SMHI

OCEANOGRAPHY No. 105, 2010

Visualization of hydrological, physical and biogeochemical modelling of the Baltic Sea using a GeoDome™.

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Front: GeoDome^{TM} visualizations at the Stockholm World Water Week, Stockholm, Sweden, September, 2010

ISSN: 0283-7714

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Summary

The ECOSUPPORT-project aims to help policy makers by supplying state-of-the-art research on the state of the Baltic Sea under different scenarios of nutrient supply, pressure from fisheries and impact of climate change. In order to make the research results accessible, a new form of scientific communication has been tested. Presentation of research data and physical, chemical and biogeochemical processes on land and in the sea were made using a special visualization platform, Uniview, which was projected onto a cupola-shaped screen inside an inflatable, enclosed dome. The visualization has been tested on different audiences including policy makers, politicians, researchers and university students. Overall, the response has been overwhelmingly positive with the audience expressing the view that the used visualization technique enhanced their understanding and receptiveness. This view was shared with the scientific presenters.

Sammanfattning

ECOSUPPORT-projektet syftar till att ta fram forskningsresultat om Östersjöns miljöstatus under olika scenarier av belastning av näringsämnen och fisketryck i ett framtida klimat. Resultaten kan ligga till grund som vägledning för beslutsfattare. För att forskningsresultaten skall kunna göras begripliga och tillgängliga har en ny form av vetenskapskommunikation prövats. Presentation av en stor mängd data samt beskrivning av fysiska och biogeokemiska processer på land och i havet gjordes med hjälp av en speciell visualiseringsplatform, Uniview, som visades på en kupolformad filmduk inuti en uppblåsbar domteater. Visualiseringen visades för olika typer av publik, t.ex. för beslutsfattare, politisk ledning, forskare och studenter. Överlag så har responsen varit mycket positiv och de flesta som tagit del av visningarna menar att den här formen av kommunikation gör det lättare att förstå och ta till sig komplexa data och sammanhang. Denna åsikt delades också av de vetenskapliga presentatörerna

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1 Introduction

The objective of the ECOSUPPORT project (Advanced modelling tool for scenarios of the Baltic Sea ECOsystem to SUPPORT decision making, www.baltex-research.eu/ecosupport/) is to use state-of-the-art models of the Baltic Sea system to help understand the combined effects of climate change, nutrient supply and fisheries on water and ecosystem status. The outcome of the project will serve as policy information and may be used as a tool for decision making as it will indicate how changes in catchment management practices and fishery pressures will impact the Baltic Sea in a changing climate.

The Baltic Sea is one of the largest estuaries in the world, with a surface area of about 370 000 km^2. The catchment area is about 4 times the size of the Baltic Sea surface area and includes 14 countries and some 85 million people. Extensive agriculture is practiced in several countries, especially in Denmark, the south of Sweden, Germany and Poland resulting in large nutrient loads to rivers downstream of these agricultural regions. Another source of large loads to the sea are point sources from urban wastewater treatment plants, particularly from large population centres such as Warsaw, St Petersburg, Riga, Stockholm and Copenhagen. The large loads of nitrogen and phosphorus to the Baltic proper contribute to large phytoplankton blooms. One sign of the large-scale eutrophication is the extensive summer and autumn blooms of the nitrogen-fixating cyanobacteria, with its preconditioning of none depletion of phosphorus while being able to use the gaseous form of nitrogen. Recently, countries around the Baltic Sea have pledged to reduce anthropogenic loads to the Baltic Sea under the Baltic Sea Action Plan (HELCOM Secretariat, 2007) which apportions nutrient reductions to each country; however, the effectiveness of measures to decrease these loads, such as changed agricultural techniques and improved wastewater treatment, is unknown for future climate conditions.

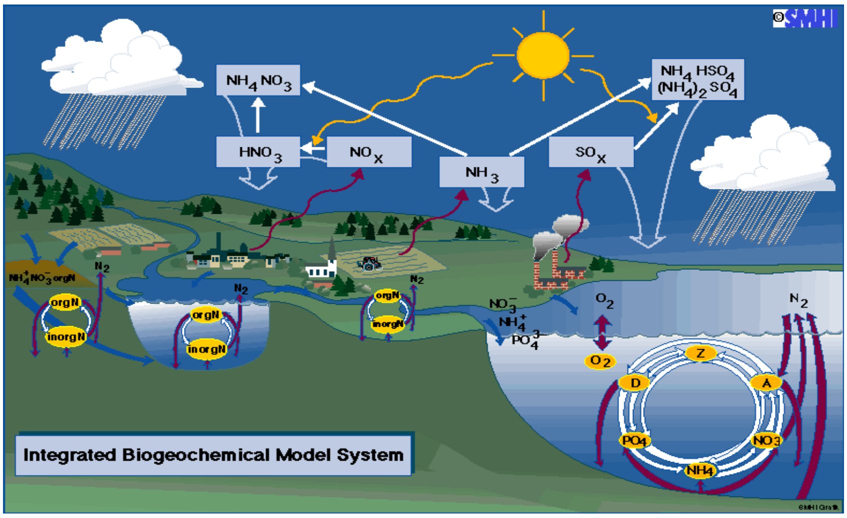

Fig.1: The integrated biogeochemical system in the atmosphere, land and sea.

The effects of the nutrient loads transported to the sea is further complicated by the unique nature of the Baltic Sea itself. The entrance to the Baltic Sea consists of the shallow and narrow Kattegat area with the sounds between Denmark and Sweden. The restriction of the entrance area hampers inflowing North Sea water. The mean fresh-water discharge to the Baltic basin is about 15 000 m^3/s and hence the Baltic Sea is strongly stratified with a permanent halocline at about 60 m depth in the Baltic proper. The renewal of deep water occurs intermittently and the inflowing water undergoes strong mixing with ambient water. As a consequence, the density of the inflowing water is decreased and the inflows are seldom large enough to enable renewal of the waters at the deepest parts of the Baltic Sea. The oxygen in the stagnant basins is consumed due to decomposition of organic material. This leads to large areas with anoxic or hypoxic conditions at the bottom (i.e. oxygen concentrations are below 0 or 2 ml/l respectively). A review of the Baltic Sea system can be found in Wulff et al. (2001) and an assessment of the impact of climate change on the system in The BACC Author Team (2008).

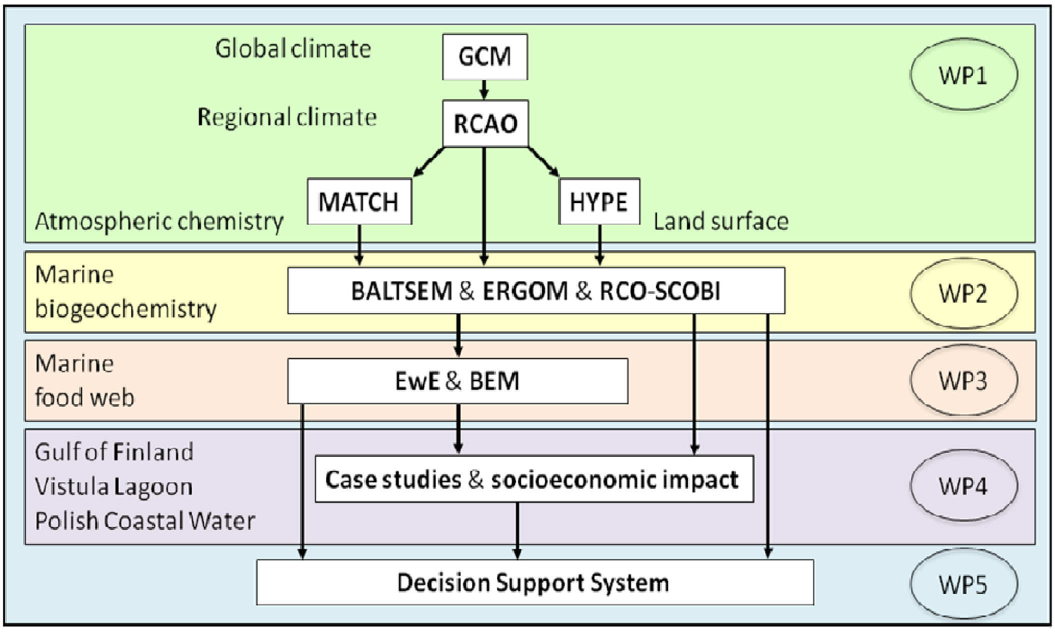

Fig.2 Models within the ECOSUPPORT project. The output of the Global Climate Models are used as boundary conditions to the regional climate model, RCAO. This model in turn gives forcing to the hydrological and atmospheric chemistry models HYPE and MATCH. These force the coupled physical – biogeochemical models BALTSEM, ERGOM and RCO-SCOBI. The output of these models give input to the ecosystem models (e.g ECOSIM/ECOPATH).

In order to capture the complex physical, chemical and biological interactions in the atmosphere, on land and in the sea (Fig. 1), a wide range of models are used within the ECOSUPPORT project (Fig. 2). This chain of models will enable process understanding as well as give possibilities to run different climate, nutrient load reduction and fishery scenarios. By making use of historical data and future projections of the climate, transient model runs from 1850 to 2100 are made possible. The future climate scenarios are prescribed by the IPCC and downscaled to regional scale from global climate models.

Visualization techniques are used within the project in order to find tools for communicating extensive project data. The visualizations will serve both as educational science communication of process understanding, as a platform for comparisons and discussions of scenarios and their uncertainties, and to give a scientific ground for decision making. In collaboration with Norrköping Visualization Centre C (www.visualiseringscenter.se), environmental research results from the ECOSUPPORT project have been shown using a portable GeoDome™

(www.geodome.info/ , Fig 3). The dome is fully enclosed, inflatable and about 20 adults can take place inside, preferably lying down on pillows on the floor. The scientific data is then projected onto a cupola-shaped screen. We have used the Uniview visualization platform (www.scalingtheuniverse.com; a 3D astronomical environment, where we fly through space, from the moon towards the earth. We then circle the earth and start the show by looking at data of population densities around the earth (Fig. 4). Thereafter we zoom in on the Baltic Sea and start conveying ECOSUPPORT data and results. An integral part of the show, is the presence of scientific experts who narrate the data shown. This is necessary both to guide the audience through the show and also to enable the audience to interact with the data and the experts. This in turn leads to more informative viewings and discussions. In addition, technical support is needed in order to safely put up the dome and to run the visualization platform.

Fig 3. The GeoDome™, with scientific researchers and presenters Patrik Wallman (hydrological research, SMHI) and Helén Andersson (oceanographic research, SMHI) (photo I. Gudmundsson, SMHI).

Fig 4a. Inside the dome: World population density projected on the Earth (photo H. Andersson, SMHI).

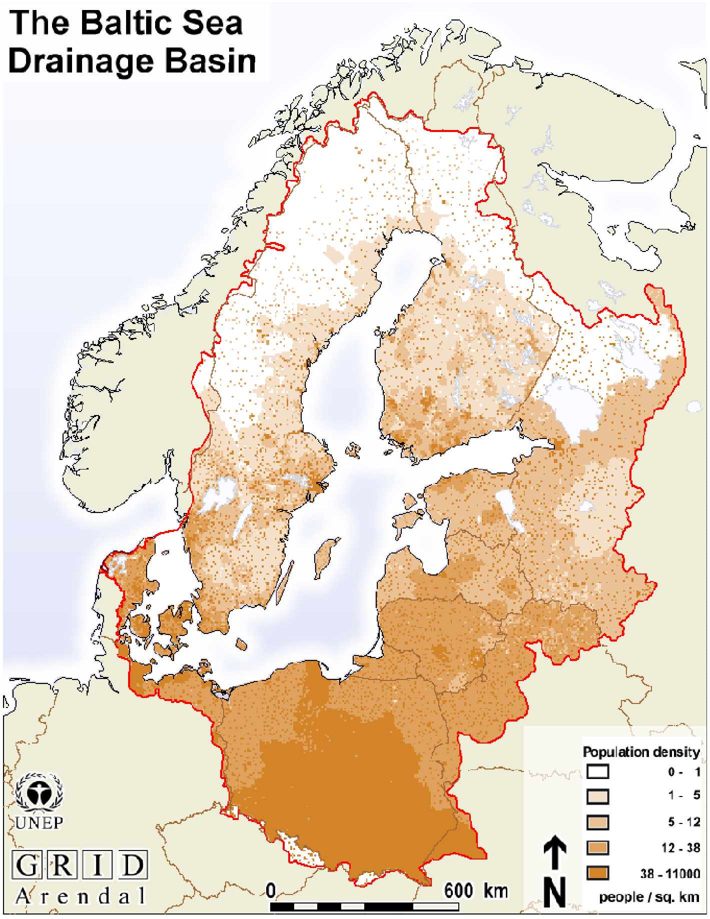

Fig 4b. Some of the data of population density (people/km^2) behind the dome projection in Fig 4a. Source of data and figure is the website of the United Nations Environment Program (http://maps.grida.no/go/graphic/population_density_in_the_baltic_sea_drainage_basin).

2 The Storyline

Before the show, a manuscript was compiled which covered the main conclusions that could be drawn from the presented projections. Since ECOSUPPORT is only about half-way through the project time, the main focus so far has been on process understanding, present-time model simulations of flow, nutrient processes in the Baltic Sea catchment and the biogeochemical processes in the ocean. A few scenarios of both future climate and future management practices were also shown, and as the project will produce more of these, and also of hindcasts, the focus of future shows will naturally move toward these. Both understanding of the past evolution of the state of the Baltic Sea and future scenarios of possible outcomes of e.g. nutrient reduction can serve as support and background for policy decisions. The model simulations shown are produced with the Balt-HYPE application of the SMHI hydrological model, HYPE (Donnelly, 2010, Lindström, In Press) and the 3D coupled physical-biogeochemical ocean model RCO-SCOBI (Meier et al., 2011, Meier et al., 2003, Eilola et al., 2009).

Below is a synopsis of the storyline and data behind the projections that have been shown in the dome so far. The extent and order of the shown material has differed somewhat between the

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different presentations. It was also emphasised that all shown simulations are preliminary and that intensive project-research is ongoing.

In 1969 humanity received for the very first time an image of the earth seen from space. The ‘earthrise’ photographed by the appollo11 from the moon was a turning point in our perspective on the earth as a system, and the blue marble is still a strong iconic visual supporting our understanding for the earth as a planet with certain boundaries.

This fragile system has however been object to severe challenges over most importantly the last two centuries: Global population has expanded significantly over this period– from 1 billion in 1800 to over 6 billion today – (the prognosis for 2050 even reaching 9 billion).

What we see here as red dots is the population density today over the globe (see Fig 4).

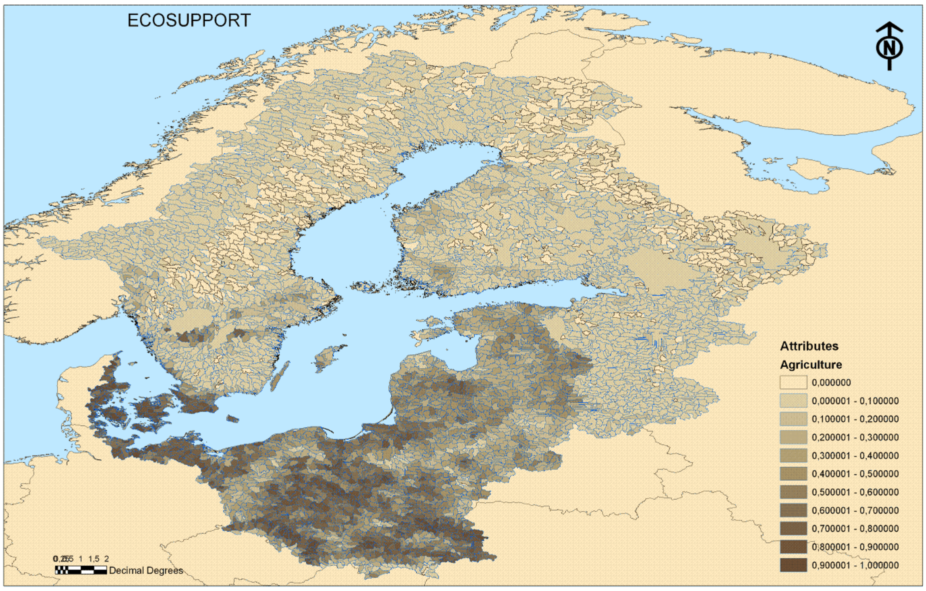
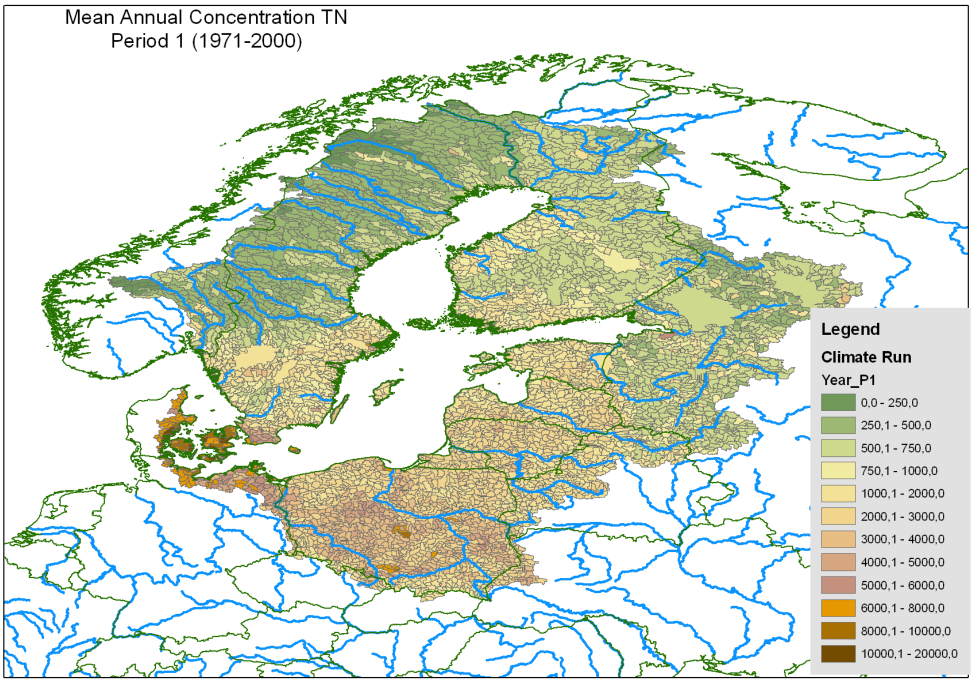


Fig. 5. Agricultural distribution (percentage agricultural area in each subbasin) in the Baltic Sea catchment.



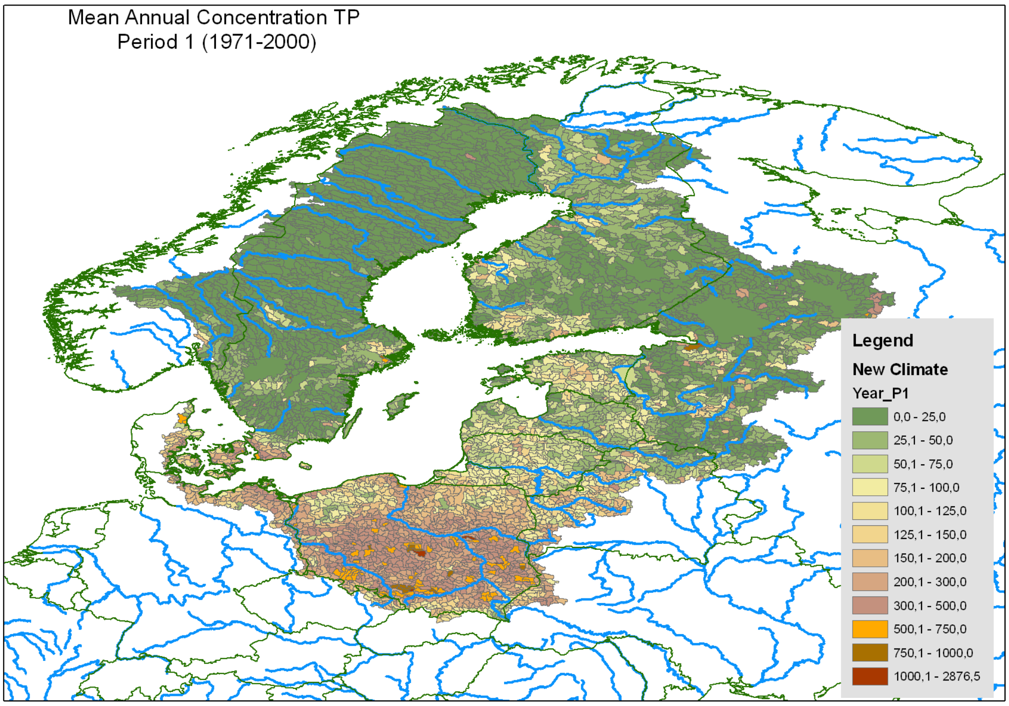


Fig. 6. Mean annual nitrogen (µg/l total N, top panel) and phosphorus (µg/l total P, lower panel) concentrations for the period 1971-2000.

Not only are we increasing in number, but an increasing consumption of resources per person is leading to both degradation and scarcity of natural resource as well as pollution of for instance surface and groundwater as well as increased emissions to the atmosphere. We will in this presentation focus on the Baltic Sea which we fly towards now.

This is the Baltic Sea basin. All rain that falls here that isn't evaporated or transpired by plants eventually makes its way to the Baltic Sea. But it isn't only freshwater that makes its way to the Baltic Sea from this basin, the water carries with it environmental pollutants including toxic substances such as heavy metals, and excess nutrients that can stimulate algal blooms in the Baltic Sea.

As you can see, the discharge from wastewater treatment plants and rural households and excess nutrients from agriculture are two important sources of nutrients. These next two pictures show how population (Fig. 4) and agriculture (Fig. 5) are distributed throughout the basin. Remembering the regions with most farming and the largest population centres, note where the largest loads of Nitrogen and Phosphorus to the Baltic Sea come from. The two following pictures show the distribution of N and P over the basin (Fig. 6).

The processes that affect nitrogen and phosphorus transformation and uptake in the ground and in water are climate dependent, as well as the runoff generation itself. Consequently, changes in climate can affect how much nutrients are transported to the Baltic Sea. Environmental goals of reduced nutrient loads will thus have to consider climate change. Here we show one climate scenario which demonstrates one possibility for how we might expect things to change. This is the A1B scenario run using the ECHAM5 global climate model (of the Max Planck Institute, Germany) and downscaled with the RCA3 model run at the Rossby Centre at SMHI. Even though precipitation is increased everywhere, river discharge sometimes decreases and that's because of increased evapotranspiration (not shown in the present report).

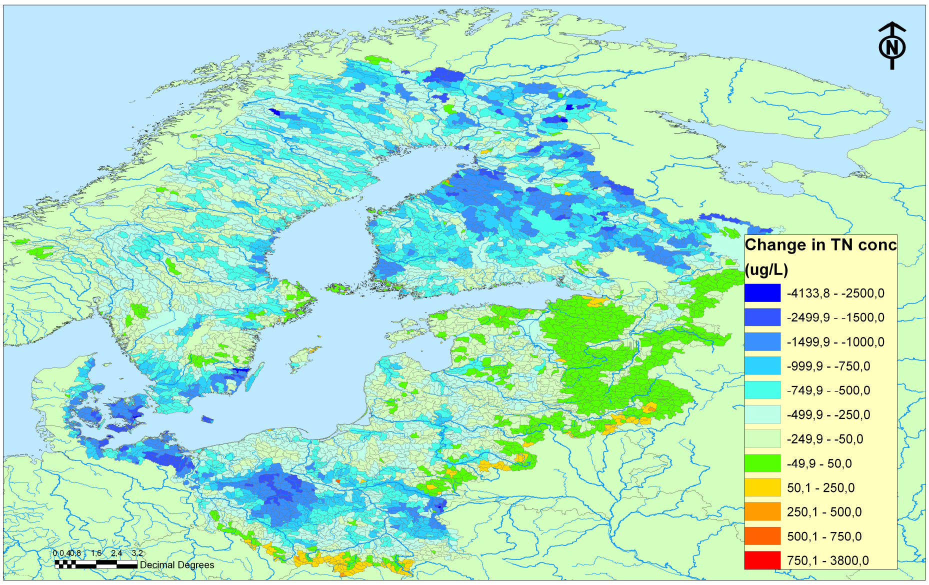


Fig. 7. Future change in total nitrogen concentrations (μg/L).

So let's see how these climatic changes affect concentrations of nitrogen and phosphorus both on land and to the Baltic Sea (Fig 7 and Fig 8). Note that here we have assumed that we haven't made any changes to what we grow, how we manage the land, handle our sewage, and that we don't assume any changes of our population.

What would happen today if we decided to clean up our act? To make sure all cities had tertiary sewage treatment and that all farms used best practices? (*Discussion of changes/result – how much do we decrease N/P – relate to "Best practice scenario*)

If society is going to spend the money to do this, we need to know if it will still be effective in a future climate. So here we show the improvements for a future climate scenario and assuming all cities had tertiary sewage treatment and that all farms used best practices (not shown in the present report). Note that we haven't taken into account any changes in population or farming density. This is an 'uncertainty' in our results and should be modelled as a scenario when possible.

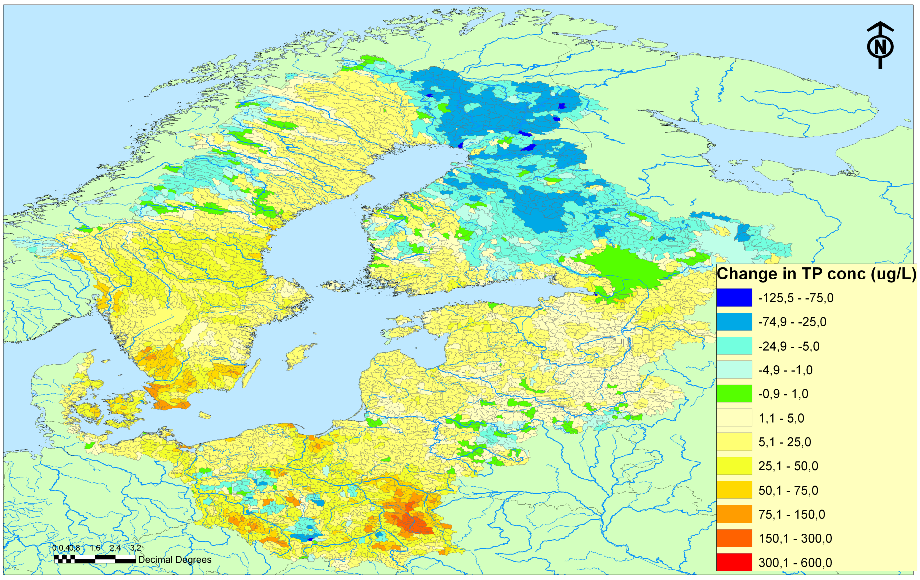


Fig. 8. Future change in total phosphorus concentrations (µg/L).

Excess nutrients from the land end up in our rivers and lakes and eventually flows into the sea. What acts as a fertilizer on land also works as a fertilizer in the sea. It is therefore also very important to understand what impact the land loads have on the state of the Baltic Sea.

The Baltic Sea is one of the largest estuaries of the world. The entrance consists of the narrow and shallow sounds between Sweden and Denmark. The topographical restriction hampers extensive exchange with the salty waters of the North Sea. In the sounds the water depth is about 10-15 meters while the deepest part of the Baltic proper is about 450 meters. Large amounts of freshwater enter the Baltic Sea from the rivers and the result is a highly stratified, brackish sea, where it can take a long time before the waters in the deeper parts get renewed. There is a large range in salinity: from about 25 psu in the inflowing Kattegat water to about 3 psu in the Bothnian Bay.

The movie (Fig. 9) shows an inflow of high salinity water from the Kattegat, through the straits between Denmark and Sweden and into the southern Baltic Sea. What we see is the salinity near the bottom of the sea. When the salty water enters it gets mixed with waters of lower salinity. The salinity of the inflow plume therefore decreases on its way into the Baltic. To be able to renew the deeper layers of the Baltic a large body of water of sufficiently high salinity needs to enter the straits. These major inflows occur seldom, it can take one to several years between them. Since it is only saltwater inflows that can ventilate the deepwater, the bottom water meanwhile becomes stagnant and oxygen levels get reduced.

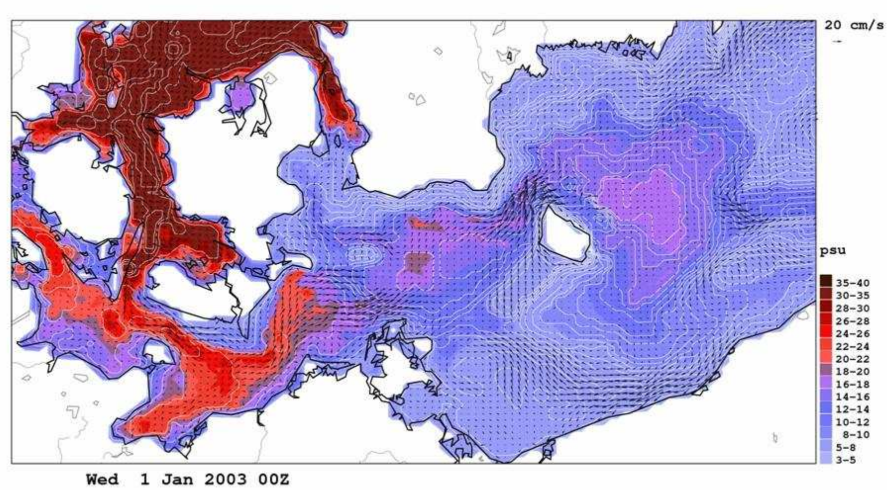


Fig.9 Snapshot from the movie of a simulated inflow of high-saline water from the Kattegat (courtsey of Anders Höglund, SMHI).

Often a substantial part of the Baltic Sea bottom water suffers from low (hypoxic) oxygen levels or no oxygen at all (anoxic). This picture (Fig. 10) shows the situation in the autumn of 2009 where grey colours are hypoxic and black colours anoxic areas.

The seldom occurring major inflows of oxygen rich North Sea water contribute to part the problems faced by the Baltic. The other part is due to the nutrient rich waters within the Baltic that enables large algal blooms. Algae, an organic matter, uses much of the oxygen in the bottom-water as it decomposes. The following photos, which are taken by the Swedish Coast Guard, show summer surface blooms of cyanobacteria (Fig. 11). These can cover large parts of the Baltic proper.

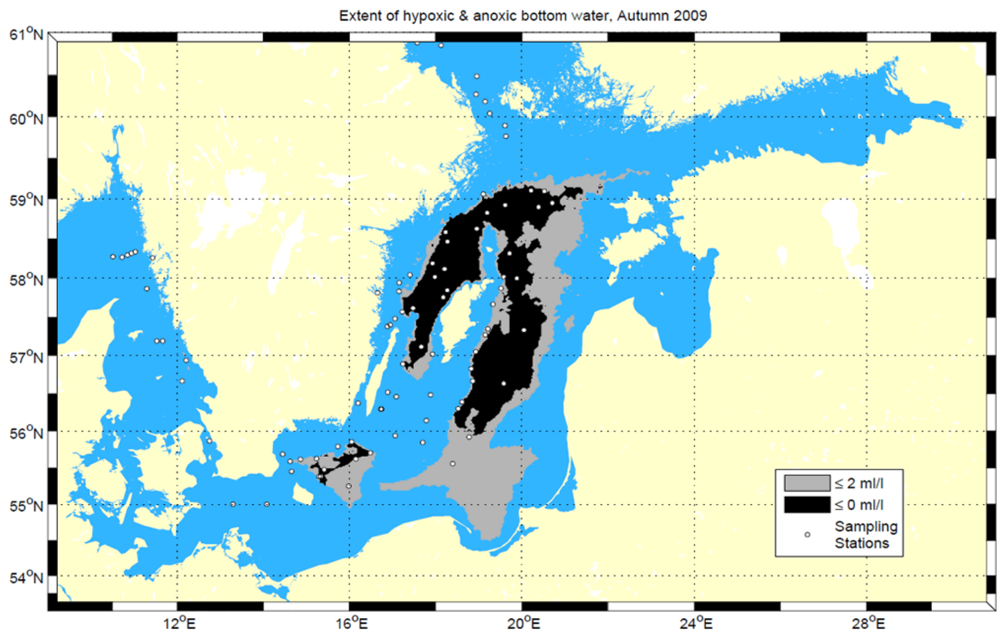


Fig 10. Anoxic and hypoxic areas in the Baltic Sea as seen from measurements during the autumn of 2009 (source: SMHI).

Earlier we saw model simulations of nutrient loads from the Baltic Sea catchment area. These nutrient loads enter the Baltic Sea from the rivers, together with nutrients from atmospheric deposition, coastal wastewater treatment plants and industrial releases and get distributed within Baltic Sea. Here we see the modelled distribution of nitrogen and phosphorus in the winter-time surface waters. The simulations are from the SMHI modell RCO-SCOBI (Fig 12 a-b). With available nutrients in the water, a phytoplankton bloom can start in the springtime when the light condition become sufficient (Fig 12 c). The bloom is largest in the south-eastern part of the Baltic Sea, as are the wintertime nutrient concentrations.

The springtime bloom uses a large part of the nitrogen in the Baltic proper, while there is still some phosphorus available (Fig. 13).

This is a prerequisite for a summer bloom of cyanobacteria (blue-green algae) in the central parts of the Baltic Sea (Fig. 14), as this species can assimilate nitrogen by fixation, i.e. it can use the gaseous form of nitrogen.

This is an advantage over the other algal groups which need their supply from the water in the form of dissolved inorganic nitrogen. The cyanobacteria blooms occur during summer and autumn, since warm water conditions is another prerequisite.

Scenarios of future sea-surface temperature changes show that there is a warming in all seasons, with the largest changes during the summer season (not shown in the present report). The scenario is modelled at SMHI with downscaled results from the Hadley Centre Model (HadCM3) of the IPCC scenario A1B.

The summer oxygen content at the bottom also becomes lower in large parts of the Baltic Sea, partly due to the warmer water's lowered capacity to hold oxygen (decreased oxygen saturation). These areas are seen as blue colours (Fig. 15). In the yellow and red areas the model shows a future scenario of more oxygen at the bottom. These areas are closely linked to bottom topography features and show areas with increased mixing due to a weakened stratification strength.

Fig. 11. Cyanobacterial blooms in the Baltic proper (photo: Swedish Coast Guard, www.kustbevakningen.se)

Projections of the future show that phytoplankton concentrations are enhanced as compared to present climate (Fig. 16). This can partly be due to increased growth efficiency in warmer water, but also due to the fact that less oxygen at the bottom results in more available phosphorus in the water, since the oxygen free environment releases sediment-bound phosphorus and the efficiency of the internal sink is reduced. The results are preliminary and subject to further analysis. This simulation does not take possible future nutrient reductions into account.

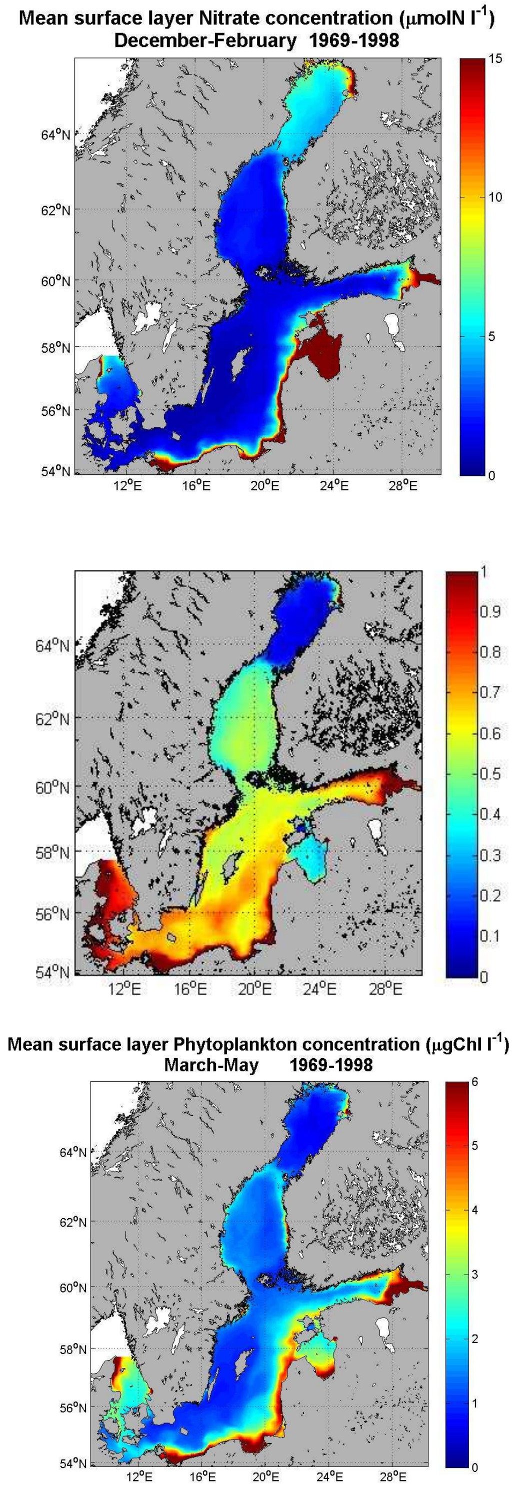


Fig 12.The mean surface-layer concentrations for the period 1969-1998 for a) winter-time nitrate (µmol/l), b) winter-time phosphate (µmol/l), and c) spring-time phytoplankton (µgChl/l). Colorbar ranges from 0-15 µmol/l, 0-1 µmol/l and 0-6 µgChl/l respectively.

In a warming climate it is of even greater concern to understand how nutrient loads to the Baltic Sea will impact the marine environment as the first simulations from land and sea do not indicate improved conditions due to climate change. Comparisons of scenarios of “business as usual” and implementations of nutrient reductions as imposed by the HELCOM Baltic Sea Action Plan (Helcom Secretariat, 2007), an ambitious program to restore good ecological status of the Baltic marine environment, in present and future climate will aid in our understanding of what measures that are needed to be taken. Such work is conducted in the BONUS+ project ECOSUPPORT.

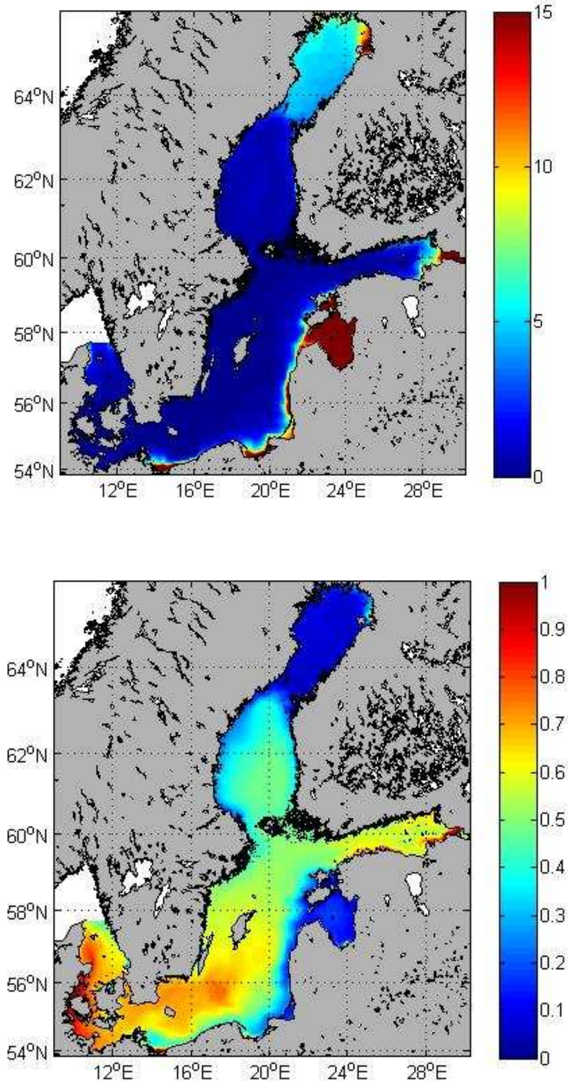


Fig. 13. Present day climatological mean (1969-1998) of spring-time surface concentrations of a) nitrogen and b) phosphorus.

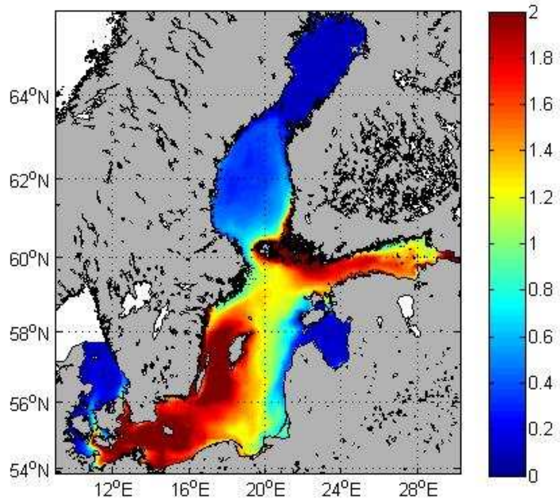


Fig 14. Present day (1969-1998) climatological mean of RCO-SCOBI simulated cyanobacterial concentrations (µgChl/l) during summer in the Batlic Sea.

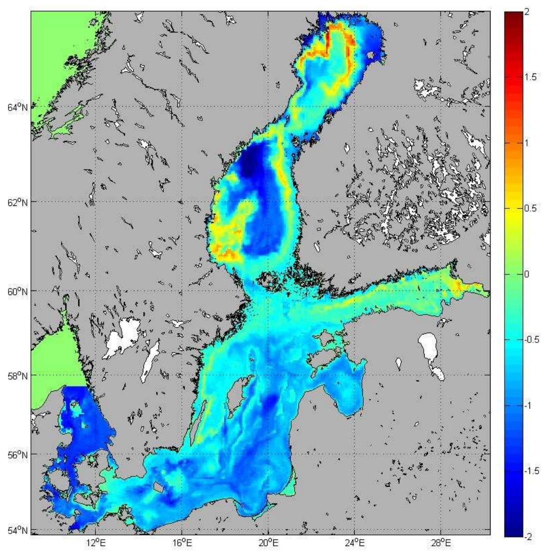


Fig. 15. Simulation of future mean change (the period 2060-2089 compared to the period 1970-1999) of oxygen concentrations (ml/l) in the bottom water. (Colorbar ranges from -2 to 2 ml/l.)

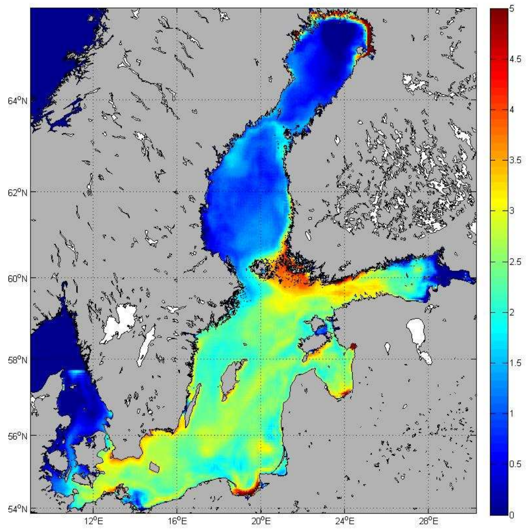


Fig. 16. Future scenario of change (the period 2060-2089 compared to the period 1970-1999) in annual mean surface concentrations (µgChl/l) of phytoplankton compared to present-day climate (Colorbar ranges from 0 to 5 .µgChl/l).

3 Accomplished visualizations as of November 2010

The first complete visualizations in the GeoDome™ were conducted at the exhibition of the Stockholm World Water Week (http://www.siwi.org/worldwaterweek). The dome was shown during three days at the conference, with about seven 30-minutes presentations per day (Figs 17-19). The visualizations attracted a large number of participants and raised a lot of interest.

Fig 17. The Stockholm World Water Week 2010. The GeoDome™ exhibited visualization of ECOSUPPORT efforts (Photos: H. Andersson, SMHI).

Fig 18. The poster advertising the visualization at Stockholm World Water Week. The poster was created by Tina Neset, CSPR, Linköping University. (Photo: H. Andersson, SMHI).

Fig 19.At the Stockholm World Water Week. A visualization is about to begin .(Photos: H. Andersson, SMHI).

The visualization platform was thereafter used without the dome but in an ordinary lecture room. This took place at The East Sweden Region "Östsam" in Norrköping (www.ostsam.se/en_default.asp), Sweden. A one-day conference was held in conjunction with the Open Days in Brussels, in order to discuss the regional situation after one year with EU's Baltic Sea Strategy. The theme of the day was "Visions, Challenges and Reality". The conference was visited by representatives from the European Parliament, the Government Offices of Sweden, SMHI, the County Administrative Board and other local and regional stakeholders.

The GeoDome™ was again shown in Sweden in November 2010, this time at Stockholm University (Fig. 20). Half-a-day was devoted to the students of the University and other interested parties that happened to pass the dome as it was put up outside the University Library. Five shows were more or less filled and many competent questions were asked by the students. Two shows were reserved for the about 50 scientists and stakeholders from all over

Europe that participated at the meeting of the EU-project CIRCLE2 (Climate Impact Research for a Larger Europe, www.circle-era.eu/np4/home.html), see Fig. 21.

Fig 20. The GeoDome™ before and after inflation at the Stockholm University. (Photos: P. Källström, Norrköping Visualisation Centre C)

One full day of visualizations in the dome took place at the Swedish Ministry of Rural Affairs (Fig 22). Seven shows were given and they were all well attended. Our host for the day was Erik Arnberg from the Ministry of the Environment. The General Director of SMHI, Lena Häll Eriksson, was present during the morning and she welcomed the visitors and introduced the shows (Fig. 23 a). The first show of the day was a “VIP”-show, dedicated to the political management of the Ministry of Rural Affairs and the Ministry of the Environment (Fig. 23 b). The other shows were pre-booked but open to all personnel at the Swedish Ministries. It was a hectic and busy day where the presenting scientists had to answer many insightful and inquisitive questions from the audience.

4 Conclusions

The visualizations of the Baltic Sea system performed using the GeoDome™ with the Uniview platform have proven to be very successful. The closeness and relaxing atmosphere created by lying in the dark in the small, enclosed inside of the dome created an easy atmosphere for asking questions and stimulating discussion. The Uniview platform aided in the taking in and understanding of both complex processes and of complex and numerous data.

Fig. 21. a) Preparations to welcome CIRCLE2 in the dome, b) the CIRCLE2 participants getting comfortable in the inside of the dome. (Photos: P. Källström, Norrköping Visualisation Centre C)

There was a clear opinion from the scientific presenters that the attention on the presentation and the understanding of the shown material was enhanced by the techniques used in these visualizations compared to an ordinary lecture room power-point presentation. The dome, being a bit more spectacular than a lecture room, also clearly creates an enhanced interest in attending a presentation of scientific data. There were also many outspoken enquiries on the possibility of having the dome and the visualization present at other exhibitions and conferences, e.g. at the HELCOM Baltic Sea Days in St Petersburg and at the 2011 exhibitions under the theme "Lifestyle" at the Swedish Embassy in Washington DC, USA.

The visualizations have so far focused on presenting the background and on-going work of the hydrological and oceanographic research performed at SMHI within the ECOSUPPORT project. As the project moves on, our focus will move towards presenting actual outcomes of the different combinations of management and climate scenarios studied in the project. The dome can then serve more as an arena of decision support for policy makers than as an educational, pedagogical tool.

Fig. 22. The dome is put up at the Ministry of Rural Affairs, Stockholm, Sweden. (Photos: P. Källström, Norrköping Visualisation Centre C)

With the different visualization techniques it will be easy to give a short scientific background to the presented material and then move on to show, compare and discuss the outcomes of different scenarios. These include different IPCC climate scenarios, different nutrient load (management) scenarios and different fishery scenarios. The platform will then be used in a more interactive and communicative way, where data is shown more to illustrate and elucidate the policy discussion. The scientific presenters will then not so much present material as lead and clarify a scientifically based discussion.

Fig 23. Visualizations at the Ministry of Rural Affairs. a) Erik Arnberg, Ministry of the Environment, Lena Häll Eriksson, General Director, SMHI, Patrik Wallman and Helén Andersson, Research & Development, SMHI. b) the political management from the Ministry of the Environment and the Ministry of Rural Affairs. (Photos: P. Källström, Norrköping Visualisation Centre C)

5 Acknowledgements

This work is part of the ECOSUPPORT project (Advanced modeling tool for scenarios of the Baltic Sea ECOsystem to SUPPORT decision making) which is jointly funded within the BONUS+ program by the European Commission and the Swedish Environmental Protection Agency (SEPA) (ref.no. 08/381). The visualizations in the dome were produced in co-operation with CSPR – the Centre for Climate Science and Policy Research at Linköping University. This work, as well as the hire of the GeoDome™, technician from Norrköping Visualization Centre C and transports was funded by the Swedish International Development Cooperation Agency (SIDA) Baltic Sea Unit. Thanks are due to Tina Neset at CSPR, Jörgen Nilsson, SMHI and Lotta Andersson, SMHI who have been driving forces behind the usage of visualization techniques of scientific data. Tina has also spent a lot of time in shaping up the “Storyline” shown in the dome. Martin Karlsson, CSPR put all of our data into the Uniview platform. He and Patric Källström, Norrköping Visualisation Centre C have been the “pilots” at the visualisations and made sure that the dome was correctly put up and that the show was properly running.

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ISSN 0283-7714