SWEDISH ENVIRONMENTAL
PROTECTION AGENCY

Ballast Water Exchange Areas
Prospects of designating BWE areas in the Baltic Proper

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SMHI

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SUMMARY

Investigations were made to find out if there are areas with suitable environments for ballast water exchange. Suitable conditions may be areas of certain depths (preferably >200 meters) or distance from the coast (preferably >200nm or >50nm).

The main focus is on the southern Baltic Proper since it is the area with the highest traffic, it has the largest of the two existing areas in the Baltic Sea >50nm from the coast.

The Baltic Sea is not very large and there are nutrients available most of the year. During spring, the biovolume is at its highest, though there are biological activities (even HABs), mainly to the end of the year. The nutrient level is not low enough to prevent indigenous species survival.

The very brackish surface waters vary between 5 psu in the Bothnian Sea to 7 psu in the southern Baltic Proper. The difference between fresh and central Baltic Proper water is not large.

There is no definite way to say what specific salinity level will kill the BW organisms since there are many different organisms in the BW. As a rule of thumb, there is always a risk that they may survive.

There is a high possibility that the surface waters in the BWE areas can be transported to protected areas or the coast and with a prevailing wind of 15 m/s it can take one day to one week, depending on the wind direction.

Important assets like fish farms can be gravely affected, depending on the contents of the BW. Also competing or predatory species may cause harm, especially in spawning areas of fish or on native species on the sea bed. There are spawning grounds very close to the southern Baltic Proper proposed BWE area.

Discharged pollutants normally affect the protected areas.

The wave climate in the Baltic Proper is not very rough, especially when comparing to more open sea areas, hence not posing as high risk to the ship or crew safety.

The total annual BWE discharge in the southern Baltic Proper is approximated to $1.9*10^9$ m^3.

Most probably, the uptake of BW in the BWE area will be comprised of previously discharged BW, but at a low concentration.

The BWE areas of interest are small. A ship will have to reduce the speed to be able to complete the exchange within the area.

CONTENTS

INTRODUCTION

The Swedish National Environmental Protection Agency commissioned and funded this report.

In the Ballast Water Convention (International Convention for the Control and Management of Ships' Ballast Water and Sediments, hereafter BWC) of the International Maritime Organization (IMO), ballast water exchange between ports is an alternative ballast water treatment until acceptable treatment systems have been developed. This alternative treatment is only valid during a temporary time period. Ballast water exchange (BWE) is today the only chance to reduce the risks of introducing and/or survival of new, alien species in an area.

In the BWC, several requirements that should be complied in order to make a BWE are listed. The main requirements are that the BWE zones should be situated >200 nautical miles (nm) from the coast and with a depth of >200meters (m). If there is no such zone along or near the shipping lanes, the BWE zones should be situated >50nm from the coast with a depth of >200m. In the Guidelines on designation of areas for ballast water exchange (G14) from the BWC, it is stated that areas of BWE can still be designated even if the stated requirements above do not comply. Though there are several other criteria listed in G14 that need to be considered when designating a BWE area.

In the Baltic Sea, there are no areas >200nm from the coast or areas >50nm with depths >200m. There are two areas >50nm from the coast with depths <200m.

There are references to two reports in this assignment (see appendix 9), that partially contains some investigations to find out if it is possible and biologically meaningful to designate BWE areas in the Baltic Sea. In lack of sufficient information, only areas >50nm from the coast are marked on maps, but in the reports there is no clear recommendation of designated areas in the Baltic Sea. These areas are partially in Swedish waters.

The aim with this report is to give an oceanographical and biological description of the areas of interest and scientifically investigate if it is possible and biologically meaningful to designate BWE areas in the Baltic Sea.

The recommendations from this report are based upon general oceanographic and biological conditions of the areas of interest and the main part of the descriptions are included in the appendices.

ASSIGNEMENT

In this report, investigations should be made to find out if there are areas that could provide a suitable environment that would reduce the risks of alien species introduction or spreading through ballast water. Suitable conditions may be areas of certain depths or salinities or other conditions that effectively can kill the organisms from the ballast water and that they do not spread beyond the BWE area. The ship (here meaning all ships/tankers/or the like containing ballast water) and crew safety demands from the BWC must be ensured and the areas need to have the capacity to be used by all the ships identified as high risk traffic for alien species introduction and spreading.

Assess, by the BWC and G14 requirements, if it is possible to designate suitable BWE areas in the Swedish waters in the Baltic Sea. Considering the requirements, the assessment should include the following issues:

- **Oceanographic conditions** – (1) Will the discharge of ballast water in the BWE area be transported towards or away from the coast? (2a) Will the organisms, discharged with the ballast water, circulate horizontally in the surface waters and by that, be present for ballast water uptake when the next ship is passing? (2b, biological condition) Will the discharged organisms die in the BWE area or in further transport after ballast water uptake from the next passing ship? (3) What is the vertical circulation like in the areas >50nm from the coast?

- **Biological conditions** – (4) Will the proposed BWE areas be affected by harmful aquatic organisms, including harmful algal blooms?

- **Environmental conditions** – (5) Are protected areas/environments affected by discharges of alien organisms in the proposed BWE areas? (6) Are protected areas/environments affected by discharges of pollutants or increased nutrient concentration in the proposed BWE areas?

- **Important assets** – (7) Are important assets, like fishery/play ground/spawning ground affected by BWE in the proposed areas?

- **Ballast water discharges** – (8) Quantification, origin and frequency.

Following guidelines from the G14 (§ 7.2.4 and § 7.2.5) should also be taken under consideration:

- The proposed BWE areas should be situated along the main shipping lanes or as close as possible.

- The exchange procedure of the ballast water in the proposed areas may not jeopardise the safety of the ship or crew.

- The proposed BWE areas should regularly be monitored in accordance with G14 § 11.1.

RESULTS

The numbered questions will be addressed one by one. Most of the results and general descriptions are described further in the appendices. The methods and data used are mainly described in the appendices. Many of the questions with a biological or environmental angle, have been answered by interviewing Inger Wallentinus and Malin Werner, active within the research programme AquAliens.

Maps displaying both of the proposed BWE areas, protected areasand major shipping lanes are displayed in figure 1 and larger maps are found at page 24-27. To the right in the figure, there are maps from the SMHI tool SeaTrackWeb including Baltic Sea Protected areas and important bird areas, not only in Swedish waters.

OCEANOGRAPHIC CONDITIONS

1. Will the discharge of ballast water in the BWE area be transported towards or away from the coast?

It will be transported (and since the BWE area is in the middle of the sea) towards a coast or protected area in the direction slilghtly to the right of the wind. The speed and direction of the surface water depends on the wind and the thickness of the surface layer of interest.
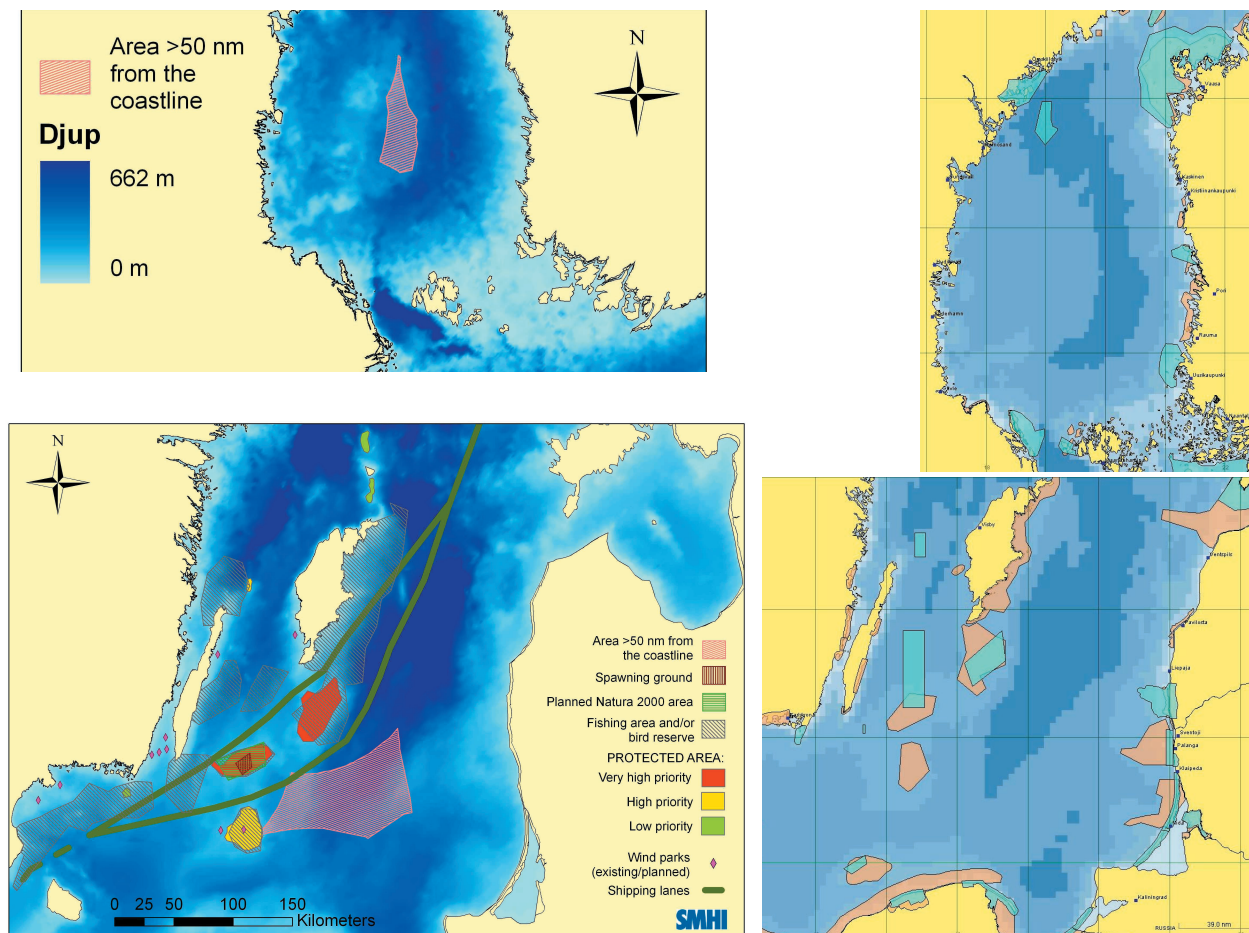

Figure 1. Maps displaying the BWE areas and the protected areas in Swedish waters to the left and protected areas in the Baltic Proper and Bothnian Sea in the figures to the right.

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Table 1. Calculated mean current speed and direction over varying depths and varying wind speeds. Calculated transportation distances for the different scenarios. Wind direction is set to 180°.

| | Current (curr) dir based on wind dir = 180 degrees, i.e. southerly winds. | | | | | | | | | |
| | Surface to 5m | | Surface to 10m | | Surface to 20m | | Surface to 40m | | Surface to 60m | |
Wind speed	mean curr speed 0-5m	mean curr dir 0-5m	mean curr speed 0-10m	mean curr dir 0-10m	mean curr speed 0-20m	mean curr dir 0-20m	mean curr speed 0-40m	mean curr dir 0-40m	mean curr speed 0-60m	mean curr dir 0-60m
5 m/s	0.04	26	0.03	34	0.03	46	0.02	64	0.02	77
10 m/s	0.08	21	0.06	28	0.03	37	0.04	50	0.03	61
15 m/s	0.12	19	0.10	24	0.09	31	0.07	42	0.06	50
Unit	m/s	degrees	m/s	degrees	m/s	degrees	m/s	degrees	m/s	degrees

Wind speed	Equals distance / day	Equals distance / 10 days	Equals distance / day	Equals distance / 10 days	Equals distance / day	Equals distance / 10 days	Equals distance / day	Equals distance / 10 days	Equals distance / day	Equals distance / 10 days
5 m/s	3.5	35.4	2.9	29.4	2.4	24.2	2.1	20.7	2.0	19.9
10 m/s	6.5	64.8	5.4	54.4	2.7	26.8	3.7	37.2	2.9	29.4
15 m/s	10.4	103.7	8.8	88.1	7.3	73.4	6.0	60.5	5.4	54.4
Unit	km/day	km/10 days	km/day	km/10 days	km/day	km/10 days	km/day	km/10 days	km/day	km/10 days

1 nm = 1.852 km
50 nm = 92.6 km

At the wind speed 5 m/s, it takes 26 days to transport the top 5 meters of the surface waters a distance of 50 nm.
At the wind speed 10 m/s, it takes 14 days to transport the top 5 meters of the surface waters a distance of 50 nm.
At the wind speed 15 m/s, it takes 9 days to transport the top 5 meters of the surface waters a distance of 50 nm.

In table 1, current speed and direction is calculated for different wind scenarios as well as the corresponding transporting distance during one or 10 days with prevailing wind. To transport the upper 5 meters a distance of 50nm, it takes:

- 26 days with a 5 m/s wind speed,
- 14 days with a 10 m/s wind speed and
- 9 days with a 15 m/s wind speed.

This depends mainly upon the dominating winds during the time of the discharge. In appendix 4, mean measured winds for each month over several years is displayed as well as modelled data displaying a time period with commonly occurring wind scenarios. In appendix 6, model data over the mean current is displayed, as well as the corresponding mean current during the chosen wind scenarios. There are also calculated tracks of
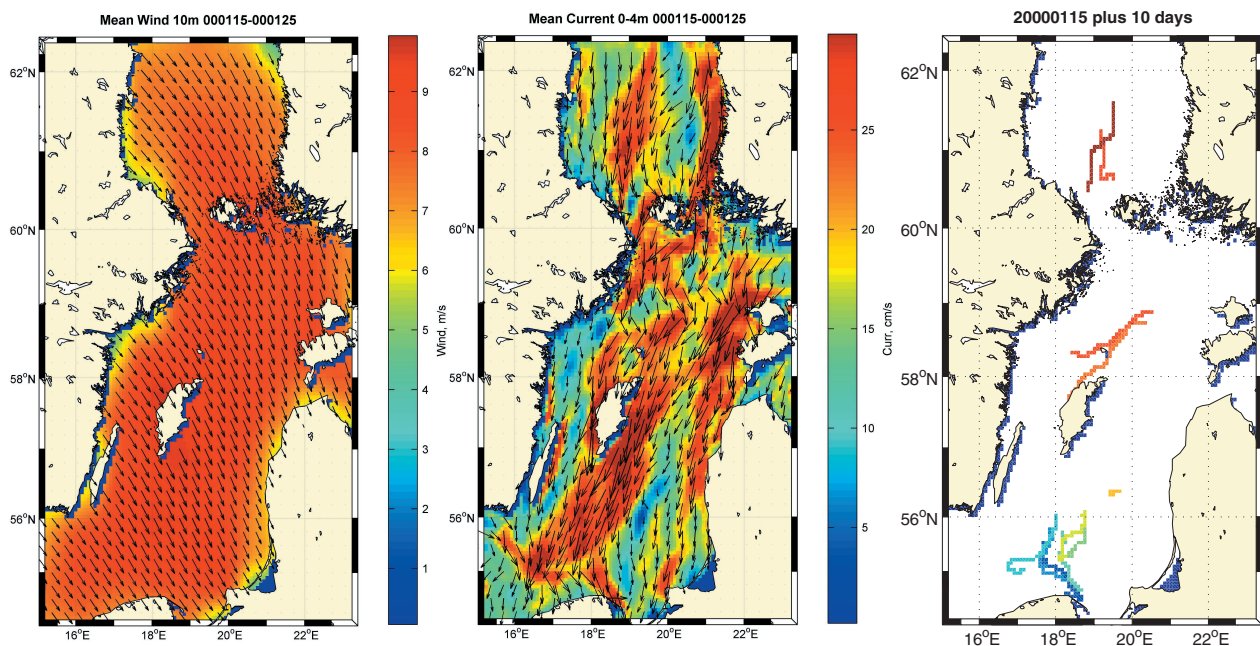

Figure 2. Modelled wind and current, mean values 000115 to 000125 and transportation of water parcels from 000115 to 000125 (starting at the upper right part of the lines).
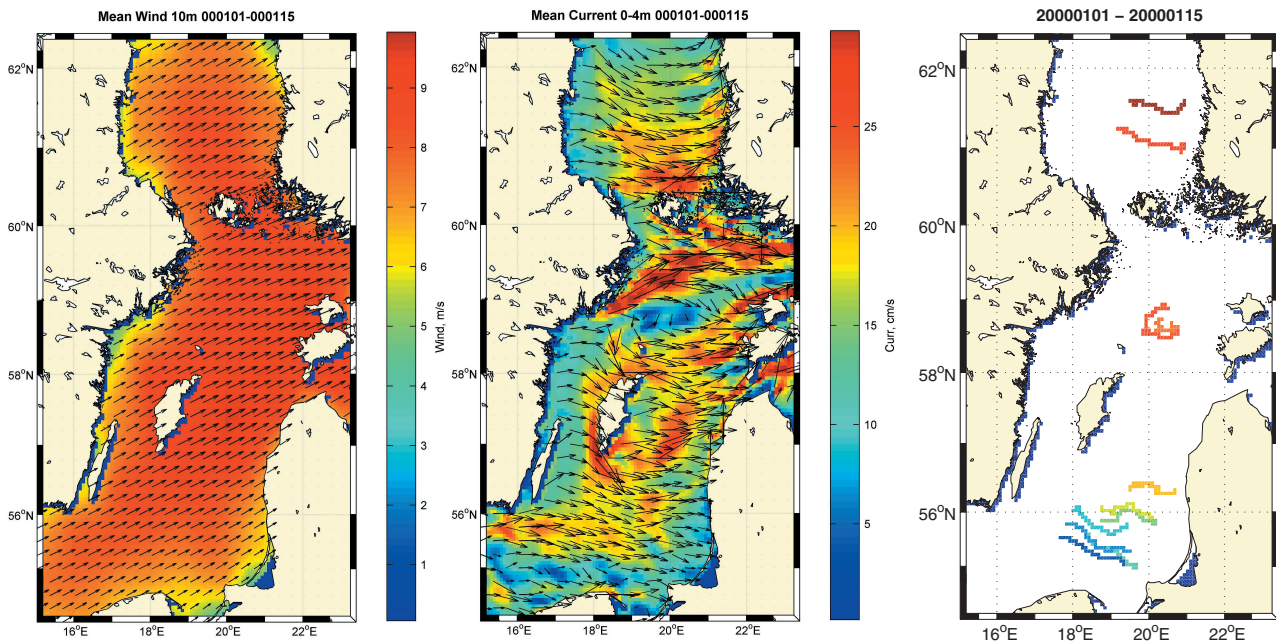
Figure 3. Modelled wind and current, mean values 000101 to 000115 and transportation of water parcels from 000101 to 000116 (starting positions at the left part of the lines).

imagined water parcels transported by the surface currents. With a prevailing wind of 15 m/s it can take one day to one week, depending on the wind direction, for the surface waters to reach the nearest protected area. The calculations are described in appendix 7.

The main force to create surface currents in the Baltic Sea is the wind and the most frequent wind direction is from the SW and W. Although, there are numerous occasions with prevailing wind from the other directions.

Depending on the strength of the wind, the direction of the surface current varies, but is slightly to the right of the direction of the wind. The stronger the wind, the narrower the deflection. The W winds often create a surface current heading towards the SE and the SW winds often create E surface currents.

Two different wind/current/transport scenarios are displayed. The first scenario is strong wind from the N-NW, (see figure 2) creating currents in the SW direction. The second scenario is strong wind from the SW, (see figure 3) creating currents in the E direction. There are also scenarios with E to NE winds, transporting the imagined water parcels towards the protected areas W and NW of the proposed BWE area in the southern Baltic Proper.

Another way of displaying the transport from the BWE area is to use model simulations from Seatrack Web, which is a particle transport model. The purpose of the simulations is to demonstrate how different parts of the Baltic Sea could be exposed to a BW discharge and how fast a discharge could be transported by the currents to different areas of interest, e.g. protected areas and coastal areas.

To capture different seasonal current conditions, the simulations covered a time period of one year. During the simulation, particles representing the BW discharge were released every 24 hours at 12 different locations distributed over the proposed discharge area in the central Baltic Sea.

The following statistical data was calculated after each run:
- (1) the maximum relative frequency of arrival of the particles to different grid cells,
- (2) the mean drift time of the particles and
- (3) the shortest drift time.

The lifetime of each particle was set to 30 days, which means that particles that had been drifting around for more than 30 days were not considered.

Figure 4 shows the maximum relative frequency of arrival for 2002. The black crosses mark the 12 discharge points and the black rectan-

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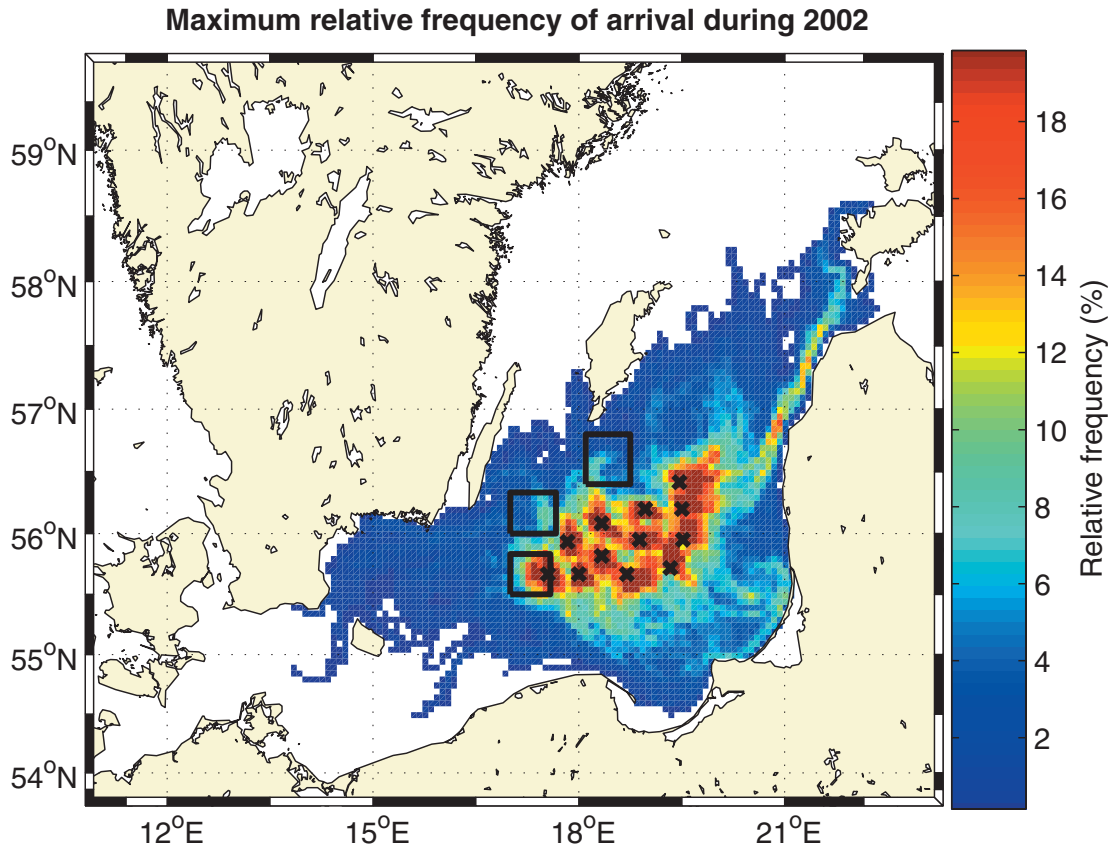## Maximum relative frequency of arrival during 2002

Figure 4. Maximum relative frequency of arrival to different parts of the model domain during 2002.

gles mark some nearby protected areas: Södra Midsjö bank (south), Norra Midsjö bank (middle) and Hoburgs bank (north). Close to the discharge points the probability approaches 100 %. However, the probability decreases fast with increasing distance to the discharge points. See the remaining runs in appendix 8.

The results for the three protected areas area summarised in table 2. The maximum relative frequency of arrival to the three areas was calculated by counting the number of particles that reached each protected area within 30 days after the time of discharge and then taking the maximum of all 12 runs. The mean drift time and the shortest drift time in the protected areas are the averages over the cells inside the rectangular boundaries of the areas.

On the basis of the simulations it is concluded that the discharges could be transported over large areas during a time period of one month. The probability that a BW discharge will reach the nearby protected areas Södra Midsjö bank, Norra Midsjö bank and Hoburgs bank is high, in particular Södra Midsjö bank seems to be heavily exposed. The simulations also showed that the discharge could reach the three protected areas within only a few days and coastal areas within 1-2 weeks.

These results are to be compared with the calculated results based on fundamental oceanographic equations (see table 4).

Table 2. Summary of the results for the protected areas.

Protected area	Statistical parameter	2002	2004
Södra Midsjö bank	Maximum relative frequency (%)	100	100
	Mean drift time averaged over the area (days)	12	9
	Shortest drift time averaged over the area (days)	1	1
Norra Midsjö bank	Maximum relative frequency (%)	26	9
	Mean drift time averaged over the area (days)	16	13
	Shortest drift time averaged over the area (days)	5	7
Hoburgs bank	Maximum relative frequency (%)	23	13
	Mean drift time averaged over the area (days)	20	19
	Shortest drift time averaged over the area (days)	9	9

2a. Will the organisms discharged with the ballast water circulate horizontally in the surface waters and by that, be present for ballast water uptake when the next ship is passing?

Most probably, the uptake of BW in the BWE area will be comprised of previously discharged BW, but at a low concentration.

By looking at the different results of transportation by the currents, referring to the previous question, the winds dominate the paths of the discharged water. Though there are many ships passing during one day which means that the currents may not transport the BW away from the BWE area before other ships enter the area, ready for BWE and by that uptake.

To make an estimate of the risk of possible uptake by the next ship, many parameters need to be included, for example traffic density, amount of BW discharges, assuming the BW is discharged within the BWE area, currents transporting the BW out of the BWE area, diffusion and wind speed (see appendix 7).

The total BWE per year was approximated to $1.9*10^9$ m^3. Approximately 220 ships pass the southern Baltic Proper per day. The longest distance from one end of the southern Baltic Proper BWE area to the other is approximately 50nm. Taking the average BW volume of a tanker/cargo ship, the ship needs to discharge 0.26 m^3 per travelled meter over 50nm. For larger ships on route, there might be a risk they have passed outside the BWE area before the BWE is completed.

There is an instant mixing, due to the discharge turbulence, so that the BW mixes in a 15 m^3 volume giving a BW concentration of 1.7% of the original concentration. Disregarding further mixing, 220 ships per day now cover approximately 1% of the total BWE area with a BW concentration of 1.7%. During the course of a day, each BW plume has spread to a 700 meter BW plume (diffusion, see appendix 7). If there is no wind mixing the BW further down, the new concentration a day after the discharge is 0.0074% of the original concentration making up a total area of 220% of the total BWE area.

Including wind mixing, the concentration will drop further. The calculations of the concentrations are only computed from day one, with no previous BW discharge, to the next. After several days, the concentration will be higher. Another factor concerning the concentration is that normally in a major shipping lane, the ships tend to follow somewhat the same route, markedly increasing the risk of BW uptake of higher concentration.

In many of the referenced texts, the concentration of the organisms in the BW is not of major importance. Some times the new organisms can survive and reproduce even at low starting numbers.

2b (biological condition). Will the discharged organisms die in the BWE area or in further transport after ballast water uptake from the next passing ship?

There is a wide variety of the BW salinity range in the ballast tanks, ranging from fresh water to marine waters. There is no real rule of thumb as to what salinity the ships entering the Baltic have in its ballast tanks.

There is also no way to say what specific salinity level will kill the BW organisms since there are many different organisms in the BW. Some can survive in a wide variety of salinities, some can not. It also depends upon where the BW is collected. Is it from a harbour with brackish water and the following BWE is conducted in brackish water; the environment is then very similar, not able to reduce the risk of survival. As a rule of thumb, there is always a risk that they may survive.

If there are only strictly marine organisms in the BW, they may not survive, but if they are capable of tolerating a wide range of salt water concentrations, there is a large risk they may survive in the brackish waters. Then they will live as long as they normally would in their original habitat. Furthermore, many freshwater organisms can survive the brackish waters.

Some organisms may survive a long time even though the new surroundings are not favourable. An example of that is the resting stage of some dinoflagellates. Other organisms may die very fast.

If there are organisms in a resting state, or sinking cysts that blends down into the BW sediments, there is a risk of the organisms surviving during a very long time. Resting stages, if resuspended into the water, can hatch after several decades and develop into HABs.

If the organisms are planktonic, it does not matter if they are released far from land, since as long as there are nutrients and light or food available, they can survive well. Also drifting, normally benthic organisms can survive, and even if they may not be able to resettle, some can continue to live and reproduce and the spores or fertilized eggs can settle, especially in the more shallow areas.

The idea of exchanging BW in the middle of the Atlantic is in the hope that the nutrient level is so low that the discharged organisms will not survive due to the lack of food and that the organisms there are adapted to live far offshore. Also, the distance to the coast is too far for neritic organisms to be able to reach the coast. The BW uptake in the middle of the Atlantic is hopefully also low in organisms able to survive in fresher water. The Baltic Sea is not very large and there are nutrients available most of the year (see appendix 2 and 3 for general hydrographic and biological descriptions).

If there are shallow areas, like the southern and northern Midsjöbank and the Hoburgsbank, near the BWE area, it offers a possible survival habitate, for the organisms needing shallower areas to survive.

3. What is the vertical circulation like in the areas >50nm from the coast?

Since there has been no investigation within this report of the buoyancy fluxes, the approximation is that the wind is the dominating factor mixing the surface layer to the lesser of the Ekman length and the pycnocline depth.

The vertical circulation can be described by the mixing of the surface layers. The thickness of the mixed layer is a function of the surface buoyancy flux (surface water getting lighter or heavier), the wind speed and the stratification (the change of density over depth).

The stronger the stratification, the harder it is for the mixing processes to mix the top layer with the water beneath. In the Baltic Proper, there is a seasonal thermocline developed during summer at about 20 meters depth which usually prevents mixing to greater depths. During autumn cooling, the surface and deeper water mix, resulting in more homogenous temperatures. There is a stable perennial halocline at 60 meters depth. Above the halocline, the salinity is rather homogeneous. The procedures are further explained in appendix 6.

In table 3, the Ekman lengths calculated using the monthly mean winds over the year (read more about the general wind climate in appendix 4) is compared to the mean pycnocline depths (read more in appendix 2). The mean winds are so low, that the pycnocline is never reached. Ekman length for wind scenarios with 5, 10 and 15 m/s is also combined with the mean pycnocline depths. In summer, the pycnocline restricts the wind induced mixing when the wind speed is 15 m/s (marked with yellow). Usually, the water layer above the pycnocline is rather well mixed, though

Table 3. Ekman layers, from the monthly mean and 5, 10 and 15 m/s winds are compared to the mean pycnocline depth. Yellow area indicate pycnocline restriction of the wind mixing depth.

	Month												Unit
	J	F	M	A	M	J	J	A	S	O	N	D	Unit
Mean wind	7	6.5	5.5	5	4.5	4.5	4	4	5	6	5.5	6.5	m/s
Pycnocline depth	60	60	60	60	60	60	20	20	40	60	60	60	m
Wind mixed depth	13.5	12.5	11	10	9	9	8	8	10	12	11	12.5	m
Wind 5 m/s mixed depth	10	10	10	10	10	10	10	10	10	10	10	10	m
Wind 10 m/s mixed depth	20	20	20	20	20	20	20	20	20	20	20	20	m
Wind 15 m/s mixed depth	35	35	35	35	35	35	20	20	35	35	35	35	m

during weaker wind scenarios, the wind induced mixing does not always reach to that depth, creating a shallower vertical mixing. The results from the southern Baltic Proper and the Bothnian Sea do not deviate much.

BIOLOGICAL CONDITIONS

4. Will the proposed BWE areas be affected by harmful aquatic organisms, including harmful algal blooms?

Yes, if harmful aquatic organisms or HAB:s are present in the BW, they will affect the area in some way. Though the BWE area might not be the area that suffers the consequences, since the algae or other organisms may need to grow in numbers to constitute for example a harmful algal bloom. While they increase, currents may transport the bloom away from the original BWE area.

Generally: if the organisms are harmful, they can or will affect the native organisms able to be affected. For example an organism harmful to fish, can or will affect the fish in the area. Also competing or predatory species may cause harm, especially in spawning areas of fish or on native species on the sea bed.

There will probably be a higher amount of native organisms affected if the BWE area is close to the coast, though pelagic organisms in the middle of the Baltic Sea can also be affected. Furthermore, there are native species caus-

ing HAB:s. Especially in summer some cyanobacteria may cause heavy blooms, such as Nodularia spumigena (potentially toxic) and Aphanizomenon flos-aquae, both of which mainly occur close to or at the surface. Thus, there is a high risk they may be taken up with ballast water loading

ENVIRONMENTAL CONDITIONS

5. Are protected areas/environments affected by discharges of alien organisms in the proposed BWE areas?

Like mentioned earlier, what is discharged can be transported to protected areas by the currents, if the organisms can live at some depth in the pelagic zone.

There are a number of protected areas more or less in the vicinity. The positions and approximated extension are marked in the maps on page 9 and in larger formats on page 24-27.

The time it takes for the wind induced current to transport a water parcel from the southern Baltic Proper BWE area to the nearest protected area is presented in table 4. These values are calculated by oceanographic equations.

The calculated values are comparable to the results from Seatrack Web. The shortest drift time averaged over the Hoburgs bank area is 9 days.

Table 4. Distances from the nearest part of the southern Baltic Proper proposed BWE area to the nearest protetcted area in each direction (top). The amount of days needed, with an ideal wind direction, for a water parcel to be transported to the protected area due to the wind speed. The direction in the table is the current direction.

	Direction							
Distance	S	SW	W	NW	N	NE	E	SE
nm	41 nm	46	0	14	15	46	26	34
km	76 km	85	0	26	28	85	48	63

	Direction							
Wind speed	S	SW	W	NW	N	NE	E	SE
5 m/s	21 days	24	0	7	8	24	13.5	18
10 m/s	12 days	13	0	4	4.5	13	7.5	10
15 m/s	7 days	8	0	2.5	3	8	4.5	6

Hoburgs bank is to the north of the BWE area, hence N is the direction to use in the table below. Since the mean wind over a year is about 5 to 6 m/s, that is the wind to use which results in a total of 8 days needed to be transported to the area. Only one days difference is a very good. Looking at the Norra Midsjö bank, the calculated value is 7 days and the modelled values 5 to 7. At the southern Midsjö bank the calculated value is 0 days and the modelled value 1.

If the organisms are harmful to a single species or to entire ecosystems, there is a clear risk of affecting protected areas. One of the difficult parts with alien species is that when they have established, they are hard to get rid of. Werner (personal communication). The fundamental difference between chemicals and living organisms, when calculating risks, is that the organisms can reproduce and actively spread further.

There are a number of bird reserves in the proximity to the proposed BWE area. Even if the BW does not contain organisms directly harmful to the birds, they may affect the food the birds eat, leading to a decreasing success of the bird breeding or less food during the wintering.

The problem with alien species is that there is hardly a way to predict how well they will behave in a new area. One species can have a very successful life in one area, causing major problems, while in a similar area of similar conditions there is hardly any noticeable impact. However, there are many examples of negative impact caused by an alien species also in very varying environments, according to Wallentinus (personal communication).

6. Are protected areas/ environments affected by discharges of pollutants or increased nutrient concentration in the proposed BWE areas?

Discharged pollutants normally affect the protected areas. A possible increase of nutrients in the surface waters, due to BW discharge, may increase the bloom capacity of the next bloom event or change the content of a normal bloom situation. A larger bloom can in turn lead to larger amounts of detritus sinking to the bottom, consuming oxygen when decomposing, hence decreasing the oxygen level at the bottom. Though probably, BW will not markedly influence the surface nutrient level, according to Wallentinus (personal communication) more than other nutrient sources from upwelling, land-runoff and atmospheric deposition.

IMPORTANT ASSETS

7. Are important assets, like fishery/play ground/spawning ground affected by BWE in the proposed areas?

There is no definite Yes or No, but a most definite Maybe, approaching Probably.

It depends on the content of the BW. BW does not have to be harmful, but if the BW contains fish parasites or organisms harmful to mussels, important assets like fish farms can be gravely affected. Mussels are the dominant organism in deep areas (hard surface) hence the effect can be very large. Also competing or predatory species may cause harm, especially in spawning areas of fish or on native species on the sea bed. Looking at the map over protected areas, there are spawning grounds very close to the southern Baltic Proper proposed BWE area.

The effect depends on many parameters, for example: where the BW comes from, what is the environment like there, what bio-region is it, the survival skills of the organisms in the new area and during the previous transport, the stress tolerance of the organism and what concentration of the organisms are there in the BW.

BALLAST WATER DISCHARGES

8. Quantification, origin and frequency.

The approximation in this report, of $1.9*10^9$ m^3, as the total annual BWE discharge in the southern Baltic Proper (see calculations and methods in appendix 7) can be compared with $2.3*10^7$ m^3 in an article by the Swedish National Environmental Protection agency (Anon. 1998). Though that total amount is based on a questionnaire, on traffic statistics and that the amount is discharged within Swedish waters. A similar study (questionnaire and traffic statistics) was conducted by Hoffrén (2006). In that study, an approximation of $4.6*10^7$ m^3 BW is discharged (though in Swedish waters) annually.

There are large sections in Leppäkoski (2006) covering these issues and the total annual BWE discharge in the Baltic Sea was there calculated to $1.2*10^8$ m^3.

By calculating the total annual BW discharge, many parameters are included and as many assumption are made. That the volume in this report differ greatly to the Leppäkoski value, is due to the different assumptions made.

In Hoffrén, some conclusions are that the discharged BW mostly originates from the Baltic Sea and the North Sea. The ships main destination from Sweden is the Baltic and the North Sea and the estimated main origin of BW leaving Sweden mostly came from other Swedish waters and the Baltic Sea.

Normally the trans-Atlantic ships and ships arriving from very far away, have had the possibility to conduct a BWE in areas >200nm from the coast at >200 meters of depth. The high risk ships are European ships, not having been able to conduct BWE at >200nm from the coast at >200 meters of depth. Wallentinus (personal communication).

The point to make is that most of the ships coming into the Baltic area have not had the possibility to make a BWE according to the basic IMO guidelines, hence being high risk ships.

DISCUSSION & CONCLUSIONS

In this report, investigations were made to find out if there are areas with suitable environments for ballast water exchange. Suitable conditions may be areas of certain depths (preferably >200 meters), salinities or other conditions that effectively can kill the organisms from the ballast water and that they do not spread to the coast or to protected areas. The main focus is on the southern Baltic Proper since it is the area with the highest traffic, it has the largest of the two existing areas in the Baltic Sea >50nm from the coast.

In the assignment there were different aspects of the questions at issue. The discussion and conclusions are divided up into these different aspects.

Oceanographic conditions

Some of the questions were about transport and mixing. In order to perform those calculations, general wind climate and current conditions needed to be investigated. The main force to create surface currents in the Baltic Sea is the wind and the most frequent wind direction is from the SW and W. Although, there are numerous occasions with prevailing wind from the other directions. The mean wind speeds are 7-8 m/s during the winter and 4-5 m/s during summer, though the variation of both speed and direction are large. During winter winds almost reach 25 m/s and during summer almost 15 m/s, but those events are not very common. The direction of the wind is dominated by south-westerly to westerly winds,

The speed of the surface current is mainly dependant on the wind speed. Depending on the strength of the wind, the direction of the surface current varies, but is slightly to the right of the direction of the wind. The mean speed and direction of the surface water depends on the wind and the thickness of the surface layer of interest. To transport the upper 5 meters a distance of 50nm, it takes:

- 26 days with a 5 m/s wind speed and
- 9 days with a 15 m/s wind speed.

The distances to the nearest protected area in each direction and the time for the surface waters to reach the areas (providing prevailing wind in the optimal direction), the amount of days to reach the areas vary between:

- 0 to 24 days with 5 m/s wind and
- between 0 to 8 days with 15 m/s wind.

The calculations corresponded well with the modelled simulations hence is concluded that the discharges could be transported over large areas during a time period of one month. The probability that a BW discharge will reach the nearby protected areas Södra Midsjö bank, Norra Midsjö bank and Hoburgs bank is high. The simulations also showed that the discharge could reach the three protected areas within only a few days and coastal areas within 1-2 weeks.

When it comes to mixing, the seasonal thermocline in the Baltic Proper is developed during summer at about 20 meters depth which prevents mixing to greater depths. During autumn cooling, the surface and deeper water mix, resulting in more homogenous temperatures. There is a stable perennial halocline at 60 meters depth. Above the halocline, the salinity is rather homogeneous.

Waves also contribute to the mixing, higher waves obviously more so than small waves. Another aspect to be included is the safety for the ship and crew. Rough wave climates pose as high risk for the ship and crew. Mainly the significant wave heights in the Baltic Proper are less than 3 meters. During the winter, the main part is below 4 meters. These are not rough scenarios, but there are occasions with significant wave height of 6-7 meters, which in many cases can pose as higher risk, though these occasions are quite scarce. As a conclusion, the wave climate in the Baltic Proper is not very rough, especially when comparing to more open sea areas.

A general description of the hydrography is needed to understand more about the environment in the area. The Baltic is a sensitive area partly due to the narrow and shallow connection to the sea. The very brackish surface waters vary between 5 psu in the Bothnian Sea to 7 psu in the southern Baltic Proper. The difference between fresh and central Baltic Proper water is not large.

There are distinct seasonal variations of many parameters in the surface waters. Connecting to above, the change is not only present in the surface, but generally throughout the mixed layer depth. The nutrients and chl-a clearly indicate biological activity, mainly during spring, but there are nutrients enough for the summer and autumn blooms. A conclusion to be made is that the nutrient level is not low enough to prevent indigenous species survival.

Biological conditions

More than 105 non indigenous species have been recorded in the brackish waters of the Baltic Sea, most of them due to shipping. Species invasions are related to the volume of BW released, the frequency of ship visits, and most importantly the environmental match of donor and recipient region of the BW (Leppäkoski, 2006).

According to Wallentinus and Leppäkoski, usually the trans-Atlantic ships and ships arriving from very far away have had the possibility to conduct a BWE in suitable areas. The high risk ships are mainly European ships, not having suitable areas along the route. Despite this, the most important donor area is the east coast of North America, having contributed to approximately 30% of all known introductions to the Baltic Sea.

The idea of exchanging BW in the middle of the Atlantic is in the hope that the nutrient level is so low that the discharged organisms will not survive due to the lack of food and that the organisms there are adapted to live far offshore. The Baltic Sea is not very large and there are nutrients available most of the year. During spring, the biovolume is at its highest, though there are biological activities (even HABs), mainly to the end of the year.

If the organisms are planktonic, it does not matter if they are released far from land, since as long as there are nutrients and light or food available, they can survive well. If there are shallow areas, like the southern and northern Midsjöbank and the Hoburgsbank, near the southern Baltic Proper proposed BWE area, it offers a possible survival area, for the organisms needing shallower areas to survive. The wind mixes the water over a certain depth, and it also transports this mixed layer from the discharge area. If the water is transported towards a protected area, like the ones mentioned above, the entire water column over the shallow area is a mixture with BW.

Another risk reducing measure is a large salinity difference between the donor and the recipient. Though there is also no way to say what specific salinity level will kill the BW organisms since there are many different organisms in the BW. As a rule of thumb, there is always a risk that they may survive.

Generally: if the organisms are harmful, they can or will affect the native organisms able to be affected. For example an organism harmful to fish, can or will affect the fish in the area. Also competing or predatory species may cause harm, especially in spawning areas of fish or on native species on the sea bed.

In the risk evaluation (Leppäkoski), factors like temperature, salinity, time of the transport and the route was analysed. In general there is a high risk when the area of origin and recipient is in the same bioregion and low risk when they are not even located next to a similar area (greater distances - lower risk). The greater the difference in salinity is between two areas, the lower the risk. For the transport time; <3 days (at 16 knots) gives high risk and >10 days gives low risk. However, that also depends on the organisms, and in general resting stages probably will survive and constitute a high risk for quite a long time.

Harbours with a high frequency of ships with BW potentially originating from outside the Baltic Proper, are exposed to a higher risk of non indigenous species introductions and are evaluated based on that. Some of the conclusions were that all chosen recipient harbours in the Baltic Proper have at least one high risk donor harbour and all the extreme and high risk donor harbours were located in Europe, but outside the Baltic.

Environmental conditions and important assets

The environment at the BWE area or in nearby protected areas, possibly with important assets, can be affected by the BW, but it is quite dependant on what the BW contains. There is a wide variety of what it can contain. If the organisms are harmful to a single species or to entire ecosystems, there is a clear risk of affecting protected areas. The effect then depends on many parameters, for example: where the BW comes from, what the donor environment is like, from what donor bioregion, the survival skills of the organisms discharged in the new area and during the previous transport, the stress tolerance of the organism and what organism concentration it is in the BW.

The organisms discharged with the BW can be transported to protected areas by the currents, if the organisms can live at some depth in the pelagic zone. There are a number of protected areas more or less in the vicinity, for example spawning grounds, fishing areas and bird reserves. Even if the BW does not contain an organism directly harmful to the birds, they may affect the food the birds eat, leading to a decreasing success of the bird breeding or less food during the wintering.

Important assets like fish farms can be gravely affected. Also competing or predatory species may cause harm, especially in spawning areas of fish or on native species on the sea bed. Looking at the map over protected areas, there are spawning grounds very close to the southern Baltic Proper proposed BWE area. Discharged pollutants normally affect the protected areas if transported to the area.

Ballast water discharges

Taking consideration to traffic intensity, what ships are passing the area, what the BW volume is, the total annual BWE discharge in the southern Baltic Proper was approximated to $1.9*10^9$ m^3. Behind the number, there are many assumptions made, especially when estimating the concentrations and calculating the risk of a ship taking up BW from a previous discharge.

Disregarding further mixing after the total BW discharge during the course of one day, the BW will cover approximately 1% of the total BWE area at a concentration of about 2 %. During the course of a day, by including diffusion, the area has spread 220% of the total BWE area, now with a concentration of 0.007%. If the wind mixes the water to greater depths, the concentration will drop further. These are calculations during one day, but after several days, the concentration will obviously be higher. Another factor concerning the concentration is that normally in a major shipping lane, the ships tend to follow somewhat the same route, markedly increasing the risk of BW uptake of higher concentration. The currents cannot transport the discharged BW in the surface waters fast enough away from the BWE area before the arrival of the next ship.

The conclusion is that most probably, the uptake of BW in the BWE area will be comprised of previously discharged BW, but to a low concentration. Though, in many of the referenced texts, the concentrations of the organisms are not of major importance. Some times the new organisms can survive and reproduce even at low starting numbers.

A final comment:
The proposed BWE in the southern Baltic Proper is situated somewhat away from the main shipping lane. It would be difficult to motivate enough to change the main shipping lane through the BWE area and the ships actually following it. In the report from the Swedish National Environmental Protection agency (Anon. 1998), a comment was that: few ships reported having exchanged ballast water while out at sea, which of none had been for the purpose of preventing the spreading of alien aquatic organisms and pathogens.

ACKNOWLEDGEMENTS

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http://www.regionblekinge.se/includes/dokument.asp?ID=Kartbok.pdf

Sydhavsvind – planeringsunderlag för utbyggnad av stora vindkraftsanläggningar till havs:
http://www.m.lst.se/documents/sydhavsvind.pdf

APPENDICES

APPENDIX 1: MAPS WITH BWE AREAS, PROTECTED AREAS AND SHIPPING LANES

Map over shipping lanes, areas >50nm from the coast, protected areas and depth range of the Baltic Sea. The first map is an overview of both areas >50nm from the coast.

The map in figure 6, includes the southern Baltic Proper BWE area, major shipping lanes, protected areas in Swedish waters. The legend describes the different areas marked in the map. The location of the different areas are gathered from Sydhavsvind and Kartbok Euroregion Baltic och Östersjön (see web addresses in the references).

The following three maps are received from the SMHI tool SeaTrackWeb. SeaTrackWeb is mainly used to calculate and give a graphical map of tracks from for example oil spill, forwards and backwards in time. The maps include Baltic Sea Protected areas and important bird areas, not only in Swedish waters. These maps have been used to calculate the distance to the nearest protected area from the proposed BWE areas.
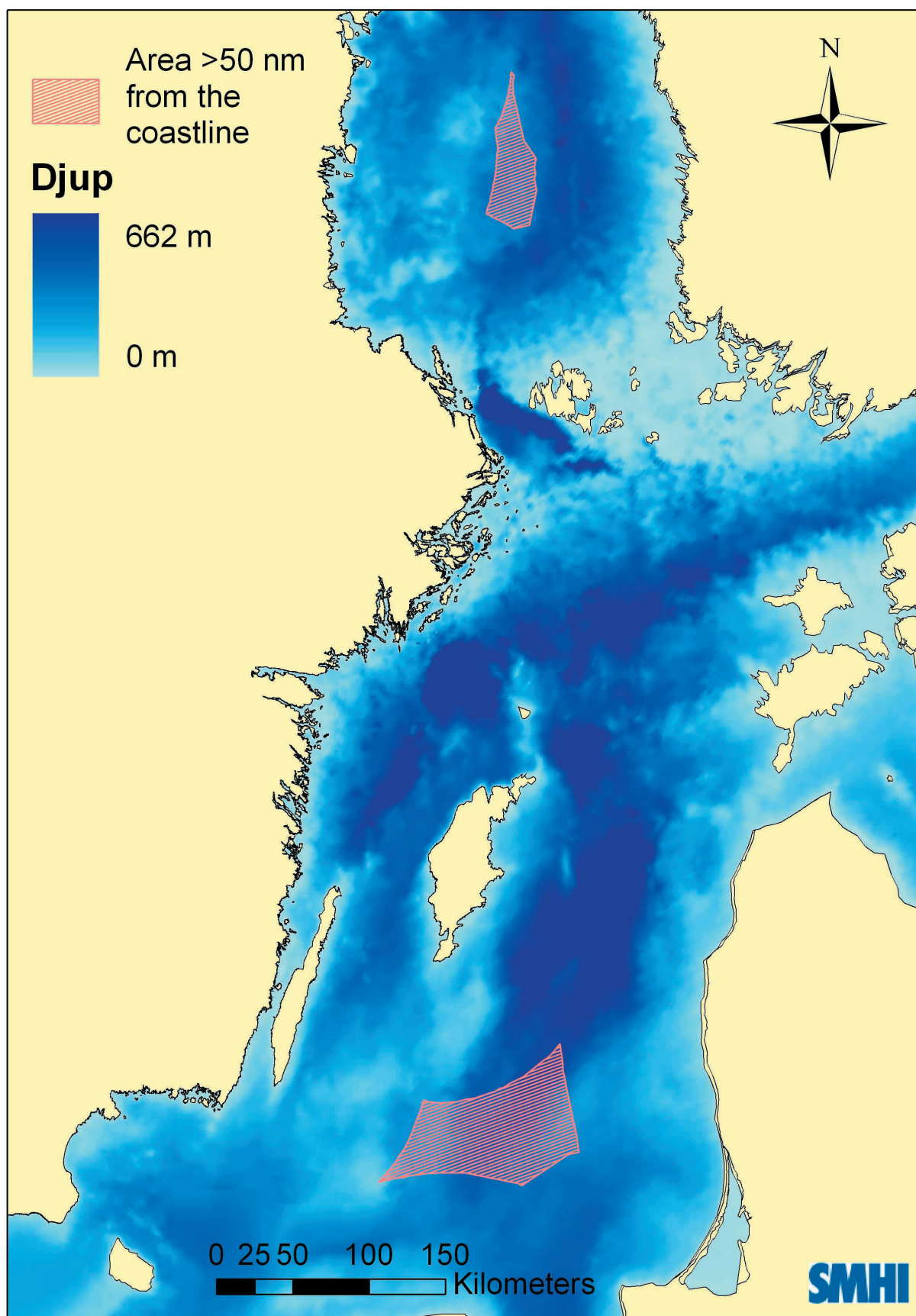
Figure 5. Overview of both areas >50nm from the coast and the depth range in the Baltic Sea.

Legend:
- Area >50 nm from the coastline
- Spawning ground
- Planned Natura 2000 area
- Fishing area and/or bird reserve
- PROTECTED AREA:
  - Very high priority
  - High priority
  - Low priority
- Wind parks (existing/planned)
- Shipping lanes

SMHI

Figure 6. Overview of the proposed southern Baltic Proper BWE area, protected areas in Swedish waters and major shipping lanes.
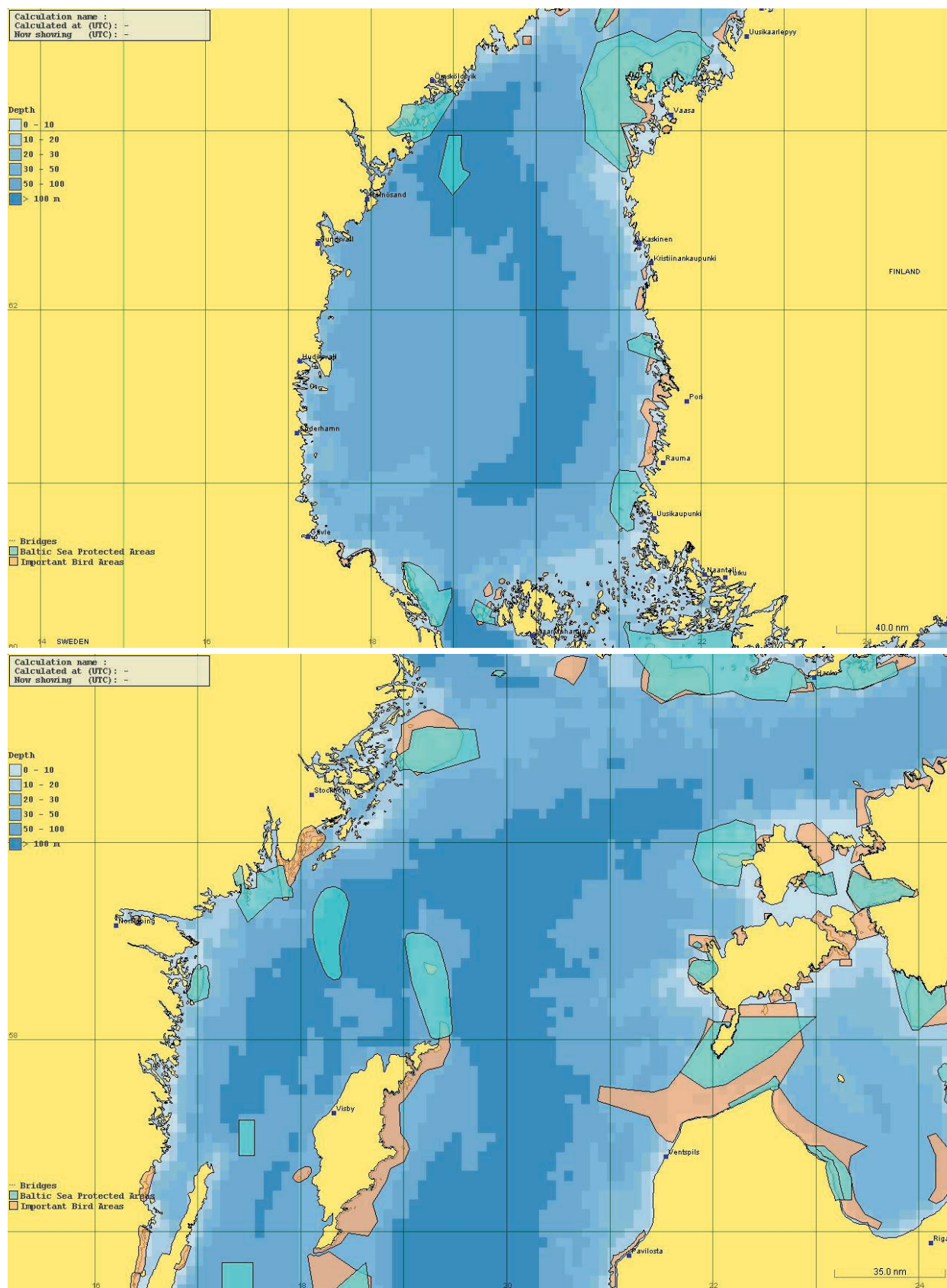
Figure 7a (top) and b (bottom). SeaTrackWeb maps of the Baltic sea, including Baltic Sea Protected areas and important bird areas, not only situated in Swedish waters. The top map is the Bothnian sea and the bottom map is the northern Baltic Proper.
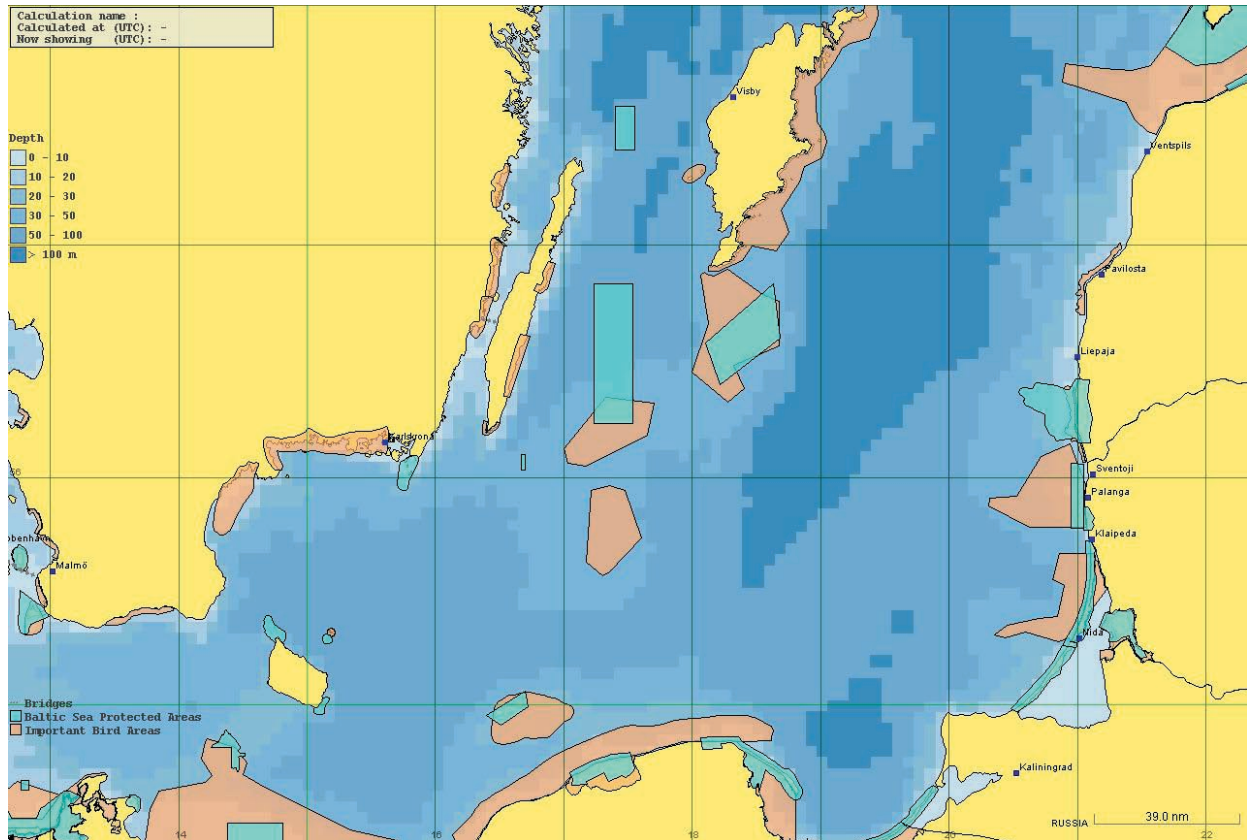
Figure 7c. SeaTrackWeb map of the southern Baltic Proper, including Baltic Sea Protected areas and important bird areas, not only situated in Swedish waters.

Table 5. The closest distance in each point of the compass from the Southern Baltic Proper proposed BWE area to a protective area. The distances are given in nm and in km (1 nm = 1852 m).

	Direction							
Distance	S	SW	W	NW	N	NE	E	SE
nm	41	46	0	14	15	46	26	34
km	76	85	0	26	28	85	48	63

In the table above, distances to the nearest protected area from the proposed BWE areas have been calculated for each direction.

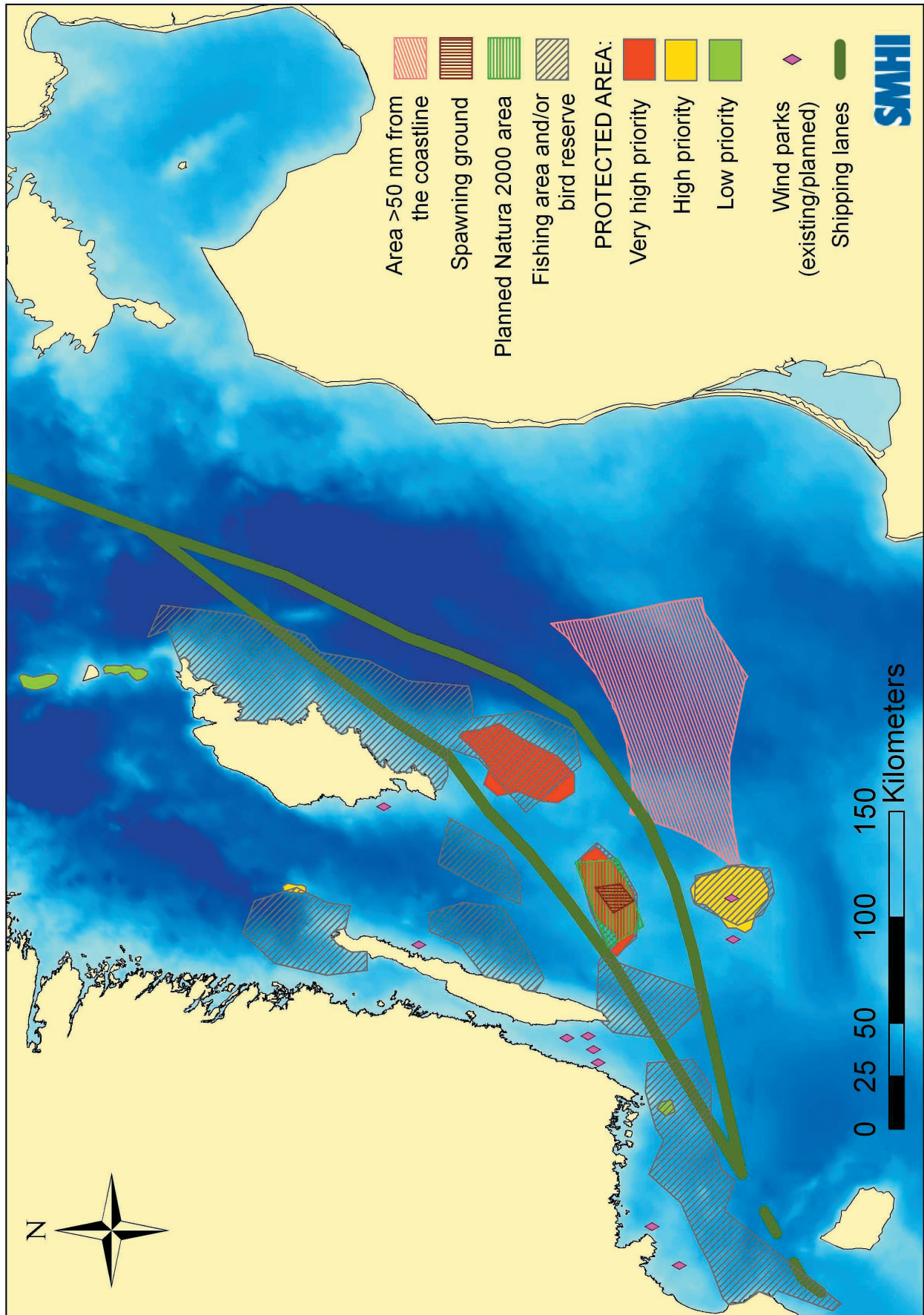In Dragsund et. al 2005 and Leppäkoski, E. & Gollasch, S. 2006, the maps indicate larger and more than two areas >50 nm from the coast. By using a 50nm buffer zone from the coast, it is clear that there are only two areas >50nm in the Baltic Sea. One in the southern Baltic Proper and one in the Bothnian Sea. There could have been a smaller area in the northern Baltic Proper, but with the Gotska Sandön, there is no area in the northern Baltic Proper. For general interest, some of the results from the northern Baltic Proper are still included.

The distances to the closest protected areas in the Bothnian sea are in most directions almost the same as the distance to the coast, which is 50nm. The same would apply to the non-existing area in the northern Baltic Proper.

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APPENDIX 2: GENERAL HYDROGRAPHIC DESCRIPTION

General description of the areas in the Baltic Proper and Bothnian Sea > 50nm from the coastline (waves and main part of currents excluded). A general salinity map for the Baltic Sea has been produced by calculating the mean of the top layer from the HIROMB model data during the entire year 2003. By the same procedure, a general circulation image was also produced.

The surface waters for a number of parameters are displayed by each month for the three areas southern Baltic Proper, northern Baltic Proper and the Bothnian Sea.

In the map below, data host stations are marked with red dots, SMHI stations with blue dots and the white dots are terminated stations. For analysis of the southern Baltic Proper, BCS III-10 and BY10 were used. For the northern Baltic Proper, BY31 and BY29 were used. In the Bothnian Sea, SR5/C4, MS4/C14 and F26 were used.

For temperature, salinity and sigmaT, the entire depth column is displayed over several years as iso plots.

The monthly mean values between 1994 and 2006 for temperature, salinity and sigmaT in the southern Baltic Proper is compiled to present the change and depth of the pycnocline depth over the year.

Figure 8. Map of stations. Data host stations are marked with red dots, SMHI stations with blue dots and the white dots are terminated stations. For analysis of the southern Baltic Proper, BCS III-10 and BY10 were used. For the northern Baltic Proper, BY31 and BY29 were used. In the Bothnian Sea, SR5/C4, MS4/C14 and F26 were used.
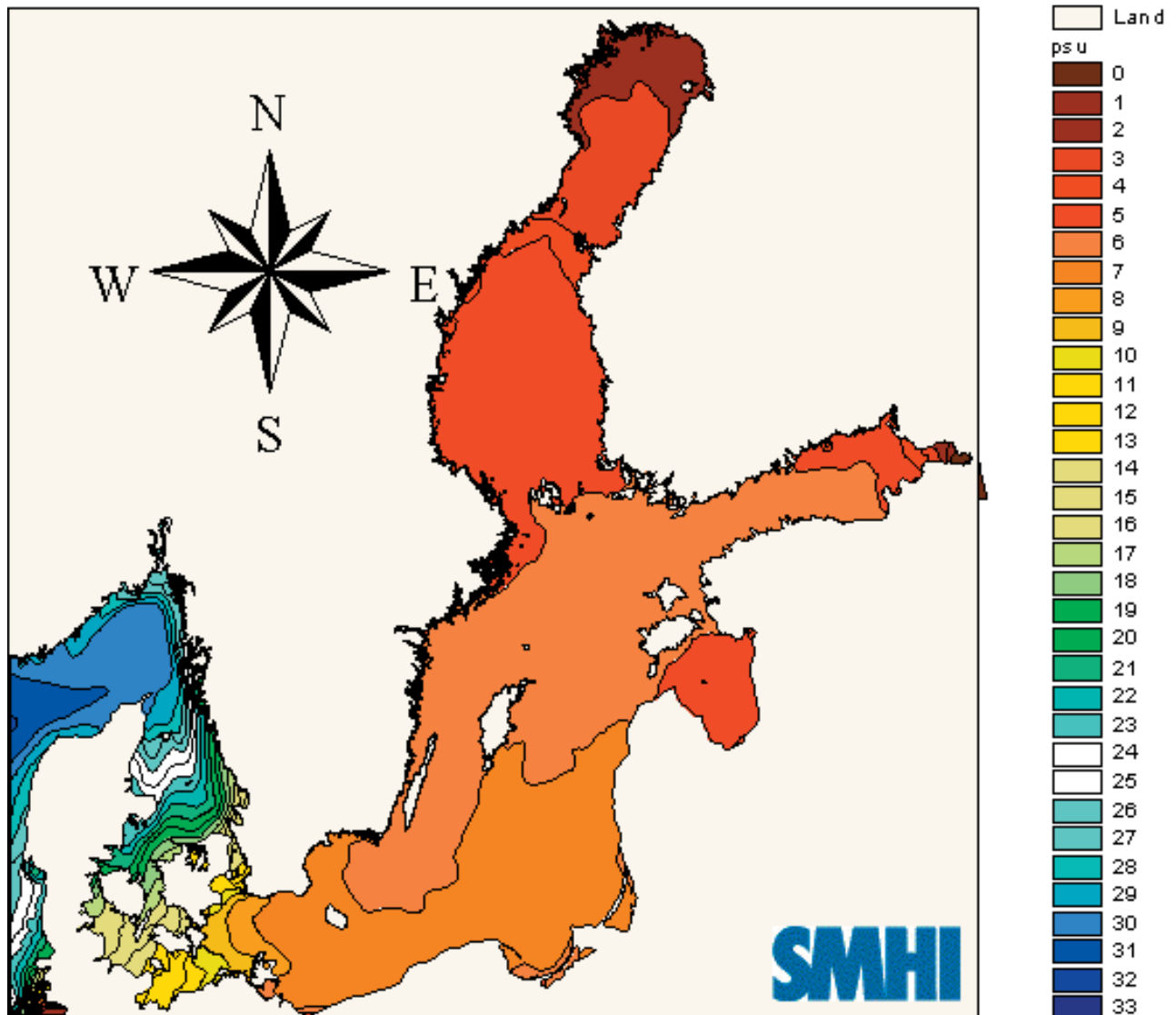
Figure 9. A general salinity map for the Baltic Sea by the mean of the top layer from the HIROMB model data during the year 2003.

The Baltic is like an estuary with a narrow and shallow connection to the sea. The greatest sill depth is about 18 meters. Due to the relatively large freshwater supply and the limited connection to the sea, the salinity in the upper layer of the Baltic Proper is about 6-7 psu with a permanent halocline at about 60 meters depth. There is also a horizontal salinity gradient from the north towards the Kattegat and the Skagerrak due to the runoff with higher levels of salinity on all levels in the inflow region in the southwest.

Most of the time, there is an outflow from the Baltic due to the relatively large freshwater supply, but every now end then, dense water from the Kattegat flows into the Baltic Proper like a dense bottom current. On its way, it entrains fresher water from above. Vertical mixing processes lift the denser water through the halocline into the upper layer where it is mixed with the freshwater supplied through the sea surface. The surface layer loses water to the ocean via the Belt Sea and Kattegat (Stigebrandt, 1985).
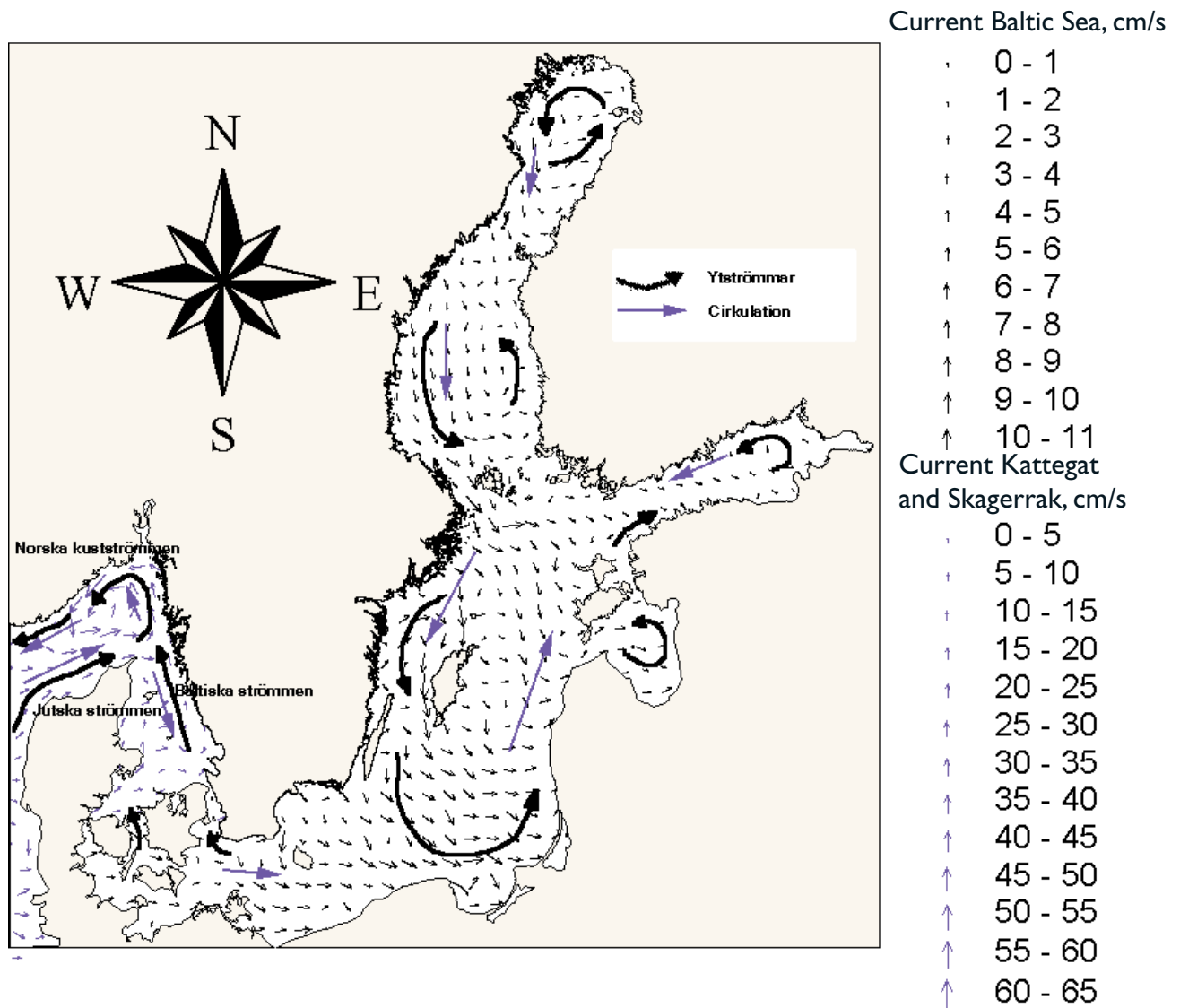
Figure 10. A general current map for the Baltic Sea by the mean of the top layer from the HIROMB model data during the year 2003.

Since the earth is a rotating system, everything is influenced by the different forces of the motion. By generalizing the mean currents from one year, the currents are clearly influenced by the Coriolis force. The fresher (mainly supplied from the northern parts) surface waters get deflected slightly to the right of its original motion until the coast prohibits further deflection. The water then continues to flow along the coast. The counterclockwise rotation of the surface currents are marked in the figure above as black arrows.

The main force to create horizontal surface currents in the Baltic Sea is the wind and the predominant wind direction is SW winds, that is most of the winds come from the south-west and the west.

Depending on the strength of the wind, the direction of the surface current gets vary, but is slightly to the right of the direction of the wind. The stronger the wind, the narrower the deflection. The westerly winds often create a surface current heading towards the south-east and the south-westerly winds often create easterly surface currents, hence the mean surface currents in the southern Baltic Proper.

Due to friction, the moving surface waters affect the water layers beneath and each layer move slower than the one above and each layer move slightly more to the right than the layer above (until the wind induced motion reaches zero). In an idealized situation, the surface current is 45 degrees to the right of the wind direction an the net current induced by the wind, is 90 degrees to the right of the wind (in the Northern Hemisphere). Normally, these angles are less than above mentioned.
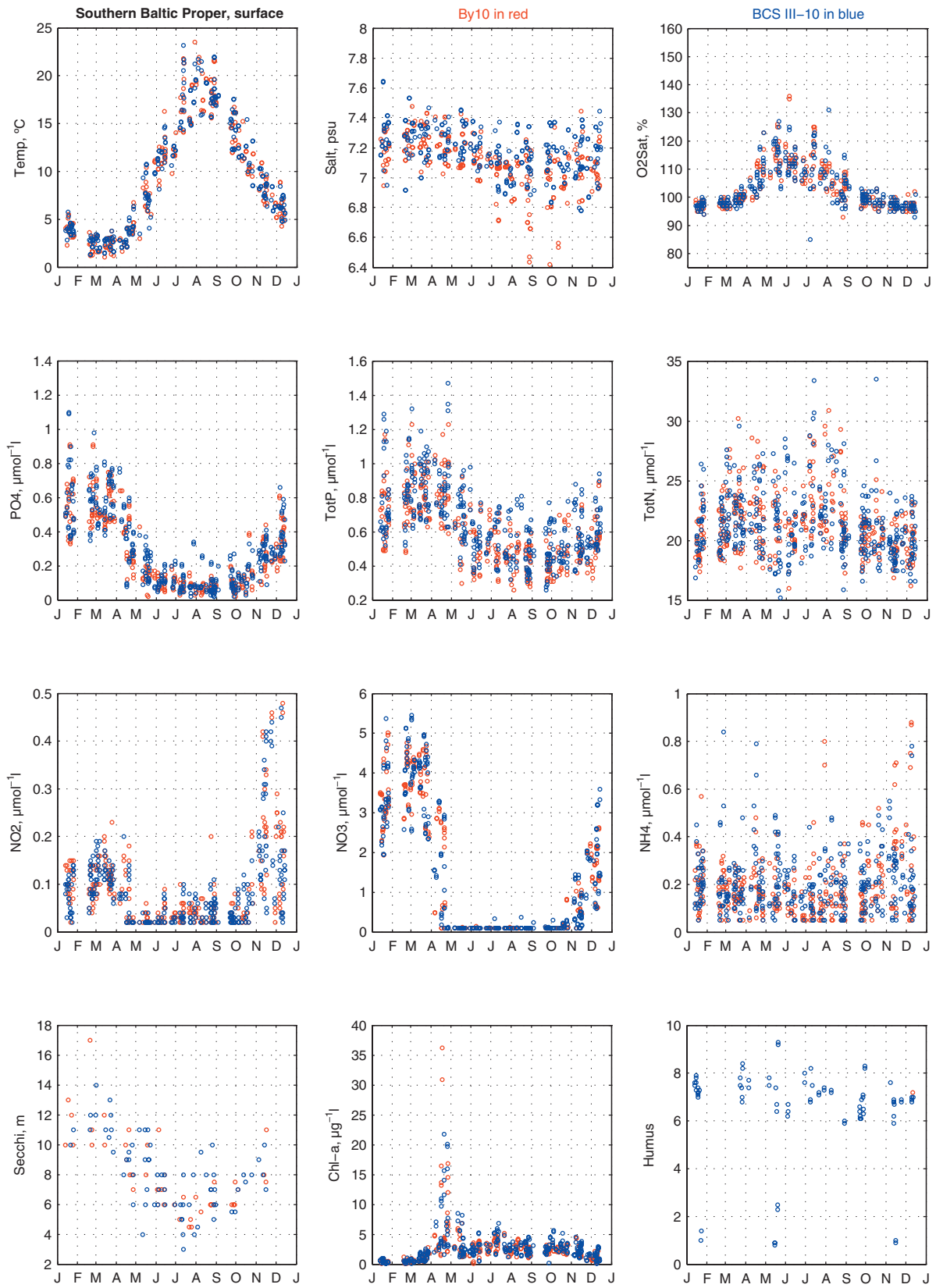
Figure 11. Surface values for a number of parameters in the southern Baltic Proper on a monthly basis from 1990 to 2006. Stations included are BY10 and BCS III-10.

31
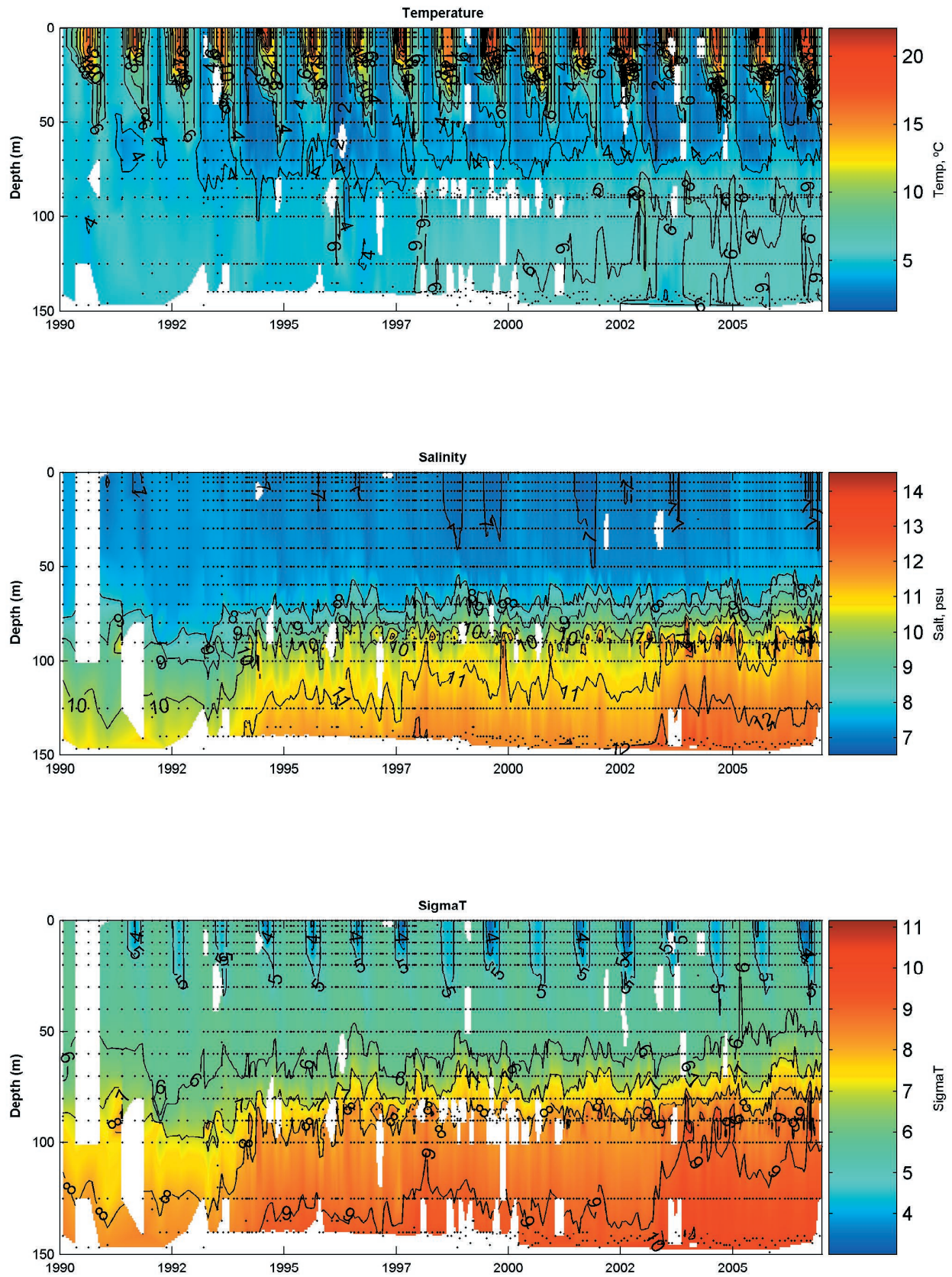
Figure 12. Iso plots of temperature, salinity and sigmaT from surface to the bottom in the southern Baltic Proper from 1990 to 2006. Stations included are BY10 and BCS III-10.
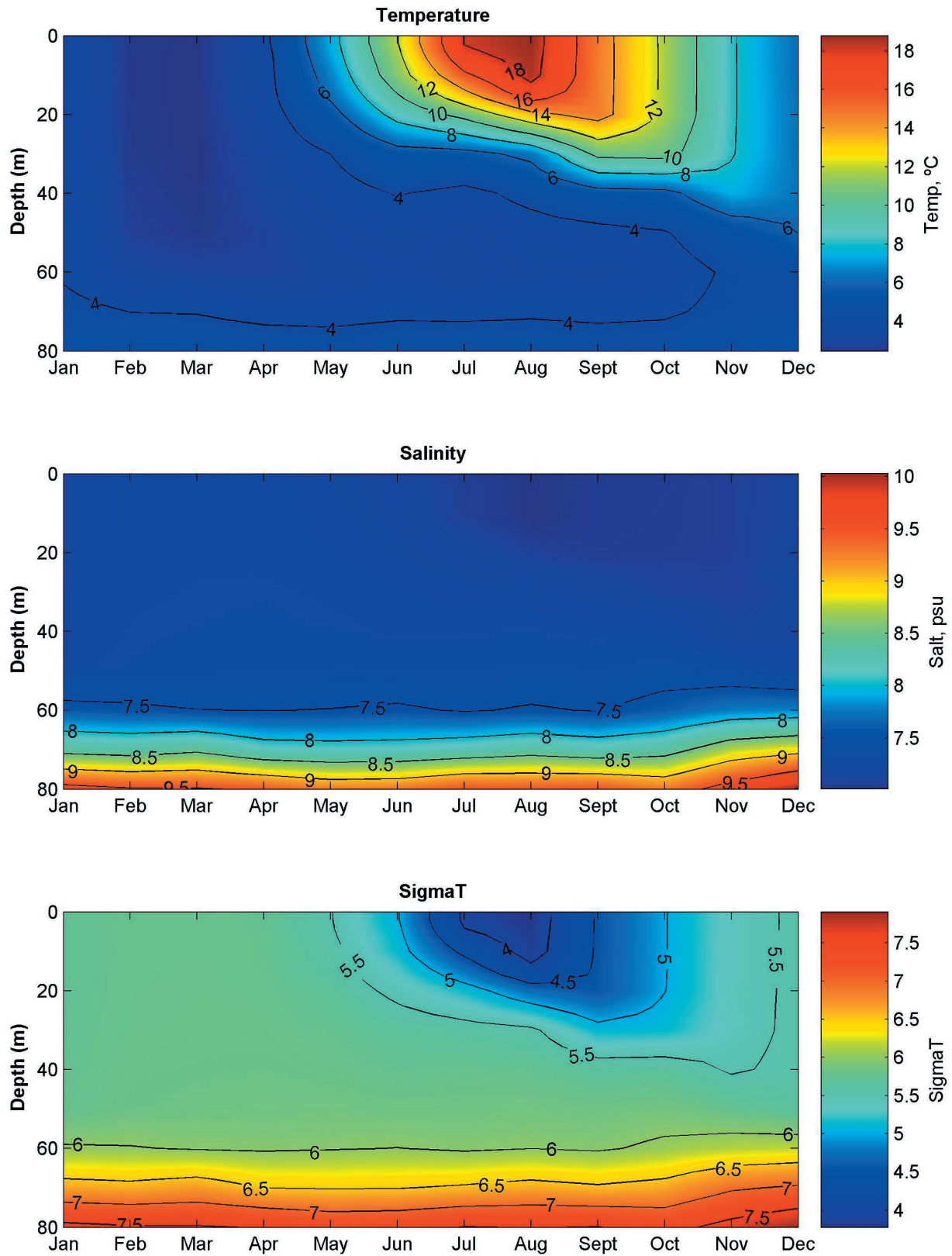
Figure 13. Iso plots of temperature, salinity and sigmaT from surface to 80 meters in the southern Baltic Proper. Monthly mean values from 1994 to 2006. Stations included are BY10 and BCS III-10.

33
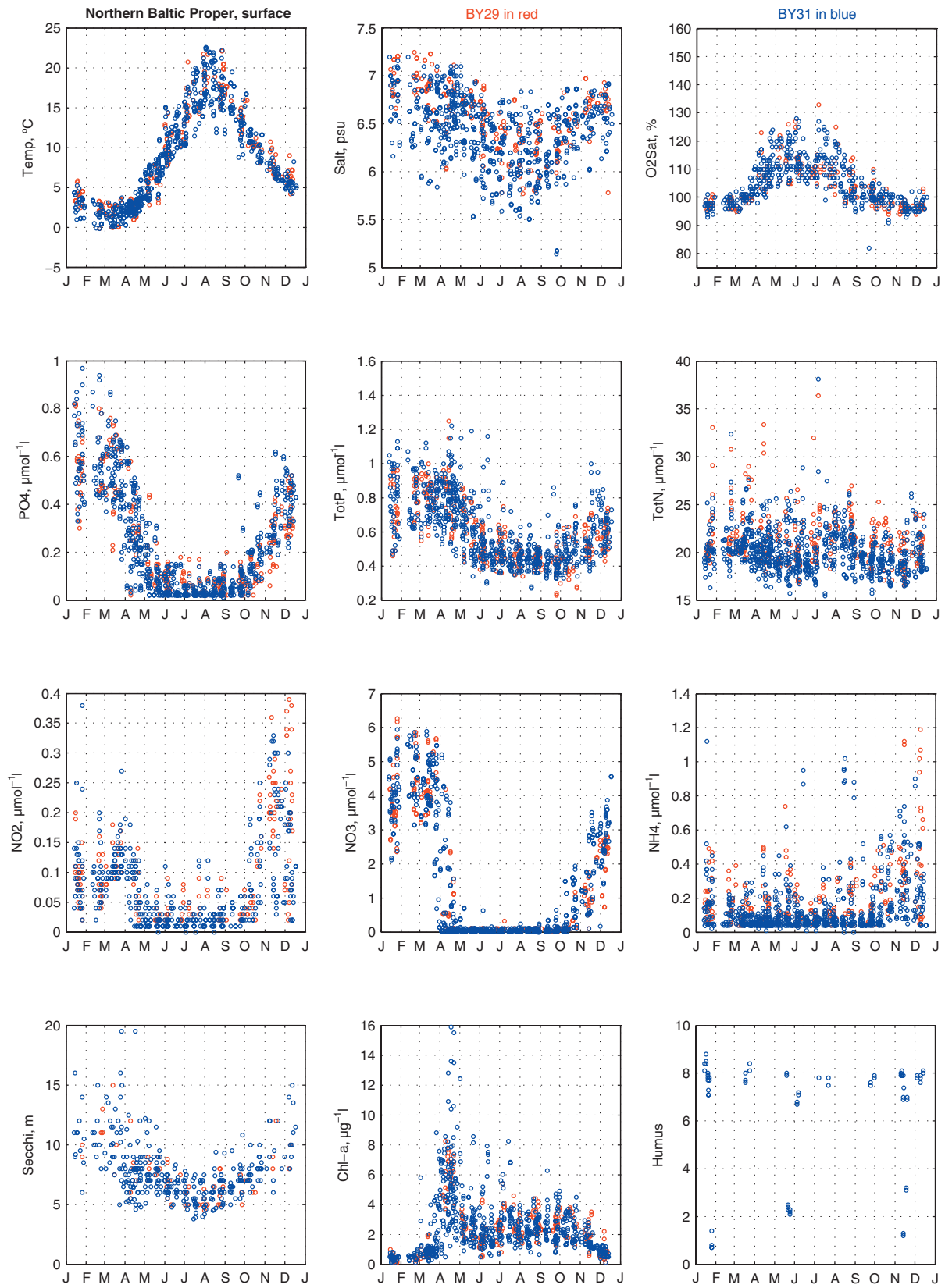
Figure 14. Surface values for a number of parameters in the northern Baltic Proper on a monthly basis from 1990 to 2006. Stations included are BY29 and BY31.
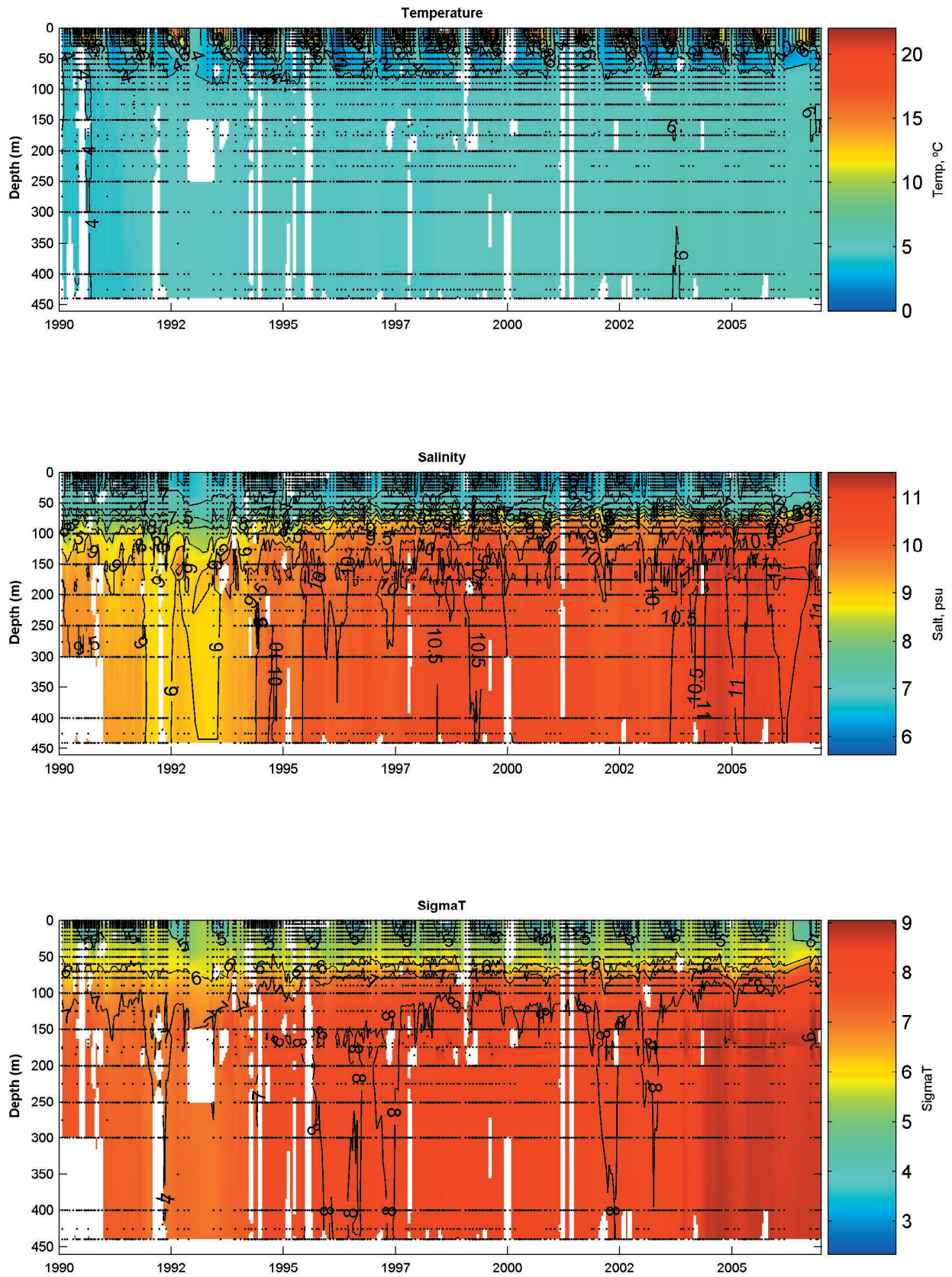
Figure 15. Iso plots of temperature, salinity and sigmaT from surface to the bottom in the northern Baltic Proper from 1990 to 2006. Stations included are BY29 and BY31.
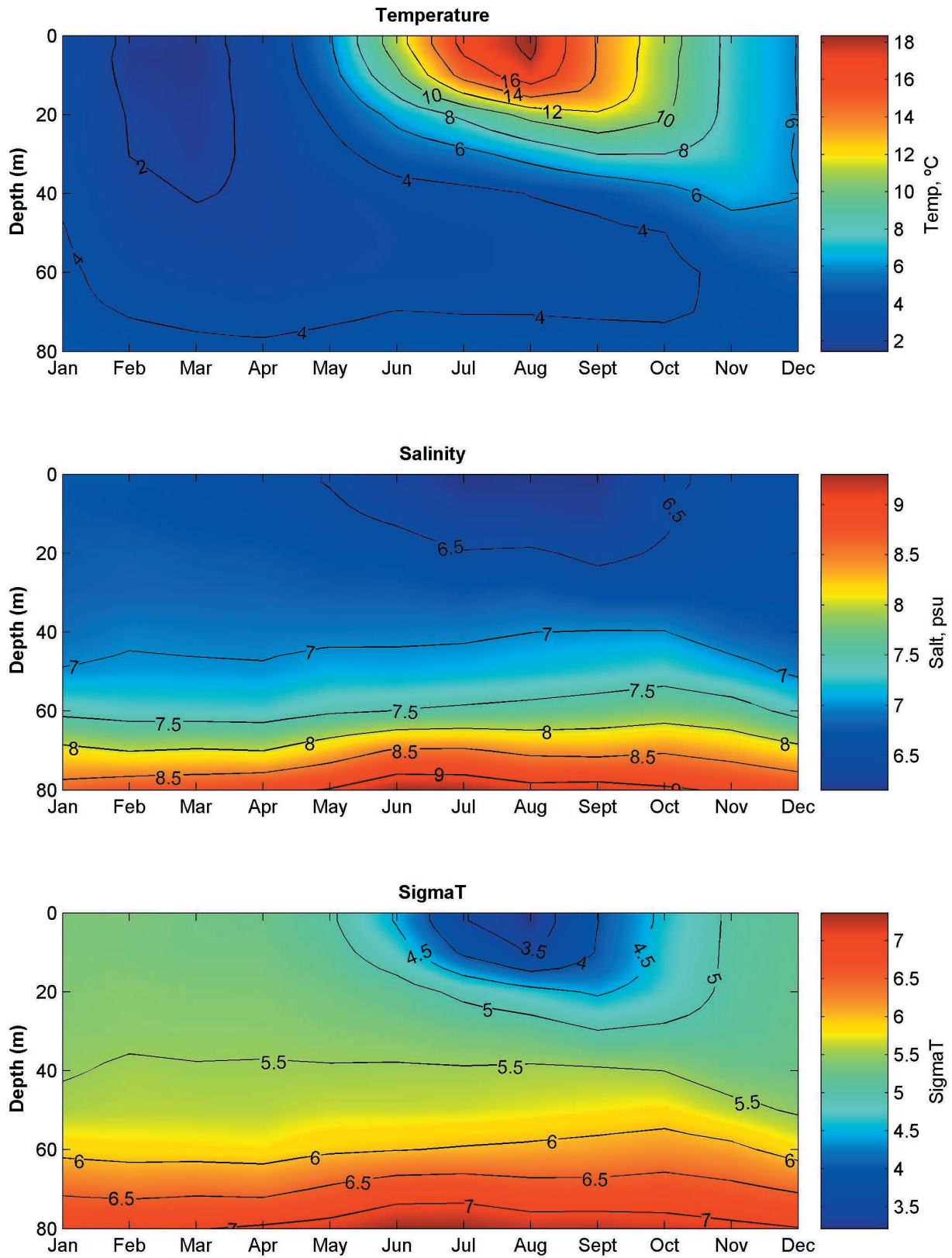
Figure 16. Iso plots of temperature, salinity and sigmaT from surface to 80 meters in the northern Baltic Proper. Monthly mean values from 1994 to 2006. Stations included are BY29 and BY31.
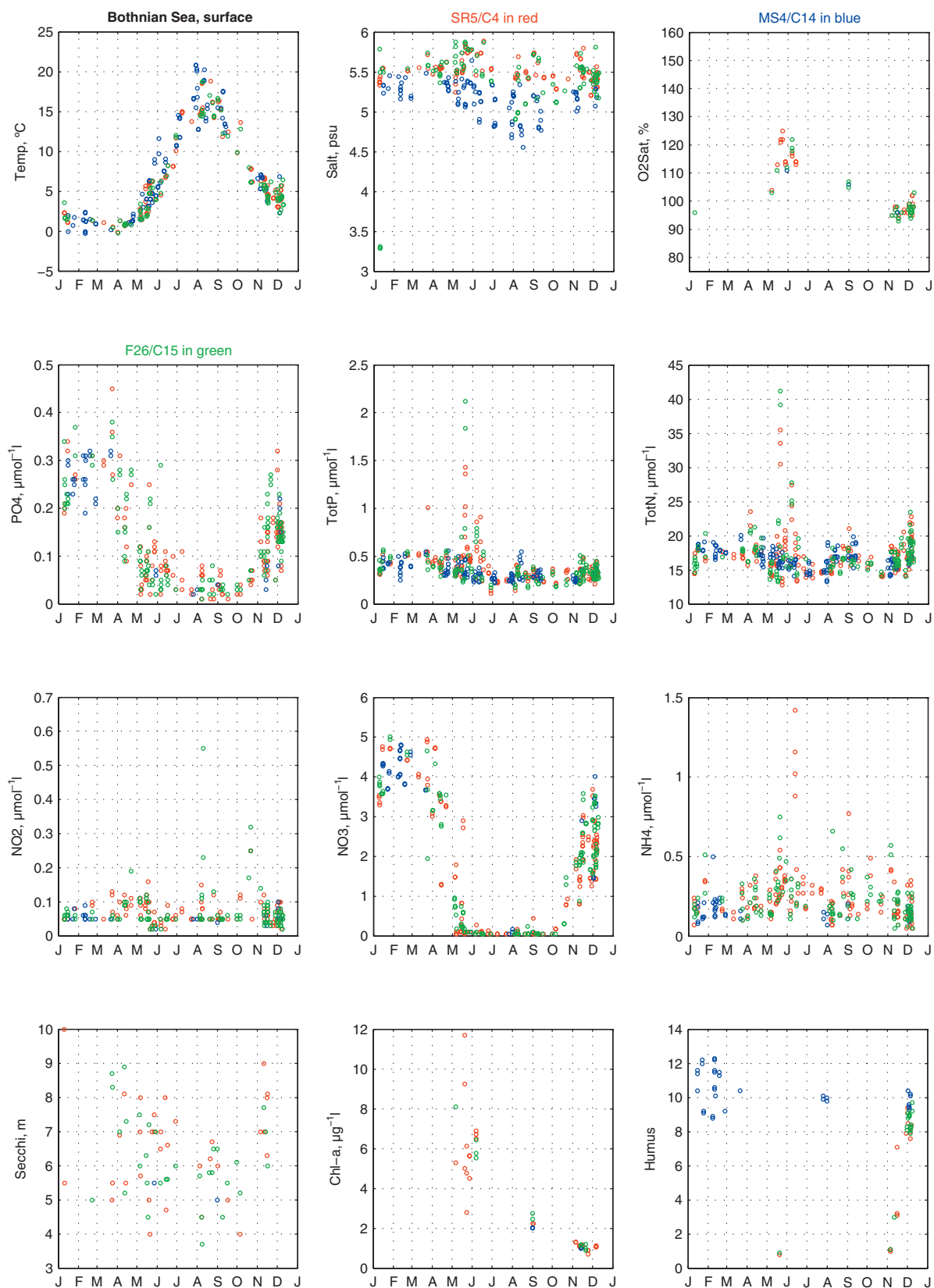
Figure 17. Surface values for a number of parameters in the Bothnian Sea on a monthly basis from 1990 to 2006. Stations included are SR5/C4, MS4/C14 and F26/C15.
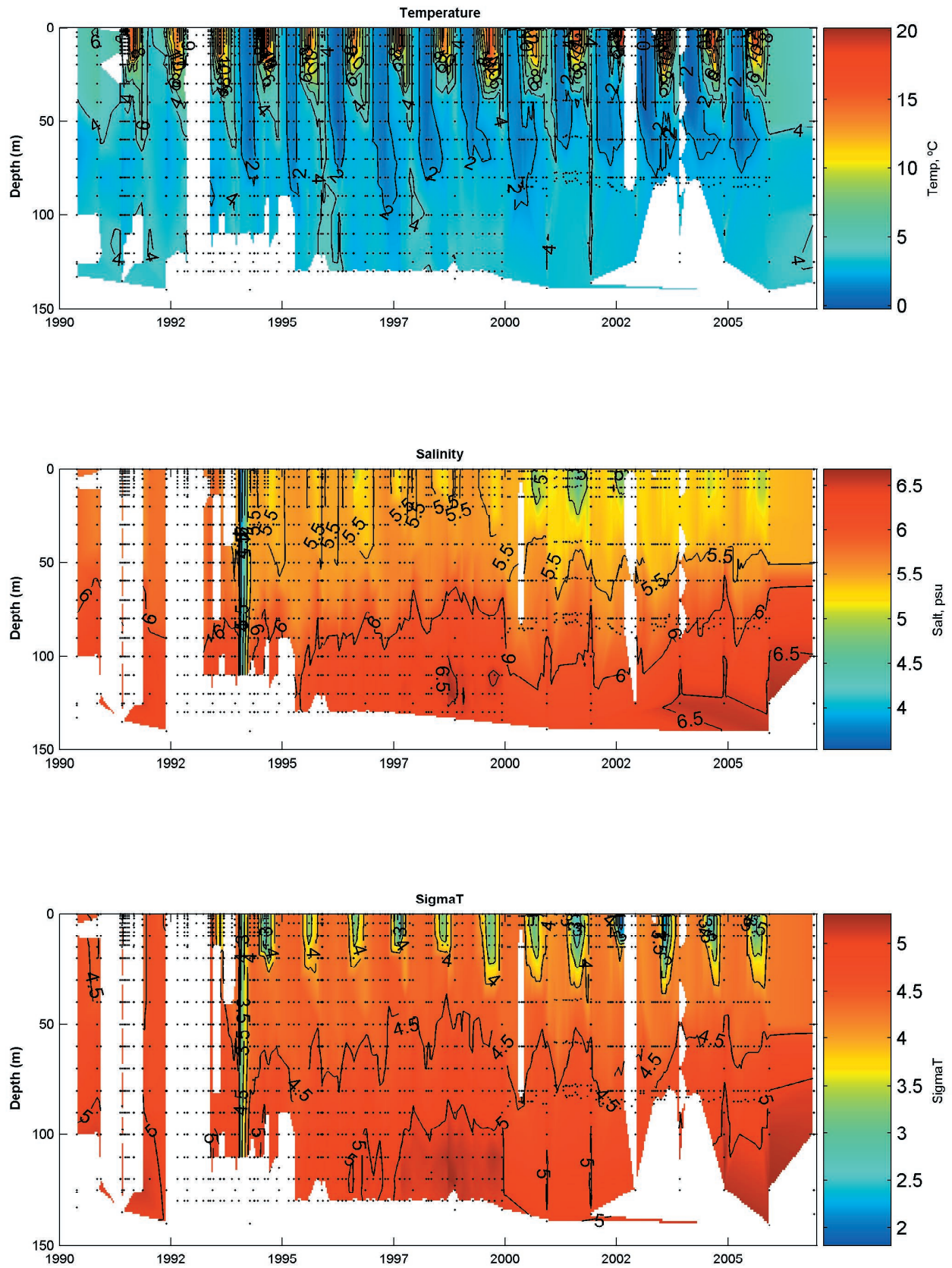
Figure 18. Iso plots of temperature, salinity and sigmaT from surface to the bottom in the Bothnian Sea from 1990 to 2006. Stations included are SR5/C4, MS4/C14 and F26/C15.

Figure 19. Iso plots of temperature, salinity and sigmaT from surface to 80 meters in the Bothnian Sea. Monthly mean values from 1994 to 2006. Stations included are SR5/C4, MS4/C14 and F26/C15.

Southern Baltic Proper

In the "dot" plots (surface values) and the iso plots (0 - 150 meters), data between 1990 and 2006 was used. In the iso plots with monthly values, data between 1994 and 2006 was used.

The "dot" plots show surface waters for a number of parameters, displayed on a monthly basis. The different stations are plotted in diff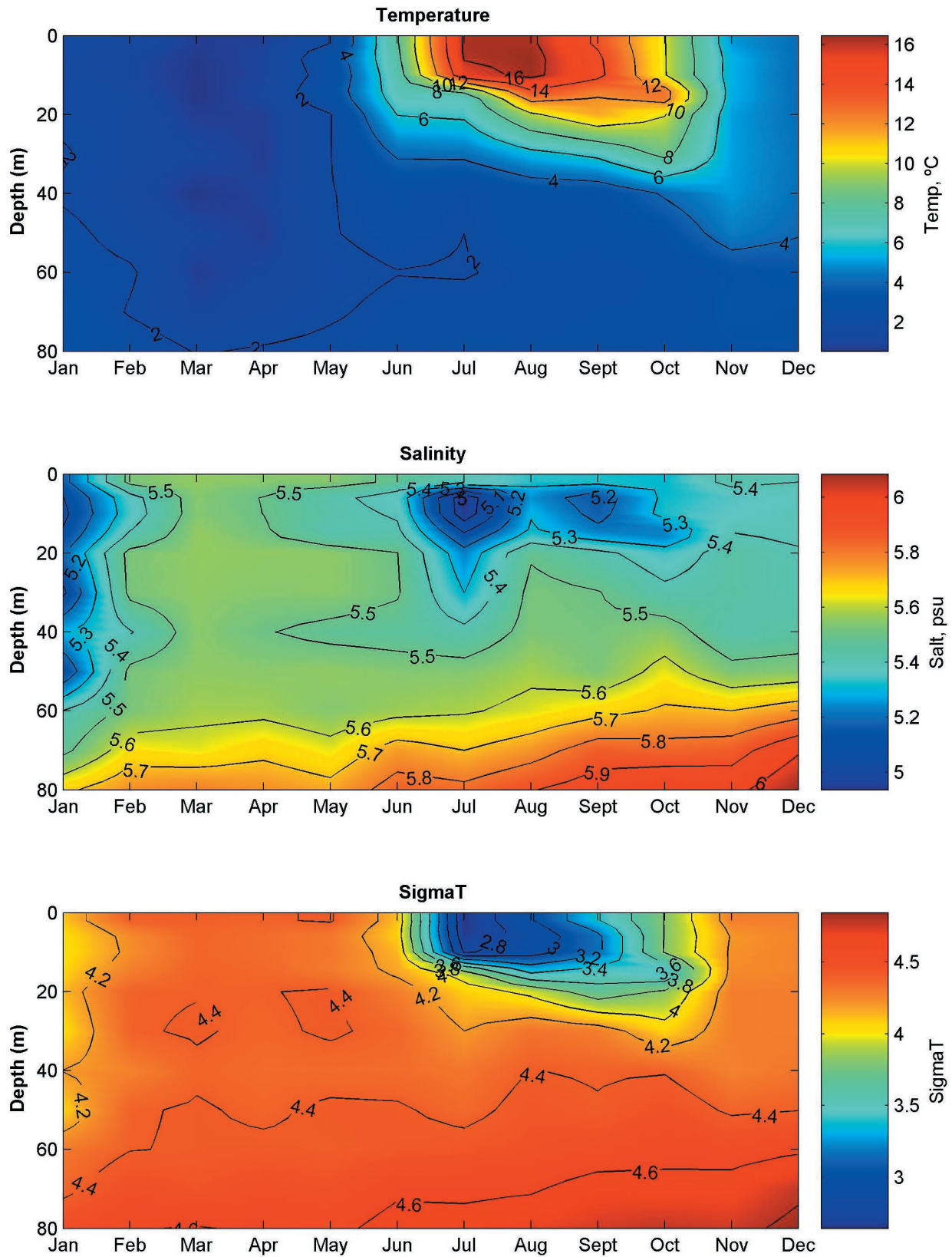erent colours to be able to make a distinction between the stations when plotted in the same figure. The stations correspond well with each other, hence represent the area well.

There are distinct seasonal changes in all but a few parameters. The salinity at BCS III-10 is quite stable around 6.8 to 7.4. There is a minor fluctuation at BY10 in late summer when the termocline prevents salinity entrainment from deeper layers and the fresh melting water from the spring has reached the area. There is no evident seasonal change in TotN, NH4 and in humus (the latter also having too little data).

The surface temperature vary from 2 degrees in March to above 20 degrees in July to August. In O2Sat (saturation), secchi, chl-a and most of the nutrients, there is clear evidence of biological activity mainly during spring, summer and early autumn (see Appendix 3 for a general biological description). In April, there is a peak in the surface chl-a, which leads to the complete drop of NO3 and reduction of PO4, TotP, NO2 and secchi depth. Though there are still nutrients enough for the summer and autumn blooms. These waters are clearly rich of nutrients to feed spring, summer and autumn blooms. Further enrichment of nutrients may lead to larger blooms.

In figure 12, isoplots from the southern Baltic Proper is plotted. The black dots are where measurements are made. The annual cycles are apparent, as well as the structure of the water over the depth. The seasonal thermoclines developed during summer overlay the cooler winter water. During autumn, the surface and deeper water temperatures are evened out. There is a stable perennial halocline at 60 meters depth. Above the halocline, the salinity is rather homogeneous. The density is a combination of the temperature and salinity, giving the seasonal/perennial pycnocline.

Wind and/or negative buoyancy (increase of surface water density relative to the surrounding – hence tends to sink) mix the surface water with deeper waters, increasing the nutrient level in the surface. How deep the mixing reaches, depends on a few factors, but mainly the mixing depth in the summer is to the seasonal thermocline. During autumn the thermocline deepens and weakens, hence the mixing can reach further, but usually not more than the thermocline depth. During strong winds in late autumn and winter, the seasonal thermocline is too weak to prevail and the mixing can, with string wind situations and negative buoyancy, reach the perennial halocline.

To estimate the depth of the mixing layers, monthly mean values for temperature, salinity and sigmaT is compiled to present the change and depth of the seasonal and perennial pycnocline over the year. In the southern Baltic Proper the mixing depths are approximately:

- 20 meters in Jul - Aug,
- 40 meters in Sept,
- 60 meters in Oct - Jun.

Northern Baltic Proper

The parameter values and the seasonal change is very similar to the southern Baltic Proper. Slight differences to point out is the seasonal variation in surface salinity. The salinity variation is mainly from (5.5 -) 6 - 7 psu. The deepest depth is about 450 meters. In the northern Baltic Proper the mixing depths are approximately:

- 20 meters in Jul - Aug,
- 30 meters in Sept,
- 60 meters in Oct - Jun.

Bothnian Sea

The seasonal change is again obvious. The values for temperature, salinity and phosphorus are slightly lower while nitrogen levels are similar to the other areas. The amount of O2Sat, secchi, chl-a and humus data is not sufficient. There is a tendency to a weaker perennial pycnocline below 80 meters. In the Bothnian Sea the mixing depths are approximately:

- 15 meters in Jul - Aug,
- 20 meters in Sept,
- 80+ meters in Oct - Jun.

APPENDIX 3: GENERAL BIOLOGICAL DESCRIPTION

The general biological description will be very brief, presenting total phytoplankton biomass plots for the Baltic Proper and the Bothnian Sea. There is also a satellite image with surface accumulation of cyanobacteria, giving an idea of the extension of some (harmful algal) bloom events.

In the two figures 20 and 21, the total biovolume at a sampling site, is calculated over the top 20 meters. The data cover all measurements made at a few selected stations during 1990 to 2005 and the sum of all the biomasses for all the species during one sampling site is displayed in the top figure on a monthly basis.

In the Baltic proper, the top figure indicates that there is biomass in the water most of the time, if not all year around. There is a peak during the spring bloom, normally consisting of diatoms and lately also dinoflagellates. Mainly during spring, summer, autumn and early winter, there is a biologic activity in the photic zone.

What organisms that would act as harmful organisms when transported into another area than the Baltic Proper, is hard to predict. Three genera (which include some of the many species regarded as harmful in Swedish waters) are presented, to give an idea of the blooming periods of some possibly harmful events.

Aphanizomenon, Nodularia and *Anabaena* are cyanobacteria able to form large mats of entangled thread like matter (*Nudularia Spumigena* also being toxic). These blooms tend to appear from June to, in the case of *Aphanizomenon*, November. Hence there is a higher risk of BW uptake of these organisms between June and November and uptake of organisms from the spring bloom during late March to June, leaving December to mid March with lower risk of organism uptake.

As mentioned, there are many harmful species present in the Swedish waters, but usually with low abundances. These harmful species can often be detected after the spring bloom.

Turning to the situation in the Bothnian bay, there is no real idea to look at the selected genera, but the top figure with the total biovolume, show similar time periods for the different blooms, but with much lower values.

Cyanobacteria blooms can affect vast areas covering the main parts of the Baltic Proper and even the main parts of the Bothnian Sea. The bloom is a nuisance mainly to tourists since the surface accumulation often appears during the summer vacation. Smaller animals can also die from drinking the infected water. In figure 22 a satellite image of a vast cyanobacterial bloom (meandering shaped patterns in the water) cover the entire Baltic Proper. The image is taken in July 2005.

The complementary information regarding chl-a, secchi and O2Saturation can be found in the previous appendix.
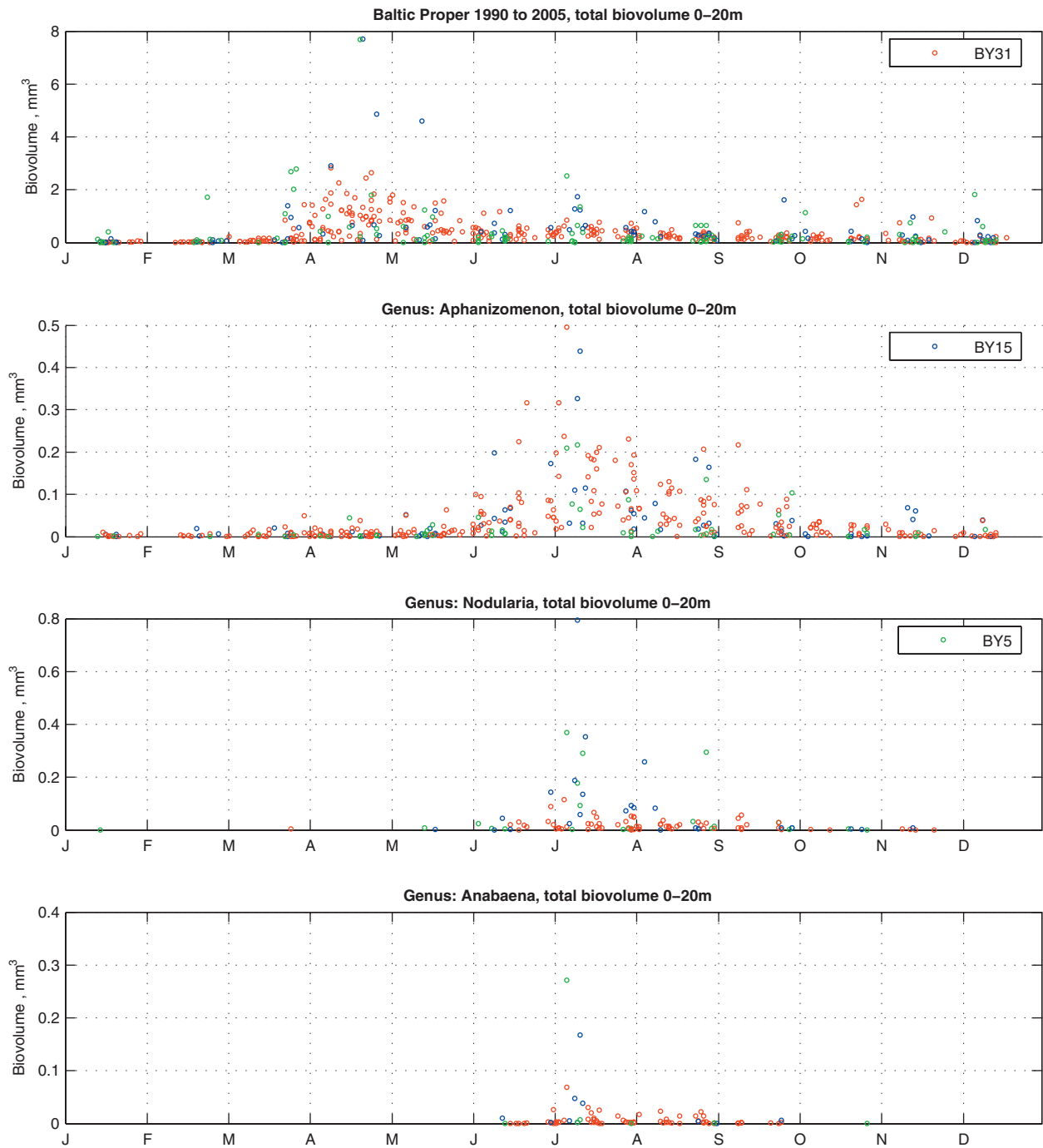
Figure 20. Total phytoplankton biovolume summed per sampling site, calculated over the top 20 meters displayed on a monthly basis. The data cover all measurements made at a few selected stations in the Baltic Proper during 1990 to 2005. A few additional plots show selected genera.
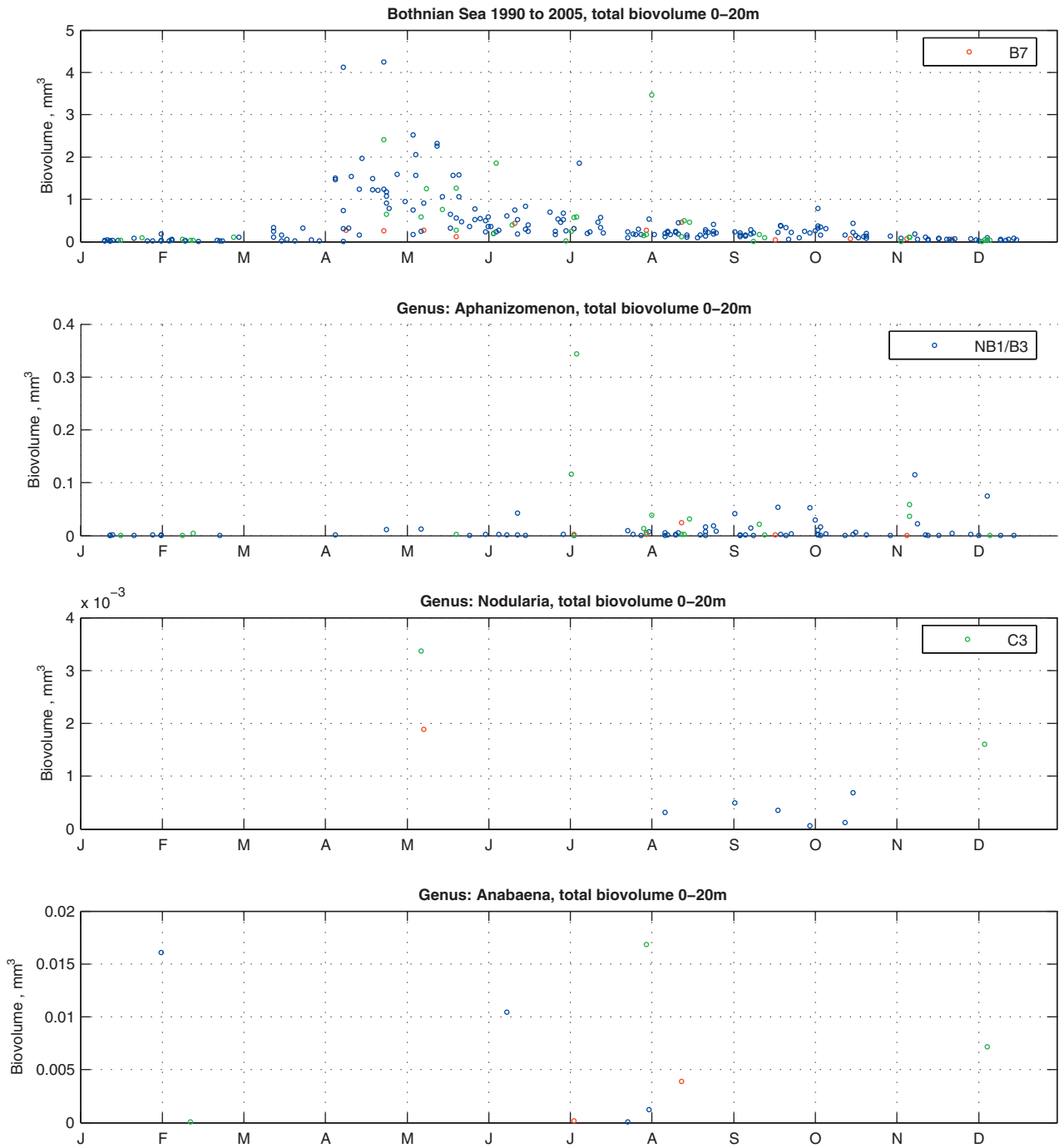
Figure 21. Total phytoplankton biovolume summed per sampling site, calculated over the top 20 meters displayed on a monthly basis. The data cover all measurements made at a few selected stations in the Bothnian Sea during 1990 to 2005. A few additional plots show selected genera.
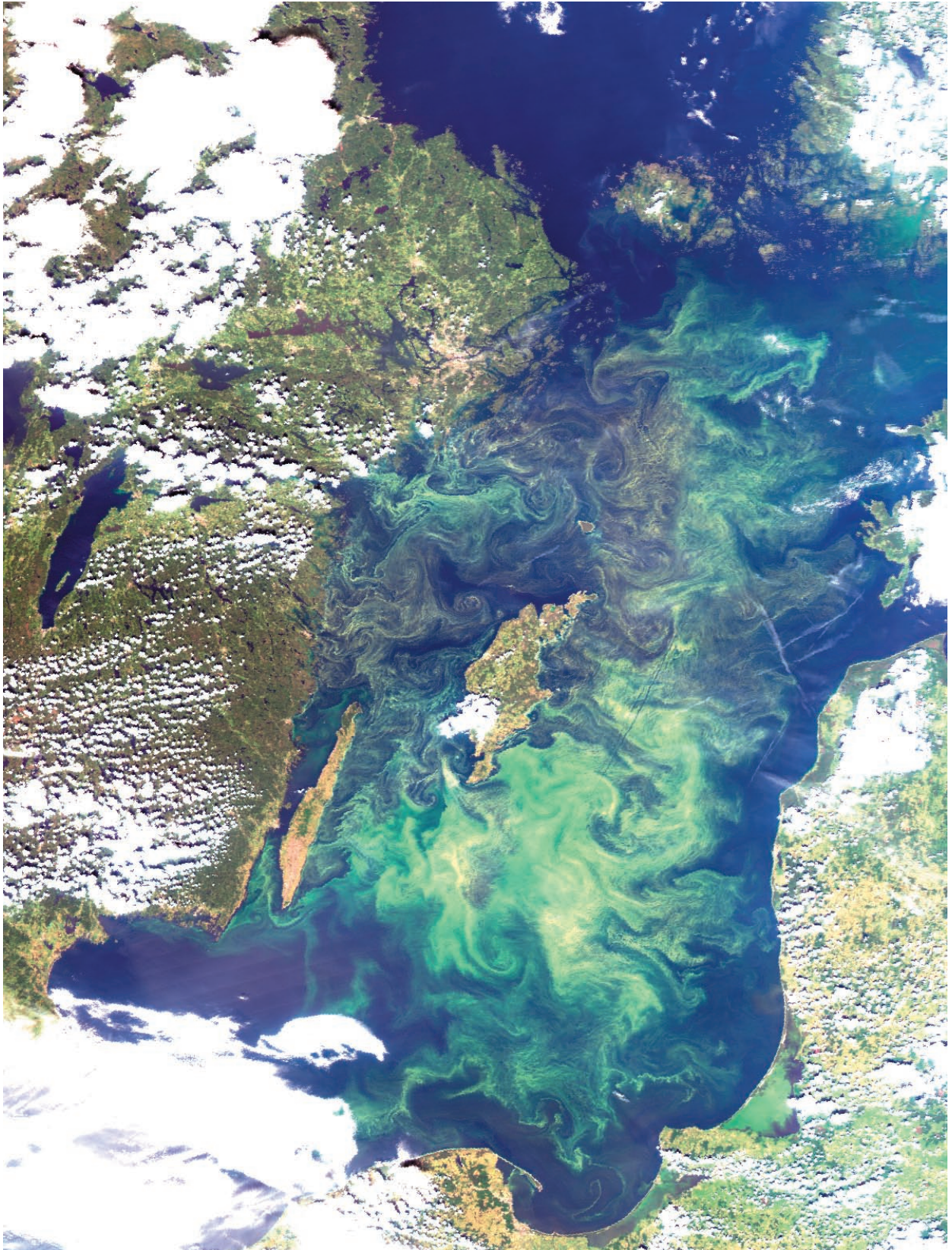
Figure 22. Satellite image (MODIS) 2005-07-08. Surface accumulations of cyanobacteria in the entire Baltic Proper.

APPENDIX 4: GENERAL WIND DESCRIPTION

The wind climate is analysed by processing measured data from Gotska Sandön, a separate island north of Gotland, and by producing case scenarios with modelled wind data from HIROMB (HIgh Resolution Operational Model for the Baltic Sea). Actual wind measurements at sea are scarce. Therefore, the wind measurements from Gotska Sandön are assumed to be representative for the entire Baltic Proper. It may be a rather fair approximation, since the speed and direction changes in the modelled wind fields are spread over large areas.

General wind

In figure 23, the wind speed from Gotska Sandön is displayed in box plots for each month from the years 1997 to 2006 (measurements every 3:rd hour). The median value is the red line in the blue box. The blue box encapsulate 50% of the data (25th percentile above and below the median), the black line is 1.5 times the inter quartile range. The red plus signs above are outliers. The median

wind speed is highest in January, about 7 m/s, and lowest in May to August, with about 4 m/s. The median values are quite low it might seem, but the many red plus signs indicate that even during summer, there can be up to 15 m/s winds and more than 20 m/s during winter.

In figure 24, wind roses for each month is plotted giving information on both main wind speed and direction per month. The top row is Jan - Mar, the next is Apr - Jun, Jul - Sep and the final row is Oct - Dec. In the figure, many stars are plotted on top of each other when the same speed and direction in the same month appear. The next figure gives complementary information of the amount of measurements each month in certain directions (a histogram).

The wind speed is marked as circles in the rose measuring 5 to 25 m/s. The 360 degrees scale outside the circles are the directions, 0 being wind from the north (N), 90 wind from the east (E) and so on. There is a dominance of SW to W winds, mainly during winter, when also the stronger winds are more common, but also during the rest of the year. Though, there are many occasions with wind from all other directions (Apr, May, Aug - Oct).
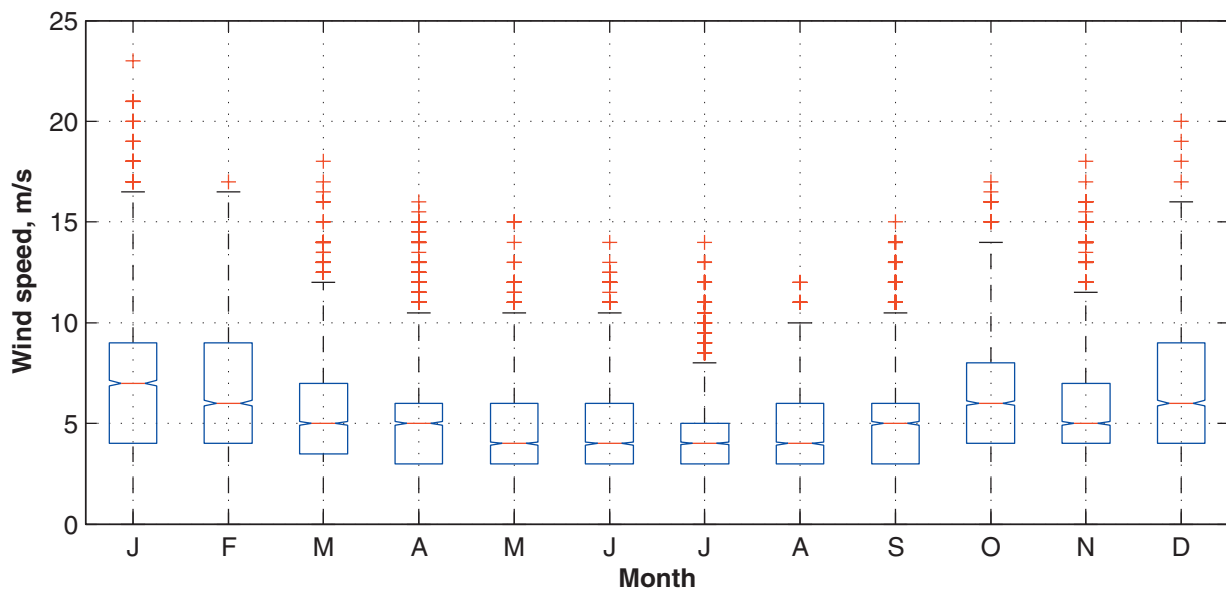
Figure 23. Box plots of mean wind speed each month at Gotska Sandön 1997 to 2006. The median value is the red line in the blue box. The blue box encapsulate 50% of the data (25th percentile above and below the median), the black line is 1.5 times the inter quartile range. The red plus signs above are outliers.
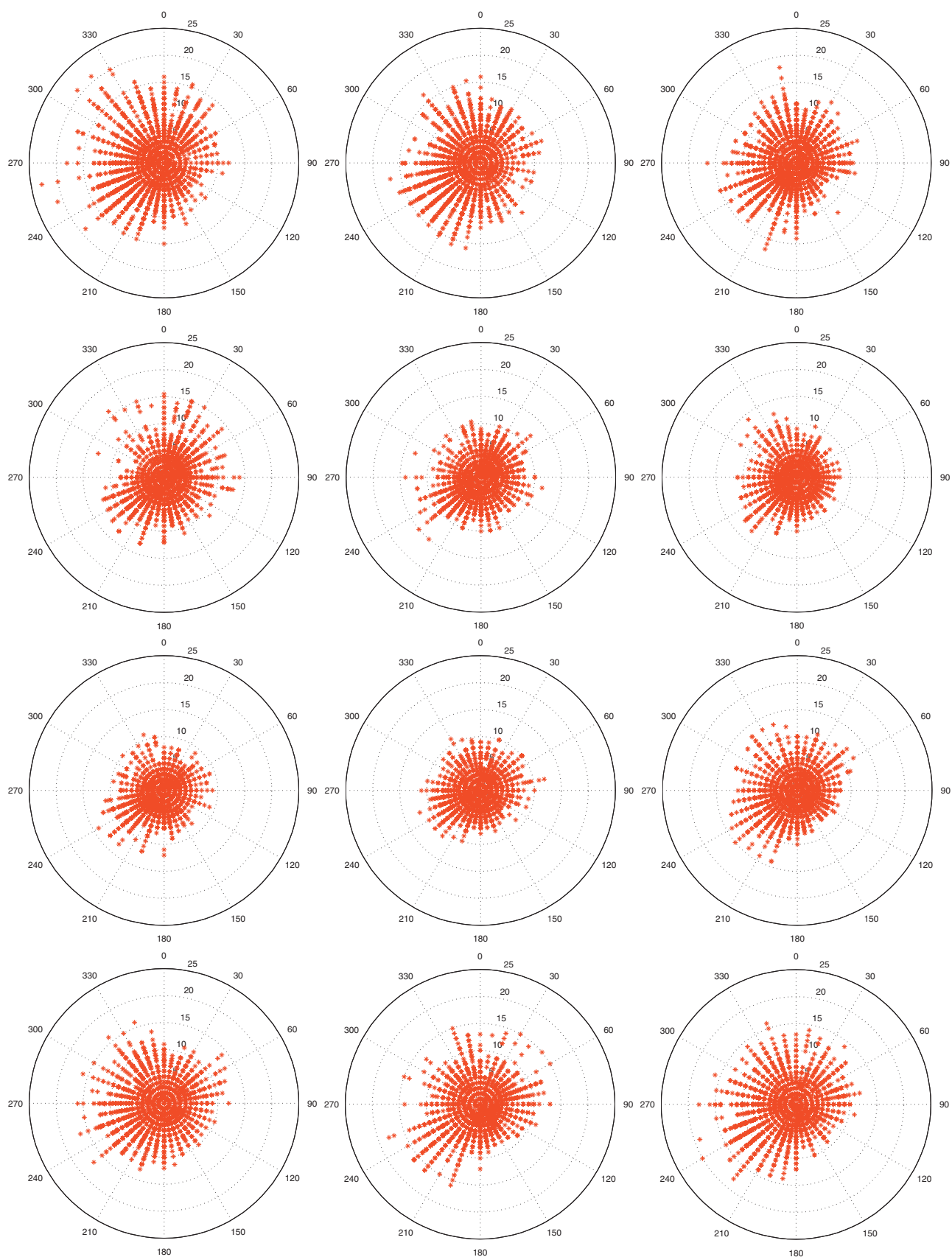
Figure 24. Wind roses from Gotska Sandön 1997 to 2006. The first row is Jan - Mar, then Apr - June, Jul - Sep, Oct - Dec. The plots indicate main direction and speed each month.
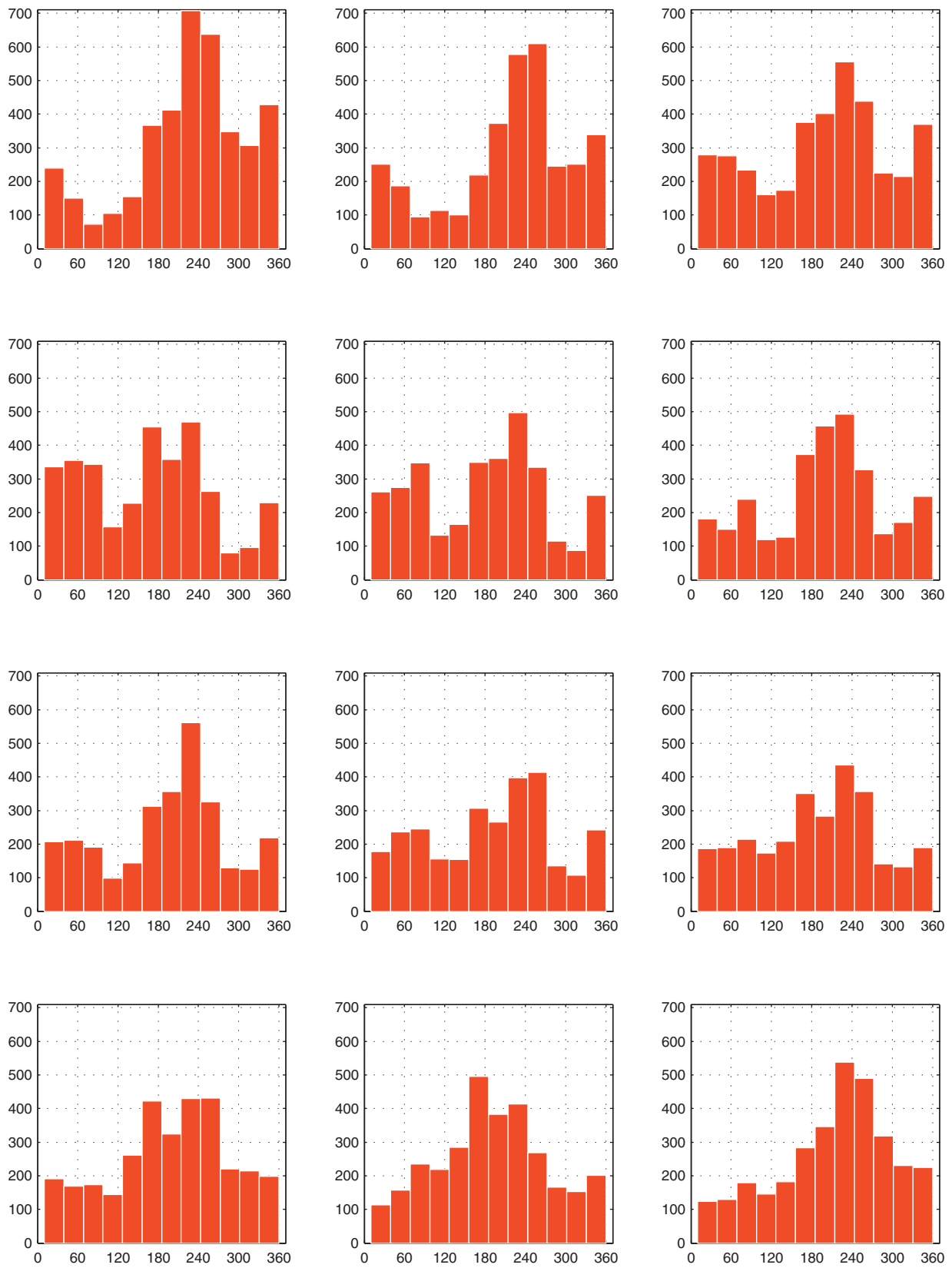
Figure 25. Wind from Gotska Sandön 1997 to 2006. The first row is Jan - Mar, then Apr - June, Jul - Sep, Oct - Dec. The plots indicate the amount of measurements each month in certain directions (a histogram). The y-axis is the amount and x-axis the direction.

Mean Wind 10m 000115-000125

Mean Wind 10m 020910-021015
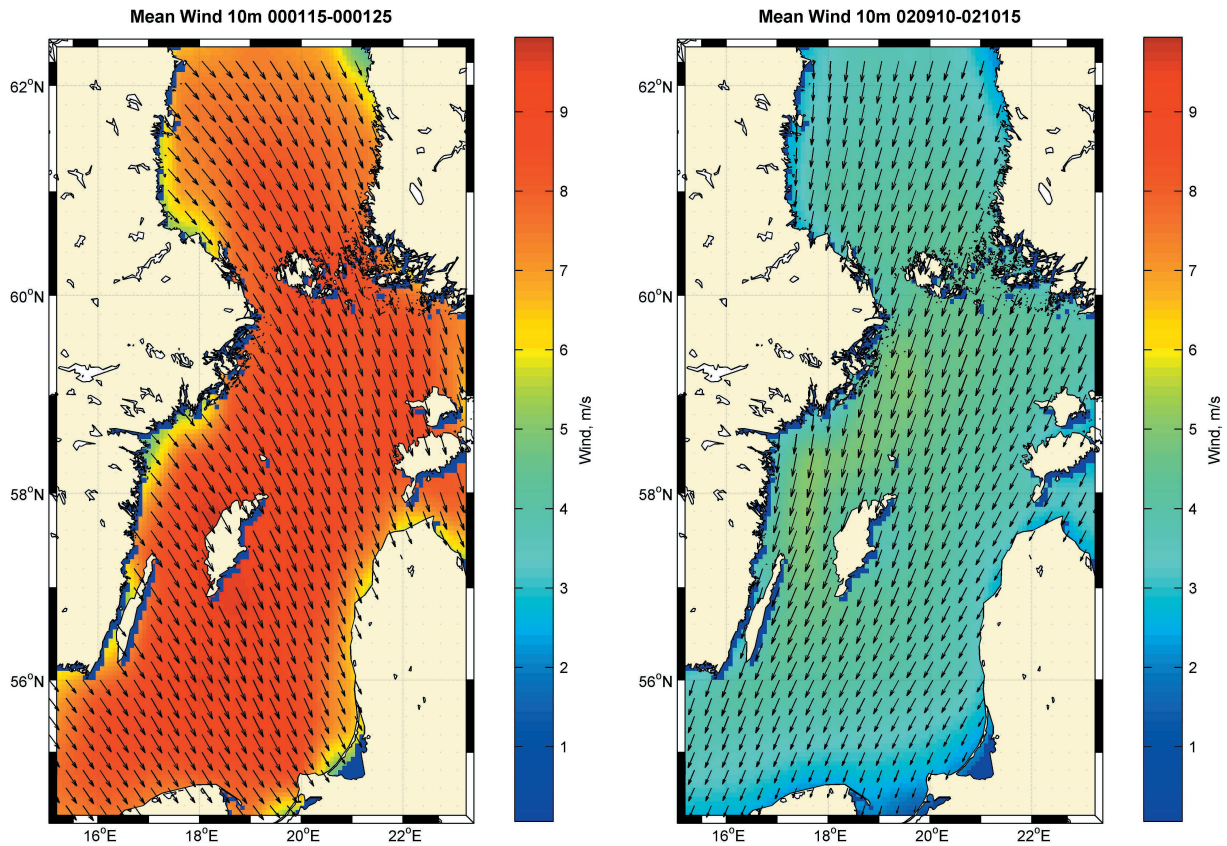
Wind scenarios

The following figures are modelled data from six different wind scenarios, to give an idea of the large variability of the wind direction and strength. Wind from Gotska sandön was used to find different wind scenarios. The wind direction may differ slightly between Gotska Sandön and the modelled data. The first scenario is strong N-NW winds during the second part of January in 2000. The wind map is produced by calculating the mean over the time period. What surface currents these winds produce, can be seen in Appendix 6, figure 30a-f. Figure 26b represents NE winds of medium strength during the 10th of September to the 15th of October 2002. Figure 26c is data from the 5th to the 25th of July 1997. The winds were weak and mainly from the north at Gotska Sandön.

Mean Wind 10m 970705-970730

Figure 26a (left), b (right) and c (bottom). Modelled wind data of different wind scenarios. Figure a is the mean wind between the 15 - 25th of January 2000. Figure b is the mean wind between the 10th of September - 15th of October 2002. Figure c is the mean wind between the 5 - 25th of July 1997. The wind speed is displayed by the background colour, with corresponding colorbar to the right, and by the lengths of the arrows. The arrows indicate the direction.

Mean Wind 10m 000101-000115

Mean Wind 10m 040901-040930

Mean Wind 10m 040615-040715

In figure 26d there are strong SW winds during the first part of January in 2000. Figure 26e represents SW winds of medium strength during September 2004. Figure 26f represents weak SW wind from the 15th of June to the 15th of July 2004.
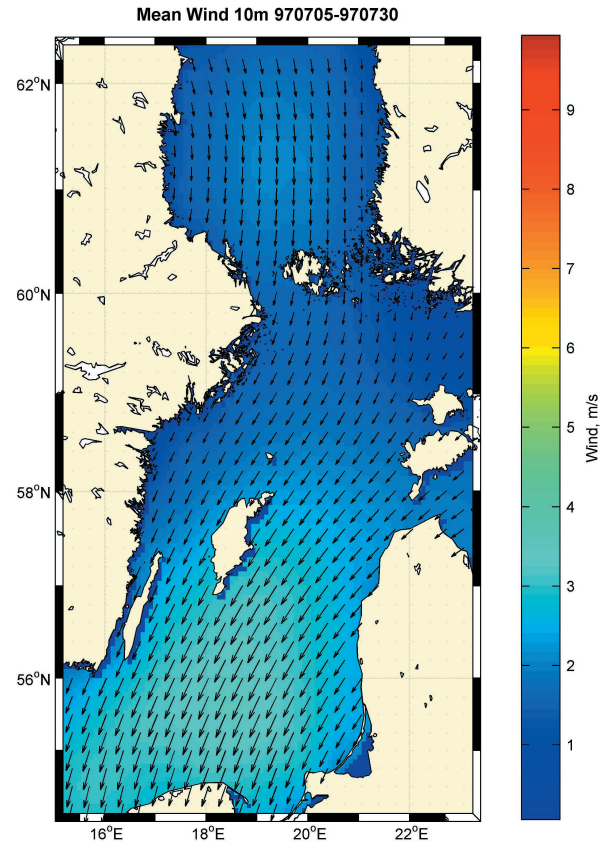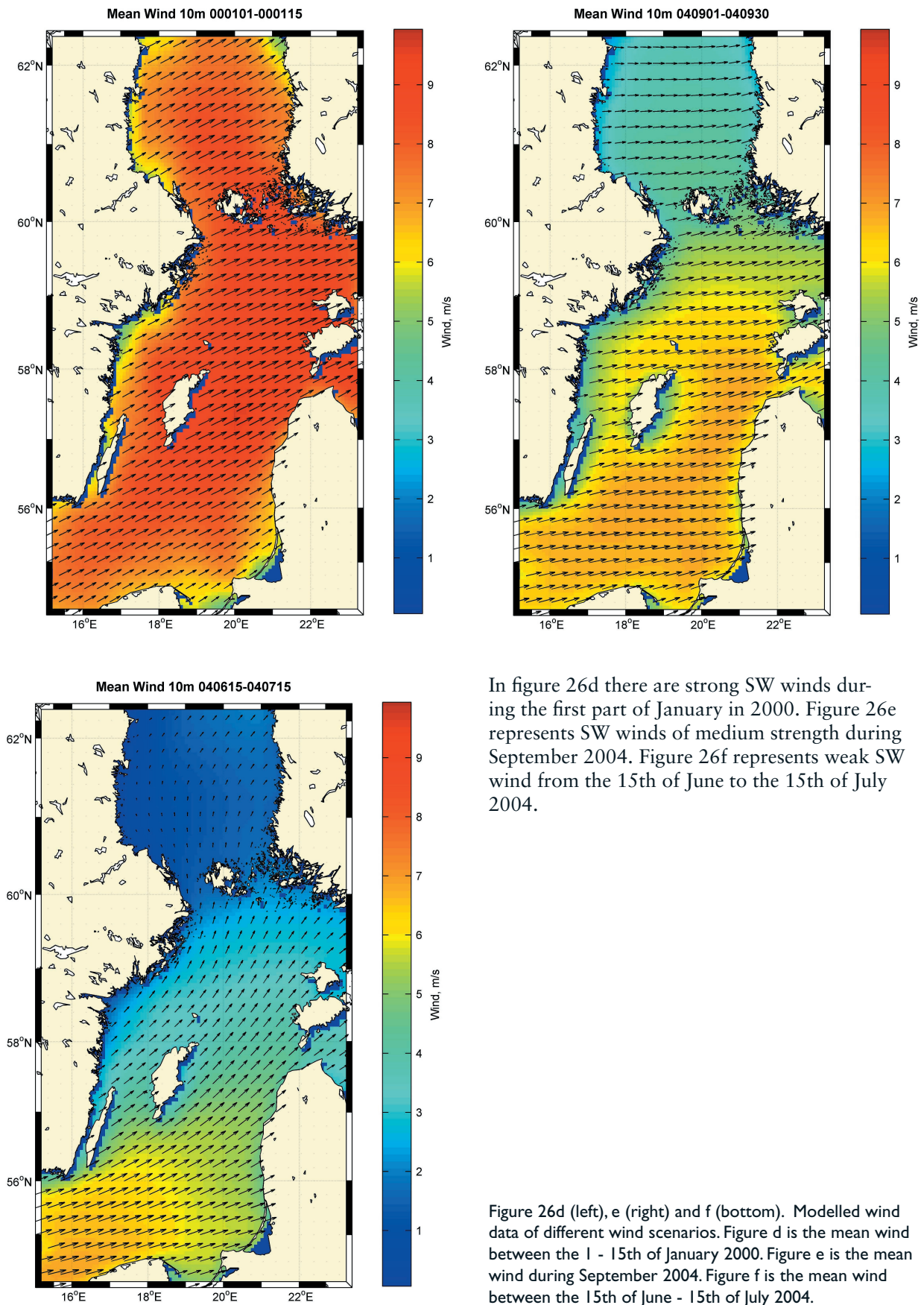
Figure 26d (left), e (right) and f (bottom). Modelled wind data of different wind scenarios. Figure d is the mean wind between the 1 - 15th of January 2000. Figure e is the mean wind during September 2004. Figure f is the mean wind between the 15th of June - 15th of July 2004.

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APPENDIX 5: GENERAL WAVE DESCRIPTION

There are only a few wave buoys in operation today in the Baltic Proper, but by the use of earlier measurements, the wave climate from stations rather close to the proposed BWE areas, have been used. To represent the southern Baltic Proper area, measurements from a buoy at Ölands Södra Grund 1978 to 1993 were processed (figure 27). Significant wave heights and wave periods are displayed by month and in a scatter plot where significant wave height is plotted against the wave period. The top images are displayed as box plots, with highest mean an median wave heights and periods in winter and lower in the summer. The median wave height in January is about 1.5 meters, but there are significant wave heights up to 7 meters, although at very rare occasions, as can be noted by the scatter plot. Mainly the wave heights during summer keep below 2 meters.

In the scatter plot, all data is used to create the sum of occasions at a specified wave period at a specified significant wave height. The numbers in the scatter plot represent the number of times that the measurements have recorded that specific combination of period and wave height. The lines in the plot are different wave steepness.

Focusing on the wave height, the very high values in the scatter plot are at lower wave heights. Mainly, the significant wave height is below 3 meters. At one occasion the wave height was over 7 meters.

Ölands Södra Grund is situated west of and closer to the coast than the proposed BWE area, therefore the wave climate at the area should be slightly tougher with slightly higher waves.

Almagrundet is situated rather close to the proposed BWE area in the northern Baltic Proper. The wave climate is similar to the one at Ölands Södra Grund, with slightly higher waves and periods. Especially the outliers are much higher at Almagrundet.

There is no station with sufficient data in the Bothnian Sea to create similar plots.

Ölands Södra Grund Wave Heights & Periods 19–Oct–1978 to 22–Jan–1993

Significant Wave Height Hs [m] — Months (J F M A M J J A S O N D)

Wave Period Tz [s] — Months (J F M A M J J A S O N D)

Legend: Outliers / 99% / mean + σ / 75% / mean / median / 25% / mean − σ / 1%

Scatter plot for Ölands Södra Grund, All observations from 19–Oct–1978 to 22–Jan–1993

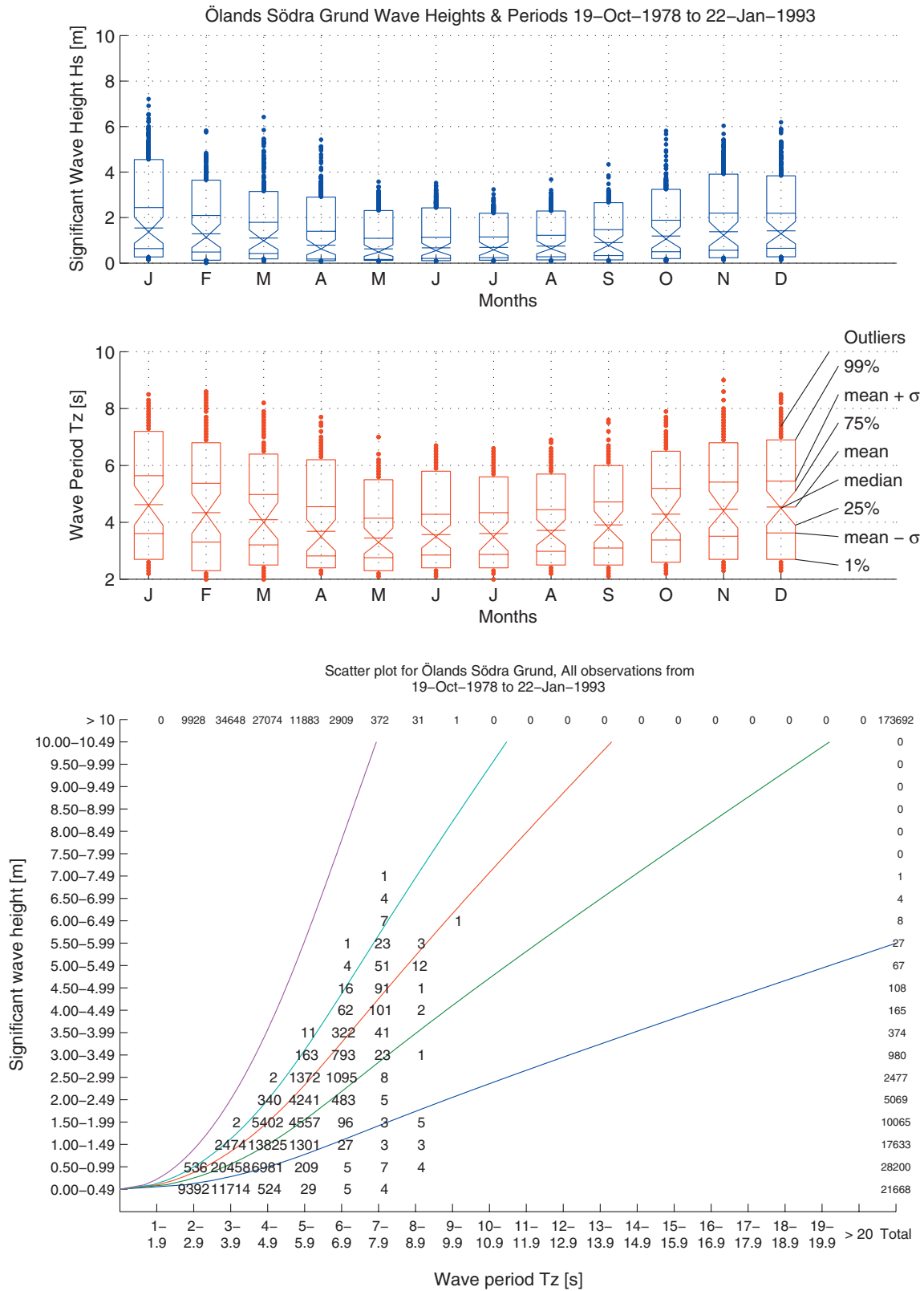| Significant wave height [m]	1–1.9	2–2.9	3–3.9	4–4.9	5–5.9	6–6.9	7–7.9	8–8.9	9–9.9	10–10.9	11–11.9	12–12.9	13–13.9	14–14.9	15–15.9	16–16.9	17–17.9	18–18.9	19–19.9	>20	Total
> 10	0	9928	34648	27074	11883	2909	372	31	1	0	0	0	0	0	0	0	0	0	0		173692
10.00–10.49																					0
9.50–9.99																					0
9.00–9.49																					0
8.50–8.99																					0
8.00–8.49																					0
7.50–7.99																					0
7.00–7.49						1															1
6.50–6.99						4															4
6.00–6.49						7	1														8
5.50–5.99					1	23	3														27
5.00–5.49					4	51	12														67
4.50–4.99					16	91	1														108
4.00–4.49					62	101	2														165
3.50–3.99				11	322	41															374
3.00–3.49				163	793	23	1														980
2.50–2.99			2	1372	1095	8															2477
2.00–2.49			340	4241	483	5															5069
1.50–1.99		2	5402	4557	96	3	5														10065
1.00–1.49		2474	13825	1301	27	3	3														17633
0.50–0.99	536	20458	6981	209	5	7	4														28200
0.00–0.49	9392	11714	524	29	5	4															21668

Wave period Tz [s]

Figure 27. Box plots and scatter plot of significant wind height and wind period at Ölands Södra Grund in the southern Baltic Proper. The time period is 1978 to 1993.
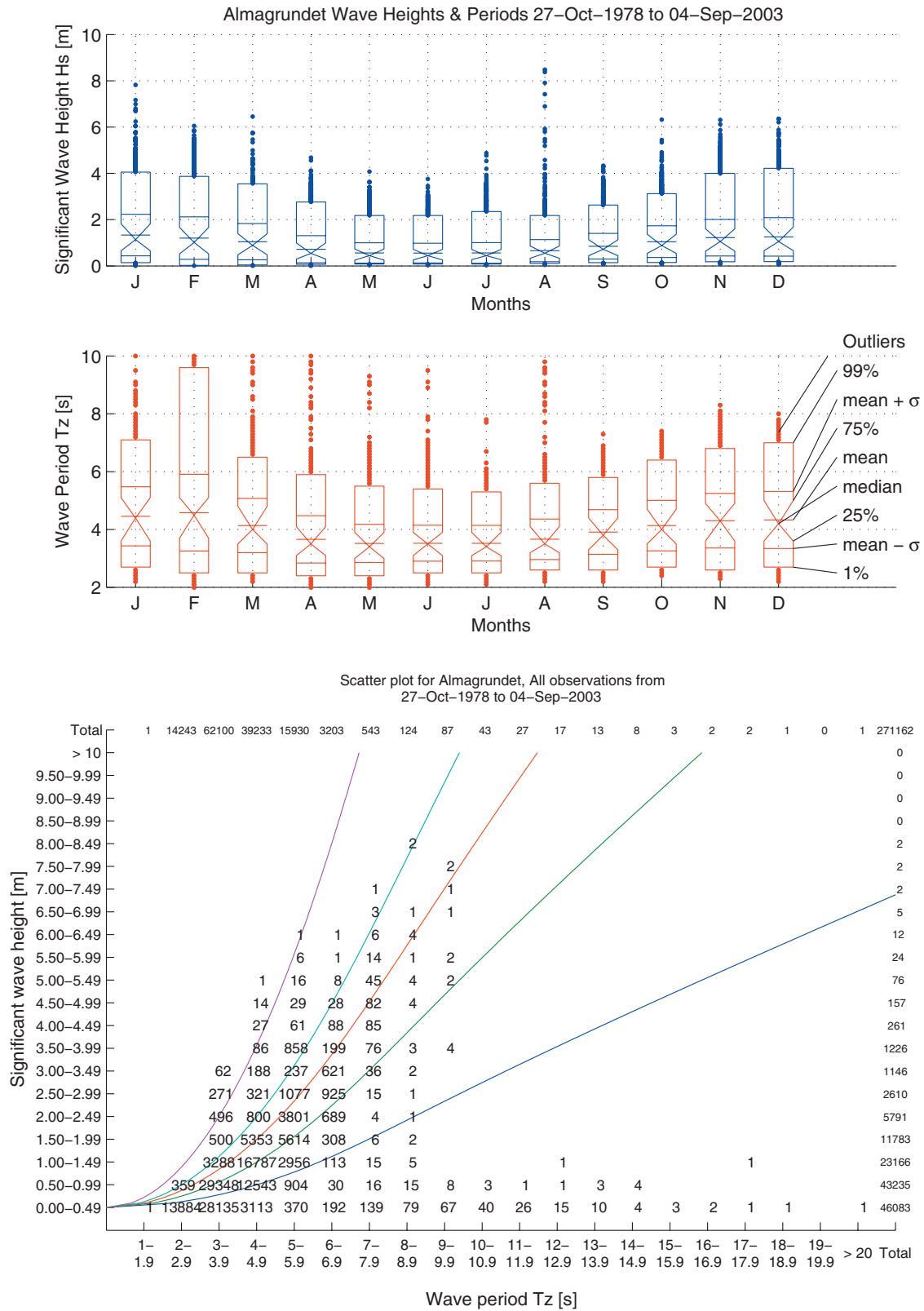
Figure 28. Box plots and scatter plot of significant wind height and wind period at Almagrundet in the northern Baltic Proper. The time period is 1978 to 2003.

APPENDIX 6: GENERAL CURRENT AND VERTICAL CIRCULATION DESCRIPTION

Since measurements of currents is scarce in the Baltic Proper, modelled data has been used. Data from the HIROMB model has been used to display the mean current over the year, divided into time periods of two months (Jan+Feb, Mar+Apr and so on). The years 2002 and 2004 were used. The figures are displayed by giving the mean current strength in colour and by the length of the arrows. The current direction is displayed by the direction of the arrows.

In the previous appendix, the mean modelled wind from six different scenarios were displayed. The corresponding current scenarios are on display in this appendix. The wind affect the surface waters, creating a surface current slightly to the right of the wind direction (in the Northern Hemisphere). This is apparent in the current figures from the different wind scenarios.

During the six time periods of the different wind scenarios, model data has been used to produce tracks from day one in the scenario (figure 31a), to 5 days after the first day, followed by 10 days after the first day and the last day of the time window from the chosen scenario. There are 7 dots in the southern Baltic Proper, 2 in the northern and 2 in the Bothnian Sea. The dots can be seen as a discharge of BW, though here, the dilution is not included. The dots represent parcels of water, transported by the currents, from the discharge areas, the path the parcel travels in time and the new location after 5 and 10 days and at the end of the period.

The figures displaying the mean current during different months and the scenario figures have rather high standard deviation values and may show slightly higher current speed than the actual values.

Mean Current 0-4m, Jan & Feb

Mean Current 0-4m, Mar & Apr

Mean Current 0-4m, May & Jun

General currents

There are rather high currents during the winter months, normally with SE to NE currents due to the predominant SW to W winds. With stronger winds, there is usually an uniformity in both the wind and current direction. During weaker winds, the directions tend to vary more. The counter-clockwise rotation is noticable at several occasions.

Figure 29a-c. Mean modelled current over two months. The left figure (a) is January and February, the right figure (b) is March and April and the bottom figure (c) is May and June. The current speed is displayed by the background color, with corresponding colorbar to the right, and by the lengths of the arrows. The arrows indicate the direction.

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Mean Current 0-4m, Jul & Aug

Mean Current 0-4m, Sep & Oct
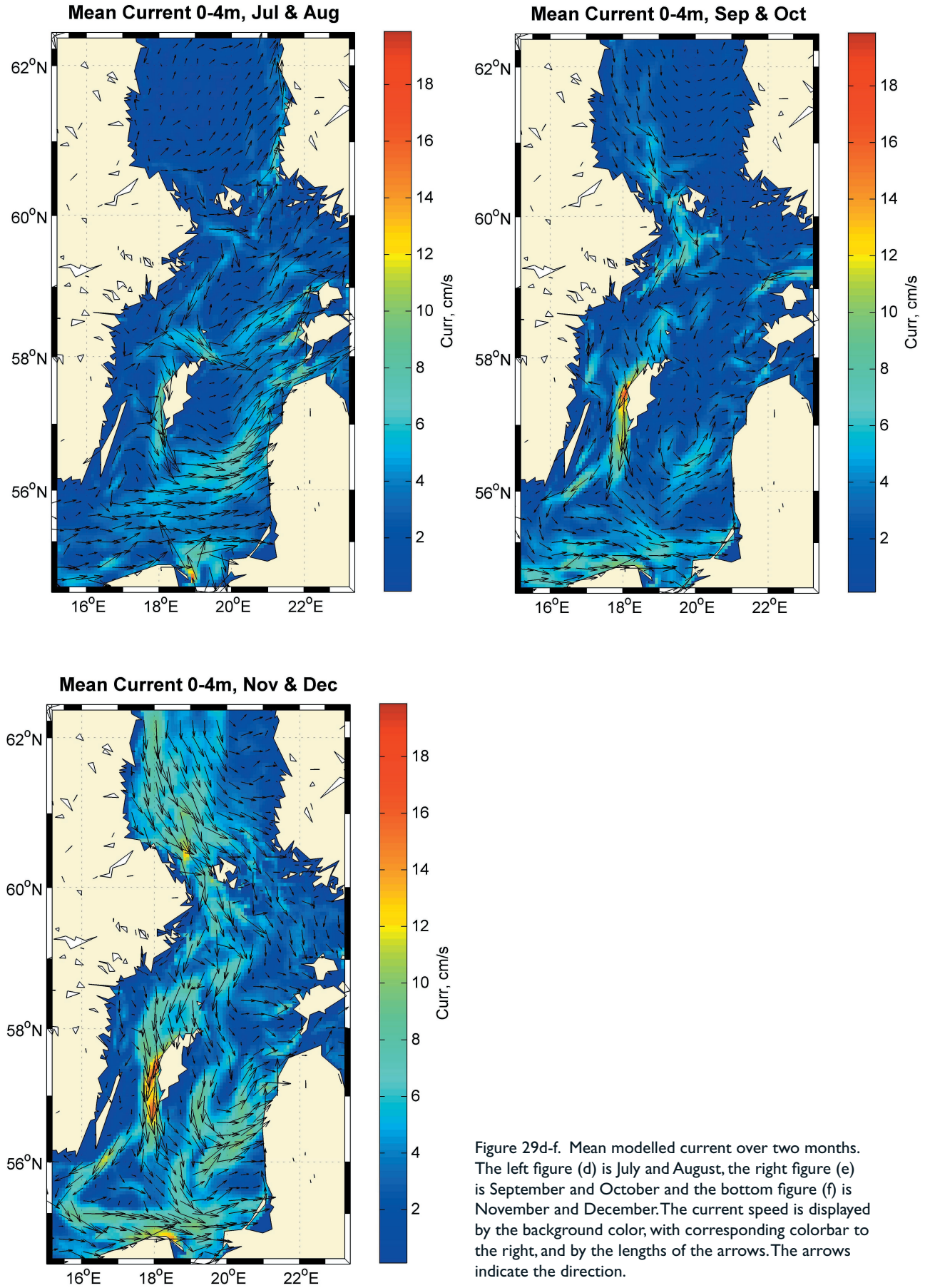
Mean Current 0-4m, Nov & Dec

Figure 29d-f. Mean modelled current over two months. The left figure (d) is July and August, the right figure (e) is September and October and the bottom figure (f) is November and December. The current speed is displayed by the background color, with corresponding colorbar to the right, and by the lengths of the arrows. The arrows indicate the direction.

55

Mean Current 0-4m 000115-000125

Mean Current 0-4m 020910-021015

Mean Current 0-4m 970705-970730
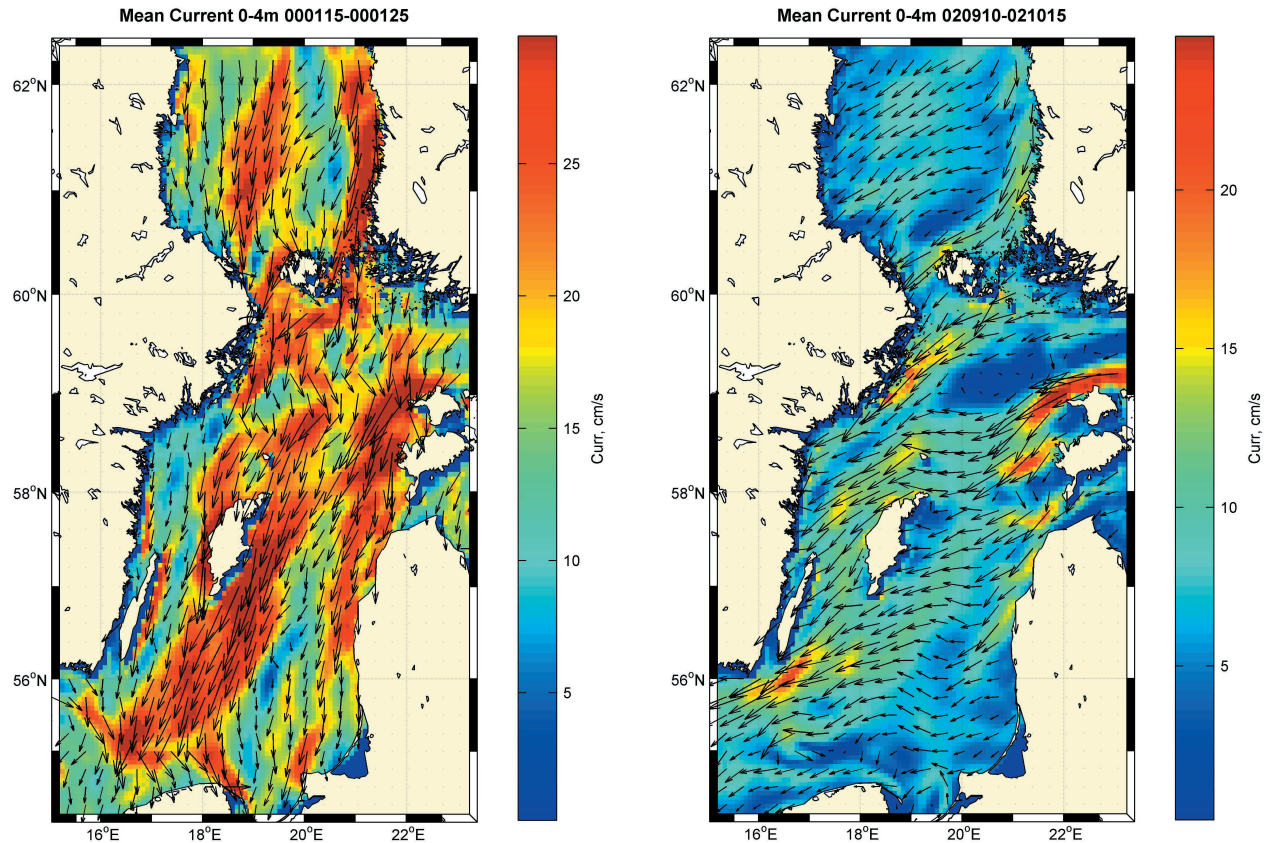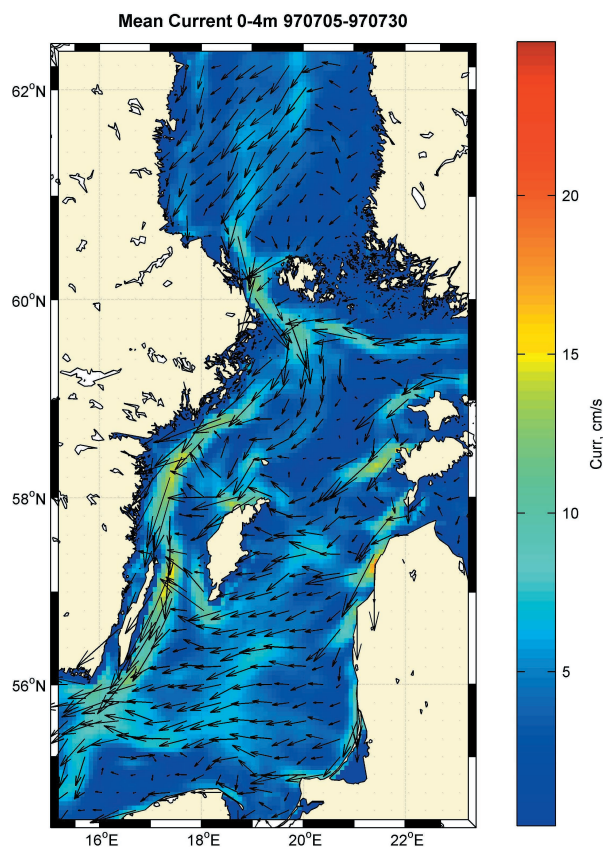
Current scenarios

The following figures are modelled current data based on the mean value during six different wind scenarios, to give an idea of the large variability of the current direction and strength. Wind from Gotska sandön was used to find different wind scenarios. The first scenario is strong N-NW winds during the second part of January in 2000, producing strong currents slightly to the right of the wind direction. Figure 30b represents NE winds of medium strength during the 10th of September to the 15th of October 2002, producing rather strong currents that flows in the SEE direction. Figure 30c is data from the 5th to the 25th of July 1997. The winds were weak and mainly from the north at Gotska Sandön. There were varying winds over the area, hence the currents do not have a unified direction. The currents in the southern Baltic Proper flow mainly to the west.

Figure 30a (left), b (right) and c (bottom). Modelled current data based on different wind scenarios. Figure a is the mean current between the 15 - 25th of January 2000. Figure b is the mean current between the 10th of September - 15th of October 2002. Figure c is the mean current between the 5 - 25th of July 1997.

Mean Current 0-4m 000101-000115

Mean Current 0-4m 040901-040930

Mean Current 0-4m 040615-040715
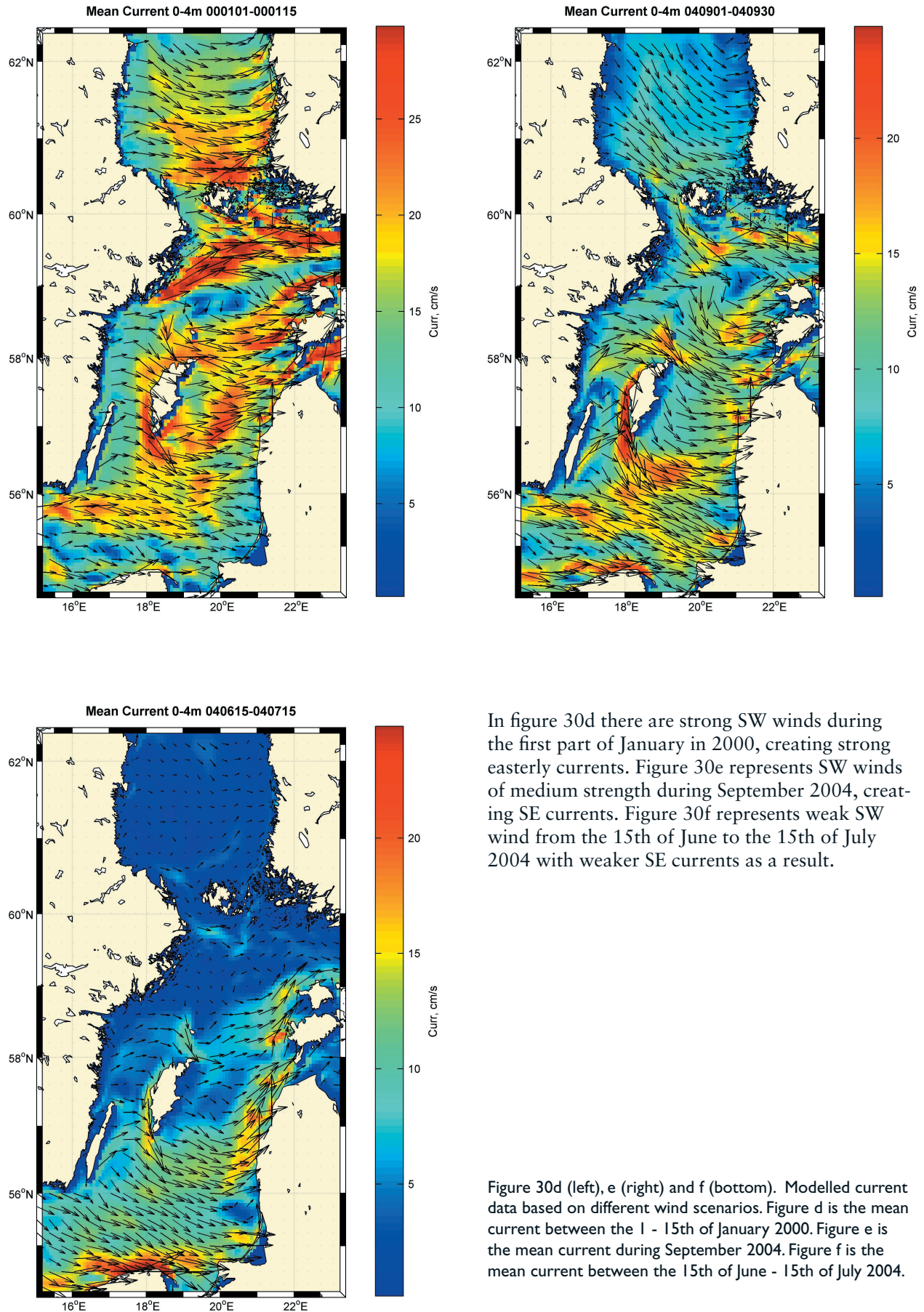
In figure 30d there are strong SW winds during the first part of January in 2000, creating strong easterly currents. Figure 30e represents SW winds of medium strength during September 2004, creating SE currents. Figure 30f represents weak SW wind from the 15th of June to the 15th of July 2004 with weaker SE currents as a result.

Figure 30d (left), e (right) and f (bottom). Modelled current data based on different wind scenarios. Figure d is the mean current between the 1 - 15th of January 2000. Figure e is the mean current during September 2004. Figure f is the mean current between the 15th of June - 15th of July 2004.

Starting position, 11 points

20000115 plus 5 days

Tracking the currents

During the six time periods of the different wind and current scenarios (see figures 26 & 30a-f), model data has been used to produce tracks from day one in the scenario (top figure). This is to give an idea of how fast and were the discharged water gets transported by the currents in differrent wind scenarios. The 3 first scenarios are with winds mainly from the north, with different strengths, producing tracks in a SW direction. The next three are winds mainly from the SW. The current speed and direction variations during these time periods affect the pathway, giving realistic pathways.

20000115 plus 10 days

Figure 31a (left), b (right) and c (bottom). Modelled current data from different wind scenarios. The dots in figure 31a indicate the starting position in all scenarios. Figure b gives the track of a fictitious water parcel after 5 days and c, the track after 10 days.

20020910 plus 5 days

20020910 plus 10 days

20020910 – 20021015

Figure 32a (left), b (right) and c (bottom). Modelled current data from different wind scenarios. The dots in figure 31a gives the track of a fictitious water parcel after 5 days, in figure b after 10 days and in figure c at the end of the time period.

19970705 plus 5 days

19970705 plus 10 days

19970705 – 19970721
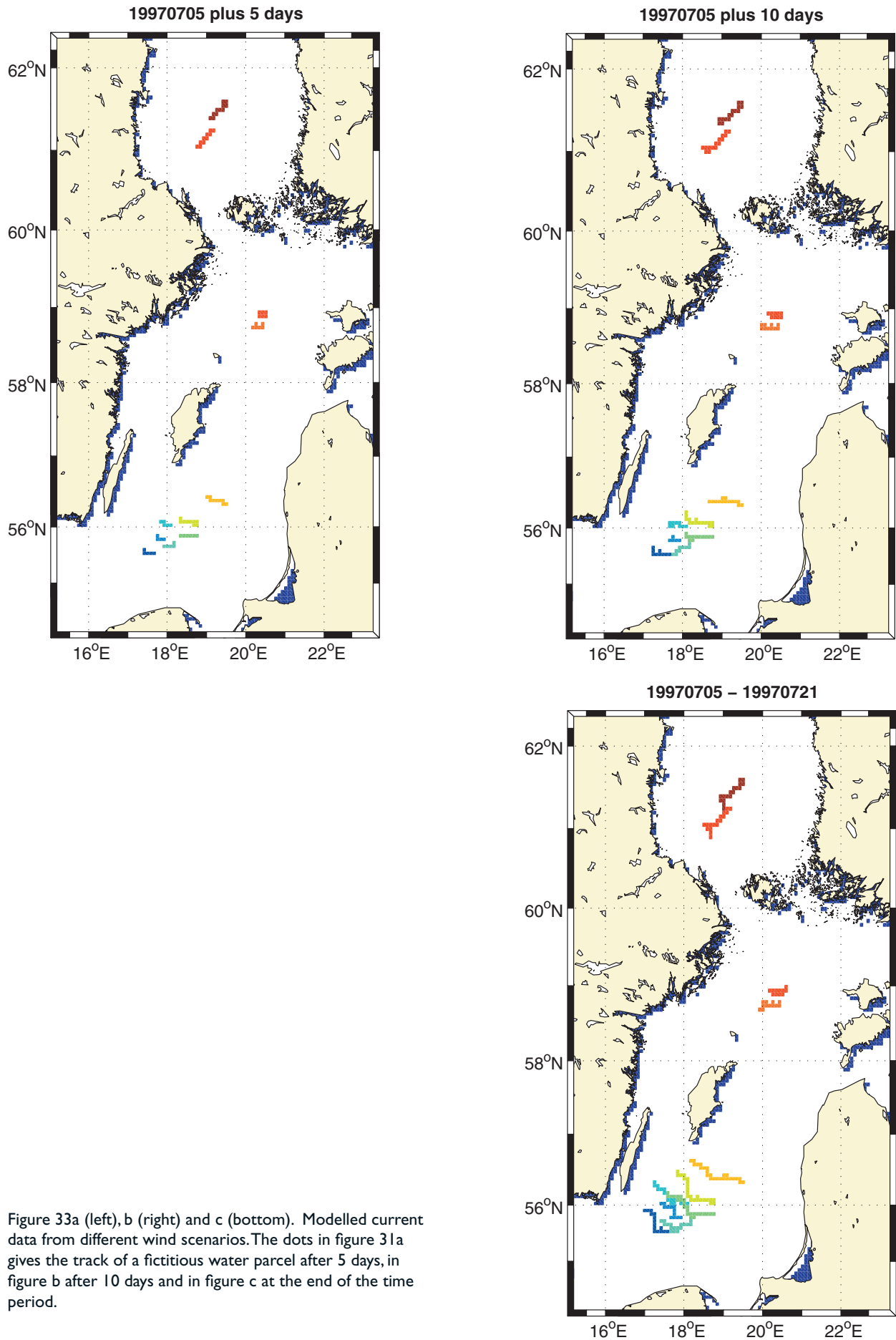
Figure 33a (left), b (right) and c (bottom). Modelled current data from different wind scenarios. The dots in figure 31a gives the track of a fictitious water parcel after 5 days, in figure b after 10 days and in figure c at the end of the time period.

20000101 plus 5 days

20000101 plus 10 days

20000101 – 20000115
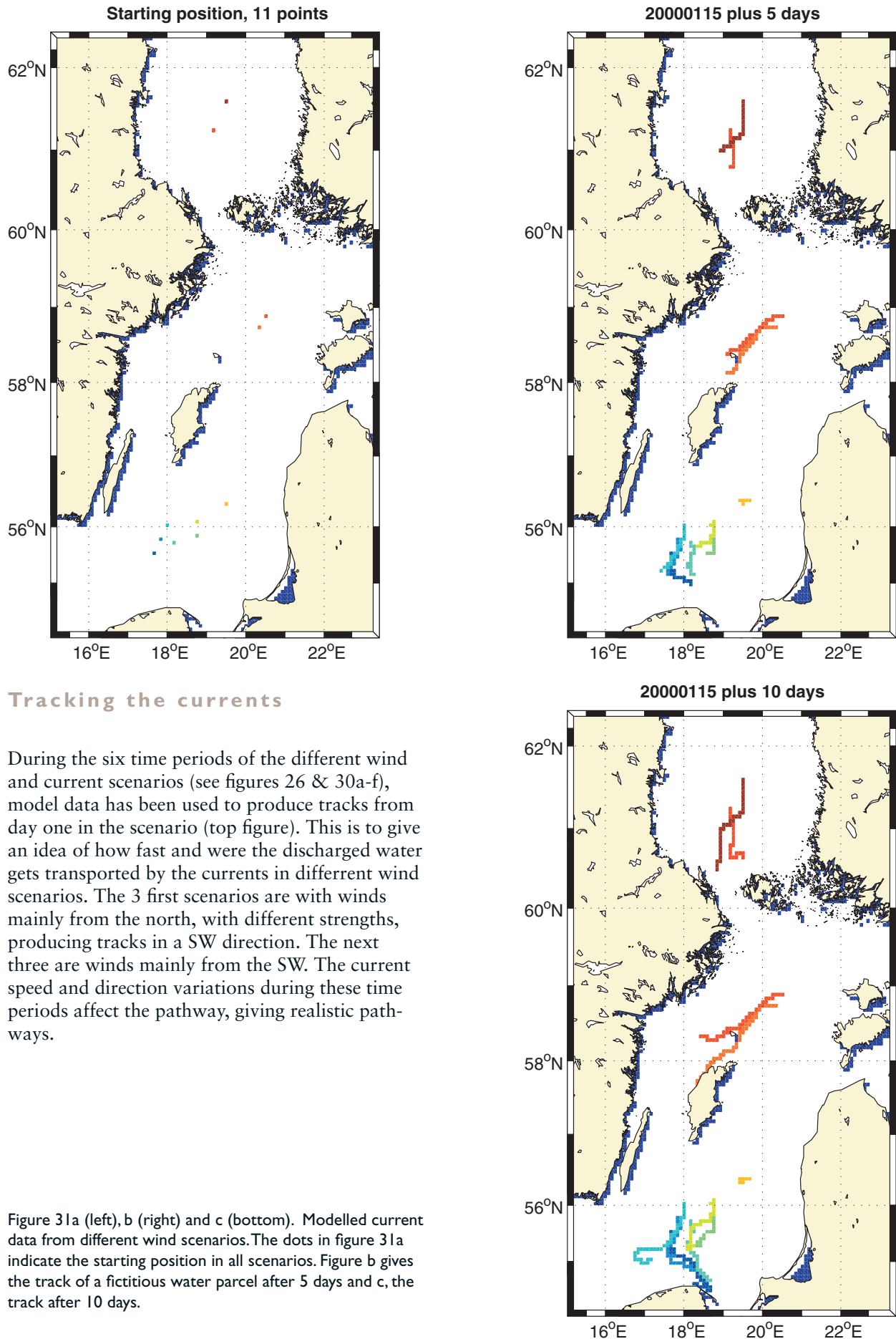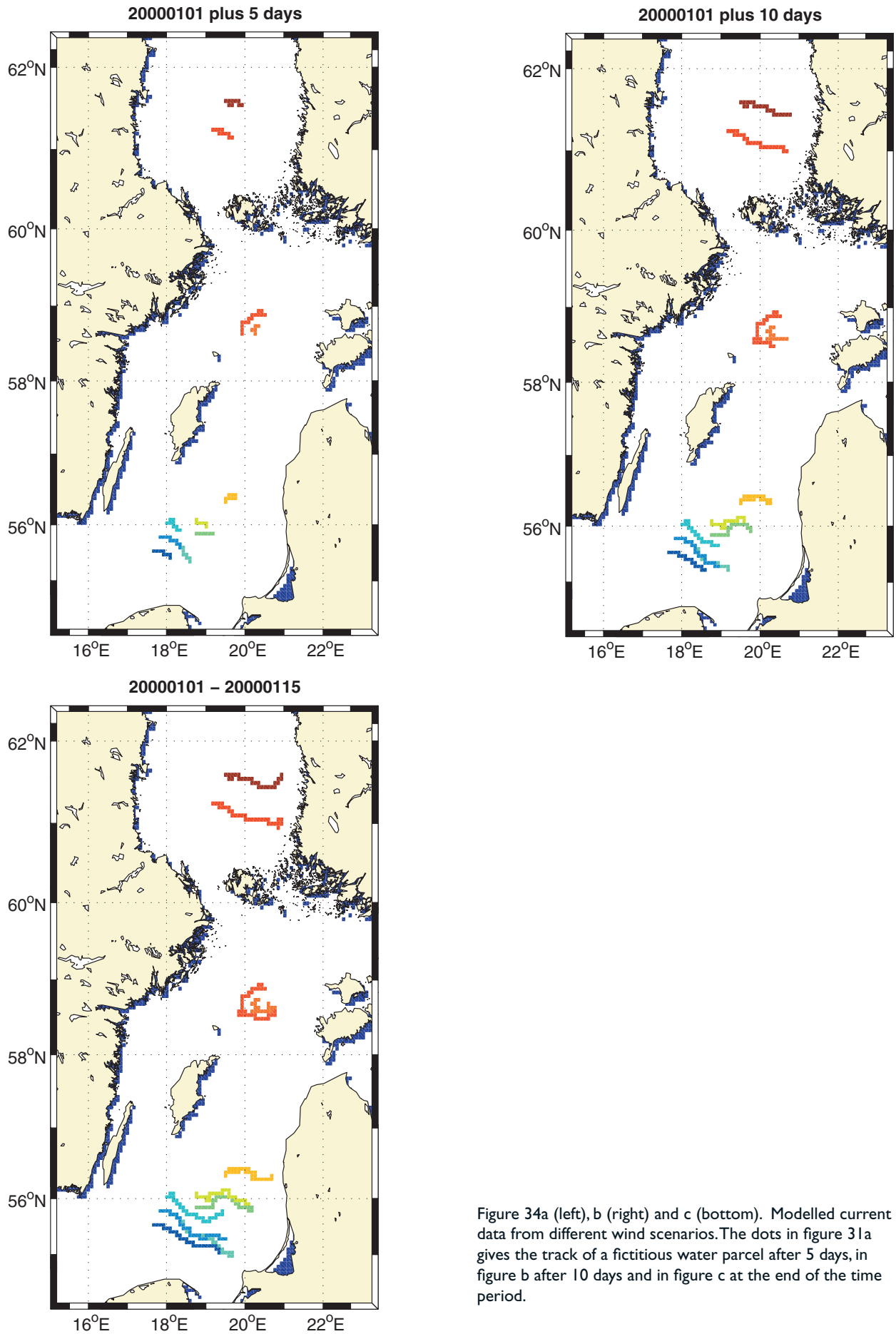
Figure 34a (left), b (right) and c (bottom). Modelled current data from different wind scenarios. The dots in figure 31a gives the track of a fictitious water parcel after 5 days, in figure b after 10 days and in figure c at the end of the time period.

20040901 plus 5 days
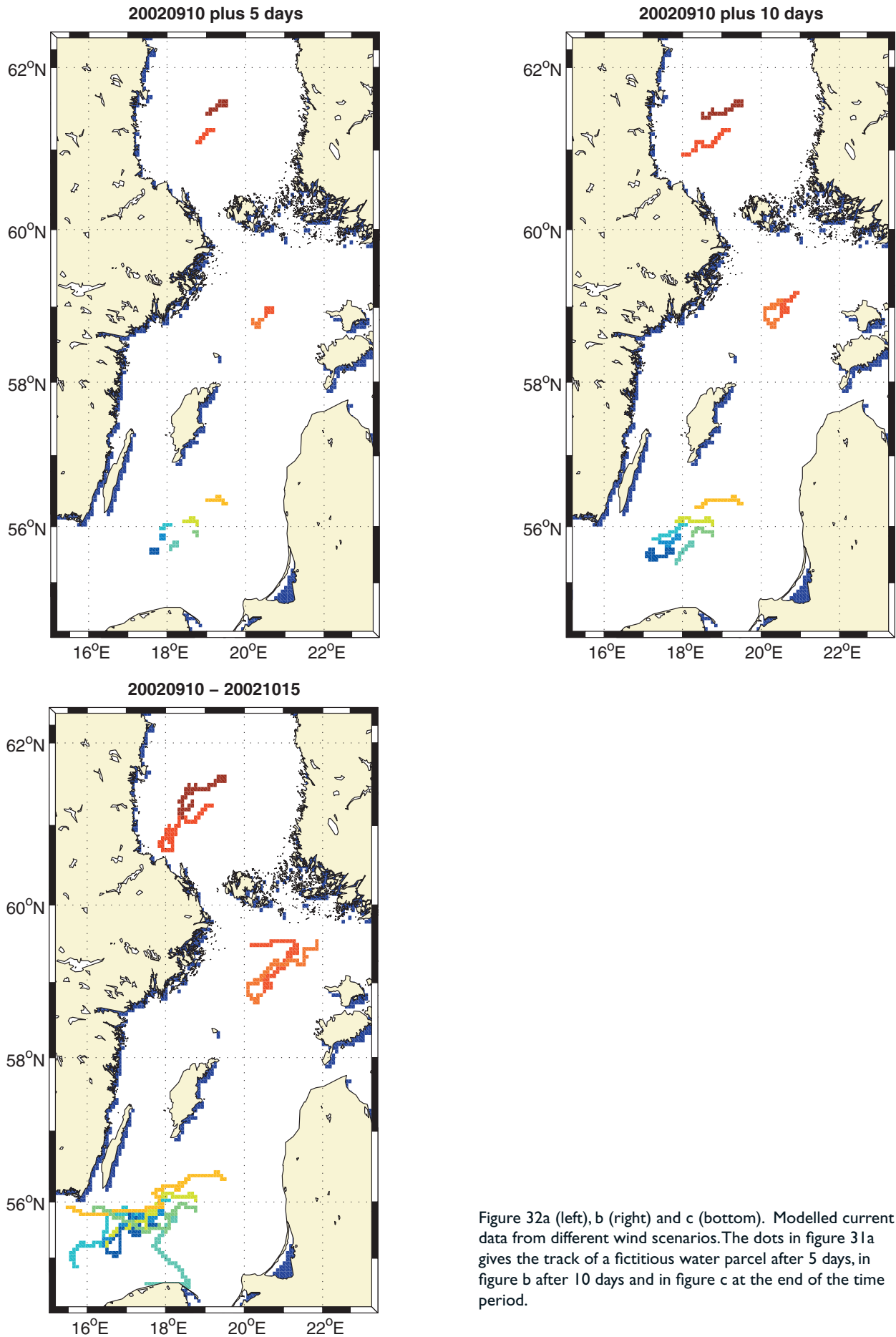
20040901 plus 10 days

20040901 − 20040930

Figure 35a (left), b (right) and c (bottom). Modelled current data from different wind scenarios. The dots in figure 31a gives the track of a fictitious water parcel after 5 days, in figure b after 10 days and in figure c at the end of the time period.

20040615 plus 5 days

20040615 plus 10 days

20040615 – 20040715

Figure 36a (left), b (right) and c (bottom). Modelled current data from different wind scenarios. The dots in figure 31a gives the track of a fictitious water parcel after 5 days, in figure b after 10 days and in figure c at the end of the time period.
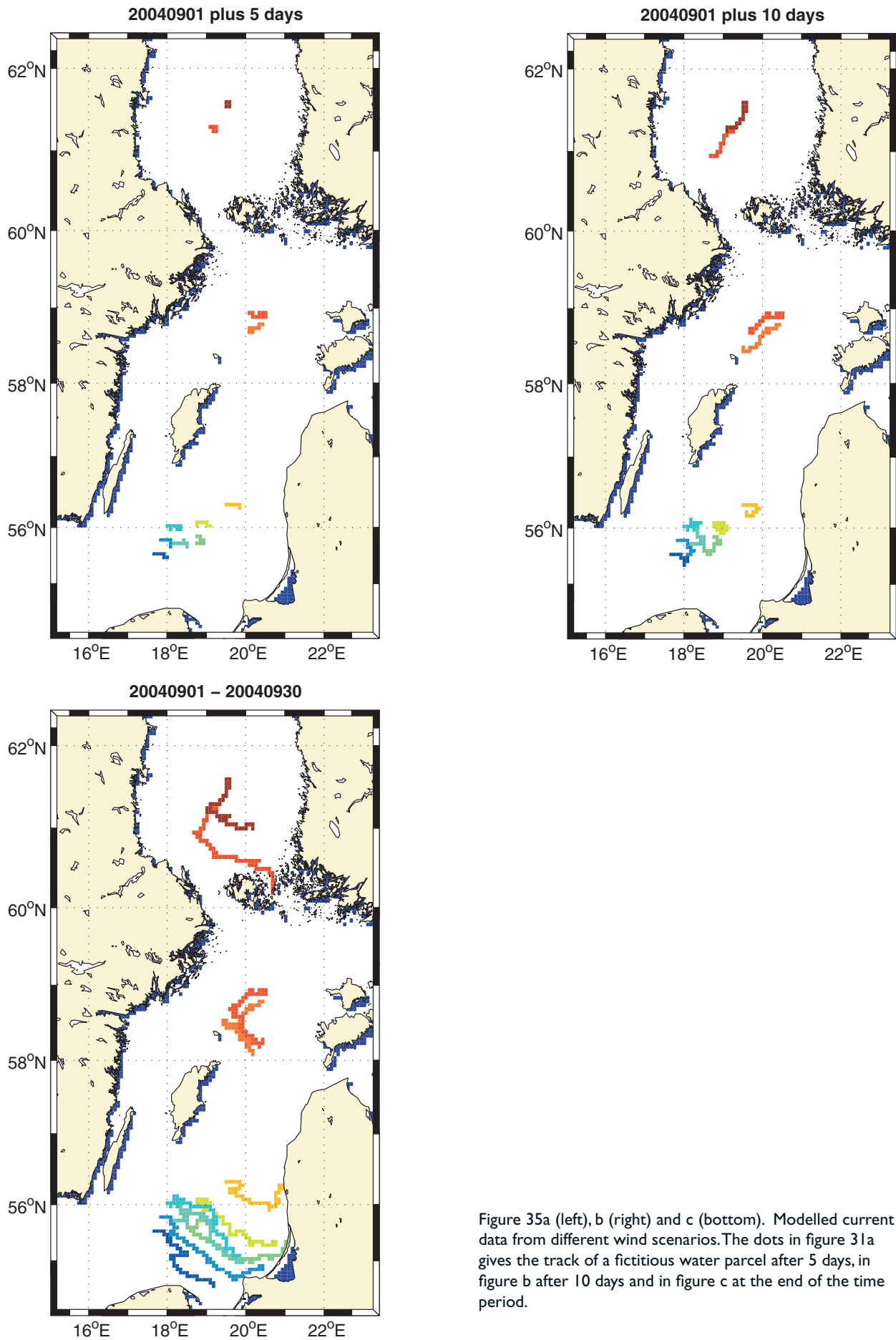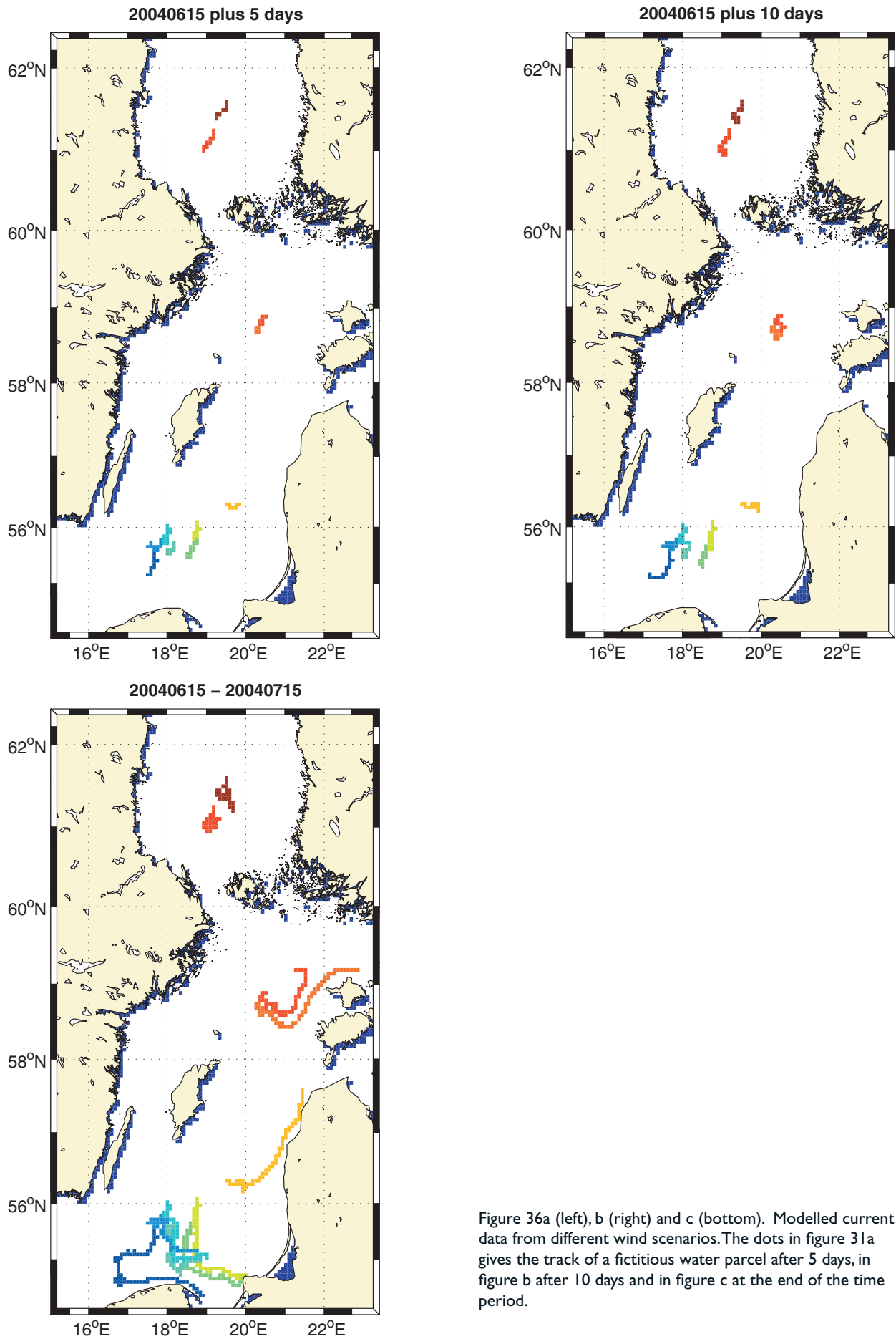
Vertical circulation

The thickness of the mixed layer is a function of the surface buoyancy flux, the wind stress and the stratification.

Fresh water is lighter than salty water and warm water is lighter than cold. Adding heat or fresher water to the surface, the surface water gets more buoyant, or there is a positive buoyancy flux. Cooling or evaporation leads to higher surface density, which in turn can make the surface water sink (negative buoyancy flux, or convection). This procedure of vertical mixing can happen on a daily basis with heating during the day and cooling at night (Nerheim, 2006).

The stratification in the water is the density structure over depth. If the water is strongly stratified, there is a strong gradient of either temperature or salinity at some depth. The stronger the stratification, the harder it is for the mixing processes to mix the top layer with the water beneath. In the Baltic Proper, there is a seasonal thermocline developed during summer at about 20 meters depth. During autumn cooling (negative buoyancy flux), the surface and deeper water mix, resulting in more homogenous temperatures. There is a stable perennial halocline at 60 meters depth. Above the halocline, the salinity is rather homogeneous.

Wind mix the surface water with deeper waters. If the buoyancy flux vanishes or is positive but small, the mixing depth due to the wind is set by the wind speed and the local Coriolis parameter

(latitude dependency). This is called the Ekman length. The seasonal thermocline usually prevents mixing below the thermocline, even though there might be stronger winds able to mix water at greater depths. Mainly the mixing depth in the summer is to the seasonal thermocline. During autumn the thermocline deepens and weakens, hence the mixing can reach further, but usually not more than the thermocline depth. During strong winds in late autumn and winter, the seasonal thermocline is too weak to prevail and the mixing can, with string wind situations and negative buoyancy, reach the perennial halocline.

There is another mixing depth aspect not mentioned above: If there is a positive bouyancy flux, the water becomes more stable and the turbulence is needed to mix the lighter water into the deeper water. The result is a new pycnocline above the older one. The new depth to the new pycnocline is called the Monin-Obukhov length.

During positive buoyancy, the depth of the wind induced mixing, is the shallowest of the mentioned length scales. Since there has been no investigation within this report of the buoyancy fluxes, the approximation is that the wind is the dominating factor mixing the surface layer to the lesser of the Ekman length and the pycnocline depth.

In table 6, the Ekman length has been calculated for different wind speeds at a latitude of 57°. In table 7, the Ekman lengths calculated using the monthly mean winds over the year is compared to the mean pycnocline depths. The mean winds are so low, that the pycnocline is never reached. Ekman length for wind scenarios with 5, 10 and 15 m/s is also combined with the mean pycnocline depths. In summer, the pycnocline restricts the wind induced mixing when the wind speed is 15 m/s (marked with yellow).

Wind speed	Ekman length
5 m/s	10 m
10 m/s	20 m
15 m/s	35 m
20 m/s	51 m
25 m/s	69 m

Table 6. Ekman lengths at the 57th latitude for different wind speeds.

Table 7. Ekman layers, from the monthly mean and 5, 10 and 15 m/s winds are compared to the mean pycnocline depth. Yellow area indicate pycnocline restriction of the wind mixing depth.

Month													Unit
	J	F	M	A	M	J	J	A	S	O	N	D	Unit
Mean wind	7	6.5	5.5	5	4.5	4.5	4	4	5	6	5.5	6.5	m/s
Pycnocline depth	60	60	60	60	60	60	20	20	40	60	60	60	m
Wind mixed depth	13.5	12.5	11	10	9	9	8	8	10	12	11	12.5	m
Wind 5 m/s mixed depth	10	10	10	10	10	10	10	10	10	10	10	10	m
Wind 10 m/s mixed depth	20	20	20	20	20	20	20	20	20	20	20	20	m
Wind 15 m/s mixed depth	35	35	35	35	35	35	20	20	35	35	35	35	m

APPENDIX 7: TRANSPORT AND DIFFUSION CALCULATIONS

Transport

The wind transfers momentum to the sea surface creating a surface current. The surface layer transfers momentum to the layer below which results in a deeper layer starting to move, though more slowly than the layer above. This is a chain reaction over depth, ending when there is no more momentum to be transferred. There is also a deviation of the direction due to the Coriolis force. In an idealized ocean, the surface current is 45° to the right of the wind direction (in the Northern Hemisphere). The current direction in each layer in the water column gets deflected to the right of the direction of the layer above. Due to the deflection of the direction, the net transport of the water is 90° to the right of the wind direction (this is when the entire depth affected by the wind is included). In reality, due to for example bathymetry and coasts, these numbers are smaller.

In previous appendices, the pycnocline depth has been discussed and its influence on mixing depth. It has a similar restrictive affect when it comes to wind induced transports. When calculating mean speed of a water layer that is in motion due to the wind, the mean current and direction is different when looking at different depths of the top water layer. If you choose to only look at the top 5 meters, the mean speed of those top 5 meters will be higher than if you choose to look at the top 10 meters of the surface waters. Since the deflection of the direction compared to the wind increases with depth, the first 5 meters have a smaller angle deflection compared to the first 10 meter layer.

Connecting these calculations to previous ones, water transport has been calculated over varying depths and varying wind speeds. The surface to 20, 40 and 60 can apply to pycnocline depths during summer, autumn and winter respectively.

The mean current over the chosen depth is calculated for a specific wind speed. The wind direction throughout table 8, is set to come from the south. If the current would not be deflected at all, the current direction would then be to the north, that is have a direction of 0°. The calculated current direction is deflected, hence the deviation from 0°. If the wind came from the north, add 180° to the values below.

Table 8. Calculated mean current speed and direction over varying depths and varying wind speeds. Calculated transportation distances for the different scenarios. Wind direction is set to 180°.

Current (curr) dir based on wind dir = 180 degrees, i.e. southerly winds.										
	Surface to 5m		Surface to 10m		Surface to 20m		Surface to 40m		Surface to 60m	
Wind speed	mean curr speed 0-5m	mean curr dir 0-5m	mean curr speed 0-10m	mean curr dir 0-10m	mean curr speed 0-20m	mean curr dir 0-20m	mean curr speed 0-40m	mean curr dir 0-40m	mean curr speed 0-60m	mean curr dir 0-60m
5 m/s	0.04	26	0.03	34	0.03	46	0.02	64	0.02	77
10 m/s	0.08	21	0.06	28	0.03	37	0.04	50	0.03	61
15 m/s	0.12	19	0.10	24	0.09	31	0.07	42	0.06	50
Unit	m/s	degrees	m/s	degrees	m/s	degrees	m/s	degrees	m/s	degrees

Wind speed	Equals distance / day	Equals distance / 10 days	Equals distance / day	Equals distance / 10 days	Equals distance / day	Equals distance / 10 days	Equals distance / day	Equals distance / 10 days	Equals distance / day	Equals distance / 10 days
5 m/s	3.5	35.4	2.9	29.4	2.4	24.2	2.1	20.7	2.0	19.9
10 m/s	6.5	64.8	5.4	54.4	2.7	26.8	3.7	37.2	2.9	29.4
15 m/s	10.4	103.7	8.8	88.1	7.3	73.4	6.0	60.5	5.4	54.4
Unit	km/day	km/10 days	km/day	km/10 days	km/day	km/10 days	km/day	km/10 days	km/day	km/10 days

1 nm	= 1.852 km
50 nm	= 92.6 km

At the wind speed 5 m/s, it takes 26 days to transport the top 5 meters of the surface waters a distance of 50 nm.
At the wind speed 10 m/s, it takes 14 days to transport the top 5 meters of the surface waters a distance of 50 nm.
At the wind speed 15 m/s, it takes 9 days to transport the top 5 meters of the surface waters a distance of 50 nm.

Table 9. Distances from the nearest part of the southern Baltic Proper proposed BWE area to the nearest protected area in each direction (top). The amount of days needed, with an ideal wind direction, for a water parcel to be transported to the protected area due to the wind speed. The direction in the table is the current direction.

	Direction							
Distance	S	SW	W	NW	N	NE	E	SE
nm	41 nm	46	0	14	15	46	26	34
km	76 km	85	0	26	28	85	48	63

	Direction							
Wind speed	S	SW	W	NW	N	NE	E	SE
5 m/s	21 days	24	0	7	8	24	13.5	18
10 m/s	12 days	13	0	4	4.5	13	7.5	10
15 m/s	7 days	8	0	2.5	3	8	4.5	6

The mean current speed in the top 5 meters is about 1% of the wind speed and the direction is about 20° at the high wind speed and about 25° at lower wind speeds.

From the current speed, transporting distance during 1 and 10 days is calculated. The distances are calculated assuming constant wind speed and direction during 1 and 10 days. The normal wind situation is varying wind speed and directions, but there are frequent occurrences with stable wind conditions, making the 10 day scenarios realistic.

Looking at the top 5 meters:
• a 5 m/s wind transports the water a distance of 3.5 km per day,
• a 10 m/s wind gives a distance of 6.5 km per day and
• a 15 m/s a distance of 10.4 km per day.

To transport the top 5 meters of the water a distance of 50 nm (distance of the proposed BWE area to the coast) it takes:

• 26 days at a 5 m/s wind speed,
• 14 days at a 10 m/s wind speed and
• 9 days at a 15 m/s wind speed.

Transport to protected areas

Looking at the southern Baltic Proper proposed BWE area, there are a number of protected areas in the proximity (see figures 6-8). Combining the distances from the nearest part of the BWE area to the nearest protected area in each direction, with transport of the top 5 meters in different wind scenarios, table 9 is compiled. The top part is a repetition of the distances to the nearest protected area and the lower part is the amount of days needed, with an ideal wind direction, to reach the protected area depending on the wind speed. The direction in the table is the current direction.

The closest protected areas are situated west and north of the BWE area. The Södra Midsjöbanken to the west, even brush against the BWE area.

Diffusion

Diffusion, or dispersion, is the phenomena that spread or dilute smoke in the air or discharges in the water. When a tracer is released into the surface layers of the sea, it will initially spread out in both the horizontal and the vertical direction. The stronger the winds, the deeper the vertical spread, though the dispersion is much faster in the horizontal than in the vertical. The tracer area increases with time, often stretched in the direction of the mean current (Nerheim, 2006).

Okubo (1971), put together experiments with tracers and by that, he found a relationship between time and variance. By plotting the value of the variance against diffusion time, he obtained a basic diffusion diagram (see figure 37). The variance ranges from 10^7 cm^2 to 10^{13} cm^2, while the time of diffusion ranges from 2 hours to a month. Though the points in the diagram scatter somewhat, there is an obvious trend. Okubo's relationship for rotary symmetric variance and time is:
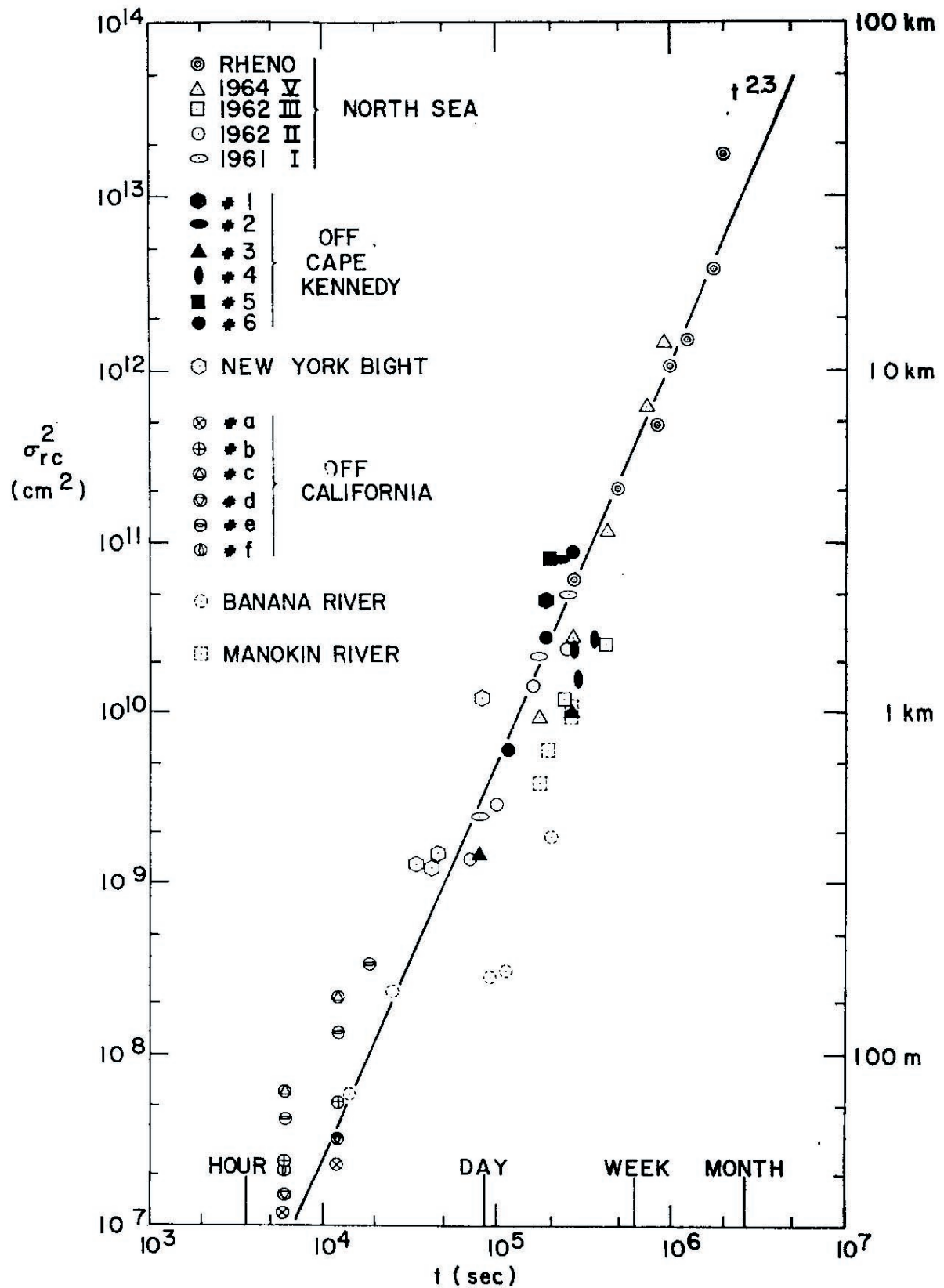
$$\text{sigma}_{rc}^2 = 0.0108 \ t^{2.34} .$$

Figure 37 Okubo's diffusion diagram for variance versus diffusion time.

Table 10. Estimates of total BWE per year in the southern Baltic Proper.

	Distribution	BW Volume (m³)	Number of ships / year	Total m³ BWE / year
Tanker	20%	60 700	16 380	$9.9*10^8$
Cargo	80%	14 600	65 520	$9.6*10^8$
Total			82 000	$1.9*10^9$

The diagram presents the empirical relation between the spread of the surface water and time, so after one day, the radius of the dilution area is 350 meters (if symmetric diffusion, the diameter is 700 meters).

Further BW uptake from recently released BW

In the following text, many assumptions are made, trying to calculate, or give an idea of, the risk of another ship taking up recently released BW from an earlier discharge.

To make an estimate, many parameters need to be included, for example traffic density, amount of BW discharges, assuming the BW is discharged within the BWE area, currents transporting the BW out of the BWE area, diffusion and wind speed.

- The area of the southern Baltic Proper is 6200 km².
- The percentage distribution of tankers versus cargo ships passing Gotland is taken from Läppäkoski, 2006. Fig 3.3, page 29, show the traffic structure in the Baltic 2005, July to November. The source is the HELCOM Automatic Identification System (AIS). Only looking at tankers and cargo ships, the tankers make up 20 % and the cargo ships 80 %.
- From Dragsund et. al, 2005, ballast capacity of some vessels and calculated time to conduct BWE is used (table 9-2).
- The number of ships passing between Öland and the Bay of Gdansk is taken from Läppäkoski, 2006. Fig 3.4, show the number of ships (excluding ferry traffic) in the Baltic Sea in 2000. There is also a calculation of the number of ships passing in 2015. The mean of the two values was used.
- The BW is mixed by the wind to different depths depending on the wind, resulting in different BW concentrations.
- Okubo's diffusion gives a 700 meter wide "street" with low concentration of BW the day after the passing.
- To facilitate the mental effort of these estimates, the assumption is that even if there is wind present, mixing the BW vertically, there is no transportation of BW out of the BWE area.

The number of ships (excluding ferry traffic) in the southern Baltic Proper in 2000 was about 58 500 and the estimation for 2015 was 105 300 giving about 82 000 ships as a mean. From Dragsund et. al, 2005, ballast capacity of container ships were listed having a BW volume of 14 600 m³ and crude oil carriers of 60 700 m³. From this the total BWE per year was calculated in the table 10.

The approximation of $1.9*10^9$ m³, as the total BWE can be compared with $2.3*10^7$ m³ in an article by Kristina Jansson at the Swedish Environmental Protection Agency. Though that total amount is based on people giving the correct answers in a questionnaire, on traffic statistics and the amount is the discharge within Swedish waters. A similar study (questionnaire and traffic statistics) was conducted by Hoffrén (2006). In that study, an approximation of $4.6*10^7$ m³ BW is discharged (though in Swedish waters) annually. The number can also be compared to the total amount of $1.2*10^8$ m³ BW that may be discharged in the Baltic annually, mentioned in the Leppäkoski report. Obviously, behind all these numbers, there are many assumptions made.

Based on these calculations, approximately 220 ships pass the southern Baltic Proper per day carrying a total of $5.3*10^6$ m³ BW. If the discharged BW during one day, makes a one meter deep layer in an undiluted concentration, the total BW area is 0.086% of the total BWE area. This is a low number, but this is not a realistic number since the diffusion and wind spread the BW to larger areas. Though this means a reduction of the concentration.

In Dragsund et. al, 2005, there is an example of an oil tanker (with BW volume 60 700 m3), going at a speed of 14 knots, needing a distance of 400nm for a complete sequential BW exchange and 600nm for the flow-through method. The southern BWE are is much smaller than that, having about 50nm as the longest distance from one end of the area to the other. Recalculating the speed of the tanker, it needs to slow down to 1.8 and 1.2 knots respectively.

Taking the average BW volume of a tanker/cargo ship (0.2*60 700+0.8*14 600), assuming the travelling distance across the BWE area is 50nm, the ship needs to discharge 0.26 m^3 per travelled meter. The time to cross the BWE area is disregarded for this fictional ship.

Another assumption is that there is an instant mixing, due to the discharge turbulence, so that the BW mixes completely to 5 meters depth and 3 meters width. The 0.26 m^3 is mixed in a 15 m3 volume giving a BW concentration of 1.7% of the original concentration (what ever the BW contains). Disregarding further mixing, one ship has now covered $2.8*10^6$ m^2, with a BW concentration of 1.7%. Say that there are 220 ships per day, and all ships choose slightly different paths, there is a total surface area of $6.1*10^7$ m^2 with a BW concentration of 1.7% making up 1% of the total BWE area. During the course of a day, each 3 meter BW plume has spread to a 700 meter BW plume. If there is no wind mixing the BW further down, the new concentration a day after the discharge, is 0.0074% of the original concentration making up a total area of $1.4*10^{10}$ m^2, which is 220% of the total BWE area.

Including wind mixing, the concentration will drop further. The calculated concentrations is for a depth of 5 meters. A 5 m/s wind mixes the water to 10 meters, and so on (see previous tables). The reduced concentrations are displayed in table 11, giving the concentration the first hours after the discharge (no diffusion) and after a day (one day of diffusion) in different wind scenarios, taking into account the seasonal thermocline during the summer.

If the 220 ships would cross the BWE area at the same time, the next ship would have a 1% risk of taking up the somewhat diluted BW from the previous ships. If the ship arrived the day after there is a definite uptake of the more diluted BW, since the BW area now is 220% of the original BWE area.

This is only calculations from one day to the next. During the second day another 220 ships pass, discharging and taking up BW. The concentration of BW increase until it levels out, by BW getting transported out of the area, organisms sinking or dying, major mixing with deeper layers during autumn and winter and so on. The levelled out concentration is not possible to calculate at this point.

An assumption is that all the ships are taking different routs. Normally in a major shipping lane, the ships tend to follow somewhat the same route, markedly increasing the risk of BW uptake of higher concentration.

In many of the referenced texts, the concentration of the organisms in the BW is not of major importance. Some times the new organisms can survive and reproduce even at low starting numbers.

Table 11. The dilution of the BW concentration due to wind mixing and presence of seasonal thermocline.

	No diffusion		One day of diffusion	
	Conc	Conc	Conc	Conc
	Winter & Autumn	Summer	Winter & Autumn	Summer
No wind	1.70%	1.70%	0.0074%	0.0074%
5 m/s	0.85%	0.85%	0.0037%	0.0037%
10 m/s	0.42%	0.42%	0.0018%	0.0018%
15 m/s	0.20%	0.42%	0.001%	0.0018%

APPENDIX 8: TRANSPORT SIMULATIONS USING SEATRACK WEB

This section shows examples from model simulations of the transport of the water from a BW discharge in the Baltic Sea. The purpose of the simulations is to demonstrate how different parts of the Baltic Sea could be exposed to a BW discharge and how fast a discharge could be transported by the currents to different areas of interest, e.g. protected areas and coastal areas.

The simulations were carried out using Seatrack Web, which is a particle transport model for oil drift forecasts in the North Sea – Baltic Sea area. In this study, however, all processes related to oil drift were excluded and the model calculated only the advection of particles, i.e. the transport by the currents. Hence, a BW discharge is represented in the model by a particle, which is moving with the ambient flow.

The flow field was taken from SMHIs operational oceanographic model for the Baltic Sea (HIROMB). The HIROMB model calculates current velocities in a regular grid with a horizontal resolution of three nautical miles and a vertical resolution ranging from 4 m at the surface to 60 m at the deepest parts.

To simplify the simulations, the particle transport was limited to a horizontal plane near the water surface and no turbulent dispersion was included. The particles were released and transported by the currents at 6 meters depth. This corresponds to the center of the next uppermost grid cell, which means that the currents are strongly affected by the wind at the water surface.

To capture different seasonal current conditions, the simulations covered a time period of one year. Two different years, 2002 and 2004, were selected for the runs. Both years contain periods with strong wind conditions, but the directional characteristics are different. During the simulation, particles representing the BW discharge were released every 24 hours at 12 different locations distributed over the proposed discharge area in the central Baltic Sea.

By keeping track of the particle trajectories and the release time of each particle, the following statistical data was calculated after each run:

- (1) the maximum relative frequency of arrival of the particles to different grid cells in the underlying HIROMB domain,
- (2) the mean drift time of the particles and
- (3) the shortest drift time.

To limit the time a discharge is affecting the surroundings, the maximum lifetime of the BW discharge was assumed to be 30 days. This means that particles that had been drifting around for more than 30 days were not considered.

The maximum relative frequency of arrival was calculated in two steps. In the first step, the relative frequency of arrival was computed separately for each of the 12 different discharge points. This was accomplished by calculating the sum of the particles that had arrived to each grid cell and dividing by the total number of discharged particles (= 365). No particle was counted more than once in each cell. Thereafter, the largest frequency of arrival from the 12 discharges was calculated. The resulting maximum relative frequency of arrival should be interpreted as the maximum probability that a BW discharge occurring somewhere in the proposed discharge area will arrive to a certain grid cell within 30 days.

The mean drift time is the average time it takes for particles originating from all discharge points to reach a certain grid cell. The shortest drift time, on the other hand, is the least time it takes to reach a certain grid cell from any of the discharge points. Hence, if there is a BW discharge somewhere in the proposed discharge area, the shortest drift time tells us how fast the species in the water could reach different areas of the Baltic Sea.

Figure 38 shows the maximum relative frequency of arrival for 2002. The black crosses mark the 12 discharge points and the black rectangles mark some nearby protected areas: Södra Midsjö bank (south), Norra Midsjö bank (middle) and Hoburgs bank (north). Close to the discharge points the probability approaches 100 % since all discharged particles must arrive to those cells. However, the probability decreases fast with increasing distance to the discharge points. As seen in the figure, Södra Midsjö bank is the most exposed protected area because of its proximity to the discharge points.

Note that the maximum relative frequency of arrival presented in the figures is calculated per grid cell and not per unit area. This implies that the absolute values of the frequencies depend on the

size of the grid cells since, the smaller the grid cells in which particle arrivals are counted, the smaller will be the relative frequency of arrival to each cell. The maximum relative frequency of arrival to the protected areas, which is listed in table 12 is, however, independent of the grid resolution.

Figures 39-40 show the corresponding mean drift time and shortest drift time for 2002. On average, discharges in the proposed discharge area could reach most parts of Södra Midsjö bank within 2 weeks and most parts of the other protected areas within 3 weeks. However, the shortest drift time to the protected areas could be only a few days (Figure 40). The shortest drift time to the coastal areas of the Baltic proper is generally 1-2 weeks in this case.
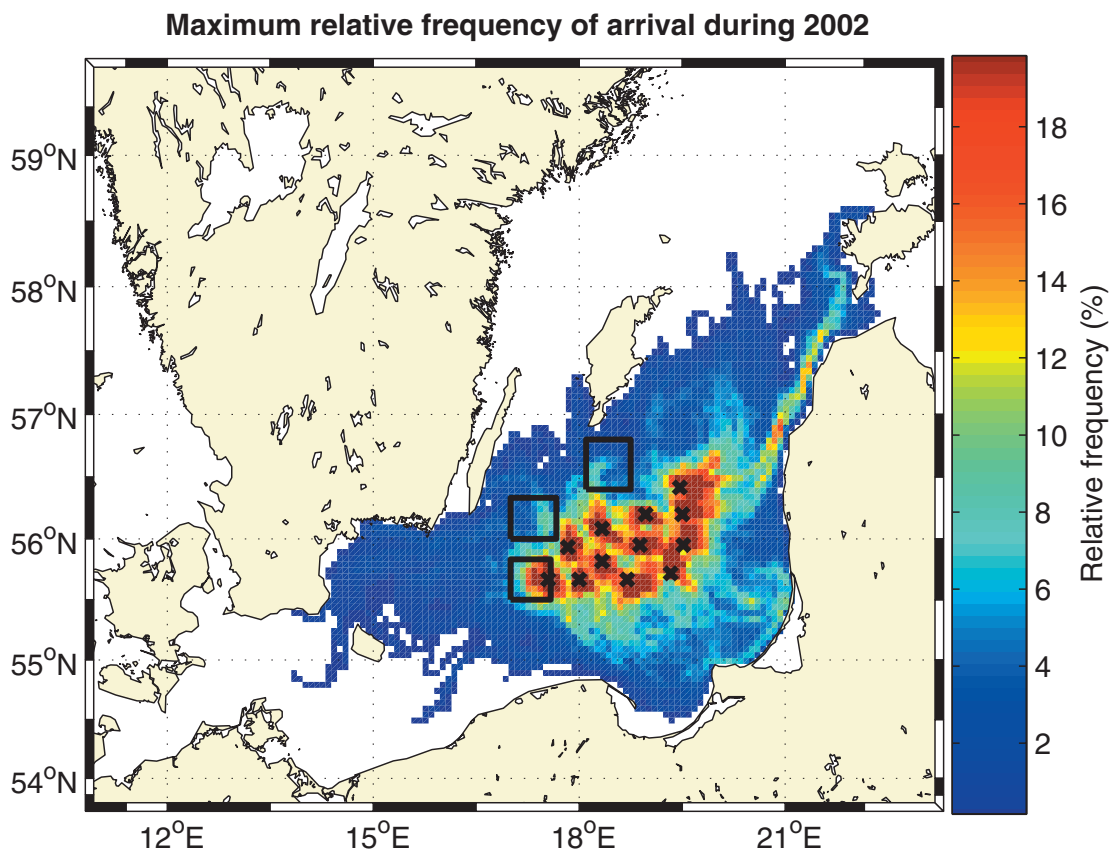

Maximum relative frequency of arrival during 2002

Figure 38. Maximum relative frequency of arrival to different parts of the model domain during 2002.

Mean drift time during 2002
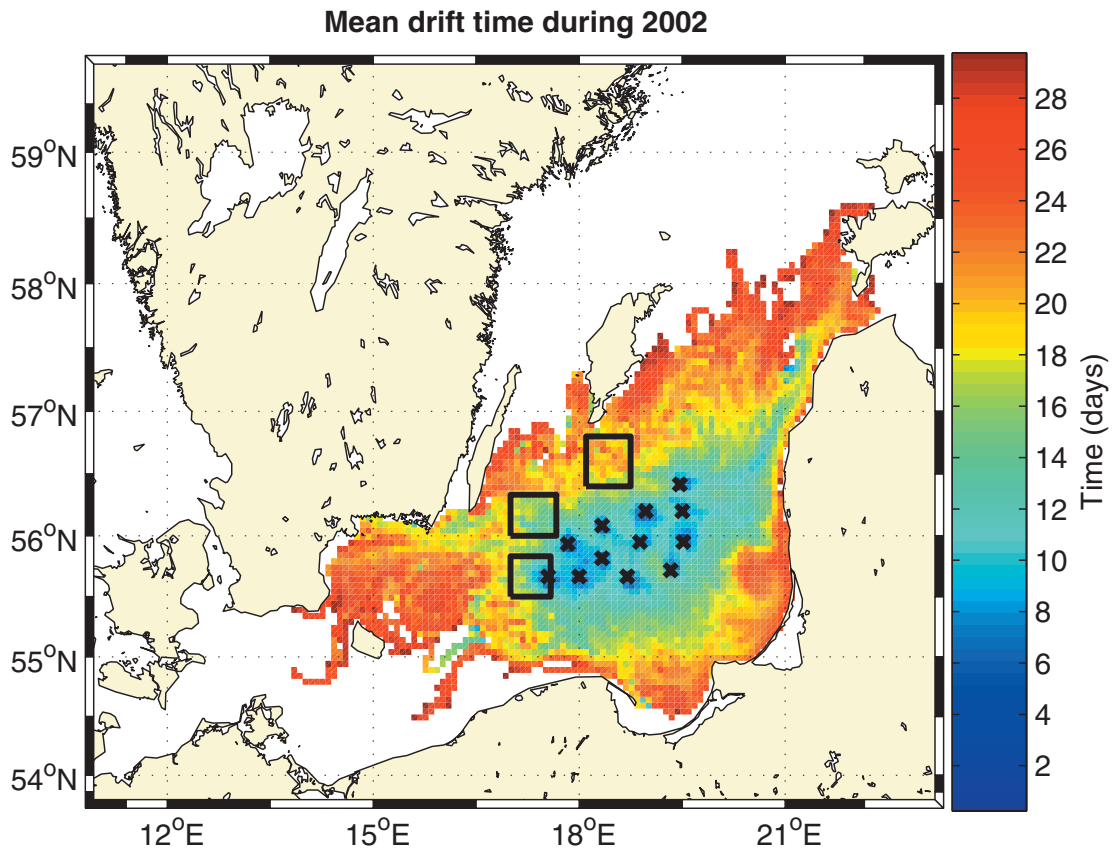
Figure 39. Mean drift time to different parts of the model domain during 2002.

Shortest drift time during 2002

Figure 40. Shortest drift time to different parts of the model domain during 2002.

Maximum relative frequency of arrival during 2004

Figure 41. Maximum relative frequency of arrival to different parts of the model domain during 2004.

Mean drift time during 2004
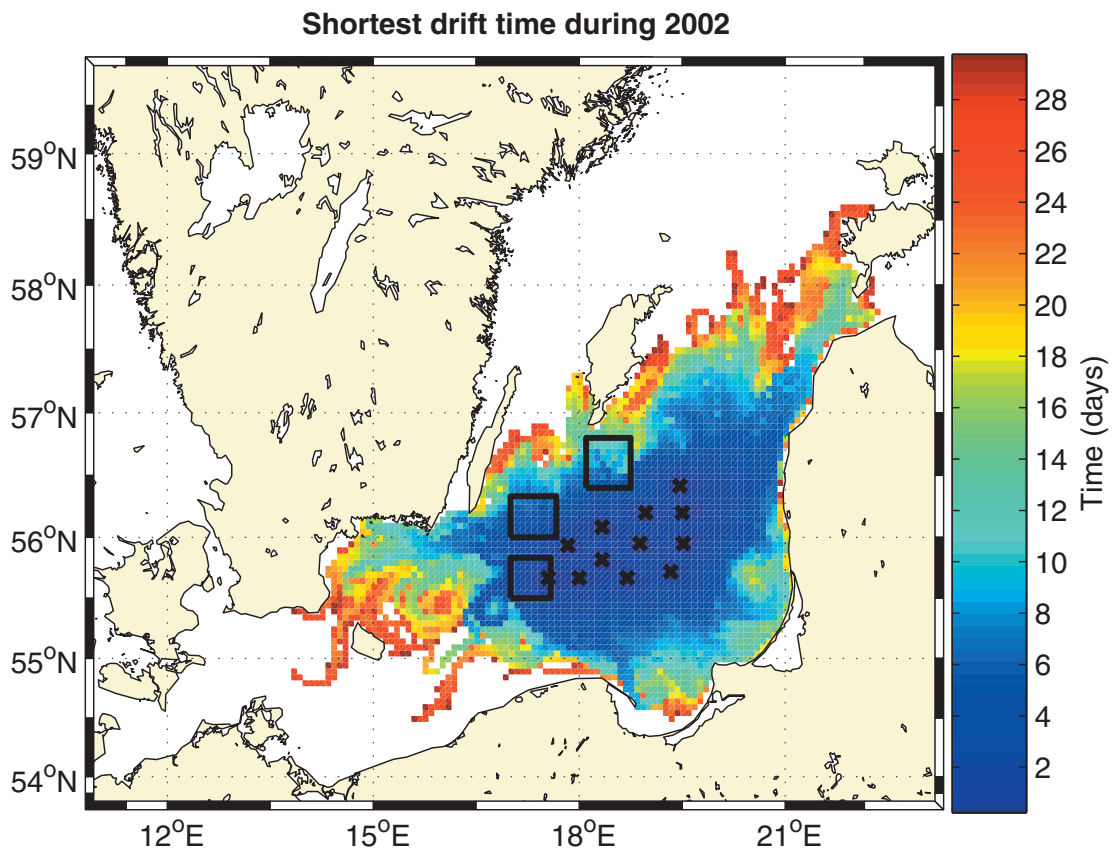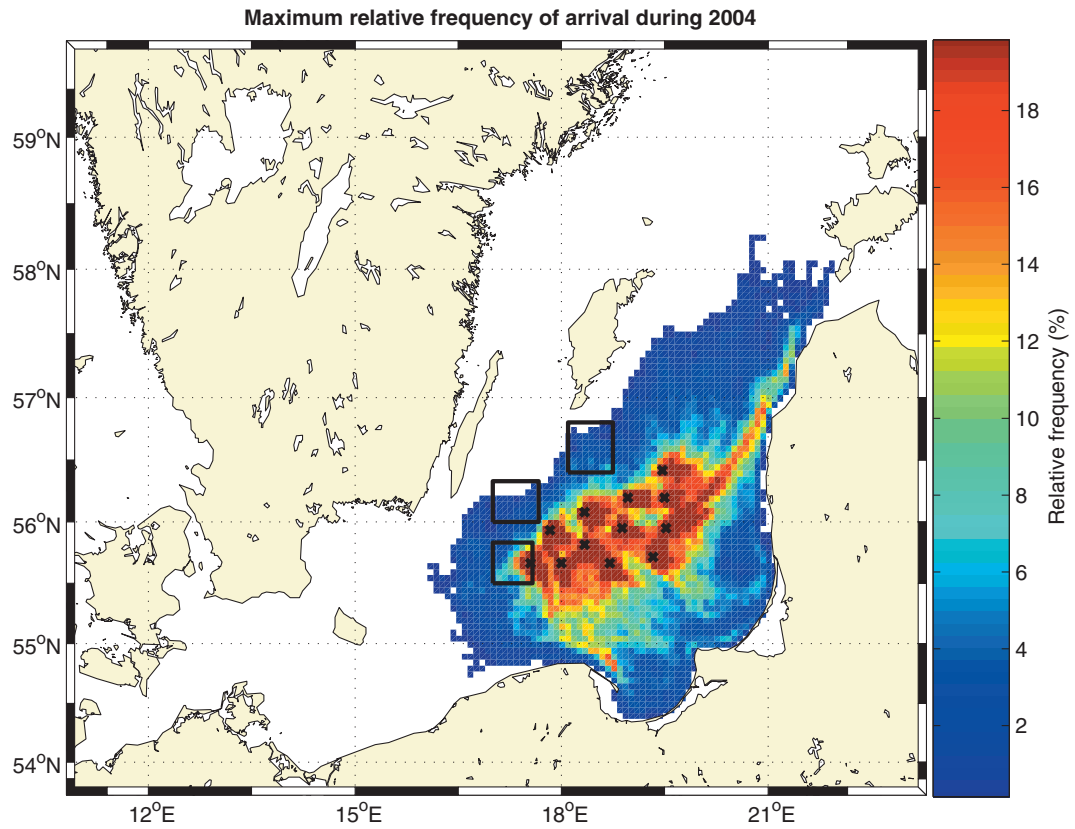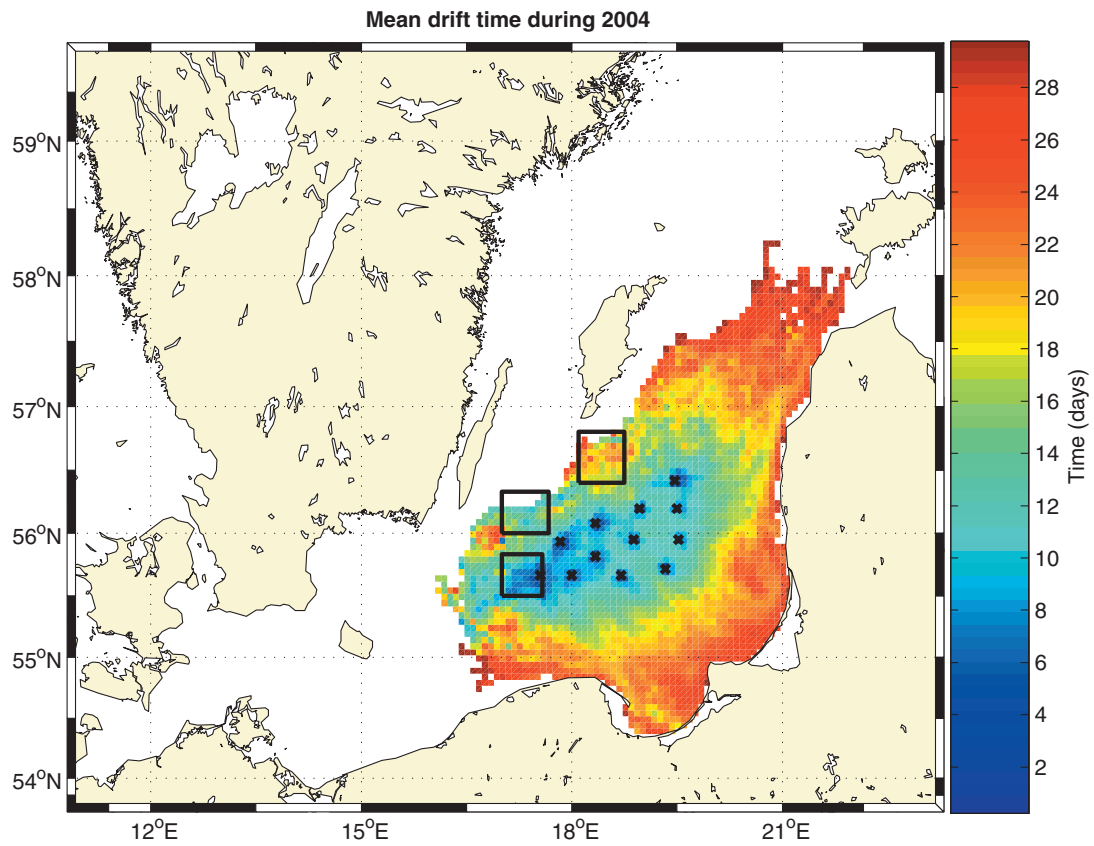

Figure 42. Mean drift time to different parts of the model domain during 2004.
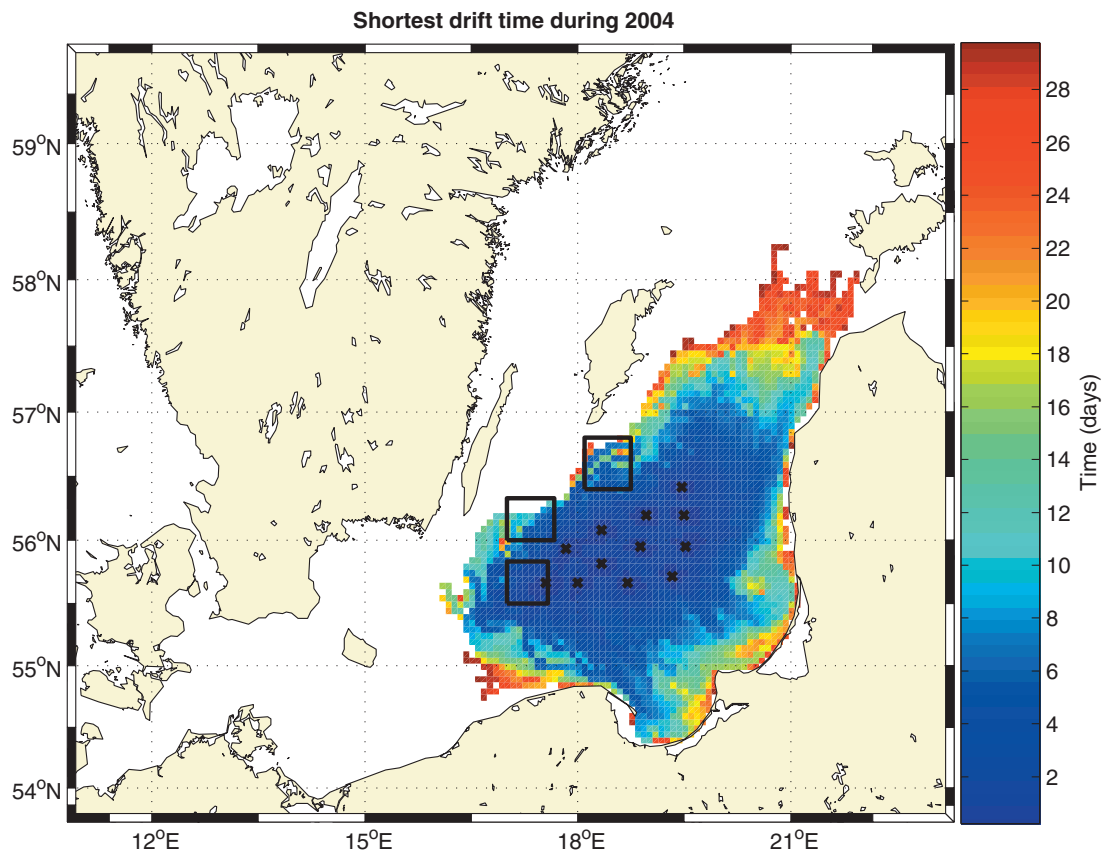
Shortest drift time during 2004

Figure 43. Shortest drift time to different parts of the model domain during 2004.

The results for 2004 are shown in figures 41-43. In this case the exposed area is shifted more eastward and, consequently, the protected areas are somewhat less exposed to discharges. However, Södra Midsjö bank is still heavily exposed to discharges in the southeast part of the proposed discharge area and the shortest drift time to the protected areas is still only a few days.

The results for the three protected areas area summarised in Table 12. The maximum relative frequency of arrival to the three areas was calculated in a similar way to the grid cells by counting the number of particles that reached each protected area within 30 days after the time of discharge and then taking the maximum of all 12 runs. The mean drift time and the shortest drift time in the protected areas are the averages over the cells inside the rectangular boundaries of the areas.

On the basis of the simulations it is concluded that the discharges could be transported over large areas during a time period of one month. The probability that a BW discharge will reach the nearby protected areas Södra Midsjö bank, Norra Midsjö bank and Hoburgs bank is high, in particular Södra Midsjö bank seems to be heavily exposed. The simulations also showed that the discharge could reach the three protected areas within only a few days and coastal areas within 1-2 weeks.

Table 12. Summary of the results for the protected areas.

Protected area	Statistical parameter	2002	2004
Södra Midsjö bank	Maximum relative frequency (%)	100	100
	Mean drift time averaged over the area (days)	12	9
	Shortest drift time averaged over the area (days)	1	1
Norra Midsjö bank	Maximum relative frequency (%)	26	9
	Mean drift time averaged over the area (days)	16	13
	Shortest drift time averaged over the area (days)	5	7
Hoburgs bank	Maximum relative frequency (%)	23	13
	Mean drift time averaged over the area (days)	20	19
	Shortest drift time averaged over the area (days)	9	9

APPENDIX 9: 3 REFERRED REPORTS

In the assignment there are references to three reports:
- OSPAR (Dragsund et. al 2005. Ballast Water Scoping Study North Western Europe),
- HELCOM (Leppäkoski, E. & Gollasch, S. 2006. Risk Assessment of Ballast Water Mediated Species Introductions – A Baltic Sea Approach) and
- BWC:s Guidelines on designation of areas for ballast water exchange (G14).

In this appendix, relevant information to this report is presented. G14 is included to present some of the governing principles and recommendations.

G14 Guidelines

G14 consists of 11 sections and some parts that are of more interest to this assignment are shown and commented below. The numbering of the chapters are taken from the guidelines.

(Comments: The reports describe the recommendations of the parameters distance from the nearest coast and the depth. The BWE, according to the BWC, can be conducted in an area >200 nm from the nearest coast and with a depth of >200 m. If a ship is unable to follow these recommendations then the BWE can be conducted in an area >50 nm from the nearest coast and with a depth of >200 m. A ship is not obligated to follow these recommendations if it means that by following the recommendations it has to make a detour or be delayed.)

7 IDENTIFICATION OF POTENTIAL SEA AREAS FOR BALLAST WATER EXCHANGE

Important resources and protected areas 7.2.3
In the designation of BWE area, Parties should consider and avoid, to the extent practicable, potential adverse impact in aquatic areas protected under national or international law, as well as other important aquatic resources including those of economic and ecological importance.

Navigational constraints:

7.2.4 Any designation of ballast water exchange areas should take into account navigation impacts, including the desirability of minimizing delays, as appropriate, taking into consideration the following:
.1 the area should be on existing routes if possible,
.2 if the area cannot be on existing routes, it should be as close as possible to them.

7.2.5 Constraints to safe navigation must be considered when selecting the location and size of the ballast water exchange area.

8 ASSESSMENT OF IDENTIFIED SEA AREAS

8.2 The identified ballast water exchange area(s) should be assessed in order to ensure that its designation will minimize any threat of harm to the environment, human health, property or resources taking into account but not limited to the following criteria:

8.2.1 Oceanographic (e.g., currents, depths)
- Currents, upwellings or eddies should be identified and considered in the evaluation process. Sea areas where currents disperse discharged ballast water away from land should be selected where possible.
- Areas where tidal flushing is poor or where a tidal stream is known to be turbid, should be avoided where possible.
- The maximum water depth available should be selected where possible.

8.2.2 Physico-chemical (e.g., salinity, nutrients, dissolved oxygen, chlorophyll 'a')
- High nutrient areas should be avoided where possible.

8.2.3 Biological (e.g., presence of Harmful Aquatic Organisms and Pathogens, including cysts; organisms density)
- Areas known to contain outbreaks, infestations, or populations of Harmful Aquatic Organisms and Pathogens (e.g. harmful algal blooms) which are likely to be taken up in Ballast Water, should be identified and avoided where possible.

8.2.4 Environmental (e.g., pollution from human activities)
- Sea area(s) that may be impacted by pol-

lution from human activities (e.g., areas nearby sewage outfalls) where there may be increased nutrients or where there may be human health issues, should be avoided where possible.
- Sensitive aquatic areas should be avoided to the extent practicable.

8.2.5 Important resources (e.g., fisheries areas, aquaculture farms)
- Location of important resources, such as key fisheries areas and aquaculture farms should be avoided.

8.2.6 Ballast water operations (e.g., quantities, source, frequency)
- A foreseen estimation of the quantities, sources and frequencies of ballast water discharges from vessels that will use the designated sea area should be considered in the assessment of such area.

8.3 An assessment of the most appropriate size of the designated ballast water exchange area needs to take into account the above considerations.

9 DESIGNATION OF SEA AREAS FOR BALLAST WATER EXCHANGE

9.1 The location and size that provide the least risk to the aquatic environment, human health, property or resources should be selected for designation. It may also be possible for the designation of a ballast water exchange area to apply over specified timeframes.

The OSPAR report

The OSPAR report describes the BWC, the situation of ballast water in Europe and on a regional basis, the designation of BWE regions and division into different biogeographical regions. Also described are possibilities, recommendations and demands regarding the handling of BW, BWE being one of the suggestions. The report also describes the quantification of ballast water transports. Domestic and intercontinental traffic is described in terms of risk assessment with recommendations based on origin, destination and route. Key factors for the survival of non indigenous species in Europe are also described.

The recommendations state that:
- before suitable methods for handling the BW are introduced and implemented, a ship should, if it is possible, conduct the BWE in areas >200nm to the nearest coast and with a depth of >200 m.
- If a ship is unable to conduct the BWE according to the BWC demands, then the BWE should be performed in designated areas >50 nm from the nearest coast and with a depth of >200 m.
- A ship should not be forced to deviate from its course or be delayed to meet these specific demands.

In areas where depth and distance from nearest land are unable to meet these specific demands (Baltic Proper), the port State can, by consulting neighbour states or other states, designate suitable (according to G14) areas for BWE

In the report there are three maps where lines shows distances of 200 and 50 nm from the coast and traffic frequency at sea during the period 2000-2002 (OSPAR report figure 2-1). There are also two figures (OSPAR report figure 5-1 &7-2) that show depth and distances of 50 nm (& 200 nm) from the coast. To be noted is that the BWE areas differ in size between the three maps (See also appendix 1 for a SMHI produced map showing depth and distances of 50 nm from the coast).

Estimated time to perform a BWE is 1-3 days depending on ship, method and capacity. An oil tanker with a speed of 14 knots needs approximately 400 nm to perform a (complete) BWE by a sequential method and approximately 600 nm for a BWE using a flow through method.

It seems hard, if possible, to find suitable BWE areas in the Baltic Proper when taking into account the geographical boundaries, traffic systems, the avoiding of detours, assurance of sufficient dilution and avoiding the risk of secondary introduction. The challenge is to find areas where BWE can safely be performed with a minimal risk of non domestic organisms surviving and/or reaching land. These designated areas may have limited risk reducing effects, but may be a better alternative than releasing non processed ballast water in harbour areas.

Focusing on the limitations of the BWE areas due to depth, it was concluded in an ICES WGBOSV meeting (2005) that no BWE area in the shallower parts of the European costal waters can be found,

but that permanently stratified water columns, like a perennial pycnocline, can offer an acceptable risk reduction.

By transporting freshwater organisms in the BW between two freshwater harbours there is a big risk for the organisms in the BW to survive in the new area. If marine water is present between these two harbours it works like a natural migration barrier to these organisms. It is recommended that the ballast water from the freshwater harbour is exchanged in the marine environment, which makes the freshwater organisms not likely to survive in the new environment. Marine organisms, which are to be included in the ballast water from the marine environment, will not likely survive when released in the new freshwater harbour. Please observe that this is just the case when using marine and freshwater ballast. When brackish water is used for ballast other rules apply, because of the ability of brackish water species to survive in a wider range of salinity. (Freshwater is here specified as <=0.5psu and marine waters as >=25 psu.)

In general it is recommended to perform the BWE when the ship is in classed as high-risk to introduce non domestic species in the new harbour. BWE should only be performed in areas according to the BWC, or in designated areas with minimal risk of the safety of the ship and crew, causing illegal actions and of the transported organisms to survive, reach land or cause harm on domestic life or natural resources.

Since it is hard, if even possible to designate BWE areas in the Baltic Proper, the recommendation in the report is to conduct further scientific investigations of the oceanography and marine biology in the possible areas. This would be the first step to take towards a more extensive evaluation of possible BWE areas.

Besides including the maps with the 50 nm areas, there are no specific areas in the Baltic Proper recommended as BWE areas in the report.

The HELCOM report

In the HELCOM report there are no specified BWE areas in the Baltic Proper. It states that IMO is working with guidelines for identifying BWE areas and a draft will probably be discussed during a meeting in 2006.

Stated in the recommendations are:

- For ballast that has its origin outside the Baltic Proper it is recommended that the BWE is performed before the ship arrives in the Baltic Proper. It is assumed that no BWE area can be identified based on meaningful biological reasoning, because of the shallowness and that possible areas are located to close to the coast.

- On few occasions for traffic within the Baltic Proper, a BWE can be needed. For example during a transport from one freshwater harbour to another, when the shipping route crosses more marine waters.

- Due to the fact that no effective system for processing the ballast water is implemented, the BWE could be the only way to reduce the introduction of aquatic invasive species (AIS). The focus should be on avoiding uptake of species during a BWE. If possible the IMO guidelines should be followed. These are for example avoiding the uptake of harmful species. BW uptake should be minimised or avoided: near blooms, near a harmful algal bloom event, near dredging, in waters with low tidal exchange of the water or during the night, when some organisms rise from deeper waters.

- In the report, risk evaluations where made, based on different parameters for the routes. High risk route is the routes where the BW uptake and discharge were made in similar bioregions and in similar climate zones. Donor harbours of low risk are often located far away and they can also have a different temperature regime than the Baltic Proper.

- Due to the wide range of salinity in the Baltic Proper and its surrounding waters, it is recommended that the route is located to areas where a BWE can be performed. All the traffic to the Baltic Proper can be divided into transoceanic routes, routes within Europe and within the Baltic Proper.

- For transoceanic routes, if safety is provided, the BWE should be conducted before it reaches the Baltic Proper. If the salinity and/or the temperature at the initial BW uptake diverge from the port of arrival, then it is not vital to conduct the BWE during the route. The

organisms will probably not survive the change in living conditions.

- For transport within Europe between two similar harbours, then the BWE should be conducted between the harbours in fully marine waters even if the recommendations regarding distance to nearest land and depth cannot be met. If the salinity and/or temperature at the ballast water intake is different from the discharge area, then there is no need for a BWE during the voyage.
- Traffic within the Baltic Proper can make a secondary spreading of the previously introduced AIS. Within the Baltic Proper it is not possible to meet the recommendations of distance of nearest land and depth. But there can be a demand for a BWE if the harbours involved has similar salinity separated by waters with higher salinity.

In the report the history regarding the introduction of non indigenous species (NIS) is discussed. There is an example where the east coast of North America is identified as the largest contributor of NIS to the Baltic Proper. Some NIS statistics is given, origin, how they came to the Baltic Proper and the amount of species that survived in freshwater, brackish water and in marine environments. Some species are very tolerant to changes in the salinity.

History and prognosis of traffic frequency and which transporting ships are listed. Invasions of species are linked to the volume of the released ballast water, the number of ships arriving to the area and most importantly - the matching of the environmental variables at the donor and recipient areas.

The traffic frequency to/from different areas is presented and the southwest part of the Baltic Proper has the highest traffic frequency. By excluding ferries, St. Petersburg has the most traffic, followed by Gothenburg and Riga. Attempts to calculate the total BW discharge in the Baltic Proper is performed, despite the scarce amount of information.

Investigations of BW has been performed and between 3 and 502 taxa where found in each study. In total 990 organisms were found (in sizes up to 15 centimetres). Most common were: diatoms, harpacticoid copeopodes, rotifers, calanoid copeopods, larvae of Gastropoda, Bivalvia and Polychaeta. Surviving in the ballast space is due to

a range of factors but studies show that the fastest decrease of living organisms is during the first three days and that most of the species were dead after ten days.

The report identifies routes that are considered as high risk routs for the spreading of AIS/NIS to the Baltic Proper. The parameters included are for example: different harbours, what has been shipped, how far, matching salinity and climate. From this you get expressions like low, medium and high risk for different parameters. Tables are created to show how the variation of for example salinity or climate is classed as low or high risk.

In the risk evaluation, factors like temperature, salinity, time of the transport and the route have been analysed. In general there is a high risk when the area of origin and recipient is in the same bioregion and low risk when they are not even located next to a similar area (greater distances - lower risk). The greater the difference in salinity is between two areas, the lower the risk. For the transport time; <3 days (at 16 knots) gives high risk and >10 days gives low risk. Harbours with a high frequency of ships with BW potentially originating from outside the Baltic Proper, are exposed to a higher risk of NIS introductions and are evaluated based on that.

Low risk was given the value 1, medium=2 and high =3 and the four parameters were summed per harbour/region and presented for a number of recipient harbours. The sum of the result were:

All the chosen recipient harbours in the Baltic Proper have at least one high risk donor harbour.

All the extreme- and high risk donor harbours were located in Europe, but outside the Baltic Proper (with two exceptions).

The donor harbours with the most high risk hits towards different recipient harbours were Rotterdam, Bremerhaven and Amsterdam.

Most of the high risk donor harbours are large central harbours in Europe.

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SMHI PUBLICATIONS

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Name of series	Published since
RMK (Rapport Meteorologi och Klimatologi)	1974
RH (Rapport Hydrologi)	1990
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1   Lennart Funkquist (1985)
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2   Barry Broman och Carsten Pettersson.
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15 års mätningar längs svenska kusten
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Slutrapport för perioden
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      Östergötlands skärgård - Vattenmiljön.

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