Climate Changes Along the German Coast

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Abstract

The present coastal zones have been developed under specific climate, sea level and human activities. A changing climate will alter these mechanisms and dynamics and result in new physical, ecological and social conditions. IPCC tries to assess the changes to be expected due to rising greenhouse gas concentrations in its IPCC Reports. The research presented here is based on a compilation of climate change descriptors referring to the Second Assessment Report (1996). It defines three scenarios with 380 (standard) and 450 and 550 ppmv CO_2 in 2050 including estimations of mean temperature, sea level, tidal range, wind speed, duration and frequency of storm surges and precipitation in winter. In 2000, IPCC defined and published a new set of four emissions scenarios (A1, A2, B1, B2) which were used in the following Third and Fourth Assessment Reports (TAR 2001) and (AR4 2007), respectively. A comparison with our descriptors defined in 2000 reveals only minor differences and confirms the validity of our approach (Table 2.3), esp. with regard to the persisting trend matching the "worst case-scenarios". A downscaling by Klimabuero in 2011 confirmed similar prospects for the Baltic Sea and the North Sea.

Author "Gerhard Weidemann" regrettably has died before the publication of this book.

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2.1 Climate Change Assessments and Scenarios of the Year 2000 (IPCC 2nd Assessment Report)

The existent coastal zones are the outcome of former climate changes and their consequences, i.e. the resulting Holocene transgression and the subsequent processes that formed the coastal regions. For almost 1000 years, humans have interfered with these dynamics through activities such as coastal protection and land reclamation. The pattern of utilisation is adapted to the structure of these particular ecosystems, but also depends on them. Therefore, changes of the biological systems induced by climate change will also influence the socio-economic systems. Thus, knowledge of changes of coastal systems induced by climate is of increasing interest as a prerequisite for future prospects.

Climate change is a natural process enhanced by human activities. Human impact is primarily driven by an increase of CO_2 and other “greenhouse” gas (GHG) concentrations in the atmosphere. The reinforcement of the greenhouse effect, thus, results in an increase of temperatures. As a consequence of natural and human impacts, an increase of the sea level is triggered by melting glaciers and ice caps (eustatic effect) as well as by thermic expansion of marine water bodies (steric effect) (Sterr 1998a). As additional relevant consequences, Sterr (1998b) mentioned seasonal changes in temperature and precipitation, changes in the main direction of winds and their forces and an increase of extreme weather conditions like storms and heavy rains. In consequence, important components of processes that form coastal morphology, such as erosion and sedimentation, may alter. The estimates of climate scenarios published by the IPCC (1996; 2nd Assessment Report) in combination with their regional downscaling (von Storch et al. 1998) were taken as a baseline for field experiments and for the interpretation of the findings of our research groups (Table 2.1).

Table 2.1 Estimates made in 2000 for the year 2050: conditions under the assumption of secular trends and two different scenarios with human impact

	Secular trend	Human impact	
		Conservative estimate	High estimate
Scenarios	Standard	Scenario I	Scenario II
CO_2	380 ppmv	450 ppmv	550 ppmv
Temperature, annual mean	As nowadays	+1.5 K	+2.5 K
Sea level (mean height)	+15 cm	+35 cm	+55 cm
Tidal range	+10 cm	+ 20 cm	+30 cm
Wind/storms	As nowadays	+ 5%	+10%
Storm surges, duration and frequency	As nowadays	+10%	+15%
Precipitation in winter	As nowadays	+8%	+15%

Vestergaard (1997) published data for the Danish Baltic Sea coast. His estimates note an increase of the sea level by about 33–46 cm, a temperature rise of 2–5 K in winter and 1–3 K in summer and an increase of precipitation of 0–20%. Changes in wind conditions are of particular importance because the water level changes on the Baltic Sea coast are determined nearly exclusively by wind. Therefore, an increase of severe wind events by 10% and a possible change in wind direction will result in a higher frequency of inundations of flat shores and in more intensive erosion as well as material transport (Sterr 1993).

2.2 Climate Change Science: According to the State of the Art in 2011 (IPCC 2007, AR4 and Beyond)

Knowledge of climate change, its physical basis, expressions and impacts has considerably improved since the publication of the Second Assessment Report (SAR) in 1996 (IPCC 1996), on which the downscaling by von Storch et al. (1998) was based, at least in part. It referred to the IS92 emissions scenarios, which had been formulated in 1992. In the year 2000, IPCC defined and published a Special Report on Emissions Scenarios (SRES) (IPCC 2000) with a new set of emissions scenarios comprising a much wider range of possible greenhouse gas (GHG) emissions and a very complex set of possible technological and societal developments, resulting in a set of 40 storylines within four "families".

The four families can be presented as follows (from Wikipedia):

A1. The A1 scenarios presuppose a more integrated world. They are characterised by:

- Rapid economic growth.
- A global population that reaches 9 billion in 2050 and then gradually declines.
- The quick spread of new and efficient technologies.
- A convergent world, i.e. income and way of life converge between regions. Extensive social and cultural interactions worldwide.

There are subsets to the A1 family based on the technological emphasis:

- A1FI has an emphasis on fossil fuels.
- A1B has a balanced emphasis on all energy sources.
- A1T has an emphasis on non-fossil energy sources.

A2. The A2 scenarios assume a more divided world. They are characterised by:

- A world of independently operating, self-reliant nations.
- Continuously increasing population.
- Regionally oriented economic development.
- Slower and more fragmented technological changes and improvements to per capita income.

B1. The B1 scenarios presuppose a world that is more integrated and more ecologically friendly. The B1 scenarios are characterised by:

- Rapid economic growth as in A1, but with rapid changes towards a service and information economy.
- A population rising to 9 billion in 2050 and then declining as in A1.
- Reductions in material intensity and the introduction of clean and resource efficient technologies.
- An emphasis is placed on global solutions to economic, social and environmental stability.

B2. The B2 scenarios assume a world that is more divided, but more ecologically friendly. The B2 scenarios are characterised by:

- A continuously increasing population, but at a slower rate than in A2.
- An emphasis on local rather than global solutions to create economic, social and environmental stability.
- Intermediate levels of economic development.

These actual SRES scenarios represent the uncertainties about future emission rates, the physical system and the driving forces. The Third Assessment Report (TAR; IPCC 2001) and the Fourth Assessment Report (AR4; IPCC 2007) use the SRES scenarios.

A comparison of the scenarios of the Second AR and of AR4 reveals the following differences:

- Atmospheric CO_2:
  - By 2010, the average atmospheric CO_2 concentration rose to ca. 390 ppmv (Dec. 2010) (co2now 2010) from ca. 361 ppmv in 1989, when v. Storch et al. (1998) published their downscaling.
  - This corresponds roughly to an increase by 13 ppmv per decade and would lead to ca. 440 ppmv CO_2 by 2050 if extrapolated linearly.
  - Between 1995 and 2005, the decadal increase rose to 19 ppmv and would lead to ca. 465 ppmv CO_2 by 2050 if extrapolated linearly (AR4, p. 2).
- Average global air temperature:
  - Best estimates for global average surface temperatures in 2090–2099 now range from +1.8 K (B1 scenario) to +4.0 K (A1FI scenario) (AR4, WG1 Table SPM.3, p. 13).
  - Using AR4 Fig. SPM.5, surface temperatures in 2050 could increase by +0.9 to +1.4 K (best guess +1.2 K) for the B1 scenario or by +2.4 to +6.4 K for the A1FI scenario (best guess +2.8 K).
  - Atmospheric 450 ppmv CO_2 equivalents (sum of GHG's) correspond to a best guess equilibrium surface temperature increase by +2.1 K, 550 ppmv to +2.9 K (IPCC 2007, Table 10.8) (*nota bene*: referring to the radiative forcing of CO_2 alone would reduce the temperature increase by ca. 0.5 K).

- Klimabuero (2011): Period 2036–2065:
  - *Nota bene*: downscaling is based on 12 different model runs using the SRES scenarios A1B, A2, B1 and B2 (the fossil intensive scenario A1FI ("worst case") was not included in the calculations).
  - North Sea coast: annual mean (reference period: 1961–1990): +1 K to +2 K (best guess: +1.6 K); summer: +1.1 K to +1.8 K.
  - Baltic coast: annual mean (reference period: 1961–1990): +1.1 to +2.3 K (best guess: +1.6 K); summer: +1.1 K to +1.8 K.
- Sea level:
  - IPCC 2007 calculates 20–80 cm higher sea levels for 2100 than today (with low to moderate contributions by melting glaciers).
  - An IPCC "Workshop on Sea Level Rise and Ice Sheet Instabilities" in 2010 (Stocker et al. 2010) stated that it is still too early to model future sea levels more precisely.
  - At present, global mean sea level rises are calculated with ca. 41 mm/year, hence >41 cm/100 years (satellite measurements) (Nerem et al. 2010).
  - A similar trend is documented for the German Bight, where the mean Tidal High Water rose between 1950 and 2005 with a rate of 41 cm/100 years (Jensen and Mudersbach 2007) (*nota bene*: this includes ca. 10 cm isostatic subsidence).
  - Assessments drawing on other calculations present higher values, e.g. Deltakommissie (2008): +0.2 to +0.4 m in 2050; Copenhagen (2009): at least double IPCC 2007 values, e.g. for the A1FI scenario >0.26 to >0.60 m in 2050; UK Climate Projections (UKCP 2009) estimates ca. 0.4–0.8 m by 2050 (High++ scenario).
  - In general, the sea level of the Baltic Sea has been following the upward trend of the North Sea level (Jensen and Mudersbach 2007) and will probably do so in the future (Zorita et al. 2010).
  - Further trends in the Baltic will strongly be subjected to changing precipitation patterns within the Baltic Sea catchment and postglacial isostatic processes (upward lift).
- Tidal range, wind/storms, storm surge durations and frequency, precipitation in winter:
  - A considerable increase of the tidal range due to greater coastal water depths has been documented by Jensen and Mudersbach (2007) and Schirmer (2010) for the German Bight.
  - Klimabuero (2011) estimates an increase of average wind speed for 2036–2065 (North Sea) in winter by −2% to +4% and 0% to +3% in autumn (*nota bene*: the "worst case" scenario A1FI is not included!) (Baltic coast winter: −1% to +4%, autumn 0% to +4%).
  - Maximum winter storm speed is estimated to change by −2% to +4% as well (0% to +3% in autumn) (Baltic coast winter: −1% to +4%, autumn +0% to +4%).
  - Stormy days may increase by −0.6% to +1.7% (winter) resp. 0% to +1.6% (autumn) (Baltic coast winter: −0.4 to +1.2, autumn +0.2 to +2 days).

Table 2.2 Compilation of calculated (scenario-based) and extrapolated trends and values for future sea levels (Mean Water MW) and Tidal High Water (MThw) in the Southern North Sea by 2050 (according to Schuchardt et al. 2008)

Source	Scenario/Data source	Parameter	Rise by 2050 (m)
IPCC (2007)	B1 (global)	MW	0.09–0.19 + x[a]
IPCC (2007)	A1B (global)	MW	0.11–0.24 + x[a]
IPCC (2007)	A1Fl (global)	MW	0.13–0.30 + x[a]
Rahmstorf and Richardson (2007)	3.4 mm/year per 1 °C increase (global)	MW	B1: 0.19–0.50 A1B: 0.29–0.75 A1Fl: 0.41–1.09
Jensen and Mudersbach (2007)	Time series of six German coastal gauges (linear extrapolation, basis 1950–2005)	MW	0.07–0.10
Jensen and Mudersbach (2007)	Ditto	MHW	0.21

[a] Unknown allowance for glacier melt

- Storm surge durations and frequency will probably increase in autumn and winter as compared to today, quantification being very limited: von Storch and Claußen (2009) estimate +30 to +110 cm storm surge heights by 2100, thus about +55 cm by 2050; up to now, an increase of storm surge duration and frequency is very likely but not calculable.
- Winter precipitation in North Germany will increase by +8% to +35% by 2050 (in summer +3% to −8%).

Table 2.2 provides a compilation of several recent estimations of possible sea levels in 2050.

2.3 Are the Climate Change Scenarios of 1998/2000 Still Valid and Applicable in 2010?

In general, the climate change assessments published by IPCC (2007) and other sources thereafter resulted in higher temperature and sea level calculations for the year 2100 than in the Second IPCC Report published in 1996 (IPCC 1996). Any climate change, however, still depends on the rate and amount of greenhouse gases emitted into the atmosphere. Therefore, we still have to formulate possible scenarios when assessing climate change impact as has been done in the beginning of this research project at the end of the 1990s. In the meantime, however, it has become

Table 2.3 Compilation of climate change descriptors defined in 1998 and 2010

	2010	Assessments as of 1998	
	Mean 2050, assessments as of 2010	Conservative estimate 2050	High estimate 2050
Scenarios		Scenario I	Scenario II
CO_2	440–465 ppmv	450 ppmv	550 ppmv
Temperature, annual mean	+1.2 to 2.8 K	+1.5 K	+2.5 K
Sea level (mean height)	+20 to +60 cm	+35 cm	+55 cm
Tidal range	No new data	+20 cm	+30 cm
Wind/storms	+4%	+5%	+10%
Storm surges, duration and frequency	Increase certain but not quantifiable	+10%	+15%
Precipitation in winter	+8% to +35%	+8%	+15%

evident that GHG emission rates are moving to the higher ("worse") SRES scenarios. Assuming that the physical basis for calculating global temperature from GHG concentrations (e.g. the radiative forcing) was and is still valid, we have to check for the proper labelling of a "conservative estimate" and a "high estimate" in 2050 (the "standard scenario" without human impact (Table 2.1) remains fixed). Table 2.3 combines the 1998 estimates for 2050 with the current 2010 state of climate change science.

Regarding Table 2.3, we must realise that the changes of climate and climate-dependent parameters formulated in 1998 are still consistent with the assessments of 2010. As far as parameters are quantified, the Conservative Scenario I describes a fairly moderate change of the future situation with a high degree of probability. It represents changes predicted by the B1, A1T, B2 and A1B scenarios, which is probably the most favourable scenario that can be reached after the disappointing results of the World Climate Congresses in Copenhagen 2009 and Cancun 2010.

The High Estimate Scenario II is still within the range of future climate change assessments; however, not as "high" and pessimistic as seen in 1998, but still appropriate to assess the impacts of a pronounced climate change on our coastal ecosystems.

2.4 The Climate Future of the German Coasts from the 2011 Perspective

As demonstrated above, the dimension of global climate change in the German coastal regions along the North Sea and the Baltic Sea still depends on the further accumulation of greenhouse gases in the atmosphere. The results of the downscaling published by the Norddeutsches Klimabuero (2011) show a fairly uniform shift in the average temperatures in the North Sea and the Baltic Sea coastal regions for 2036–2065 (3 decades centred around 2050). The fossil intensive scenario A1FI ("worst case"), however, was not included in the calculation. Regarding that the

Table 2.4 Maximum differences of seasonal mean temperatures and precipitation for 2036–2065 and 2071–2100 (Klimabuero 2011)

Region	North Sea Coast		Baltic Sea Coast	
Period	2036–2065	2071–2100	2036–2065	2071–2100
ΔT summer	+1.8 K	+4.8 K	+1.8 K	+5 K
ΔT winter	+2.8 K	+4.4 K	+3 K	+4.8 K
Δ precipitation summer	+5%	−43%	+2%	−38%
Δ precipitation winter	+30%	+51%	+39%	+64%

actual global emission rates are soaring and run along the highest SRES rates (and that the World Climate Conferences in Copenhagen and Cancun did not decide on any effective measures), we must assume that future temperatures, precipitation and the sea level rise will follow the upper values presented by the Klimabuero (2011).

Table 2.4 lists the upper values published by the Klimabuero (2011) separately for the North Sea and the Baltic Sea coasts, summer and winter and for 2050 (2036–2065) and 2085 (2071–2100).

On a long-term scale, it becomes evident that, based on the actual state of the art in downscaling, the medium- (2050) and long-term (2100) pessimistic assessments of climate change show a near-exponential increase in average temperature and a differentiated gradient. Until 2050, the actual trends continue, with winter temperatures rising faster than summer temperatures and winter precipitation increasing strongly.

These trends are very similar for the North Sea and the Baltic region. Regarding their water mass budgets, however, the enclosed Baltic Sea will react stronger to climate change than the open North Sea: the increase in winter precipitation and river discharge will probably provoke lower salinity in winter and spring and higher salinity in summer and autumn due to evaporation. On the other hand, the cold winters of 2009/10 and 2010/11 may signal a high variability of seasonal weather patterns with extreme events still possible.

Recent modelling of the consequences of the rapid decline of the arctic sea ice cover for the Northern European weather patterns (Petoukhov and Semenov 2010) shows that a distinct winter cooling is possible, if not probable, as an iceless arctic ocean feeds more energy into the atmosphere and displaces the traditional circulation patterns, favouring the transport of very cold Siberian air masses into Northwest Europe.

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