Technical White Paper

Outline of a Technical Solution to a Global Cryospheric Climate Monitoring System

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Executive summary

The greatest environmental challenge to the human civilisation of today, maybe the greatest of all challenges of all times, is global climate change. However, there are many "maybes" related to this challenge, which hamper overall political consensus and the necessary actions that might be necessary in order to reduce our contributions to a changing climate and to mitigate the climate changes that will take place in any case. Therefore, it is of utmost importance to establish facts. The Earth's health should be monitored continuously and the rather subtle trends of a changing climate should be detected, quantified and applied in climate modelling followed by impact analysis in order to develop a more certain prognosis.

There is a very strong political impetus behind climate change issues. The most well known is the United Nations Framework Convention on Climate Change's Kyoto Protocol and related activities. However, there are a lot of other activities – from international to national levels related to emission gas reductions, climate scenario studies, climate change impact analysis and climate monitoring. Climate monitoring is receiving more and more attention as anthropogenic climate changes seem visible today and since the climate unquestionably has been changing the last 1-2 decades. This high-level political focus, also on climate monitoring, is reflected in global monitoring initiatives like GCOS, GMES and GEO.

Some of the best natural indicators of climate change can be found in the cryosphere, i.e. masses of sea ice, land ice, snow and permafrost. Already, observations indicate that the Arctic may be free of sea ice during the summer within 50-100 years. More extreme weather patterns are already observed in the continental Europe, with more floods and hurricanes.

The purpose of the system outlined here is to provide regular and long-term delivery of products based on observations of essential variables in the cryosphere, in particular for the polar regions. Satellite sensors are the main data source and in situ measurements are included when long-term delivery can be secured. There will be a comprehensive portfolio of products that will be made available to relevant user groups for sea ice, seasonal snow, glaciers/ice sheets, lake/river ice and permafrost. The product portfolio includes digital maps of relevant geophysical variables as well as climate-change indicator products.

Historically, Europe has gone in the forefront of polar exploration and polar research. The momentum of European polar and cryospheric research is in general still high, and there are lot of world-leading expertise in Europe with R&D results from numerous projects to draw on. There is an overwhelming base of scientific and technological results to build upon when developing a service for cryospheric climate change monitoring. Therefore, it is possible to establish a world-class consortium of service providers, developers, users and strategic organisations behind the system and service outlined here. Much of the R&D in Europe has taken place within the EU framework programmes for research and development as well as in ESA's programmes. Hence, the climate monitoring service proposed would be a horizontal service drawing on parts of other services and the infrastructure they are building upon.

A successful cryospheric climate monitoring service infrastructure needs to be flexible, scalable and distributed. Also, with the long-term perspective of climate monitoring, it is necessary to establish a sustainable service. The service proposed is building on a network approach making it possible to integrate sub-services provided by geographically distributed expert groups into a one-stop shopping web service. The web service builds on standards such that it can be easily integrated in "super-systems", like portals for climate monitoring services. The backbone in the network consists of legally mandated organisations hosting the climate product databases. They will secure sustainability of the service. It is proposed that the product production chains, developed by scientific expert organisations (like universities and other research organisations), migrate into mandate organisations as the production chains become fully operational. Further formal collaboration with the expert groups will secure that the expertise is not lost from the service in the future. This is important for a living service that needs to include new algorithms, satellite systems and sensors as they emerge.

Contents

Preface

This report was originally written as a proposal for a climate monitoring system and service for development within European Space Agency's GMES Service Element (GSE). However, we learnt that neither ESA, nor the relevant prime contractor, were prepared to initiate such a large endeavour as climate monitoring, even if limited to the cryosphere. Serious cryospheric climate monitoring would have consumed a significant part of the budget, and other more short-term issues received more attention and therefore were selected for implementation.

In spite of the lack of success of establishing an operational climate monitoring service within GSE this time, the draft document received a lot of attention when it begun to circulate within various parts of ESA, space agencies in general and other organisations related to climate monitoring. Key experts within those organisations have commented that what the report proposes represents a logical way to go and an innovative solution to climate monitoring building very well on the results already obtained within numerous projects.

Based on this feedback, the authors decided to make a final, standalone version of this report, which we hope will continue to circulate in the corridors of the offices of climate monitoring experts and decision makers for a while. The report gives by no means a complete description of such a system. However, we hope the result of this dissemination process is that the report will contribute to a successful realisation of global cryospheric climate monitoring system in the near future, which is identified as an urgent issue by international initiatives such as GCOS, GMES and GEO.

Rune Solberg
On behalf of the author team,
July 2006

1 Introduction

The greatest environmental challenge to the human civilisation of today, maybe the greatest of all challenges of all times, is global climate change. However, there are many "maybes" related to this challenge, which hamper overall political consensus and the necessary actions that might be necessary to reduce our contributions to a changing climate and to mitigate the climate changes that will take place in any case.

Therefore, it is of the utmost importance to establish facts. The Earth's health should be monitored continuously and rather subtle trends of a changing climate should be detected, quantified and applied in climate modelling in order to develop more certain prognosis for the future. There is a political consensus on a broad scale that such monitoring is needed, e.g., reflected in initiatives like GCOS, GMES and GEO.

Some of the best natural indicators of climate change can be found in the cryosphere, i.e. masses of sea ice, land ice, snow and permafrost. Already, observations indicate that the Arctic may be free of sea ice during the summer within 50-100 years. More extreme weather patterns are already observed in the continental Europe, with more floods and hurricanes.

This system outlined here aims to provide a significant and consolidated step towards a sustainable, long-term monitoring service of the cryosphere. The service has the potential to be the European contribution to a global cryospheric service to the UN and to GEO. It aims at providing European decision makers with the best and most accurate climate change monitoring system and service for the cryosphere. This will give Europe an independent and the best information foundation for international discussions and negotiations, hopefully leading to correct and timely actions to reduce an accelerating changing climate. Of similar importance, it will provide Europe with regional information that will help decision makers at every political level to start mitigation actions in time so we can adapt to a changing climate, avoiding as much as possible catastrophic impacts due to more extreme weather, increasing sea level, changes in the Gulf stream, etc.

The proposal represents a horizontal service in the sense that it builds as much as possible on existing organisations, infrastructure, services, and research and development results. This is certainly the most effective use of resources. However, it is also necessary to do some new development and adaptation of infrastructure in order to establish the best possible solution to cryospheric climate monitoring in Europe as well as utilising GMES technology and infrastructure already developed or under development by other EC and ESA projects. The service is also horizontal in the sense that it has brought in leading scientific groups in Europe for establishing the service. Additionally, of great importance, the proposed service has already been able to establish links to important

Figure 1.1. Some of the best natural indicators of climate change can be found in the cryosphere

climate and cryospheric monitoring and user-federation organisations worldwide in order to be in the best possible position for developing a service precisely meeting the most important user needs.

The objective of the proposed cryospheric climate monitoring service is to provide regular and long-term delivery of products based on observations of essential variables in the cryosphere, in particular for the polar regions. Satellite sensors are the main data source and in situ measurements are included when long-term delivery can be secured. There will be a comprehensive portfolio of products available to relevant user groups for:

- Sea ice
- Glaciers and ice sheets
- Seasonal snow
- Lake and river ice
- Permafrost

The product portfolio includes digital maps of relevant geophysical variables as well as climate-change indicator products.

The service proposed builds on algorithms and an advanced flexible infrastructure developed by numerous EC and ESA R&D projects. It is a network approach making it possible to integrate the various sub-services provided by geographically distributed expert groups into a one-stop shopping web service. The web-service builds on standards so it can be easily integrated in “super-systems”, like WMO’s portal for climate monitoring services. The backbone in the network consists of legally mandated organisations hosting the climate product databases. They will secure sustainability of the service. It is proposed that the product production chains developed by scientific expert organisations (like universities and other research organisations) migrate into mandate organisations as the production chains become fully operational. Further formal collaboration with the expert groups will secure that the expertise is not lost from the service. This is important for a living service that will include new algorithms, satellite systems, sensors, etc as they emerge in the future.

2 Why climate monitoring?

Observations of climate change indicators and climate model scenarios indicate that the global climate will change with increasing speed in the coming years with one of the most significant changes being a global warming. Although there will be warming on the global scale there will be large regional variations in the climate that will affect various parts of the world differently. In fact, Europe is maybe the most sensitive region in the world and it is not known whether we will experience regional cooling or warming in the future (IPCC, 2001). Anyway, it is most likely that global warming will change the living conditions in Europe significantly. The weather will become more extreme and the population distribution will change as a consequence of changes in the living conditions set by the local climate.

The cryosphere consists of frozen water on the Earth's land and sea surfaces. It includes all snow and ice deposits, such as glaciers, ice caps, ice sheets, and sea ice; seasonal and permanent snow cover, lake and river ice, permafrost and seasonally frozen ground. The largest geographical component of the cryosphere is seasonal snow cover. It covers up to 33% of the Earth's total land surfaces. About 98% of this can be found in the northern hemisphere. Glaciers are large, thickened masses of ice, which accumulate through snowfall over long periods of time. The thickness of the glacier depends on the quantity of snow that falls during the winter months, how much of it that melts during the summer months, and how the glacier moves. About 75% of the world's fresh water is stored in glaciers and ice sheets. During the winter seasons, sea ice typically covers 14-16 million km^2 of the Arctic Ocean and 17-20 million km^2 of the Southern Ocean around Antarctica. The sea ice extent fluctuates with the seasons, influencing both human activities and biological habitats. In addition to ocean ice, sea ice includes frozen lakes and rivers. Permafrost is soil, silt and rocks located in perpetually cold areas that remain at or below a temperature of 0°C for long periods. A thin layer may thaw during summer months, though the majority of the permafrost in a given location will remain frozen until the local climate possibly changes.

Figure 2.1. Nearly 24% percent of the world's exposed surface contains permafrost (International Permafrost Association)

The Arctic region is expected to experience the largest climate change effects in response to higher atmospheric greenhouse gas concentrations. Current climate models predict a greater warming for the Arctic than the rest of the world. Already the vast ice packs – so crucial to Arctic peoples for wildlife, travel and hunting – are diminishing, though with great annual variations.

The Greenland ice sheet is the largest single freshwater source in the Northern Hemisphere, containing enough water to raise the global sea level by about 7 m. Interestingly, it is situated near the two main regions of oceanic overturning (Labrador and Irminger Seas) while its southern section is particularly sensitive to atmospheric warming. Although the Antarctic ice sheet is nine times larger in volume, only Greenland exhibits substantial seasonal melting, with runoff representing approximately half of the total mass loss making it far more sensitive to a warming trend. It is, thus, expected to increase its freshwater contribution through enhanced surface melt by 20-50% per degree of warming (Ohmura et al. 1996; Janssens and Huybrechts 2000).

Glacier ice outside of Antarctica and Greenland only accounts for 0.5% of the total glacier ice on this planet, but these smaller ice masses are in fact a larger contributor to sea level rise today and in the near future. One of the reasons for this is that these glaciers are located in areas with higher temperatures than Antarctica and Greenland. Svalbard, for example, is located at the Northern end of the North Atlantic current, in addition to be located at the boundary between cold polar air masses and milder maritime air masses. Ocean currents and air fluctuations are very likely to be affected by a change in climate, and glaciers on Svalbard will thus react more strongly to climate change.

Changes seen in the Arctic are the early signs of climate changes that are likely to affect much of the world over the next decades. The Arctic temperature has increased at almost twice the rate compared to that of the rest of the world over the past few decades, in particular during the winter. Arctic warming is likely to occur at twice the global average rate over the next century (ACIA, 2004). Europe also seems to be particularly vulnerable. Up to now, the global average temperature has increased by about 0.7°C and the European average temperature by 0.95°C during the past hundred years. According to the European Environment Agency (EEA) temperatures are predicted to increase by 1.4–5.8°C globally and 2.0–6.3°C in Europe by the year 2100 (EEA, 2004).

3 Political impetus

There is a very strong political impetus behind climate change issues. The most well known is the United Nations Framework Convention on Climate Change's Kyoto Protocol and related activities. However, there are a lot of other activities from international to national levels related to emission gas reductions, climate scenario studies, climate change impact analysis and climate monitoring.

In order to understand and better predict the development of the climate, continuous long-term observations of climatic variables are crucial. This has for a long time been recognised by scientists, and the political awareness is increasing. There are several international political documents and decisions that support improved monitoring of the climate, some of the most important listed below:

- **UN, Kyoto Protocol 9.1**: "Provide the best available scientific information and assessment on climate change and its impacts, 10.d: Participate and co-operate in international scientific research programmes to reduce uncertainties related to the climate system and the adverse impacts of climate change" (UN, 1997)
- **UN, COP10, 6-17 December 2004, Buenos Aires, Decision -/CP.10, Implementation of the global observing system for climate**: "Encourages Parties to enhance their work and collaboration on observation of the essential climate variables and on development of climate products to support the needs of the Convention, including through participation in the Global Climate Observing System cooperation mechanism" (UN, 2004)
- **EC, 6th Environmental Action Plan**: "Improved monitoring of climate change is needed" (EC, 2001)
- **EC, Action Plan for Implementing the European Space policy**: "The strategy for Earth observation being defined by the GMES initiative should serve as a basis for co-operation in support of the commitments Europe has made in these global fora. Furthermore, Europe is well placed to significantly contribute to global climate observing systems for which space represents a crucial technology." (EC, 2003)
- **WMO/GCOS & GEO**: "...our capacity to monitor climate and environmental changes is still largely inadequate…" (WMO, 2004)
- **Arctic Council**: "Continuation of long-term records is crucial, along with upgrading and expanding the observing systems that monitor snow and ice features, runoff from major rivers, ocean parameters, and changes in vegetation, biodiversity and ecosystem processes." (ACIA, 2004)
- **EEA**: "A key area for the EEA work is the development and the annual update of a core set of indicators for each of the five topic areas the Agency is addressing namely: water, air and climate change, nature and biodiversity, terrestrial environment, waste and material flows." (EEA, 2004)
- **GMES, Action Plan**: "The following selected priorities will contribute to the core capacity services, and cover topics at global, European, regional and local levels: … climate change " (EC, 2004)
- **GEO**: "…the 10-Year Implementation Plan, including but not limited to the following:.. Comprehensive monitoring of global and regional climate on annual, decadal, and longer time scales, and enabling information products related to climate variability and change…" (GEO, 2004)

Figure 3.1. The GMES initiative might be the solution to the, by the UN, identified urgent need more than a decade ago for systematic climate monitoring

Climate monitoring is needed in order to provide evidence of climatic changes, to quantify changes, to improve climate scenario analysis and to better understand climate change impacts. United Nations' World Meteorological Organisation (WMO) is a key international organiser of climate monitoring with its initiative for a Global Climate Observing system (GCOS). The ideas for an operational GCOS can be found in the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (WMO, 2004). A list of the essential climate variables to monitor is also listed there, based on WMO's recommendations and justifications. However, GCOS is a system of systems, and the individual systems need to be implemented through other initiatives. On the worldwide level much of the space-based monitoring will most likely be co-ordination by the global Group of Earth Observations (GEO) initiative (GEO, 2004). The Global Monitoring for Environment and Security (GMES) initiative, taken by the European Union and European Space Agency, will be the most important European contribution to the GEO initiative. Climate change monitoring is stated as a key issue in the GMES programme.

4 The climate monitoring user community

The science of climate research, climatology, goes back to the 19th century, and it is closely linked to meteorology, yet also many other disciplines, in particular for studies of the past climate (paleoclimatology). However, climate studies got another dimension in the last decade when climate change got on the international political agenda. Information about the climate and climate change is definitely not entirely a scientific discipline any more. Increasingly more focus is put on climate change monitoring, including analysis and preparation of information to decision makers and people in general (including media and interest organisations).

4.1 Who is the user community?

When dealing with the climate monitoring community, it might be helpful trying to structure the community (even if it hard to capture every organisation and individual in a simple structure):

- Scientific research
- Information providers
- Decision makers
- Public
- Industry and public administration

The scientific research community's interests are typically related to direct and indirect measurements of climate change and comparison (including validation) of climate models. The dominating research groups are university institutes and research departments in meteorological offices. Information providers are a broad group ranging from mass media to international organisations providing information to intergovernmental decision makers. The group also includes national bodies analysing and providing information to ministries, who structures and edit the information to the politicians. Most countries put some resources in collecting and preparing information on climate change to politicians. The group decision makers include politicians acting on the national level, individuals and organisations appointed by them to act based on information received, and more super-national organisations like European Union and the United Nations. Finally, we have the public, people in general, whose interest and opinions influence on the decision makers.

With the steadily increasing focus the media, people and decision makers have put on climate change issues the user community of climate change information has grown rapidly the last 1-2 decades. Climate change is now one of the "hottest" issues on the international agenda, and most people in the industrialised nations are concerned about these issues.

The public "flavour" of the user community should be noted. The academic as well as the political focus on climate change is driven by public needs. Therefore, the area is mostly funded through governmental budgets, and the funding mechanisms for a cryospheric climate monitoring service have to reflect this. However, the segment represented by industry and public administration will very likely grow much as awareness of climate change is increasing, and in particular as concrete effects of climate changes appear (like changes in the precipitation pattern). Therefore, there will be a growing market for tailored pay-for services in the future.

Table 4.1. Examples of user types in the defined user groups

Scientific research	Information providers	Decision makers	Public	Industry and public administration
Climate modellers	Ministerial appointed institutes	National ministries	The citizen	Shipping
Climate impact analysers	Interest organisations	Federating organisations	Media	Offshore
Climatologists	Institutes of federating organisations	Political summits	Education	Public authorities
				Insurance

4.2 What information do they need?

Generally most users need measurements on how the climate changes. Exactly what each user group needs is mostly a question about aggregation of information in time and space. In other words, what time resolution do you want and for how large a geographical area?

The research community would typically require detailed information – high temporal resolution as well as local or regional measurements. For climate model validation, it might be a map of sea ice concentration at 50 km resolution and averaged in time over a period of one month. Such a map can be directly compared to a climate model output on sea ice extent.

The other user groups would typically like to see the information on higher aggregation levels. An aggregation level might be related to the area of interest, e.g. a particular nation or a more global perspective. On the highest level, it might be the maximum and minimum annual sea ice extent in the Arctic. It might even be the result of a trend analysis of these extreme values over as many years as possible. For information providers, decision makers and the public, so-called climate change indicator variables are of particular interest. A climate change indicator variable is a quantity measuring a potential change in the geo-bio-physical system, where the variable is related to an expected response due to climate change. Information providers would typically be interested in measuring many variables to see if they all indicate the same change in the climate.

The exact choice of geophysical variables and indicator variables to be monitored as well as the exact product specification for each of these variables will be determined through a dialog with users linked to the project. However, an up-front overview of the users needs has been developed and is presented in Chapter 7. The variables are certainly linked to the main components of the cryosphere: Sea, lake and river ice; glaciers and ice sheets; seasonal snow; and permafrost.

5 A model for a climate monitoring service infrastructure

Climate monitoring of the whole cryosphere is an inherently very complex endeavour. Vast areas have to be monitored, many variables should be measured, several satellites and sensors need to be applied, correspondingly many algorithms need to be used, there are many actors (organisations) involved in monitoring and the user community is broad and diverse. A climate monitoring service needs to reflect this situation.

5.1 Overall requirements

A successful cryospheric climate monitoring service infrastructure needs to be flexible, scalable and distributed. Also, with the long-term perspective of climate monitoring, it is in particular important to establish a sustainable service. This means that the service should in the long term be operated by mandate organisations. But support by more pure research and development organisations will also be important in the future as the infrastructure has to be further improved and developed as new satellite systems and sensors emerge with corresponding opportunities for steadily better monitoring.

There already exist services based on satellite earth observation of the cryosphere, e.g. for meteorological applications. A climate monitoring service should draw on these as much as possible in order to utilise the resources optimally. Therefore, the climate monitoring service should be a horizontal service drawing on parts of other services and the infrastructure they are built upon.

There are also several previous and ongoing projects that potentially can contribute with results to the development of a cryospheric climate monitoring service. Some of these projects have been run in the framework of GMES activities and have developed results that should be captured when developing concrete services. The service model and infrastructure outlined below would not be possible without several of these projects. This is further documented in Chapter 6.

The model proposed is based on the assumption that existing organisations and infrastructure will be utilised. No unrealistic organisational changes (like a central body for climate monitoring) or advanced new technology development is foreseen. The model draws on the existing expertise and capabilities in the way they are today.

5.2 The model

Figure 5.1 illustrates the three main components or building blocks in the model. The model proposed builds on the one-stop-shopping concept for web services. The user finds all services and products on one web site. However, behind the service is a distributed system of databases and product production chains hosted by various organisations. The databases are hosted by organisations having a mandate to provide specific climate information. The production of the products to be stored in the databases may take place in other organisations. For new algorithms

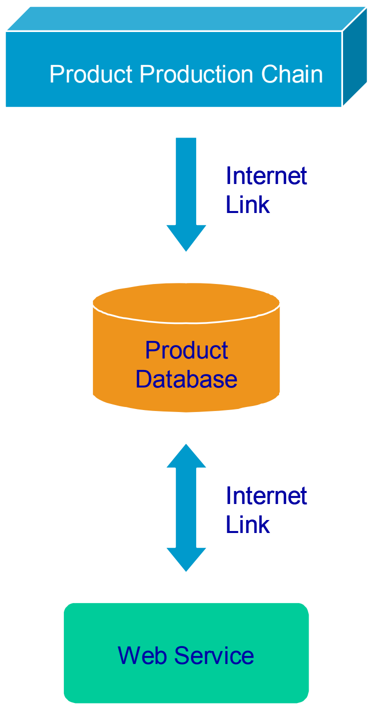

Figure 5.1. The components or building blocks of the conceptual infrastructure model

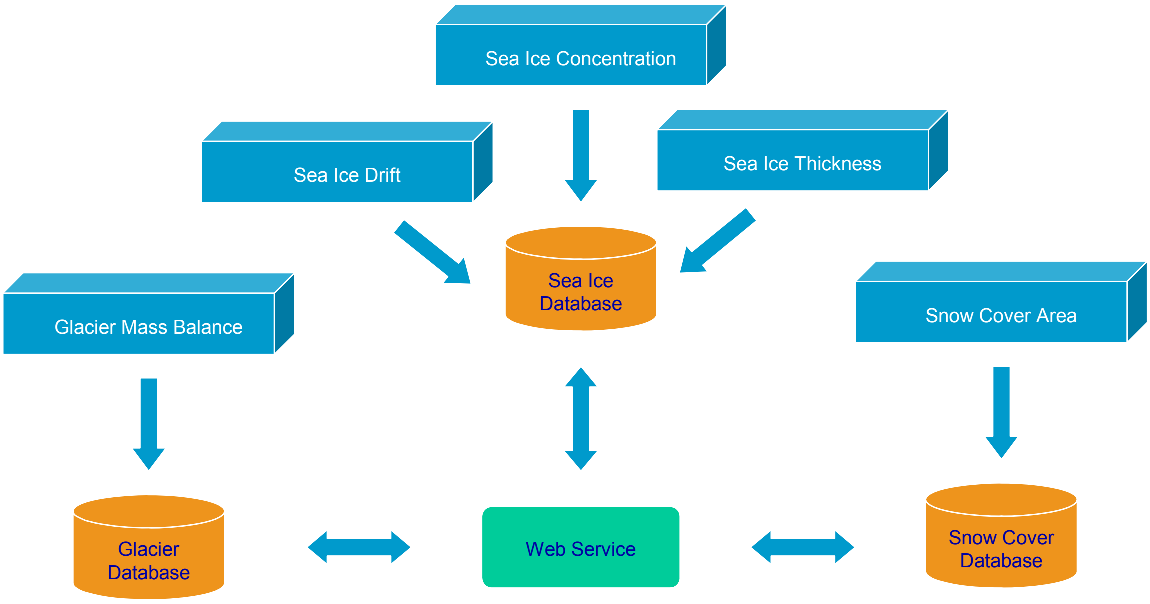

Figure 5.2. A hypothetical example of a cryospheric climate monitoring system built with the components illustrated in Figure 5.1

and products, it is most convenient and best for quality assurance and algorithm improvements that the production takes place in a research and development organisation. However, in the long term, these product production chains should be moved to mandate organisations, most likely the database host organisations, in order to assure long-term sustainability. Yet, an R&D link should in general be kept with the originating organisation for further improvements as new sensors and algorithms emerge.

Figure 5.2 shows a hypothetical example of a cryospheric climate monitoring system. There are five product production chains where cryospheric geophysical variables are retrieved from remote sensing and in situ data. The retrieved variables are represented in products based on standard and agreed-upon data formats. The data are transferred from the host organisations of the product production chains to the database hosts (product producer and database host might be the same organisation). The databases are hosted by mandate organisations specialising in one or more components of the cryosphere (like Arctic sea ice). The web service – the link between the databases and users providing tools for product search, simple analysis, retrieval and background information and metadata – is also run by a mandate organisation (might be one of the database host organisations).

The components described already exist from past and current projects in the EU Framework programmes for R&D as well as ESA projects. The use of them in this service is a matter of agreeing exactly upon which components to use, some tailoring to the concrete service to be developed and integration and deployment of the components.

6 The existing science and technology base

Climate change monitoring by means of remote sensing is a relatively new discipline. It has taken place more or less systematically for around four decades. However, it is only within the last 10-15 years that long time series of observations have been available. So, it is just recently that climate change monitoring by satellite has started to gain real impetus, and it is rapidly growing due to the strong international political focus. In situ measurements have taken place for hundreds of years, however, automatic measurements have only taken place on a large scale for a few decades.

There is an overwhelming base of scientific and technological results to build upon when developing a service for cryospheric climate change monitoring. Much of the development in Europe has taken place within the EC framework programmes for research and development as well as in ESA's programmes. We will in the following just indicate some recent research and development results and some projects identified as significant potential contributors to algorithms and technology infrastructure in the cryospheric climate monitoring service.

6.1 Some related algorithm research results

Sea ice extent has been retrieved by remote sensing for 2-3 decades, and the retrieval accuracy of sea ice concentration has been much improved in the last 10-15 years. Sea ice drift measurement has also become feasible as new sensors have been developed, and retrieval of sea ice thickness is now emerging.

6.1.1 Sea ice

Sea ice concentration: The EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF) has been developing a European operational service for daily sea ice monitoring since 1997. The OSI SAF is a long-term project, at least until 2012. This commitment assures a continuous development and the algorithms used are under constant validation. The OSI SAF team is also participating within other related projects such as the FP5 IOMASA and EuroClim where more development on sea ice algorithms and use of sea ice products are central tasks.

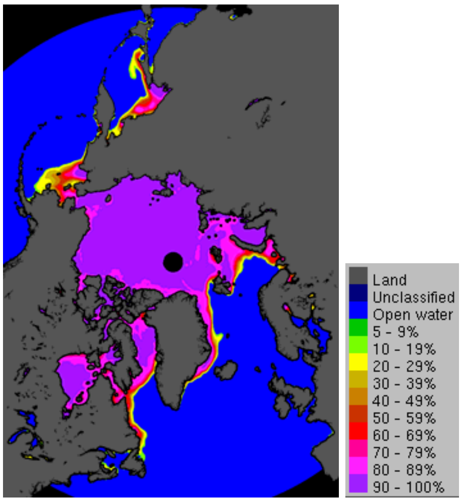

Figure 6.1. Mean sea ice concentration for April 2005 derived by the OSI SAF algorithm applied in EuroClim

In the OSI SAF development the state-of-the-art sea ice concentration algorithms were tested and validated and the best was chosen. This resulted in a hybrid algorithm using a combination of the NASA team and Comiso-Bootstrap algorithms. More details about the algorithm development, product validation and system design can be found at http://saf.met.no, see also (Breivik et al 2001).

During the EuroClim project methods for aggregating products for monthly, seasonal and annual products were developed, as well as monitoring of inter-calibration between the different SSM/I sensors. This is important when studying long-term changes since single satellites have a limited lifetime.

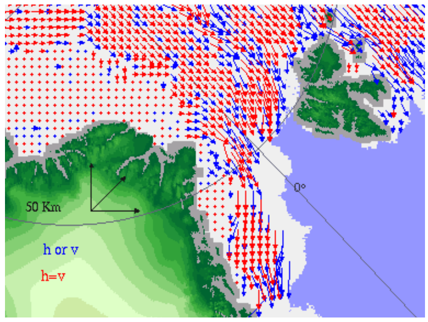

Figure *6.2: Enhanced resolution sea ice drift in the Fram Strait derived from AMSR-E data. April 27-29,* 2005

Sea ice drift: On short time scales, sea ice drift data are used by modellers either for validation or for assimilation. On the long run, sea ice drift time series do have climatic applications. The decrease of multi-year sea ice in the Arctic is considered to be a major indicator of climatic change. Some controversies exist on the relative importance of multi-year sea ice melting in the central Arctic basin and the multi-year sea ice export through the Fram strait. Multi-year sea ice discrimination is now possible using scatterometers and SAR. Preliminary studies involving scientific methodology and instrumental inputs are under way to estimate the different terms of the balance not only in terms of surface flux but also in terms of volume flux. MERSEA (EU) is behind some of these scientific developments (Ezraty et al. 2006a, 2006b, 2006c and 2006d). Also DAMOCLES (recently approved EC 6th framework project) will support the science/technical developments to extend the drift data estimation capability to the future EUMETSAT ASCAT scatterometer.

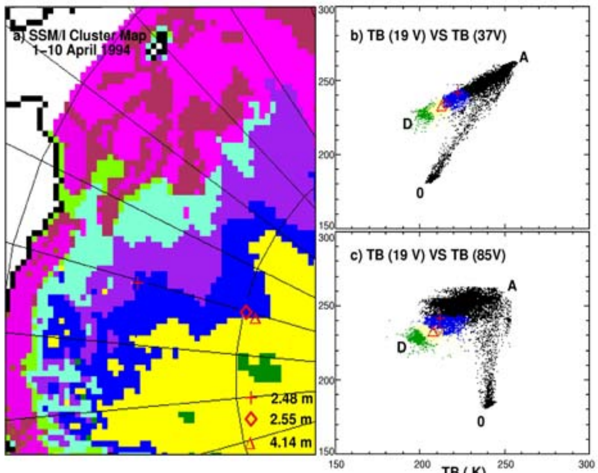

Figure 6.3. SSMI cluster analysis. Left: *colour-coded distinct isoclasses that correspond to different mean ice thicknesses.* Right: *2 pairs of brightness temperature data showing separation of isoclasses*

Sea ice thickness: Preliminary results from cluster analysis of passive microwaves appear to show a relationship with mean sea ice thickness. This approach, proposed by J. Comiso at NASA GSFC (Comiso 1990, Wadhams and Comiso 1992) and being developed in collaboration with researchers at SAMS and UCAM-DAMTP, would provide a long time series (back to the launch of SMMR in 1978) of sea ice isoclasses. These isoclasses are defined by the emissivity characteristics of the ice cover, which are related to the type of sea ice type and its development history. The cluster analysis algorithm will be implemented and validated against submarine ice thickness data. Implementation will also allow the results to be tested against other in situ measurements including moored upward-looking sonar and field campaigns. Research on matching of submarine ice draft statistics from 1991 for UK and US datasets with SSM/I emissivity isoclasses was part of the EuroClim project. Work is now progressing internally in UCAM-DAMTP and SAMS.

6.1.2 Snow

Operational snow cover area (SCA) mapping by optical sensors has taken place for more than two decades, but there are many recent and ongoing projects improving accuracy and temporal coverage. Additionally, recent projects have developed algorithms for new snow parameters. Since snow parameters may change rapidly there is a need for frequent mapping. To achieve frequent mapping sensors with medium-to-low spatial resolution have to be used.

Snow cover area: The requirement of frequent mapping has limited the number of satellite sensors that is usable operationally down to the NOAA AVHRR, Terra and Aqua MODIS, ENVISAT MERIS, AATSR and a few other sensors of low and moderate spatial resolution. (Radarsat and ENVISAT ASAR are relevant only for wet snow.) This situation led very early to the development of fractional SCA retrieval for the Norwegian mountain region, a region very important for hydropower production (Østrem et al. 1979, Andersen 1982, Solberg and Andersen 1994). Recent development of SCA retrieval includes a reflectance-model-based algorithm working particularly for boreal-forest regions (Metsämäki et al., 2005). The most recent and accurate approaches for fractional SCA retrieval build on the spectral unmixing approach. Advancements of this approach have taken place in recent national and international projects – in particular SnowMan (2001-2004) funded by the Norwegian Research Council, the EC projects SnowTools (1996-1998), EnviSnow (2002-2005) and EuroClim (2001-2005). Some of the results are demonstrated in the ESA project EOhydro (2004-2006). The SCA products for climate monitoring should be built on algorithms from these projects (e.g., see Eastwood 2003 and Solberg et al. 2005).

Snow temperature: The snow temperature at surface (STS) variable refers to the skin surface temperature of the snow cover. It can be observed by means of remote sensing in the thermal region of the electromagnetic spectrum using sensors like AVHRR, MODIS and AATSR. The observed radiance emitted from Earth's surface can conveniently be transformed to the quantity of brightness temperature according to Planck's law. The main issue for retrieval of snow surface temperature is to correct for the atmospheric attenuation. The core of any algorithm for retrieval of surface temperature is therefore to combine at least two observed brightness temperature images into one real surface temperature image. The polar atmospheres are not very well known, but a few algorithms exist for retrieval of sea surface temperatures (e.g., Key's algorithm, Key et al. 1997). A sea surface temperature algorithm has now been tailored to snow temperature mapping, validated by the projects SnowMan, EnviSnow and EuroClim, and is available for this climate monitoring service (Amlien and Solberg 2003).

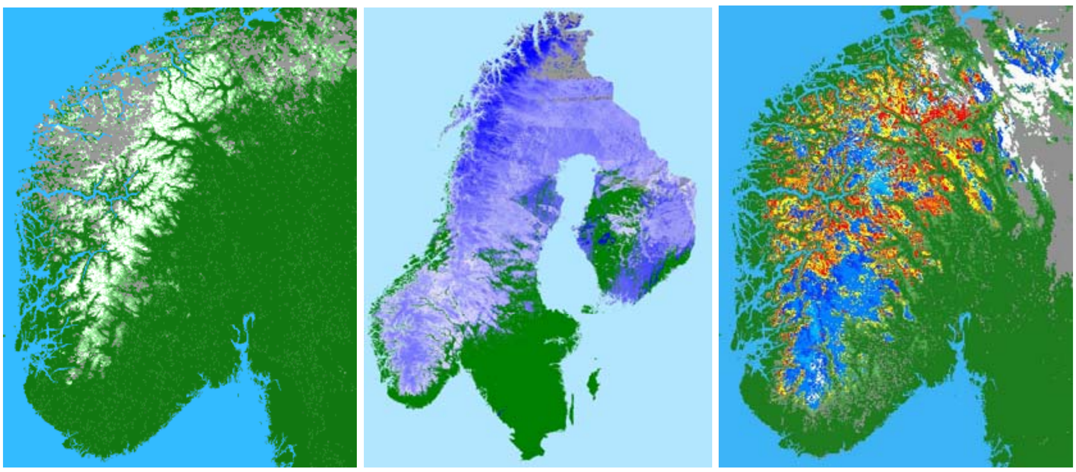

Figure 6.4. Examples of the climatic snow products developed by the EuroClim project: a) Snow cover area (SCA) (left) with snow-free areas in green and snow cover in white; b) Snow temperature at surface (STS) (middle) showing temperatures around 0°C in white and lower temperatures in deeper blue (about –10°C in the north) and c) Snow surface wetness (SSW) (right) where light blue and yellow are areas there the snow has just started to melt. Clouds are in grey in all maps

Snow wetness: The ideal approach based on optical data would be to apply a retrieval algorithm for liquid water contents in the snow. However, this would require an imaging spectrometer with optimally located spectral channels for measuring a liquid-water molecular absorption feature. SAR may also be used to detect wet snow, but is not practical for operational global monitoring (mainly due to revisiting frequency and costs). The approach we propose here is to infer snow surface wetness (SSW) from a combination of measurements of snow temperature (STS) and snow grain size (SGS) in a time series of observations. This can be done using sensors like AVHRR, MODIS, AATSR and MERIS. The temperature observations give a good indication of where wet snow may potentially be present, but are in themselves not accurate enough to provide very strong evidence of wet snow. However, a strong indication of a wet snow surface is a rapid increase of the effective grain size observed simultaneously with a snow surface temperature of approximately 0°C. The approach has been developed and validated by the projects SnowMan, EnviSnow and EuroClim (Solberg et al. 2004).

Snow water equivalent and snow depth: The snow water equivalent (SWE), given typically in mm, refers to the total amount of snow when converted to the equivalent mass of liquid water. It is a product of snow depth (SD) and snow density. SWE, or SD, is a key variable both for hydrology and climatology. Space-borne microwave radiometers, such as AMSR-E, are in practice the only systems that are able to provide information on SWE or SD over large areas. The problem in SWE monitoring using microwave radiometers is their high sensitivity to spatial and temporal variations of snow grain size (see e.g. Pulliainen and Hallikainen, 2001). This causes systematic errors for stand-alone satellite data retrieval algorithms. An operationally feasible method to eliminate these problems is the assimilation of satellite data to a ground-observation-based background field interpolated from SD observations at synoptic weather stations (Pulliainen et al. 2002 and Pulliainen et al. 2005).

6.1.3 Glaciers and ice sheets

Small glaciers are responding on changes in climate, e.g. on air temperature and precipitation, on a decadal scale. Therefore, such glaciers are important climate change indicator. Glacier mass balance measurements are used to monitor whether glaciers are retreating or advancing. The traditional method for mass balance measurements is by direct in situ stake measurements at the end of the accumulation and ablation seasons, respectively. Only a few glaciers can be measured and these are mostly selected on the basis of their accessibility rather than how representative they are. Remote sensing imagery allows monitoring of large, remote and inaccessible areas at comparatively low cost.

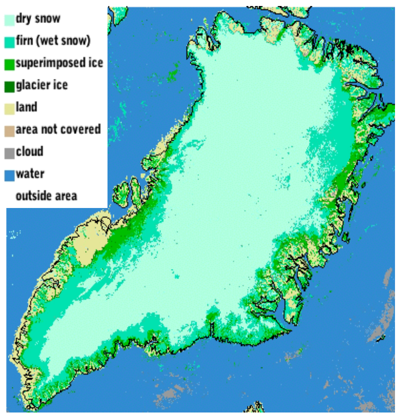

Figure 6.5. An example of a glacier surface type (GST) product for Greenland developed by the EuroClim project

Greenland: Over the past few years significant efforts have been undertaken to gain insight into the mass balance conditions of the Greenland ice sheet. Research from extensive field programs, including ice-penetrating radar, laser altimetry, GPS measurements and automatic weather stations, have been carried out recently in connection with several projects. One such project is the ICEMON (www.icemon.dk) carried out by the Geological Survey of Denmark and Greenland (GEUS). During the ICEMON project several mass balance stations have been established on selected areas on the

Greenland ice sheet margin. Within the EuroClim project a surface classification product for the entire Greenland ice sheet has been developed. The glacier surface type (GST) product is based on a grouped-criteria technique with spectral thresholds for the surface classification on a pixel-by-pixel basis. The spectral variability of ice and snow reflectance is exploited in order to determine different facies on the ice sheet. There are three classes in the product: glacier ice, firn and dry snow. The product proposed for the this climate monitoring service could be based on the EuroClim algorithm with the extension of including information from in situ measurements from the network of automatic measurement stations operated by GEUS.

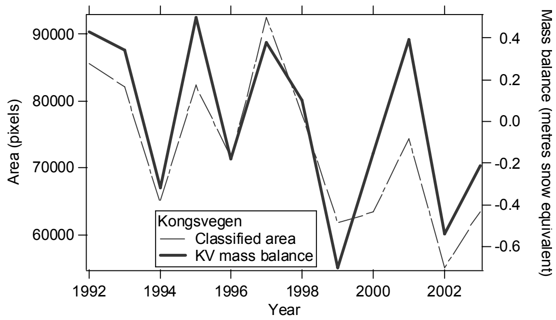

Figure 6.6. The area size of the class on the upper part of the glacier, as determined with a k-means classification, correlates remarkably well with the mass balance for all glaciers in the Svalbard study area. This correlation led to the development of the Arctic glacier mass balance algorithm applied in the EuroClim project

Glaciers: Glaciers outside of Antarctica and Greenland only account for 0.5% of the total glacier ice on this planet, but these smaller ice masses are in fact a larger contributor to sea level rise today and in the near future. One of the reasons for this is that these glaciers are located in areas with higher temperatures than Antarctica and Greenland. Svalbard, for example, is located at the northern end of the North Atlantic current, in addition to be located at the boundary between cold polar air masses and milder maritime air masses. Ocean currents and air fluctuations are very likely to be affected by a change in climate, and glaciers on Svalbard will thus react more strongly to climate change. On Svalbard, an exceptional time series of glacier mass balance measurements from the 1960s until the present day has been conducted on glaciers in the Kongsfjorden area around Ny-Ålesund (Lefauconnier and others, 1999). However, this time series has a drawback in the fact that it covers only three glaciers in a small region that may not be representative of Svalbard as a whole. Over the last decade a number of scientific undertakings have been launched to remedy this, by exploring satellite remote sensing as a tool for glacier mass balance monitoring. A review of some of these has been published in König et al. (2004). Later, the following projects – among others – have taken some of the approaches further:

- "Envisat MERIS and ASAR used for Snow and Glacier Ice Studies", an ESA Prodex contract with the Norwegian Polar Institute 1999-2002. This is the project that initiated the methods to be employed in the Svalbard glacier monitoring sub-service. (See http://www.arcus.org/Witness_the_Arctic/Winter_00_01/mem_insert.pdf, p. 2)
- EuroClim, in which the same methods have been developed to a pre-operational stage (see http://euroclim.nr.no/viewpage.php?title=Glacier+Svalbard&page=status/wp2/glacier_svalbard/glacier_svalbard.html)
- Envitools, which attempts to enhance our understanding of the interaction of microwaves with snow and ice cover, and to develop new methods for retrieval of cryospheric variables from SAR data (see http://projects.itek.norut.no/envitools/index.htm).
- GLIMS, which is a large-scale monitoring system for glacier surface area using optical imagery (seehttp://www.glims.org/)

The algorithm developed in the EuroClim project is based on a k-means classification of the glacier surface in synthetic aperture (SAR) imagery (ERS and ENVISAT ASAR has been used so far). The area extent of one of the classified areas shows a remarkable correlation with glacier mass balance, which can be used for mass balance prediction (Figure 6.6). It is proposed to use this new algorithm for glacier monitoring on Svalbard. The algorithm may also be used on a much larger scale in the Arctic region, but this will need more validation.

6.1.4 Lake and river ice

Satellite data in the visible spectral range has been shown to be useful for monitoring the break-up dates of lakes in North America (Wynne et al. 1998). 81 lakes of various sizes were monitored during the period 1980-1994 by means of GOES-VISSR, which has a spatial resolution of 900 m. The study revealed a trend towards earlier ice break-up and later formation dates. In a similar work (Reinart and Pärn 2003) monitored the ice melting of Lake Peipsi between Estonia and Russia during the winter 2002 by means of Terra MODIS data with a spatial resolution of 250 m.

The Canadian CRYSYS project – which is part of NASA's EOS program – uses modelling, in situ, airborne and spaceborne data in the research of cryospheric variable retrieval. The current research on lake-ice is focusing on the use of passive microwave and SAR algorithms in order to monitor the formation date of lake ice and the ice break-up date. Intensive studies of the Great Slave Lake have confirmed that passive microwave data from SSM/I are useful for separating lake ice and open water and following the development of the lake ice. SSM/I have also been used for validation of lake ice simulation models. Results are consistent with visible AVHRR data. ERS-data have been used to verify model simulations of lake ice development in shallow lakes (Duguay and Lafleur 2003). RADARSAT data have been used to monitor the ice development on sub-Arctic lakes in Canada (Duguay et al. 2002). The multi-beam configuration made it possible to obtain frequent acquisitions in order to precisely determine the dates for ice formation and break-up.

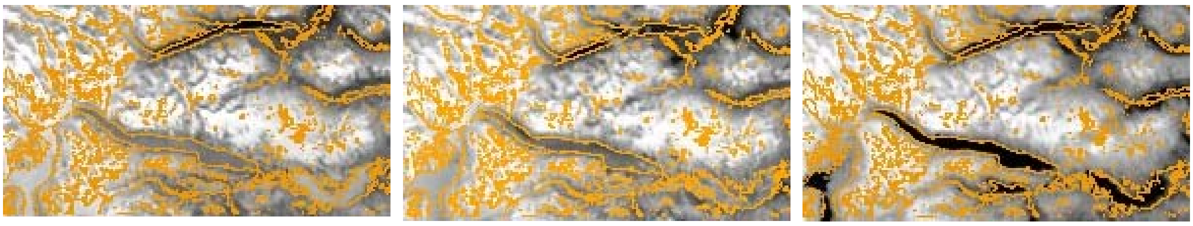

Figure 6.7. A time series of MODIS 250 m pixel size images with an overlaid lake contour map (in yellow). The lake Gjende in the upper part of the images is open in all three images, while the Bygdin lake in the lower part of the images is frozen in the left image, the ice just starts to break up in the middle image and the water is totally open in the right image. The width of the two lakes varies between 0.5 and 1 km

The Norwegian Computing Center has in a recent study found Terra MODIS and ENVISAT MERIS to be suitable sensors for monitoring lakes of a size from a few square kilometres and upward. The approach is based on experience from snow cover monitoring and is able to detect break-up dates quite accurately. Figure 6.7 shows the development of a few lakes in the Norwegian mountain area Jotunheimen during the spring.

6.1.5 Permafrost

Studies of seasonally frozen ground and permafrost areas use satellite remote sensing data to detect surface freeze/thaw conditions. Existing applications typically use optical and thermal wavelengths, and passive and active microwave sensing ranging in spatial resolution from low resolution to very high resolution. Current relevant satellites and sensors include IKONOS, Spot, Landsat, AVHRR, MODIS, SMMR, AMSR-E, ERS-1 and RADARSAT.

High and moderate resolution optical satellites in the visible and NIR spectral range are used to map surface conditions or features typical to permafrost or seasonally frozen ground. The relationship between surface conditions or features and the ground thermal regime needs to be provided. Based on these known relationships significant information can be obtained. Vegetation is one of the most obvious indicators of sub-surface conditions; the NDVI can for example be related to active layer depth in combination with other parameters. Ground subsidence is an indication of the melting of ice rich permafrost.

Studies show that there is good agreement between near-surface ground temperature curves and the land surface temperatures obtained from AVHRR and MODIS. Satellite land surface temperatures could potentially be used to drive the numerical models to simulate the development of the active layer, but further calibration and validation are definitely needed.

SAR images might provide information on the timing, duration and regional progression of the near-surface soil freeze/thaw status with a high spatial resolution. However, repeat times of existing satellites are relatively long compared to the rate of change. One of the most recent initiatives is the proposed NASA Cold Land Processes Mission (Cline et al., 1999). Several options are suggested in terms of measurement requirements, including:

- Active microwave backscattering measurements at two frequencies (dual-polarization, L-band and X-band) using unfocused SAR
- Active microwave backscattering measurements at one frequency (single or dual polarization, L-band or S-band) using unfocused SAR
- High frequency passive microwave radiometer with two frequencies (dual polarization 19 and 37 GHz)

The main application of passive microwave data is to infer soil freeze/thaw conditions. This application is derived from the fact that the thermal microwave radiation depends on its physical temperature, composition and physical structure. An algorithm has been developed to investigate the timing, duration and number of days and aerial extent of the near-surface soil freeze/thaw status (Zhang et al. 2004). AMSR-E has lower frequency channels and higher resolution, which may be superior for detecting soil freeze/thaw cycles.

Soil freeze-thaw monitoring by passive microwave sensors seems to be the best option for climate monitoring of permafrost. It can be based on current experience with passive microwave monitoring as well as snow cover monitoring in the consortium. Snow is one of the most important factors that affects the distribution and evolution of permafrost. The snow cover and snow depth need to be taken directly into account when retrieving permafrost. Secondary factors are vegetation and soil type.

6.2 Some related technological development

The Cryospheric Climate Monitoring Service should build its infrastructure on results from past projects. It should also stick to solutions that are open for bringing in new results from ongoing projects as well as sticking to open solutions and standards that will make it possible to upgrade the infrastructure incrementally in the future as new technology and new conceptual solutions become available. Utilising the European technology base is very important as Europe has invested a lot in GMES-relevant technology development, and some of it would be a very good starting platform for this service – and certainly the best use of resources in general.

The aim is to integrate best solutions from a number of projects into the infrastructure solution to be applied here. This requires that the projects have applied open solutions and standards that enable integration of sub-components into the infrastructure for the Cryospheric Climate Monitoring Service. The next section indicates the broad technology base available. A non-exhaustive list of relevant projects and technical solutions follows in the section after the next.

6.2.1 Relevant EC and ESA programs in general

The European Commission and the European Space Agency have funded many projects with results relevant and important for the development (in particular integration) of infrastructure for a climate monitoring service. Several of the project partners have been or are present in several of these projects. It would go too far to try describing all of them here. A few selected and very relevant projects are briefly described in the next section. Here, we will rather refer to some of the most relevant programs and activities going on and that we propose that the developers of infrastructure to this service keep an eye on and, for the most relevant projects, establish (or continue) a close dialogue.

EC Framework Programmes:

- **Information Society Technology (IST):** The programme (http://www.cordis.lu/fp6/ist.htm) has a special area for risk management, and within this there is a section for development and demonstration of GMES-relevant technology. Additionally, IST has in at least the two previous framework programmes carried out several relevant projects (in particular within the previous programme on ICT for the environment). Strategic documents on IST's future role in monitoring of the environment can be found at http://www.prisma-eu.net/accesspages/environ.htm
- **Aeronautics and Space**: The programme (http://www.cordis.lu/fp6/aerospace.htm) has a specific area for GMES. There are several large integrated projects there as well as some smaller projects (STREPs). The main focus of the programme is integration and demonstration of services, not so much development of new methods and technology. However, the programme is an interesting arena for evaluation and selection of new technologies
- **Sustainable Development, Global Change and Ecosystems**: The programme (http://www.cordis.lu/fp6/sustdev.htm) has a lot of projects oriented towards global change monitoring, but is not primarily oriented towards technology development. This programme, too, has an activity oriented towards GMES (observation systems) where integration and demonstration is one of the major aims

ESA programmes:

- **Research and Technology Development (RTD):** The RTD group defines and implements the RTD strategy and plan, aimed at studying and evaluating up-to-date tools and techniques for the operation of the EO ground segment infrastructures and facilities, which provide EO data and related information services, and at stimulating and supporting innovative applications and novel means of data utilisation, with the final goal of maximizing availability and use of the data sensed by instruments on board of Earth Observation satellites (http://earth.esa.int/rtd/Projects/)
- **Earth Observation Market Development (EOMD):** The EOMD programme provides financial support to industry for well-identified business opportunities for validated EO-based geo-information services. With the support of the EOMD programme, leading value-adding companies are working with well-established market owners and their clients, to develop a stronger market for EO data and information services (http://www.eomd.esa.int/contracts/contract_contract.asp)
- **Data User Element (DUP):** DUE is a programmatic component of the Earth Observation Envelope Programme (EOEP), an optional programme of the European Space Agency, currently subscribed by 14 ESA Member States. The DUE mission is to favour the establishment of a long-term relationship between the user communities and Earth Observation. It is a continuation on a larger scale of the Data User Programme (DUP) (http://dup.esrin.esa.it/projectsintro.asp)
- **General Studies Programme (GSP):** The General Studies Programme (GSP) interfaces in different ways with all of ESA's programmes, but its main role is to act as a "think tank", laying the groundwork for the agency's future activities (http://www.esa.int/SPECIALS/GSP/index.html)

There are also two important standardisation initiatives that should be taken into account when integrating and developing technology for this service:

- **Infrastructure for Spatial Information in Europe (INSPIRE):** In collaboration and consultation with the INSPIRE Expert Group and the European Environmental Agency, the services Eurostat, Joint Research Centre and the Directorate-General for the Environment of the European Commission have developed a work programme of preparatory actions to support the future implementation of an EC proposal for a Directive aimed at establishing an Infrastructure for Spatial Information in Europe, INSPIRE (http://www.ec-gis.org/inspire/home.html). The aim of the work programme is to draft Implementing Rules on implementation issues as called for in the proposal for an INSPIRE Directive. To this end, the Preparatory Phase (2005-2006) work programme summarises the requirements of the proposal for an INSPIRE Directive. It presents the process by which the European Commission will proceed in developing the Implementing Rules through the participation of stakeholders in the drafting and review activities. Environmental policy and stakeholder requirements will be addressed and various groups of stakeholder experts will be called on to assist the Commission services in charge of co-ordination and consolidation. Terms of reference have been included for those various groups.

- **Open Geospatial Consortium, Inc. (OGC):** OGC is a non-profit, international, voluntary consensus standards organization that is leading the development of standards for geospatial and location-based services (http://www.opengeospatial.org/). Through the member-driven consensus programs, OGC works with government, private industry, and academia to create open and extensible software application programming interfaces for geographic information systems (GIS) and other mainstream technologies.

6.2.2 EuroClim

The EuroClim project (2001-2005) was funded by the EC Information Society Technology (IST) programme (see http://euroclim.nr.no). The main goal of the project was to develop an advanced climate monitoring and prediction system for Europe. The project had three main focuses:

1. To develop a web service for providing climate information
2. To develop a satellite-data oriented system producing a portfolio of observation products to be provided through the web service
3. To improve a climate model on cryospheric modelling and to utilise satellite observations for validation of the model. The climate model produces a portfolio of climate projection products to be provided through the portal as well

The web-service was released in the summer of 2005 (www.euroclim.net).

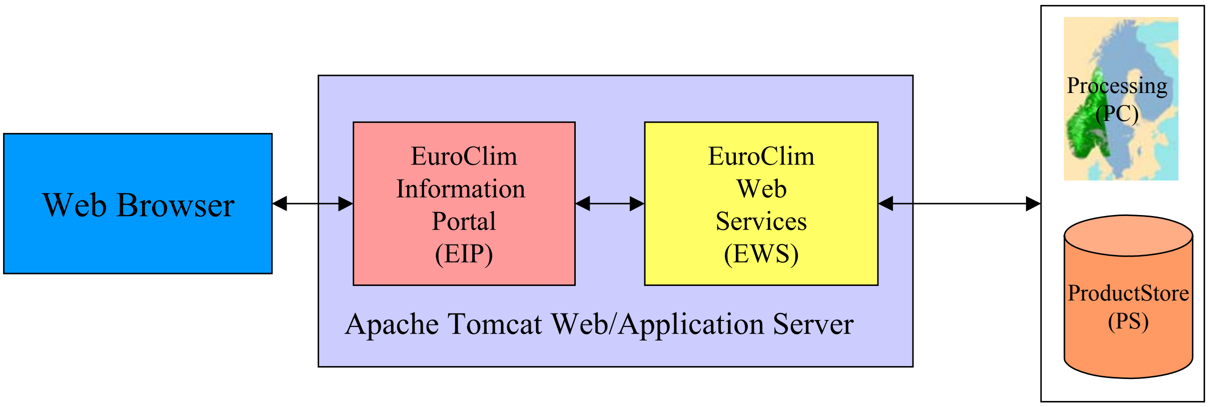

Figure 6.8. Overall EuroClim prototype system components

The EuroClim application is built using the Java 2 Enterprise Edition Framework (J2EE), a framework for development of distributed systems. The EuroClim Information Portal provides the link between the user and EuroClim's distributed functionality and data. The Information Portal graphical user interface is implemented through a series of web pages. The Information Portal communicates with EuroClim Web Services to respond to the user actions. The Web Services is a web service running on, possibly, any machine in the EuroClim network. The Web Services receives request from the Information Portal, processes it, and returns a response. The communication of web service request/response consists in sending XML documents over HTTP channels.

In EuroClim, the Web Services provides a known set of interface methods that are called by the Information Portal to set and retrieve the necessary information. EuroClim Web Services is the gateway between the EuroClim Information Portal client and Product Store, and between the Information Portal and EuroClim Interactive Processing, where the processing of the products is executed. The main function of the EuroClim Web Services is to generate an XML request that Product Store or Interactive Processing can understand.

The purpose of the Product Store is to give the other EuroClim components access to products stored in any database in the system. The Cryospheric Product Production Framework interfaces the Product Store to populate and update the EuroClim databases. The framework handles automatic processing of the remote sensing and in situ datasets for the extraction of cryospheric variables and generation of the actual observational products. A simple controller controls the product generation, where one dataset is processed at the time, running the process through the necessary steps. A Climate Model Postprocessor transfers the climate model output data from its original structure to EuroClim raster products.

In addition to the mentioned web pages, a good entry point for learning more about the results of the EuroClim project is the project's final report (Solberg, 2005b).

6.2.3 DISMAR

The overall objective of DISMAR is to develop an advanced (intelligent) information system for monitoring and forecasting marine environment for the improved management of pollution crises in the coastal and ocean regions of Europe, in support of public administrations and emergency services responsible for prevention, mitigation and recovery of crises such as oil spill pollution and harmful algal blooms (HAB) (see http://www.nersc.no/Projects/dismar/). DISMAR will provide a single entry point, via a web portal, to several services delivering satellite data and other observations as well as model results conforming to international standards for both metadata and data.

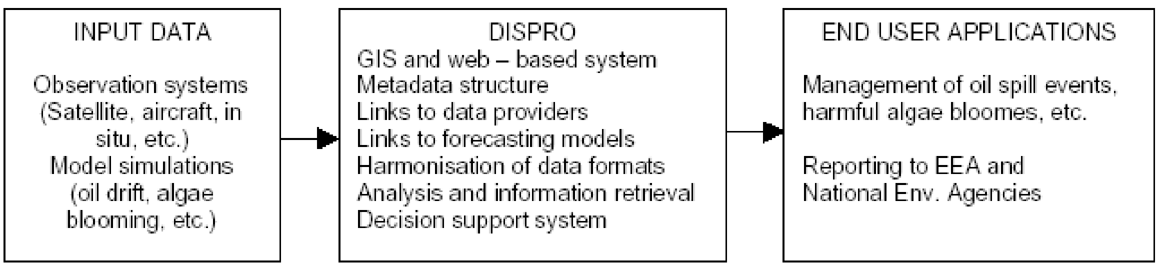

Figure 6.9. The DISPRO service chain

A prototype decision support system (DISPRO) is being developed, for integration and distribution of multi-source data and results from numerical models. The DISPRO architecture is consistent with INSPIRE's general model of an SDI (Spatial Data Infrastructure). DISPRO is a multi-tier system with four main groups of components: user applications, geo-processing and catalogue services, catalogues and content repositories. Implementation is based on INSPIRE, OpenGIS and W3C standards, using Open Source software where available. Metadata plays a central role in DISPRO. All data products and services are described in an accompanying metadata file. The latter is a profile of the ISO 19115 geographic metadata standard restricted mainly to the core 'discovery' metadata elements. Metadata are provided in XML format, validated against an XML Schema. The metadata are stored in a native XML database and transformed to HTML for presentation using XSLT stylesheets.

The DISPRO system will be demonstrated in six coastal zone and ocean areas in Europe where Web Map servers are installed: (1) North Sea/Skagerrak area, (2) German coast, (3) coast of Italy, (4) coast of France, (5) coast of UK and (6) South-West Ireland. Users will get online access to a number of earth observation in situ and model data and products. Satellite ocean colour data and SAR images will be used in combination with FerryBox data, oil drift model and ecosystem models to show how algae blooms and oil spills can be monitored and forecasted. Aircraft observations using infrared and ultraviolet sensors and coastal radar will be used to observe water quality parameters on local scale. Users in each of the demonstration areas will be involved in testing and evaluation of the distributed system.

6.2.4 GlobICE

Sea ice plays a key role in the polar and global climate system. Hence information on sea ice will improve our understanding of the role of the Arctic in the global climate. The topics of GlobICE are restricted to sea ice motion, deformation and flux based on the analysis of ESA's SAR archive with 13 years of ERS-1, ERS-2 and ENVISAT data. The main purpose of the project is to define, implement and validate a sea ice information system to support the CliC project and the broader scientific community of climate change with validated products. The project will run for three years starting now. Project partners are UCL/MSSL (prime), KSPT, JPL, UK Hadley Centre, AWI, IFREMER, PSC and Planetary Visions Ltd.

In addition to the mentioned objectives the project will provide quantitative calibration and validation of the products through comparison with both in-situ and independent EO data sets. Further, the project will ensure use of the data by a number of core users, each with interests in different aspects for the data. The users will report on the usefulness of their data and provide quantitative estimates of the improvements in model performance achieved. Finally, promotion and dissemination of the data generated will be achieved through the project web site, through two user meetings and by the production of a promotional CD-ROM.

The product archive will be a database that will contain a lot of intermediate data files from the sea ice products processing, in addition to the level 1B SAR images (in native and/or geo-located, rectified and map-projected format), and other data such as ancillary, in-situ, models, historical and EO data. The archive will be accessed through a Live Access Server (LAS), which will be developed by KSPT through this project. Flexible access to the product archive shall be provided via the LAS. The LAS is responsible for handling request from interactive users and software processes. Requests can:

- Visualize data with on-the-fly graphics
- Request custom subsets of variables
- Access background reference material about the data
- Compare variables from distributed locations

The "Web Application Server" is a J2EE application framework handling HTTP requests. Internally there are Java APIs and clients connect using HTTP. For database access the "Web application Server" uses JDBC. The HTTP server is a server accepting HTTP requests. In addition it must support CGI-BIN. The "Ad-hoc Processing" is a CGI-BIN processing EO data. Processing includes:

- Generate quick-look images on-the-fly to support browsing and visualize data
- Generate custom subsets of variables
- Compare variables from distributed locations

The "Ad-hoc Processing" received commands in XML format from the "Web Application Server" via the "HTTP Server". The command contains URLs where the EO data can be downloaded. The EO data is normally locally stored. The result of the processing is stored in a downloadable area and an XML document, containing the URL where the processing output can be downloaded, is generated.

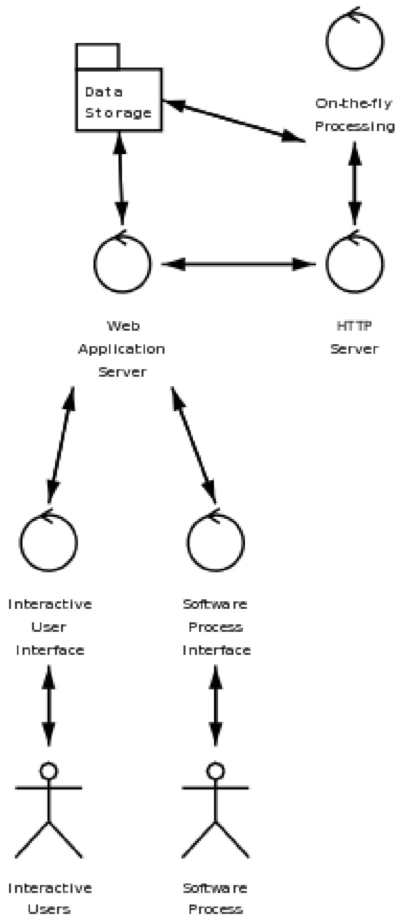

Figure 6.10. Live Access Server decomposed. Note that "Historical Database" is part of "Data Storage"

6.2.5 SSE and MASS

SSE is ESA's initiative for a generic ground segment approach. This includes easy catalogue access and EO and GIS service workflows. SSE is based on SOAP (see http://earth.esa.int/rtd/Events/EC_ESA_WS_2004/Marchetti.ppt).

MASS (Multi-Application Support Service) (http://mail.spacebel.com:8080) is a project that implemented SSE. The project provides a demonstrator of an e-business architecture for the integration of end-to-end services in the Earth Observation (EO) segment.

Product storage (put, find and get) and on-line processing can easily be translated to SSE services, because they already send and receive XML over HTTP. The processing module is an HTTP interface to a HDF5 processing unit. The processing unit can:

- Convert raster to JPEG and in the same operation do subset
- Subtract on raster from another, convert to JPEG and in the same operation do subset
- Compute average from several rasters, convert to JPEG and in the same operation do subset

If the climate monitoring service goes for using EuroClim's product storage and processing subsystems both of them, as they are to day, offer an HTTP interface where XML is sent as requests and responses. To make them SSE compliant, the following steps have to be accomplished:

- Input and output have to be adjusted to the SSE/MASS ICD, and XML Schema Definitions (XSD) has to be defined. KSPT has experience from this in the MASS project, where SAR processing in form of Oil Spill Detection and Ship Detection was adjusted to the MASS Toolbox and MASS ICD
- When XSDs are defined, WSDLs have to be generated. XMLSpy does this
- The infrastructure behind the MASS Toolbox has to be developed. This is relatively easy because they are already available as HTTP services. The infrastructure for SAR processing can be reused from the MASS project, but with some modifications.
- Stylesheets (XSL) has to be defined for the web portal

6.2.6 ACE-GIS

ACE-GIS (http://www.acegis.net) intersects the fields of geographic information and e-commerce technology. ACE-GIS provides better and more efficient tools for the development, deployment and composition of distributed web services with special emphasis on geographical information and e-commerce services. The tools developed in ACE-GIS are intended to simplify the process of integrating existing services into a service chain or software composition.

The necessary steps to integrate the climate monitoring service into ACE-GIS will not be much different than as described for SSE. ACE-GIS is basically a way to register and describe web services in repositories (UDDI, ebXML). ACE-GIS is different in the service creation environment, which seems to have the potential to be much more automated than in SSE.

7 General user requirements

The main characteristics of the needs of the user community have, to a large degree, been determined by previous projects. These general requirements are presented below, including a list of the most relevant cryospheric geophysical variables to monitor. However, we start by outlining the approach that should be used to determine the precise and detailed user requirements for this service.

7.1 Service specification approach

A close dialogue with the users should determine which products should be produced and in precise detail the specification of each of them. This is foreseen taking place in an iterative manner. First, the current understanding of the user needs will be used to draft the products and the service in general. The users will then act upon this draft, which results in a refinement of the specification (iteration 1). The users will then receive sample products through a draft service based on the refined specification and try them out in real applications in their organisation. All practical experience tells that these first trials will result in slightly modified requirements. These are then implemented by the project (iteration 2). The process will then go on in the same manner until it converges. For moderately complex products and services, convergence will usually be reached after 3-4 iterations.

7.2 Most relevant geophysical variables

The climate monitoring service will focus on the geophysical part of the cryosphere. The major components are sea ice, seasonal snow, glaciers and ice sheets, lake and river ice, and permafrost. A series of geophysical variables can be observed and is of interest to retrieve from these components. Table 7.1 indicates the most frequently mentioned geophysical variables. Note also that from these a large set of climate change indicator variables can be retrieved. Some relevant indicator variables are listed in Table 7.2.

Table 7.1. Some relevant cryospheric geophysical variables to retrieve for climate monitoring

Cryospheric component	**Geophysical variables**
Sea ice	Extent, concentration (ice fraction per area unit), thickness, drift (speed and direction), albedo
Seasonal snow	Extent, coverage (snow fraction per area unit), albedo, depth, water equivalent, surface temperature, wetness
Glaciers and ice sheets	Surface type, mass balance, ice volume
Lake and river ice	Presence of ice, ice thickness
Permafrost	Presence of permafrost, thaw depth

Table 7.2. Some relevant climate change indicator variables

Cryospheric component	**Indicator variables**
Sea ice	Minimum and maximum seasonal extent, number of ice days (per area unit), break-up date (per area unit), refreeze date (per area unit)
Seasonal snow	Number of snow days (per area unit), date of snow-free surface (per area unit), first snowmelt start date (per area unit)
Glaciers and ice sheets	Annual minimum and maximum area of each surface type, first date of surface melt (per area unit), equilibrium line altitude (average or contour map)
Lake and river ice	Break-up date, refreeze date, maximum ice thickness
Permafrost	Surface thaw date, day of surface refreeze, number of thaw days

7.3 General service requirements

The following characteristics are crucial to a climate monitoring service in general:

1. **Long-term monitoring**: In order to be able to measure actual climate change (and not only normal fluctuations in the weather pattern) long time series of observations are necessary. At least a few decades would normally be needed. This means that back-processing existing remote sensing data is extremely valuable. It also means that it is an important duty of today's decision makers to continue existing long time series of remote sensing data and, in addition, establishing measurements of new variables when technology enables.
2. **Consistency over time**: In order to establish long time series of observations, a number of sensors have to be applied over time. Performance varies between sensors of the same type and new generations of sensors are developed. Climate monitoring needs to account for this by inter-sensor calibration as well as compensation for other differences in the sensor characteristics.
3. **Accuracy**: Accuracy is important in order to be able to measure subtle changes of a variable over time. But more important than the absolute accuracy is to have a measure of actual accuracy. By knowing the accuracy at any time, for each observation, it is possible to make trend analyses of the time series and detect a variable's change over time as long as the change is above the level of noise (uncertainty).

A consequence of these requirements is that it is not necessarily straightforward to convert a product aimed for, e.g., a near-real-time and practical-application-oriented product to a climate monitoring product. However, when the data source is not just a short-time experiment (but preferably an operational satellite-sensor system), when the sensor is regularly calibrated and when the accuracy of the variable retrieval algorithm is known – then the product (and the corresponding sensor and algorithm) is a good candidate for development into a climate-monitoring product.

7.4 General product requirements

There are some differences in the requirements for climate products between the five user groups listed in Chapter 4. The scientific users typically need very detailed products allowing further computation for their applications. A climate modeller, e.g., would need a map of a geophysical variable he is modelling in order to be able to use the products for model validation. The other user groups – information providers, decision makers, the public and industry and public administration – typically need higher-level products easily showing and quantifying climate change. We will use here the term 'climate indicator product' for those higher-level products. Some examples are shown in Table 7.2. Indicators are normally selected based on criteria like relevance to people and the environment, reliable and long-term measurements and clear relationship to the force of change in question (CCME 2003). Trend analysis of variables from such products might easily document local, regional and global climatic changes.

Note that climate change indicators are valuable to the research community as well. By combining an expert selection of variables – maybe from different major components like the ocean, land and the atmosphere – it might be possible to measure, e.g., changes in the interaction between these major components. Such climate indices will be further discussed in Section 10.2.

Some characteristics of climate products are mentioned in the following:

1. **Aggregation over time**: Due to the large natural variability of the weather from day to day, a standard approach is to aggregate observations to cover a given period of time, like a month or a season. Aggregation over time might then also be used to reduce the effects of random errors.
2. **Statistical measures for the aggregation period**: Statistics for the aggregation period are valuable as a measure of variation within the period. Therefore, it is usually recommendable to calculate at least minimum, maximum, standard deviation and maybe also fractiles for each aggregation period.
3. **Accuracy**: A measure of accuracy should be provided with the product. For a map (raster) product, it might be for each area unit (raster element).
4. **Baseline products**: We will here term products of aggregated cryospheric geophysical variable represented in map-like products (e.g., rasters) as a baseline product. As mentioned above, these are typically aimed for scientific applications. Also, the products will be the basis for deriving the indicator products (therefore the term "baseline").
5. **Indicator products**: This term will be used for all products derived from the baseline products. They need to be defined in close collaboration with the user community in order to fulfil the user requirements for each application.
6. **Trends**: Users would often be interested in measuring how a variable or indicator develops over time. The most important (frequently used) trends should be pre-calculated and made available through the web service. It would also be very valuable for the user if a trend-analysing tool could be provided online so the user can select variable, time frame and region of interest for an objective statistical trend analysis. Such a tool was developed in the EuroClim project .

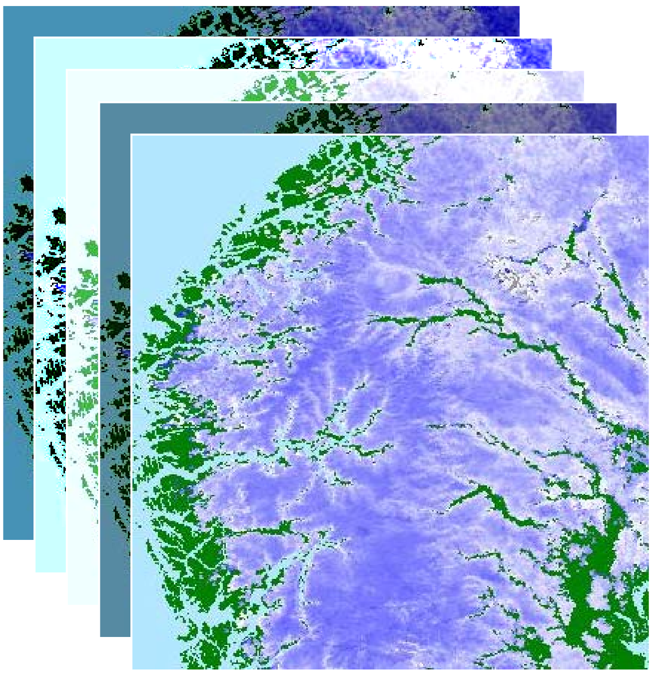

Figure 7.1. Example of a baseline product (showing snow surface temperature) consisting of five raster layers with aggregated information for the given aggregation period: Mean (top layer), minimum, maximum, standard deviation and number of observations

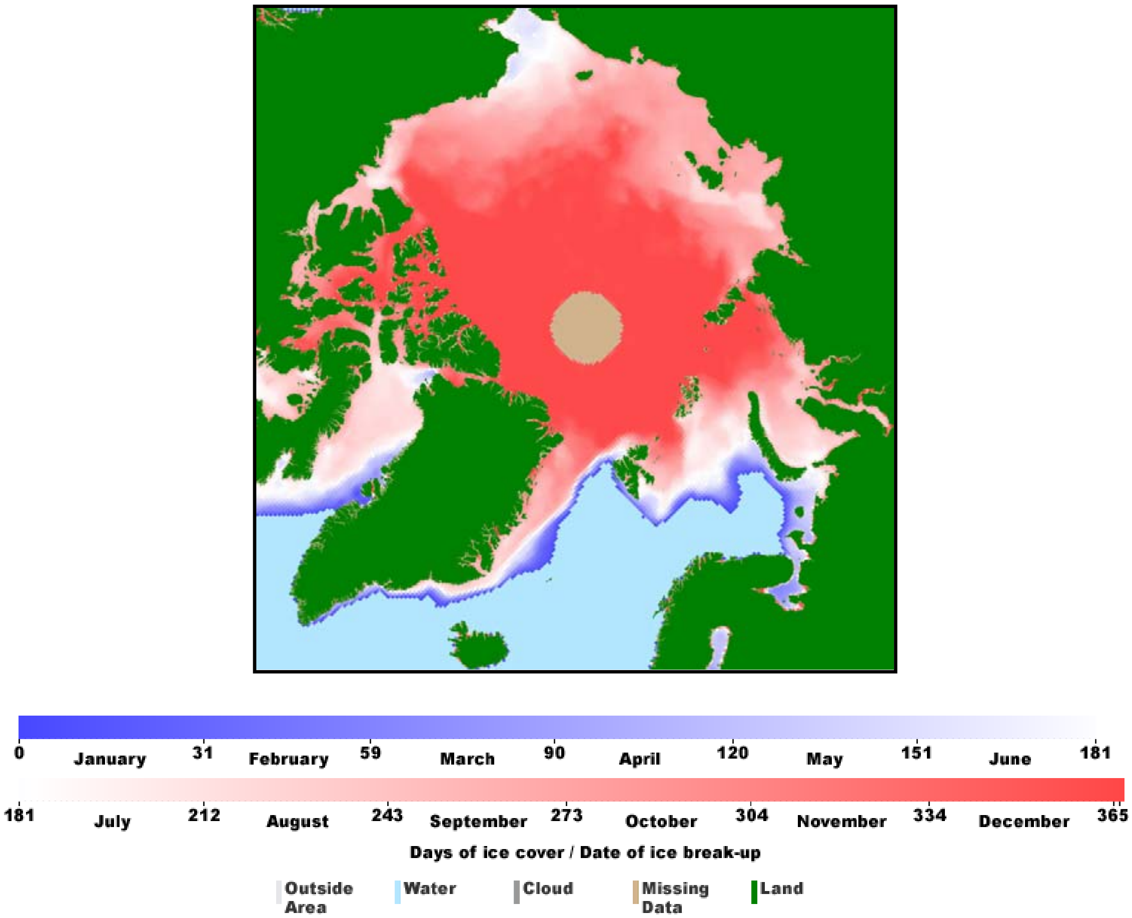

Figure 7.2. Example of a climate change indicator map product. The map shows the number of days with ice cover for 2003 (EuroClim project)

8 Outline of the service proposed

This chapter outlines the service – including operational goals, system infrastructure, implementation and management. It is also explains how the service will be sustainable, and explains how the service answers requirements for service development in GMES.

8.1 Operational goals

There are many issues to take into account when developing a service for cryospheric climate monitoring, as explained in the previous chapters. Some operational goals for the development of such a service are described in the following.

Main goal:
The goal of the climate monitoring service is to provide regular and long-term delivery of products based on observations of essential climate variables in the cryosphere (in particular for the polar regions) and where satellite sensors are the main data source and in situ measurements are included when long-term delivery is feasible.

Sub-goals:
1. **Novelty**: The service should not replicate other services, but include new and novel products and algorithms of importance at a pan-European level.
2. **User groups**: Work together with the main user actors in Europe who need climate monitoring information related to the cryosphere. The service should be developed and maintained in close collaboration with the scientific community to assure the necessary scientific support and quality.
3. **Strategic links**: Collaborate closely with strategic organisations (including intermediaries) in order to establish a service that supports international agreements and the needs of important user groups in general and not only the specific needs of a few key users.
4. **Time series**: Establish long time series of products for essential variables based on both back-processing of existing data and establishing new time series that will be of great value in the future when the series becomes longer.
5. **Climate consistent products**: The algorithms used must retrieve variables with quantities consistent between sensors and with known accuracy enabling reliable trend analysis.
6. **One-stop-shopping service**: Many users need a multitude of variables in order to obtain reliability for analysis of climate changes. To make the service convenient to use, all products should be available through an easy-to-use web service based on a one-stop-shopping concept with functionality for searching, browsing, analysing and downloading products.
7. **Flexible and scalable infrastructure**: The infrastructure connecting sub-services of climate products should be a state-of-the-art flexible and scalable solution in order to easily allow new sub-services to be connected and in order to adapt to other organisational changes that will occur in a living service.
8. **Adaptable to changing user requirements**: The infrastructure and tools used must be such that the service can be easily modified and updated according to changes in user requirements as well as new requirements due to inclusion of new users.
9. **Business model**: Climate change monitoring is typically motivated by governmental decisions, which is also reflected in the funding that follows the decisions. Commercial companies may find business opportunities delivering services to these governmental tasks. However, the majority of the effort is still carried out by governmental institutions strongly supported by the academic sector. Based on these facts, this proposed service

aims to be a no-cost service open to all relevant users. However, we will also aim to deliver tailored products to the industry, like long-term sea ice statistics, that are of interest for, e.g., offshore activities in polar regions.

10. **Contribution to WMO and GEO**: WMO has developed a long-term strategic plan for the development of a global climate monitoring system composed of a series of thematic monitoring systems, the Global Climate Observing system (GCOS) (see WMO, 2004). A similar initiative is taken by GEO, where climate monitoring is only one theme in a large Global Earth Observation System of Systems (GEOSS) (see GEO, 2004). A bold strategic as well as operational goal for this service is to contribute to these systems. The Cryospheric Climate Monitoring Service actually has the potential of being Europe's contribution on cryospheric climate monitoring to these two international initiatives.
11. **Contribute directly to strategic assessment reports**: A few key organisations and groups report regularly to political decision makers at international levels where strategic decisions for climate change mitigation and adaptation are taken. This service should aim at contributing to a few such reports when we have been able to establish and analyse long time series of observations (2-3 decades). The international bodies should include EEA, AMAP and IPCC.

8.2 A staged development plan

It is proposed that the development, demonstration and operationalisation of this service are implemented in a staged manner through the project period:

- **Stage 1**: Integrate already demonstrated products and service infrastructure into a consolidated service for cryospheric climate monitoring.
- **Stage 2**: Expand the service with new products currently under development, expand the geographical coverage for some of the products and improve the service infrastructure.
- **Stage 3**: Final infrastructure improvements aiming for an operational service.

The main focus of Stage 1 is to establish a regional service, i.e. providing products covering the Euro-Arctic region (however, mature global products will also be included at this stage). As the Euro-Arctic area is maybe the most sensitive area to global climate change, it is of utmost importance to establish a portfolio of products at regional scale (e.g., higher spatial resolution than would be needed globally). Stage 1 will also be important for establishing the collaboration with the user groups and precisely determining their needs through tailoring and delivery of the products.

In Stage 2, the main focus will be to expand the service to global coverage. Since the climate in Europe is influenced by changes in other parts of the world, it is necessary for a European service to include this global perspective. Sustainable European global monitoring with independent observations of climate change will also put Europe in a strong position in

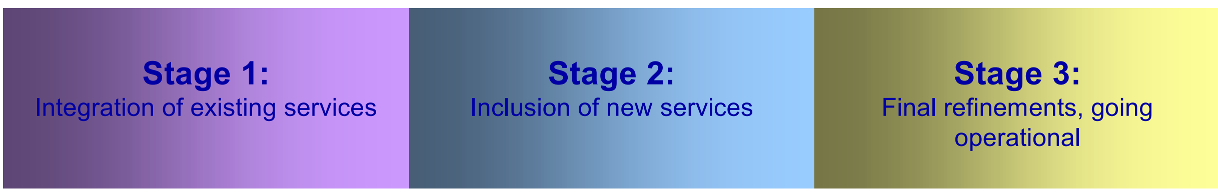

Figure 8.1: The three development stages for the cryospheric climate monitoring service

international discussions and negotiations. Stage 2 will additionally include improvements of the infrastructure and the product portfolio as new R&D results are assimilated into this service.

Stage 3 is the last stage of development before the service goes operational. There might be some more products based on the capabilities of the established infrastructure, and there will be a final batch of improvements based on the experience obtained in the project. Final management steps will also be carried out in order to prepare for an operational service.

The proposed inclusion of the sub-services, described in more detail in Chapter 10, is outlined in Table 8.1. These sub-services have already existing or defined portfolios of baseline products. The indicator products will be developed through a process with the users as described in Chapter 7.

Table 8.1. Overview of the geophysical parameters and geographical coverage for the three stages of development in the cryospheric climate monitoring service

Product group	**Stage 1**	**Stage 2**	**Stage 3**
Sea ice	*Regional*: Sea ice thickness, Fram sea ice flux, sea ice drift for the Arctic *Global*: Sea ice concentration, sea ice drift	*Global*: Sea ice thickness, sea ice indices	Refinements
Seasonal snow	*Regional*: Snow cover, snow temperature and snow wetness for Fennoscandia. Snow water equivalent and snow depth for Eurasia *Global*: None	*Regional*: Snow temperature and snow wetness are expanded to the whole Euro-Arctic region *Global*: Snow cover, snow water equivalent and snow depth	*Global*: Snow cover, snow temperature and snow wetness Refinements
Glaciers and ice sheets	*Regional*: Surface type for Greenland and Svalbard *Global*: None	*Regional*: Mass balance for Greenland and Svalbard, surface type for Antarctica *Global*: Surface type for a selection of key glaciers worldwide	*Global*: Mass balance for selected key glaciers worldwide
Lake and river ice	*Regional*: Break-up and refreeze dates for main lakes and rivers in Fennoscandia *Global*: None	*Global*: Break-up and refreeze dates for selected lakes and rivers	Refinements
Permafrost	*Regional*: Thaw and refreeze dates for Eurasia *Global*: None	*Global*: Thaw and refreeze dates for all regions with permafrost	Refinements

The service infrastructure will be based on the conceptual model outlined in Chapter 5. Figure 8.2 shows the overall concept of the service based on the building blocks outlined there. The sub-service level is shown at the bottom. This level receives remote sensing data from satellites and in situ measurement stations. The sub-services will typically be run by the developing expert organisations (often research institutes) at the beginning of the service provision. The next level is the database level operated by legally mandated organisations (securing sustainability). In the long term, the sub-services will migrate into the database host organisations to obtain sustainability of the whole service. The web server level runs the web portal system and the immediate underlying functionality (like online data analysis). The web server will be operated by the system developers at the beginning, but transferred to a legally mandated organisation (e.g., a database host) when the service goes operational. The client level represents the web-browser applications run by the user community. All sub-systems work together over Internet connections.

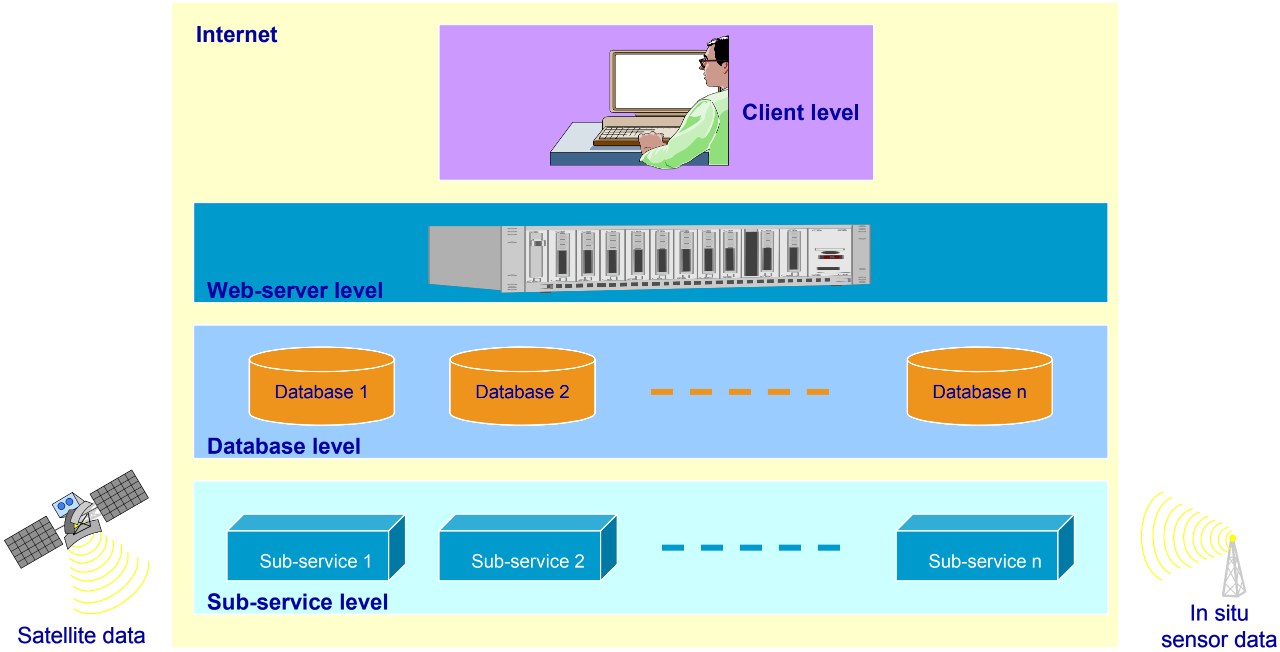

Figure 8.2. Overall conceptual model for the service

The long-term focus of a climate monitoring service is extremely important to serve the user community properly. In addition to securing sustainability by migrating all service infrastructure to legally mandated organisations, it is of utmost importance to be able to rely on long-term data provision from satellites and networks of in situ measurement stations. So far in the era of satellite remote sensing, most satellite systems have been experimental. Satellites like CryoSat may provide data that could have been extremely valuable for climate monitoring. However, short-lived experimental systems will not be able to provide the desperately needed long time series of data. Therefore, this service will aim at the use of operational satellite systems (like NOAA, DSM and NPOESS) and other systems that in practice demonstrate a long-term focus (like C-band SAR from ERS, ENVISAT and Radarsat, and optical data from MODIS). However, in order to obtain real European sustainability in satellite data provision, European satellites will have to be the main source of data in the future. The emerging and very promising Sentinel satellite programme could be the long-term solution to this. However, this requires that the selection of sensors and their characteristics are suitable to cryospheric climate monitoring, and that there is sufficient political support for the satellite system to secure a pipeline of new satellites for substitution of old satellites (i.e., a true operational system like for the NOAA and NPOESS satellites).

8.3 Answering GMES requirements

The following explains how the cryospheric climate monitoring service will meet crucial GMES service requirements:

Demonstrate progress towards long-term sustainability:

- Organisations with already established service infrastructure (staff, computers, etc.) will be given priority when selecting sub-service providers.
- Legally mandated organisations will be given priority. Such mandates are typically related to national needs.
- All database hosts will be legally mandated organisations from the start of the project period.
- Sub-services will migrate toward legally mandated organisations through and after the project period.

Deliver services and benefits to users on progressively larger scales:

- By working with two users groups, *key users* (with Service Level Agreement, SLA) and *other users* (other active users), we are open for bringing in new users with SLAs incrementally. It also allows users to learn about the service, through an active dialogue with the service providers, for a period before committing to an SLA.
- The flexible infrastructure solution will allow for incremental inclusion of new sub-services and new products as user needs grow.
- The sub-services will grow from a more regional focus at the beginning of the project period toward global coverage at the end of the period.

Establish a durable, open, distributed GMES service provision network:

- The use of a flexible and scalable architecture and infrastructure that is open for gradual expansion (e.g., by inclusion of new sub-service providers) without requiring any changes in the existing infrastructure (that would otherwise have been costly).
- The use of open standards for software tools, data exchange protocols and data formats allow easy changes of software components as well as the possibility to link systems together (like WMO's and GEO's "system of systems" concepts). This approach is particularly important for a climate monitoring service which has to be sustainable over decades (with backward and forward compatibility).

Establish standards and working practices for GMES services:

- The service aims to contribute strongly to establishing standards for climate monitoring products (building on initiatives like INSPIRE and co-ordinated with WMO and EUMETSAT). This is of great importance for a climate monitoring service with a long-term perspective.
- The service also aims for strong contributions to best practices of web-services for monitoring purposes (building on, e.g., OGC standards).

9 Consortium behind the service

Historically, Europe has been in the forefront of polar exploration and polar research. The momentum of European polar and cryospheric research is still high, and there is lots of world-leading expertise in Europe and R&D results from numerous projects to draw on.

It has been possible to establish a world-class consortium of service providers and developers behind this service. They are briefly described in the following sections. More details about the project partners can be found in Chapter 11.

The team behind development and provision of the Cryospheric Climate Monitoring Service is composed of strong and relevant R&D institutes, companies and legally mandated organisations in Europe. The group brings in experience, algorithms, methodology, technology and prototype systems from dozens of relevant projects that have been carried out in the last couple of decades. The climate monitoring service proposed would have been far from feasible if it had not been for this heritage – the best possible starting point for the integration and tailoring of necessary components into what will be an operational and sustainable service established during a period of three years.

Table 9.1 lists the project partners behind the service and their main role(s) within it. More details about their actual technical contributions are provided in Chapter 10.

Table 9.1. The partners behind the Cryospheric Climate Monitoring Service and their overall roles in the service development and provision

Partner	Short name	Role in service		
		Sub-service provider	Database host	Infrastructure development
Finnish Meteorological Institute	FMI	X	X	
French Research Institute for Exploitation of the Sea	IFREMER	X		
Geological Survey of Denmark and Greenland	GEUS	X	X	
Helsinki University of Technology	HUT	X		
Kongsberg Spacetec	KSPT			X
Nansen Environmental and Remote Sensing Center	NERSC	X		
NORUT Information Technology	NORUT			X
Norwegian Computing Center	NR	X		X
Norwegian Meteorological Institute	MET.NO	X	X	
Norwegian Polar Institute	NPI	X	X	
Scottish Association for Marine Science	SAMS	X		
UNEP/GRID-Arendal	GRID-A			X*
University of Bristol	BGC-UB	X		
University of Cambridge	UCAM-DAMTP	X		
Vexcel UK	VEXCEL			X

**) Liaison between sub-services and users for user requirement specification and indicator product development*

10 Technical description of the service

This chapter provides a full description of the main elements of the service proposed as well as the activity for indicator product development. The process for system infrastructure development – integration of available technology and prototype systems, refinements and options for general improvements of infrastructure's functionality – is also described here.

The chapter follows with an introduction to the technical overview of the contents of the service and the infrastructure architecture. Table 10.1 provides overall information about the baseline products proposed. There is a production chain behind each of these baseline products. In some cases a production chain depends on the output of another chain (or a semi-finished product). This must be taken into consideration when developing and phasing into the service the various production chains.

Table 10.1. Overview of the baseline products, their characteristics, providers and project phase when products will be available. For the project phase column, the number refers to the project phase and the letters refers to geographical coverage (R=regional, Ar=Arctic region, G=global). Indicator products will be derived from one or a combination of baseline products

Product group	Baseline products	Provider	Spatial resolution	Sensors	Project phase
Sea Ice	Sea Ice Concentration	MET.NO	10 km	SSM/I (alt. AMSR-E)	1
	Sea Ice Drift	IFREMER	62.5 km	SeaWinds or QuickSCAT + SSM/I	1
	Sea Ice Drift	IFREMER	31.12 km	SeaWinds or QuickSCAT + AMSR-E	1
	Sea Ice Thickness	SAMS/ DAMTP	6.25 km	AMSR-E	1/R, 2/G
	Fram Strait Sea Ice Flux	NERSC	N/A	ASAR (alt. Radarsat) + AMSR-E	1
Seasonal snow	Regional Snow Cover	MET.NO	1 km	AVHRR + synop (in situ)	1
	Snow Temperature	NR	1 km	MODIS (alt. AATSR)	1/R, 2/Ar, 3/G
	Snow Wetness	NR	1 km	MODIS (alt. MERIS/AATSR)	1/R, 2/Ar, 3/G
	Snow Depth	HUT/FMI	25 km	AMSR-E	1/R, 2/G
	Snow Water Equivalent	HUT/FMI	25 km	AMSR-E	1/R, 2/G
	Global Snow Cover	MET.NO/ NR	10 km	SSM/I (alt. AMSR-E) + AVHRR (alt. MODIS)	2
Glaciers and ice sheets	Greenland Glacier Surface Type	GEUS	1 km	MODIS + AMS (in situ)	1
	Greenland Mass Balance	BGC-UB	1 km	AVHRR (alt. AATSR or MODIS)	2
	Svalbard Glacier Surface Type	NPI	20 m	ASAR (alt. Radarsat)	1
	Svalbard Glacier Balance Area	NPI	20 m	ASAR (alt. Radarsat)	2
Lake and river ice	Waterbody Surface State	NR	500 m	MODIS (alt. MERIS/AATSR)	1/R, 2/G
Permafrost	Soil Surface Frost	MET.NO/ NR	25 km	SSM/I (alt. AMSR-E) + global snow cover product	1/R, 2/G

Figure 10.1 shows the service infrastructure architecture based on the building blocks defined in Chapter 5. For each product group, the corresponding set of production chains are linked to a corresponding database. The databases are hosted by legally mandated organisations. Some, but not all, production chains are hosted by legally mandated organisations. The host depends on who has the best expertise on the corresponding algorithms, and in a relative new discipline like climate monitoring the majority of such expertise is still in academic organisations. However, the long-term plan for the service is that all production chains should migrate into legally mandate organisations (probably, in practice, the database host organisations).

Production chains for indicator products will be produced by add-on modules to the production chains for baseline products. An indicator product will usually be based on one or a combination of two or a few baseline products. In the case of baseline products from different sub-service providers being applied in the production of an indicator product, baseline products will be retrieved from the database (the databases are the interfaces between the sub-services).

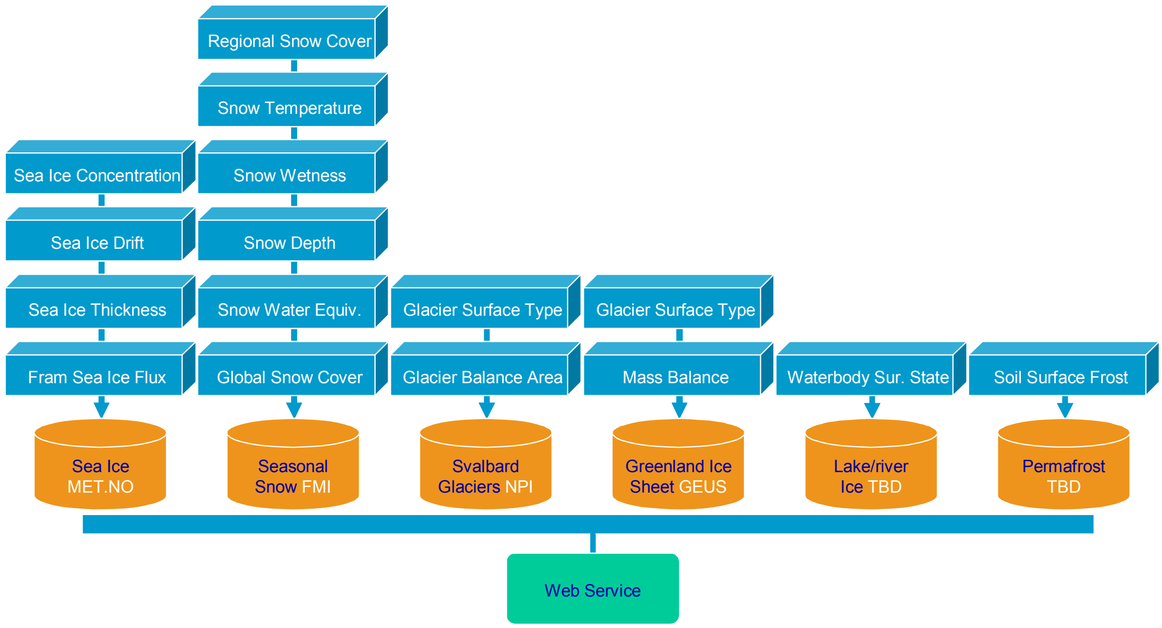

Figure 10.1. The service infrastructure architecture showing the proposed baseline production chains and the databases with their respective host organisations

The Cryospheric Climate Monitoring Service has the potential to make significant contributions in the near future to political high-level decisions on climate change mitigation and adaptation. This will depend on the service's capability of delivering trend analysis of historical time series of remote sensing data (20-30 years of data). Table 10.2 gives an overview of this potential for each baseline product. As the table shows, many products have potential for back-processing of historical data. It is mainly a funding question whether this potential will result in real contributions.

Table 10.2. Overview of the potential for processing long time series based on historical remote sensing data for the baseline products. Long time series will allow further analysis, in particular for trends. Reliable trend calculations will be provided to, e.g., EEA, AMAP and IPCC

Product group	Baseline products	Sensors for current products	Potential sensors for back-processing	Start year for historical time series
Sea Ice	Sea Ice Concentration	SSM/I (alt. AMSR-E)	SSM/I	1972
	Sea Ice Drift	SeaWinds + SSM/I	SSM/I	1987
	Sea Ice Thickness	AMSR-E	SMMR, SSM/I	1978
	Fram Strait Sea Ice Flux	ASAR (alt. Radarsat) + AMSR-E	ERS + SSM/I	1991
Seasonal snow	Regional Snow Cover	AVHRR + synop (in situ)	AVHRR	1978
	Snow Temperature	MODIS (alt. ATSR)	AVHRR	1978
	Snow Wetness	MODIS (alt. MERIS/AATSR)	AVHRR	1978
	Snow Depth	AMSR-E	SSM/I	1987
	Snow Water Equivalent	AMSR-E	SSM/I	2002
	Global Snow Cover	SSM/I (alt. AMSR-E) + AVHRR (alt. MODIS)	SSM/I + AVHRR	1987
Glaciers and ice sheets	Greenland Glacier Surface Type	MODIS + AMS (in situ)	AVHRR	1978
	Greenland Mass Balance	AVHRR (alt. AATSR or MODIS)	AVHRR	1978
	Svalbard Glacier Surface Type	ASAR (alt. Radarsat)	ERS	1991
	Svalbard Glacier Balance Area	ASAR (alt. Radarsat)	ERS	1991
Lake and river ice	Waterbody Surface State	MODIS (alt. MERIS/AATSR)	AVHRR	1978
Permafrost	Soil Surface Frost	SSM/I (alt. AMSR-E) + global snow cover product	SSM/I + AVHRR	1987

As explained in previous chapters, the rather comprehensive portfolio of sub-services in the Cryospheric Climate Monitoring Service would not have been possible if it was not for the many past and current projects that have developed and validated the algorithms applied here. Table 10.3 gives an overview of past and current projects the sub-services rely directly on.

Table 10.3. Overview of past and current projects the sub-services in the Cryospheric Climate Monitoring Service rely on

Product group	**Sub-service**	**Past and current related projects**
Sea Ice	Sea Ice Concentration	EUMETSAT OSI SAF
	Sea Ice Drift	ICEMON
	Sea Ice Thickness	EuroClim
	Fram Strait Sea Ice Flux	ICEMON
Seasonal snow	Regional Snow Cover	EuroClim, EnviSnow
	Snow Temperature	EuroClim, EnviSnow
	Snow Wetness	EuroClim, EnviSnow
	Snow Depth	EUMETSAT H-SAF
	Snow Water Equivalent	EUMETSAT H-SAF
	Global Snow Cover	EuroClim, SnowTools
Glaciers and ice sheets	Greenland Glacier Surface Type	EuroClim, DK Icemon
	Greenland Mass Balance	*
	Svalbard Glacier Surface Type	EuroClim
	Svalbard Glacier Balance Area	EuroClim
Lake and river ice	Waterbody Surface State	EuroClim, SnowMan
Permafrost	Soil Surface Frost	EuroClim

*) The project “Mass balance and freshwater contribution of the Greenland ice sheet: a combined modelling and observational approach”

10.1 Sub-services providing cryospheric climate products

This section describes in detail all sub-services proposed to be included in the initial version of the cryospheric climate monitoring service. A sub-service is typically a production chain for climate products generating one product or a group of related products. During the course development the sub-services will be extended for production of climate change indicator products.

10.1.1 Sea ice

10.1.1.1 Sea ice concentration

10.1.1.1.1 Sub-service Description

Products
Global aggregated sea ice products: Sea Ice Concentration (SIC) and Sea Ice Edge (SIE). One product will be set up to cover the Northern Hemisphere and one for the Southern Hemisphere. Monthly, seasonal and annual products will be produced.

Algorithms
The service will be based on the daily sea ice products from the EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF). The aggregation will be done by averaging over the respective periods for the monthly, seasonal and annual products. The OSI SAF sea ice products are derived for daily monitoring and input to operational models. There is however a need for climate consistent products utilising delayed mode quality control of the data taking into account the latest upgrades of the systems. To produce a climatic consistent time series a consistent source of NWP model data must be applied. Attention will be put on assessing the differences in response between different individual satellites.

Team behind
Implementation will be done by the OSI SAF team at MET.NO. The team is responsible for the developments for the OSI SAF Sea Ice processing run at MET.NO under a contract with EUMETSAT. The team is also a part of the EuroClim project and have been developing the production chain for climatological processing of sea ice in EuroClim. The service will be implemented and integrated into the operational data processing and service system at MET.NO. The operational department at MET.NO will be responsible for running the service.

Infrastructure for production
The current operational software used for the OSI SAF Sea Ice processing running at MET.NO for EUMETSAT will be adapted for the aggregation and used for climate product production. This infrastructure is more than capable of performing such a service within its fully operational constraints.

Sub-service validation
The daily products from the OSI SAF are routinely validated by operational ice services at MET.NO and at the Danish Meteorological Institute (DMI). This validation shows high quality during the autumn, winter and spring periods, while the microwave sensors have some problems during summer seasons because of melting ponds on the sea ice. The OSI SAF team is working on this problem and the sea ice climate sub-service will benefit from

this work. Validation documents can be found at http://saf.met.no/ under "Scientific and technical documents".

10.1.1.1.2 Sub-service contribution to GMES development

The aim of the sub-service is to provide a consistent set of sea ice data for long term climate monitoring. Within the GMES framework it is important to ensure maximum synergy between European funded efforts on global monitoring. It is also of great importance to ensure operational sustainability beyond the development and implementation phase. The proposed co-ordination with EUMETSAT OSI SAF is an adequate answer to these requirements.

10.1.1.1.3 Links to other projects

This service will benefit from the development in the EUMETSAT OSI SAF project and the reprocessing of SSM/I data back to 1987 that OSI SAF will be doing during 2005 and first half of 2006.

10.1.1.1.4 Potential for production of historical time series

Through the collaboration with the EUMETSAT OSI SAF project data back to 1987 will be available, hence a time series of products of 20 years.

10.1.1.1.5 Sub-service targets

The performance targets will be: The monthly, seasonal and annual products will be updated regularly by end of each month, season and year, and *within 1 day* after the end of the aggregation period**.** The jobs will be automatically trigged as a part of MET.NO's operational system. The accuracy will be as stated in the OSI SAF product manual (http://saf.met.no/ under "Scientific and technical documents"), 10% for SIC and 10 km for SIE.

10.1.1.1.6 Sub-service evolution

The service will take advantage of the OSI SAF activity on reprocessing of Sea Ice products back to 1987, which will be performed within April 2006.

10.1.1.2 Sea ice drift

10.1.1.2.1 Sub-service description

Products

A global aggregated sea ice drift product at 62.5 km × 62.5 km grid resolution will be provided for the Arctic. A preliminary Antarctic drift product is under evaluation and planned to be provided later in the project. Monthly and seasonal products will be produced.

Algorithms

IFREMER provides medium resolution products generated from SeaWinds/QuikSCAT scatterometer data and SSM/I passive microwave radiometer data. The intermediate ice drift maps derived from backscatter data and brightness temperature data are produced by IFREMER. These intermediate drift maps are in turn used to produce a merged drift product, which is the best available daily sea ice drift field. A typical winter period for ice motion estimates starts on October 1st and ends on April 30th, the following year. The next scatterometer (ASCAT) should be flown by ESA/EUMETSAT; the launch is presently

planned for 2006. The grid of the drift product is a rectangular subset of the 12.5 km × 12.5 km "high resolution" polar stereographic projection used by NSIDC. The ice drift algorithm relies on: (1) The estimation of the field of Laplacian of either a combination of the SeaWinds VV and HH polarised backscatter maps or the SSM/I 85 GHz HH and VV polarised brightness temperature maps; (2) A pattern matching procedure based on maximum correlation between three-day or six-day lagged maps; and (3) A drift validation step based on the time averaged ECMWF wind field and local statistics on ice motion. Full information on the data processing and products are available at:
ftp://ftp.ifremer.fr/ifremer/cersat/products/gridded/psi-drift/documentation/.

Team behind
The CERSAT (Centre ERS d'Archivage et de Traitement - French ERS Processing and Archiving Facility) is part of IFREMER (French Research Institute for Exploitation of the Sea). CERSAT has evolved into a multi-mission data centre for archiving, processing and validating data from space borne sensors (such as altimeters, scatterometers, radiometers, SAR). CERSAT has developed the production chain to be used for this sub-service.

Infrastructure for production
IFREMER has developed a production chain for sea ice type and drift products. The climate products will be derived from this production chain by aggregating daily products into the respective aggregation periods.

Sub-service validation
Quality control procedures for product generation and service delivery are implemented at each of the processing chains. The global sea ice monitoring service previously delivered by the ICEMON project has undergone validation by several end users. The feedback from these users was in turn used to upgrade and revise product outputs and supply chains. Continuing the practice established by ICEMON, the solicitation of feedback from service recipients for the purpose of product validation will be ongoing. Validation of the algorithm has shown that:

- The drift vector accuracy obtained from the scatterometer is quite near the theoretical uncertainty (5.1 km) directly and mainly driven by the pixel size (12.5 × 12.5 km).
- Scatterometer drift data are reliable earlier (early freezing period) and later (early melting period) than the SSM/I drift.
- SeaWinds swath geometry enables drift vectors to be estimated around the North Pole area (mainly multi-year ice).

10.1.1.2.2 Sub-service contribution to GMES development
The aim of the sub service is to provide a consistent set of sea ice drift products for long-term climate monitoring.

10.1.1.2.3 Links to other projects
This sub-service builds on previous service provision of daily sea ice drift mapping aimed at "tactical" applications.

10.1.1.2.4 Potential for production of historical time series
A historical time series could be produced by processing SSM/I data back to 1987 with the algorithm in Ezraty 2006a (although with less accuracy than the current algorithm).

10.1.1.2.5 Sub-service targets
The monthly, seasonal and annual products will be updated regularly at the end of each aggregation period. Drift vectors with an accuracy better than 5.5 km.

10.1.1.2.6 Sub-service evolution
The service will take advantage of the development in other projects, in particular ASCAT/METOP, for adaptation and validation to new sensors etc.

10.1.1.3 Sea ice thickness

10.1.1.3.1 Sub-service description

Products
Measuring sea ice thickness from satellite sensors is notoriously difficult, and the time scales required by a climate monitoring product mean that the data products have to be based on an existing long-term data series, which for polar regions can only mean passive microwave. Modern techniques, such as altimetry, are still in their infancy and cannot yet provide the spatial coverage and spatial and temporal resolution necessary for a climate change product.

The product proposed is a sea ice classification from which thickness can be inferred based on cluster analysis of multi-channel passive microwave data. This provides scope for producing an initial time series of ice-thickness-class products as the heritage of this type of sensor goes back to SMMR (launched on Nimbus-7 in 1978). Through use of data from this up to 1987 and then DMSP SSM/I (1987 to present) and AMSR-E (2002 to present) there is the basis for sea ice thickness products covering the last 27 years, a critical period in Arctic climate change. With upcoming SSMIS and CMIS sensors this product can be continued well into the future.

Algorithms
An established side-product of deriving ice concentration values from multi-channel passive microwave data (SMMR, SSM/I and AMSR) is the ratio between first-year and multi-year ice. The basic two-channel approach of the Comiso Bootstrap (Comiso, 1984) and the NASA Team (Cavalieri et al., 1984) algorithms delineate between first and multi-year ice according to difference in emissivity. This produces reasonable results but has large errors because of the multi-year ice signature being dependent on the scattering property of the material, especially the freeboard layer that includes the snow cover. An improved analysis of this surface type signature, using all available sensor channels, can be conducted using an automated cluster technique (Comiso, 1990). The results from this, confirmed by aircraft and submarine data (Comiso et al., 1991), are consistent with the emissivity of the ice being modified each summer and with ice from each cluster basically having the same history. An added benefit of this approach is improved detection of new ice types.

Team behind
The team for this sub-service is a partnership between Scottish Association for Marine Science (SAMS) and University of Cambridge, Department of Applied Mathematics and Theoretical Physics (UCAM-DAMTP). SAMS operates the EuroClim sea ice node and produces the Sea Ice Concentration (SIC) products. SAMS will provide the operationalisation and production of data products using the cluster analysis algorithm. UCAM-DAMTP is a EuroClim partner providing submarine ice thickness validation data. UCAM-DAMTP will

provide scientific advice and data from past submarine fieldwork to validate/calibrate the cluster analysis product.

Infrastructure for product production
The sub-service proposed here will build on the EuroClim sea ice node at SAMS and submarine data analysis facilities at UCAM-DAMTP.

10.1.1.3.2 Sub-service validation

The principal validation activity has been submarine expeditions by the UK and US navies to the Arctic over the period covered by multi-channel passive microwave measurements. For the UK the years covered are 1979, 1985, 1987-88, 1990-1992, 1994, 1996 and 2004. For the US the years covered are 1986-1994, 1996-1998. Validation will be tailored to the data products. UK data is restricted access to UCAM-DAMTP only and covers the European sector of the Arctic. US data has been released through NSIDC and has no restrictions but is spatially limited to the central Arctic only.

10.1.1.3.3 Sub-service contribution to GMES development

This will be the first time cluster analysis approach has been used over a long series of data rather than on single images. It will be the first service for remotely sensed sea ice thickness products.

10.1.1.3.4 Links to other projects

This sub-service product does not require results and data from other services or other projects.

10.1.1.3.5 Potential for production of historical time series

The product of this sub-service is based on multi-channel passive microwave data. These sensors have a history and data archive dating back to the launch of SMMR in 1978. Ice thickness data from UK submarines, to be used by the sub-service provider in developing the product and validation, is available for 1979, 1985, 1987-1992, 1994, 1996 and 2004. Therefore, we would aim to provide 27 years temporal coverage in the sea ice thickness product, which would provide more information on a time of major changes in the Arctic sea ice extent and volume.

10.1.1.3.6 Sub-service targets

- Operational goals: To provide sea ice isoclass data which provides good mapping of sea ice type and from this an overall estimate of average sea ice thickness in the Arctic. Refinement of the product will take place as new sensors (SSMIS and CMIS) become operational. We will also investigate incorporation of satellite altimeter data if this can be proven to be reliable.
- Accuracy: ±0.25 m of the average ice thickness for an isoclass
- Delivery time: Within 5 days of the end of the aggregation period (monthly, seasonal, annual) but nominally 2 days
- Long time series: Processing of multi-channel passive microwave data using cluster analysis technique to derive sea ice type/thickness for the period 1978 to present

10.1.1.3.7 Sub-service evolution

Incorporate modern sensors as they become available. Merge in data from altimetry (radar or laser) sensors when reliable results can be proved and sensors are more operational rather than experimental. UCAM-DAMTP and SAMS are partners in the CryoSat consortium.

10.1.1.4 Fram Strait sea ice flux

10.1.1.4.1 Sub-service description

Products

The Fram Strait is the main area for sea ice and liquid freshwater export from the Arctic Ocean to the Nordic Seas and the North Atlantic. The sea ice flux is a key climate parameter, which is monitored by Upward-Looking Sonars (ULS) on fixed moorings at 79°N in the Fram Strait. Ice drift retrieval from satellite data has been done using passive microwave and scatterometer data, but the resolution and seasonal coverage of these data is not as good as for Wide-swath SAR data. The proposed service aims to produce more accurate estimates of the area flux. When the ice flux measurements are taken regularly over longer periods (months, years) without any serious interruptions they will be valuable for climate research purposes. Ice volume flux calculations for climate purposes will also require ice thickness data to be included.

Ice area flux in the Fram Strait derived from a sequence of ASAR images was started to be produced as a seasonal and long-term monitoring in the ICEMON project. Since February 2004, NERSC has produced ice area flux profiles across 79°N in order to be used together with thickness data from moorings for estimation of volume fluxes. The time interval between the images is presently 3 days. Time series of ice flux through the Fram Strait is a key climate parameter. Monitoring by SAR requires regular acquisition and production of ASAR wide-swath data from ENVISAT and later from other SAR missions, such as RADARSAT 2. The products produced represent sea ice drift (km/day), sea ice concentration (%) and sea ice area flux (km^2/day). The ice concentration and feature map with ice displacement vectors are in raster-format with overlay graphics. The flux values are tabulated and in ASCII format. The measurements will be aggregated into monthly, seasonal and annual products.

Algorithms

The first step is to obtain ice concentration from satellite data for the overlapping area of the two SAR images used to retrieve ice displacement vectors. Ice concentration is obtained in detail from a SAR backscatter analysis, also with the aid of passive microwave data (using presently SSM/I, soon also AMSR-E) for giving the reliable but coarse-scale ice concentration isolines. The SAR image pair is collocated before ice displacement is retrieved. This is presently done manually, because automatic algorithms have problems to retrieve accurate ice drift in the marginal ice zone. The manual analysis is a guarantee that the ice drift vectors are reliable. The ice-area-flux is derived by taking the profile across 79ºN of ice concentration and the north-south component of the sea ice drift vectors. Timed series of SAR images are used to map ice drift independent of cloud and light conditions. In the Fram Strait, wide swath SAR images can cover the whole strait. This allows the total ice area flux to be mapped by SAR data, provided that images are obtained at regular intervals (for example every 3-6 days), and that ice features can be recognised in the sequence of SAR images.

The ASAR (or ScanSAR) images are range-normalised backscatter images of 400 km width (ASAR WS mode), using 1 or 2 scenes along track with 300 m pixel size. The orbits used are selected to have a maximum of overlap in range (at least 200 km). The SSM/I (or AMSR) sea ice concentration maps are existing products using NORSEX-85H passive microwave algorithm, and these data are assimilated into the detailed (SAR) product. The spatial resolution of the ice velocity profile across 79ºN is about 20 km.

Team behind
The Nansen Environmental and Remote Sensing Center (NERSC) will develop the Fram Strait Sea Ice Flux sub-service. SAR data will be provided by ESA (ENVISAT ASAR) and by KSAT for RADARSAT data (through the SatHav project).

Infrastructure for product production
NERSC has developed an in-house production chain for the product generation, including manual and automatic processing steps.

10.1.1.4.2 Sub-service validation

The main quality question is the accuracy of the derived ice area flux. Since the ice drift vectors are retrieved manually, the accuracy is determined by pixel size, geo-location and detection capability of features used to estimate the displacement. Geo-location is controlled against coastlines. The accuracy of individually retrieved vectors is of order 5 km. The overall estimate of ice flux, assuming three-day sampling interval, is ±12%. For interpolated drift vectors across 79ºN, the accuracy can be lower, especially near the marginal ice zone where detection capability is low. The accuracy of the flux estimate will be calculated when data from a whole seasonal cycle is available. Comparison of point measurements of ice drift from the ULS moorings will be done when a full seasonal cycle of data is available.

10.1.1.4.3 Sub-service contribution to GMES development

The sea ice flux in the Fram Strait is a key cryospheric parameter which is required to monitor (WMO, 2004). The added value here is that regular coverage of wide-swath SAR data from ENVISAT is provided. Due to the coverage by SAR data every three days, the estimation of the ice flux is significantly improved.

10.1.1.4.4 Links to other projects

The Fram Strait ice flux is linked to the high-resolution ice charting service for the Svalbard area conducted by met.no because some of the same SAR data will be used in both sub-services. The SAR based ice flux products are linked to the ice-drift products provided by IFREMER. The SAR products have higher resolution than the IFREMER products and will be used to validate IFREMER´s products. There is also a link to the Norwegian SatHav project, where RADARSAT data is provided by KSAT.

10.1.1.4.5 Potential for production of historical time series

There is a potential to produce time series going back 2-3 decades using the Polar Pathfinder ice drift data set available at NSIDC, which is based on AVHRR and other non-SAR sensors. SAR-based ice flux using RADARSAT ScanSAR data back to 1998 is possible. NERSC has done initial studies to use archived RADARSAT data. The ERS SAR archive can potentially be used to produce ice area flux from 1991.

10.1.1.4.6 Sub-service targets

The performance targets will be:

- Accuracy of individually retrieved vectors of order 5 km.
- Overall ice flux estimate within ±12%.
- Near real-time delivery depending on the availability of SAR data in near real time.
- Build up time series over many years, using data from new SAR missions.
- Combine area flux with thickness from ULS data and CryoSat.

10.1.1.4.7 Sub-service evolution

Integration of ice drift and area flux estimates from wide-swath SAR with other sensors (scatterometer, SSM/I, AMSR-E and ASAR Global Monitoring Mode) to provide products with different resolution and coverage. Ice drift and area flux will also be extended to include other straits in the Arctic.

10.1.2 Seasonal snow

10.1.2.1 Regional snow cover

10.1.2.1.1 Sub-service description

Products
Regional aggregated multi-sensor snow cover area covering Fennoscandia based on a fusion of AVHRR and in situ network of meteorological measurement stations. This product is based on daily observations. The daily observations are used to derive aggregated monthly, seasonal and annual products for a climatological time series of snow cover area.

Algorithms
The algorithms for snow covered area, using single sensors, have been developed in EuroClim and combined into a multi-sensor analysis.

Team behind
Norwegian Meteorological Institute (MET.NO) developed these algorithms for single sensor and multi-sensor analysis of snow cover area. The EuroClim project has developed and set up a prototype system for producing snow covered area products. The service will be implemented and integrated into the operational data processing and service environment at MET.NO. The operational department at MET.NO will be responsible for running the service.

Infrastructure for product production
This service will be based on the existing EuroClim infrastructure built up during this project.

10.1.2.1.2 Sub-service validation

The algorithm was validated during the EuroClim project and shown to be suitable for further operational use in snow cover monitoring.

10.1.2.1.3 Sub-service contribution to GMES development

This is a new algorithm and the product has not been provided operationally before. The fusion of satellite data and in situ measurements is regarded as an innovative new approach to obtain increased accuracy.

10.1.2.1.4 Links to other projects

This service builds on the CEC FP5 EuroClim project, where the methods and processing software was developed.

10.1.2.1.5 Potential for production of historical time series

Products back to 2002 are currently available. NOAA AVHRR archive data may be reprocessed after a modification of the algorithm to get a much longer time series. NOAA AVHRR archive data from 1978 exists, but there are some gaps in the time series for the first years.

10.1.2.1.6 Sub-service targets
The performance targets will be:
- The monthly, seasonal and annual products updated regularly by the end of each month, season and year, and *within 10 days.* The processing jobs will be automatically triggered as a part of MET.NO's operational system.
- The target is to have 95% accuracy when comparing with meteorological ground observations of snow cover during a one year period.

10.1.2.1.7 Sub-service evolution
The service can be further developed and extended by including more results from the EuroClim and EnviSnow projects:
- A multi-sensor approach combining several optical sensors, like MODIS and MERIS/AATSR. This would give better spatial resolution as well as better temporal coverage.
- A multi-sensor approach also including C-band SAR for wet snow conditions (like ENVISAT ASAR and Radarsat). Would enable more observations in periods with wet snow.
- A multi-sensor time-series approach where a time series of multi-sensor data is analysed simultaneously. Further accuracy can be expected as a snow cover model can be used to avoid misinterpretation of data.

10.1.2.2 Global snow cover

10.1.2.2.1 Sub-service description

Products
Global multi-sensor snow cover from SSM/I passive microwave radiometer and AVHRR optical data. One product produced for the northern hemisphere, with an optional extension for the southern hemisphere. Global swath from SSM/I and AVHRR will be processed to daily snow products. The daily products are used to derive aggregated monthly and annual means for climatological time series.

Algorithms
For SSM/I data the NASA algorithm for global applications will be used with refinements developed by D. Hiltbrunner in the SnowTools. For AVHRR data the algorithm developed in the EuroClim project will be used. These single-sensor retrieval results will be merged in a multi-sensor analysis developed in the EuroClim project.

Team behind
The OSI SAF (Ocean and Sea Ice Satellite Application Facility, EUMETSAT project) team at Norwegian Meteorological Institute (MET.NO) and the remote sensing team at the Norwegian Computing Center (NR) will do implementation. These two teams have long experience in both algorithm development and setting systems into operational service through various EU, EUMETSAT and ESA projects, both for daily and long-term monitoring. The service will be implemented and integrated into the operational data processing and service environment. The operational department at MET.NO will be responsible for running the service.

Infrastructure for product production
The current software used for the OSI SAF sea ice processing running operationally at MET.NO for EUMETSAT will be adapted for the snow cover algorithms and used for the production. This system is fully capable of performing such a service within its operational constraints. Global swath data from SSM/I are currently received at MET.NO as well as AVHRR data covering Europe. With the launch of METOP in 2006, global AVHRR swath data will also be available at MET.NO through the near-real time data dissemination from EUMETSAT.

10.1.2.2.2 Sub-service validation
The SSM/I NASA algorithm has been well validated for the Northern Hemisphere, and together with the refinements of D. Hiltbrunner this provides the state-of-the-art. The AVHRR algorithm was developed in the EuroClim project, and is currently used by this project. The new multi-sensor algorithm will be validated through national activities in collaboration with this activity. The service will include a quality control module that performs automatic comparison with in situ snow cover and snow depth measurements from the international network of meteorological ground stations in order to check consistency.

10.1.2.2.3 Sub-service contribution to GMES development
The multi-sensor algorithm is entirely new and represents a significant step forward for the state of the art of global snow cover retrieval.

10.1.2.2.4 Links to other projects
National projects in Norway will support the development of methods and the service.

10.1.2.2.5 Potential for production of historical time series
A historical time series of products can be produced by processing of SSM/I and AVHRR data back to 1987.

10.1.2.2.6 Sub-service targets
The performance targets will be:
- The monthly, seasonal and yearly products updated regularly by the end of each month, season and year, and *within 1 day.* The processing jobs will be automatically triggered as a part of MET.NO's operational system.
- The accuracy will be different according to which satellite data are used. For cloudy conditions only SSM/I data are used. For cloud-free conditions AVHRR and SSM/I will be used in a multi-sensor approach. Because SSM/I has lower resolution than AVHRR, the accuracy will be lower when only SSM/I is used. The target is to have 95% overall accuracy of the AVHRR algorithm and 90% for the SSM/I algorithm, when comparing with meteorological ground observations of snow cover during one year. Accuracy information will be provided with each product.

10.1.2.2.7 Sub-service evolution
The service can be further improved by adapting the algorithm to include other satellite microwave sensors, such as AMSU flying on the operational NOAA polar orbiting satellites. The optical part can also be improved by the use of MODIS or similar sensors.

10.1.2.3 Snow temperature

10.1.2.3.1 Sub-service description

Products
The snow temperature at surface (STS) variable refers to the surface temperature of the snow cover. Regional aggregated snow temperature products covering incrementally larger areas throughout the project are foreseen (Stage 1: Fennoscandia; Stage 2: Arctic region; and Stage 3: Global). The regional product (Stage 1) will be of 1 km resolution. It is still to be determined from the user needs what will be a proper resolution for the Arctic and globally. The product is based on daily observations. The daily observations are used to derive aggregated monthly, seasonal and annual products for a climatological time series. Each product will include aggregated average, minimum, maximum and standard deviation of the observed variable together with number of observations and a measure of accuracy.

Algorithms
STS can be retrieved by means of remote sensing in the thermal region of the electromagnetic spectrum. The digital values of the remotely sensed data represent the radiance within a specified spectral band. For thermal data, the observed radiance emitted from Earth's surface can be transformed to the quantity of brightness temperature according to Planck’s law. The main issue for retrieval of snow surface temperature is to correct for the atmospheric attenuation. The core of the algorithm is to combine at least two observed brightness temperature images into one real surface temperature image. Snow-free surfaces are masked out. Areas with fractional snow coverage, forests, build-up areas or open water are not analysed. The algorithm has been developed in the EuroClim and EnviSnow projects (Amlien and Solberg 2003).

Team behind
The Norwegian Computing Center (NR) has developed the algorithm. It has been integrated in a prototype service developed by the EuroClim project.

Infrastructure for product production
This service will be based on the existing distributed EuroClim infrastructure built up during this project. NR is running the production chain for this product. When the service goes operational, it will be taken over by a legally mandated organisation.

10.1.2.3.2 Sub-service validation

The algorithm was validated in the EuroClim and EnviSnow projects and has shown to be suitable for further operational use in snow cover monitoring. An accuracy of ±0.5ºC was found during validation campaigns at our test site in the Jotunheimen mountain area of South Norway.

10.1.2.3.3 Sub-service contribution to GMES development

This is a new algorithm and the product has not been provided operationally before.

10.1.2.3.4 Links to other projects

This service builds on the CEC FP5 EuroClim project, where the methods and processing software was developed.

10.1.2.3.5 Potential for production of historical time series

NOAA AVHRR archive data may be reprocessed after a modification of the algorithm to get a much longer time series. NOAA AVHRR archive data from 1978 exists, but there are some gaps in the time series for the first years.

10.1.2.3.6 Sub-service targets

The performance targets will be:

- The monthly, seasonal and annual products updated regularly by the end of the corresponding aggregation period *within one week.*
- The target is to obtain ±0.5ºC for 100% snow covered areas for 95% of the time in average.

10.1.2.3.7 Sub-service evolution

Sub-service evolution options include:

- The service is planned to be further developed and extended in a step-wise way from regional (Fennoscandia), via hemispherical (central Arctic area) to global during the course of the project. The spatial resolution of the Arctic and global products need to be determined in a dialogue with the users. If it will be lower than the product for Fennoscandia (1 km), we should consider to continue providing the high-resolution product for Europe and, accordingly, lower resolution on the worldwide scale.
- The algorithm is currently running on MODIS data, but preliminary tests show that AATSR is suitable as well. Depending on operational aspects like access and costs related to data provision, tailoring to AATSR can also be done in the project.

10.1.2.4 Snow wetness

10.1.2.4.1 Sub-service description

Products

The snow surface wetness (SSW) variable refers to presence of liquid water in the upper surface layer of the snow cover. Regional aggregated snow surface wetness products covering incrementally larger areas throughout the project are foreseen (Stage 1: Fennoscandia; Stage 2: Arctic region; and Stage 3: Global). The regional product (Stage 1) will be of 1 km resolution. It is still to be determined from the user needs what will be a proper resolution for the Arctic and globally. The product is based on daily observations. The daily observations are used to derive aggregated monthly, seasonal and annual products for a climatological time series. Each product will include aggregated average, minimum, maximum and standard deviation of the observed variable together with number of observations and a measure of accuracy.

Algorithms

An excellent solution to regional and global monitoring of SSW would be to use SAR, e.g., C-band SAR from ENVISAT ASAR or Radarsat. However, frequent global coverage is still not practically feasible due to costs as well as technological limitations. A good alternative is to use available low-cost optical data of medium resolution. The ideal approach based on optical data would have been to apply a retrieval algorithm for liquid water volume in the snow. However, this would require an imaging spectrometer with optimally located spectral bands for measuring a liquid-water molecular absorption feature. The approach we propose here is to infer snow surface wetness from a combination of measurements of snow temperature (STS) and snow grain size (SGS) in a time series of observations. The temperature observations give a good indication of where wet snow potentially may be present, but are in themselves not accurate enough to provide strong enough evidence of wet snow. However, a strong indication of a wet snow surface is a rapid increase in the effective grain size simultaneously with a snow surface temperature of approximately 0°C. An algorithm based on this approach has been developed in the EuroClim and EnviSnow projects (Solberg et al. 2004).

Team behind

The Norwegian Computing Center (NR) has developed the algorithm. It has been integrated in a prototype service developed by the EuroClim project.

Infrastructure for product production

This service will be based on the existing distributed EuroClim infrastructure built up during this project. NR is running the production chain for this product. When the service goes operational, it will be taken over by a legally mandated organisation.

10.1.2.4.2 Sub-service validation

The algorithm was validated in the EuroClim and EnviSnow projects and has shown to be suitable for further operational use in snow cover monitoring. A very good agreement with observations from the network of in situ meteorological stations has been shown during the validation period for the South Norway region.

10.1.2.4.3 Sub-service contribution to GMES development

This is a new algorithm and the product has not been provided operationally before.

10.1.2.4.4 Links to other projects

This service builds on the CEC FP5 EuroClim project, where the methods and processing software was developed.

10.1.2.4.5 Potential for production of historical time series

NOAA AVHRR archive data may be reprocessed after a modification of the algorithm to get a much longer time series. NOAA AVHRR archive data from 1978 exists, but there are some gaps in the time series for the first years. Also, less accuracy must be expected than when using the MODIS version of the algorithm.

10.1.2.4.6 Sub-service targets

The performance targets will be:

- The monthly, seasonal and annual products updated regularly by the end of the corresponding aggregation period *within one week.*
- The target is to obtain correct snow wetness classes for 100% snow covered areas for 95% of the time.

10.1.2.4.7 Sub-service evolution

Sub-service evolution options include:

- The service is planned to be further developed and extended in a step-wise way from regional (Fennoscandia), via hemispherical (central Arctic area) to global during the course of the project. The spatial resolution of the Arctic and global products need to be determined in a dialogue with the users. If it will be lower than the product for Fennoscandia (1 km), we should consider to continue providing the high-resolution product for Europe and, accordingly, lower resolution on the worldwide scale.
- The algorithm is currently running on MODIS data, but preliminary tests show that AATSR or a combination of AATSR and MERIS is suitable as well. Depending on operational aspects like access and costs for data provision, tailoring to ENVISAT data can also be done in the project.

10.1.2.5 Snow depth and water equivalent

10.1.2.5.1 Sub-service description

Products
The Finnish Meteorological Institute (FMI) and Helsinki University of Technology (HUT) will establish and implement an operational system for monitoring and mapping snow water equivalent (SWE) and/or snow depth (SD). The two products will both cover the northern Eurasia. There will be monthly, seasonal and annual aggregated raster products of 25 km × 25 km resolution. Climatological products based on historical archived data (e.g. past SSM/I observations) will be demonstrated for some selected periods.

Algorithms
The algorithm is based on development in several research projects by HUT. The algorithm to be used in this project will is based on Aqua AMSR-E passive microwave radiometer. In the current project, the method will be implemented in an operational production chain.

Team behind
The algorithm and processing chain are developed in collaboration between FMI and HUT.

Infrastructure for product production
FMI will downlink the EOS-AQUA AMSR-E data at Sodankylä receiving station. The data are transmitted from Sodankylä to FMI-Helsinki in real time. FMI operates the processor that will be developed jointly by FMI and HUT. In addition to near-real time processing required for hydrological applications, the climatological products can be processed using archived data.

10.1.2.5.2 Sub-service validation

Finland will serve as a validation site for the SWE/SD product. Additionally, snow information from synoptic weather stations in Eurasia is used. Finland has a comprehensive network of snow in situ measurement stations, about 700 precipitation stations, where daily observations of snow depth and coverage are made. More detailed but considerably less frequent measurements are made at the 162 snow courses managed by SYKE. A snow course is a 2-4 km long trail through various terrains typical of the locality. Measurements from each snow course are typically made once a month (on the 16^{th} day). For the SWE product a quality parameter describing the result of the data assimilation model is followed and a comparison with validation measurements (in Finland) is performed before product release.

For other regions of Eurasia, the product validation is carried out by comparing the SWE/SD information with SD information from synoptic weather stations.

10.1.2.5.3 Sub-service contribution to GMES development

The respective algorithms are new and expected to provide Europe with significantly more accurate products than available in the past.

10.1.2.5.4 Links to other projects

The work to be conducted is directly linked to H-SAF activities of EUMETSAT. FMI and HUT together with the Finnish Environment Institute (SYKE) are responsible for European-scale hydrological snow mapping applications of the H-SAF starting in 2005.

10.1.2.5.5 Potential for production of historical time series

The planned funding enables the production of historical time series for a few selected periods from a total time span from 1978 to 2005 (e.g. SWE information for the second month of the year for five separated years). The selected periods will be chosen based on climatological reference data. The applicable space-borne microwave radiometers include SMMR, SSM/I and AMSR-E.

10.1.2.5.6 Sub-service targets

Targets are delivery the first day after the aggregation period and with an accuracy corresponding to 30 mm water equivalent.

10.1.2.5.7 Service evolution

The SWE/SD service will evolve as follows:

- Year 1: Pre-operational
- Year 2: Semi-operational
- Year 3: Fully operational

10.1.3 Glaciers and ice sheets

10.1.3.1 Greenland ice sheet surface type

10.1.3.1.1 Sub-service description

Products
GEUS will produce two sets of products for the Cryospheric Climate Monitoring Service, namely (1) satellite-based products of crucial surface property variables (Glacier Surface Type, GST) and (Glacier Melt Area, GMA), and (2) “online” in situ data from operational Automatic Mass balance Stations (AMS) deployed at important transects around the margin of the Greenland ice sheet to monitor melting and mass balance of the ice sheet.

Satellite products
The GST and GMA products are based on a production chain developed by GEUS. The system has been demonstrated on MODIS data from 2000 and onward. The system produces integrated products on monthly, seasonal and annual basis. In addition to this, the statistical parameters average, minimum, maximum, standard deviation and a quality index number are produced.

In situ products
A station concept for fully automatic field data collection of surface climate and mass balance parameters has been developed and implemented on the Greenland ice sheet. At six-hour intervals data are transmitted by satellite to Copenhagen and can be made available soon after. The stations deployed so far on the Greenland ice sheet cover three transects in east, south and west Greenland, respectively. Fully equipped stations sample the following data: Air temperature, wind speed and direction, humidity, incoming shortwave radiation, reflected shortwave radiation, incoming long-wave radiation, snow accumulation and ablation. The small stations only collect information on ablation.

Algorithms
The algorithms behind the satellite products have been developed, tested and implemented in the EuroClim project. The GST product displays a robust algorithm to separate different surface types on the ice sheet, from which changes in area of melting glacier ice can be traced over time. The GMA shows the total melt area also on temporal basis.

Team behind
The Geological Survey of Denmark and Greenland (GEUS) has developed the algorithms and processing chains, and GEUS is hosting the database for these products.

Infrastructure for product production
GEUS has an established infrastructure for product production of GST and GMA information on a dedicated server, which runs in cluster of servers developed in the EuroClim project. The AMS concept has been developed and implemented on the Greenland ice sheet in the ICEMON project. All data are automatically collected and stored in a datalogger. At each transect three AMS stations cover the outermost, middle and uppermost part of the ablation zone. In each transect end a fully equipped station is deployed and in between a small station is deployed. Development is ongoing for AMS product production, which is planned to be finished by the end of 2005.

10.1.3.1.2 Sub-service validation

The satellite products GST and GMA have already been through validation ending in 2004 within the EuroClim project. The ICEMON project will finish in 2005 with validation activity during the autumn 2005.

10.1.3.1.3 Sub-service contribution to GMES development

The products developed for satellite and in situ monitoring of Greenland represents entirely new results and a novel approach to monitor a climatologically very important region of the cryosphere.

10.1.3.1.4 Links to other projects

This service builds on the CEC FP5 EuroClim project, where the methods and processing software was developed.

10.1.3.1.5 Potential for production of historical time series

NOAA AVHRR archive data may be reprocessed after a modification of the algorithm to get a much longer time series. NOAA AVHRR archive data from 1978 exists, but there are some gaps in the time series for the first years. Also, less accuracy must be expected than when using the MODIS version of the algorithm.

10.1.3.1.6 Sub-service targets

To provide satellite products no later than one week after each accumulation period and to provide AMS products within two days after transmission from Greenland.

10.1.3.1.7 Sub-service evolution

A multi-sensor satellite-plus-in-situ (AMS) algorithm is under consideration. The corresponding product will be dynamically calibrated and quality assured by the use of AMS data. The remote sensing part of the sub-service could also be improved by including passive microwave data and SAR data.

10.1.3.2 Greenland ice sheet mass balance

10.1.3.2.1 Sub-service description

Products

Monthly, seasonal and annual raster grids (maps) of net surface mass balance (in metres of water equivalent) on a distributed 5 km (or 1 km) grid over the whole of the Greenland ice sheet. Annual solid ice fluxes across grounding lines from surface velocity and ice thickness measurements. These two components provide the total regionally differentiated freshwater contribution of the ice sheet.

Algorithms

We use a surface mass balance model (SMB) for the ice sheet adapted and updated from Greuell and Genthon (2004). The sub-surface snow diagensis module is designed to compute the physical properties of a 25 m deep firn layer (water budget, snow/ice mass and snow/ice density).

The surface temperature and mass flux that force the SMB model at its top boundary are available from ECMWF operational analysis data (and from re-analysis going back to 1957). They need to be downscaled, however, to the resolution of the SMB model, and this is done using a physically-based scheme that incorporates orographic and lapse-rate effects. The sub-surface temperature in the SMB model as well as any changes in snow properties and water budget are updated every model time step. The runoff will be tracked down toward the ocean, the flow direction being the maximum downhill slope. If no water reaches the ice surface, the position of a slush layer is computed. This layer may later on refreeze as “superimposed ice”. Alternatively, superimposed ice formation could be parameterized as proportional to the temperature gradient at the snow/ice interface. Finally, the model calculates dry snow densification by settling and compaction.

For the service proposed here we would provide estimates of runoff along the coast by tracking melt downslope along with estimates of the solid ice flux from the ice sheet from surface velocity measurements at the grounding lines of outlet glaciers. These provide mean annual solid ice fluxes. Obtaining sub-annual temporal resolution for the solid ice flux requires the use of satellite gravity from, for example, GRACE. We will investigate incorporating these data at a later stage.

Team behind
Bristol Glaciology Centre (BGC) at the University of Bristol is behind this sub-service.

Infrastructure for product production
The BGC has adequate high-performance computing facilities for undertaking the work.

10.1.3.2.2 Sub-service validation

Validation and calibration of the model will be undertaken in two steps. The first will be to validate the climatology over Greenland produced by the ECMWF downscaling scheme using data from the GC-NETwork of automatic weather stations (AWS) and AVHRR-derived surface temperature data. A thorough validation of energy and mass fluxes will be required, and it is therefore beneficial that GC-NET AWS are equipped with sonic height rangers to detect timing and amplitude of individual precipitation events as well as the ablation rate. Once this has been completed, we will undertake a detailed calibration and validation of the SMB model with the aid of further in situ and satellite observations provided by GEUS. First, we will use estimates of snowmelt extent from passive microwave radiometry, which cover the period from 1979-present, to compare with the melt area estimates derived from the model. Second, validation of the sub-surface scheme (and, by default, the entire coupled model setup) will be achieved by comparing modelled ablation estimates with *in-situ* measurements made by the GEUS and IMAU since 1991. It is expected that these two validation activities will lead to some tuning of the SMB model.

10.1.3.2.3 Sub-service contribution to GMES development

This is an entirely new product that is currently not available.

10.1.3.2.4 Links to other projects

This sub-service is an evolution of a tri-national research project funded nationally between the UK, Netherlands and Norway with aim of producing a climatology of freshwater fluxes from the Greenland ice sheet using a regional area climate model. This sub-service is closely allied to, and builds on, the Greenland sub-service for ice sheet surface type. The same surface type products will be used in this sub-service and the products can be used to improve the land/ice/snow masks in the model and to constrain the melt extent estimation.

10.1.3.2.5 Potential for production of historical time series

One of the aims of the nationally-funded project, that provided the funds for the development of the methodology, is to produce an historical time series dating back to the earliest reliable global climate re-analysis, 1957, and extending up to 2003. There are no plans, however, to produce data operationally. It is possible, therefore, to combine the time series that will be generated in this sub-service back to 1957.

10.1.3.2.6 Sub-service targets

Model development and validation complete after 18 months. Operational products available thereafter.

10.1.3.2.7 Sub-service evolution

Use of MODIS data will replace the use of AVHRR when the final implementation is running. The model will be designed to be modular, self-contained and portable and it will, therefore, be possible for a service receiver to run it operationally if required. Further validation of the model output will be undertaken as data become available.

10.1.3.3 Svalbard glaciers

10.1.3.3.1 Sub-service Description

Products

Aggregated glacier mass balance for Svalbard, derived from the following products:

- Glacier Surface Type (firn area extent) as observed directly by SAR over a representative selection of Svalbard glaciers. The firn area extent reacts to long-term changes in glacier mass balance. Several years of negative (or positive) glacier mass balance will lead to a decrease (increase) of the firn area size.
- Glacier Balance Area, derived from a k-means classification of the same data. The area extent of one of the resulting classes is highly correlated to the glacier's mass balance, and it is possible to relate this to absolute mass balance values.

Aggregated annual mass balance values for all of Svalbard will be produced.

Algorithms

The service will be based on synthetic aperture radar (SAR) data from the Envisat ASAR and similar instruments. At present, the firn area extent is derived by thresholding the SAR image at certain values, but work is planned to enable detection of the firn area by pattern recognition techniques. Glacier mass balance area is computed by applying a k-means classification of the glacier surface into three classes. A few mass balance measurements from the field are needed to calibrate the relation to absolute mass balance values.

Team behind

The service will be co-ordinated by the glaciology group at the Norwegian Polar Institute. The actual data processing will take place at the institute's Environmental Data Section.

Infrastructure for production

A prototype processing chain was developed in the EuroClim project, and will, with some improvements and adjustments, become fully operational at the NPI in the project period.

10.1.3.3.2 Sub-service validation

The service will be validated by yearly field surveys of selected glaciers. The field surveys have been carried out regularly since 1967, as a part of a glacier mass-balance-monitoring programme.

10.1.3.3.3 Sub-service contribution to GMES development

Glacier mass balance is a good indicator for climatic change. Traditionally, indicator data on changes in mass balance have been obtained by field measurements, or indirectly by observing changes in glacier surface area or front line positions. However, field measurements are very time consuming and work intensive. Such techniques allow only a selected few glaciers to be monitored, and the glacier selection tend to be based on accessibility rather than representativity (see http://www.npolar.no/sverdrup/GlaciologyResearch.htm). Surface area and frontline positions can be observed from space, allowing monitoring of large areas at a comparatively low cost, but due to certain characteristics of glacier behaviour this does not give a reliable measure of the mass balance. Recent work at the Norwegian Polar Institute within the EuroClim project has overcome these obstacles, and led to new methods for monitoring changes in glacier mass balance employing synthetic aperture radar (SAR) data.

10.1.3.3.4 Links to other projects

This service builds on the CEC FP5 EuroClim project, where the methods and processing software was developed.

10.1.3.3.5 Potential for production of historical time series

Data are already processed back to the first years of ERS-1, which means that older SAR data for the current algorithm is not available.

10.1.3.3.6 Sub-service targets

Glacier Surface Type (GST) and Glacier Balance Area (GBA) maps and statistics are to be delivered annually. Data processing will be an on-going task, and the maps and statistics will be updated continuously. Based on these, the aggregated annual mass balance values for all of Svalbard will be compiled annually.

10.1.3.3.7 Sub-service evolution

The sub-service is currently in a prototype mode. It is planned to become fully operational after a 6-month initialization period. This period is required for verification and validation, testing the system on glaciers in other regions, and certain improvements to the processing chain (such as improved error handling). When the Svalbard monitoring system is operational, an expansion to cover other Arctic regions is foreseeable. System tests in Greenland are already planned in collaboration with GEUS.

10.1.4 Lake and river ice

10.1.4.1 Water-body surface state

10.1.4.1.1 Sub-service description

Products
The Water-body Surface State (WSS) variable refers to the phase of the surface for the freshwater body-types lakes and rivers (liquid water or ice; possibly also snow and water on top of an ice layer). Time series of WSS products will show break-up and refreeze dates for the lakes (as well as giving information about the transition periods). Regionally aggregated products covering incrementally larger areas throughout the project are foreseen (Stage 1: Fennoscandia and Stage 2: Global). The products will show the average state of selected lakes within the region of interest. It is still to be determined from the user needs which lakes to select. The product is based on daily observations. The daily observations are used to derive aggregated monthly, seasonal and annual products for a climatological time series. Each product will include aggregated average, minimum, maximum and standard deviation of the observed variable together with number of observations and a measure of accuracy.

Algorithms
A preliminary approach for the lake and river surface state retrieval has been developed. It is based on moderate resolution optical data, like MODIS and MERIS. A time series of observations is analysed, and change detection is used to measure the presence and quantities of changes of the surface state. The approach builds on a model for the behaviour of the surface over time, statistically and spectrally. See example images shown in Section 6.1.4.

Team behind
The Norwegian Computing Center (NR) has developed the approach.

Infrastructure for product production
This sub-service will be based on the infrastructure chosen for the Cryospheric Climate Monitoring Service. It will be run by NR until it is fully developed. Then it will be taken over by a legally mandated organisation.

10.1.4.1.2 Sub-service validation
The algorithm will be validated for lakes in the South Norway region based on in situ measurements from field campaigns.

10.1.4.1.3 Sub-service contribution to GMES development
This is a new approach and the product has not been provided operationally before.

10.1.4.1.4 Links to other projects
National projects in Norway will support the development of methods and the service.

10.1.4.1.5 Potential for production of historical time series
NOAA AVHRR archive data may be reprocessed after a modification of the algorithm to get a much longer time series. NOAA AVHRR archive data from 1978 exists, but there are some

gaps in the time series for the first years. Also, there will be lower spatial resolution than when using the MODIS version of the algorithm (1 km compared to 0.5 km).

10.1.4.1.6 Sub-service targets

The performance targets will be:

- The monthly, seasonal and annual products updated regularly by the end of the corresponding aggregation period *within one week.*
- The target is to obtain correct water surface classes for 95% of the area of the lakes covered.
- The spatial resolution of the raster products will be 500 m.

10.1.4.1.7 Sub-service evolution

Sub-service evolution options include:

- The service is planned to be further developed and extended inn a step-wise way from regional (Fennoscandia) to global during the course of the project. The lakes to be covered will be carefully distributed based on a dialogue with the users.
- The approach is currently studied for MODIS data, but a combination of AATSR and MERIS should be suitable as well. Depending on operational aspects like access and costs for data provision, tailoring to ENVISAT can also be done in the project.

10.1.5 Permafrost

10.1.5.1 Soil surface frost

10.1.5.1.1 Sub-service description

Products
The Soil Surface Frost (SSF) variable refers to whether the soil ground surface is frozen or not. Time series of SSF products will show thaw and refreeze dates for areas with permafrost or seasonally frozen ground (as well as giving information about the transition periods). Regionally aggregated products covering incrementally larger areas throughout the project are foreseen (Stage 1: Eurasia and Stage 2: Global). The spatial resolution of the product will be 25 km. The product is based on daily observations. The daily observations are used to derive aggregated monthly, seasonal and annual products for a climatological time series. Each product will include aggregated average, minimum, maximum and standard deviation of the observed variable together with number of observation and a measure of accuracy.

Algorithms
The team behind is currently working on an algorithm based on a multi-sensor approach. The basic approach is to use a passive microwave radiometer to determine the soil surface state. SSM/I and AMSR-E are currently the most suitable sensors available. However, snow cover attenuates the signal. Therefore, we will use the global snow cover product as input to the soil surface frost retrieval algorithm and thereby obtain a reliable estimate of the state of the soil surface. The algorithms used will be based on the existing algorithms both for snow cover and soil surface frost. These existing algorithms will be validated and refined based on comparison with in situ observation of snow cover, snow depth and soil surface conditions.

Team behind
The Norwegian Meteorological Institute (MET.NO) and the Norwegian Computing Center (NR) are behind the approach being developed.

Infrastructure for product production
The two teams have long experience in both algorithm development and setting systems into operational service through various EU, EUMETSAT and ESA projects, both for daily and long-term monitoring. The service will be implemented and integrated into the operational data processing and service environment at MET.NO. The operational department will be responsible for running the service.

10.1.5.1.2 Sub-service validation
The algorithm will be validated by a comparison of time series of in situ measurements of snow cover and soil surface conditions. The observed surface temperature (0-10 cm) will be used together with observations of soil temperature below this (~100 cm depth). Observations from the network of permafrost observation stations will be used.

10.1.5.1.3 Sub-service contribution to GMES development
The multi-sensor algorithm is new and represents a step forward of the state of the art for frozen soil retrieval. This service will ensure European monitoring of soil surface frost and permafrost, which represent important global environmental parameters.

10.1.5.1.4 Links to other projects

This service will be directly linked to the service for global snow cover (see Section 10.1.2.2), as snow cover is input to the Soil Surface Frost algorithm.

10.1.5.1.5 Potential for production of historical time series

The Soil Surface Frost product will be based on SSM/I and AMSR-E data. SSM/I data exist back to 1987, so there is a potential for producing a 20 years time series.

10.1.5.1.6 Sub-service targets

The performance targets are:

- The monthly, seasonal and annual products updated regularly by the end of the corresponding aggregation period *within 1 day.*
- The target is to have 95% overall accuracy of the algorithm when comparing with meteorological ground observations during one year.
- The spatial resolution of the raster products will be 25 km.

10.1.5.1.7 Sub-service evolution

The service is planned to be further developed and extended in a step-wise way from regional (Eurasia) to global during the course of the project.

10.2 Development of climate change indicator products

Many users – in particular in the user groups for information providers, decision makers, the public, and industry and public administration – need higher-level products easily showing and quantifying climate change. Such indicator variables are simple measurements that can be used to represent a more complex situation. Examples of climate change indicators are: changes in sea level, trends in the position of glacier fronts, and length of ice-free periods on lakes and rivers. Indicators are normally selected based on criteria including: relevance to people and the environment, reliable and long-term measurements, and clear relationship to the force of change in question (CCME 2003). Indicators are used to provide an overview of a situation and a focal point for explaining trends and consequences of climate change. With the use of effective graphics and clear, accessible text, they can be effective methods of communicating information on the state of the climate.

The cryospheric climate monitoring service will have a special activity on development of climate change indicator products. This activity will be lead by UNEP/GRID-Arendal and supported by thematic experts representing each of the geophysical variable groups (sea ice, seasonal snow, glaciers/ice sheets, river/lake ice and permafrost).

10.2.1 Liaison between service development and users

In this section we describe contributions to the service that will focus on developing cryosphere indicators and indices to meet the needs of specific user groups.

1. **Survey and report on existing indicators based on cryospheric data**: A report will be prepared that surveys existing cryosphere indicator initiatives on national and international scales. These indicator initiatives will be described, classified and discussed in terms of scope, types of products, underlying datasets and targeted user groups. The developers of the initiatives will be invited to provide comments on gaps and needs. This report will be updated annually, and will serve as an ongoing resource document for the project. As well as identifying specific needs, this report will promote collaboration with other initiatives and reduce duplication of effort.
2. **Facilitate use of cryospheric data by identifying data needs and matching these needs with service providers**: This will be accomplished through discussions and written communications with potential user groups, especially focusing on projects and assessments conducted through Arctic Council, UN agencies and other international processes.
3. **Collaborate with the Indicator Development Group to meet the needs of specific users**: GRID-Arendal will facilitate the process through providing advice and assistance in coming up with the right products in the right formats (see also Section 10.2.2). GRID-Arendal will also provide contributions in writing explanatory text, producing graphics, and in layout and design to ensure that the final products are of the highest quality.
4. **Monitor the impact**: GRID-Arendal will assess and report on the impact of the products developed through this project and make recommendations on how to improve services based on this assessment. This will be accomplished through assessing indicators of product distribution and by following up directly with users to determine how the products influenced their work. This should be done as an iterative process.

10.2.2 Indicator Development Group

Indicator products will be developed for sea ice, seasonal snow, glaciers/ice sheets, lake/river ice and permafrost. An expert will be appointed for each of these thematic areas to work together with GRID-Arendal for the indicator product development. There will be special meetings where these experts come together to exchange ideas, thereby better utilising development results as far as possible for thematic across-area synergy.

We will use sea ice for scientific and educational users as an example of indicator product development in the following. Vexcel UK will take a co-ordinating role for the development and implementation of climate change indicator products for sea ice based on the outcome of the liaison activity performed by GRID-Arendal. There will be similar activities and ideas for the other geophysical product groups.

Simple indices can be used in studies of trends in high-latitude climate and in studies of tele-connections between the polar regions and lower latitude climate. This is a new concept that enables scientists to avoid the need to study 4D (space-time) data fields, which requires expertise in data sources and access to large volumes of data. For example, one index will express the degree of export of ice from the Russian shelf compared to seasonal average. Another index will express the ice concentration in the Barents Sea compared to the seasonal average. Another could ultimately express the thickness anomaly of sea ice north of Greenland. This will be built on baseline products from the proposed sub-services.

The indices will include new data sources such as ice drift, which to date has been used very little in climate studies but will be made visible to the broader climate research community through this activity.

The indices will be available via the web service in simple graphic and downloadable data formats. These can be linked to other established hemispheric indices such as the Arctic Oscillation (which will be included in the web service) and low latitude phenomena such as the Quasi-Biennial Oscillation (which will be linked via other climate websites). The indices will be selected carefully to represent in simple scalar form as many as possible of the key, large-scale climate processes taking place in the polar regions. The service will be aimed at scientists, at undergraduate and graduate level students who will be able to carry out simple analyses or use the indices within more complex analyses, and teachers who will be able to use the material to illustrate climate and high latitude processes in a simple graphic format with their students. The material will be constantly updated. The web service should also contain useful background information and explanations on the indices.

The indices will be grouped as follows:

- **Hemispheric indices**: These describe the large-scale behaviour of (ocean,) ice and atmospheric conditions at a temporal resolution of a month to a year covering the Arctic and Antarctic respectively. This will be of interest to scientists, environmentalists and teachers for investigating large-scale trends and “the big picture” of high latitude climate.
- **Regional indices**: These represent a novel element of the service, because they are based on key regions in the Arctic and Antarctic and are designed to “capture” the behaviour of climate in regions that are key for climate change, including the Fram Strait (where ice exits the Arctic) and the East Siberian Sea (where there has been a massive reduction in summer sea ice coverage). These regional indices will be useful for serious scientific study and for others who are interested in regional phenomena that reflect conditions in their own areas (e.g. Russia, Canada).

10.3 Service infrastructure

The following sections present the approach to establish a first version of the service infrastructure and how it can be further improved throughout the project period.

10.3.1 Standardisation

In order to best meet the declared objectives of the service – regarding a sustainable, long-term climate observation system – service infrastructure should be designed, defined, and implemented in accordance with previous and current standardisation initiatives. We should especially follow progression in the WMO GCOS and GEO GEOSS initiatives. The latter lays out a work plan including to engage with:

- WMO Commission for Basic Systems for inputs on GEOSS architecture.
- GCOS to develop mechanisms for aligning the strategic plans and activities.
- GMES to pursue coordination with the GEOSS 10 Year-Implementation Plan targets.

Although this may seem an ambitious plan and GEOSS takes on perhaps an overwhelming objective, one should notice that the Open Geospatial Organization (OGC) has joined GEO, and OGC has been invited to participate in the GEO Working Group on Architecture and Data.

OGC is well renovated for rapidly producing practical and concrete industry standards for service specification and system interoperability, and to provide tools and basic data types for product data interpretation (relevant examples are: WEB mapping standards, sensor XML, JPEG2000/GML integration). Important OGC standards are adopted by ISO, and the two organizations have ongoing cooperation for exchange of draft proposals and reviewing efforts. Regarding the economical forces and roles of leading software companies within geo-systems in OGC, one can expect a massive thrust towards open data definitions and system interoperability, mostly obtained through definition of open geo-services.

The service will actively monitor standardisation development, and seek to implement these and adjust infrastructure architecture and data formats, to be as conformant as possible to a future common service infrastructure. In this way the project may also contribute to long-term open system development, and work as input to standardisation efforts regarding usability and practical applications.

10.3.2 Infrastructure integration – first system version

As it would be to go too far here to describe a solution for the whole infrastructure of the service, the process of establishing such an infrastructure is briefly outlined instead. Of the relevant projects behind this proposal, EuroClim seems to have developed the most mature infrastructure so far for a climate monitoring system. However, it does not mean that it includes all the best components and has applied all the best solutions throughout the system. Other projects, in particular those listed in Section 6.2, have developed innovative solutions to specific problems.

Therefore, it is recommended to use EuroClim as a starting point and substitute/improve components in order to utilise the best solutions available today (with the cost restrictions present in the project setting the limits). The improvements should be done in an incremental and iterative way in order to keep control of costs and progress in general. The improvements should be based on a priority list developed by the service's system experts and agreed upon by the project leader team. Improvements will then be implemented one by one with the time and resources set aside for this purpose.

It is recommended to establish a Change Control Board (CCB), which decides on the actions to be taken from the decisions by the project management, in an incremental way. The CCB is composed of a team of key people in the system development group as well as key people liaising with the users. This is a standard solution to ensure that a system is developed in accordance with user needs in a controlled and cost-effective way. The current and highest prioritised step of modifications and improvements decided by the project management will result in an plan from the CCB of what to carry out of work by the system developing partners, and this results in a new release of the system (the result of one increment). This concludes one iteration in the development, and the next takes over.

10.3.3 Infrastructure advancements

The following sub-sections present potential improvements to the infrastructure of the service that should be considered. The necessary expertise already exists in the consortium for the implementation of these options.

10.3.3.1 Databases

The service system should use open-source or low-cost database systems to ensure low operational costs, especial for educational and research partners. EuroClim ensured this by successfully using PostgreSQL. The conclusions from the EuroClim project are that PostgreSQL is reliable and has high availability. If the service system requirements require a database system with strong emphasises on scalability, high availability, reliability and supportability, MaxDB by MySQL should be considered. MaxDB is a high-quality GPL-licensed enterprise database system. If MaxDB is chosen, the EuroClim system can still be used because the software uses standard SQL and ODBC to communicate with the database.

10.3.3.2 Distributed systems and web services

The EuroClim system has used mainly SOAP over HTTP and XML over HTTP, and some CORBA for the distributed interfaces of the system. For this service it seems obvious that the distributed interfaces should be more uniform than in the EuroClim project, and the project should continue to use open standards. It should be a system of web services based on so called Service Oriented Architecture (SOA).

The Java Enterprise Service Bus (ESB), which was released in 2005 by Sun, should be considered. Enterprise Service Bus is a common software bus for web services in an infrastructure of applications, and is most probably the start of standardisation of Java-based integration. Java Enterprise Service Bus and Java Beans 3.0 are key components of the Java Enterprise Edition 5.0 (JEE5) that was also released in 2005. Sun promises that JEE5 will significantly ease the integration of Java-applications into systems of web services based on services oriented architecture.

Java Server Faces (JSF) should also be considered. JSF is an API for: representing User Interface (UI) components and managing their state; handling events, server-side validation, and data conversion; defining page navigation; supporting internationalisation and accessibility; and providing extensibility for all these features. JSF offers a clean separation between behaviour and presentation. JSF maps HTTP requests to component-specific event handling and manages UI elements as state-full objects on the server. The separation of logic from presentation also allows each member of a web application development team to focus on his or her piece in the development process, and it provides a simple programming model to link the pieces. The team behind this service, with many partners and developers, will benefit from this. Another important feature of JSF is that JSF does not limit the developer to a particular scripting technology or mark-up language.

10.3.3.3 Security – data integrity

In order for end-users to be able to verify the correctness of data contents provided by the service, it is recommended to provide some means of data integrity mechanism on uploaded product files. The service should consider the use of digital signatures and certificates and implement this as a field of the product file. Enhancements in this area should be:

1. A signature mechanism that can be enabled on relevant products.
2. A signature verification mechanism for end users
3. A rudimentary management system for certificates
4. Optionally; a document signing policy module

10.3.3.4 Security – denial of service

There should be a strong protection mechanism that secures the communication between the machines in the network. The existing solution in EuroClim leaves the service relatively unprotected against:

1. Denial of service attacks (service disruption)
2. Integrity violations on communications
3. Misuse and unauthorised access

To reduce the risk of such attacks the service should consider the use of machine/server authentication as well. Such enhancements should be comprised of:

1. Use of server certificates and HTTPS/TLS for protection between machines
2. A rudimentary management system for administration of certificates/machines
3. Optionally a stronger authentication mechanism than username/passwords for system managers and administrators of the machines

10.3.3.5 Network performance

Transferring of huge quantities of data is time consuming. The use of JPEG2000 compression algorithms can be considered for reducing transition time for browsing products displayed via the portal. JPEG2000 can give up to three times compression ratio for lossless compression.

10.3.3.6 Ontologies to support a dynamic data distribution framework

To achieve a very flexible data distribution network, the dynamic combination of independent web services is required. Existing technologies have proven sufficient to implement basic system integration. However, as the sheer number of such services increases it will become more important to provide tools that allow not only people but also software to quickly find the services they need and integrate them dynamically, while minimizing the burden for those who wish to list their services. To achieve this aim, technology needs to provide standard ways of adding semantics to information so that both humans and machines can understand it. The emerging area of ontologies is seen as the technology needed to resolve this deficiency.

An ontology defines the terms used to describe and represent an area of knowledge. Research in the area of ontology (with respect to software development) began in the 1990s. However, recent standards have enabled the technology to begin to be applied in the commercial world. Despite encouraging signs, considerable work is still required to realise its potential in industrial settings. Many example systems now exist to highlight how the new technological standards can be leveraged, however, there are many challenges to be overcome to realise their benefits. There are many sources describing the research problems associated with the utilisation and sharing of ontologies within web services.

Ontology is an area of ICT probably not mature enough to be applied in this service yet. However, for long-term development of the system behind the service, ontologies should be seriously considered. What is most important to do today is to stick to standards such that the service we develop will be prepared for inclusion of ontologies in the future.

11 Description of the partners

Each of the organisations behind this report and key persons within the respective organisations are briefly described in the following.

11.1 Finnish Meteorological Institute

Ilmatieteen laitos (Finnish Meteorological Institute, FMI) is a research and service agency under the Ministry of Transport and Communications. FMI focus on weather and safety, change of climate and adaptation to it, atmospheric influences on the environment and mankind, and space and atmospheres. The Finnish Meteorological Institute is very active in the area of atmospheric remote sensing. FMI has participated in the design and construction of OMI (EOS-AURA), GOMOS (ENVISAT) and OSIRIS (ODIN) satellite instruments. The main research subject of the Finnish Meteorological Institute is the Earth's atmosphere. Other research topics include global change studies, earth observation and near space and solar influence on the planet's atmospheres. FMI has actively participated in numerous international projects. Currently, FMI participates in many EU 6th framework programme projects, hosts the ozone SAF (Satellite Application Facility) for EUMETSAT, participates in ESA's GMES Service Element for atmospheric remote sensing (Promote) and operates FIN-CoPac (Gomos data processing facility) for ESA.

Jarkko T. Koskinen has a doctorate degree from TKK in electrical engineering. He is currently research professor and head of Earth Observation Division in FMI. He is a delegate to several international organisations (ESA, EU, EUMETSAT, GEO). Previously, he has worked with TKK, SYKE and Tekes where his responsibility was the co-ordination of the national earth observation programme. Prof. Koskinen has also been a visiting scientist in 1994-1995 at ESA-ESRIN and 1999-2000 at JPL. His research interests include microwave remote sensing of snow and boreal forest and SAR interferometry. He has authored more than 70 international publications. Prof. Koskinen will work on the snow algorithms in the project.

11.2 IFREMER

Institut français de recherche pour l'exploitation de la mer (IFREMER) is a public body of industrial and commercial nature. Created on 5 June 1984 it is the only French organization with an entirely maritime purpose. It operates under the joint auspices of the Ministries of Research, Agriculture and Fisheries, Transport and Housing and Environment. The annual budget is approximately 150 million euros. The staff is composed of 1,385 executives, researchers, engineers, sailors, technicians and administrative persons, within 72 laboratories and research departments located in 24 centres along the mainland coast and in the French overseas territories. IFREMER operates seven research vessels, two manned submersibles, one 6000-metre ROV (Remotely Operated Vehicle) and testing facilities. Being involved in all the marine science and technology fields, IFREMER has the capability of solving different problems with an integrated approach. IFREMER's scope of actions can be divided into four main areas, each of them including different topics: Understanding, assessing, developing and managing the ocean resources; Improving knowledge, protection and restoration methods for marine environment; Production and management of equipment of national interest; and Helping the socio-economic development of the maritime world.

Robert Ezraty is senior scientist at IFREMER's centre in Brest. He is in charge of the sea ice project at IFREMER. He graduated from Ecole d'Ingénieur de Marseille (1968) and holds a Docteur Ingénieur degree in fluid mechanics from Institut de Mécanique Statistique de la Turbulence, Université d'Aix-Marseille (1971). He participated to several scatterometer-based sea ice projects: Co-PI Sea ice applications of the ESA/ERS-AMI/wind, Co-PI in the NSCAT sea ice /validation activities. Invited participant to the NASA QuikSCAT sea-ice validation activities. Principal Investigator of a NASDA/NASA-approved sea ice scatterometer project. He was also co-PI in European Supported Projects: IMSI (1994-1998), CONVECTION (1998-2002) and DAMOCLES (2005-2009). He is also co-PI of the ESA-supported projects ICEMON (2003-2004) and GlobIce (2005-2008). He is member of the ESA/EUMETSAT ASCAT Science Advisory Group.

Jean-François Piolle (CERSAT) holds a diploma of Computer Engineering, INSA, Rennes, 1996. From 1996-onwards he works as a computer engineer at CERSAT/IFREMER (Brest). He is now in charge of the operations, planning and developments related to CERSAT. He has been responsible for the data management and dissemination at CERSAT for two years. He is currently in charge of the IFREMER contribution to the ESA/Medspiration project.

Fanny Ardhuin is a post doc scientist who joined the sea ice group at IFREMER in Brest in 2004. She is supported both by CNES and IFREMER. She holds a PhD degree (2001) from Université Paul Sabatier, Toulouse. Her background is the study of the atmospheric boundary layer using UHF-RASS radar. She also worked on oil slick detection using SAR data. Her main task now is to promote the use the IFREMER's sea ice database through scientific geophysical projects, for instance the EC supported DAMOCLES project and the ESA-supported GlobIce project.

11.3 Geological Survey of Denmark and Greenland

Danmark og Grønlands Geologiske Undersøgelser (Geological Survey of Denmark and Greenland; GEUS) has over 30 years of experience in research and assessment of the Greenland ice sheet mass balance. Focus of the Greenland glaciology has been on mapping, data collection, process studies and assessment of changes and sensitivity within the most sensitive region of the ice sheet, namely the marginal ablation area. The long experience combined with the long-term monitoring has qualified the institution as the Danish source for ice sheet and climate information. The long experience on collecting data and recent implementation of novel technology for this has brought GEUS to a lead position regarding combined in situ and satellite monitoring of the melting of the Greenland ice sheet.

Carl Egede Bøggild, Senior Research Scientist, has a PhD degree in geophysics from the Niels Bohr Institute (University of Copenhagen) and over 24 years of experience on nearly all aspects of glaciological research and monitoring of the Greenland ice sheet. He has been involved in data collection, analysis, processing and data management as well as modelling, parameterisation (including development of algorithms) of both in situ and satellite data. He has published over 35 journal articles and has been a principal investigator on several national and international research projects. He is presently the principal investigator of a nationally funded research project to develop and implement national monitoring of the Greenland ice sheet mass balance and surface climate ICEMON (see: www.icemon.dk).

11.4 Helsinki University of Technology

Teknillinen korkeakoulu (Helsinki University of Technology, TKK) is the oldest and largest technical university in Finland, dating back to 1849 when the Helsinki Technical School was founded. It provides education in all technical fields and personnel is over 2500. The total number of students is 15000. Laboratory of Space Technology (LST) was established in 1988. The total annual number of person years is about 35. The director of LST started research on microwave remote sensing at TKK in 1972. The main research activity of the laboratory is microwave remote sensing, including the following fields: Development of microwave and millimetre wave radars and radiometers (including the development of satellite sensor technology); Airborne and ground-based measurements of geophysical targets; Development of inversion algorithms to interpret experimental data; Use of satellite data for various applications (main applications: forest, snow, sea ice, water quality); Theoretical and empirical modelling of targets; and Development of ground truth instruments to support remote sensing. LST operates a short SC-7 Skyvan aircraft. The regular instrumentation of the aircraft consists of the HUTRAD microwave radiometer system (6.8-94 GHz), the HUTSLAR side-looking airborne radar (9.5 GHz) and the AISA imaging spectrometer (400-900 nm).

Jouni Pulliainen, professor, holds a D.Sc (Tech.) degree in electrical engineering (Helsinki University of Technology, 1994). Scientific activities (210 publications) include assimilation of remote sensing data to physical models in environmental monitoring and forecasting, use of active and passive sensors for forest research, hydrology and cryospheric applications, modelling of emission and backscatter, and optical remote sensing of water quality. He has been a principal investigator of several nationally funded research projects. He is also assistant project manager in EC projects for LST in the 5th framework Programme and manager of ESA contracts.

11.5 Kongsberg Spacetec

Kongsberg Spacetec AS was established in 1984. The business focus is delivery of meteorological turnkey ground stations and value-added applications, environmental and surveillance ground station systems, system engineering, training, maintenance and support. Kongsberg Spacetec has close co-operation with many of the larger international space companies, and has been involved in several of the large European Earth observation programs, including ESA's ERS and ENVISAT programs, as well as EUMETSAT's MSG and METOP programs. Through this, Kongsberg Spacetec has gained experience in working with large development projects, both as prime and sub-contractor. Kongsberg Spacetec possesses a highly skilled staff and management working in accordance with quality routines fulfilling the ECSS (European Cooperation for Space Standardisation) software engineering standards. The ISO 9001 certificate was received in February 1998. Web page: http://www.spacetec.no.

Tove Tennvassås (M.Sc in Physics from University of Tromsø) has been and is project leader for several projects in the company: ICEMON, SOFOCCLE, ERS-1/2 and Radarsat-1 (SAR processors), EUCLID RTP and EuroClim. She has been system engineer in the following projects: Multi-Application Support Service System (ESA project), ENVISAT ASAR processing facility and general SAR processors development and maintenance. She is responsible for marine applications and market development.

Jørn Vegard Røsnes (M.Sc in Computer Science from University of Tromsø) is software engineer for development of web services, web applications and web catalogue systems. Experience from KNMI's (www.knmi.nl) OMBE catalogue and processing system, the ESA funded MASS project (today Service Support Environment) and EuroClim. Programming languages/scripts: Java, C++, C, SQL, Velocity, Java Server Pages and more. Experience with tools and environments such as Apache Ant, Axis, Struts, Tomcat, Turbine, Xerces, Xalan, Expresso Framework, JDBC, JDOM, ODBC, Oracle Database, PostgreSQL, mySQL, SOAP, XML, XSD, XSL, WMS and more.

11.6 Nansen Environmental and Remote Sensing Center

Nansen Senter for Miljø og Fjernmåling (Nansen Environmental and Remote Sensing Center, NERSC) was founded in 1986 as an independent non-profit research institute affiliated with the University of Bergen. NERSC performs interdisciplinary basic and applied research related to the physical environment, natural resources and climate by integrated use of satellite and aircraft remote sensing, in situ observations and numerical modelling tools. The centre plans and executes international research programs funded by research councils, governmental agencies and industry mainly focused 1) development and validation of remote sensing methods in earth observation, 2) applications of remote sensing in coastal zone management, marine monitoring and forecasting of ocean physical and biological variables, marine pollution and sea ice, 3) development of numerical models for studies of marine environmental parameters and global/regional climate variations, 4) development of assimilation techniques for utilization of remote sensing data in ocean dynamics, coupled ecology as well as water quality modelling and 5) global and regional climate studies with focus on the role of sea ice and ocean circulation at high latitudes.

Stein Sandven, Research Director, has investigated marine, coastal and polar remote sensing, polar oceanography and sea ice since 1979. He is leader and participant in several national and international research projects and coordinator of many projects funded by EU and ESA, such as OSIMS, IMSI, IWICOS, SITHOS and DISMAR. He has been leader of EuroGOOS Arctic Task Team since 2001 and member of ESA CryoSat CalVal team since 2002 and supervised M.Sc. and Ph.D. students. He is presently coordinating the sea ice work in MERSEA integrated project.

Other personnel from NERSC to be involved is: *Kjell Kloster* (senior scientist), responsible for SAR data ordering, SAR analysis and production of high-resolution ice charts in the Kara Sea and ice flux estimates in the Fram Strait; *Mohamed Babiker* (scientist), responsible for GIS and image analysis using ARC/GIS and ERDAS Imagine and production of final products for the users; *Laurent Bertino* (research leader), leader of the modelling and data assimilation group at NERSC and responsible for operating the TOPAZ system (he will be responsible for formatting and distribution of ice forecasting products to users); *Torill Hamre* (scientist) responsible for software maintenance and upgrade and of the processing system for remote sensing data; and *Morten Stette* (scientist) responsible for web site, data distribution and archiving.

11.7 NORUT Information Technology

NORUT Information Technology Ltd (NORUT IT) located in Tromsø, Norway is an applied research institute in the field of earth science and information technology. NORUT IT research areas include environmental and resource monitoring, remote sensing and image processing technology, geographical information network, distributed multimedia applications, high speed data communication, and object-oriented methods for data modelling and system development. The institute has since it was established in 1984 had a large activity in research and development of earth-observation application. This activity includes issues like distributed system architectures and service infrastructures, data modelling, data management and service definitions. NORUT IT combines earth observation science with computer science and software development.

Eirik Malnes, senior research scientist in the Earth Observation Group. He received his M.Sc. degree in 1991 and his Ph.D. in 1994 from the University of Tromsø in space plasma physics with special focus on incoherent scattering radar. From 1994 to 1997 he held a postdoc position in Tromsø and Grenoble, France. From 1997 to 2001 he was a senior scientist at The Norwegian Defense Research Establishment (FFI) working with active and passive radar applications. From 2001 he has been employed at NORUT IT as a senior scientist. His field of interest is various applications of Synthetic Aperture Radar (SAR), including physical modelling of scattering mechanisms and statistical signal processing in connection with earth observation of snow, sea ice, glaciers and floods. He is currently project leader of several national and international projects related to remote sensing of the cryosphere and floods.

Asgeir Finnseth, senior research scientist, received his M.Sc. degree in computing science at University of Tromsø in 1989, and has more than 20 years of experience in the area of software development. His main interest in recent years has been on distributed systems for processing of geographical information.

Gudmundur S. Jøkulsson, senior research scientist, received his M.Sc. degree in computing science at University of Tromsø in 1991, with focus on communication technology and distributed systems. In the recent years his main interest has been within geospatial applications, system integration and services, including profiles and application schemas development derived from OGC standards.

11.8 Norwegian Computing Center

Norsk Regnesentral (Norwegian Computing Center, NR) was established in 1958 as an independent research institute. Since then, NR has been a centre for advanced R&D within information technology and statistical-mathematical modelling. NR has Norway's largest research group within statistical-mathematical modelling and is heavily into remote sensing as well as modelling of natural resources – like oil and gas reservoirs and hydroelectric power generation – and estimation of the population of whales and fish, forestry and agriculture. The remote sensing research aims particularly at development of image analysis and classification methods. NR has long experience in development of algorithms for retrieval of cryospheric parameters (related to snow and sea ice) and bio-physical parameters (related to forest and vegetation in general). At the end of 2004, NR had 60 employees including 50 research scientists. Some research scientists have part-time professorships at the University of Oslo and the Norwegian University of Science and Technology (NTNU) in Trondheim.

Rune Solberg, chief scientist, is head of the Remote Sensing Group at NR. He has over 20 years of experience within the field of remote sensing research, and he has worked on algorithms for retrieval of cryospheric variables for more than 15 years. His current main interests are optical and multi-sensor retrieval of snow variables with applications in climate change monitoring and hydrological modelling. He has co-ordinated several EC projects on remote sensing R&D for the last ten years, including the EuroClim project which developed a prototype system for monitoring of cryospheric variables and climate modelling in the Euro-Arctic region.

11.9 Norwegian Meteorological Institute

Meteorologisk Institutt (Norwegian Meteorological Institute, met.no) was founded in 1866. Today, met.no has approximately 500 employees. The main office is in Oslo and there are regional offices in Tromsø and Bergen. Met.no provides the public meteorological services for both civil and military purposes. Among the core activities of met.no are developing and improving operational models, tasks related to environmental emergency services, and general climate research and climatological services (observations, databases and general climatological information). Section for remote sensing in the R&D Department is working with utilization of various satellite data in now-casting of weather and sea state and for assimilation in numerical weather and sea state models. Satellite data are read down locally and received via networks. In the EUMETSAT Ocean & Sea Ice Satellite Application Facility, O&SI SAF, met.no is hosting the operational High Latitude Centre responsible for the daily sea ice products. An automatic analysis system, which derives sea ice products by combining satellite data from different sensors, has been developed and implemented for operational use.

Lars-Anders Breivik, head of Remote Sensing Section, R&D Department, Cand. Scient. in Meteorology, University of Oslo (1987). Breivik has 12 years of experience with work on utilization of remote sensing data in operational meteorology and oceanography. From 1998 to 2001 he was project manager for the development of the High Latitude Ocean & Sea Ice Satellite Application Facility (O&SI SAF), EUMETSAT. Breivik is member of EUMETSAT STG Science Working Group and ESA/EUMETSAT ASCAT Science Advisory Group

Steinar Eastwood, Cand. Scient. in Meteorology from the University of Oslo. His research experience covers objective analysis of data from optical and microwave sensors in polar orbits in the fields of sea surface temperature, radiative fluxes, sea ice, snow cover and precipitation during his eight years of employment at met.no.

11.10 Norwegian Polar Institute

Norsk Polarinstitutt (Norwegian Polar Institute; NPI) is Norway's central institute for research, environmental monitoring and mapping in the polar regions. NPI is a directorate under Norway's Ministry of Environment. The institute is responsible for environmental management and counselling, environmental data collection and dissemination, and topographic and thematic mapping in the Arctic and Antarctic regions. NPI coordinates the national environmental monitoring programme in Svalbard and the Northern Seas. NPI has its head office Tromsø, and operates research stations in Svalbard and Antarctica, and the research vessel R/V Lance.

Jack Kohler is a research scientist in polar hydrology, currently in charge of NPI's mass balance program in Svalbard. He holds a PhD in glacial hydrology from the University of Minnesota (1992), and has over 15 years of experience in Arctic and Antarctic fieldwork. His current research interests include: relation between climate and mass balance; operational glaciology; and relation of snow-pack dynamics to terrestrial ecosystems.

Stein Tronstad is head of the Environmental Data Section at the NPI, and coordinates NPI's environmental data and remote sensing services. He is a chartered civil engineer from the Norwegian Institute of Technology in Trondheim (1983). Tronstad is a member of the steering group in the Norwegian Space Centre funded programme SatHav, which is intended to facilitate the development of operational, satellite-based environmental monitoring in Norway.

11.11 Scottish Association for Marine Science

The Scottish Association for Marine Science (SAMS) is one of the oldest oceanographic organisations in the world. SAMS was formerly a component institute of the Centre for Coastal and Marine Sciences (CCMS), one of key research centres of the UK Natural Environment Research Council (NERC). SAMS regained organisational independence in 2001 and is now is a Collaborative Centre of the NERC. The central aims of SAMS are to undertake long-term and fundamental strategic research, to contribute to and support the national and international marine science community and to underpin the societal and educational needs of the UK and wider Community. SAMS consists of 62 academic staff, 30 technical staff and 23 PhD students.

Nick Hughes has been a research scientist since 1994. He has been involved in development of remote sensing algorithms to determine sea ice parameters for the IRIS and EuroClim EC 5th Framework projects and leads the Cryospheric Variables Group within EuroClim. In April 2004 he participated in the Royal Navy’s ICEX-04 on board the submarine *HMS Tireless* as a sea ice advisor. He has also been involved in numerous field campaigns in the Arctic and Antarctic.

11.12 UNEP/GRID-Arendal

UNEP/GRID-Arendal is the official United Nations Environment Programme Key Polar Centre, established as a concrete follow-up of the recommendations of the World Commission on Environment and Development. The Polar Programme provides services in environmental information, assessment and capacity building, and has staff based in Norway, Sweden and Canada. UNEP/GRID-Arendal has official observer status at Arctic Council Senior Arctic Officials and working group meetings. UNEP/GRID-Arendal has 15 years experience in the development of indicators as tools for state of environment reporting. Methodology developed through UNEP/GRID-Arendal has been applied throughout the world, for countries, regions and urban areas. GRID-A contributes to UNEP’s state of environment reporting (GEO: Global Environment Outlook) and leads the development of the Polar sections of the annual reports (Yearbooks) and the 5-year reports (GEO 4 will be released in 2007).

Joan Eamer (MSc, Zoology, Univ. British Columbia), has over ten years experience in development of indicators and state of environment reporting in northern Canada, including development of the first SOE report for the Yukon, development of an indicator series for the Arctic Borderlands (a region of northern Alaska, Yukon and Northwest Territories) and development of status and trends reporting for the Ecological Monitoring and Assessment Network for Northern Canada (EMAN-North). She has also reviewed and contributed to regional and national environmental indicator development and reporting, including Canada’s national State of Environment report series, national climate change indicators, and the Mackenzie Basin State of Aquatic Environment Report. She worked for Environment

Canada's Northern Conservation Division, as head of the Ecosystem Health Division, for the past 15 years, and joining UNEP/GRID-Arendal as Manager of the Polar Programme in early 2005.

Hugo Ahlenius (MSc, Physical Geography, Uppsala Univ.) specializes in GIS, cartography and interactive web-based mapping applications. He has developed and advised on many mapping projects for Arctic Council working groups, and produced graphics for print and web-based publications. The most recent of these is the Vital Arctic Graphics, released at the UNEP Governing Council session in 2005 (http://www.vitalgraphics.net/arctic.cfm).

11.13 University of Bristol

Bristol Glaciology Centre (BGC) of the University of Bristol has many years experience in the analysis and interpretation of satellite data from the polar regions including active and passive microwave sensors, infra-red radiometry and particularly radar and laser altimetry of the ice sheets. In addition the BGC has extensive modelling expertise. Within the framework of the JOINT RAPID UK/Dutch/Norwegian programme they are developing a surface mass balance model for incorporation into a high-resolution GCM. Jonathan Bamber is the PI on this activity.

Jonathan L. Bamber has a degree in physics (Bristol) and a PhD in glaciology/remote sensing (Cantab). Prof Bamber has 22 years experience in the analysis of airborne/satellite data sets from the polar regions, specialising in the use of radar and laser altimetry over the Greenland and Antarctic ice sheets and more recently in combining these data with models of the cryosphere-climate system. He has published over 50 journal articles on these topics and was the lead editor on a major new textbook on the mass balance of the cryosphere.

11.14 University of Cambridge

Department of Applied Mathematics and Theoretical Physics (UCAM-DAMTP) of University of Cambridge carries out research of world class excellence in many areas of fluid dynamics and wave propagation, in addition to its work in cosmology, quantum computing and other leading-edge areas of theoretical physics. Relevant research fields include geophysical (including ocean) fluid dynamics, atmospheric dynamics, turbulence, acoustic wave theory and stochastic wave propagation. The Polar Ocean Physics Group works on sea ice properties and dynamics, with international links and extensive field experience. DAMTP has, in addition, wide expertise in ocean acoustics, solid mechanics (relevant to ice studies), theoretical physics, numerical methods and computing techniques as well as laboratory facilities such as cold rooms. The Department is graded *5 in the latest Research Assessment Exercise, the highest possible rating.

Peter Wadhams, professor of Ocean Physics, has 35 years of experience in research into sea ice and ocean processes in the Arctic and the Antarctic – he is the UK's most experienced sea ice researcher. He has led 40 polar research expeditions, working on the dynamics and thermodynamics of sea ice; sea ice thickness; waves in ice; icebergs; ocean convection and kindred topics. He is currently co-ordinator of the EC FP5 GreenICE project and partner in two other current EC Arctic projects. He was director of the Scott Polar Research Institute in Cambridge from 1987-92 and has an ScD from Cambridge University and a Polar Medal from the Queen as well as being winner of the 1990 Italgas Prize for Environmental Sciences. He is currently on the Scientific Committee of the European Environment Agency.

Martin Doble has prepared, planned and led six successful winter field programmes in the Arctic and Antarctic (three aboard the Polarstern). He maintains close links with German (AWI) and Danish (KMS, DTU) groups and is currently working on the comparison and integration of ice thickness determined by tiltmeter, electromagnetic and laser systems, as part of the current EU GreenICE programme (EVK2-2001-00280). He also took part in the recent Canadian CASES experiment aboard the new scientific icebreaker Amundsen, deploying drifting buoys into the Beaufort Sea to track the ice motion there. His previous research concentrated on Antarctic sea ice growth and motion, describing and modelling a new mechanism for pancake ice growth.

11.15 Vexcel UK

Vexcel UK was established in 2001, as a subsidiary of Vexcel Corporation based in Colorado, USA. The company has focused on the development of marine and polar applications of earth observation, including such topics as infrastructure for future sea ice services and an offshore wind energy database for the energy industry. Of relevance to this proposed project, Vexcel is in the process of completing a study with NASA's Goddard Institute of Space Studies and the UK Met Office looking into the role of sea ice in the climate, with several publications under preparation. Vexcel UK has experience in working with a wide variety of polar and marine users and in understanding their requirements as well as the technological potential and limitations of earth observation data in meeting these requirements. Vexcel UK also, through work with the Royal Navy, has experience in the development of advanced EO data visualization techniques which the Navy uses for its fleet weather services. Vexcel UK has expertise and technology for the end-to-end capture, processing and dissemination of data from commercial EO satellites.

Key personnel from Vexcel UK include *Kim Partington*, the Managing Director of Vexcel UK, and *David Simonin*, who has strong experience in the role of sea in climate. Kim Partington has a background in polar applications of earth observation. In his previous roles he has been manager of NASA's Polar Program, chief scientist at the US National Ice Center and associate professor at the University of Alaska Fairbanks. David Simonin has a PhD in SAR remote sensing of the ocean and has been involved in the last three years at Vexcel UK in investigating the role of sea ice in climate through GCMs (HADCM3 and GISS Model E) and through satellite observations.

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