage elected officials and scientific experts in public information and participatory initiatives.

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[6] This section is based on Poumadère *et al.* (2005).

[7] To add to the realism of the Committee setting, we also generated newspaper articles dated between 2004 and 2030, and between 2031 and 2050, describing local developments, climate change findings and SLR impacts.

4. Cost–benefit analysis of protection options; study and model possible futures.
5. Protect against Rhone river flooding (integrate the upstream area into planning; free up river expansion zone).
6. Create a coordinating decision structure.
7. Interdisciplinary synthesis of studies, review of relevant knowledge.
8. Create the conditions favourable to possible retreat (accompany the population on economic, social and psychological levels).

In 2050, the reconvened Committee chose "*retreat*":

1. Strong laws and decrees of application (determine retreat zones, organise long-term medical response, economic and psychological accompanying measures, create solidarity fund).
2. Restore the Rhone Delta's hydraulic function (protective spill areas for the city of Arles and the Baux Valley, Bourg Plain).
3. Continue flood reduction programme.
4. Create a unitary management organisation.
5. Develop a culture of "territorial evolution" (facilitate acceptance of change by the population…).
6. Prepare for crises (in public health, political confidence, etc.).
7. Redistribute local economy.

In interviews, the extreme SLR scenario was often rejected as far-fetched. More salient for interviewees was the severe Rhone river flooding experienced just before the workshop in 2003. In contrast, the workshop group plunged very seriously into the simulation, rarely stepping out of role to question the credibility of the scenarios or the hypothetical decision-making context. The group united in the goal of developing the best possible transdisciplinary responses to risk. Recommendations were both well-discussed and consensual.

Particularly striking was the willingness from 2050 to see the Rhone Delta be reclaimed by nature: protective actions could be justified only by loss of economic activities, and these would be more appropriately localised in other zones. Participants also showed great confidence that Camargue cultural identity could survive SLR and a retreat to the north.

Policy Implications

The policy implications of a potential WAIS collapse remain difficult to assess. The above analysis makes clear that the probability of collapse is unknown, let alone how this probability can be influenced by emission abatement. Similarly, although the eventual consequence on global sea levels is clear (a 5–6 metre rise), the speed of this rise is unknown. Furthermore, the impacts of a 5–6 metre sea level rise are only known in very crude terms. A risk analysis, based on probability multiplied by the scale of the impact, is thus presently impossible. Based on the existing scientific evidence, Oppenheimer and Alley (2004) argue that allowing a doubling of CO_2 poses a significant, although poorly quantified, risk of disintegration of the WAIS. They note that the onset of the collapse may lag behind the increase in greenhouse gas concentration. Based on this, they argue that a precautionary approach would suggest this concentration be avoided. They make an explicit link between mitigation and the risk of the WAIS collapse. However, as the collapse mechanism is contested, other glacial experts may disagree with this view.

The three case studies make clear that adaptation would be difficult, even in highly developed and well-organised countries such as France, the Netherlands and the UK. The Dutch case study concludes that abandoning a large part of the densely-populated country may well be the result. The Netherlands is well-known to be threatened by sea level rise, but is by no means unique. If the Dutch cannot cope with their well-developed flood management technology and institutions, the chances are that other river deltas cannot cope either. Evacuating the Rhine delta might be a national trauma, but evacuating the densely-populated Asian mega-deltas such as the Ganges-Brahmaputra, Mekong, and Changjiang would likely be a calamity of international proportions (see population estimates in Woodroffe *et al.* (2005).[8] The economic and social ramifications would be enormous, even if one disregards the higher order effects. The preliminary conclusion is that a WAIS collapse is something that should rather be avoided, even if the rate of collapse was slower than considered in the case studies.

However, our scientific understanding is not sufficient to understand how much control we have over this potential event. The three case studies agree that the lead time of the warning would be crucial in shaping the response. This calls for close monitoring of the WAIS, combined with detailed process and modelling studies of the potential for collapse (see also Oppenheimer and Alley, 2004). If this understanding improves, a formal risk analysis could become possible, and the link of this risk to mitigation policy could be better demonstrated. However, beyond the science, the case studies show that if extreme change was forecast, the warning should be clear to the public and the politicians to maximise the effectiveness of any response. Can science produce such estimates when such events will inevitably remain couched in probabilities rather than certainties? Further, the case studies suggest that decisive action may be incompatible with the current democratic system in European countries.

Keller *et al.* (2000, 2004) analyse the implications of the possibility of a THC collapse on near-term emission reduction policy targets. They showed that the risk of a THC collapse would substantially increase the rationale for

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[8] A referee put it on the same scale as the partitioning of British India into Bangladesh, India, and Pakistan.

emission abatement, as long as it can be avoided; this is consistent with the precautionary approach of Oppenheimer and Alley (2004). They also show that, once it becomes clear that a collapse can no longer be avoided, the optimal emission abatement falls and even falls below the case without a THC collapse. This is because in this case, it would be better to invest resources into preparing for the consequences. Although the mechanisms and implications of the THC and the WAIS are very different, there is little reason to assume that, qualitatively, the policy implications of a WAIS collapse would be different (supported by the stylised decision analysis of Guillerminet and Tol, 2005).

Discussion and Conclusion

This paper offers a first glance at how societies may or may not cope with extreme sea level rise. The three case studies suggest that, although protection is technically possible, a combination of accommodation and retreat is the more likely adaptation strategy. The face of London would change dramatically, while the Rhine and Rhone delta would be largely given up. In the case of the Rhine, this would imply a major relocation of population and industry. Compared to other climate change impacts, this is a very large impact. Note that France, the UK, and the Netherlands are not particularly vulnerable. Large impacts in these countries imply much larger effects elsewhere. Although we do not know the probability of a WAIS collapse, let alone how this probability responds to greenhouse gas emission reduction, this does present itself as a clear case for precautionary emission abatement. It should be noted, however, that a potential WAIS collapse is but one of many arguments for and against greenhouse gas emission reduction, and it need not be a decisive argument. It should also be noted that emission abatement does not necessarily prevent a WAIS collapse, as abatement may be too little or too late, or the WAIS may collapse for other reasons.

The applications of participatory techniques to help relevant policymakers and stakeholders engage into a serious assessment of a remote and low-probability environmental risk proved to be successful. The flexibility of these techniques and the possibility of combining design elements of several techniques in a methodologically consistent manner were demonstrated. The results indicate that participatory techniques can usefully complement formal methods of risk analysis and they are also valuable in exploring the risk perceptions and risk attitudes of key stakeholder groups if their delegates at the workshop correctly represent the wider community.

Much remains to be done. An improved, quantitative understanding of the WAIS and its response to climate change is essential although quite difficult as shown by Vaughan and Spouge, 2002). Impact models need to be improved to be able to analyse the effects of a 5–6 metre sea level rise over a range of timescales. The adaptation policy studies presented here need to be replicated elsewhere—and the methodology needs to be adjusted to take into account the interdependencies between the cases. The preliminary findings of this study suggest that such research is scientifically challenging and highly relevant to climate and coastal management policy.

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