Chapter 2. Past climate variability

Dear colleagues,

We have discussed the final version of the Chapter 2.2. with the contributors and come to conclusion that chapter has to be Annex [Ax] with the information on climate change in the Baltic Sea Basin during the Postglacial time (between 14,000 – 11,000 cal yr BP). In the last years the Russian researches have obtained detailed data on climate and environment changes in the above period. Unfortunately these studies are mostly in Russian, thus in accessible to English – speaking colleagues. However, it is obvious that not being able to read these materials is problematic to understanding the complete climate-environment change pattern over the entire area of the Baltic Sea Basin. In this period climate change was drastic and dramatic on the area free from glaciation including most part of the north –western Russia, the Karelian Isthmus, a large part of the Baltica countries (Estonia, Litva and Latvia) and Poland. Summarizing this data of great impotent for estimating possible critical limits of climatic changes and their consequences on the continental biota primarily and hydrological indices also. We think that **ANNEX "Climate changes during the Lateglacial time (15,000 – 11,500 cal yr BP) in the Baltic Sea Basin" will be include 10 – 15 Word pages and a few figures**. Also we propose to place a detailed stratigraphic diagram of climate events in the Baltic Sea Basin for the last 14,000 years tied to the classic Scandinavian scale, ice core scale (Greenland cores Dye3, GRIP, CISP2 and NGRP) and tephra chronologies. Evidence of rapid climate changes and their consequences have acquired a special significance for understanding causes of the modern climate changes and for modeling climate.

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2.1. Introduction and summary *(5 pp = 7 Word pages without figures)*

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Introduction

Quantitative past climate data obtained using new methods and technology have improved the testing and tuning of numerical climate models. In addition, this data helps understanding causes and mechanisms of climate variations. The 2007 IPCC Report includes paleoclimatic materials as an individual Chapter where it is emphasized that historical climate data might be very important when studying global climate system sensitivity to various internal and external factors. In practice, almost all future climate scenarios are based on the gradual, though relatively fast, increase in global temperature due to greenhouse gases concentration growth in the atmosphere, primarily, carbon dioxide and methane.

However, analyses of the paleoclimatic records show that relatively long-term past warm periods were followed by a shift to much colder weather, and vice versa, cooling periods changed to rapid (of the order of a few decades) warmings. These abrupt climate changes are assumed to be related to nonlinear processes in the climate system. At some threshold values the climate system can transit "jump wise" from one stable condition to another one, almost "instantaneously" within first few decades. Chemical analyses of air trapped in Greenland and Antarctica ice cores indicate that the periods of abrupt warmings correlate with high concentrations of greenhouse gases in the atmosphere and coolings with their low values. The mechanism of these abrupt climate events is likely to depend on a massive influx of fresh glacial meltwater into the ocean and intensified hydrological cycle under global warming. In high latitudes, abrupt climate changes are most noticeable, especially in the areas adjoining the continental ice sheet. The Baltic Sea Basin is believed to be a key region in studying the causes of the past abrupt climate change. Independent tree-ring, ice-core, clay-varve, tephra ash layers, ^{14}C, ^{10}Be and other chronologies have been used to develop a detailed timescale with the accuracy of up to few years for Lateglacial-Holocene climate events.

The first timescale of climate events for this period was established for the Baltic Sea Basin about 100 years ago. For many years it has been used as a classic timescale to analyze paleodata from other regions of the Northern Hemisphere. Analyses of multiproxy data made it possible to quantitatively estimate the amplitude of climatic variations in different parts of the Baltic Sea Basin. As a result, an assessment has been made of environmental implications of these variations and their influence on the early human migration in this region. Studying these processes based on paleodata analysis is directly related to developing long-term future climate forecasts for next decades. Of particular interest is the climate change data over the past thousand years.

Summary

History of the basins that had existed on the territory of the modern Baltic Sea since the last deglaciation has been already studied for more than a hundred years. Nevertheless, the issues are still questionable of both the chronologies of transgression-regression phases of the pre-historic Baltic basins and their spatial characteristics. Greenland ice cores with annual layers, abundant radiocarbon dates obtained from studies on lake and continental sections, varve chronologies and other data allow us to obtain both a detailed time frame of climate events for the past 14,000-15,000 years and to determine the age of warming-cooling boundaries revealed from spore-pollen records and tied to the classic Scandinavian scale. Tree-ring chronologies are very important in reconstructing the Lateglacial-Holocene events. Attempts have been made to extend tree-ring Holocene chronologies to the Lateglacial by updating them with the "floating" sections of the dendrochronological scale.

The final deglaciation stage in the Baltic Sea Basin is supposedly related to an abrupt warming at the Bølling/Allerød interstadial which started about 14,600 cal yr BP. At that time arboreal vegetation first appeared in ice-free regions of the Baltic Sea Basin. The warming was interrupted with a series of cold events. The strongest cooling of approximately 1000 years long (the Younger Dryas) has begun at about 12,700 cal yr BP and ended about 11,600-11,500 cal yr BP, at the Holocene boundary.

About 11,200 years ago, a cold interval– the Preboreal Oscillation – occurred which then shifted to an extended warming of 2000 years long and the arboreal vegetation expanded rapidly throughout the Baltic Sea Basin. The subsequent two cooling periods about 9,300 and 8350 – 8150 are indicated in Greenland ice cores, North Atlantic marine sediments, clay-varve chronologies, and other proxy data.

The second 8.2 ka cool event of about 160 to 200 years long has been known long ago. This cold episode correlates with mountain glaciation in the Alps and Scandinavia and reduction in warm-loving tree species in pollen spectra from different parts of the Baltic Sea Basin. These cold episodes are theorized to be related to a massive meltwater surge outflow to the North Atlantic from Ice Lakes Superior and Agassiz that were formed after the destruction of the Laurentian Ice Sheet. The 8.2 ka event was the last cooling episode of the Early Holocene followed by a stable and relatively warm climate period with summer temperatures of 1-2^{0}C higher than the present ones.

The period between 7500 and 5500 cal yr BP ago was the warmest one for the entire Baltic Basin area, though the times of maximum temperatures were not synchronous in different parts of the region. In Sweden territory, pollen and chironomids chronologies show that the times of maximum temperatures changed in parts of Sweden between 7900 and 5700 cal BP with the amplitude varying from 0.8 to 1.0^0C and higher. In the Northern Finland, maximum temperatures took place between 7500 and 7000 cal BP, and in north-western Russia, about 5800 to 5000 cal BP. The negative Northern Hemisphere temperature trend and increased climate instability are typical of the Late Holocene interval.

The Baltic Sea region cooling about 5000 to 4500 cal yr BP coincided with decreased summer solar radiation incoming to the earth's surface due to astronomical factors. Greenland ice core data indicates significant oscillations in the concentration of greenhouse gases in the atmosphere, in particular, methane. Chironomids and pollen proxies allow us to reconstruct a two-stage nature of air temperature decrease in the Late Holocene. The first stage occurred between 5000 and 4500 cal yr BP and the second one between 4300 and 3300 (2800) cal yr BP . During each period the temperature drop was not less than 1^0C. A complicated climate changes in the Baltic Sea region in the Lateglacial and the Holocene was reflected in lake levels' status, vegetation changes, and in the formation of a complex hydrographical network. These environmental changes affected the stages of ancient man migration in this territory.

Chapter 2.2. Climate changes during the Holocene (the last 10.000 yr)

(25 pp = 33 Word pages without figures)

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Chapter 2.2 Structure:

2.2.1. Methods and sources of the paleoclimatic reconstruction for the Holocene time
- Pollen and plant macrofossils analysis
- Fossil insect data
- Dendroclimatological evidence
- Archeological data
- Other evidence
- Dating control

2.2.2. Climate variability during the Holocene in the Baltic Sea Basin
- The Early Holocene oscillations

The 8.2 ka cool event
The Atlantic warming
The late Holocene cooling

2.2.3. Causes of the climatic changes in the Late Glacial - Holocene time
Solar radiation factors (astronomical, solar activity)
Volcanic eruptions influence
Gas composition changes in the atmosphere
Other factors

2.2.4 Climate changes and their consequences on the continental biota and ancient man's migration during the Holocene in the Baltic Sea Basin
Conclusion
References

ANNEX
Ax Climate and environmental changes during the Lategglacial time in the Baltic Sea Basin (15,000 – 11,500 cal yr BP) (*about 10 – 15 Word pages without figures*)

Chapter 2.3. The historical time frame (1000 yr) ***(25 pp = 33 Word pages without figures)***

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Provisional Chapter Summary

In chapter 2.3 is described past climate variability of the Baltic Sea Basin area during the last millennium. Older climatic conditions of holocene contains the chapter 2.2, and contemporary climatic change of the last 200 years are presented in chapter 3. The results presents current state of knowledge and are based only on published scientific literature.

After short description of data sources and methods, the main climatic factors are presented. Among them solar factors, atmospheric circulation and volcanic eruptions seems be the most important. The anthropogenic factor is important for contemporary climate (see chapter 3). In the description of the climatic variability we pay attention mainly on thermal and precipitation conditions, with respect to extreme values. According to scientific literature during the last millennium were divide three phases: Medieval Warm Period (MWP before 1350 AD), Transitional Period (TP 1350-1550 AD) and Little Ice Age (LIA 1550-1850 AD). There exists also some shorter phases connected mainly with solar activity or large volcanic eruptions. In one annex are presented the most unusual climatic events for each Century of the last Millennium.

Chapter 2.3 Structure:

References [in separate file is prepared the bibliography]
Examples of style of reference note used in Springer publications:

Article in Journal:

Büntgen U, Tegel W, Nicolussi K, McCormick M, Frank D, Trouet V, Kaplan JO, Herzig F, Heussner K-U, Wanner H, Luterbacher J, Esper J (2011) 2500 Years of European Climate Variability and Human Susceptibility. Science 331: 578-582

Dobrovolný P, Moberg A, Brázdil R, Pfister C, Glaser R, Wilson R, van Engelen A, Limanówka D, Kiss A, Halíčková M, Macková J, Riemann D, Luterbacher J, Böhm R (2010) Monthly, seasonal and annual temperature reconstructions for Central Europe derived from documentary evidence and instrumental records since AD 1500. Climatic Change 101: 69-107. doi:10.1007/s10584-009-9724-x

Eriksson Ch, Omsted A, Overland JE, Percival DB,Mofjeld HO (2007) Characterizing of European Sub-Arctic Winter Climate since 1500 Using Ice, Temperature, and Atmospheric Circulation Time Series. Journal of Climate 20: 5316-5334

Glaser R, Riemann D (2009) A thousand year record of climate variation for Central Europe at a monthly resolution. J Quat Sci 24(5):437–449

Helama S, Timonen M, Lindholm M, Merilainen J, Eronen M (2005) Extracting long-period climate fluctuations from treering chronologies over timescales of centuries to millennia. Int. J. Climatol. **25:** 1767–1779

Klimanov VA, Koff T, Punning Y-M (1985) Climatic conditions in the North-West Baltic during the past 2000 years. Izvestiya of Russian Academy of Sciences Geographical Series 1: 89-96 (in Russian)

Koslowski G, Glaser R (1999) Variations in reconstructed ice winter severity in the western Baltic from 1501 to 1995 and their implications for the North Atlantic Oscillation. Climatic Change 41:175–191

Book:

Glaser R (2008) Klimageschichte Mitteleuropas. 1200 Jahre Wetter, Klima, Katastrophen. [History of Climate for Central Europe: 1200 years of weather, climate and catastrophes], Primus Verlag, Wissenschaftliche Buchgesellschaft, Darmstadt

Grove JM (1988) *The Little Ice Age.* Methuen & Co., London, New York, 498 pp.

Lamb HH (1977) Climate: Present, past and future. Vol. 2: Climatic history and the future. Methuen & Co Ltd London

Przybylak R, Majorowicz J, Brázdil R, Kejna M eds (2010) The Polish Climate in the European Context: An Historical Overview. Springer Science + Business Media B.V. Dordrecht Heidelberg London New York, pp.535. DOI 10.1007/978-90-481-3167-9_19

Chapter in the book:

Klimenko I, Solomina O (2010) Climatic Variations in the East European Plain during the Last Millennium: State of the Art. [in:] Przybylak R. et al. (eds) The Polish Climate in the European Context: An Historical Overview. Chapter 3. Springer. Dordrecht Heidelberg London New York, p. 71-101

Annex

Ax Selected List of Unusual Climatic Events for each Century of the last Millennium

Format of annex will be discussed (format of the table?)

Chapter 3. Recent (mainly 200 years) and current climate change

3.1. Introduction and summary

3.2. Atmosphere

Leader author: Anna Rutgersson

Contributing authors: Jaak Jaagus, Frederik Schenk, Martin Stendel, also additional co-authors

Structure agreed upon at the meeting in Uppsala **16 May 2011**

3.2.1. Large scale circulation

Number of deep cyclones (<980 hPa) in the North Atlantic/European sector in winter (DJFM) counted by 20 periods has increased from 1968/69-1987/88 to 1988/89-2007/08. Thereby, the area of maximum number of cyclones located in the North Atlantic between Greenland and Iceland has extended to the north-east towards the Barents Sea (Fig. 3.2.12). Its influence on the Baltic Sea area has increased. At the same time, a weak increase of SLP in winter and spring during 1961–2005 is recorded in the Czech Republic located on the southern border of the Baltic Sea Basin.

3.2.2. Surface pressure and winds

A detail analysis of trends and regime shifts was performed for upper wind components on 850 and 500 hPa level measured at the Tallinn Aerological Station during 1955-2007. An increasing trend in time series of the zonal component was earlier detected in February and of the meridional component in March for 1955-1999. Using the updated series these trends did not persist. At the same time, multiple regime shifts were clearly detected

3.2.3. Temperature

Earlier studies have detected quite a significant surface air temperature increase in the Baltic Sea region during 1871-2004 (BACC 2008). The 20th century was divided into three main phases: warming in the beginning of the century until the 1930s, later cooling until 1960s and another distinct warming during the last decades of the time series. Linear trend of the annual mean temperature was 0.10 K per decade north of 60°N and 0.07 K per decade south of 60°N in the Baltic Sea Basin. It can be seen that the warming trend has continued during last the years with an exception in winter. Two last cold winters (2009/2010 and 2010/2011) have caused the smoothed curve to turn downward.

3.2.4 Precipitation

Precipitation trends in the Baltic Sea Basin have not been such uniform as the temperature changes. There have been regions and seasons of precipitation increase as well as of decrease (BACC 2008). Nevertheless, a general increase in precipitation during the cold half-year has been typical for the northern Europe during the last decades. During the short period 1979-2008 less precipitation was observed in northern and central, and more precipitation in southern Baltic Sea region (Lehmann et al. 2011). Trend patterns for single seasons were rather different.

3.2.5 Cloudiness and radiation

Mean cloudiness and sunshine duration have had remarkable long-term fluctuations over the Baltic Sea Basin during the 20^{th} century. Thereby, the trends were of nearly opposite sign between the northern (Estonia) and southern (Poland) parts of the study region (BACC 2008). There is a trend to less cloud cover over the Baltic Sea basin by -1% per decade with seasonal contribution in 1970–2008 during spring and autumn. Increasing cloud cover was detected for those parts of Scandinavia exposed to westerlies, the Kola Peninsula and southeast from the Gulf of Finland (Fig. 3.2.10), which is mostly contributed during winter and summer. Negative trend revealed in the Bothnian Sea and Kattegat.

3.3. Land

3.3.1. Hydrology

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Russia: still unsettled; have contacted Valery Vuglinsky (vvuglins@vv4218.spb.edu);member of SSC plus previous LA, hence not possible as contributing author
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Background:

The hydrology author team is in the process of going through lately (since 2006) published papers dealing with current and past hydrology of the Baltic Basin. In addition, national and wider databases (e.g., Nordic version of the European Water Archive (EWA) of the Flow Regimes from International Experimental and Network Data Project [FRIEND]) are being browsed for a (potentially) harmonised view of the changes, although these have been published in various reports, too. The original BACC Hydrology appears somewhat biased towards information from the Nordic countries, whereas Russia, specifically, was under-represented given that it hosts the largest of the catchments (Neva). We therefore aim at putting a strong emphasis on ironing out the bias where possible. The planned new Annex "Physioraphic Nature of the Baltic Sea drainage basin"is suggested to include a coherent description of catchments of the Baltic Sea basin listed by country, for example, as follows:

- number
- size
- land use (perhaps with a general overview of "anthropogenic factor")
- drainage density (perhaps with a connection to bedrock and sediment properties + topography)
- regulation (dams etc.)
- lakes (%)
- mean runoff

plus:

- sources of data and uncertainties
- national& other data (cf. App. 4.3 in BACC I)
- knowns and unknowns per country/region

So far analysed papers mostly confirm the findings reported in BACC (2008). There are ca. half-a-dozen new papers where discharge and runoff has been studied in a broad context, plus more numerous papers dealing with single catchments or small regions in various countries.A much larger selection of papers has been published lately on projected future changes in hydrology. There is a need to adjust the 'grey zone' between chapters 3.3.1 and 4.3.2.

Below, some key publications are briefly introduced.

For long-term (century time-scale) changes, Hansson at al. (2010) report - based on temperature and atmospheric circulation indicesfrom year 1500 onwards- that runoff to the Baltic appears to be strongly linked to temperature, wind and rotational circulation components in the northern region and Gulf of Finland. On the contrary, in the south runoffis more associated with rotational and deformation circulation components. Although decadal and regional variability is large, no significant long-term change has been detected in total river runoff to the Baltic Sea during 500 years. Analysis of runoff sensitivity to temperature suggests that southern regions may become drier with rising air temperatures, whereas in the north and around Gulf of Finland, warmer temperatures are associated with larger river runoff. Over the past 500 years, the total river runoff to the Baltic Sea has decreased in response to temperature increase by 3%, or 450 m3/s, per C°.

Regarding decadal changes, Hisdal et al. (2009) have revised and extended their earlier analysis (Hisdal et. al. 2003) included in BACC. Currently, the data consists of more than 160 streamflow records.The Mann-Kendall trend test was applied to study changes in annual and seasonal streamflow as well as floods and droughts for three periods (Fig. 1):

- 1961-2000
- 1941-2002
- 1920-2002

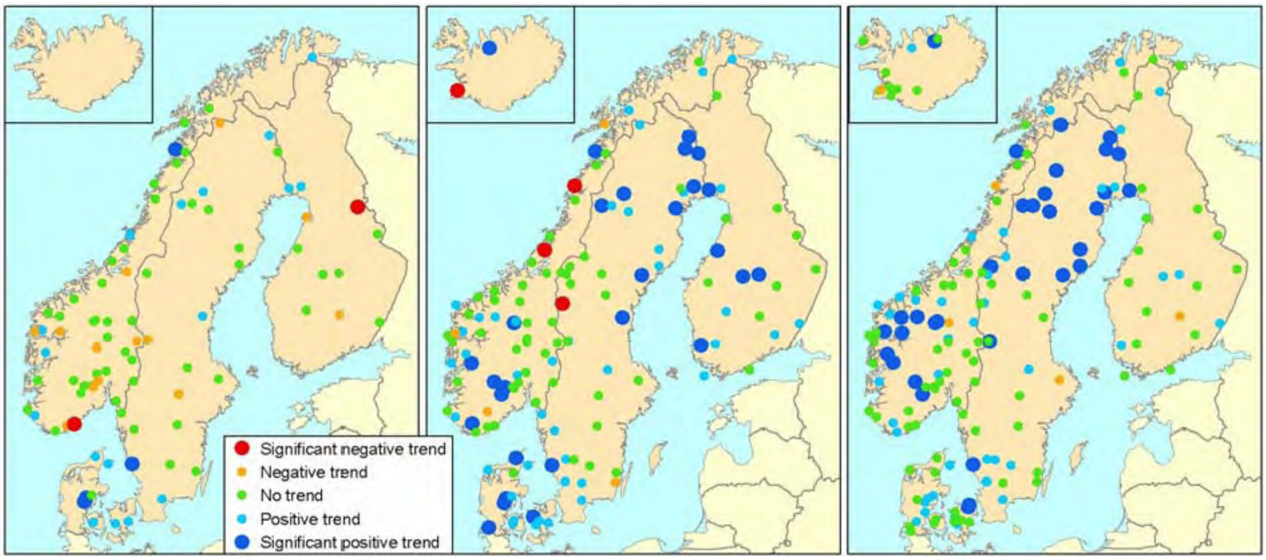

Figure 1.Trends in annual stream flow for the periods 1920-2002 (left), 1941-2002 (middle) and 1961-2000 (right). Hisdal et al 2009.

Regional patterns detected by Hisdal et al. (2009) were influenced by the analysed period and the selection of stations. However, generally trends towards increased streamflow dominated annual values plus winter and spring seasons. Trends in summer flow were highly depended on the analysed period whereas no trend was found for the autumn season. A signal towards earlier snowmelt floods was clear. Comparison of the findings to various streamflow scenarios demonstrated that the strongest detected trends are coherent with changes expected in the scenario period, for example increased winter discharge and earlier snowmelt floods. However, there are also expected changes that are not reflected in the trends, such as an increase in autumn discharge in Norway.
As a conclusion,Hisdal et al. (2009) suggest that the observed temperature increase has clearly affected the streamflow in the Nordic countries. These changes correspond well with the estimated consequences of a projected temperature increase, whereas the impact of the observed and projected precipitation increase on streamflow is somewhat ambiguous.

An example of a recent regional study is one by Klavins et al. (2009), where ice and discharge regimes were studied in 17 rivers in the Baltic countries and Belarus. Both ice regime and seasonal river discharge werr demonstrated to be strongly influenced by large-scale atmospheric circulation processes over North Atlantic manifesting through close correlation with North Atlantic Oscillation (NAO) index.

Anticipated contents of the Hydrology chapter, 15 pages(chapter structures ought to be in harmony, hence exact order as well as contents subject to alterations):

1 Introduction (1 page)
[more detailed catchment information will be given in the Appendix “General Physiography…”]

2 Briefing of BACC I findingsfor background (1 page; perhaps largely in table format)

3 Basin-scale broad changes in discharge patterns(4-5 pages)
- Long term (century)
- Short term (decadal)

4 Regional and seasonal variations, and trends (4-5 pages)
- Recent and present changes in regional discharge patterns
- Recent and present changes in seasonal discharge patterns

5 Extreme events; floods and droughts (1-2 pages)

6 Conclusions plus synthesis of the findings (1-2 pages)
- Discussion on the reasons for changes (climatic and non-climatic)
- Discussion on the effects on and interactions with biotic and other abiotic systems (with reference to other relevant sections)

3.3.2. Terrestrial cryosphere

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Content

1. Background
   - Roles and importance of the terrestrial cryosphere components
   - Terrestrial cryosphere of the Baltic Sea watershed area
     (Short description of the mean cryospheric conditions, regional variation and extremes; based on the BACC I Appendix A.1.3.5)
   - Sources of data and uncertainties
   - Summary and analysis of the BACC I finding
   - Summary and analysis of the findings in other large assessments since 2007

2. Recent and present changes in seasonal snow cover
   2.1 Snow cover formation, duration and melt
   2.2 Snow depth and snow water equivalent
   2.3 Snow cover extent
   2.4 Snow structure and properties
   2.5 Extreme events

3. Recent and present changes in glacier mass balances

4. Recent and present changes in ground frost
   4.1 Seasonal ground frost
      - Formation, duration and melt
      - Depth and extent
   4.2 Permafrost
      - Depth and extent
5. Discussion and conclusions
      - Synthesis of the findings.
      - Possible reasons for changes (climatic and non-climatic)
      - Effects on and interactions with other biotic and abiotic systems

Summary (version 1.9.2011)

Terrestrial cryosphere of the Baltic Sea watershed area includes seasonal snow cover, Swedish glaciers and frozen ground (some permafrost areas and seasonally frozen soils). Components of terrestrial cryosphere are affected by seasonal weather, especially winter air temperature and form of precipitation, and by long-term changes in climate. Changes in seasonal snow cover (amount, extent and duration), glacier mass balance and ground frost have several climatological, ecological and socio-economical consequences.

According the published literature up to preparation of the first BACC report (2007), several climate related changes had been observed in the snow cover in the Baltic Sea watershed area. In whole of the northern Eurasia, winter air temperatures had been observed to rise. In the southwestern regions of the watershed area a decrease had been seen in the snow depth due to this and to an increase in the liquid proportion of precipitation during wintertime, while an increase in snow storage and in duration of snow cover had been observed in the north-eastern regions. In Finland and in Sweden the risen temperatures had led to intensified wintertime snow melt in some parts of the country, and a recent decrease in snow cover duration and water equivalent had been observed in the southern parts of all the Fennoscandian countries. On the other hand, total snow storage had increased in east and north. In the Scandic mountains there had been enhancement of precipitation and, according to that, thicker snow covers. In Estonia a recent negative trend had been observed in duration of the snow cover, snow depth and in snow water equivalent. Decrease in snow cover days had been observed also in Latvia. Same kinds of trends were found also in Lithuania and in Poland. In the northwest of the eastern European plain, snow storage had increased in accordance with the winter temperatures and precipitation.

Since publication of the first BACC report (2007), other significant assessments have been published, with some emphasis on Northern European cryospheric conditions.

The Global outlook for snow and ice (UNEP, 2007) reports that the Northern Hemisphere mean monthly snow-cover extent has declined at a rate of 1.3 % per decade during the recent 40 years. It also reports the long-term increase in snow depth and duration of snow cover in some parts of the northern Eurasia. A decreasing trend in winter time northern hemisphere snow covered area is also reported by Lemke and Ren (2007) in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (AR4). They conclude that lowlands in central Europe have seen recent reductions in annual snow cover duration, but greater snow depth but shorter snow season has been observed in Finland and in the former Soviet Union area. In an assessment by Voight et al. (2010), decreasing trends in European snow depth, snow cover extent and length of the snow season are reported, except in the northern parts of Scandinavia. This assessment also points out the observed cumulative loss in glacier ice thickness in inland Scandinavia during period of 1967-2008.

In this chapter the knowledge described in the previous paragraphs will be updated based on the recent literature on the observed recent (up to 200 years) and current change in the snow cover, and also in other components of the terrestrial cryospheric regime. When appropriate, findings are divided according the countries. Some findings are valid for the whole Baltic Sea watershed area, and for some cryospheric components the perspective has to be restricted to limited areas only - glaciers are found only in Sweden in the Baltic Sea watershed area, and also permafrost is a marginal phenomenon.

3.4. Baltic Sea

3.4.1. Marine circulation and stratification

Lead author: Jüri Elken

Chapter summary pending

3.4.2. Sea Ice

Lead author: Jari Haapala

Chapter summary pending

3.4.3. Sea level and wind waves

Lead author: Birgit Hünicke (Helmholtz-Zentrum Geesthacht, Germany)

Contributing Authors:
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The chapter 'Sea level and wind waves' will give a comprehensive overview of the state of the art of sea-level related research in the Baltic Sea on recent and current time scales. It will be structured into three main sections, focusing on mean sea-levels, extreme sea-levels and wind waves.
A general introduction will describe the importance of studying sea-level within the context of anthropogenic climate change on global to regional scales by briefly describing possible impacts and explaining the role of global versus regional sea-level values. The relationship between studies of mean and extreme sea-levels and their connection to studies of wind waves will be outlined. After the three main sections, a conclusion will summarise the findings.

Mean Baltic Sea-level change

The first Section will focus on the main factors affecting mean Baltic sea-level change, considering global, regional and local scales. Short definitions of existing classifications of these factors will be given and discussed. At global scales, the brief discussion will include factors such as the thermal expansion of the water column, melting and flow of land ice masses, land movement due to GIA effect and other technical effects, but also gravitational effects of ice disappearance and uncertainties in terrestrial water storage.

At regional to local scales, meteorological influences (e.g. the influence of atmospheric forcing factors or changes in the water balance, salinity changes or circulation changes), and land movement effects due to the glacio-isostatic Adjustment or other tectonic influences will be outlined in more detail. Although land movement effects (e.g. GIA) do not stand in direct relation to the issue of anthropogenic climate change on time-scales of decades to centuries, these effects are a major driver of sea-level change in the Baltic Area and therefore need to be focused on in more detail.

As the study of sea-level changes would not be possible without observations, one subsection will focus on the up-to-date availability of sea-level observations, including tide gauge records, and available datasets of satellite altimetry and other advanced geodetic techniques (GPS measurements). The homogeneity of these datasets will be briefly discussed, also in terms of availability due to different data sources (e.g. Permanent Service for Mean Sea Level, national Data Sources) and the role of absolute versus relative sea-level measurements. Also, the role of Baltic Sea level observations within the context of global mean sea-level studies will be pointed out, as the Baltic Sea is one of the world's most investigated areas in terms of long-term sea-level measurements at tide-gauges.

Following, the available knowledge of Baltic Sea level variability within the observational period (around 1800-today) will be presented with focus on mean observed sea-level trends. The outcome of the different research studies will be mapped for the whole Baltic area (probably for each country, if available), labeling the relative (to land) and absolute values calculated from the different studies, including uncertainties. As the relative values are the important ones for regional impact studies, absolute values allow for a comparison with global mean sea-level values. The question of accelerating Baltic sea-level rise will also be discussed. Finally, a closer look at uncertainties and caveats due to several reasons (e.g. different national height and measurement systems, different used data sources), and also due to different applied statistical methods to analyse the datasets will be presented. This is also necessary to understand the uncertainties of a global mean sea-level value in relation to a regional value.

Extreme Baltic Sea levels

Physical factors for extreme sea-level events in the Baltic Sea will be briefly discussed, including the travel of meteorologically forced positive-negative surge zones along the Baltic Sea, components and typical courses of (local) storm surges and the development of minimum sea-level events (negative surges). Statistics and long-term trends of extreme sea-level will be discussed based on the available literature, focusing on return periods and return values and long-term variations in annual extremes and their connections with storm climatology. A short overview of prominent events will be given and storm surge prone areas in the Baltic Sea will be named. A map of a collection of observed historical water level maxima in the Baltic Sea will be compiled. Finally, results out of hydrodynamic modelling approaches will be compared and discussed.

Wind waves

Sources of wind wave climatologies will be discussed with focus on visual observations and instrumental measurements, regional and basic-wide simulations as well as long-term wave properties (including average and extreme heights, occurrence distributions, height-period combinations). A map will be compiled showing all up-to-date available long-term wave observations (visual and instrumental). Spatial-temporal patterns of variations will be described by focusing on inter-annual to (multi)-decadal changes and spatial patterns of variations. Consequences to safety, coastal evolution and ice cover length will be briefly issued.

Chapter 4. Modelling future climate change

4.1. Introduction and summary

4.2. Skill of methods for describing regional climate futures

Leader author: Joanna Wibig

Weather forecast and climate scenario, emission scenarios, definition of downscaling (Joanna Wibig)

Development of global circulation models (GCMs) has created a best tool for studying how the climate can change in the future. They give the description of climate in a set of grid points regularly distributed in space and time with the same density over lands and oceans. Their temporal resolution is very high, however, their spatial resolution is too low. A lot of very important processes like cloud formation, convection, precipitation occur in a spatial scale much smaller than the distance between grid points. It means that the taking them into consideration needs parametrization - simple statistical models giving an approximate description of these, so called sub-grid, processes. Low resolution means also that the topography, coastline, processes at the land-air, ocean-air and land-ocean boundaries are much simplified in these models.

Because of low spatial resolution GCMs do not give a realistic description of regional and local climate. It is therefore necessary to downscale the GCMs results. Downscaling is understood as a process linking large scale variables with small scale ones. There are two different ways of downscaling. One of the them uses regional climate models (RCMs) nested in GCMs. RCMs have much higher resolution and can better describe local features. The other group of downscaling methods uses statistical relations between the large scale variables being result of GCMs with small scale variables describing regional and/or local climate conditions.

Climate projections differ significantly from forecasting a weather. Forecasts can’t predict a weather with high accuracy far beyond a few days. Weather models are based on observations in a very large but limited set of points and these observations are made with limited accuracy. Small disturbances in the data can cause a large effect on weather after some time. It was shown by Lorenz (1960) and is known as a “butterfly effect”. Climate models are not interested in a weather on particular day or month but in statistical features of states of the atmosphere over a long time period, ie. chaotic weather averaged over a long enough time.

There are also other differences between weather and climate. Weather is forecasted for a relatively short time - a few days, usually less than two weeks. That is why weather changes are caused mainly by changes in the atmosphere. Even changes in the oceanic processes exert only very limited influence on weather because of evidently higher time scale of typical processes occurring in the oceans. In the case of climate the other factors have to be taken into account. Climate variations are also caused by changes in the environment: ocean, vegetation, ice, solar changes and composition of the atmosphere. Some of these changes can be predicted with high accuracy, but the other not. Among them there are land use changes and a composition of the atmosphere with the strongest emphasis on concentration of so called greenhouse gases (GHG), sulphur compounds and aerosols. They all exert a very strong impact on climate. Future climate changes are in high degree related to the degree of these changes, so predicting climate requires reliably information on an atmosphere composition and land use. But unfortunately the concentration of GHG in the future atmosphere is not known and is very difficult to be predicted because of enormously big amount of factors influencing it. Instead of it we can make some scenarios of future evolution of population and economy on the world and than the other scenarios how the climate will change if particular scenario happens.

A set of such scenarios was developed by the International Panel on Climate Change (IPCC) and published in the Special Report on Emission Scenarios (..., SRES). These scenarios represent different possibilities of future evolution determining driving forces. The most important factors are demographic development, socio-economic changes and technological development. They all exert a strong impact on future greenhouse gas emissions and land use pattern. There are 40 SRES scenarios, divided into four families based on four storylines: A1, A2, B1 and B2. These storylines differ in speed of population change, technological development, economic growth and convergence among regions. Three groups of scenarios are distinguished within A1 family: A1F1, A1T and A1B. They differ in degree of exploration of alternative energy resources. A1F1 group consists of scenarios with high fossil fuel use. Scenarios in A1T group characterize high percentage of non-fossil fuel energy sources. The diversified, balanced fossil fuel scenarios are collected in A1B group. Each of the other families creates only one group. Scenarios in particular groups differ in the approach used to characterize future emissions basing on the same development path defined by projected population and socio-economic changes and technological development. No scenario is privileged. No probability is assigned to any scenario. They all define ranges of future greenhouse gases (GHG) emissions and land use changes, particularly agriculture land and forest area. These ranges widen with time because of rising uncertainties of demographic, socio-economical and technological development. Total carbon emissions cumulated from all sources (and sinks) range from about 770 to 2540 GtC at the end of the 21st century.

Beside uncertainty related to our poor information on land use and GHG there are other sources of errors in models. Among them are limited number of input data and their limited accuracy which, according to the chaotic nature of weather, causes that the very small difference in initial conditions can lead to slightly different climate features as each simulation gives different set of weather realization. If it is the only source of error the differences between different simulations should be hold within the ranges of typical climate variability. Unfortunately it is not the case. Because many sub-grid processes have to be represented in models in a simplified, usually statistical form, and are not very well predicted by these models. For example modeling of cloud formation, their optical and radiative features and creation of atmospheric precipitation are still burden with considerable error.

Because of all these errors climate models should be evaluated on the real climate past or current. It can be done by comparison of simulations with observations. It could lead to selection of the best model, but unfortunately it is not possible. Usually one model can better describe one parameter than the other model, but this second describes better the other variable or the same one but in the other part of the world. Of course it is possible to exclude some models, but still we have a set of models which are quite good but still far from the excellence. We can estimate the differences between simulations and real climate data on the ground of so called reference period from which we have observational data. These differences, usually called biases, vary in space and typically also in daily and annual cycles.

The models give the description of climate in set of grid points. Each grid point represents the conditions that exists in a region surrounding this point, being the mean value for this region. It is a reason why the distributions of simulated variables are usually smoothed in comparison with station data. Simulations underestimate the highest values and overestimate the lowest ones (Deque, 2007). It means that the bias is also different in different parts of distribution.

There is really a big number of sources of errors of climate predictions, so preparing a scenario for future is a big challenge. Any singular method can't be used for all variables and regions.

- Dynamical downscaling - why we use RCMs, and what kind of improvements we can suspect, how different RCMs differ (~5 pages Philip Lorenz)
- Statistical downscaling:
  - Perfect prognosis methods: linear (multivariate regression models, canonical correlation analysis) and nonlinear (analogs, cluster analysis, neural nets) (~5 pages Rasmus Benestad)

Fig. 1 An autumn picture of Rondane mountain range in Norway showing the geographical extent of fresh snow. The snow cover depends on the local temperature, in addition to snow fall. Photo: R.E. Benestad.

The fundamental criterion for downscaling is that the local variable of interest depends on the large-scale conditions as well as the local geographical conditions. The large-scale situation is described by a *predictor*, represented by the symbol $\boldsymbol{X}$ in mathematical equations. The local variable is usually referred to as the *predictand* and symbol y, whereas the geographical parameters are denoted by symbol g. It is usually not possible to explain the predictand completely in terms of X and g, and the contribution from local small-scale processes are in principle not downscalable, and is therefore described as small-scale noise η. Mathematically, this can be expressed as follows:

$$y = f(\mathbf{X},g) + \eta.$$

Fig. 1 illustrates how the local conditions depend on the geography and the large-scale situation. The snow only stays where the temperature is below freezing, which is only above a certain elevation. Furthermore, the large coherent extent of the snow shows that the local temperature is part of a larger pattern. The exact value may vary from location to location (small-scale noise η), but it is possible to say from this picture that the temperature in the snow-covered region is mainly below freezing.

In the illustration above, the large-scale condition ***X*** is the snow-cover, but it is better to use a predictor with a more direct physical relationship to the predictand. Often ***X*** can be the mean sea-level pressure or the large-scale temperature pattern.

Different aspects of local and regional climates have different characteristics. For instance, the description of temperature tends to provide spatial patterns which are closely tied with the elevation (Livingstone et al, 1999), as shown in the illustration above. However, for variations in time, the anomalies tend to vary slowly with distance (Hansen et al., 2006). Furthermore, the temperature is close to being normally distributed, which makes linear techniques, such as least squares methods (Wilks, 1995) suitable for modelling temperature changes. The large spatial extension of the temperature anomalies suggests that they are well-suited for downscaling, having a close association with large-scale conditions. The day-to-day changes in the temperature can also be understood in terms of advection, passage of fronts, and radiative forcing (cloudiness).

Precipitation differs from the temperature in several respects. One particular property that precipitation has, but few other climate variables, is two types of statistical distributions depending on whether there is a wet day or not. For dry days, the distribution is just zero. For wet days, there is another distribution describing the frequency of getting certain amounts. The wet-day distributions cannot be assumed to be normally distributed, but are better described by an exponential or a gamma distribution (Vlček & Huth, 2009). Rain may furthermore be generated by large-scale cloud systems or by local convective storms. Furthermore, mountain ranges (up-slope orographic forcing and rain shadows) and the distance to the coast affect the rainfall statistics. The time evolution of precipitation is characterised by the persistence of rainy days and dry spells, as well as the transition probability between wet and dry.

Wind can be characterised by two variables: the wind speed and its direction (alternatively the zonal and meridional components) (Pryor et al. 2005). Local wind is often a result of chaotic turbulence in addition to the large-scale flow of the free atmosphere above. The flow over geographical features may not be well correlated with the large-scale air flow, and wind direction and speed may change substantially over short distances. Nevertheless, extreme winds are often associated with deep low-pressure systems/storms.

Because of these differences, different statistical techniques may be required to provide an adequate description of the aspects that we are interested in. The statistical methods can be classified as perfect prognosis methods (Maraun et al., 2010), consisting of linear (multivariate regression models,canonical correlation analysis), and non-linear methods (analogs, cluster analysis, neural nets). The linear methods are often adequate for describing temperature, but it is also possible to transform some of the other variables so that linear methods may be applied to the terms of either side of an equation describing their dependence. The different models also differ in their calibration strategies and how they are optimised. In addition to these, it may be possible to downscale the shape of the probability density function (pdf) directly, rather than the day-to-day variability of some variable. Downscaling of pdfs seem promising, but does not belong to either the PerfProg or the MOS categories.

EOFs – a framework for representing the large scales in predictors

The predictors ***X*** in downscaling involve identifying large-scale spatial patterns of some variable (e.g. temperature or mean sea-level pressure) that co-varies with the predictand. It is then important to find the same type of patterns in the climate model. The large-scale variability can be described in terms of orthogonal empirical functions (EOFs) (Lorenz, 1956; North, 1982), a kind of principal component analysis (PCA) (Strang, 1988), or in terms of a set of grid point (ref Huth). The spatial structures of the EOFs describe a set of spatially coherent 'modes' that describe the variations of the gridded data. The leading modes describe the structures that are most pronounced and with the greatest spatial scales, and the higher order modes are associated with less variance and smaller spatial scales.

Often, only a small number of leading EOFs represent real features, whereas the higher order EOFs describe noise (Wilks, 1995). It is therefore possible to describe the main features of a gridded data in terms of a relatively small number of EOFs. Each spatial EOF pattern is associated with a vector of weights, describing how strongly this pattern is present at any time of the record. This vector is often referred to as 'principal component' (PC). The PCs are the basis for the downscaling model calibration, for instance a multiple regression against the predictand. The benefit of using of EOFs is that they are orthogonal and make the model calibration easier and more robust (no co-linearity).

PerfProg – a brand of calibration strategies.

The brand 'perfect prognosis methods' (PerfProg) describe a class of empirical-statistical downscaling models that involve a specific strategy for model calibration (Wilks, 1995). These use gridded observations or re-analyses (Kalnay et al. 1996; Simmons and Gibson, 2000) to calibrate against a predictand. First a predictor is taken from historical data, usually gridded analysis or re-analysis, and then a relation is found with the predictand (downscaling model calibration). Then the climate model results are compared with the predictors used to calibrate the downscaling model, and steps are made to ensure that model results correspond with the calibration data (e.g. through a regression analysis). The PerfProg method may involve linear and non-linear methods.

A different strategy, known as 'model output statistics' (MOS) use the model output directly in the calibration of the statistical models, rather than gridded observations. MOS can only be used when the model has been run for a period for which there are predictand data, and when the model is constrained by observations so that it is fed information about the day-to-day variations. While MOS can correct for systematic biases, such as shifts in location of storm tracks, the PerfProg strategy assumes that the model results are unbiased. In addition to the PerfProg and MOS strategies, it is possible to employ a hybrid method, involving common EOFs (Benestad, 2001), more on which will be discussed later.

For empirical-statistical downscaling, it is crucial that the same spatial patterns identified as having a strong association with the predictand are found in the climate model results that are used for prediction of local climate characteristics. One way to do this is to carry out two separate EOF analysis, and then use a regression analysis to ensure that similar patterns are used in the climate model (PerfProg). It is also possible to combine the gridded observation and the climate model results on the same grid (by interpolation, and removing e.g. the mean value to by-pass bias problems), and then carry out a 'common EOF' analysis. When using common EOFs, only the part of the PCs representing the observations are used for calibration. This means that the time series are no longer orthogonal, but this strategy ensures that they describe exactly the same spatial pattern in the observations as in the climate model results (Benestad, 2001). The use of common EOFs also eliminates a second step of regression, and hence is simpler in mathematical terms as well as omits one variance-reducing analysis stage.

Different types of downscaling models

Once the framework for representing the large-scales is established, one can proceed with the task of actually calibrating the downscaling models. There are different options, and the best choice depends on the type of predictand. If the relationship between the predictor and predictand is expected to reflect the two sides of an equation (ideally with the same physical units), then the simple linear approach is probably the best choice. If the relationship between the large and small scales are theoretically known, it is also possible to apply a transform to the quantity on either side of the equation to make the quantities linearly dependent. Whenever possible, a linear model is to be preferred for the reasons of simplicity and transparency.

Linear methods

Linear methods include regression, for instance least-mean-squares estimation. If the data are normally distributed (Gaussian), then an ordinary linear model (OLM) can be employed in a regression analysis, but for non-Gaussian data, a generalised linear model (GLM) should be used. For Gaussian data, canonical correlation analysis (CCA) (Busuioc et al., 1999) and singular vector decomposition (SVD) are alternatives to regression (Bretherton et al., 1992). The difference between these approaches, is that regression minimizes the root-mean-square errors (distance between predictions and observations), the CCA maximizes the correlation, and SVD maximizes the co-variance between two fields.

The calibration of the linear models gives a set of coefficients describing how the different PCs should be weighted (a scaling factor) for get an optimal fit. Moreover, the linear methods involves weighting a combination of time series differently so that their sum gives the best reproduction of a given 'truth'. If the training set involves many different series, it is possible to find a set of combination that can provide a good fit even if there is no real link between the predictand and predictor. This situation is known as 'over-fit' (Wilks, 1995), and, hence, multiple regression should involve stepwise screening to avoid over-fit. The set of coefficients can be applied to the spatial patterns (EOFs) - in addition to the PCs – and hence the sum of the weighted patterns describes the spatial structure in the predictor that is associated with the variations in the predictand. This pattern is referred to as 'regression pattern', and can provide a basis for evaluation. In many cases, there are a priori information about what this pattern should look like, such as a spatial map of correlation coefficients. In all cases, the downscaling models should be evaluated on independent (out-of-sample) data, which were not used for calibrating the model.

Non-linear methods

The non-linear methods involve various strategies, such as analogs, weather classification, cluster analysis, and neural nets. The analog model, weather classification, and cluster analysis all involve a re-sampling of past measurements. These re-sampling techniques suffer from one caveat, that tails of the distributions will be distorted because the sampling cannot produce new record-breaking values (Benestad, 2008). Even stationary series are expected to produce new record-breaking events, given sufficiently long intervals for observations. Theory of independent and identically distributed (iid) series shows that the expected occurrence of new record-breaking events will converge towards zero, but never actually become zero. Nevertheless, this implies that the upper and lower tails of the distribution of the results from the re-sampling methods may be distorted, and that the results may have to be re-calibrated. A re-calibration can be performed once the theoretical pdf is known through local quantile mapping.

Analog models

The simplest non-linear method is the analog model (Zorita and von Storch, 1999; Timbal et al., 2008), which simply involves searching the record of past events and taking the day that most closely matches the situation one wants to predict. The observed value for the predictand for this day is then used as predictand. Typically, the situation is described in terms of mean sea-level pressure (MSLP) patterns, and the task is to find the MSLP from the past records that most closely matches the one that the climate model predicts for the future. There are a number of different criteria for selecting the 'most similar state'. A simple scheme is to apply pattern correlation. The search may also be based on how similar the states are in terms of an EOF-analysis. Such a search uses the leading EOFs to define an 'ndimensional' space (Imbert & Benestad, 2005), and defines the day with the least euclidean distance between the PC loadings for the historical record and the predicted situation as the best analog.

Cluster analysis

It is also possible to base the predictions on a number of closest states (Wilks, 1995), either by taking the mean of the days with close matches. Another approach is to use the observed values for the all the days that match the predicted state, and construct a statistical distribution (histogram). From this sample, or a fitted probability density distribution, one may draw a random value. In some cases, the PC loadings may cluster into different groups in the EOF space, and then it is possible to use these clusters for defining the number of days with similar states. A cluster analysis is used to group the EOFs into different regimes.

Neural nets

Neural nets involve various adaptive learning algorithms, like 'artificial intelligence' (Hewitson and Crane, 2002; Wilby et al., 1998). These may be effective at identifying signals and patterns, but it can be difficult to understand their physical meaning. Often, neural nets are used to prepare the data before the actual downscaling, for instance by classifying the data in terms of 'self-organised maps' (SOMS). The disadvantage with neural nets is that they need long time series for proper calibration, and it is important to test the results to see if they identified real relationships. Neural nets may provide a fit that is fortuitous rather than real, and care must therefore be exercised when employing these. It is also hard to see what actually happens within the calibration process, and such non-linear techniques have some times been characterised as a 'black box'.
(Imbert & Benestad, 2005)

Advantages with perfect prognosis methods

The advantage with the perfect prognosis methods, linear and non-linear, is that they add and make use of additional empirical information, thereby providing more realistic results than the raw model results. Models provide a simplistic and idealised description of the real world, and most global climate models are not designed to describe local details. The perfect prognosis methods moreover provide a bridge between model and real observations, mapping (in mathematical terms) the model results onto real data. Often, the quality of the GCM results may be assessed though empirical-statistical downscaling (ESD).

Even regional climate models (RCMs) are limited in terms of describing the local scale, as their resolution may not provide an adequate description of the real terrain (smoothed surface description), and the parametrisation of small-scale processes may not account for local spatial variability in vegetation, hydrology, and elevation. Furthermore, RCMs may have systematic biases, and the different choices for the representation of small-scale processes (parameterisation packages, often referred to as 'model physics' although these are statistical models) may give different results. Hence, RCMs may introduce additional uncertainties (Pillippo et al., 2008).

Finally, perfect prognosis methods are fast to run, and ideally for downscaling a large ensemble of GCMs and over entire simulation runs. RCMs, on the other hand, tend to be more computationally demanding, which limits the number of realisations that can be provided. The strengths and weaknesses of perfect prognosis methods and the RCMs are independent of each other, so that both approaches should be employed and the results should be compared. Converging results provide additional confidence, whereas diverging results bring on the question about which is more reliable.

Disadvantages

The main disadvantage of all empirical-statistical downscaling (ESD) is that they are limited in terms of predicting variables for which there are long and good quality observations. This means that ESD can be applied to locations were measurements have been made for a long time, for instance of temperature or precipitation. The time resolution of the measurements, as well as of the predictors, also limits the type of results that can be achieved. RCMs, on the other hand, can provide a complete picture in time, space, for different time scales, and with internally consistent relations between the different variables. The consistency between the different variables may, however, not necessarily match that seen in the real world, and hence the term 'physically consistent' is inappropriate for describing these models.

The perfect prognosis methods also make a number of assumptions, such as the relationship between predictand and predictor does not change over time. Similar assumptions are made for the parametrisation used in both GCMs and RCMs, for instance the relationship between aerosols and cloud drops, between gravity waves and the mean flow, surface vegetation and the temperature/water, etc. As far as possible, these statistical models are based on a physical understanding (e.g. bulk formula for wind stress, convection schemes), and hence are based on more information than just a statistical analysis. It is important to evaluate the robustness of these statistical models, by dividing the data into two parts, use one part for calibration and the other for verification. Furthermore, the model results may be used as surrogate data, using the first half of the simulation run to represent the observations. A surrogate for the predictand can be taken from a grid point, whereas the predictor is taken to be the large-scale pattern.

The choice between representing the predictors in terms of EOFs or as grid-point values, may also introduce differences (Huth, 2004). The results may even be sensitive to the size of the predictor domain (Benestad, 2011), for which a subjective choice must be made. If the domain is too large, unrelated noise may 'drown' the relationship between the predictor and predictand, and negatively correlated teleconnections may give incorrect signs (Benestad et al. 2008).

Errors in observations will hamper the construction and evaluation of perfect prognosis methods. In some cases, it may be possible to get around this problem by excluding suspect numbers. For instance, if there is a small number of very large errors (outliers), then the calibration(Imbert & Benestad, 2005) may be carried out on a subset of the data. However, care must be exercised for not 'mining' the data and 'cherry-picking' the data. It is always a good idea to test the models on out-of-sample (independent) data.

Sometimes it may be difficult to identify which variables to use as predictors. It is important that the predictors 'carry the signal' that we want to predict. MSLP may for instance be a poor choice for climate change scenarios, as there may not be a close link between the pressure patterns and a general warming. The predictors should also exhibit a strong relationship with the predictand, so that a large portion of the predictand variance can be reproduced. For regression analysis, the portion of the variance is reflected in the R^2-statistic (Wilks, 1995). Finally, the perfect prognosis methods hinge on the GCMs' ability to reproduce the regional details, and hence similar structures in the predictors as seen in the observations.

All the requirements regarding predictors, restrict the choice, which can be a limiting factor to successful employment of perfect prognosis methods. For temperature, however, large-scale temperature fields from re-analyses seem to be a workable solution to the choice of predictors (Benestad, 2011; Hanssen-Bauer et al., 2005). The benefit is also the lower risk of non-stationarity, as the local temperature is expected to be a part of the larger temperature structure for physical reasons.

It is more tricky to find suitable predictors for precipitation. Large-scale precipitation, which can be taken from re-analyses, is expected to contain long-term signal, but is often not strongly related to the local precipitation measurements. The reason is that precipitation from re-analyses are prognoses that are not directly constrained by observations, and that these prognoses suffer from biases and model shortcomings. Another issue is whether the GCMs are able to reproduce the general regional spatial precipitation structures. For daily precipitation, the data are strongly non-Gaussian, and may exhibit a different statistical distribution to the precipitation structure over larger areas. MSLP does not (at least explicitly) hold information about the air's thermodynamic character (temperature and humidity), and may not contain all of the climate change signal.

Most of the weaknesses with perfect prognosis methods, however, can be explored. ESD should not be seen as merely a way to get a value, but as an advanced form for analysis, where different relations can be tested. For instance, the question about non-stationarity can be tested through appropriate experimentation, where the predictors and predictand are split into two parts, with one being used for calibration and the other for evaluation. The ESD models may also be developed entirely on GCM data, taking a grid-point as the predictand and a larger area as predictor. Furthermore, spatial analysis of results from neighbouring stations and R^2-statistics can provide useful information about the quality of the results (Benestad, 2011). Since RCMs and ESD are independent and complimentary means of downscaling, with different weaknesses and strengths, it is also important to carry out both and look for where the results converge and diverge.

The weaknesses discussed above may not involve the greatest uncertainties associated with downscaling. Often the regional picture provided by different GCMs, or even different runs with the same GCM, vary substantially (Giorgi, et al., 2008; Chen et al., 2006). Hence, it is important to sample the spread of possible solutions through large ensembles of GCM runs (such as CMIP3 and CMIP5). Since ESD is computationally cheap and effective, it provides a well-suited means for providing information about probabilities and confidence ranges. ESD can also be used to downscale local climate for remote locations far apart (Benestad, 2011). RCMs, on the other hand, is more limited in terms of number, region, and length of runs, but provide a more comprehensive picture of space and interrelations for a smaller selection of climate projections.

A final comment about ESD is the possibility to downscale the shape of pdfs directly. New promising methods are being developed for 24-hr precipitation, and preliminary results suggest that it may be possible to predict changes in percentiles once the change in the -wet-day mean precipitation and the wet-day frequency is known. This type of approach is discussed in more detail in Benestad et al. (2008) and Benestad (2007).

References:

1. Benestad, R.E., 'A new global set of downscaled temperature scenarios', J. Climate, 15 April 2011 issue , Vol. 24, No. 8, 2080-2098. doi: 10.1175/2010JCLI3687.1
2. Benestad, R.E., Hanssen-Bauer, I. And Chen, D.(2008) “Empirical-Statistical Downscaling”, World Scientific Publishers, ISBN 978-981-281-912-3
3. Benestad, R.E. 'A Simple Test for Changes in Statistical Distributions', Eos, 89 (41), 7 October 2008, p. 389-390
4. Benestad, R.E.: Novel Methods for Inferring Future Changes in Extreme Rainfall over Northern Europe, Climate Research, CR34:195-210, doi: 10.3354/cr00693
5. Benestad, R.E. (2001) A comparison between two empirical downscaling strategies, Int. J. Climatology,Vol 21, Issue 13, pp.1645-1668. [DOI 10.1002/joc.703]
6. Bretherton, C.S and Smith, C. and Wallace, J.M. (1992) An Intercomparison of Methods for finding Coupled Patterns in Climate Data, J. Clim., 5, 541-560

7. Busuioc, A., H. von Storch and R. Schnur (1999) Verification of GCM-Generated Regional Seasonal Precipitation for Current Climate and of Statistical Downscaling Estimates under Changing Climate Conditions, J. Clim., 12, 258
8. Busuioc, A., D. Chen, C. Hellström (2001) Performance of statistical downscaling models in gcm validation and regional climate change estimates: application for swedish precipitation, Int. J. Climatol. 21: 557–578 (2001)
9. Chen, D. , C. Achberger, J. Räisänen and C. Hellström (2006), Using statistical downscaling to quantify the GCM-related uncertainty in regional climate change scenarios: A case study of Swedish precipitation, Advances in Atmospheric Sciences, Volume 23, Number 1, 54-60, DOI: 10.1007/s00376-006-0006-5
10. Giorgi F., N.S. Diffenbaugh, X.J. Gao, E. Coppola, S.K. Dash, O. Frumento, S.A. Rauscher , A. Remedio, I. Seidou Sanda, A. Steiner, B. Sylla and A.S. Zakey (2008), The Regional Climate Change Hyper-Matrix Framework, Eos, 89, 45, 445-456
11. Hanssen-Bauer I., Achberger C., Benestad R.E., Chen D., Førland E.J (2005) Statistical downscaling of climate scenarios over Scandinavia: A review Clim. Res. 29 255-268
12. Hansen, J., Mki. Sato, R. Ruedy, K. Lo, D.W. Lea, and M. Medina-Elizade, 2006: Global temperature change. *Proc. Natl. Acad. Sci.*, **103**, 14288-14293, doi:10.1073/pnas.0606291103.
13. Hewitson B.C. and R.G. Crane (2002) Self-organizing maps: applications to synoptic climatology, Clim. Res., 22,13-26
14. R. Huth (2004), Sensitivity of Local Daily Temperature Change Estimates to the Selection of Downscaling Models and Predictors, J. Clim., 17, 640-652
15. Imbert, A. & R.E. Benestad (2005) An improvement of analog model strategy for more reliable local climate change scenarios Theoretical and Applied Climatology 82, p. 245-255, DOI: 10.1007/s00704-005-0133-4
16. Livingstone, D.M., A.F. Lotter and I.R. Walker (1999), The Decrease in Summer Surface Water Temperature with Altitude in Swiss Alpine Lakes: A Comparison with Air Temperature Lapse Rates *Arctic, Antarctic, and Alpine Research* Vol. 31, No. 4, pp. 341-352
17. Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Wollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K.C. Mo , C. Ropelewski, J. Wang, A. Leetmaa, R. Reynolds, R. Jenne and D. Joseph (1996), The NCEP/NCAR 40-Year Reanalysis Project, Bullit Am. Met. Soc.,, 77, 437-471, March
18. Lorenz, E.N. (1956) Empirical Orthogonal Functions and Statistical Weather Prediction Department of Meteorology, MIT, USA, Sci. rep., #1, (NTIS AD 110268)
19. Maraun, D., F. Wetterhall, R.E. Chandler, E.J. Kendon, M. Widmann, S. Brienen, H.W. Rust, T. Sauter, M. Themeβl, V.K.C. Venema, K.P. Chun, C.M. Goodess, R.G. Jones, C. Onof, M. Vrac, I. Thiele-Eich (2010), Precipitation downscaling under climate change: Recent developements to bridge the gap between dynamical models and the end user, Reviews of Geophysics, 48, 2009RG000314
20. North G.R. , T.L. Bell and R.F. Cahalan (1982), Sampling Errors in the Estimation of Empirical Orthogonal Functions, Mon.Weath. Rev., 110, 699-706
21. Pryor, S.C., J.T. School and R.J. Barthelmie (2005) Climate change impacts on wind speeds and wind energy density in northern Europe: empirical downscaling of multiple AOGCMs, Climate Research, 29, 183-198
22. Simmons, A.J. and Gibson, J.K (2000) The ERA-40 Project Plan, ECMWF, ERA-40 Project Report Series, #1, www.ecmwf.int
23. Strang, G. ,(1988) Linear Algebra and its Application, Harcourt Brace & Company, San Diego, California, USA
24. Timbal B, P. Hope and S. Charles (2008) Evaluating the Consistency between Statistically Downscaled and Global Dynamical Model Climate Change Projections, J. Clim., 21, 22, 6052-6059
25. Vlček, O. and R. Huth (2009) Is daily precipitation Gamma-distributed? Adverse effects of an incorrect use of the Kolmogorov–Smirnov test, Atmospheric Research 93 (2009) 759–766

26. Wilby, R. L., T. M. L. Wigley, D. Conway, P. D. Jones, B. C. Hewitson, J. Main, and D. S. Wilks (1998), Statistical downscaling of general circulation model output: A comparison of methods, Water Resour. Res., 34(11), 2995–3008, doi:10.1029/98WR02577.
27. Wilks, D.S. (1995), Statistical Methods in the Atmospheric Sciences, Academic Press, Orlando, Florida, USA, pp467
28. Zorita E. and H. von Storch (1999) The Analog Method as a Simple Statistical Downscaling Technique: Comparison with More Complicated Methods, J.Clim., 12, 2474-2489

- Model Output Statistics (~5 pages Joanna Wibig)

- Evaluation techniques (~5 pages Douglas Maraun)
- Ensembles, how to use them, how to assess an error of projection? (~5 pages Erik Kjellström)
- Projections in impact studies (~4 pages)
- Regional climate futures based on analysis of driving factors (~4 pages)

short description what it is for, links to literature explaining details, concentrate on advantages, shortcomings and limitations shown on examples

References:

Benestad RE, Hanssen-Bauer I, Chen D, 2008, *Empirical-statistical downscaling*, World Scientific Publishing Co. Pte. Ltd., 216 pp.

Maraun D, Wetterhall F, Ireson AM, Chandler RE, Kendon EJ, Widmann M, Brienen S, Rust HW, Sauter T, Themessl M, Venema VKC, Chun KP, Goodess CM, Jones RG, Onof C, Vrac M, Thiele-Eich I, 2010, Precipitation downscaling under climate change, recent developments to bridge the gap between dynamical models and the end user, *Reviews of Geophysics*,

4.3. Projections of future climate change

Lead author: Ole Bøssing Christensen

Contributing authors: Erik Kjellström, Torben Sonnenborg, Aslak Grinsted, Markus Meier

4.3.1. Atmospheric changes (T, P, Wind, DTR, extremes)

Ole B. Christensen and Erik Kjellström

The ENSEMBLES project, as well as a large government-funded simulation efforts by several institutions, but mainly the SMHI, have increased the available base of regional climate change simulations considerably,compared to the state at the time of BACC-1. As a consequence of this, we have better documentation for estimates of climate change over the Baltic Basin. Furthermore, we have some indication of the uncertainty of these projections, mainly of the part of the uncertainty which are related to model shortcomings and climate variability.

In the next few years, the CORDEX project, in particular EURO-CORDEX, will provide ensembles of high-resolution simulations with spatial resolution down to around 10 km for Europe, including our area of interest. This resolution is expected to facilitate considerably the applicability of RCM data as input to various impacts models.

4.3.2. Hydrological changes incl. terrestrial cryosphere

Torben Sonnenborg

No conclusions formed yet, but there are many new investigations to discuss.

4.3.3. Sea level

Aslak Grinsted

4.3.4. Marine physical changes incl. sea ice, storm surges and wind waves

Markus Meier

More publications are available than at the time of BACC-1. Quantification of uncertainties is possible with the help of ensemble modelling. No surprise for physical variables. But new aspects from coupled physical-biogeochemical modelling.

Chapter 5. Impacts (in competition with non-climatic drivers)

5.1. Introduction and summary

5.2. Impact on the environment

5.2.1 Atmospheric chemistry

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Main questions

Which countries and emissions sources contribute to air pollution in the Baltic region. Now and in previous 100-200 years. How well can we quantify this?

General comment: literature used will focus (as requested by BACC-II) on papers from year 2006 and onwards. However, as the previous BACC-I report didn't cover atmospheric chemistry in much detail, key papers from earlier years might be appropriate.

Introduction

General introduction. Discussion of pros and cons of observations and models for estimating concentrations and depositions. What is available, where. Relative importance of atmospheric deposition of especially nitrogen compounds to land and sea, compared to other inputs (reference: European Nitrogen Assessment).

Emissions

Main sources of emissions to air - shipping, industry, agriculture etc., including trends and projections. Shipping emissions receive extra focus as they have been continuously increasing during this century, and regulations have so far been rather lax. This is starting to change, and large emission measurement programmes are underway to evaluate both the emissions and the expected changes.

Focus shipping-work on Baltic and nearby sea areas - 3-4 pages in draft - overview of emission estimates, and assessment of accuracy, making use of new measurements. Recent changes in regulations - measured impacts on emissions (remote sensing technologies, etc.), as well as discussion of longer term trends and expectations.

Emissions from land-based sources - brief overview only, since little new information. Short review of historical trends for different pollutants, then future projections (IPCC, GEA, ...) assigned most focus. Discussion of uncertainties in these emissions estimates and future trends.

Depositions & Concentrations

Overview of current knowledge of measured and modelled depositions (and/or concentrations) of Sulphur, Nitrogen, Ozone HM? Other? Past estimates and projected trends. (Observations? Sediments?) Illustrations of modelled fields and varability from ensembles of chemical transport model (CTM) calculations, from both European scale and global scale models. Modelled future trends -- results from some future scenarios. Refs to e.g Stevenson et al. (2006), Geels et al. (2011), Andersson et al. (SMHI), Bartnicki et al., 2011.

Focus: How well can we estimate deposition to land and sea surfaces?

A few pages (3-5, including refs) on the status and uncertainties associated with modelling deposition of gases and particles. Need to consider both land and sea, but deposition rates over sea are even more challenging than those of land. Something on uncertainties in wet-deposition ... comparison of modelled and measured values is possible over land-areas at least. That isn't the case for dry-deposition, so the dry-deposition needs more discussion.

Climate impacts?

The main climate impacts are probably C-sequistration issues associated with N-deposition changes and ozone-effects, and (probably more important for this region) aerosols. However, another chapter will deal with aerosols, so no action planned in this chapter on that. (Need to discuss with aerosol lead author).

Conclusions

Here we summarise and try to present a concise answer to the starting question.

5.2.2 Terrestrial ecosystems

Leader author: Pekka Niemelä, Coastal Geography Group (University of Turku, Åbo Akademi)

Contributing authors:
Risto Kalliola, Jari Valkama, Michael von Numers, Terry V. Callaghan, (Abisko Scientific Research Station)
Seppo Kellomäki (University of Eastern Finland)
Esa Lehikoinen, (University of Turku)
Kari Saikkonen (MTT, Finland)
Guy Schurgers (University of Lund)

General chapter summary:

Based on meetings and correspondence with authors it was agreed that the general aim of the chapter is to summarize the current knowledge of climate change on terrestrial ecosystems in the Baltic Sea Basin.

We have simplified and reorganized the previous chapter structure. The chapter structure is now divided into three main terrestrial ecosystems: coastal and archipelago ecosystems, agricultural ecosystems and forest ecosystems. In addition, we pay attention how different ecosystems may interact with each other and especially with aquatic ecosystems. The analysis is limited on Baltic Sea Basin. Although our summary covers the main terrestrial ecosystems of the area the special emphasis of the chapter is on unique archipelago and coastal ecosystems along the Gulf of Bothnia and the Gulf of Finland. The uniqueness of the Baltic Sea archipelago and coastal terrestrial ecosystems are based on the combination of land uplift, climatic change and interaction with brackish water/terrestrial ecosystems. This approach has earlier received very little attention although it is of extreme importance for maintaining biodiversity and nature conservation of Baltic Sea archipelago and coastal ecosystems.

Changes in land use and climate change affect both agricultural and forest ecosystems. The aim of the second part of the chapter is to evaluate those land use and climate driven changes on terrestrial ecosystems in the Baltic Sea catchment area and what are the possible consequences for coastal and archipelago ecosystems. In forest ecosystems our main emphasis is on natural and semi-natural ecosystems in order to avoid overlap with Chapter 5.3.1. "Agriculture and forestry".

Structure of the chapter:

5.1. Background

5.2. Archipelago ecosystems (Coastal Geography Group, Esa Lehikoinen)
- 5.2.1. Changes in species distributions
- 5.2.2. Climate related invasions
- 5.2.3. Interactions between terrestrial and marine ecosystems

5.3. Agricultural ecosystems (Kari Saikkonen)
- 5.3.1 Changes in land use in agricultural ecosystems
- 5.3.2. Interactions between agricultural and marine ecosystems in the Baltic Sea Basin

5.4. Forest ecosystems
- 5.4.1. Climate related changes in forest structure (Seppo Kellomäki, Terry Callaghan)

5.2.3 Freshwater biogeochemistry

Leader author: Christoph Humborg

Contributing authors: PirkkoKortelainen, Reiner Giesler, Hans Estrup Andersen, GitteBlicherMathiesen, GesaWeyhenmeyer, Thorsten Blenckner, GustafHugelius, Jens Hartmann, Markus Venohr, Matthias Gardesen

Structure agreed upon at the meeting at BNI Sweden May 5 together with the co-authors

1.1 General freshwater biogeochemical patterns in the Baltic Sea catchment;

The Baltic Sea is an estuarine system with water residence times of some 30 years, highly susceptible to changes in riverine loads of biogenic elements (C, N, P, Si) [*Conley et al.*, 2009a; *Eilola et al.*, 2009; *Humborg et al.*, 2007; *Meier*, 2007; *Wulff et al.*, 1990]. Two major drivers, i.e., the changes in life style which boosts cultural eutrophication and global warming, may significantly alter the transport of biogenic elements to the Baltic Sea in the near future [*Arheimer et al.*, 2005; *Hagg et al.*]. These changes can be expected to be much more severe compared to the variations in riverine fluxes observed over the last 35 years [*HELCOM*, 2004], since changes in life style translates directly into anthropogenic nutrient emissions and riverine fluxes [*Hagg et al.*, ; *Howarth et al.*, 1996] and the foreseen changes in temperatures and rainfall will alter the hydrological patterns in the catchment fundamentally [*Graham*, 1999; *Graham and Bergstrom*, 2000; 2001; *Weyhenmeyer et al.*, 2004]. Additional drivers as damming, hydrological alterations [*Dynesius and Nilsson*, 1994; *Humborg et al.*, 2006; *Humborg et al.*, 2008a; *Nilsson et al.*, 2005], forestry and wetland management (refs) and atmospheric deposition [*Monteith et al.*, 2007; *Weyhenmeyer*, 2008] are compounding factors affecting freshwater biogeochemistry especially in the boreal watersheds.

The aim of this chapter is to summarize the current knowledge on various drivers affecting freshwater biogeochemistry and focuses on riverine nutrient and carbon fluxes in the Baltic Sea catchment. Quantification the effects of single drivers on freshwater biogeochemistry is generally a challenging task, however, wherever possible we will summarize the current knowledge on the effect of global warming as such and its interplay with co-effecting man-made drivers.

1.2 The Baltic Sea catchment

The drainage basin of the Baltic Sea can be divided into a northern boreal part that drains into the Gulf of Bothnia (Bothnian Bay=BB and Bothnian Sea=BS) and a south eastern part that drains into the rest of the Baltic Sea (Baltic proper=BP, Gulf of Finland =GF, Gulf of Riga=GR, Danish Sounds=D, Kattegat=KT; Figures 1 and 2).

1.2.1 Boreal part of the BS catchment

The northern watersheds draining into the Gulf of Bothnia are generally densely populated (Table x) and less eutrophic compared with the cultivated watersheds of the southeast. The dominating land cover in the north is boreal forest and wetlands. Bedrocks are dominated by acid volcanic and plutonic acid rocks (mainly granites); soil types are dominated by till [*Durr et al.*, 2005]. The mean slope of the western boreal watersheds draining mainly Sweden is much steeper and the specific runoff is roughly two times higher than in the eastern Finnish watersheds (Table x).

1.2.2 Cultivated part of the BS catchment

The watersheds of the southeast are dominated by agriculture (Table 1; Figure 2). Sedimentary rocks dominate the southeastern part of the Baltic Sea catchment, whereas in the watersheds of the Oder and Vistula non- to semi-consolidated sedimentary rocks dominate and in the watershed of the Nemunas and Daugava consolidated sedimentary rocks are predominating (check Neva) [*Durr et al.*, 2005]. Most rivers can be described as lowland rivers with a mean slope less than 1º.River nutrient loads, especially from the Neva, Oder, Vistula, Daugava and Nemunas Rivers, contribute most to riverine mass fluxes to the central and southern basins of the Baltic Sea [*Stålnacke et al.*, 1999b].The largest nutrient mass fluxes come from the rivers Oder and Vistula, draining Poland and its 38 million inhabitants, about half of the population of the entire Baltic Sea catchment [*Hannerz and Destouni*, 2006]. Specific discharge is much less compared to the boreal watersheds.

1.3 Drivers affecting freshwater biogeochemistry

Freshwater biogeochemistry in relatively unperturbed aquatic systems within the Baltic Sea catchment and background loads of the biogenic elements C, N, P and Si is a result of its weathering regime characterizing total ionic strength, pH, and alkalinity as well as vegetation cover and vegetation forms. Generally, weathering reaction charges rain water with basic cations and anions including dissolved inorganic carbon, orthophosphate and silicic acid when infiltrating natural soils [*Drever*, 1997]. N is entering by biological N fixation and organic carbon stems from recently produced (mainly litter and root exudates[*Fröberg et al.*, 2003; *Giesler et al.*, 2007; *Jonsson et al.*, 2007; *Karltun et al.*, 2005; *van Hees et al.*, 2005]) and older stored soil organic carbon [*Vonk et al.*, 2008; *Vonk and Gustafsson*, 2009]. However, the bedrock composition dominated by acid volcanic and plutonic acid rocks as well as the occurrence of coniferous forests and wetlands storing huge amounts of organic carbon leads to a freshwater composition in the boreal watersheds that is characterized by a low ionic strength, low alkalinity on the one hand and high concentrations of humic and fulvic acids that form the major pool for dissolved organic carbon and nitrogen. These relatively unperturbed conditions can be found in the well studiedKalixälven[*Humborg et al.*, 2004; *Ingri et al.*, 1997]. Background loads and concentrations in the cultivated watersheds are difficult estimate because these landscapes have been influenced heavily for many centuries. However, the occurrence of sedimentary bedrocks in the cultivated watersheds and the higher temperatures that increase weathering reactions leads to a higher ionic strength and higher alkalinity.

Relatively undisturbed concentration of biogenic elements can still be found in the northernmost unregulated Swedish and Finnish watersheds. In most of the watersheds of the Baltic Sea catchment the following drivers mainly affect freshwater biogeochemistry:

1.3.1 Cultural eutrophication

Cultural eutrophication is by far the most investigated and well understood driver for freshwater biogeochemistry. Numerous studies in lakes and rivers show the effects of agricultural practices and of urban and industrial point sources on nutrient concentrations [*Arheimer et al.*, 2004; *Conley et al.*, 2009b; *Ekholm et al.*, 2007; *Humborg et al.*, 2008b; *Iital et al.*, ; *Kronvang et al.*, 2009; *Larsson et al.*, 1985; *Lindgren et al.*, 2007; *Lysiak-Pastuszak et al.*, 2004; *Raike et al.*, 2003; *Rheinheimer*, 1998; *Stålnacke et al.*, 1999a] and the subsequent effects for aquatic ecosystems, as decreased turbidity, widespread anoxia and loss in biodiversity [*Blenckner et al.*, 2006].

1.3.2 Damming, hydrological alterations

Damming is much more frequent in the boreal rivers owing to its higher effectiveness in terms of power generation [*Humborg et al.*, 2000; *Humborg et al.*, 2008b]; major reservoirs located in the headwaters can hold between 30-70% of their annual water discharge [*Dynesius and Nilsson*, 1994; *Nilsson et al.*, 2005]. In contrast, damming is much less frequent in the low-land rivers of the southeastern catchment of the Baltic Sea and mostly minor dams and reservoirs, with short water residence times, were built there [*Humborg et al.*, 2006]. However, there is a fair amount of literature reporting ”oligotrophication” of river systems as an effect of damming.

1.3.3 Forestry, wetland management

1.3.4 Atmospheric deposition

1.3.5 Hydrology (this is an extra chapter in the BACC book and cross-linkages has been discussed in March with the other BACC lead authors

1.4 Sources, transformations and exports of biogenic elements to the Baltic Sea

The net export of biogenic elements as particulate, dissolved or gaseous constituents to the Baltic Sea is the result of natural and man-made sources and the transformations of matter along the aquatic continuum formed by streams, lakes, and rivers. These transformations include biological processes (formation and degradation of biomass in the widest sense) and physico-chemical processes (particle formation, sedimentation, burial and gas exchange leading to an overall retention of biogenic elements [*Behrendt and Opitz*, 1999; *Kortelainen et al.*, 2001; *Kortelainen et al.*, 2004; *Kortelainen et al.*, 2006; *Venohr et al.*, 2005]) before they reach the Baltic Sea. **In this chapter, we will present and discuss the patterns in freshwater biogeochemistry within the catchment of the Baltic Sea by presenting i) the background sources and loads and if applicable additional man-made sources and loads ii) the transformations of biogeochemical dissolved, particulate and gaseous constituent along the aquatic continuum, iii) the possible co-effects of climate on cultural eutrophication [*Blenckner et al.*, 2006; *Jeppesen et al.*, ; *Jeppesen et al.*, 2009], forestry and wetland management (refs), hydrological alterations (refs) and atmospheric deposition [*Weyhenmeyer*, 2004; *Weyhenmeyer et al.*, 2004; *Weyhenmeyer*, 2008] and iv) the current and possible future export patterns of biogenic elements to the Baltic Sea (Fig x).**
5-8 word pages on each driver

5.2.4 Marine biogeochemistry

Leader author: Bernd Schneider

Contributing authors: Bernd Schneider

This chapter summary was discussed with the Contributing Authors during the BSSC and we agreed upon a few changes in order to avoid overlap within the Biogeochemistry Chapter and with other sub-chapters. However, these changes are not yet accounted for in the text below but will be reflected in the first drafts which will be discussed during a CA meeting on September 26/27.

0. Introduction

- Definition of biogeochemical cycles, relationship/differences to the „Ecosystem" Chapter;
- Relevant elements: C, O (H2S), N, P, Si, Fe and their importance for biogeochemistry;
- Steady state concept: relationship between inputs, concentrations, residence times;
- Attribution of major changes in the last two centuries: climate vs. biogeochemical (e.g. eutrophication) forcing;
- Purpose of the "Biogeochemistry" Chapter;

1. Changes in external forcing

- Summary of riverine nutrient inputs given in the previous BACC book;
- Summary of new results for riverine inputs presented in the "Freshwater Biogeochemistry" chapter, in particular DOC and alkalinity;
- Atmospheric deposition of nutrients based on measurements;
- Modelling atmospheric deposition of nutrients (possibly input from 5.2.1 "Atmospheric chemistry");
- Increase of atmospheric CO2;
- Climate induced physical forcing (input from 3.4.1 "Marine circulation and stratification" and possibly from 3.4.2 "Sea ice");

1.1 Present day understanding of BGC-fluxes

- New and older literature:
  - Books, HELCOM, other literature ...
- Nutrients:
  - In addition to Section 1, discuss the role of different forms of nutrients and processes causing transformations between the forms: Dissolved, particulate, inorganic, organic, biologically available or biologically inert.
  - In addition to Section 1, discuss relative importance of different loads: Rivers, point sources, atmosphere, fixation, open boundary, anthropogenic, natural.
  - Pools and concentrations: Water, Sediment. Typical vertical profile, horizontal maps, transects, and tables (and estimations of turn over time scales? Move pool discussion to budgets?). …
  - Changes in time:
    - Seasonal variations.
    - Historical records of nutrients, oxygen, pH.
- Baltic Sea specific conditions affecting the BGC fluxes:

- Fjord like, brackish, shallow Sea with some deep pits and a shallow entrance area.
    - A large fraction of produced organic matter reaches the sediments.
    - Long residence time makes internal processes and sediment-water exchanges important.
    - Export of nutrients from the Baltic Sea is forced to take place from surface layer.
    - Regional differences:
        - Separation in sub basins, North-south gradients.
    - Physical impact on BGC fluxes:
        - Seasonal cycles, light, bathymetry, stratification, ice, temperature, salinity, yellow substances.
        - Transports: Physical circulation and vertical mixing, sinking, re-suspension.
- Oxygen-H2S:
    - Discuss differences between surface water – deep water, Air-Sea gas exchange and temp-salt dependent O2 saturation dynamics.
    - Nutrients vs. oxygen relations.
    - Hypoxia-anoxia dynamics. Hypoxic areas and volumes vs. DIP and DIN.
- Generalized description of pathways and fluxes:
    - Uptake of nutrients to biological production of organic matter (oxygen production).
    - Export production, sinking of nutrients in particulate form, sedimentation.
    - Decomposition, dissolution and mineralization in water and in the sediments (oxygen consumption, H2S production).
    - Wintertime increase of surface layer pool of nutrients.
    - Permanent (burial, denitrification, anamox, sequestering) and more temporal (redox dependent) internal sinks.
- Relation to the ecosystem:
    - Eutrophication and climate
- Relation to acidification:
    - Eutrophication and climate

1.2 Model approaches and process parameterizations

- Introduction to biogeochemical models:
    - Books, other literature ...
    - Briefly categorise different types of models
        - Budget model, process based model, 1D and 3D model
    - Review of existing coupled physical-biogeochemical models of the Baltic Sea.

- State of the art and climate modelling:
    - Processes descriptions
    - Model performance. Evaluation results.
    - The concepts of climate and nutrient load scenarios and ensemble modelling.

2. Observations and modelling approaches

The aim of this section is to summarise in general terms an overview of the present knowledge and understanding about the marine biogeochemical cycles of nutrients and oxygen in the Baltic Sea and some basic concepts of how this understanding is introduced and described especially in the state-of-the art biogeochemical models that are used for climate modelling of the Baltic Sea. The discussions in this section does not take into account the biogeochemical cycling on geological time scales but is more concerned with processes that may be relevant on time scales shorter than about 200 years.

3. Organic matter production

3.1. Rates and controlling factors

The subchapter summarizes production of particulate organic matter in the Baltic Sea during the past 200 years, describes the incorporation of dissolved nutrients (mainly N and P) and the export (sedimentation) of organic matter from the euphotic zone.

3.1.1. Phytoplankton and primary production

- Brief overview of phytoplankton seasonal succession in the Baltic sea, role of spring bloom for sedimentation
- Overview of rates in different subbasins: primary production and sedimentation, historical changes (table with PP and sedimentation)

3.1.1.1. Spring bloom

- Diatom/dinoflagellate oscillations
- Impact of eutrophication and climate effects (stratification, river plumes) in observations and published biogeochemical models
- Grazing and sedimentation (zooplankton mismatch, mesocosm experiments, effect of bloom species composition on sedimentation)

3.1.1.2. Summer communities and cyanobacteria blooms

- Changes in summer phytoplankton biomass, species composition and primary production
  - Nutrient sources, new and regenerated production, climate and eutrophication effects
- Grazing and sedimentation of summer communities
  - Climate effect on zooplankton, microbial loop
- Cyanobacteria blooms
  - 200-year changes in bloom frequency
  - Climate effects (summer temperatures, salinity)
  - eutrophication (N/P ratios), P source for blooms
  - Importance as source of new nitrogen -> N fixation rates

3.1.1.3. Autumn blooms

- Eutrophication and climate effects (mixing/stratification)
- Species composition and sedimentation
- Zooplankton grazing

3.1.1.4. Organic matter production based on allochthonous DOM

- Bothnian Bay, incorporation of DOM in biomass, sedimentation
- Climate effects

3.1.2 The marine CO2 system

- Biological and physical control of the surface water CO_2 partial pressure (total CO_2): diurnal and seasonal cycles;
- The use of CO_2 measurements for production estimates;
- Variability of the pH and relationship between alkalinity and pH distributions;
- Spatial and seasonal distribution of calcium carbonate saturation;
- The effect of increasing atmospheric CO_2: ocean acidification;
- CO_2 gas exchange, the Baltic Sea: sink or source for atmospheric CO_2?

3.1.3. Nitrogen transformations

- Pathways of nitrogen transformations;
- Importance of nitrification;
- Denitrification rates: Incubation experiments, mass balance and model approaches;
- Contribution by anammox;
- Denitrification in the water column vs. denitrification in sediments;

3.1.4 Oxygen depletion and H2S formation

- Hydrographic causes for oxygen depletion
- Biogeochemical causes for oxygen depletion and H2S formation
- Oxygen conditions in historic times
- Oxygen depletion and eutrophication

3.1.5 Phosphorus transformations

- Organic phosphorus compounds in sediments: source, forms, amount
- Release of inorganic phosphate from organic forms: microbiological and abiotic degradation
- Other sources for dissolved inorganic phosphate in the sea floor
- Binding of dissolved inorganic and organic phosphorus into solid phases in sediments: different mechanisms, contributing elements, sorption surfaces, chemistry of the solution, effects of microbes and benthic fauna
- Release of phosphate from solid phases to dissolved form in sediments: different factors affecting the release; hypoxia, other elements, chemistry of the solution, microbes and benthic fauna
- The past changes in phosphorus transformations in the Baltic area
- The potential effects of environmental changes in the future on phosphorus transformations in the Baltic Sea sediments (*or in chapter 4?*)

3.1.6 Carbon, nitrogen and phosphorus burial in the sediments

- Cycling and burial of carbon, nitrogen and phosphorus are linked, general issues concerning sedimentation and burial of particulate material and the sedimentation environment in the Baltic Sea; effect of oxygen conditions, benthic fauna, microbial activity, sediment properties, salinity, inorganic particles
- Carbon: mechanisms of burial, buried forms in the sediments, methods used in determination of burial, current knowledge about carbon burial in the Baltic sediments
- Nitrogen: mechanisms of burial, buried forms in the sediments, methods used in determination of burial, current knowledge about nitrogen burial in the Baltic sediments
- Phosphorus: mechanisms of burial, buried forms in the sediments, methods used in determination of phosphorus burial, current knowledge about phosphorus burial in the Baltic sediments
- The past changes in burial of carbon, nitrogen and phosphorus in the Baltic area
- The potential effects of environmental changes on burial of carbon, nitrogen and phosphorus in the sediments (*or in chapter 4?*)

4. Response to potential future changes

4.1 Eutrophication

- Political legislations (reduction?)
- Economic development (increase?)
- Possible effects on biogeochemistry and oxygen
- increase atm. pCO2, changes in alkalinity

4.2 Acidification

4.3 Climate change

- response of BGC to changes in temperature, runoff, salinity

5.2.5 Marine ecosystems

Leader author: Markku Viitasalo

Contributing authors: Thorsten Blenckner, Anna Gårdmark, Lena Kautsky, Harri Kuosa, Martin Lindegren, Alf Norkko, Kalle Olli, Johan Wikner

Introduction and background

A brief review of main changes in knowledge re climate change and Baltic Sea since BACC I. We also explain which type of interactions and climate effects are included in the review.

Known system level variations and fluctuations in the Baltic Sea are reviewed, and their possible connections to climate change are evaluated. We also classify different indirect and direct impacts to those promoting individual-level, physiological and species-, population- and community level responses in the ecosystem.

Manifestations of climate change in the different ecosystem compartments

Indirect and direct influences and impacts of climate change on different ecosystem compartments are reviewed. The pelagic ecosystem, deep benthic ecosystem, sublittoral ecosystem and winter ecosystem are separately dealt with.

Analysis of effects of climate change on food web structure?

Observations and cause-effect relationships of trophic changes in the different Baltic Sea basins are reviewed. A special attention is paid to the influence of cliamte change on functioning of the microbial loop and their relationships to primary production in different baltic sub-basins.

Furthermore, we review and evaluate the evidence and reasons of possible cascading effects in the food chain, including the top predators (fish, seabirds and seals). The evidence for system-level regime shifts in the past few decades are also critically evaluated.

Modelling approaches to climate change

A review of the performance and reliability of ecosystem models is given. A special attention is given to the potential of various models to contribute to knowledge of the future effcts of climate change on the ecosystem of the Baltic Sea.

Summary and conclusions

A conceptual model of the effects of climate change on the ecosystem of the Baltic Sea is drafted and the strength and variability of the cause-effect links is evaluated. From the conceptual model we attempt to achieve a hypothesis on how climate change will affect the biogeochemical functioning and functional and species biodiversity of the Baltic Sea. Also, the main gaps in knowledge and issues of dissent are identified.

Finally, a brief account on potentially policy-relevant effects of climate change on the marine ecosystem is given.

5.3. Socio-economic impacts

5.3.1 Agriculture and forestry

Leader author: Michael Köhl

Chapter 5.3.1 Socio-economic impacts on agriculture and forestry

Prof. Dr. Michael Köhl (University of Hamburg, Department of Wood Science, Institute for World Forestry)

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Chapter Outline

Hypothesis

Climate change impacts the vulnerability and productivity of agricultural and forestry land use, predominantly by changes in precipitation, drought stress periods and potential natural disturbances. An increase of CO2 concentrations, mean temperatures and nitrogen disposals, on the other hand, is expected to lead to an increased ecosystem production and growth trends, especially in previous boundary zones with limiting climate conditions. Land use potentials will change as a consequence of those impacts, but as well as by adaptation and mitigation measures. Both impacts, climate change and human response, will have an effect on and change socio-economic conditions.

Main questions

What impact on land use structures (forestry and agriculture) is recorded / to be expected due to climate change? What uncertainties are related to those estimates?
What socio-economic consequences are to be related to those impacts?
What adaptation and mitigation measures are taken, what socio-economic impact can be related to those measures?

Goal

The assessment aims at a description of the current knowledge on the impact of climate change on land use structures of managed agricultural and forestry land and its socio
economic impacts. The Assessment is further extended on the impact of adaptation and mitigation measures insofar those and related impacts are based on scientific results – political intentions etc. are not considered.
The main emphasis is on managed land to avoid overlapping with chapter 5.2.2 Terrestrial ecosystems, which focuses on natural and semi-natural ecosystems

5.3.2 Urban complexes

Leader author: Sonja Deppisch

Authors: Deppisch, S.; Janßen, H.; Juhola, S.; Richter, M.; Vanhanen, H.

5.1 Introduction / Background
Will be written at the end – depending on Lead Author agreement of common chapter introductions or consistentsubchapter introductions (concerning content)

5.2 Past, current and future impacts of climate change on urban complexes

5.2.1 Vulnerability, potential Impacts, adaptation (still to be explored)
=> urban complexes as human dominated systems: future potential cc impacts are not given as negative / positive impacts yet as they are up to changes: adaptation measures might change vulnerability or might try to benefit from cc in urban complexes
=> What is considered as vulnerability, as impact, as adaptation? Negative / positive Impacts up to perspective (social differences / differences in interest)

5.2.2 Land-use (and further changes) and future climate change
Climate change is not the only phenomenon affecting the climate in urban areas of the Baltic Sea Region. Urban areas are influenced by their own climatic conditions by altering e.g. their radiation budget. Average temperatures rose due to urbanization in the 20th century in Uppsala (Bergström and Moberg, 2002), Stockholm (Moberg et al., 2002) and St. Petersburg (Jones and Lister, 2002). Furthermore, city growth, together with increasing heavy rainfall, can increase flood risks in urban areas like in Helsingborg (Semadeni-Davies et al., 2008a). Urban areas are usually characterized by higher temperatures than the surrounding countryside, this urban heat island effect was proved for various cities like Stockholm (Bolund and Hunhammar, 1999; Gustavsson et al., 2001; Moberg and Bergström, 1997; Moberg et al., 2002), Malmö (Bärring et al., 1985), Göteborg (Svensson, 2002) and Uppsala (Moberg and Bergström, 1997). Urban cold islands appeared, too, for example in Göteborg (Svensson and Eliasson, 2002). These effects are not unique over the entire urban area and depend on the urban land use. In Göteborg there are differences of up to 6,8 °C between land use categories (Eliasson and Svensson, 2003).

Further issues still to be explored:
Other changes in land-use patterns affecting climate change impacts in urban complexes (including adaptation measures) Climate change not the only driver for change in urban complexes, many further essential drivers for change urban complexes (demographic change, land-use changes, political changes etc.) and interacting with climate change impacts (also with cc impacts somewhere else as e.g. Stockholm is expecting high immigration rates)

5.2.3 Past, current and future impacts of climate change
5.2.3.1 Natural resources and ecosystem services (Henri Vanhanen)
The one and prominent feature of natural resources in urban areas are its green spaces. For residents these are places recreation from jogging to berry picking and simple relaxation. Though having a significant aesthetic and recreational value, urban woodlands, parks and roadside plantings produce a vast number of other ecosystem services beneficial for nature, human health and functionality of urban infrastructure. These green spaces offer ecosystem services such as biodiversity sheltering, reducing the effects of pollution, reducing noise, flood prevention by regulating runoff, water purification, prevention of erosion and carbon and nitrogen sequestration. Besides green spaces urban areas hold within its territory the same natural resources and ecosystem services as sparsely habited countryside: farmland, water supplies and fisheries.

Climate change will have direct physiological effects to urban green spaces (trees, plantings, and crop) through change in precipitation and temperature. Increased heat, drought and moisture stress can enhance the susceptibility to pathogens and pests. The predicted rise in average temperature will also favor both native and invasive pests that can increase into epidemic levels and alter the function of the ecosystem services whether they would be of urban woodlands or farmlands. Especially climate change will increase and enhance the survival of wide range of non-native invasive pests. Though climate change posses threats to urban ecosystem services the need for building land through demographic change will lead to land-use changes and thus fragmentation and decreasing of green spaces from urban areas.

Further potential issues still to be explored (SD, MR):
Potential impacts of sea level rise: In addition to the increase in erosion of natural shorelines in e.g. Tallin (Kont et al., 2003) and Pärnu (Hilpert et al., 2007), salt or brackish water can intrude into aquifers and contaminate groundwaters, this was showed for Gdansk (Staudt et al., 2006; Schmidt-Thomé et al., 2006) and Tallin (Hilpert et al., 2007). This will lead to problems in water supply of urban areas, in watering of green areas or cooling demand (Kundzewicz, 2009) and in drinking water supply (f.e. in Pärnu (EUCC, 2004), Porvoo (Virkki et al., 2006) and Gdansk (Staudt et al., 2006)). The danger of water contamination triggered by storm surges or heavy rainfalls will increase f.e. for Porvoo, Loviisa (Virkki et al., 2006) and Stockholm (Schmidt-Thomé et al., 2006; Meier et al., 2006). Sea level rise will also affect protected areas, recreational areas and open areas like parks in Gdansk (Staudt et al., 2006) Pärnu (Kont et al., 2008), (Klein and Staudt, 2006) and Porvoo and Loviisa (Virkki et al., 2006).

5.2.3.2 Urban services technology: Technical infrastructure and management (Sonja Deppisch, Michael Richter)
The climate change impacts which will affect technical infrastructure in most cases are expected to be sea level rise and the changing precipitation patterns, particularly flooding caused by expected increase in heavy precipitation events. As the net-sea level rise is expected to be higher in the southern Baltic Sea, cities like Gdansk will be more affected. Main infrastructures like dikes, port facilities, industrial areas, warehouses, transportation routes, drainage water systems and sewage plants as well as ground water recharge areas will be vulnerable (Schmidt- Thomé et al., 2006; Staudt et al., 2006). Industrial facilities including harbours will be affected in Gdansk (Staudt et al., 2006; Pruszak and Zawadzka, 2008; Schmidt-Thomé et al., 2006), Sczeczin and Kolobrzeg (Pruszak and Zawadzka, 2008), Tallinn, Pärnu, Kuressaare, Haapsalu, Kärdla, Sillamäe and Narva-Joesuu (Kont et al., 2008; Klein and Staudt, 2006) and when considering worst-case scenarios, Stockholm, too (Ekelund, 2007). Nevertheless, generally lower impacts (or later occurring impacts) of sea level rise can be expected in more northern Baltic cities like Stockholm (Graham et al., 2006; Meier and Broman, 2003; Viehhauser et al., 2006), Helsinki (Lehtonen and Luoma, 2006), Pärnu (Klein and Staudt, 2006) and Loviisa (Virkki et al., 2006). The expected increase of heavy precipitation (and: rapid snow melting) events could cause surface floods due to undersized urban drainage and sewage water systems such as in the cities Porvoo (Virkki et al., 2006), Loviisa (Virkki et al., 2006), Helsingborg (Semadeni-Davies et al., 2008b), Kalmar (Olsson et al., 2009), Lund (Niemczynowicz, 1989), Stockholm (Sverige, 2007) and Uppsala (Viehhauser et al., 2006).

Further issues still to be explored:
Inland cities in the Baltic Sea Basin: Droughts as threat
Inland / Coastal cities: Drinking water supply systems.
Energy, heating and communication infrastructure – power plants, utilities, lines, and systems (e.g. district heating; multi-utility tunnel systems as in Stockholm and Helsinki: metro, sewage, water, electricity, and telecom)

5.2.3.3 Buildings, housing, settlement structure (Sonja Deppisch, Michael Richter)
Sea level rise is the most important impact of climate change for settlement structures so far. In combination with eventually rising storm surges, there will not only be severe impacts to southern cities like Gdansk (Staudt et al., 2006). Housing facilities and residential areas will be at risk, too in Tallin (Hilpert et al., 2007) and Loviisa (Virkki et al., 2006). The settlements of cities like Helsinki (Lehtonen and Luoma, 2006) and Pärnu (Klein and Staudt, 2006) will possibly not or only be slightly affected by sea level rise.

Further issues still to be explored:
Storm surges and floods caused by strong precipitation events –impacts on buildings, settlement structure (some parts of towns threatened by flooding on a regular basis)
Inland-cities in the Baltic Sea Basin: Urban heat island (UHI) and building / settlement structure / size of cities (small, medium-sized, big)

5.2.3.4 Human health and well-being (Sonja Deppisch, Michael Richter)
The impacts of climate on human health and well-being are diverse. Even if cold stress seems to be more important in countries like Sweden (Svensson et al., 2003), with a changing climate heat stress and the demand for cooling in houses, health-care institutions, schools and work places is expected to increase during the summer for example in Gothenburg (Svensson et al., 2003; Thorsson et al., 2011) and Stockholm (Baccini et al., 2011; Rocklöv et al., 2009). Positive effects on human health could be expected through milder winters and accompanying less cold stress in cities like Oslo (Nafstad et al., 2001). Other health-related effects of climate change in cities will be changes in air quality (Eliasson and Holmer, 1990) and for example increasing incidence of tick-borne encephalitis in endemic regions in Stockholm County (Lindgren, 1998).

Further issues still to be explored (SD, HV):
UHI-effect and warming climate – coastal cities and inland cities;
Mainly affected social groups - Effect of heat (summer) on well-being and comfort in cities (urban heat island effect), effect on health and mortality in general and on specific social groups mosquito transmitted diseases e.g. Chikungunya, which caused epidemic in the northern Italy. They have a great potential to cause seasonal epidemics even in northern parts as they are frequently transported from tropics to Europe with floral trade.

5.2.3.5 Socioeconomic structure (Sirkku Juhola, Holger Janßen)
1. Review of studies on impacts of climate change on different sectors of the urban economy
2. Review of studies on impacts of climate change on urban population, vulnerability of particular sectors of society
3. Review of adaptation strategies of urban areas/cities in the Baltic Sea basin.
Climate change will have impacts on the socio-economic structures in the cities around the Baltic Sea. The number of studies on the impacts of climate change on different economic sectors is slowly increasing, and this section will review and analyse the literature on the different sectors, such as industry, fisheries, maritime traffic and ports and recreational economy and tourism. Cities around the Baltic Sea have begun to pursue adaptation strategies of which aim is to prepare the cities to the impacts of climate change. This part reviews the available studies of urban adaptation strategies in the Baltic Sea basin.

Further issues still to be explored:
Insurance and adaptation in cities

5.3 Synthesis / Conclusion: Impacts of climate change on urban complexes
- Main lines of argumentation to be found in the literature – agreements
- Disagreements

 Lacking research
 Missing links

References

Baccini, M., Kosatsky, T., Analitis, A., Anderson, H.R., D'Ovidio, M., Menne, B., 2011. Impact of heat on mortality in 15 European cities: attributable deaths under different weather scenarios. Journal of Epidemiology & Community Health (65), 64–70.

Bärring, L., Mattsson, J.O., Lindqvist, S., 1985. Canyon geometry, street temperatures and urban heat island in Malmö, Sweden. Journal of Climate 5, 433–444.

Bergström, H., Moberg, A., 2002. Daily Air Temperature and Pressure Series for Uppsala (1722-1998). Climatic Change (53), 213–252.

Bolund, P., Hunhammar, S., 1999. Ecosystem services in urban areas. Ecological Economics (29), 293–301.

Ekelund, N., 2007. Adapting to Climate Change in Stockholm. City of Stockholm, Environment and Health Administration, 36 pp. Accessed 10 November 2010.

Eliasson, I., Svensson, M.K., 2003. Spatial air temperature variations and urban land use - a statistical approach. Meteorological applications (10), 135–149.

Eliasson, I., Holmer, B., 1990. Urban Heat Island Circulation in Göteborg, Sweden. Theoretical and Applied Climatology (42), 187–196.

EUCC, 2004. Managing the Baltic Sea: Coastline Reports 2, 4, 5, 6, 12.

Graham, L.P., Andreasson, J., Persson, G., 2006. Impacts of future climate change and sea level rise in the Stockholm region: Part 1 - The effect on water levels in Lake Mälaren. Special Paper. Geological Survey of Finland (41), 131–141.

Gustavsson, T., Bogren, J., Green, C., 2001. Road climate in cities: A study of the Stockholm Area, South-East Sweden. Meteorological applications (8), 481–489.

Hilpert, K., Mannke Franziska, Schmidt-Thome, P., 2007. Towards climate change adaptation strategies in the Baltic Sea Region: Developing policies and adaptation strategies to climate change in the Baltic Sea region. Geological Survey of Finland, Espoo, 16 pp. http://www.gsf.fi/projects/astra/sites/download/ASTRA_Policy_Paper_web.pdf. Accessed 7 September 2010.

Jones, P.D., Lister, D.H., 2002. The Daily Temperature Record for St. Petersburg (1743–1996). Climatic Change (53), 253–267.

Klein, J., Staudt, M., 2006. Evaluation of future sea level rise impacts in Pärnu / Estonia, in: Schmidt-Thomé, P. (Ed.), Sea level change affecting the spatial development in the Baltic Sea Region (Seareg), pp. 71–81.

Kont, A., Ratas, U., Rivis, R., Jaagus, J., Aunap, R., 2008. Implications of sea-level rise for Estonia. Journal of Coastal Research 24 (2), 423–431.

Kont, A., Jaagus, J., Aunap, R., 2003. Climate change scenarios and the effect of sea-level rise for Estonia. Global and planetary change 36 (1), 1–15. http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6VF0-45W366R-1-D&_cdi=5996&_user=5191549&_pii=S0921818102001492&_orig=search&_coverDate=03%2F31%2F2003&_sk=999639998&view=c&wchp=dGLzVzzzSkzk&md5=8bf0d5416d9623b2ec441321c283f4f7&ie=/sdarticle.pdf.

Kundzewicz, Z.W., 2009. Adaptation to floods and droughts in the Baltic Sea basin under climate change. Boreal Environment Research 14 (1), 193–203.

Lehtonen, S., Luoma, S., 2006. Incorporating sea level rise scenarios in Helsinki City planning, in: Schmidt- Thomé, P. (Ed.), Sea level change affecting the spatial development in the Baltic Sea Region (Seareg), pp.83–94.

Lindgren, E., 1998. Climate change, tick-borne encephalitis and vaccination needs in Sweden—a prediction model. Ecological Modelling (110), 55–63.

Meier, H.E.M., Andréasson, J., Broman, B., Graham, L.P., Kjellström, E., Persson, G., Viehhauser, M., 2006. Climate change scenario simulations of wind, sea level, and river discharge in the Baltic

Sea and Lake Mälaren region – a dynamical downscaling approach from global to local scales. SMHI Reports Meteorology and Climatology 109, Norrköping, 68 pp. http://www.smhi.se/sgn0106/if/biblioteket/rapporter_pdf/RMK109.pdf. Accessed 17 September 2010.
Meier, M., Broman, B.K., 2003. Simulated sea level in past and future climate of the Baltic Sea. Rossby Centre, Swedish Meteorological and Hydrological Insitute, Norrköping.
Moberg, A., Bergström, H., Ruiz Krigsmann, J., Svanered, O., 2002. Daily Air Temperature and Pressure Series for Stockholm (1756 - 1998). Climatic Change (53), 171–212.
Moberg, A., Bergström, H., 1997. Homogenization of Swedish temperature data. Part III: the long temperature records from Uppsala and Stockholm. International Journal of Climatology 17, 667–699.
Nafstad, P., Skrondal, A., Bjertness, E., 2001. Mortality and temperature in Oslo, Norway, 1990–1995. European Journal of Epidemiology 17, 621–627.
Niemczynowicz, J., 1989. Impact of the greenhouse effect on sewerage systems—Lund case study. Hydrological Sciences Journal 34 (6), 651–666.
Olsson, J., Berggren, K., Olofsson, M., Viklander, M., 2009. Applying climate model precipitation scenarios for urban hydrological assessment: A case study in Kalmar City, Sweden. Atmospheric Research (92), 364–375.
Pruszak, Z., Zawadzka, E., 2008. Potential implications of sea-level rise for Poland. Journal of Coastal Research 24 (2), 410–422.
Rocklöv, J., Forsberg, B., Meister, K., 2009. Winter mortality modifies the heat-mortality association the following summer. European Respiratory Journal 33, 245–251.
Schmidt-Thomé, P., Viehhauser, M., Staudt, M., 2006. A decision support frame for climate change impacts on sea level and river runoff: case studies of the Stockholm and Gdansk areas in the Baltic Sea region. Quaternary international (145-146), 135–144. http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B6VGS-4H877JR-1-F&_cdi=6046&_user=5191549&_pii=S1040618205001205&_orig=search&_coverDate=03%2F31%2F2006&_sk=998549999&view=c&wchp=dGLbVlzzSkzV&_valck=1&md5=85efba9f5beccdcf8bd371e95252a1ca&ie=/sdarticle.pdf.
Semadeni-Davies, A., Hernebring, C., Svensson, G., Gustafsson, L.G., 2008a. The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Suburban stormwater. Journal of hydrology (350), 114–125.
Semadeni-Davies, A., Hernebring, C., Svensson, G., Gustafsson, L.G., 2008b. The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Combined sewer system. Journal of hydrology (350),100–113.
Staudt, M., Kordalski, Z., Zmuda, J., 2006. Assessment of modelled sea level rise impacts in the Gdansk region, Poland, in: Schmidt-Thomé, P. (Ed.), Sea level change affecting the spatial development in the Baltic Sea Region (Seareg), pp. 121–130.
Svensson, M.K., 2002. Urban Climate in Relation to Land Use, Planning and Comfort. Doctoral Thesis, Göteborg.
Svensson, M.K., Thorsson, S., Lindqvist, S., 2003. A geographical information system model for creating bioclimatic maps – examples from a high, mid-latitude city. International Journal of Biometeorology (47), 102– 112.
Svensson, M.K., Eliasson, I., 2002. Diurnal air temperatures in built-up areas in relation to urban planning. Landscape and Urban Planning (61), 37–54.
Sverige, 2007. Sweden facing climate change: Threats and opportunities ; final report from the Swedish Commission on Climate and Vulnerability. Fritze, Stockholm, 679 pp.
Thorsson, S., Lindberg, F., Björklund, J., Holmer, B., Rayner, D., 2011. Potential changes in outdoor thermal comfort conditions in Gothenburg, Sweden due to climate change: the influence of urban geometry. International Journal of Climatology 31, 324–335.

Viehhauser, M., Larsson, K., Stalnacke, J., 2006. Impacts of future climate change and sea level rise in the Stockholm region: Part II - GIS analysis of future flooding risks at regional and municipal scales. Special Paper. Geological Survey of Finland (41), 143–154.
Virkki, H., Orenius, O., Kallio, H., 2006. Sea level rise and flood risk assessment in Itä-Uusimaa. Special Paper. Geological Survey of Finland 41, 95–106.

5.3.3 Coastal erosion and coastline changes

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Plan of the chapter:

1. Factors influencing coast development
2. Development and types of Baltic Sea coasts
3. Processes shaping coastal areas
   Sediment transportation
   Accumulation and progradation
   Erosion and retreat
4. Coast response for climatic changes
5. Socio-economic response for coast erosion

Summary

The coastal zone is one of the most dynamic environments, where natural factors such as storm surges, water level fluctuations, wind force or plant existence are the result of climate conditions. Among them the leading role is played by the sea level change and storm waves. These two factors are responsible for coastal land erosion and accumulation, as well as the emergence of beaches and their variability. On the other hand, human activity in coastal areas is forced by climatic events affecting settlement and local economy. The climatic changes and their influence on the environment are a fact. The natural or anthropogenic elements of it often show surprising changes, not comparable with the earlier observations. Coasts are mainly vulnerable to extreme events.

Factors affecting coastal relief and geomorphology are influencing also each other. Their intensity depends on season (producing by different weather). Winds are stronger during autumn-spring period. Sea waving is stronger during autumn-winter period that is caused by weather fronts coming from west to east (mainly). Plants grow from spring to summer. Human impact is bigger during summer vacations.

On the South Baltic coast there are two typical coastal land profiles: dune and cliff. Dune profile shows dune ridge or ridges of height 5 to mainly 12 m amsl (above mean sea level). Typical cliff coast profile shows cliffed moraine relief with height from several to hundred meters.. Angle of the cliff slope vary due to different material building moraine: clay, till or sand deposits. Te top of the cliff have different height: covered by hillocks or depressions shaped by glacifluvial waters.

In the northern part of Baltic, in Estonia, Sweden or Finland coasts are also made by rocks, softer like limestone or harder like sandstone or igneous. On this part of Baltic coast there has been a land growth in connection with the isostatic movements uplifting Scandinavia.

Coasts are experiencing the adverse consequences of hazards related to climate change and mainly with sea level fluctuations. The impact of climate change on coasts is exacerbated by increasing human activities impacts.

Adaptation costs for climate change are much lower than damage costs without any adaptation. But right now lokla society is mainly prepared for so far known and measured extreme events. Only a few local administrations targeted towards increasing the risks

The valuation of costs and benefits of climate change for the coast is difficult because some climate change impacts are difficult to assign a value. Also impacts, on human activities or health and natural biodiversity, are difficult to value.

Some countries will have benefits from future climate change but others lose out, there is no guarantee how changes may affect on local coastal economy.

There are proposed two types of actions in management strategies. The first one strategy called hold on coastal line should prepare protection of coast and neighborhood areas for future coastal changes. The second one, more resilient and dependent on human adaptation for coastal changes areas says that, in some places coast should be not protected and left as possible in natural way. It may help in protection due to natural process inflow on coastal land.

Of course it is more complicated because of local authorities respond for coastal management may have other point of thinking in relation of coastal development and its protection against erosion. Also it is worth to remember that administrative borders in coastal areas and efforts made for it stabilizations are different in Baltic countries and even may vary in bordering lands. Some of these action are complicating morphodynamics changes due to artificial coast stabilization in one place and its natural progress in other. Coast is one linear environment that knows no national and decision-making boundaries.

On the other hand, the coastal zone is a very dynamic environment. The land's height position may be changing rapidly due to natural processes. Nowadays we mainly observe the retreat of the land due to storm surges and sea level increase. This development requires infrastructure for higher coastal protection.

Figs: maps of coast types and its dynamics, profiles of coastal relief and its changes, map or profile of typical human impact.
Any photos?
Literature:

Chapter 6. Attributing causes of regional climate change

6.1. Introduction and summary

6.2. Global warming

Leader author: Jonas Bhend

Summary

Most of the observed global warming over the second half of the twentieth century has been attributed to anthropogenic influence – mainly increasing atmospheric greenhouse gas concentrations. In this section, we assess whether the influence of the factors causing global warming can be identified as causing regional climate change in the Baltic Sea area as well. The last assessment of climate change in the Baltic Sea (the BACC author team, 2008) identified a lack of regional studies that can robustly attribute recent trends in climate to increased greenhouse gases. Since the last assessment, a few such studies have become available.

Summertime near-surface warming in northern Europe has been detected to exceed natural internal variability of the climate system and has been attributed to anthropogenic influences. Furthermore, there is evidence of an increasing likelihood of very warm seasons in northern Europe due to human influence in all seasons. The attribution of recent warming to anthropogenic influence is further supported by various studies using continental to global constraints and looking at different aspects of the warming such as extreme temperatures, growing-season length and the onset of spring. In addition, the observed warming in the Baltic Sea area is found to be consistent with the anthropogenic signal derived from model simulations.

Circulation in the northern hemisphere – the North Atlantic Oscillation in particular – strongly affect weather and climate in the Baltic Sea area. A human influence on global sea-level pressure changes has been detected, however, it is also found that models underestimate observed circulation changes especially in the northern hemisphere.

No formal detection and attribution study for regional precipitation in northern Europe is available so far. Anthropogenic influence on observed changes in precipitation has been successfully detected at the global scale, in the Arctic and in northern midlatitude precipitation extremes. Consistent with the assessments of circulation changes, climate models are found to underestimate observed precipitation changes as well. Correspondence of observed and simulated changes in precipitation increases after removing the effect of the major mode of circulation variability.

Attribution of changes in physical properties of the Baltic Sea such as changes in salinity or ocean heat content to human influence has not yet been achieved. Reconstructed salinity and integrated temperature changes for the past 500 years, however, suggest that the most recent changes are not exceptional in the light of historic variability.

The assessment of what caused recent observed change is obviously conditional on our understanding of the climate system. The deficiencies in reproducing observed changes in circulation and precipitation in present-day climate models point to gaps in our understanding. To what extent the lack

of understanding of regional circulation changes affects attribution of recent warming to human influence is still a matter of debate, but evidence accumulated so far suggests that warming can be robustly attributed to human influence in summer. Furthermore, additional information on the effect of locally important forcing mechanisms such as aerosols and land-use changes will affect attribution results. Therefore, the here presented evidence for an emerging anthropogenic signal at the regional scale has to be revisited periodically in the light of new findings.

6.3. Aerosols (natural and pollutants)

Leader author: Hans-Christen Hansson

Intro

It's a little unclear to me but I think the intention that each of the subchapters should focus on the possible influence on the regional climate by their respective topic. The Intro should then probably be used to describe the structure and content of the chapter, i.e. subchapters, and give some of the major conclusions. I guess we also have to come up with some statement on the importance of Global warming, Aerosols and Land use in the development of the regional climate.

a) Global warming (JB)
b) Aerosols (HCH)
c) Land use and resource management M-J L-G

Outline subchapter Aerosols

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- Aerosols, The basics about aerosols and climate
  - Influence on climate
  - Sources
  - Formation in the atmosphere
  - Direct effect
  - Aerosol – Cloud Interaction
  - Indirect effects
  - The total aerosol climate effect and climate sensitivity

- Aerosols and Air quality
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  - Convention of Long Range and Transboundary Air Pollutants (CLTRAP)
  - Influence on the Baltic region

- Air Quality and Climate globally
  - Air pollutants both heat and cool the climate
  - Major anthropogenic climate forcing components
  - Co beneficial mitigation of Air Quality and Climate change

- Regional climate influence of natural and anthropogenic aerosols and other air pollutants
  - Regional emissions of climate forcing air pollutants during the last 50 years
  - Observed and possible climate effects
  - Future emission changes and resulting AQ and CC effects

Summary

The effects of atmospheric aerosols on climate are emphasized in the 4th assessment by IPCC (2007). The aerosols affect the present climate through a set of different processes. Aerosols both cool and

heat the climate, direct cooling by scattering sun light back to space and indirectly by affecting the albedo and increasing the life time of clouds. Certain aerosols heat the climate, e.g. soot, by absorbing the sun light thus heating the surrounding atmosphere and through decreasing the life time of the clouds. However it is many different atmospheric processes involving particles that have a potential effect on climate. These processes and their influence on climate are in most cases not well known.

This lacking knowledge gives not only a fairly large uncertainty in determining present climate influence of the aerosols but also the future climate effect of increasing greenhouse gases, e.g. CO_2. The reason is the present uncertain influence of aerosols makes it difficult to estimate the influence of the present greenhouse gases. This information is crucial in determining how much increasing CO_2, e.g. at a doubling of the natural CO_2 concentrations, 550 ppm, will heat the future climate. The expected increase in global temperature at a doubling of the CO_2 concentration will according to the IPCC most likely be in the range of +1.5 – +4.5^{o}C. The IPCC report further stated that it was ‘‘very unlikely’’ (less than 5% probability) that the climate sensitivity is less than 1.5 ^{o}C, but was unable to recommend a corresponding very unlikely upper bound to the estimate, stating rather that on the basis of present understanding values greater than 4.5 ^{o}C could not be excluded. This uncertainty is clearly dominated by the lacking knowledge of the influence of the aerosol on climate (Schwartz et al., 2010).

The natural atmospheric super micron aerosol originates mainly from sea spray and from the large arid areas and deserts while the submicron aerosol mainly is secondary originating from nucleation processes forming new particles that grow in size by condensable gases and in interaction with clouds and cloud water chemical processes. Anthropogenic emissions are mainly adding to the submicron aerosol and have increase the total submicron aerosol globally seen with a factor 2-3 (Kiehl and Rodhe, 1995). The submicron aerosol dominate climate influencing processes as light scattering and cloud formation processes implying a substantial influence of anthropogenic aerosols.

Airborne particles affect human health and is presently the major air pollution effect, e.g. from economical point of view. The magnitude of this is illustrated by the number of premature deaths which has been estimated to about 300 000 per year in the EU (WMO, 2002). The long distance transported share of particulate matter reach often more than 50% in big cities in central Europe and dominate the mortality effects, e.g. long distance transported aerosols causes more than 2/3 of air pollution induced premature deaths in Sweden (Forsberg et al, 2005). Other air pollutants as ozone has besides considerable health effects also damage crops and forests.

Particles, including black carbon and ozone, are called Short Lived Climate Forcing components (SLCF) due to their relatively short life time in the atmosphere, thus affect the closest region, and are air pollutants and affects climate. Concerning these pollutants abatement will thus affect climate. Climate change mitigation will in turn affect air quality. This implies that an integrated air quality and climate change abatement policy is needed for a cost effective mitigation (Amann et al. 2008).
SLCFs impact the region where they are emitted or formed. Particles typically have a life time of up to a week giving them a transport distance of mostly less than 2000 km. Ozone is a hemispheric pollutant as it has a life time of about a month. If the global climatic influence of particles and ozone is as estimated by IPCC the regional climate effect probably is considerable to cause such global impact. The sulfur emissions in Europe was about 50 Mtons/y 1980, at that time estimated to about 20% the global anthropogenic sulfur emission. The European emission has decreased more than 80%. So far the only effect reported is decreased occasions of observed fog with more than 50% (Vautard et al., 2009). Still regional climate models are not able to describe the effect of regional SLCF’s.

6.4. Land cover and resource management

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Chapter summary pending

1. Introduction
    keywords: short chapter summary, definitions etc.

2. Feedbacks between land surface and atmosphere
keywords: describing the mechanisms
    2.1 Radiation and energy balance
keywords: available net radiation, energy usage, sensible and latent heat fluxes
    2.2 Feedbacks
        2.2.1 Biophysical feedbacks
            keywords: albedo, hydrological cycle feedbacks
        2.2.2 Biogeochemical feedbacks
            keywords: carbon sources/sinks

3. Historical land cover changes and feedbacks
keywords: provide “evidence of the existence of feedbacks”, natural vegetation changes, anthropogenic land use changes
    3.1 Natural vegetation changes
    3.2 Land use changes

4. Potential future trends in land cover and associated feedbacks
    4.1 Resource management
keywords: changes in policies, decision making in agriculture/forestry sectors, water resource management
    4.2 Future land cover change scenarios
    4.3 Biophysical feedbacks
    4.4 Biogeochemical feedbacks

1. Introduction

This chapter seeks to review our current understanding of land cover changes, both in terms of land use and natural vegetation changes, and how these land surface dynamic processes influence regional climate change in the Baltic Sea Basin.

Understanding of land cover-climate feedbacks has increased over the last decade through sensitivity studies with global Earth System Models (ESMs) (IPCC, 2007). Since the mechanisms involved in, especially, biophysical feedbacks are governed by regional mechanisms, the use of regional climate and vegetation models could potentially identify feedbacks not captured at the course resolution of global models. For the Baltic Sea region such studies are few to non-existing, but within the scope of Europe some studies are available. These studies,however,address the role of potential natural vegetation changes but are important contributors to the understanding of the underlying terrestrial and atmospheric processes and are thus valuable in terms of exploring the climatic sensitivity to land cover changes. Natural ecosystem responses to climate are however comparably slow and the resulting feedbacks identified in available regional modelling experiments are often weaker than those feedbacks identified in global studies, many of which, however, are based on the assumption of extreme shifts in vegetation cover (e.g. Bala et al., 2007).A growing number of regional future land use scenarios (predominantly over Europe rather than purely focusing on the Baltic Sea region) enable a more realistic approach to explore the role of land cover changes in regional climate change.

2. Feedbacks between land surface and atmosphere

Radiation and energy balance (Patrick Samuelsson):

Changes in land use and resource management are important contributors to regional climate change since they determine the land cover and thus influence the interaction between the land surface and the atmosphere both in terms of radiation and energy balance.In addition, climate induced natural vegetation changes may cause feedbacks to climate, especially in the boundary zones between the major biomes (e.g. the tundra-boreal forest ecotone). The physical properties of the land surface and the underlying terrestrial processes interact with the lower atmosphere according to the following principles:

Biophysical feedbacks (Anna Wramneby, Thomas Kleinen):

Vegetation related feedbacks to climate are categorized into two subgroups 1) biophysical feedbacks related to structural changes in the vegetation and 2) biogeochemical feedbacksrelated to terrestrial carbon sinks and sources (Findell et al., 2007). In terms of attributing causes to regional climate changes the biophysical feedbacks are of particular interest since these exert a direct measurable effect on regional climate. Biogeochemical feedbacks are more relevant for the global climate due to the quickly dissolving characteristics of CO2 in the atmosphere and can therefore be regarded as having an indirect effect on regional climate. Here we focus on our current understanding of the direct effect of biophysical feedbacks and future trends in these feedbacks associated with changes in land use and resource management. However, it is important to remember that many of the socio-economic factors controlling future land use policies take the indirect biogeochemical processes rather than the direct biophysical ones into consideration (Jackson et al., 2008). The reason for this is presumably the numerous research studies available on CO2 and its role in global climate and terrestrial change. In other words, our current understanding of land cover changes and their biophysical feedbacks in regional climate change is limited in comparison to the large scale carbon cycle feedbacks.

Albedo feedbacks

The albedo can be defined as the proportion of the incoming solar radiation reflected by a surface. As such the albedo influences the energy available at the land surface. The sharpest contrast in the albedo would be between open land and forested areas, especially in the presence of snow since snow would be completely exposed on open land but partly covered in a forested area (the snow masking effect).Since the albedo feedback under these circumstances has been shown to be of significant magnitude (Bala et al., 2007) even the slightest change in species composition or land management in terms of forest thinning could give rise to important albedo feedbacks (Vesala et al., 2005).

Hydrological cycle feedbacks

Hydrological cycle feedbacks are related to structural changes in the vegetation in terms of changes in Leaf Area Index (LAI, the ratio of one-sided foliar area to the ground area covered), roughness length and rooting depth. Whereas LAI influences the amount of interceptive water and energy usage at the land surface partitioned into sensible and latent heat, the roughness length affects the turbulent mixing of the heat fluxes to the atmosphere. Rooting depth is important since a deeper and/or more extensive root system makes it easier to extract soil water. A comprehensive vegetation cover also reduces runoff.In environments where neither temperature nor water limits vegetation growth, the vegetation present tends to flourish, which increasesboth LAI and the roughness of the surface. Since the vegetation recycles or transpires water through the leaf stomata, increasing LAIs are also associated with an increasing evapotranspiration,which results in a larger fraction of the surface-atmosphere energy flux being partitioned into latent heat at the expense of sensible heat. Sensible heat warms the atmosphere close to the vegetation surface, whereas latent heat is stored in the released water vapour and warms the atmosphere first when condensation occurs, typically some distance away and further up in the atmosphere. The hydrological cycle feedback associated with a strong evapotranspiration is therefore a dampening effect on local to regional temperatures since more energy is needed in the process of vaporization.An increasing roughness length would then tend to emphasize the feedback through increased turbulent mixing in the atmosphere.

3. Historical land cover changes and feedbacks

Natural changes (Mari-José Gaillard):

For obvious reasons current and future trends in vegetation-climate feedbacks are to a large extentcontrolled by/a consequence of human induced land use changes (). Pre-historic climate changes may however to a significant effect also have been attributed tonatural vegetation changes. Studies of historic and pre-historic vegetation related changes in regional climate also provide important evidence of the existence of a land cover-climate feedback system.

Land use changes (Anne-Birgitte Nielsen):

4. Potential future trends in land cover and associated feedbacks

Resource management (Johan Bergh):

Bindi and Olesen, 2011: The responses of agriculture in Europe to climate change
Anderson et al., 2011: Biophysical considerations in forestry for climate protection

Future land cover change scenarios and associated feedbacks (Anna Wramneby + Thomas Kleinen):

Globally, a number of future land use change scenarios have been explored and over the recent decades regional scenarios have emerged for different parts of the world (Alcamo et al., 2008). Regional studies pinpointing future changes in the Baltic Sea region arevery limited, but over the European domain a growing number of future land use scenarios are becoming available. The difficulty in moving focus from global to regional future land use scenarios lies in the variety of possible outcomes since more details and locally specific questions need to be considered at the regional scale (Carter et al., 2007; Alcamo et al., 2008; Metzger et al., 2010).

As concluded in the 1st Assessment Report of Climate Change for the Baltic Sea Basin - BACC I (Smith et al., 2008), future land use trends in Europe are associated with comparably rapid technological progress suggesting that the required food production will be sustained by a smaller agricultural land fraction. Abandoning agricultural land enables reforestation in large areas and this is also the current and future general trend according to available land use scenarios in Europe (e.g. Rounsevell et al.,2006).The general future land use trend in Europe could be assumed to be applicable also for the Baltic Sea region although a few studies conversely have indicated a sustained or even an expansion in the agricultural fractionfor some of the Baltic Sea countries (e.g. Denmark and Finland inAudsley et al., 2006). The feedbacks to climate from such regional land use changes are to a large extent relativelyunexplored. Biogeochemical feedbacks from regional land use changes have been discussed in the concept of global climate change in some studies (Carter et al., 2007; Rounsevell andReay, 2009) but the direct biophysical feedbacks in relation to expected land use changesare yet to be addressed.

A wide range of global land cover-atmosphere modelling experiments have been performed over the last decades to infer the role of land surface dynamics both in terms of CO2 exchange and biophysical factors. The majority of these studies have however either explored the role of extreme shifts in land cover (Bala et al., 2007) or investigated the role of potential natural vegetation changes (). Global modelling also implies a grid resolution far larger than the scale necessary to capture local to regional processes (Hibbard et al., 2007). Since the biophysical feedbacks are likely to play a more dominant role in regional rather than global climate change, our understanding of the underlying mechanisms and what to expect regionally in the future is only starting to emerge.

Biophysical feedbacks to the regional climate mean state

Studies of potential natural vegetation changes and their biophysical feedbacks to regional climate give some indications of what to expect in the future since the underlying mechanisms are likely to be similar for natural vegetation and land use vegetation. For the European domain such studies of future biophysical feedbacks from potential natural vegetation changes point in the direction towards a boreal tree line advance into the tundra regions in northerly regions (Barents Sea region: Göttel et al., 2008; Europe: Smith et al., 2010; Wramneby et al., 2010). The most significant feedback associated withthe forest expansionat these northerly latitudeswould be the well-known albedo feedback in terms of an albedo reduction, which also (at least according to a number of global studies (Betts, 2000; Bala et al., 2007))is presumed to be strong enough to offset the climate gains from increased carbon sequestration. The albedo effect would be most significant in winter and spring when forests mask snow causing an additional regional temperature rise. The feedback loop becomes strengthen as an even warmer climate and an extensive snowmelt also indicate an earlier and longer growing season, which in turn promotes further forest expansion.

While the albedo feedback and its amplifying effect on climate warming is expected to be the most important biophysical feedback in boreal regions (Strengers et al., 2010) such as northern Europe, alarger forest fraction also implies a contrasting biophysical feedback mechanism in terms of enhanced evapotranspiration. This feedback may however be of minor importance for the boreal forests dominated by needleleaved evergreens since these forests are associated with a comparably weak evapotranspiration rate(Bonan et al., 2008). For the part of the Baltic Sea region that falls within the boundaries of a more temperate climate,the role of evapotranspiration might however be of greater importance because of the dominance of broadleaved deciduous forests although some disagreement prevails about the role of temperate forests in climate change (South et al., 2011).Significant feedbacks from such changes in thehydrological cycle were for example identified in Wramneby et al. (2010), who applied the regional climate-vegetation model RCA-GUESS (Smith et al., 2010) over Europe to investigate the role of long-term vegetation-climate feedbacks from future greenhouse forcing to changes in mean climate. In central Europe CO2 fertilization and increased water use efficiency caused vegetation to respond positively, increased leafiness (higher LAI) enhancing evapotranspiration and mitigating regional climate warming. The hydrological cycle feedback in central Europe sharply contrasted the response in southern Europe, where significant future warming and reduced precipitation restricted plant growth and survival. The drier future summers, predicted in southern Europe, were associated with a decline in LAI due to soil water limitation and reduced evapotranspiration amplifying regional climate warming.

Given that the majority ofavailable future land use scenarios at the European scale point in the direction towards increasing fractions of forested areas in parallel with a reduction in agricultural land, proposesthat the resulting feedback syndromes could be similar to those identified above. This would imply a positive (warmer climate) albedo mediated feedback in winter when previously snow covered agricultural land becomes replaced by snow masking forested areas and at least potentially a negative (colder climate) feedback from an enhanced hydrological cycling in summer due to higher LAIs.The biophysical feedback effects on precipitation and cloudiness over Europe are less clear. Wramneby et al. (2010)was for example not able to find any evidence that variations in cloudiness and precipitation over Europe could be attributed to vegetation dynamics. The lack of any established relationship between an increased/reduced evapotranspiration and precipitation and cloud formation over Europe could be attributed to the fact these are strongly determined by Atlantic convection. This may tend to overwhelm any feedback signal from vegetation-mediated changes in evapotranspiration. Also, the ratio between sensible and latent heat exerts strong local control on temperature, but effects on cloud formation and precipitation will take place at the site of condensation, further away and higher up in the atmosphere, diffusing the signal (Wramneby et al., 2010).Incorporating the role of likely land use scenarios might however strengthen the feedbacks identified so far and potentially also discover feedbacks syndromes in precipitation and cloudiness.

Biophysical feedbacks to regional climate variability

The long-term effects of biophysical feedbacks on regional climate change may very well go in line with the features suggested above. Future land cover changes are however not only interesting in terms of feedbacks to the regional mean climate state. Recent studies have emphasized the role of feedbacks in climate variability and have shown that thatland cover-climate feedbacks might behave very differently from those feedbacks expected in the long-term. Although changes in land use are often considered as non-climatic causes to increased climate variability, a growing number of studies have also been able to show that processes at the land surface may contribute to increased climate variability through direct land surface feedbacks. Such direct biophysical feedbacks to climate were for example shown in Seneviratne et al. (2006),who performed a suite of climate sensitivity model simulations with and without soil moisture responses to infer the role of the land surface, attributing a substantial fraction of the future temperature variability in Europe to land surface processes mediated by soil moisture feedbacks.In one aspect, climate variability gives us a better understanding of climate change, since the concrete consequences already have been observed through recent years extreme climate events in terms of floods and droughts. For the European domain, and certainly relevant also for the Baltic Sea countries, such events have already had severe consequences (Della-Marta et al. 2007).A subsequent study, about the role of land cover-atmosphere feedbacks as explanatory factors behind recent European climate variability, has recently revealed the possibility that the climate beneficial long-term cooling effects from forests maintaining a reasonable evapotranspiration rate as compared to open land could be reversed at least in the beginning of a heat wave (Teuling et al., 2011). By comparing eddy flux tower measurements from the European FLUXNETsites,Teuling et al. (2011) could show that the evapotranspiration from water conservative forests is significantly less in comparison to open land in the initial state of a heat wave. Conversely, as the heat wave continues soil moisture depletion prevents further cooling over open land whereas forests can continue to cool the atmosphere.

Summary

This chapter sought to review our current understanding of land cover changes as a cause to regional climate change in the Baltic Sea Basin. The main findings are as follows:
Biophysical land cover-atmosphere feedbacks have been important contributors to regional climate changes in the past.
Studies of feedbacks to climate in response to potential natural vegetation changes and large-scale land use changes explore the sensitivity of climate to vegetation changes and have during the recent decades increased our understanding of the underlying mechanisms.
Studies of biophysical feedbacks in response toavailable future land use scenarios do not exist at the regional scale such as the Baltic Sea Region.
Regional future land use scenarios are emerging. The general future land use trend in Europe according to the majority of available scenarios points in the direction of a conversion of agricultural land into forests.
Feedbacks associated with forest expansion in temperate, boreal and arctic regions are related to albedo reductions (warming) in winterand early spring. The role of hydrological cycle feedbacks in these climate zonesare less understood but could be relevant in spring and summer at least in temperate climate zones.
It is expected that the outcomes from additional regional to local future land use scenarioswill widely diverge as more detailed information becomes incorporated into the models. This would in turnyield multiple possible outcomesrelated to the resulting biophysical feedbacks.
Climate policies of today barely reflect the consequences of biophysical land-atmosphere feedbacks.
Biophysical land cover feedbacks in a short-term perspective could contrast those feedbacks relevant in the long run.

References

Alcamo et al., 2008 J. Alcamo, K. Kok, G. Busch and J. Priess, Searching for the future of land: scenarios from the local to global scale. In: J. Alcamo, Editor, Environmental Futures – the Practice of Environmental Scenario Analysisvol. 2, Elsevier (2008), pp. 67–103 (Chapter 4).
Audsley E, Pearn KR, Simota C, Cojocaro G, Koutsidou E, Rounsevell MDA, Trnka M, Alexandrov V(2006) What can scenario modeling tell us about future European scale land use and what not? AgrEcosystEnv 9:148-162.
Bala G, Caldeira K, Wickett M, Phillips TJ, Lobell DB, Delire C, Mirin A (2007) Combined climate and carbon-cycle effects of large-scale deforestation. ProcNatlAcadSci USA 104 6550-6555 doi:10.1073/pnas.0608998104.
Betts RA (2000) Offset of the potential carbon sink from boreal forestation by decreases in surface albedo. Nature 408 187-190. (Maybe too old by now)
Bonan GB (2008) Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests. Science 2008 320(5882):1444-9.
Carter, T.R., R.N. Jones, X. Lu, S. Bhadwal, C. Conde, L.O. Mearns, B.C. O’Neill, M.D.A. Rounsevell and M.B. Zurek, 2007: New Assessment Methods and the Characterisation of Future Conditions. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 133-171.
Della-Marta, P. M., M. R. Haylock, J. Luterbacher, and H. Wanner (2007), Doubled length of western European summer heat waves since 1880, J. Geophys. Res., 112, D15103, doi:10.1029/2007JD008510.

Findell KL, Shevliakova E, Milly PCD, Stouffer RJ (2007) Modeled impact of anthropogenic land cover change on climate. Journal of Climate, 20(14) doi:10.1175/JCLI4185.1.

GöttelH, Alexander J, Keup-Thiel E, Reichid D, Hagemann S, Blome T, Wolf A, Jacob D (2008) Influence of changed vegetation fields on regional climate simulations in the Barents Sea Region. Clim Change 78 35-50 doi:10.1007/s10584-007-9341-5.

Hibbard KA, Meehl GA, Cox PM, Friedlingstein P (2007) A strategy for climate change stabilization experiments. EOS Transactions AGU 88 217-221.

Intergovernmental Panel on Climate Change (IPCC)(2007) IPCC Fourth Assessment Report – Climate Change 2007.

Jackson, RB, JT Randerson, JG Canadell, RG Anderson, R Avissar, DD Baldocchi, GB Bonan, K Caldeira, NS Diffenbaugh, CB Field, BA Hungate, EG Jobbágy, LM Kueppers, MD Nosetto, DE Pataki (2008) Protecting climate with forests.

Environmental Research Letters 3 044006, dx.doi.org/10.1088/1748-9326/3/4/044006.

Metzger, M.J, Rounsevell, M., van den Heiligenberg, H.A.R.M., Perez-Soba, M. and Soto Hardiman, P. (2010) How Personal Judgment Influences Scenario Development: an Example for Future Rural Development in Europe, Ecology and Society, 15 5.

Rounsevell, M., Reginster, I., Araujo, M.B., Carter, T.R., Dendoncker, N., Ewert, F., House, J.I., Kankaanpaa, S., Leemens, R., Metzger, M.J, Schmidt, C., Smith, P. and Tuck, G. (2006) A coherent set of future land use change scenarios for Europe, Agriculture, Ecosystems and Environment114(1) p.57-68 doi:10.1016/j.agee.2005.11.027Rounsevell, M. and Reay, D. (2009) Land use and climate change in the UK, Land use policy26 p.S160-S169 doi:10.1016/j.landusepol.2009.09.007

Seneviratne, S.I., D. Lüthi, M. Litschi, and C. Schär, 2006: Land-atmosphere coupling and climate change in Europe. Nature, 443, 205-209.

Smith B, Samuelsson P, Wramneby A, Rummukainen M (2011) A model of the coupled dynamics of climate, vegetation and terrestrial ecosystem biogeochemistry for regional applications.Tellus A 63: 87-106 doi: 10.1111/j.1600-0870.2010.00477.x

Smith B, Aasa A, Ahas R, Blenckner T, Callaghan T, de Chazal J, Humborg C, Jönsson AM, Kellomäki S, Kull A, Lehikoinen E, Mander Ü, Nõges P, Nõges T, Rounsevell M, Sofiev M, Tryjanowski P, Wolf A (2008)Climate-related change in terrestrial and freshwater ecosystems. In: BACC Author Team, Assessment of Climate Change for the Baltic Sea Basin.Springer-Verlag, Berlin, pp 221-308.

South DB, Lee X, Messina MG (2011) Will afforestation in temperate zones warm the Earth? Journal of Horticulture and Forestry Vol 3(7) pp 195-199.

Strengers, B. J., Müller, C., Schaeffer, M., Haarsma, R. J., Severijns, C., Gerten, D., Schaphoff, S., van den Houdt, R. and Oostenrijk, R. (2010), Assessing 20th century climate–vegetation feedbacks of land-use change and natural vegetation dynamics in a fully coupled vegetation–climate model. International Journal of Climatology, 30: 2055–2065. doi: 10.1002/joc.2132

Teuling, A.J., S.I. Seneviratne; R. Stöckli; M. Reichstein; E. Moors; P. Ciais; S. Luyssaert; B. van den Hurk; C. Ammann; C. Bernhofer; E. Dellwik; D. Gianelle; B. Gielen; T. Grünwald; K. Klumpp; L. Montagnani; C. Moureaux; M. Sottocornola; and G. Wohlfahrt (2010), Contrasting response of European forest and grassland energy exchange to heatwaves. Nature Geosci.,3, 722-727, doi:10.1038/ngeo950

Vesala T et al.(2005) Effect of thinning on surface fluxes in a boreal forest. Global Biogeochem Cycles 19 GB2001 doi:10.1029/2004GB002316.

Wramneby A, Smith B, Samuelsson P (2010), Hot spots of vegetation-climate feedbacks under future greenhouse forcing in Europe. J Geophys Res115 D21119 doi:10.1029/2010JD014307