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Contents

1. Introduction.....	1
1.1 Sampling strategy design methods.....	1
1.2 Ad hoc sampling strategy design in ODON.....	1
2. Relevant issues for sampling strategy design	2
2.1 Period selection for ODON study	2
2.2 Key physical scales to be resolved.....	3
2.3 Data counting strategy in ad hoc sampling design.....	4
3. Introduction to existing observing system	4
3.1 Satellite system	4
3.2 In-situ monitoring system	6
4. Ad hoc designed SST observing networks	7
4.1 SST OSE design for assessing existing networks.....	8
4.2 SST observing network design for filling gaps.....	10
5. Ad hoc sampling design for Sea Surface Salinity (SSS)	11
5.1 Assessment of existing SSS monitoring networks.....	13
5.2 The role of satellite SSS monitoring	13
6. Ad hoc sampling design for temperature and salinity profiles	14
7. Conclusions and discussions	17
8. Acknowledgement	17
References.....	18

List of tables

Table 1 Temporal coverage of the different satellite products used in ODON.	4
Table 2 Number of satellite observations per day in 2001	7
Table 3 Number of in-situ SST observations in 2001 in the Baltic-North Sea for different averaging boxes.....	7
Table 4 Selected combination of SST observing networks for SST OSEs.....	9
Table 5 Number of SST observations per day for combined observing networks in Table 4...	10
Table 6 Availability of SSS observations from in-situ observing systems in the Baltic-North Sea in different averaging boxes	12
Table 7 Accuracy of satellite sea surface salinity measurements with different averaging scales	13
Table 8 Ad hoc Sea Surface Salinity observing networks for OSSEs, OSEs and SOPEs.....	14
Table 9 Availability of temperature salinity profile observations from in-situ observing system in the Baltic-North Sea in different averaging boxes.....	15
Table 10 Ad hoc T/S profile observing networks for OSSEs, OSEs and SOPEs.....	16

List of figures

Figure 1 A schematic map of important spatial-temporal scales for the Baltic-North Sea physical oceanography	3
Figure 2 Regions covered by the different satellite products used in ODON. The Red line indicates the area of the SAF product, blue of the BSH Baltic product and green the area of the BSH North Sea product. Gray shading indicates bathymetry.	5
Figure 3 BSH TSG (left) and SMHI Ferrybox (right) coverage in 2001.....	6
Figure 4 Percentage of satellite data coverage (night) with 20km by 20km by 3-day average (left panel) and in-situ SST stations (right panel) in 2001.....	11
Figure 5 Surface salinity stations (or sections) in 2001	12
Figure 6 T/S profile stations in 2001.	15

Ad hoc sampling strategy design

1. Introduction

1.1 Sampling strategy design methods

A sampling strategy means where, when and how to make sampling from the real world, which is the core of an observing system. Cost-effectiveness of an observing system mainly depends on its sampling strategy. EU FP5th Program funded project ODON (Optimal Design of Observing Networks) aims to rationalise existing thermo-saline observing networks in the Baltic-North Sea. This consists of

- assessing cost-effectiveness of existing thermo-saline observing networks,
- assessing modelling requirements to observations,
- design more cost-effective thermo-saline observing networks based on existing ones, and
- assessing cost-effectiveness of newly designed thermo-saline observing networks.

The quality of an observing system can be evaluated by using different methods, e.g., Observing System Experiments (OSE), Observing System Simulation Experiment (OSSE), Observation Product Evaluation (hereafter referred as OPE) and Simulated Observation Product Evaluation (hereafter referred as SOPE) etc. OSE is an impact study carried out with existing observations: two parallel data assimilations or model runs are carried out, with and without the observing system to be evaluated; resulting analyses and subsequent forecasts are then compared. OSSE is similar to the OSE except the observations to be tested are simulated rather than real: simulated observations are produced from a numerical model integration assumed to be the 'known truth' and usually called the 'nature run'. The OSE and OSSE have been used in numerical weather prediction for a couple of decades to quantify the usefulness of atmosphere observing systems (e.g., Atlas, 1997, Kelly 1997). An OPE evaluates the quality of a given observing system by using effective data coverage, sampling error and quality of observation objective analysis products while a SOPE is that same as the OPE except that the simulated observations are used (She 1996a, 1996b).

The advantage of the OSE and OSSE is that contribution from model dynamics is used in reconstructing the ocean status together with observations, which may reduce data requirements from observing systems. However these experiments are very much time consuming and costly. The OPE and SOPE require much less computing time but only statistical relations (i.e., spatial-temporal covariance structure) are used in re-constructing the ocean field.

1.2 Ad hoc sampling strategy design in ODON

The original description of the ad hoc design task in ODON DoW is very simplified – written as *'Design ad hoc sampling strategies by using rectangular sampling arrays with different sampling distances, together with existing ferry/XBT sections. Technologies of both mooring buoy and profiler (drifting and mooring floats) arrays are included'*. The original intention is to use OSSEs to get a rough indication of how high the sampling resolution is required for operational models. Only rectangular sampling arrays will be designed with different spatial-

temporal sampling resolutions, e.g., 100*100 km² and monthly. However this is mainly of theoretical interest because such rectangular sampling arrays are far from real and existing observing networks. Hence we decide to largely extend the ad hoc design to serve following purposes: one is to select sampling strategies for assessing the effectiveness of existing and planned thermal-saline observing networks and modelling requirements to observations, the other is to design some sampling strategies to complement existing and planned observing networks - but mainly based on qualitative considerations, e.g., physical and practical operational considerations.

Part of these ad hoc designed sampling strategies will be used in OPE, SOPE, OSE and OSSE in other ODON Workpackages.

Thermal-saline observing networks in the Baltic-North Sea include both temperature and salinity measurements. Due to different techniques used in surface and sub-surface observing networks, the ad hoc sampling strategy design is divided into three parts: Sea Surface Temperature (SST) sampling design, Sea Surface Salinity (SSS) sampling design and sub-surface temperature/salinity (T/S) sampling design.

The report is organised as follows: section 2 discusses several pre-set issues for the ad hoc sampling strategy design, e.g., time period to be used, key physical scales and box size used for counting observations. Existing satellite and in-situ observing networks for temperature and salinity in the Baltic and North Sea are introduced in sections 3. Section 4 through section 6 discuss the strategies and results for selecting and designing a variety of combinations of observing networks for OPE, SOPE, OSE and OSSE experiments.

2. Relevant issues for sampling strategy design

In this section we discuss several highly relevant issues for sampling strategy design, including time period selection, physical scale analysis and the definition of an appropriate box size for estimating the number of observations.

2.1 Period selection for ODON study

Due to heavy computational load for OSEs and OSSEs, it is impossible for us to select a too long period. As our major concern is to improve short term operational forecasting, a one-year period is selected for the ODON study.

The best year to use for sampling study, OSE and OSSE studies is an important issue to resolve. The following criteria are used to find the most suitable year:

- most of the existing observation stations in that year shall be available,
- the quality of the observations shall be the highest available,
- the observation networks shall reflect the state-of-the-art in operational marine monitoring, and
- model forcing data shall reflect the state-of-the-art (e.g., daily river runoff).

Year 2001 was finally chosen because it was the year that fulfilled the criteria best possible:

- it was the first year for SAF satellite SST, which reflects the state-of-the-art of satellite SST products
- it was the first year with a large amount of Ferrybox observations in the region,

- it was a year where daily river runoff were available,
- it was the most recent year that we could get most of the CTD measurements in the Baltic-North Sea, and
- year 2001 was not an abnormal year regarding to marine and weather conditions in the Baltic and North Sea.

2.2 Key physical scales to be resolved

To design a sampling strategy ad hoc, we first have to know what kind of physical scales are going to be resolved by the sampling strategy. For operational coastal-shelf sea forecast, interested physical scales are related to topography forcing, barotropic and baroclinic Rossby deformation radius, weather forcing, tidal forcing and river run-off.

For the Baltic-North Sea the small marine synoptic scales are represented by the baroclinic Rossby deformation radius, tides and river run-off. The processes are typically eddies, fronts, river plumes and internal tides with a scale of 1-10nm in space and one hour to days in time. Barotropic features in the region results from weather forcing as well as topographic and tidal forcing. The large scale of the barotropic features is hundreds of kilometres in space (i.e., basin scale). The temporal scale ranges from days (weather forcing) to months (e.g., topographic forced circulation). The small scale of the barotropic features is tens of kilometres in space (width of narrow straits or sills) and a few hours in time (tidal waves). Long-term Baltic-North Sea water exchange is driven by wind-forcing and baroclinic pressure gradient/river run-off, which have a basin scale in space and days to seasons scale in time. The space-time ordering of the scales are shown schematically in Fig.1.

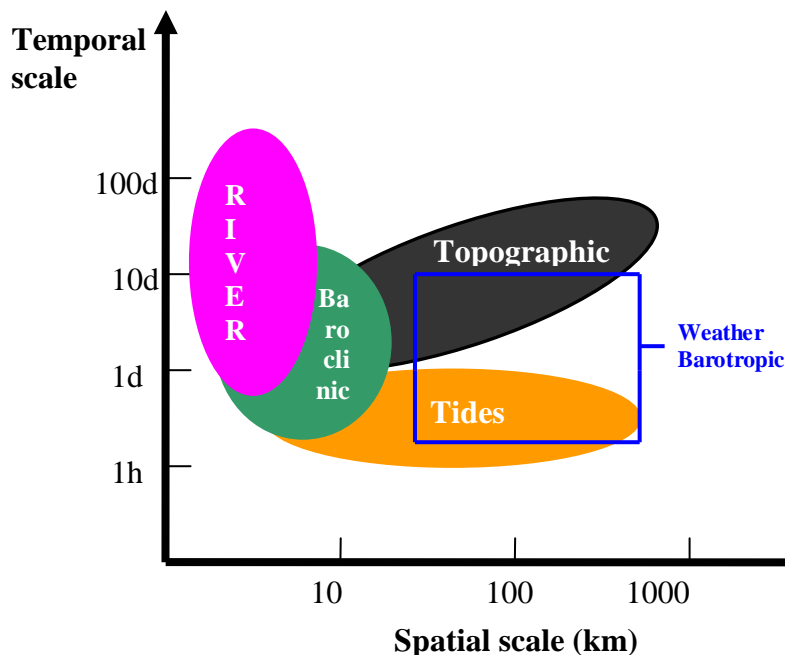


Figure 1 A schematic map of important spatial-temporal scales for the Baltic-North Sea physical oceanography

2.3 Data counting strategy in ad hoc sampling design

A certain kind of scale and box averaging has to be selected when the data coverage has to be estimated. The spatial and temporal box will be used in counting the number of observations. The selection of the averaging box size is based on the scale analysis in the sub-section 2.2. A small box of 1nm by 1nm by 1h is used to reflect the small scale of the key physical processes in the Baltic-North Sea. A larger box of 6nm by 6nm by 1day is used for the large physical scales. The data coverage calculations in the following are performed by counting the number of averaging boxes where at least one observation is available. Both in-situ and satellite data have been quality controlled prior to the data coverage calculations.

It should be noted that, ideally, independent observations should be made to estimate the effective data coverage, based on e.g. spatial and temporal correlation scales. However, in an ad hoc study, the above counting method is sufficient.

3. Introduction to existing observing system

3.1 Satellite system

In the Baltic-North Sea region, satellite SST data can currently be retrieved from the infrared sensors of NOAA AVHRR, AATSR (ENVISAT), MSG (MeteoSat Second Generation) and MODIS (AQUA and TERRA). In addition the microwave sensor AMSR-E on the AQUA satellite provides SST observations. The MSG satellites have been providing SSTs (one snapshot every 15 minutes) since end of January 2003, covering areas up to 60N. However the quality of the MSG SST observations in North Sea – Baltic region is unknown. AATSR is not currently freely available as a near real-time product for operational agencies. MODIS is now providing a 4.6km resolution SST products but not in a near real time mode. AMSR-E has no limit of cloud coverage. However its low resolution (0.25 degree), land contamination and low quality (accuracy of about 1°C) make it improper for SST analysis in coastal-shelf seas. NOAA AVHRR is thus still the only proved source for generating operational SST products. ODON has collected SST data in 2001 from 2 satellite products: METEOSAT Ocean and Sea Ice SAF and BSH (Bundesamt für Seeschifffahrt und Hydrographie). The SAF SST product is based on NOAA AVHRR No. 14 and No. 16 and the BSH product is from the NOAA AVHRR No. 12. The spatial coverage of the two products is shown in Fig. 2 and the temporal coverage in Table 1.

Table 1 Temporal coverage of the different satellite products used in ODON.

Product	NOAA Sat.	Area	Obs. in 2001	Day/night	Res. (km)
SAF-1	14	North Sea + Baltic Sea	1 Jan. – 30 Jun.	N	2
SAF-2	14	North Sea + Baltic Sea	24 Jun. – 5 Nov.	D+N	2
SAF-2	16	North Sea + Baltic Sea	24 Jun. – 31 Dec.	D+N	2
BSH-b	12	Baltic Sea	1 Jan – 31 Dec.	D+N	1.2
BSH-n	12	North Sea	1 Jan. – 31 Dec.	D+N	1.5

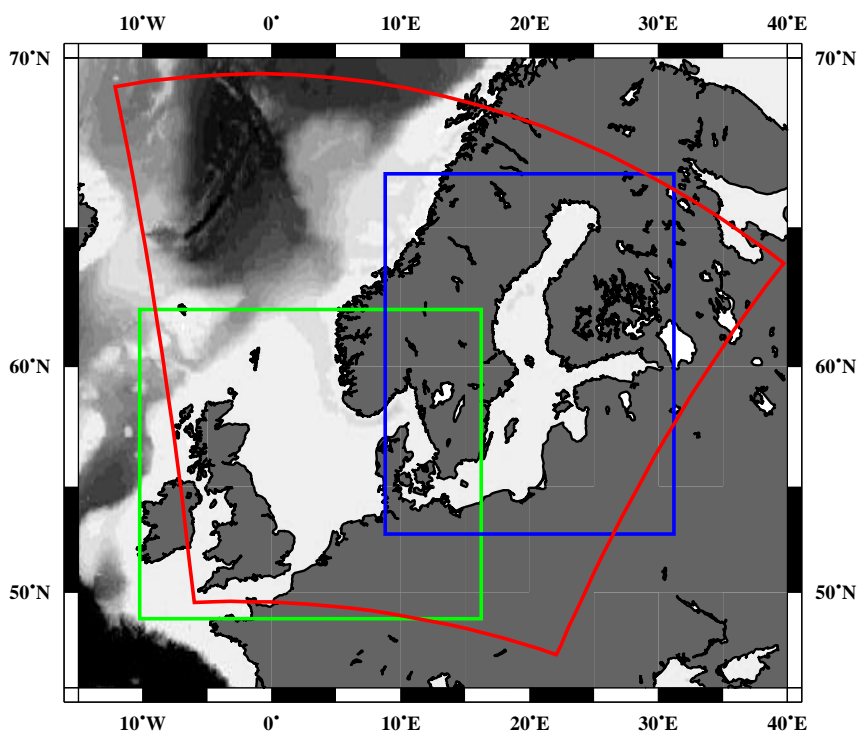


Figure 2 Regions covered by the different satellite products used in ODON. The red line indicates the area of the SAF product, blue of the BSH Baltic product and green the area of the BSH North Sea product. Gray shading indicates bathymetry.

More details about the satellite SST products used in ODON in can be found in Høyer and She (2004).

3.2 In-situ monitoring system

In-situ temperature and salinity observations in the Baltic-North Sea are obtained from Ship of Opportunities, moored buoys, Ferrybox, CTD casts from monitoring and research cruises, undulated profilers (e.g., Delphin) and thermosalinograph (TSG). The undulated profilers and TSG are normally attached to the monitoring and research cruises. The data transmitted through the GTS system include SST observations from fixed platforms and ship of opportunity. In the rest of the report, the data from this observing network are called GTS observations. All in-situ networks contribute to SST whereas SSS is obtained from all in-situ networks except for the GTS observations. Only moored buoys, monitoring and research cruises and undulated profilers contribute to the T/S profile measurements. There are some overlaps between the GTS and moored buoy data: about 24% of the GTS data are from moored buoy observations, which contain 3 physical-biochemical monitoring buoys and 10 wave monitoring buoys that also provide SST data.

In addition to the 13 buoys included in GTS, the ODON project has collected data from another 6 moored buoys for physical-biochemical monitoring.

TSG and Ferrybox provide continuous surface measurements (SST and SSS). TSG sections are made once a year by BSH for the entire North Sea and western Baltic during 10 July – 24 August (Fig. 3 – left panel) when conducting environmental monitoring. The Ferrybox measurements include two parts: one part made by SMHI research vessels in the Baltic Sea (as a test phase of the Ferrybox lines, Fig. 3 – right panel) and the other part made by a cargo ship from Ålborg to Nuuk (Fig. 4 – right panel). There are just a few repeated sections in SMHI underway measurements but the cargo line from Ålborg to Nuuk provides repeated sections.

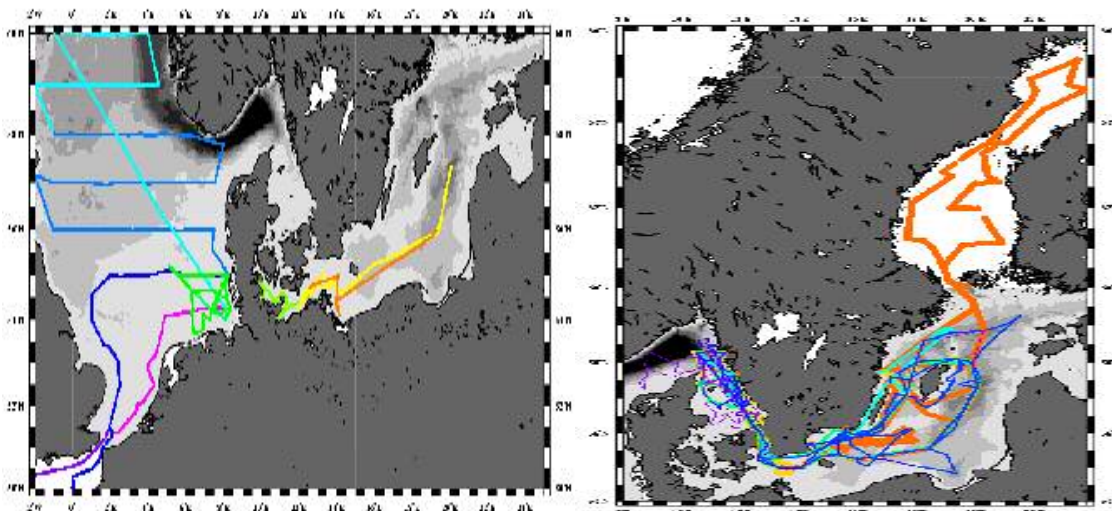


Figure 3 BSH TSG (left) and SMHI Ferrybox (right) coverage in 2001

The undulated profilers perform continuous T/S profile measurements. In the ODON project, two kinds of undulated profilers are included. One is the Delphin, used by BSH for North Sea monitoring and the other is the Scanfish used by IOPAS for western Baltic Sea monitoring.

Among these in-situ measurements, only GTS data are widely shared by operational agencies in an operational mode. The Ferrybox and buoy measurements are transferred in near-real time

but have not been widely shared. More details of in-situ observations can be found in Høyer and She (2004).

4. Ad hoc designed SST observing networks

In this study, a variety of SST sampling strategies will be proposed for

1. assessing correspondent SST observing systems and atmosphere/ocean model requirements to SST observations and
2. filling gaps of existing SST observing networks.

The SST observing networks include both satellite and in-situ observing systems. Table 2 and Table 3 show total number of gridded data from satellite and different in-situ SST observing networks.

Table 2 Number of satellite observations per day in 2001

Instruments		Number of SST observations per day		Total number of effective days
		1nm x 1nm x 1h	6nm x 6nm x 1day	
Satellite 12	Day	71542	3029	365
	Night	82152	3258	365
Satellite 14	Day	29966	1276	134
	Night	35325	1381	309
Satellite 16	Day	30291	1188	191
	Night	30043	1223	191

Table 3 Number of in-situ SST observations in 2001 in the Baltic-North Sea for different averaging boxes

In-situ observing systems	Code	Number of observations		Percentage (%)	
		1nm x 1nm x 1h	6nm x 6nm x 1day	1nm x 1nm x 1h	6nm x 6nm x 1day
CTD stations	1	4523	3989	2.2	7.9
Ship of opportunity	2	86168	33191	42.6	65.8
TSG	3	7016	1129	3.5	2.2
Ferrybox1 (SMHI underway)	4	25462	4025	12.6	8.0
Ferrybox2 (Ålborg-Nuuk)	7	8855	2222	4.4	4.4
Undulated profilers	5	3648	621	1.8	1.2
Fixed platforms	6	66772	5243	33.0	10.4
All in-situ		202444	50420	100.0	100.0

The total number of surface water grid boxes is about 7.32 million during one day for the hourly averaged 1nm x 1nm grid. Out of these grid boxes, the in-situ observations fill on average 555 per day while the satellite system contributes 126 thousand per day. This means on average the amount of in-situ SST is negligibly small. Even after considering the differences in quality (the satellite SST error is 0.65°C. and in-situ data are considered to be accurate) and the larger averaging scale of temporal-spatial box, in-situ SST coverage is still considerably less than satellite SST. For example, for 20km x 20km x 3days averaging box, satellite SST has a yearly averaged coverage of about 65% while in-situ SST only cover 7.5% (Høyer and She, 2004). This means, that satellite SST generally dominates the coverage of SST observing networks in the Baltic and North Sea. However during the winter time, the cloudy weather can wipe out most of the satellite observations. In these cases, in-situ SST may still play an important role for marine and weather forecast. This issue will be further considered in the ad hoc SST sampling strategy design.

The satellite, GTS and moored buoy observing networks are currently running on an operational basis, which can be regarded as background systems. It is shown that SST observations from the background systems have taken account of over 99.9% of the total amount of data. Other in-situ observing networks, such as Ferrybox, TSG, CTD stations and undulated profilers, can be regarded as adjustable systems, among which Ferrybox is the most important contributor to the SST observing networks.

4.1 SST OSE design for assessing existing networks

To reach the first objective, SST OSE will be used within the ODON project. Based on the preliminary assessment of existing SST observing networks, we believe that the existing operational SST observations are in general sufficient for most of the Baltic-North Sea region to make a daily 10 minutes longitude by 6 minutes latitude gridded map, provided that 3 satellites are available and an efficient multi-platform spatial and temporal Optimal Interpolation scheme is used. This means that we will have sufficient observations to make OSEs for quantitative assessment of the major SST observing networks.

The first objective can be broken into following subtasks:

1. To assess general impacts of SST forcing on weather-ocean forecast
2. To evaluate the importance of near real-time SST data-exchange within existing SST observing networks
3. To assess impacts of SST observing networks with different number of satellites on weather-ocean forecast
4. To assess contributions from important adjustable in-situ observing systems (Ferrybox and thermosalinograph (TSG))
5. To assess contributions of high resolution SST forcing on extreme weather-ocean forecast
6. To assess contributions from in-situ SST in cloudy weather

To design OSEs for the above subtasks, two questions have to be answered:

- what kind of combination of observing networks should be chosen?
- what periods should be used?

The former is relatively strait forward based on the above objectives while the latter is more complicated. The time period chosen for the experiments should be feasible to the computing limit, data availability and physical significance. Table 4 gives the selected combination of observing networks for SST OSEs and sampling study. As shown in the table, different observing networks are selected to assess correspondent objectives. In general, the objectives of the experiments named S1, S2 and S3 are to test only the impact of different satellite products, while the SI experiments also differ in the amount of in-situ observations. In Table 4, for experiment SI3, ‘-buoy’ means buoy measurements are taken out and ‘1/36’ means that one from every 36 observations is taken as validation data. These experiments can be performed by using different methods: OPE, SOPE, OSE and OSSE because the amount of SST observations is relatively large.

Table 4 Selected combination of SST observing networks for SST OSEs

Objectives	Network code	Observing Network	Control run	Experiment Period	Validation data(SST)
Assess general impacts of SST forcing	SI1	Sat. 12, 14, 16+ GTS	ECSST	May	1/36 over all in-situ SST
Evaluate the importance of near real-time SST data-exchange	SI2	All	SI1	May	1/36 over all in-situ SST
Assess impacts of SST observing networks with different number of satellites	S1	Sat. 14+ GTS + buoy	S1-S2-S3	Jul. 20– Aug. 4	CTD+ IOPAS+ Delphin
	S2	Sat. 14, 16 +GTS+buoy		Jul. 20 – Aug. 4	
	S3	Sat. 12, 14, 16 + GTS + buoy		Jul. 20 – Aug. 4	
Assessment of Ferrybox and TSG	SI3	Sat. 12, 14, 16+GTS+ Ferrybox+ TSG	S3-buoy	Jul. 20 – Aug. 4	CTD+ Buoy
Assess high res. SST influence on extreme cases	SI4	All	ECSST	Nov.9-13 Dec.19-23	1/36 over storm influenced region
Assess in-situ data impacts in cloudy situations	SI5	All	Satellite only	Feb. 3-9 Feb. 25-Mar. 1	1/36 over all in-situ

The number of observations used in the selected sampling strategies is shown in Table 5. As the Ferrybox2 data were obtained quite late, the data have not been included in the statistics of Table 5. It is seen that satellite data are still dominant in all the SST observing networks in Table 4, but the number of SST observations varies a lot for different networks. The highest daily data coverage is in OSE SI1 and SI2 (in May), which gives 215524 observations and the

lowest data coverage is in February and storm periods, which only gives 43-51 thousand data per day.

Table 5 Number of SST observations per day for combined observing networks in Table 4

Observing networks	Number of observations per day							
	Satellite	GTS	Buoy (non-GTS)	Ferry	TSG	CTD	Undu. Profiler	Sub-total (in situ)
S1	45819	280	223	0	0	0	0	503
S2	98657	280	223	0	0	0	0	503
S3	191437	280	223	0	0	0	0	503
SI1	215524	268	0	0	0	0	0	268
SI2	215524	268	120	63	0	15	0	466
SI3	191437	280	223	86	231	0	0	837
SI4	51175	323	113	32	0	4	3	475
SI5	43574	297	113	84	0	20	0	514

4.2 SST observing network design for filling gaps

Though the SST observations are in average sufficient for Baltic-North Sea forecast, the data coverage is inhomogeneous both in space and time. This is seen in Figure 4, which shows the yearly averaged satellite data coverage estimated with a 20km by 20km by 3day box. In addition the spatial distribution of all in-situ SST stations is shown to the right. The figures indicate that the eastern and northern Baltic Seas are the most gapped areas for both satellite and in-situ SST observations. A further investigation shows that the large satellite data gaps in these areas only occur in winter period. It is thus suggested that some Ferrybox lines should be added in this area. In practice, ferry lines from Riga (Latvia) to Helsinki (Finland) and from Klaipeda (Lithuania) to Sassnitz (Germany) could be proper candidates for enhancing the SST monitoring in the eastern Baltic Sea.

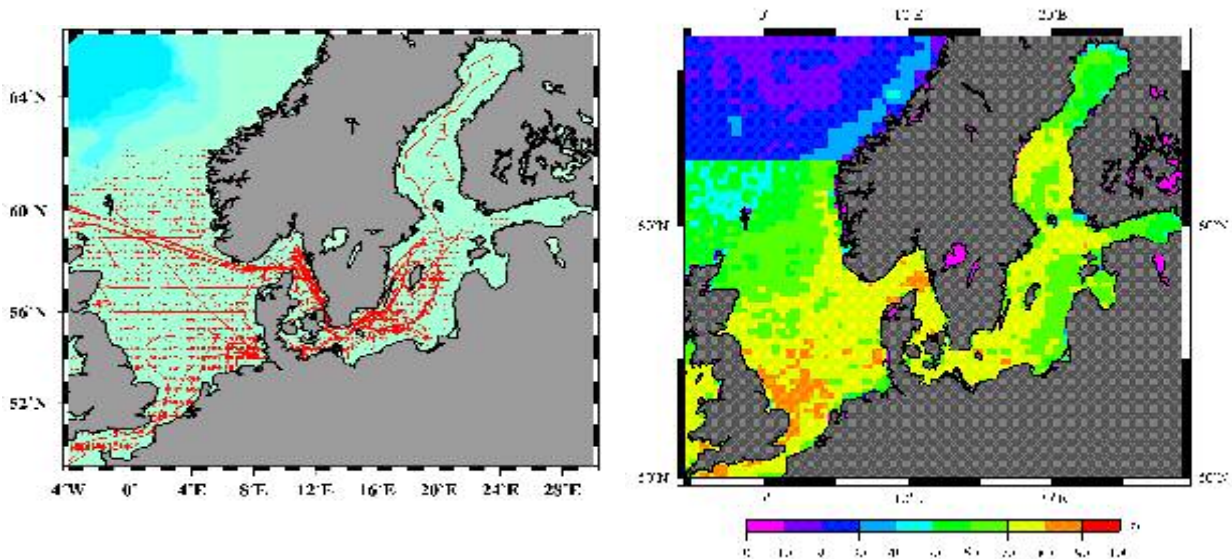


Figure 4 In-situ SST stations (left panel) and percentage of satellite data coverage (night) with 20km by 20km by 3-day average (right panel) in 2001.

5. Ad hoc sampling design for Sea Surface Salinity (SSS)

SSS observing network assessment and design are not explicitly mentioned in ODON DoW. However, SSS monitoring techniques are much different from that of T/S profiles. For the Baltic-North Sea region, continuous underway monitoring using TSG is a key technique for the SSS in-situ monitoring while buoys and monitoring cruises are the major approaches obtaining T/S profiles. Furthermore, remote sensing SSS observations from satellite will be available in 2007. With regards to the timing of implementing the observations in the data assimilation for the Baltic-North Sea operational forecast, the authors think that the SSS assimilation may come into reality before the T/S profile assimilation. This is because T/S profile measurements will be less frequent than SSS measurements and it is also more difficult to exchange T/S profile measurements in a near real-time mode.

Based on the above considerations we include an additional SSS monitoring network assessment and design part in ODON.

As shown in Table 6, SSS measurements are very sparse compared with SST. To obtain a meaningful data coverage for assimilation, the focused physical scales here should be larger than in SST observing networks. We use the 6nm by 6nm by 1day grid box, representing the large scales, to assess the SSS observing networks. It is shown that the SSS observation coverage is about 0.34% (10643 out of 3089360). Monitoring cruises and Ferrybox are the two major contributors to SSS monitoring network. However, current operational availability for these data is very low. Only some buoy measurements are shared in an operational mode within BOOS (Baltic Sea Operational Oceanography System) partners. Within 3-5 years, SSS measurements from Ferrybox and satellites will very possibly be used in an operational mode, which can be used in operational forecasts. Offline SSS measurements (e.g., from national monitoring cruises and Ferrybox), however, may be used in hindcast or re-initialisation of operational models, within 1-2 years.

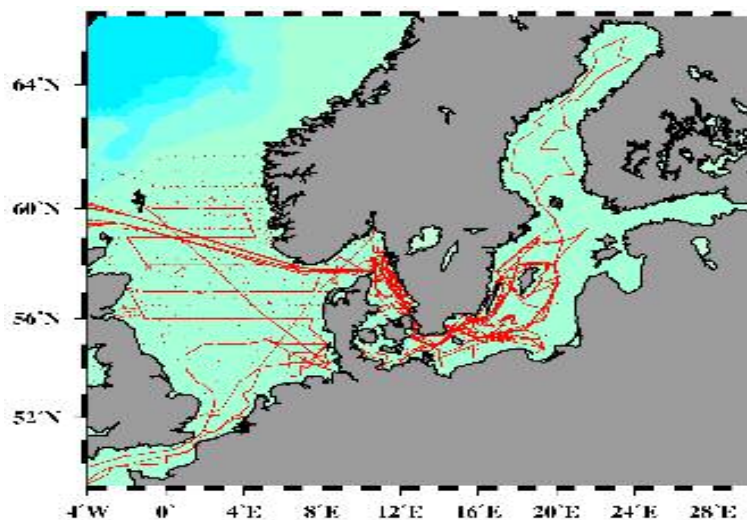


Figure 5 Surface salinity stations (or sections) in 2001

In addition to data exchange and operational data availability, there are several other important issues on SSS operational monitoring. Some of these are

1. to which extend existing SSS observations may contribute to marine forecast, providing the operational data exchange issue has been solved
2. the role of satellite SSS monitoring and
3. how to improve the existing in-situ SSS monitoring networks in a cost-effective way

This section makes ad hoc sampling designs dealing the first two issues.

Table 6 Availability of SSS observations from in-situ observing systems in the Baltic-North Sea in different averaging boxes

In-situ observing systems	Code	Number of observations		Percentage (%)	
		1nm x 1nm x 1h	6nm x 6nm x 1day	1nm x 1nm x 1h	6nm x 6nm x 1day
CTD stations	1	4563	4103	6.8	32.0
GTS	2	0	0	0	0
TSG	3	7016	1125	10.5	8.8
Ferrybox1	4	25492	4046	38.3	31.5
Ferrybox2	7	8913	2244	13.4	17.5
Undulated profilers	5	3648	618	5.5	4.8
Moored buoys	6	16999	720	25.5	5.6
All in-situ		66631	12856	100.0	100.0

5.1 Assessment of existing SSS monitoring networks

The assessment of existing monitoring networks consists of

- An overall assessment
- An assessment of the monitoring situation in heavily monitored areas, such as transition waters
- An assessment of the important SSS monitoring networks, e.g., Ferrybox, TSG and monitoring cruises

The overall assessment of the existing SSS monitoring networks in 2001 can be carried out by using an OSE: i.e., two model runs with and without the SSS data assimilation. Similarly three other OSEs are designed to assess the transition water SSS monitoring network, TSG monitoring and Ferrybox monitoring.

5.2 The role of satellite SSS monitoring

ESA has, since 1993, conducted several feasibility studies and activities for the development of a 'Microwave Imaging Radiometer with Aperture Synthesis' (MIRAS). This Earth-observation instrument is intended particularly for the measurement of soil moisture and ocean salinity on a global scale. The MIRAS has been extended to SMOS (Soil Moisture and Ocean Salinity Mission), which forms the core of the second ESA Earth Explorer mission, scheduled

for launch in early 2007. Existing research has shown that the satellite SSS monitoring has different accuracies with different averaging boxes: the larger the averaging box, the higher the accuracy. Table 7 gives such an averaging-scale-dependent accuracy relationship, based on the existing research results (Swift, 1993; Boutin etc, 2003). It should be noticed that the accuracy shown in the table is for the averaged value. It may not be appropriate to use the satellite SSS with large averaging box for data assimilation in areas with large SSS variation, say, coastal areas.

Table 7 Accuracy of satellite sea surface salinity measurements for different averaging scales

Spatial averaging box (km ²)	Temporal interval (days)	Accuracy (psu)
10x10	3	1-2
40x40	3	0.7
50x50	3	0.5
100x100	10	0.1-0.5
200x200	10	<0.1

The role of the satellite SSS monitoring in coastal-shelf sea prediction can only be carried out through the OSSE or SOPE since the SSS observations are currently far from sufficient to perform the OSE or OPE. Proposed ad hoc SSS designs for OSSE, OSE, OPE and SOPE experiments are described in Table 8. Models used for conducting these experiments may not necessarily be the models which generate the proxy ocean, especially for the OSEs. Due to extremely large computing load for conducting such experiments, some of the experiments in Table 8 may not be carried out in ODON.

Table 8 Ad hoc Sea Surface Salinity observing networks for OSSEs, OSEs and SOPEs

Objectives	Network code	Observing Network	Control run	Experim. Period	Validation data(SSS)
Assess existing SSS observing networks in 2001	OSE-1	All in-situ SSS observing systems	A model run without assimilation	July 10 – Sep. 10	1/36 of all in-situ SSS
Assess existing SSS observing networks in transition waters	OSE-2	All in-situ SSS in transition waters	A assim. run only outside transition waters	July 10 – Sep. 10	1/36 of all in-situ SSS
Assess Ferrybox SSS monitoring along the North Sea boundary	OSE-3	Ferrybox along North Sea open boundary	The same as OSE-1 control run	July 10 – Sep. 10	All other in-situ SSS
Assess BSH TSG monitoring program	OSE-4	BSH TSG monitoring program	The same as OSE-1 control run	July 10 - Aug. 20	All other in-situ SSS in relevant area
Assess satellite SSS monitoring program	SOPE	Satellite SSS 10*10 km ² 50*50 km ² 100*100 km ² 200*200 km ²	N/A	Full year	Proxy ocean (model truth)
	OSSE-1	Satellite SSS 100*100 km ² , +OSE-1	A model run with OSE-1 assimilated	July 10 – Sep. 10	Proxy ocean

6. Ad hoc sampling design for temperature and salinity profiles

Currently T/S profile observations are mainly obtained from national environment monitoring programmes, including CTD casts, buoys and undulated profilers. Buoy measurements have a very high temporal resolution, normally one hour but a very limited number of locations; undulated profiler attached to research cruises can provide T/S profiles with very high spatial resolution but it is not a common practice - only BSH and IOPAS have done that; CTD cast is a standard monitoring component in national environment monitoring programmes. As shown in Table 8 and Fig. 6, the total number of T/S profile measurements is just 7227 for a 6nm by 6nm by one day average, where CTD casts account for more than half (58.1%). The spatial coverage is relatively large in the North Sea and southern Baltic Sea. Such a spatial-temporal coverage (about 0.24% of all 6nm by 6nm by 1-day boxes) may not generate an efficient data assimilation, even in a hindcast mode. This is also due to the non-coordinated monitoring programmes which are carried out in different times. Considering that the budget for national environment monitoring programmes may not be largely increased, the ad hoc T/S profile sampling design here will mainly focus on some scenario studies with a budget level comparable to the existing one. The idea of the ad hoc design for the T/S profile monitoring is

to put the limited resources in a coordinated and physically significant way. This consists of following scenario studies:

1. A coordinated CTD cast sampling network with a resolution of 30'x18' in space counts for 3762 CTD casts, which may give a good chance for re-initialise our 3D operational Baltic-North Sea models.
2. A CTD sampling network along important boundaries of basins and sub-basins, at a temporal resolution of 12 times a year and a reasonable spatial resolution, combined with buoys at informative locations.
3. A national monitoring program with an undulated profiler attached

Table 10 gives the ad hoc designed T/S observing networks for OSE, OSSE and SOPE.

Table 9 Availability of temperature salinity profile observations from in-situ observing system in the Baltic-North Sea in different averaging boxes

In-situ observing systems	Code	Number of observations		Percentage (%)	
		1nm x 1nm x 1h	6nm x 6nm x 1day	1nm x 1nm x 1h	6nm x 6nm x 1day
CTD stations	1	4677	4201	8.3	58.1
Undulated profilers	5	4202	673	6.4	9.3
Moored buoys	6	56530	2353	85.3	32.6
All in-situ		65409	7227	100.0	100.0

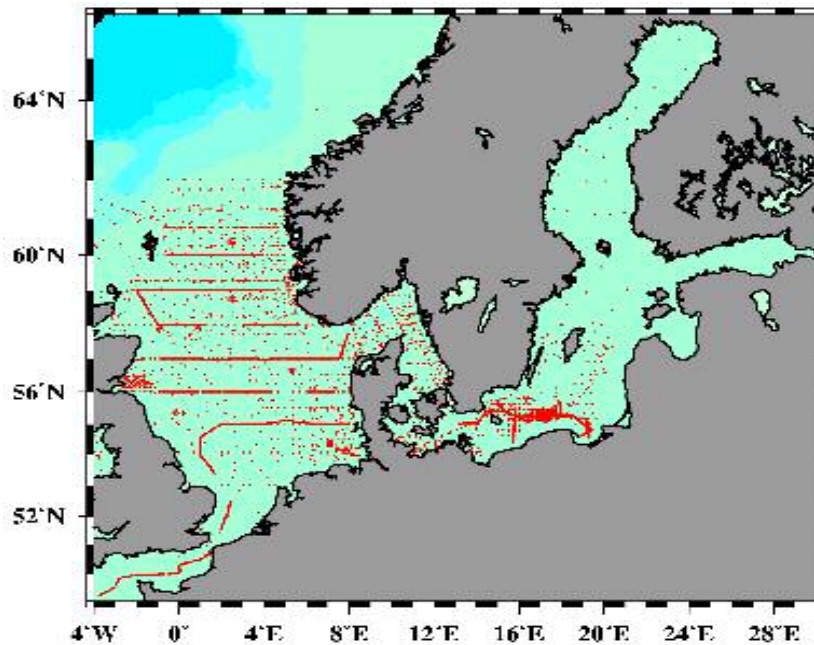


Figure 6 T/S profile stations in 2001.

Table 10 Ad hoc T/S profile observing networks for OSSEs, OSEs and SOPEs

Objectives	Network code	Observing Network	Control run	Experim. Period	Validation data
Assess existing T/S profile observing networks	OSE1 or OSSE1	All T/S profile obs. networks	An assimilation with SSS & SST only	July 1 – Sep. 30	1/36 over all the T/S profiles or Proxy ocean
Assess the model requirement & a coordinated network	OSSE2 or SOPE1	A sampling array with 20'x12', 30'x12' in space & 1-4 times a year	OSSE1	July 1 – Sep. 30	Proxy ocean
Assess an open boundary observing system	OSE2 or OSSE3	T/S profile monitoring along the 59.5N line in the North Sea, 12 times a year	A model run with climatological T/S as open boundary conditions	July 1 - Sep. 30	T/S observations or proxy ocean
Assess an observing network for key sections	OSSE4	T/S profile monitoring along sections cross sills or entrance of sub-basin	OSSE1 or OSSE2	July 1 - Sep. 30	Proxy ocean
Assess an national monitoring program with undulated profilers	OSSE5 or OSE3	BSH Delphin	An assimilation run without Delphin data	July 1 – Sep. 30	T/S observations or proxy ocean

7. Conclusions and discussions

In this report, sampling strategies are designed based on data availability, physical and operational modelling considerations, aiming to investigate following issues:

- Are the current SST, SSS and T/S profile observing networks in the Baltic-North Sea sufficient for operational modelling?
- As a cost-effective tool for SST and SSS monitoring, how can additional Ferrybox lines be added to fill the gaps in existing monitoring networks?
- How will the satellite SSS monitoring improve the in-situ SSS monitoring networks?
- If a coordinated monitoring action is taken among the Baltic-North Sea national environmental monitoring agencies, will it be a better than the current monitoring networks?
- How large impact will a T/S open boundary monitoring system have on the operational modelling?
- How large an impact will a T/S monitoring system with undulated profilers have on the operational modelling?

The designed sampling strategies will be used in different kinds of observing system evaluation methods (OSE, OSSE, OPE and SOPE) to reach a quantitative answer of the quality of these sampling strategies. Since all the designs have their own physical and practical considerations, results from the above evaluation experiments could be useful for optimise existing thermal-saline observing networks in the Baltic-North Sea.

Of course, the ad hoc sampling strategy design is limited due to its qualitative feature. The rational design of the observing networks is in progress in ODON, which is based on quantitative scale analysis, effective data coverage, signal-noise ratio analysis and information analysis.

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