Changing coastal and marine conditions

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Abstract

The ocean plays an important role as an agent in the global climate system as well as a relevant resource for humans in the coastal zones. The presently emerging anthropogenic climate change has an impact on the performance of the global player “ocean” as well as on the risks in coastal zones. In this paper we examine a model simulation of the past 1000 years and a projection for the coming 100 years under the IPCC SRES scenario A2. We consider the Atlantic overturning circulation, and the risk of storm surges along the North Sea coast. In both cases, we find a marked change: a reduction of the meridional overturning by 25% and more, and an crease of wind-related water levels by 30 and more cm.

1 Introduction

The ocean, which covers some 70% of the Earth surface, is a key component for the climate system. First, it is the thermal inertia of the ocean, which adds persistence to the climate system; also, the ocean is responsible for the transport of large amounts of momentum and heat. Another most important function is the storage of substances, in particular carbon.

On the other hand is the ocean surface an important resource for human economic activities, in particular shipping, fishing, off-shore industry; such activity is concentrated in coastal zones, where human activity is often in conflict with another outstanding function of the coastal sea, namely the maintenance of rich ecosystems. The utility of economic activities as well as the functioning of coastal ecosystems depend to some extent on the natural risks of coastal zones, namely secular water level variations, storm related extreme water levels and high wind waves related to intense storms.

Because of the ongoing emissions of radiatively active substances into the atmosphere and the inertia of the economic and political system, the IPCC[1] expects significant changes of the climate in the coming century – in the following, we will consider two examples of the changes, which are considered plausible for the upcoming century.

Both major aspects of the ocean, the global agent as well as the regional resource and risk, cover a broad range of issues, which obviously cannot be dealt with in a short contributions like this one. Also, there is no need for a comprehensive account, as the IPCC has covered the various aspects with great care and detail (Houghton et al., 2001). Therefore, we limit ourselves to two relevant issues, to which we think we can contribute something significant. The variability and change of the North Atlantic overturning circulation (Section 2) is a property of the “global agent” ocean. Storm surge statistic along the North Sea coast (Section 3) is an example of change with immediate implications for land-use and coastal defense.

2 The long global perspective of “Erik den Røde”

We have performed a millennium-years integration “Erik den Røde” with the state-of-the-art climate model ECHO-G, which is a combination from the ocean model HOPE-G in T42 resolution and the atmospheric model ECHAM4 in T30 resolution. The model was exposed to estimated time-variable historical external forcing related to solar and volcanic activity and changing atmospheric concentrations of greenhouse gases (Figure 1; for details refer to Zorita et al., 2004, or González-Rouco et al., 2003). The simulation was initiated in the year 900 AD; the first 100 years were used to allow the model to equilibrate. After the year 1990, the simulation was continued with constant solar forcing and no volcanic activity but with increasing greenhouse gas concentration as specified by the IPCC SRES scenario A2.[2] Figure

[1] Intergovernmental Panel of Climate Change – see Houghton et al. (1996, 2001)
[2] The A2 scenario assumes large increases of future greenhouse gas emissions (Houghton et a., 2001) – according to this storyline, the carbon dioxide gas emissions are about 30 Gt/yr at the end of the 21st century; the concentrations amount to 800-900 ppm; at the same time the sulphur emissions are assumed to be reduced to about 60-70 million tons sulphur per year; the climate impact is guessed to be a temperature change of 3.8 K and a sea level rise of 40 cm.

1 shows the time history of the effective solar activity, greenhouse-gas and volcanic-aerosol concentrations used to force the model for the period of interest, 1000-2100.

The model integrates and stores all relevant oceanic and atmospheric variables. The “Erik den Røde”-simulation has been examined mostly with respect to air temperature variations (Figure 1). The model simulates correctly a gradual cooling from a relatively warm plateau in the 11th and 12th century, with a coolest period during the “Late Maunder Minimum” (LMM); since the middle of the 19th century temperatures are steadily increasing. The pattern of variation is consistent with commonly accepted knowledge, but the intensity of temperature variations is discussed controversially: The LMM temperatures in Europe compare favorably with regional reconstructions (KIHZ Consortium, 2004, Zorita et al., 2004), but are considerably too strong when compared with historical estimates derived through regression of proxy data on temperature but comparable to borehole estimates (Briffa and Osborn, 2002).

In the following we examine the intensity of the Atlantic meridional overturning circulation. Marked changes emerge in the simulation since the beginning of the industrialization consistent with previous simulations (Wood et al., 1999). In this case, however, there are additionally eight earlier centuries without significant human interference. These additional data allows us to compare the anthropogenic signal against the “noise” level of natural fluctuations.

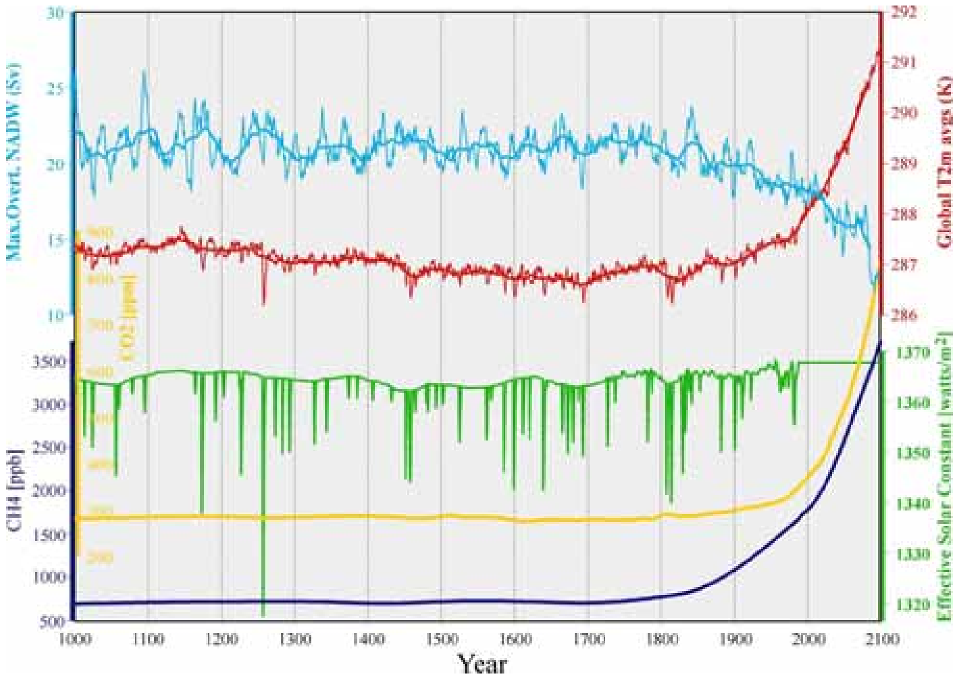

Figure 1. *Time series of annually averaged variables in the "Erik den Røde" simulation – the forcing factors: solar energy intercepted (variations are due to changing solar output and presence of volcanic aerosols in the atmosphere; green) and greenhouse gases (carbon dioxide (yellow) and methane (dark blue)), - the globally averaged air temperature (red), and the North Atlantic Deep Water index NADW (light blue). The forcing until 1990 is estimated from observations and indirect evidence; after 1990 the natural forcing factors are assumed to be constant, and the greenhouse-gas concentrations are increased according to the IPCC SRES scenario A2.*

The large-scale circulation of the Atlantic has a northward component near the surface of the ocean, a downward movement in sub-polar waters and a southward return flow at the lower levels of the basin. The net deep water production rate in the North Atlantic is estimated to be currently 15±2 Sv (Ganachaud and Wunsch, 2000). This circulation transports heat from the south to the North Atlantic, contributing to Europe's mild climate (e.g. Rahmstorf, 2002). Therefore, it is crucial to determine how it may change in the future. This circulation can be well represented by the meridional stream function (Figure 2) - the current is parallel to the streamlines.

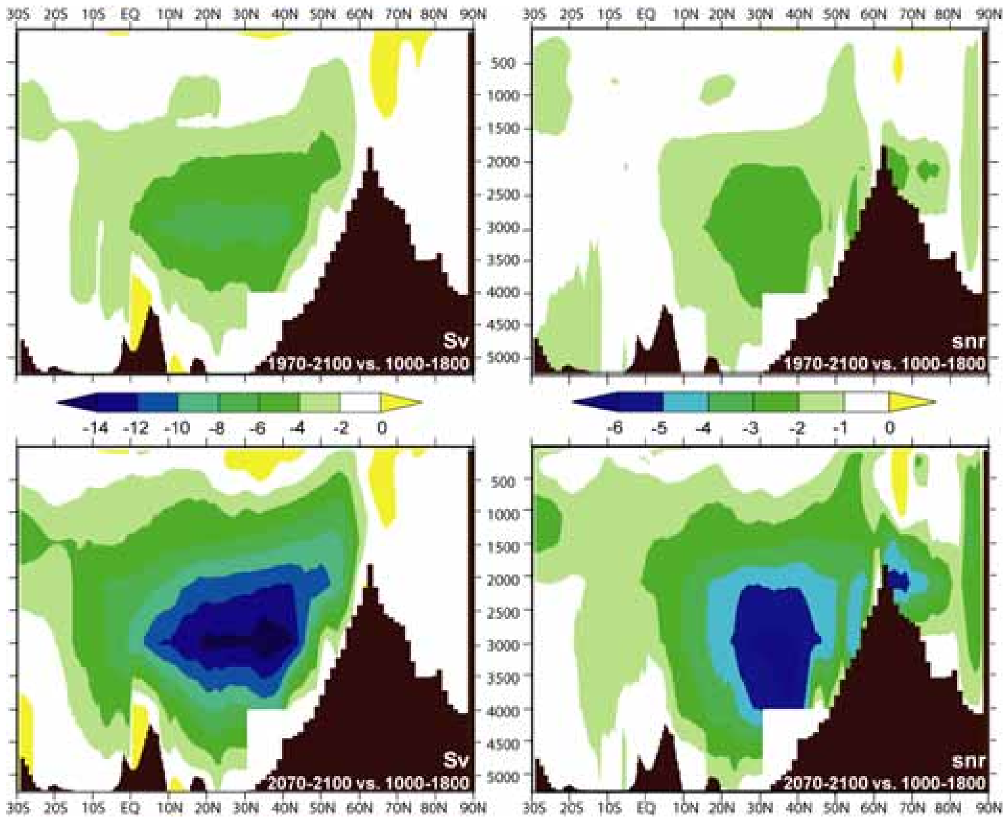

Figure 2. *Meridional stream-function of the North Atlantic overturning circulation. Shown are 30-year deviations from the 1000-1800 pre-industrial "normal" in Sverdrup (left) and signal-to-noise ratios of these changes (i.e., 30-yr anomalies divided by two standard deviations of 30-year mean variations during pre-industrial times; right). Top:1970-2000; Bottom: 2070-2100 according to the A2 scenario.*

An index for the intensity of the Atlantic meridional overturning circulation is the "North Atlantic Deep Water formation" NADW[3]. Figure 1 shows the temporal development of the NADW since the year 100 until today and into the next hundred years. Until the beginning of the industrialization, the NADW was on average about 22 Sv, thus slightly larger than es8timated from observations. The NADW did not vary strongly - intermittent anomalies were of the order of ±2 Sv with somewhat larger values in the initial phase. Since 1850 the NADW is declining. On average, the NADW during 1850-2000 amounts to about 19-20 Sv in the simulation, which is at

[3] Which is defined to be the maximum of the stream function between 200 m and 2000 m, and between 40°N and 90°N.

the lower end of the variability during the last millennium.[4] In the coming 100 years, under A2 emissions, the decline continues to a level of about 12 Sv, way beyond the level of natural variations during the last millennium.

The standard deviation of the 30-year running mean NADW during 1000-1850 is estimated to be 0.52 Sv, so that all 30-year mean deviations larger than about ±1 Sv may be considered statistically significant. The recent changes (Figure 2) during 1970-2000 are significant, with reductions of -4 Sv and more, and signal-to-noise ratios of up to 3. At the end of the 21st century the reductions are really strong in the A2 scenario, with a reduction of -10 Sv and more, and a signal-to-noise ratio of -5 and more.

3 North Sea storms surge statistics

Our other case deals with storm surges along the North Sea coast. Historically, this was and is a key risk of coastal life - Figure 3 shows a graphical representation of a severe flood in the 17th century[5] as well as a photograph of a dyke shortly before failing with severe consequences for the population during the disastrous storm surge in February 1962 in Germany.

The critical quantity for storm surges is simply the water level plus the effect of waves. The wave effect depends on various local conditions, for instance the shape of the dyke and the morphodynamic in the area in front of the coastline The water elevation depends on the mean water level, reflecting the volume of water filling the global ocean basins, on the regional windiness, and on the astronomical tides. Changes in water volume and local windiness as well as changing morphological conditions such as dredging of shipping channels can play a significant role for future storm surge evolution (Wyrtki, 1993).

Global climate change scenarios account for the change in volume and for changing regional weather conditions, in particular storms. For the former, the IPCC has issued as best guess an increase by 40 cm until the end of this century for the A2 scenario. Estimates for the later are more difficult, because of the insufficient resolution of global climate models to resolve regional changes.

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[4] This change is consistent with Wood et al.'s (1999) simulation of changes during industrial times.

[5] Refer to, e.g., Jakubowski-Thiessen (2004) and Petersen and Rohde (1977) for a historical account of past storm surges and the public perceptions.

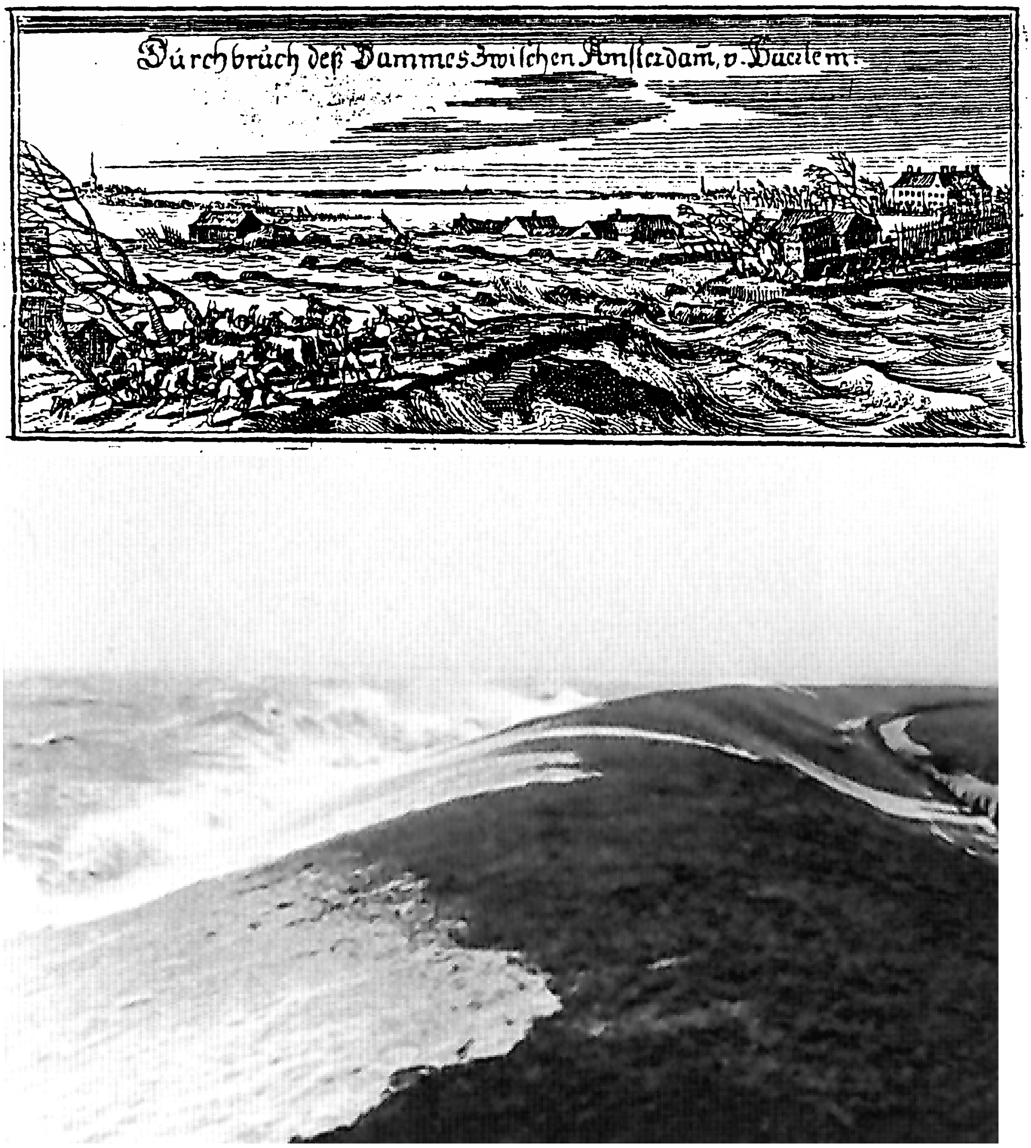

Figure 3. *Storm surges in the North Sea area. Top: Historical account from 1675 in Holland (after Jakubowski-Thiessen, 2004); bottom: February 1962 storm in the Elbe estuary (after Petersen and Rohde, 1977)*

To overcome these problems, “downscaling” methods have been developed – one such method is to expose a regional atmospheric model to the large scale changes of a global model, and to let the regional model estimate the regional change as a response to large-scale atmospheric flow and regional physiographic detail. In the European project PRUDENCE (Christensen et al., 2003) the A2 climate change scenario, as determined by a global model of the Hadley center, has been downscaled with a series of different regional models; the effect was in all cases similar, namely a moderate increase of high wind speeds in most parts of the North Sea during winter.

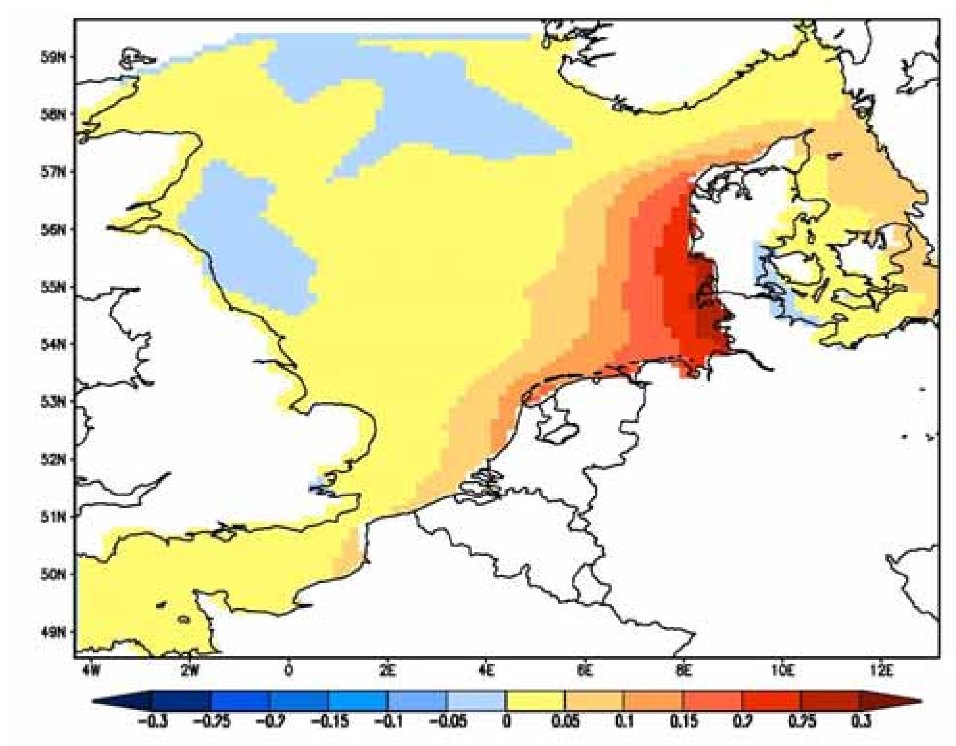

Figure 4. *Expected effect of largest windstorm caused surge heights in the North Sea according to an A2 climate change scenario – using a chain of models: a Hadley Center global climate model, the regional atmospheric model of the Danish Meteorological Service, and the storm surge model of GKSS.. Units: m.*

These simulated winds have been used to run a storm surge model (Woth, 2004). Figure 4 shows the expected storm-related increase in the largest high water levels[6] as simulated by running the storm surge model with the output of the Danish Meteorological service regional atmospheric model. The largest effect is along the southern and eastern coast, with maximum values of 30 cm and more along the Northern Frisian Wadden Sea. Together with the expected rise of mean water levels

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[6] Here defined as the 99.5%ile during winter sampled every half an hour – thus the level is exceeded on averaged during approximately 10 hours within a 3-month winter season.

of 40 cm, the total increase is 70 cm at the end of the 21st century under the assumptions of the rather severe A2 scenario.

If a different regional climate model is used, then rather similar changes along the North Sea coast[7] are obtained (Figure 5). Along the eastern coast of the North Sea significant increases, beyond the range of normal year-to-year variations would have to be expected according to four different regional models al forced with global scenarios form a Hadley center A2-simulation. If an ECHAM-scenario A2 is used, quantitatively similar results are obtained.

Kommentar [hvs1]: Hier war der Halbsatz drin.

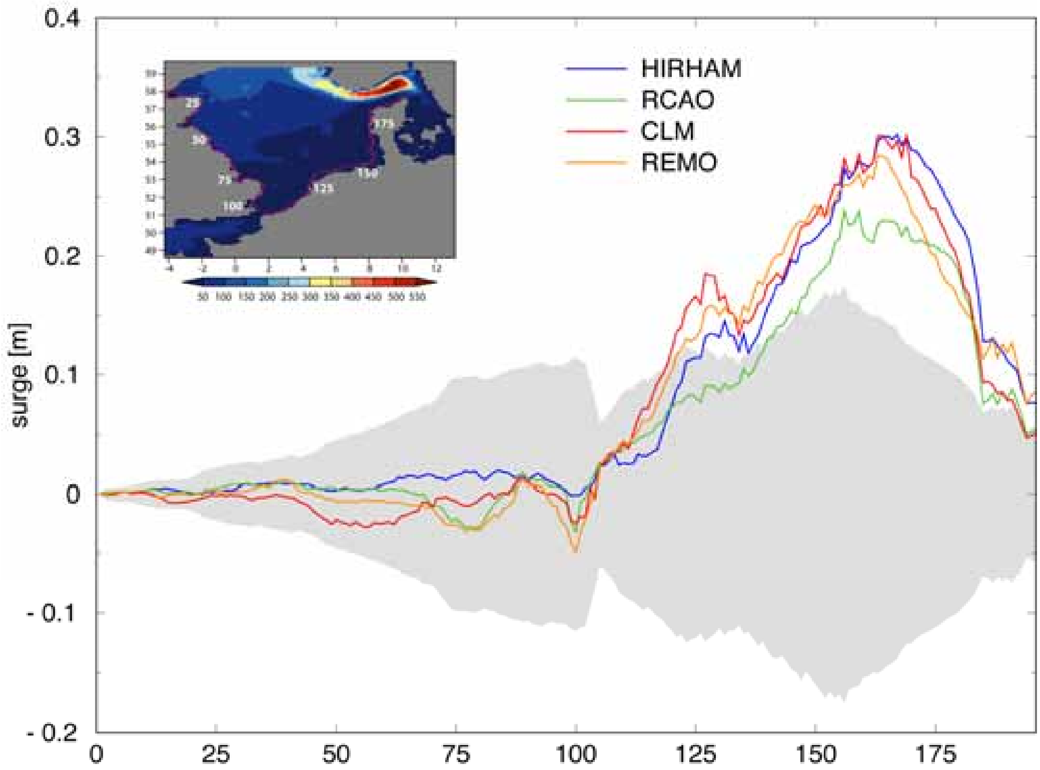

Figure 5. *PRUDENCE estimated changes of storm-related changing water level heights along the North Sea coast (red line in inset). The grey area marks the 95% confidence of interannnual variability, and the four lines the estimates by four participating regional climate models, which all downscale the same global climate change scenario prepared with the Hadley Center model and the A2 scenario.*

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[7] Here more specifically: along the 10 m depth line along the coastline.

4 Conclusions

The described increase of 70 cm water level during storm conditions at the eastern North Sea coast and the reduction of the NADW by more than 1/3 are high numbers – but uncertain numbers. They are valid only for the scenario A2, and they depend to some extent on the specific global climate model used. When a different model is used, somewhat different numbers emerge – but they share the same sign, and they are significant. Scenario A2 is a relatively pessimistic scenario, and it may very well be that the future emissions of radiatively active substances will follow a much more environmentally friendly path. If a different equally probable scenario is used, for instance B2, the expected effect at the end of the 21st century is smaller but nevertheless significant. the best guess of temperature rise is 2.8 K, of sea level rise is 35 cm (Houghton et al., 2001), and of the level of the deep water formation is about 15 Sv.

In case of the storm surge scenarios, we have no access to B2-simulations – but A2 scenarios simulated with different global models have been prepared: similar but nevertheless different storm surge implications are found; in spite of the uncertainties the proposed numbers should cause practitioners of coastal defense to be prepared for changing risks and to reconsider their strategies on the long term.

We have reported about possible and plausible future change; the changes we are describing as possible for the future are significant, but If we assume a linear growth over time[8], then the A2-increase in wind-related water levels present decades would be 7 cm per decade (or less) – thus the effect is not really detectable at this time and in the next years, but the situation may become serious in the decades to come.

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[8] It is more realistic to assume a moderately exponential increase, with slower increase in the early decades and faster increase later.

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