TOWARDS AN ESA BALTIC INITIATIVE

DATA AND INFRASTRUCTURES

Context

The goals of the data and infrastructure sessions were to characterize gaps and identify high-level requirements and associated solutions for support ICT infrastructure in the Baltic region, including the basis for integrating a Baltic Regional Earth Observation Exploitation Platform. The sessions therefore focused on existing and near-future initiatives that could contribute to a Baltic initiative, including the Collaborative Ground Segments (CollGS) of the Baltic member states, the data and resources of national and regional environmental institutions, public European initiatives, as well as a subset of relevant commercial providers.

The Collaborative Ground Segments

The Collaborative Ground Segments **complement** the Copernicus data access with a wealth of data and services typically addressing national needs and user groups. The CollGS of Baltic region member states are seen as fundamental building blocks of a Baltic initiative.

Representatives of Baltic member states CollGSs, and in particular Finland, Germany, Poland and Sweden, expressed interest in providing services to a Baltic Initiative, with a portfolio spanning from provisioning of EO data to virtual environments for data processing. They also expressed their openness to collaborate and coordinate activity and offerings in order to support a Baltic initiative, by, e.g. sharing processing resources among the different centers.

Additional services proposed include access to data and services typically not covered by European initiatives, such as national/commercial mission data, or specific services such as Near/Quasi Real Time data access.

The arrival of public big data infrastructures (such as DIAS) reduce the need for investment in infrastructure and services on local level at least for what regards basic data access and processing services for Copernicus data; while data and services not covered by DIAS (such as specific regional in-situ data) are naturally collocated in the CollGSs.

The Baltic Environment Institutes

The various national and regional environment institutes addressing the Baltic provide a rich and diverse collection of in-situ data and resources that can be used together with EO data for analysis and validation activities, and have a clear role as data/service providers in a Baltic initiative. Some also have strong internal IT expertise by which they can provide higher-level services for data and computing.

They are also natural users of such an initiative, as their scientific activities greatly benefit from the systematic acquisition of EO data to fill the gaps in the collection of in-situ data.

A challenge to be addressed in a regional initiative is the high level of heterogeneity of the available in-situ data, as well as the integration of in-situ and satellite data.

Big Data Infrastructures and Exploitation Platforms

A number of public and private big data solutions (e.g. back end infrastructures or front end platforms) can also contribute to a regional initiative for the Baltic:

The upcoming Copernicus Data and Information Access Service (DIAS, DG-GROW), will provide access to and processing of core Copernicus data on a public and powerful big data infrastructure. DIAS will be openly available, with free data access and competitively costed processing services, and is therefore of prime relevance in this context.

The DG-Connect driven European Open Science Cloud (EOSC) will similarly federate a number of public infrastructures, some of which (e.g. EU-DAT) are already present in the Baltic member states, and is relevant to the Baltic initiative. Similarly, the NextGEOSS data hub, under the patronage of DG-RTD, also aims at providing data and services to Geo-data users, and my contribute in the more medium term future.

The ESA Thematic Exploitation Platforms (TEPs), provide thematic front end services to the big data infrastructure back-ends, and are now approaching their pre-operational phase. The thematic perspective only partially overlaps with the regional perspective (which is inherently multi-thematic), and a Baltic initiative can therefore leverage existing services from multiple TEPs.

Finally, several private companies also provide elements of solutions in support of data exploitation, notably Google (Google Earth Engine), Amazon (Amazon Web Services), and SAP (Hanah).

Conclusion and recommendations

Users have highlighted the need for a Baltic initiative as an enabler of data exploitation, still considered a complex activity especially on regional level. The initiative would also be the desired multiplier for EO satellite data awareness, as this class of data is still “new” compared to the in-situ information traditionally available.

It was agreed that:

1. An initiative addressing data access, services, and ICT infrastructure on a regional level is required in the Baltic.
2. The Baltic initiative shall provide regionally specific easy-to-use services in support of environmental data exploitation at multiple levels, from raw data access through production campaigns to access to processing resources. In addition, Near Real Time access is a requirement for many users.
3. The Baltic initiative must favor leveraging existing resources over developing new ones. This includes the Collaborative Ground Segments of Baltic member states; the Copernicus Data and Information Access Service (DIAS); the ESA Thematic Exploitation Platforms; existing data and resources of the Baltic environmental institutes; as well as potentially the European Open Science Cloud and NextGEOSS.
4. The Baltic initiative is consequently primarily an aggregator of existing services and resources.
5. The data and infrastructure services of the Baltic initiative shall be open to both scientific and commercial exploitation, with low entry barriers. Wide access, even if quota limited, is considered more important than having a restricted number of successful pilot projects.

6. Basic common needs (such as mutualized pre-processing of EO data) must be formulated and addressed.
7. Synergistic use of in-situ and satellite data is a key objective for a Baltic initiative. Simplification of the access to national and in-situ data is also a major challenge to be undertaken in the context of the initiative, with common agreed standards (OGC, INSPIRE) adopted for data access.
8. Specific algorithms needed for Baltic Sea and its drainage basin should be developed in joint R&D projects associated with the initiative

Science Component

Scientific Challenges for the Baltic

The Baltic Sea drainage basin covers about 20% of Europe, with roughly 85 Million people living at the shores of the Baltic Sea. In the highly populated south, the temperate climate hosts intensive agriculture and industry while in the northern part, the landscape is boreal and rural. The semi-enclosed Baltic Sea has a complex bathymetry, large horizontal and vertical gradients in salinity and extended hypoxic and anoxic bottom areas. The Baltic Sea is characterized by a large freshwater supply from the catchment area, long retention times of water masses and an excess of nutrients entering the sea. With further warming and associated changes in the hydrological cycle, a change in salinity and nutrient status is expected, with consequences for marine ecosystems and their services for human use.

Climate change, as well as other anthropogenic and natural changes in the atmosphere, on land and in the sea, exerts different pressures on the natural and human-shaped environment of the region. These pressures include regional warming, declining sea ice cover, sea level rise, deoxygenation, acidification, changing precipitation and runoff patterns as well as changing frequency of high impact events like storm surges, floods, drought and heat periods. It has been shown that the observed environmental changes are often caused by a mixture of interwoven factors, among them climate change and its associated impacts, eutrophication, pollution, fisheries, land cover change and others. Each of these factors has a scientific and a societal dimension, which are often interdependent, and which makes the identification of a single or even dominant factor responsible for the change difficult.

The Baltic from Space Workshop relied on the expertise of Baltic earth to define the main scientific priorities that could be the basis for the scientific component of the Baltic Initiative. Baltic Earth inherits the scientific legacy and researcher network of BALTEX which ended in June 2013 after 20 years of successful activity (www.baltex-research.eu). Baltic Earth builds on the infrastructure (secretariat, conferences, publication series) and international scientific network of BALTEX (people and institutions) but represents a new, more holistic perspective on the Baltic Sea region, encompassing processes in the atmosphere, on land and in the sea, as well as processes evoked by and feeding back on human activity.
Baltic Earth Grand Challenges

A unifying endeavour that underpins many joint activities of Baltic Earth aims to articulate **Grand Challenges** for research on issues of fundamental importance for informing the science-based management of the environment of the Baltic Sea region. Baltic Earth catalyses a research community-wide process to identify the most pressing scientific issues, knowledge gaps and uncertainties and promotes efforts to address them through new studies, collaborations, synthesis and the development of tools. Six Grand Challenges have been identified in the Baltic earth Science Plan:

http://www.baltic-earth.eu/material/Baltic_Earth_Science_Plan_2017.pdf

Salinity dynamics: The salinity in the Baltic Sea is not a mere oceanographic topic but involves the complete water and energy cycle. It is also an elementary factor controlling the ecosystems of the Baltic Sea. The salinity dynamics is controlled by net precipitation, river runoff and the compensating inflow of higher saline waters from the Kattegat. Furthermore, due to the expected increase in precipitation, first studies of future development indicate even 2-3 PSU decrease in salinity to the end of the century. Since the Baltic Sea ecosystem has adapted to the present salinity regime, expected changes would exert an enormous stress on marine fauna and flora with associated negative socialeconomic consequences for the Baltic Sea countries. The present understanding of salinity changes is still very limited, and future projections of the salinity evolution are rather uncertain. More detailed investigations on regional precipitation patterns (runoff), atmospheric variability (wind), highly saline water inflows, the exchange between the subbasins and turbulent mixing processes are still needed. Furthermore, there is also a need for new climate projections simulations with improved atmospheric and oceanographic (coupled) model systems. Suggested key research areas are the interrelation between decadal/climate variability and salinity, water mass exchange and major Baltic inflows (do we understand the dynamics of the present-day salinity distribution, can we predict MBIs?), detailed studies on the regional salinity distribution/variability and associated circulation patterns (including salinity fluxes between the coastal areas and the open sea and within the sub-basins).

Land-Sea biogeochemical linkages: This topic involves the problems of euthrophication and acidification. A lot of experimental data and sophisticated model tools are available but there is a lack of process understanding, and proper process parametrizations are missing. The processes occurring within the drainage area greatly influence the functioning of the Baltic Sea ecosystem. First of all, river runoff affects the Baltic Sea salinity, which is the key element for the marine biogeochemistry in general. Moreover, rivers supply the Baltic with great loads of different chemical substances. In most cases (e.g. nutrients, carbon, alkalinity, some organic pollutants and heavy metals), these loads are well recognized. However, some gaps still exist within the present databases. One example is missing data from the Neva River, incidentally the largest river entering the Baltic Sea. For some other chemical substances (e.g. pharmaceuticals) the terrestrial loads are still insufficiently described. On the other hand, the pathways of several substances, after entering the marine system remain unrecognized. Still, little is known about the transformation mechanisms occurring within the mixing zone. Since the geological structures, anthropogenic influences, types of the vegetation are different in the different parts of the catchment, the detailed studies are required for the individual sub-basins. Key suggested research areas are C, N, P cycles studies for the understanding primary production mechanism and organic matter transformations in the Baltic Sea, transformations and pathways of terrestrial organic matter, influence of the terrestrial input on the carbonate system, extension of the databases with the missing terrestrial loads data of the key chemical substances (e.g. Neva River).

Natural hazards and extreme events: A natural hazard is a naturally occurring extreme event with a negative effect on people or the environment. Natural hazards may have severe implications for human life as they potentially generate economic losses and damage ecosystems. A better understanding of their major causes and implications enables society to be better prepared and to save human lives and mitigate economic losses. Many natural hazards are of hydro-meteorological origins (storms, waves, flooding, droughts) and are often caused by a mixture of several factors (e.g. a storm surge in combination with precipitation and river runoff, which might generate extreme flooding). Average changes in the recent climate in the Baltic Sea region are relatively well described, but the uncertainty is much larger for extreme conditions. These extreme events pose a substantial threat to infrastructures or ecosystems albeit their relative rareness. The shortage of available data on these events reduces the statistical significance in the analysis and the capability to predict them.

This is generally well recognized regarding infrastructure such as dam safety and urban flooding risks, but the range of ecosystem services at risk is more poorly defined, from vital societal functions such as drinking water supply to biodiversity. The resilience and adaptation capability of terrestrial and marine ecosystems and organisms as well as human society to environmental changes depends very much on the future severity and frequency of extreme events.

There are meteorological implications of global warming, which may be the cause for changed frequencies of these extreme events. Storm tracks on the Northern Hemisphere seem to have shifted slightly northward during the last century as a consequence of global warming, and there are indications of additional Northern Hemisphere circulation changes due to the significant reduction of Arctic ice cover. Their connections, however, are not clearly understood and described, and there is a need to further investigate this with a Baltic Sea perspective. Hence, key processes and factors (e.g. atmospheric circulation, Arctic sea ice, snow) responsible for the changes in extreme events in the study region as well as their interlinkages, need to be better understood. An improved understanding of air-sea-land processes and the development of more detailed models is crucial.

Sea level and coastal dynamics: Sea level dynamics in the Baltic Sea are influenced by meteorological, astronomical, hydrological and geological factors. As a semi-enclosed sea, the dynamics of Baltic Sea sea level at different time scales range from minutes to millennia. At very short time scales variations are associated with e.g. waves, currents, seiches, or meteo-tsunamis. Although of small amplitude, tides may also sometimes play a role in Baltic Sea sea level dynamics. Factors that are relevant at increasingly longer time scales include, among others, variations in wind and sea level pressure, river runoff, presence of sea ice and spill-over of water masses from the North Atlantic or expansion of the water column by thermosteric effects, land uplift/subsidence and sediment accumulation. Also the contribution from short-term events (e.g. their frequency or intensity) may vary over longer time scales.

The effects of such drivers on Baltic Sea sea-level can be regionally and temporally quite heterogeneous. Good understanding of Baltic Sea sea-level dynamics, their mechanisms of variability, and the assessment of variability and change over the past are prerequisite for both, improved forecasting on short to medium time scales and for reducing uncertainty associated with projections of future sea-level rise caused by anthropogenic climate change.

The Baltic Sea coastal sea-level is one of the best and longest sampled by tide gauges. Several high-resolution satellite products provide the means to analyze absolute (as opposed to relative coastal sea-level) dynamics in the sea interior, albeit for shorter periods. Increasingly also model reconstructions and projections become available for both, mean and extreme sea level variability.

There is still incomplete knowledge on the dynamics of short term sea level variations, in particular on their climatology and their long-term variability and change. Moreover, a more systematic assessment of interaction between variations at different time scales and their impact on extreme sea levels is still missing. Also, an improved understanding of the connections between Baltic Sea, North Sea and North Atlantic sea level and of the link between Baltic Sea sea level and large scale atmospheric circulation patterns such as the North Atlantic Oscillation is needed. While it is known that there is a strong influence of such atmospheric circulation patterns on winter time Baltic Sea sea level variability, it is not yet known why this influence was less pronounced in the early 20th century.

The quantification of contributions from climatic factors responsible for the observed and projected long-term trends and multi-decadal variations in Baltic Sea sea level through the 20th and 21st centuries need to be improved as well. This comprises, for example, multi-decadal trends in the wind regimes, salinity, and glacial isostatic adjustment or sea-ice cover, together with changes in ocean dynamics in the North Atlantic that may have an influence on sea-level rise. Quantification of these contributions provides an essential prerequisite for improving detection and attribution of anthropogenic signals in Baltic Sea sea-level rise and variability. In particular, research on the attribution of observed changes to causes and on the plausibility and consistency between observed and expected changes is needed.

There is substantial and increasing need in information about future sea level changes on time scales from seasons to decades. This refers to both, mean and extreme sea levels. Any progress to better address these issues for the Baltic Sea will be a substantial step forward. Although the data basis for the analysis of Baltic Sea sea-level is very favorable, a systematic comparison of tide-gauges and high resolution satellite products is just starting. In addition, more high-resolution ocean and atmosphere-ocean regional simulations of the Baltic Sea are becoming available. Consistent analysis of all data sets is needed and will help to benchmark the skill of the various products, in particular of regional climate models at multi-decadal timescales, and will help to quantify the relative importance of the different factors contributing to Baltic Sea sea level dynamics.

Regional variability of water and energy exchanges: Knowledge of the water and energy cycles in the Earth system is an inherent part of regional climate studies. It has been the focus of 20 years of BALTEX activities and remains one of the grand challenges for the scientific community. However, the understanding of the processes and their incorporation into reliable models remains insufficient, which is evident by the poor performance of recent climate models in simulating the hydroclimate.

During BALTEX major progress has been reached in observational and modelling activities, as well as in scientific collaboration and infrastructure including the build-up of dedicated BALTEX data centres. Also remote sensing data have been evaluated to increase our understanding about the regional distribution of different parameters such as cloud distribution from satellites and precipitation fields from Doppler radars.

It is well known today that precipitation and evaporation are among those parameters causing the largest problems for weather prediction, meteorological reanalysis and regional climate studies. Although new knowledge has been gained with regard to the water and energy cycles, still major improvements are needed. For instance, regional climate studies based upon coupled atmosphere - land-surface-ocean models still suffer from biases in simulated precipitation and evaporation with the result that most coupled models do not have a closed water cycle and hydrological applications need bias correction when the output of regional climate models is used. Although there now exist a few estimates of the components of the water cycle in the Baltic Sea region, results of the various, applied methods differ considerably and for most methods uncertainty estimates are not available.

The assessment of numerous hydrological studies for the different sub-basins of the Baltic Sea catchment area reveals that the approaches to calculate the water cycle over land differ and are not coordinated. Hence, homogenous datasets for the whole catchment area are lacking with the consequence that in hindcast simulations, Baltic Sea models are usually driven by runoff from hydrological models instead of measurements.

Multiple drivers for regional Earth system changes: Societal efforts to manage the marine, terrestrial and atmospheric environment of the Baltic Sea region and to promote a sustainable human presence – meeting present societal needs without deleterious impacts on the conditions passed on to future generations – are hindered by incomplete understanding of the complex of drivers, interactions and historical factors responsible for the current detrimental state of the environment and ecosystems. Such gaps in understanding inhibit reliable predictions of how the marine system and the surrounding land areas, watershed and atmosphere may respond to ongoing and future projected trends in multiple drivers, or to management interventions.

The Second Assessment of Climate Change for the Baltic Sea Basin focused on regional climate change and its associated impacts, including the documentation of regional detection and attribution efforts, but also highlighted a mixture of interwoven factors, such as eutrophication, pollution, fisheries, hydrographic engineering, agricultural and forestry practices and land cover change, responsible for the current situation and of potential importance as drivers of future changes. Current observational datasets, system understanding and available modelling tools are insufficient to ascribe key dimensions of change to a single or even dominant factor or to construct credible scenarios of future changes. Two overall problem complexes concern the causes and impacts of eutrophication and climate change. Studies in these areas have traditionally been pursued by separate communities of researchers using different methods and approaches, adopting a diversity of baseline datasets and scenarios, and focusing on different spatial and temporal scales. There has likewise been relatively little collaboration across the science-social science divide, or between terrestrial, freshwater and marine scientists in related fields.

There is a need for increased cooperation among researchers having specialised knowledge of different components of the coupled biophysical-societal system of the Baltic Sea region, in the dynamics of which an understanding of the inter-related role of multiple drivers and their impacts on regional Earth system changes may be sought. Key disciplines include meteorology and climate science, oceanography, hydrology, marine, terrestrial and freshwater ecology, microbiology and biogeochemistry, as well as economists, human geographers, political scientists and engineers. A more integrated researcher effort needs to be complemented with an identification of key missing datasets on drivers and responses, their variations over past decades and across the region. A consensus should be sought on the relevant interactions to explore and the key knowledge gaps that need to be filled in order to develop reliable predictive models, applicable at the regional scale of the Baltic Sea.

Key findings and recommendations

Based on the presenations and discussion of the workshop, the following points represents a summary of the main messages and recommendations for the fisrt set of scientific activities to be launched as part of the ESA baltic Initiative:

- The overaching goal is to achieve a **comprehensive integrated assessment** of the Baltic Sea physical and biogeochemical environment that makes **optimal combined use of satellite EO, in situ data and models**.
- Tackling the Grand Challenges of the Baltic Earth Science Plan will substantially benefit by using Earth Observation methods.
- Baltic has special needs, many global producs cannot be used, high resolution is required.
- The great knowledge and solid structure of the Baltic scientific community and high density of in-situ data in the region is an asset for the sucess of the initiative. The Baltic Sea region

is among the best studied regions in the world from several disciplinary perspectives, with good data availability, and with many scientific and management aspects providing an analogue for comparison to other regions. In this sense, the Baltic Sea region may act as a laboratory for reasoning about similar issues in other regions.

- It is of critical importance to link activities with existing regional initiatives and programmes at Baltic and national levels. This includes BONUS and its potential follow on in 2021.

Carbon dynamics:

A better observation and characterisation of the carbon dynamic in the Baltic is key element to undertand eutrophication and marine biogeochemistry and ecosystems. Can we asses Carbon dynamics, as key of eutrophication, from an integrated use of EO, models, and ground based data?

Main restrictions for using biogeochemical products (i.e. ocean colour level 2 products) in the Baltic Sea for scientific investigations is data quality. So, far the only level-2 products we can retrieve reliably are Secchi depth and suspended matter/turbidity (e.g., Chlorophyll-a is overestimated whilst CDOM is highly underestimated). This means that in order to use any of these products **we need to improve the product retrieval over optical Case-2 waters with high CDOM absorption:**

- This requires improved atmospheric correction models and better parameterisation of the inherent optical properties (IOP's), i.e. absorption and scattering properties to improve the water models included in the data processors.
- Vital to validate the products; both standard products and those that are developed
- **It is urgently needed to develop reliable long-term data records of dedicated Baltic case-2 products (CDOM, Chlorophyll-a);**

May new HR data, such as Sentinel-2, may provide new information on coastal areas including biogeochemical feedbacks. **This is an area of interest to be further investigated.**
- What S2 may provide to the science area?
- Is a S2/S3 synergy possible?

Sea level dynamics:

A good knowledge of sea level and its dynamics is a key element for the Baltic Sea water budget, storm surges, coastal erosion and the main climate change impact, also as indicator of circulation and mesoscale currents, Water budget, Salinity cycle, etc..

Is the current constellation of satellite altimeters adequate to capture extreme sea level condition - how will the Sentinel 3A/B/C/D solve this? E.g., major salt water inflows are driven by extreme weather conditions which effect the sea level of the Baltic Sea (extreme high and low levels). Several questions need to be addressed:

- How does seasonal presence of sea ice influence our knowledge of sea level conditions in the Baltic?
- How does the very large global isostatic rebound affect unification of height datums - i.e., our ability to connect in-situ tide gauges with satellite derived sea level or using the geoid?
- Is our knowledge about other physical phenomena likes tides (Baltic is considered tide free) and out knowledge on bathymetry and coastal sea level variations adequate?

- Taking into account that sea level in the Baltic Sea varies from "minutes to millennia": To what extent can remote sensing and new techniques improve the knowledge on sea level dynamics in the Baltic Sea?
- What should the contributions from remote sensing, in-situ observations and modelling efforts look like in an optimal (sea level) observing system?
- Taking into account that changes and variations in Baltic Sea sea level interact with other oceanographic processes, for example, major saltwater inflows: To what extent can remote sensing contribute to describe and monitor changes and variability in the regional sea level budget?

Regarding long term sea level variations, ESA Sea level CCI is valid in the central southern Baltic, but not in the rest of the Baltic. This is due to coastal and sea ice effects (well known issues). In addition, the coastal/sea ice issues are not reflected in the error estimates of the CCI. **A new multi-mission dedicated product is urgently needed for the Baltic Sea:**

- Is it needed to go more coastal. Data are there, but need better treatment. Baltic Sea is an obvious test area for coastal applications;
- Is monthly resolution may be insufficient (e.g. 10 days be much better) for instance for resolving inflows;

Regarding short term sea level observations, e.g. storm surges, satellite altimetry observations need to be combined with other sources of information – typically tide gauges and/or models – to resolve the temporal and spatial scales of the Baltic Sea. **What are the wishes for combined sea level products from a scientific and an operational point of view?**

Absolute sea level observations, height system unification and GNSS-Levelling require the knowledge of the global static geoid. For GNSS-Levelling geometric and gravimetric reference frames need to be compatible. Sea level observations require knowledge about vertical changes of the geometric shape of the Earth. Mass variations cause variations of the reference equipotential surface. This has impact on absolute sea level observations, height systems and GNSS-Levelling.

- **What is the role of the GOCE static geoid?**
- **What is the impact of reference frame incompatibilities?**
- **How can vertical changes of land be observed on a systematic base?**
- **What is the impact of mass variations and how can it be observed?**

Physical Oceanography:

Salinity & physics, biogeochemical feedbacks, seal level dynamics, natural hazards and extreme events are interlinked with each other. The Baltic Sea must be understood as part of the earth system, thus requires an **Earth system approach.**

To understand the system requires a **combined observation and modeling approach**. Remote sensing observations reveal details on a 10 m - 1km scale which also requires very high resolution modeling.

Modeling can be used to integrate very high resolution 2-d earth observations from remote sensing on high resolution time and vertical space scales (data assimilation, nudging)

The combined analysis of high resolution modeling and earth observations (big data problem) requires high storage capacities, new software tools and support by the data management.

1. Are basin-scale and meso/submeso-scale dynamical features like fronts, upwelling, jet currents, eddies & filaments well know and understood in the Baltic context?:
- Do we have enough information (EO data products, in-situ data) to resolve them?
- Are models advanced enough to provide a good description of the main 4D physical processes in the Baltic sea?
- What would be needed?

2. Less saline and more saline waters take occasionally different pathways on their spreading, the waters also carry environmental constituents from their place of formation:
- How much can we identify water column dynamical features using their surface signatures?
- Can we estimate deep dynamical features using new methods of remote sensing (salinity, sea level, waves, currents, SST, color?) used for efficient data assimilation in numerical models?

3. Closing of water budget of the Baltic and problems to find good parameterizations to vertical mixing in the extreme complicated stratification conditions of the Baltic sea is a challenge:
- What is needed to close the water budget? i.e., What are the open questions? What is the missing data/information/knowledge?

4. The combined analysis of high resolution modeling and Earth observations (big data problem) requires high storage capacities, new software tools and support by the data management.
- A scientific exploitation platform for the Baltic including satellite products, in-situ data and processing capacity is needed?
- If so, how it should be?

Climate/Water/Energy:

Presently a climate warming is going on in the Baltic Sea region, and will continue throughout the 21st century (BACC I; II).

- *Later, changes in the water cycle are expected to become obvious (BACC I; II).*
- *Changes in heat and water balances will have a variety of effects on terrestrial and marine ecosystems – some predictable such and some hardly predictable (BACC I; II).*
- *Major challenge today is to integrate, to make visible and to communicate reliable Earth observations on climate change. Here satellite products may take the lead to integrate the observations.*

Discussion 1: ESA and Baltic Earth should develop satellite and model products relevant to all aspects of the heat, hydrologic and CO_2 cycles and integrate these into the BALTEX Box concept both in real time and as long-term averages.

Discussion 2: ESA and Baltic Earth should develop a joint internet information platform that together with expert statements review and comments the outcome from.

Application Development Component

Introduction and Overview

Operational uptake of EO based information services at overall regional level remains limited in the Baltic region beyond sea ice information and the EMSA CleanSeaNet service. In part this is due to the necessity to customize the processing of the EO data due to various specific geographic factors but the lack of customization of the EO derived information with respect to priority monitoring and analysis requirements also constrains the immediate uptake.

At the same time, demand for enhanced EO based information is evolving, driven by two sets of developments:

- Implementation and evolution of regional level cooperation fora, strategies and environmental agreements (eg HELCOM).
- Common requirements over many of the Baltic States at national level linked to evolution of issues such as ecosystem adaption to climate change pressures, increased monitoring and reporting requirements (eg due to EU legislation) and changing economic activities, demographics and associated infrastructure development

The Baltic area is covered by a large number of cooperation agreements, environmental protection legislation and thematic fora. Those where enhanced EO derived information currently see greatest potential impact include:

- The Helsinki Convention addressing coastal and marine environment protection, ecosystems and natural resource management and climate impacts
- The EU Baltic Regional Strategy addressing the three pillars “increase prosperity”, “save the sea” and “connect the region”,
- The Council of Baltic Sea States working to address “regional identity”, “a sustainable and prosperous region” and “a safe and secure region”

The elements of each of these three fora are further disaggregated into a set of activities, targets, objectives etc. Given the geographic setting and the resulting interconnections between economic development and environmental sustainability, there is a high degree of common concerns. These are summarized in the table below.

Activity Domain	Helcom	EU Baltic Regional Strategy	Council of Baltic Sea States
develop competitiveness		■	■
support climate adatpation/resilience	■	■	■
manage water quality	■	■	■
protect wildlife	■		
ensure clean/safe shipping	■	■	■
maintain and enhance biodiversity	■	■	■
reduce pollution risk	■	■	■
ensure effective pollution response capability	■	■	■
foster sustainable agriculture	■	■	■
develop sustianable aquaculture	■	■	■
protect fishing resources	■	■	■
develop tourism		■	■
implement effective maritime spatial planning	■	■	■
implement effective territorial planning		■	■
develop renewable energy resources		■	■
establish effective crime fighting networks		■	■

In addition, there are a number of cooperation networks to support the development and implementation of actions related to sustainable development, social inclusion and cultural heritage. Examples include the Union of Baltic Cities, the Baltic Sea Chambers of Commerce Association, the Baltic Development Forum, the Baltic Sea Forum and the Baltic Sea States Subregional Cooperaton Forum.

At national level, demand for EO based information is driven by expanding efforts to implement EU legislation such as the Water Framework Directive, the Marine Strategy Framework Directive, the Maritime Spatial Planning Directive, the Habitats Directive and the EU Maritime, Biodiversity, Soils and Forest Strategies.

Addressing the priority interests in monitoring, analysing and assessing the different aspects of Baltic economic development, security cooperation and environmental sustainability requires addressing a set of fundamental issues constraining the application of EO derived information within the Baltic region. These include the need for customized processing capabilities that taken explicitly into account the various geographic peculiarities of the Baltic environment (eg the water properties, the complex variations in coastline and bathymetry) as well as the issues associated with the use of optical remote sensing techniques at high latitudes. Therefore, in many cases, priority application development actions identified by the relevant stakeholders in the region must be complemented by dedicated technical developments of the underlying information extraction routines that ensure EO based information can be used in a Baltic setting.

Priority Application development requirements identified during the workshop are therefore structured into three groups of activity:

- National developments to support effective implementation of legislation and addressing regional priorities by individual member states
- Pan-national developments to support the regional level activities
- Underlying technical developments that will enable the application of satellite EO derived information to address the two development lines listed above

Priority Developments at National Level

The following issues were identified as priority national interests with respect to increased use of EO derived information

1 **Integrated data collection and analysis for Maritime Spatial Planning, Marine Strategy Framework Directive and Water Framework Directive.** Each of these directives requires the collection and analysis of a range of information over the marine and coastal domain. This includes habitat status information, coastal hydrographic information, metocean and water quality parameters etc, much of which can be provided systematically using EO data sources integrated with in-situ instruments. Due to the history of the development and application of these directives, the data collection has been built up in an unstructured manner in most areas, without structured utilization of EO derived information. Establishing an operational framework to collect and generate the required data using methodologies that can optimise the effort required for measurement, analysis and reporting against the requirements coming from all three directives was identified as a key interest for several of the countries in the region. In particular, by minimising the additional effort required to implement maritime spatial planning data collection and analysis requirements, this development would ensure effective and efficient support to the targeted growth for the blue economy in the region. In addition, the possibility of extending MFSD and WFD monitoring to also support the monitoring of declared MPAs was requested.

2 **Development of fully interoperable Territorial and Maritime Spatial Planning capabilities.** Given the geographic situation of the Baltic region, changes in the territorial

planning regime can have immediate consequences for the maritime spatial planning in the region. There is also an interaction in the opposite direction although this is expected to take place over slower timescales. Interoperable territorial and maritime spatial planning is currently being considered within a dedicated regional expert group supported by Helcom and the VASAB committee under the Baltic Strategy . However, the current disparity in data collection and information analysis methodologies that generally exists represents a constraint in terms of putting in place a single integrated mapping and analysis capability. By integrating EO derived information into the different mapping, planning and analysis actions

Pan-National Developments for Baltic Region

1. **Enhanced capability to characterize natural capital and ecosystem regulating and supporting services at regional level**. This includes the use of state of the art approaches to characterizing the status and health of key habitats such as coastal lagoons and sea grass beds, boreal forests and peat/grasslands. Capabilities of interest include high resolution water quality monitoring for coastal areas, benthic habitat status and coastline change mapping, forest health status (including connectivity/fragmentation and biodiversity assessments) and grassland/peatland status. To support these characterizations there is a broad recognition that the use of EO must go beyond basic vegetation index and other routine EO based information products and instead be effectively integrated into a more sophisticated and representative set of indicators together with all available in-situ data, regionally valid models and state of the art methodologies linked to ecosystem service assessment.
2. **Enhancement of regional Baltic modelling capabilities through EO data assimilation and building inter-operability**. At present the higher resolution transport models underpinning key Helcom analyses are sub-regional and integrating outputs into overall Baltic level conclusions can be complex. These models support the characterization of nutrient and sediment flux into the Baltic as well as other materials such as waste. However they cannot at present be systematically used to provide an integrated assessment of transport from river/estuary system to the wider Baltic system. The combination of the sub-regional models together with wide area characterization of marine environment and metocean conditions was identified as a possible development approach to address this limitation.
3. **Demonstration of integrated monitoring approaches for WFD** connecting land management practices, inland water body properties, hydrological transport and coastal water quality. At present, the three focal areas for the Helcom assessment of pressures on the Baltic environment focus on agriculture, industrial releases and marine litter/noise and regular assessments of these pressures are compiled. However at present there is little structured action to generate integrated analyses of the dynamics of the pressure factors and the response dynamics of the Baltic system to these pressures. By demonstrating an integrated monitoring and assessment approach for key drainage networks into the Baltic, the combination of EO and in-situ measurements of agriculture activities and related pressures, industrial releases, transport dynamics and coastal/marine habitat response could be used to provide added value over the standard on-going Helcom assessments. The possibility was also considered to use the transport modelling parameters as proxies for the transport of certain waste constituents to try to characterize dominant sources of marine litter.

In addition, the Helcom State and Conservation Group has conducted an assessment on the state of knowledge and data collection systems in the Baltic and identified a number of gaps and requirements for dedicated developments. Many of these relate to the integration of EO derived information. The main priorities identified are summarized below:

- Biodiversity – main interests identified where there is significant potential for integrating EO derived information include addressing gaps in knowledge of critical habitat coverage and status, development of robust methodologies to assess cumulative impacts on biodiversity in different sub-regions, assessing the impact of different measures to protect and restore biodiversity and supporting improved models of species spreading. In addition, dedicated actions to restore biodiversity in particular sub-regions complemented by the establishment/improvement of designated Marine Protected Area are being considered. The scope for detecting and characterizing Invasive Alien Species status in the Baltic region was also identified as a possible area of interest, initially focussing on the delineation and monitoring of high risk areas.
- Eutrophication – main interests identified included harmonization of open sea and coastal assessments of eutrophication and the development and validation of structured methodologies for integration of EO and Ferrybox data into standard assessment activities (in particular for chlorophyll-a concentrations and Secchi depth/turbidity)
- Seafloor integrity – the main interest relates to the development of robust methodologies to characterize changes in benthic habitats and link these to human activity such as trawling, dredging etc. The contribution from EO would clearly be in relation to habitats in coastal and shallow water areas.
- Contaminants – main interests are to assess factors affecting remobilizaton of radionuclides and highly toxic materials from historic dump sites and improved characterization of the impact of oil pollution on biodiversity in the region

Two areas of significant interest where the contribution of EO derived information could not be identified were underwater noise and marine litter. Any developments that could support Helcom actions in these domains would be extremely well received.

Underlying Technical Developments to be addressed

The following technical developments were identified as necessary to address blockages constraining the use of EO derived information in the Baltic region:

1 Baltic Water Quality Retrieval Algorithm Development

Current generic retrieval algorithms for the Baltic region are not adequate as they do not account for the unique water properties of the region, the hydrographic structure of the Baltic coastline (and consequences) and the high latitude impact on solar illumination angle. Current EO based water quality retrieval capabilities are not usable for the Baltic region and monitoring is currently based exclusively on in-situ sampling and laboratory analysis which is costly and time consuming. At the same time, Sentinel 2 data is increasingly of interest for coastal water quality due to the superior spatial resolution enabling the retrieval of water quality parameters closer to the coastline. However there are two constraints limiting the wider use of Sentinel 2 data – the fact that the centre frequency of the instrument channels are optimized for the retrieval of terrestrial parameters (ie not water parameters) and the fact that the optical effects of the coastal environment must still be taken into account in the retrieval water leaving radiance measurements. Development and validation of a customized algorithm for water quality retrieval that could also support joint use of Sentinel 2 and Sentinel 3 data (and by extension Landsat/MODIS/MERIS joint utilisation for historical statistics) would represent a key step in enabling wider use of EO based techniques for

Baltic environmental monitoring. This development was identified as the top priority issue to be addressed for the region in the closing discussion.

2 Baltic Coastal Altimeter Processing Algorithm Development

Given the geometry of the Baltic Sea, only a very limited number of conventional satellite based radar altimeter measurements can be used to support the retrieval of ocean parameters. Complications due to bathymetry variations, land contamination and propagation path corrections all require more complex processing of the altimeter data to enable the extraction of parameters of interest. At present, no such systematic processing capability exists, limiting the capability to use satellite data in priority Earth Science and coastal management applications such as sea level dynamics and coastal current characterization. A dedicated development effort was requested to put in place and validate the performance of a systematic capability to pre-process key radar altimeter datasets (both currently operational systems and historic data archives) that can address all of the limiting issues and generate the metocean parameters of interest.