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REMOTE SENSING IN THE NORTHERN DIMENSION: OVERVIEW AND APPLICATIONS

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Foreword

The *Northern Dimension Research Centre* (NORDI) is a research institute run by *Lappeenranta University of Technology* (LUT). NORDI was established in the spring of 2003 to co-ordinate research into Russia.

NORDI's mission is to conduct research into Russia and issues related to Russia's relations with the *European Union* (EU), with the aim of providing up-to-date information on different fields of technology and economics. NORDI's core research areas are Russian business and economy, energy and the environment, the forest cluster, the ICT sector, as well as Russia's logistics and transport infrastructure. The most outstanding characteristic of NORDI's research activities is the way in which it integrates technology and economics.

LUT has a long tradition in performing research and educating students in the field of communist and post-communist economies. From this perspective, LUT is ideally located in Eastern Finland near the border between the EU and Russia.

The *Machine Vision and Pattern Recognition Research Group* (MVPR) belongs to the *Laboratory of Information Processing*, which is part of the *Department of Information Technology* at LUT. The research fields of the group are machine vision, pattern recognition, image processing, and their applications.

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Abbreviations and Acronyms

AARI	Arctic and Antarctic Research Institute
ADEOS	Advance Earth Observation Satellite (aka. Midori)
ALOS	Advanced Land Observing Satellite
ASAR	Advanced Synthetic Aperture Radar
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
CDOM	Coloured Dissolved Organic Matter
CEOS	Committee on Earth Observation Satellites
CERES	Clouds and the Earth's Radiant Energy System
chl-a	Chlorophyll-a
cm	Centimetre
CNES	Centre National d'Etudes Spatiales
DOM	Dissolved Organic Matter
Envisat	Environmental Satellite
EO	Earth Observation
EOS	Earth Observing System
ESA	European Space Agency
ETM+	Enhanced Thematic Mapper Plus
EU	European Union
FIMR	Finnish Institute of Marine Research (Merentutkimuslaitos)
FMI	Finnish Meteorology Institute (Ilmatieteen laitos)
FNU	Formazine Nephelometric Unit
GEOS	Geo-stationary Earth Observing Satellite
GEOSS	Global Earth Observation System of Systems
GLI	Global Imager
GOMOS	Global Ozone Monitoring by Occultation of Stars
HRG	High Resolution Geometric
HRS	High Resolution Stereo
HRV	High Resolution Visible
HRVIR	High Resolution Visible and Infra-Red
HUT	Helsinki University of Technology
HUT Space Lab	Laboratory of Space Technology at HUT
IGOS	Integrated Global Observation Strategy
IR	Infra-Red
IRS	Indian Remote Sensing
ISRSE	International Symposium on Remote Sensing of Environment
km	Kilometre
K-nn	K-Nearest Neightbour
LUT	Lappeenranta University of Technology
m	Metre

mm	Millimetre
MERIS	Medium Resolution Imaging Spectrometer
METLA	Finnish Forest Research Institute (Metsäntutkimuslaitos)
MISR	Multi-angle Imaging Spectro-Radiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
MOPITT	Measurement of Pollution in the Troposphere
MSS	MultiSpectral Scanner
NASA	National Aeronautics and Space Administration
NIR	Near Infra-Red
nm	Nanometre
NOAA	National Oceanic and Atmospheric Administration
NORDI	Northern Dimension Research Centre
NPOESS	National Polar-orbiting Operational Environmental Satellite System
RBV	Return Beam Vidicon
ROSCOSMOS	Russian Federal Space Agency
SALMON	Satellite Remote Sensing for Lake Monitoring
SAR	Synthetic Aperture Radar
SeaWIFS	Sea-viewing Wide Field-of-view Sensor
SOOP	Ship of Opportunity
SPIN-2	Space Information-2 Meter
SPOT	Système Pour l'Observation de la Terre
SYKE	Finnish Environment Institute (Suomen Ympäristökeskus)
TEKES	National Technology Agency of Finland
TIROS	Television Infrared Observation Satellite
TIR	Thermal Infra-Red
TM	Thematic Mapper
UN	United Nations
USGS	United States Geological Survey
VNIIKAM	Institute of Remote Sensing Methods for Geology
VNIITSLesresurs	All-Russian Research and Information Center for Forest Resources
VTT	Technical Research Centre of Finland (Valtion Tieteellinen Tutkimuskeskus)
μm	Micrometre

Abstract

With the recent increase in environmental awareness, the need for data on the environment is growing. However, as the process of gathering data by in situ measurements is time-consuming and expensive, satellite instruments are often used to acquire information in a cost-effective way with remote sensing techniques.

This document provides an introduction to the remote sensing techniques and equipment used in environmental monitoring. The areal focus is on the Northern Dimension of the European Union. International co-operation and organisations are discussed in addition to region-specific applications.

Applications of monitoring the water quality in the Baltic sea and inland waters are discussed, as well as monitoring the ice cover of arctic regions. Stocktaking, mapping and hot spot detection are important areas of forest monitoring. Atmospheric applications include monitoring of gas concentrations, and ground area monitoring can be used for example in urban planning.

Tiivistelmä

Viime aikoina kasvanut ympäristötietoisuus on tuonut mukanaan lisääntyneen tarpeen mittauksille ympäristön tilasta. Mittausten tekeminen manuaalisesti paikan päällä on aikaavievää ja kallista. Ratkaisuna tähän voidaan käyttää satelliittien kaukokartoitusinstrumenteilla tuotettua dataa, jonka avulla mittaustiedot saadaan kattamaan laajempia alueita kustannustehokkaasti.

Tämä dokumentti esittelee kaukokartoituksen periaatteita ja sovelluksia. Alueellinen painotus on Euroopan Unionin pohjoisella ulottuvuudella. Kansainvälinen yhteistyö ja organisaatiot esitellään lyhyesti.

Vesialueiden sovelluksista esitellään vedenlaadun monitorointi Itämerellä ja sisävesillä sekä Itämeren ja arktisten alueiden jäätilanteen monitorointi. Inventointi ja nopeasti muuttuvien alueiden havainnointi ovat tärkeitä metsäalueiden monitoroinnin sovelluksia. Lisäksi esimerkiksi ilmakehästä voidaan seurata erilaisia kaasukeskittymiä ja maa-alueilla satelliittikuvia voidaan käyttää kaupunkisuunnittelussa.

1 Introduction

This document provides an introduction to the field of remote sensing and environmental monitoring in the area of the Northern Dimension of the European Union[1] [1]. It has been written as an initial survey to the topic, with the purpose of finding out promising areas for future research and co-operation. The document describes current activities and possibilities in the field, with areal focus on Finland and Russia. In addition to these goals, the document includes an extensive list of references to further information, to be used as a starting point in case a reader needs more comprehensive knowledge on a certain topic.

The need for observational data about the environment is constantly increasing [2]. Preservation of the environment and keeping our planet healthy is a constant hot topic, and the field is looking for new methods of controlling and observing the effect of human activities on the environment. An increase can also be observed in the need of environmental data for financial purposes, such as planning land cover use, or stocktaking of woods for determining their value. With the technology taking further steps in monitoring techniques, the possibilities for applications making use of the acquired data increase.

Environmental issues do not respect state borders. Even though different nations may have different practices, regulations and laws with regard to environmental issues, the environment spreads the effects of negligence of one nation to others. Therefore international co-operation has become very important and effective in the field of environmental monitoring. Often the organisations providing and using the data are highly networked with international partners.

As is often the case, technical development moves on with the power of promising views on cost savings in the future. Considering the financial side instead of 'green' values, predicting changes in the environment may lead to remarkable savings. It has been stated that if the temperature forecasts were more precise just by one degree of Fahrenheit, the United States alone would save $1 billion on annual electricity costs [3]. Droughts cost several billion dollars to the agriculture annually, and with recent events like the tsunami in Asia in 2004 and the hurricanes in the Caribbean in 2005, the value of predicting such disasters is clear.

The usability of remote sensing data has been limited due to restrictions in technical capabilities.Now that technology makes it possible to get high resolution imagery in several spectral bands at the same time, also the number of possibilities where remote sensing data can be used has increased. Section 2 of this document will describe remote sensing more thoroughly, but for now it can be considered just as imaging from a satellite, as that is the way we will mostly refer to it here.

The advantages of remote sensing when compared to traditional methods of environmental data gathering are often the same, regardless of the application area. A larger area can be measured at

[1] The *Northern Dimension of the European Union* is an initiative for increasing co-operation and addressing region-specific issues in northern Europe. The initiative covers the Nordic countries, the Baltic States and Russia.

once, instead of pinpointed sample locations. This leads to increased coverage of measurements in the area under surveillance. In addition, the need for field measurements requiring time and effort reduces. The data can be collected far more often and even from locations where it would be difficult to arrange manual sample taking. Sometimes the cost of traditional mapping methods has already become too expensive when compared to the acquired information [4].

Finally, as the requirements to monitor environmental issues are increasing all the time with the rise of environmental awareness, the price tag on the monitoring activities grows in importance. Recently the European Union has also shown grown interest in giving regulations on environmental issues, such as the *Water Framework Directive* [5], forcing the nations to act on the requirements. As a general rule of thumb it can be stated that by using remote sensing data, information can be acquired in greater quantities with lower cost than by field measurements alone.

This document has been written in a co-operation project between the *Machine Vision and Pattern Recognition Research group* of the *Laboratory of Information Processing* and the *Northern Dimension Research Centre* (NORDI) at *Lappeenranta University of Technology* (LUT). Considering its physical location, Lappeenranta University of Technology is conveniently situated for building co-operation between Finland and Russia. NORDI is working actively on projects dealing with the Russian economy and other related matters. There are, therefore, connections and expertise for building co-operation. The *Laboratory of Information Processing* has also experience in joint research projects with Russian partners.

Even though this document often refers to Finnish applications as examples because of the better availability of information, the Northern Dimension perspective is strongly included. Information on the use of remote sensing data in different applications of environmental monitoring, both on the Finnish and Russian side, will be given as examples whenever available. On some topics, actions of other countries are briefly mentioned as well, due to similar activities in the same or similar environment. The fields of environmental monitoring discussed here are water, forest, atmosphere, and ground monitoring. The topics have been selected and weighted according to the importance of the field in the discussed region. Although a major application all over the world, weather forecasting has been left out.

The rest of this document is organised in the following way: section 2 describes the principles of remote sensing. The equipment used to gather the data and the ways to gain access to it are described, with some mentions of the organisations in the process. Sections 3 and 4 will give a more detailed overview of applications, techniques and problems related to the monitoring of water bodies and forests, respectively. More brief descriptions of atmospheric and ground applications will be given in Sections 5 and 6. Finally, Section 7 summarises and draws conclusions on the topics discussed in the document.

2 Remote Sensing and Environmental Monitoring

Remote sensing, as defined by Lillesand and Kiefer [6], is "*the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation.*" The term *remote sensing* was first used by Evelyn Pruitt in 1950, but the first proposal of using a rocket as a platform for photography arose as early as in 1891 [7]. Although the term can be used with this broad definition to cover everything from the reader reading this paper to Envisat mapping the ozone layer over Antarctica, in this document we will mainly discuss spaceborne remote sensing instruments and applications. Therefore the term *remote sensing* is used here mostly to refer to spaceborne measurements. This section will proceed by briefly describing the methods of remote sensing, followed by an introduction of instruments and satellites. In the end, different organisations, co-operation, and sources of remote sensing data for the user will be discussed.

Remote sensing can be thought of as recording electromagnetic radiation reflected from or emitted by an object. There are two possible approaches to this task. Passive remote sensing takes advantage of the radiation originating from the sun, while in active remote sensing radiation is emitted by the sensor and its reflection is recorded. This concept is depicted in Figure 1.

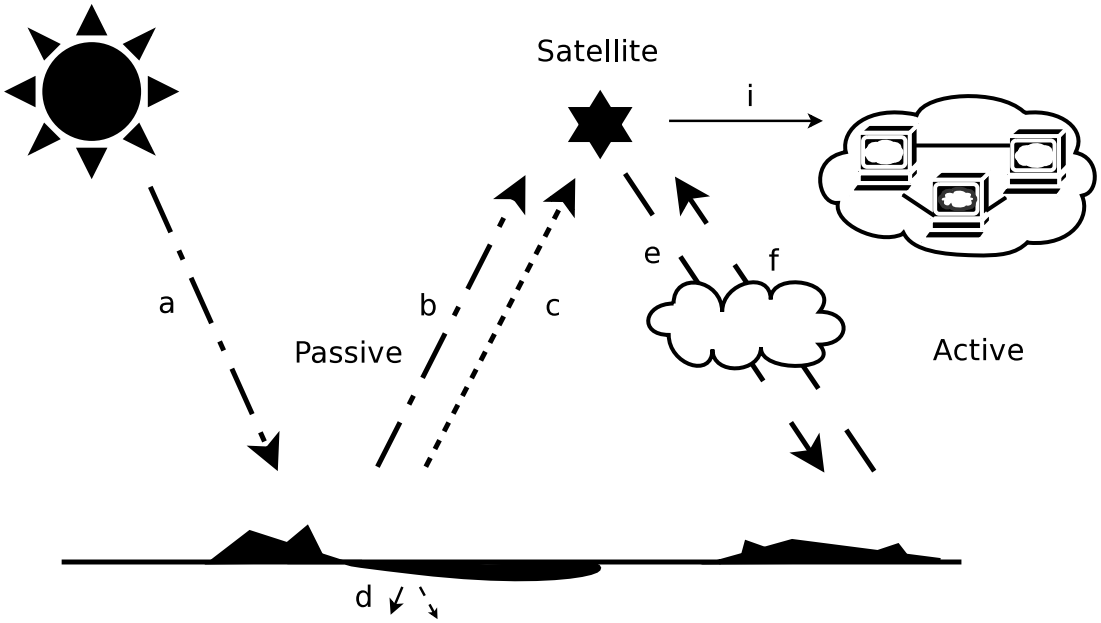

Figure 1: The process of remote sensing. Image partially after [6].

Figure 1 shows the principles of active and passive remote sensing. Passive remote sensing starts with the sun radiating through the atmosphere towards the Earth (a). Some of the radiation is reflected back to the atmosphere, where some of it is dispersed and some will continue all the way back to the space for satellite payload sensors to register (b). The surface of the Earth (ground, water) also gathers some energy from the radiation, which is emitted back to the atmosphere and then to the space (c). A part of the radiation is also absorbed by and transmitted

to the Earth (d). A downside of passive sensing is, that it is dependent on the sun. In cloudy weather, the clouds may block the radiation from reaching the satellite.

Active sensing, on the other, hand uses radiation originating from the sensor itself (e, f). All kinds of radars are active remote sensing instruments. Active instruments are capable of imaging at all hours of the day, and usually employ such wavelengths that clouds can be seen through. In the end the satellite, active or passive instruments aboard it, delivers the measured data back to the Earth for analysis (i).

By what wavelengths are reflected and absorbed, conclusions on what is seen in the image can be drawn. Even the colours that we see are just a certain range of wavelengths that objects either reflect or absorb in varying intensities. The continuous distribution formed by the reflectance/absorption spectrum is often referred to as the *spectral fingerprint* or *spectral signature*.

The reflectance of certain materials is strongly biased to a certain part of the spectrum. For example, separating rocks from water is quite straightforward due to significant differences in their spectral signatures. Often the general level separation of surface cover could be done quite easily just on the basis of the visible area of the spectrum, as rocks do look quite different from the ocean, but using other regions of the spectrum gives more possibilities. Figure 2 displays the electromagnetic spectrum and the names of different spectral ranges.

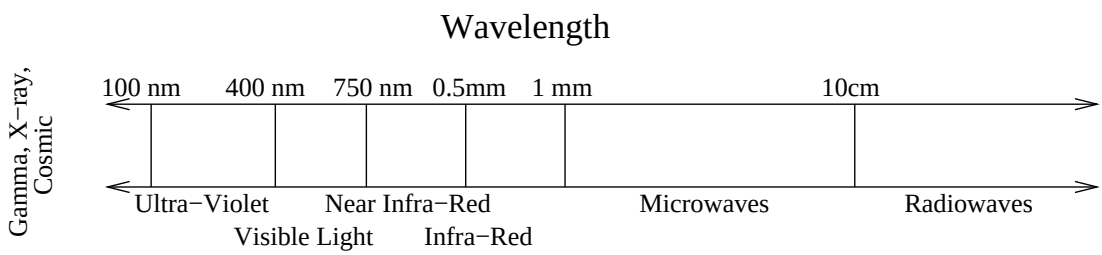

Figure 2: The electromagnetic spectrum, and titles for different wavelength regions. Notice that the scale in the image is not correct.

The passive instruments used in remote sensing applications usually image selected wavelengths in the region from just below visible light to the end of the infra-red area. Often *near infra-red* (NIR) is used together with visible light to create *false colour images*[2]. NIR is very useful for example in vegetation monitoring, as different plant species are often separable by their absorption in the NIR-area. Likewise, other wavelengths reveal other parameters of the underlying surface. Often the actual valuable information is not that easily available, but has to be calculated by finding correlations between different wavelenghts. Active instruments usually work in the longer wavelength areas, nowadays most often in the microwave section of the spectrum. Due to the much longer wavelengths compared to visible light, the microwaves are able to penetrate the atmosphere in almost any conditions, thus removing the problem of cloudy weather [6].

[2]Images where colours are used to represent some other wavelengths than in reality.

Knowing that properties of objects can be discovered by monitoring the electromagnetic radiation they reflect, the instruments used for the observation are now considered. Measurements can be done with anything from a handheld spectrometer focusing on a small area of the ground to an instrument carried on board a satellite and imaging the width of several hundred kilometres at a time. Here we will mainly focus on large scale imaging (or rather one done high up from the ground).

Mere space monitoring is not enough, at least not with the current state-of-the-art instruments. Calibration data is needed for designing algorithms and finding correlations between image properties and environmental phenomena. In some applications, even nearly concurrent *in situ* measurements are needed for the calibration of satellite data due to natural changes in the imaging environment, such as the seasons of the year [8].

There are also other problems related to the remote sensing process besides finding the right compositions of spectral channels to figure out the desired parameters of the nature. The atmosphere interferes with the signal, and corrections must be done before using images taken on consecutive days/weeks together. Also mapping a pixel in the image to the place on the surface it represents can be problematic. This is necessary, however, for without attaching the image to a map, it is impossible to connect image data and measured calibration data. In addition, mapping is necessary for combining several images into a mosaic image.

2.1 Our Eyes in the Sky

Like the scope of what activities can be classified as remote sensing is quite large, so is the variety of equipment used to perform those activities. Even when focusing on the part of the definition containing only photographic methods, there have still been all kinds of ways to manage the act. The progress has moved on from cameras strapped to carrier pigeons and kites to high-tech satellites tirelessly orbiting the Earth [7]. This section will introduce the general properties and terminology of satellite instruments.

The monitoring application sets some constrains on the data being used. Depending on what is being monitored, an instrument with suitable spatial, temporal and spectral resolution should be selected as the data source. In addition to these, also the price of the data sets some constraint on the selection. The spatial resolution defines how large one pixel in the image is in the nature. Most of the environmental monitoring satellites have spatial resolution from 10 m to 1 km, with the most accurate commercial satellites reaching to slightly better than 1m accuracy. Speculations on the military satellites of the United States give their precision around 10 cm [9]. Figure 3 illustrates the meaning of spatial resolution.

Temporal resolution defines the rate of how often the satellite images a certain area. This is often called *global coverage*, meaning the time it takes for the satellite to image the whole Earth surface. Depending on the phenomenon under observation, data might be needed once a day,

(a)

(b)

Figure 3: Example of the meaning of spatial resolution [10]: (a) 10 m pixel; (b) 2 m pixel.

once a week, or only once in a year. In some applications, like weather forecasting, networks of satellites are used to get more frequent data. The swath width of the satellite describes how wide an area the satellite is capable of imaging in one moment. This factor acts as a link between the temporal and spatial resolution of the satellite. The narrower the measured area on the ground, the narrower the recorded pixels.

The spectral resolution defines the band width and number of spectral bands. The narrower the bands, the more precise the measurements. The bands in a single instrument are often concentrated on a certain wavelength range, depending on planned usage areas. When there are several narrow bands in a certain wavelength range, precise measurements on that spectral range can be made. In contrast, if there are wider bands in a wider area of the spectrum, the instrument is more versatile. Instruments capable of imaging in several (generally more than 10) spectral bands are often called *multispectral*. In the same way, the term *hyperspectral* is used of instruments imaging more than 100 different, usually very narrow, spectral bands. In [6], the term *ultraspectral* is used to denote instruments capable of imaging thousands of narrow spectral bands, allowing enhanced separation between objects with closely similar spectral signatures.

Ever since the first experimental images received from TIROS-1 [11] (*Television Infrared Observation Satellite*, launched in 1960) showed the usefulness of satellite monitoring of the earth, better and better instruments have been taken to orbit. According to the *Committee on Earth Observation Satellites* (CEOS), there were 68 active satellite missions monitoring the Earth in January 2005 [12]. They exist for different purposes, from the traditional collection of weather forecasting data to monitoring ships for oil slicks.

Table 1 lists some example spectral bands and their spatial resolution from some of the popular satellites/instruments in environmental remote sensing. The list is not comprehensive, but its purpose is to give an idea of what kind of bands there are. This section proceeds to introducing a few satellites in further detail. Even though weather forecasting is a type of environmental monitoring, and the starting point for the development of earth observing satellites, here we will concentrate our focus on earth surface monitoring.

2.2 Spaceborne Instruments

This section will give a description of some of the most commonly used satellites and instruments in the field of environmental monitoring. First, Landsat and TERRA from NASA will be described, followed by the French SPOT-series. An important area with regard to this document, Russian satellites, will be described in their own subsection. Finally, Envisat from ESA and a brief mention of other satellites in addition to references for further information will be given.

Table 1: Some satellites and examples of instruments aboard them. Sample bands and their spatial resolution for the band are given in [6][13]. The shown bands are examples of the bands in the instruments, not complete listings.

Satellite	Instrument	Sensitivity (μm)	Resolution (m)
Landsat-5	TM	0.45-0.52	30
		0.52-0.60	30
		0.63-0.69	30
		0.76-0.90	30
		1.55-1.75	30
		10.4-12.5	120
		2.08-2.35	30
Landsat-7	ETM+	Same as Landsat-5 TM bands	30 (thermal band 60m)
		0.50-0.90	15
SPOT-2	HRV	0.51-0.73	10
or alternatively		0.50-0.59	20
		0.61-0.68	20
		0.79-0.89	20
SPOT-4	HRVIR	0.50-0.59	20
		0.79-0.89	20
		...	10
SPOT-5	HRG	0.51-0.73	5 (2.5 by interpolation)
		0.79-0.89	10
		...	10
TERRA/AQUA	MODIS	0.62-0.67	250
		0.84-0.88	250
		0.46-0.48	500
		0.55-0.57	500
		...	500
		0.41-0.42	1000
		0.44-0.45	1000
		...	1000
IKONOS		0.45-0.90	1
		0.45-0.52	4
		0.51-0.60	4
		...	4

2.2.1 NASA - Landsat and TERRA

First launched in 1972, the Landsat series provides the longest continuous dataset of earth surface level images available with over 30 years of operation. The technology of the payload instruments has been constantly improving, starting from the 80m spatial resolution with RBV (*Return Beam Vidicon*) and MSS (*MultiSpectral Scanner*) instruments in Landsat-1 and -2, to the 15m spatial resolution of ETM+ (*Enhanced Thematic Mapper Plus*) in Landsat-7 [6]. Table 1 lists the bands and resolutions of the still operational Landsat satellites 5 and 7.

Currently satellites 5 and 7 are still operational, even though Landsat-7, launched in 1999 lost 25% of its coverage in 2003 due to a broken scan line corrector mechanism in the ETM+ instrument [14]. *United States Geological Survey* (USGS) still provides data from Landsat-7, removing the problem of missing pixels caused by the damage by combining several consecutive scenes of the area [14]. Called the 'workhorse satellite' in [15], Landsat-5 continues to provide data after more than 20 years of operation. However, with no further satellites coming to the series, instruments providing similar data are to be placed aboard NPOESS-C1 satellite scheduled for launch in 2009 [16]. See `http://ldcm.nasa.gov` for further details on *Landsat Data Continuity Mission*. EO-1 satellite mission also provides similar kind of data [17].

The first attempt[3] to place a hyperspectral scanning system to the orbit in 1997 failed due to problems in control and communications. The *Moderate Resolution Imaging Spectroradiometer* (MODIS), carried as payload aboard the *Earth Observing System* (EOS) flagship satellite TERRA is the first instrument in orbit capable of imaging 36 spectral bands [6]. Also the sister satellite of TERRA, AQUA, carries a similar MODIS instrument. As the names reveal, TERRA is mainly meant for ground monitoring, while AQUA is targeted for ocean and water monitoring. The satellites are also known as EOS-AM and EOS-PM, as related to the times they cross the equator [18]. Together, these two satellites provide complete coverage of the Earth's surface every 1 to 2 days [18]. Samples of the spectral ranges of the MODIS instrument are shown in Table 1, and a full listing can be found for example in [6] or `http://modis.gsfc.nasa.gov/`. The bands are suited for land, ocean and atmospheric monitoring, all of which can be done simultaneously. The spatial resolution of the resultant images is only moderate, from 250 m to 1 km, with a swath width of 2330 km [6].

The MODIS instrument is widely used by scientists to study different environmental phenomena. Besides providing useful bands for observing a multitude of features on the Earth, the data from the MODIS instruments is available free of charge (see Section 2.4). Praks *et al.* [19] have stated that "MODIS spectrometer is one of the most interesting instruments for operative spectral monitoring applications because its frequent coverage, good availability and cheap image price."

[3] Clark satellite by NASA, 1997, 384 bands

In addition to MODIS, TERRA carries several other instruments that have been widely used in environmental monitoring. ASTER, CERES, MISR and MOPITT all give their contribution to the value of TERRA, creating imagery for example for studying vegetation, rock types, volcanoes, clouds, radiation, atmospheric aerosols, and surface features [6].

2.2.2 French SPOT series

The French *Centre National d'Etudes Spatiales* (CNES) has also been active in the earth observation front for a long time. Their *Système Pour l'Observation de la Terre* (SPOT) program has been providing data since 1986. Five satellites have been launched in the series so far, three of them still providing data from the orbit. More than 20 countries receive data from the SPOT satellites [6][20].

SPOT-2, as did the ceased -1 and -3, carries two identical HRV (*High Resolution Visible*) imaging systems, which can be operated either in a single black and white panchromatic mode, or in a multispectral colour IR mode. Due to the capability to rotate a planar mirror 27 degrees to either side, it is possible to create stereoscopic images of adjacent passes [6].

SPOT-4, launched in 1998, carries an improved scanner called *High Resolution Visible and Infrared* (HRVIR). A new band in the mid-IR area improves the capabilities for vegetation monitoring, mineral discrimination, and soil moisture mapping. In addition, a new instrument with approximately 1 km spatial resolution, called *Vegetation*, has been added. It uses three of the same bands as HRVIR, but includes a new band in the blue portion of the spectrum for oceanographic applications [6].

The newest satellite in the SPOT-series, SPOT-5, carries again more improved instruments than its predecessors. HRG (*High Resolution Geometric*) images with the spatial resolution of 2.5 m - 5 m in the panchromatic mode, and with 10 m resolution in the multispectral more. Stereoscopic images can be formed from images taken along the flightpath with different angles. Thus, only one pass over an area is required to create a stereoscopic image. Another instrument, HRS (*High Resolution Stereo*) takes images from the front of and behind the satellite, allowing the construction of stereoscopic images [20].

2.2.3 Russian satellites

Russia has always been a strong nation in the field of space activities. However, currently also Russian researchers often use satellites of other nations, due to problems in getting data from Russian satellites [21]. Satellites such as RESURS series, METEOR-3 series and SPIN series have shown Russian expertise in space-based imaging as well [6][22]. For example SPIN-2 produces panchromatic images of the visible light area with 1.56 m spatial resolution [6]. The

formerly classified data from SPIN-2, originally meant to cover the biggest cities of the United States and the world, is available at *Microsoft's Terra Server* (`www.terraserver.com`) [6]. The most recent addition to the Russian set of remote sensing satellites is the MONITOR-E, providing better than 1 m resolution [23].

Getting information on Russian satellite systems is difficult. Considering the achievements of Russia in space activities (e.g. maintenance of the international space station, when the NASA shuttle program was halted), it would seem likely that there would be plenty of information available on Russian satellites as well. However, possibly due to political reasons, the information seems not to be easily available. Most of the information that can be found on the satellites is usually available only in Russian. This seems to be typical for other information in the field of remote sensing as well, and makes acquiring the information a tedious process.

2.2.4 ESA and others

The *European Space Agency* (ESA) is also active in the field of environmental remote sensing. Launched in 2002, Envisat is currently a popular satellite in environmental monitoring. The *MEdium Resolution Imaging Spectrometer* (MERIS) is a 15-band spectrometer, imaging the Earth with 300m spatial resolution in visible and near-infrared area. The primary mission of MERIS is the mapping of the oceans. Global coverage can be attained every three days [24]. Envisat also carries other instruments, allowing it to do the complete check-over of the Earth's environment it was designed for. The instruments provide also data that can be used as continuation to the data from ERS-satellites. One of the most notable instruments besides MERIS is the *Advanced Synthetic Aperture Radar* (ASAR) [25].

There are many other satellites and satellite programs that would certainly be worth mentioning here. One of the most commonly used ones is the *Advanced Very High Resolution Radiometer* (AVHRR), first launched to orbit in 1978, and attached to newer satellites of the *National Oceanic and Atmospheric Administration* (NOAA) as well. The current AVHRR provides approximately 1km spatial resolution, and is used for example in mapping clouds and sea surface temperature [26]. An instrument similar to MODIS, the *Global Imager* (GLI) was launched to the orbit aboard the *Advanced Earth Observation Satellite II* (ADEOS-II) by Japan in 2002 [27]. A more recent addition to the family of hyperspectral instruments orbiting the Earth is HYPERION aboard the EO-1 satellite. It images 220 channels simultaneously with 30 m spatial resolution [28]. IKONOS, QuickBird and OrbView-3 satellites provide commercially available high spatial resolution data in the visible light area [6]. Other satellites worth mentioning include the *Indian Remote Sensing* (IRS) program satellites and the French JASON, along with many others not mentioned here.

Considering the number of satellites developed and pushed into orbit, the list given above is fairly short. There are several other satellites in addition to those listed, which provide information on Earth variables. With the speed of development and often fairly short lifespan of the

satellites it is not practical to provide a comprehensive list of the satellites watching the Earth. However, a good reference on what satellites there are and will be, is the *Earth Observation Handbook* at `http://www.eohandbook.com/`.

2.3 Many Players in International Co-operation

With the number of international organisations working in the field of remote sensing, it can be easily stated that the issues that are being monitored are truly an international matter. Changes in the state of the environment do not respect state borders, and thus managing the environmental issues also requires tight international co-operation between different nations. There are organisations that exist for the sole purpose of handling political issues of co-operation, while some just gather up researchers to solve the technical problems at hand. Next, international organisations are introduced, followed by Russian and Finnish institutions.

GEOSS, *Global Earth Observation System of Systems*, is currently one of the major issues in international co-operation. In the beginning of 2005, 61 countries with the support of nearly 40 organisations agreed on a 10-year plan for monitoring the Earth more effectively. The process had been started earlier, but a clear connection of raised interest and the tsunami in Asia at the turn of the year could be observed [29].

The goal of GEOSS is to "connect the scientific dots". There is a wide variety of different observations for separate purposes, but they are traditionally used only for the original purpose. GEOSS aims at making use of the combined measurement data from all the separate sources, counting in buoys in the oceans, land based stations, satellites, and other possible sources of measurement data [29].

To really be able to create GEOSS in the way it is meant to be, true international co-operation is needed. Nations and space agencies must be willing to give out their data for common use, otherwise the system will not work. Considering how politically sensitive nations have been about satellite imagery of their territory, there are plenty of issues to be solved in negotiations before the data will flow freely. However, all representatives of space agencies and other related institutions taking part in the *International Symposium on Remote Sensing of Environment* (ISRSE) 2005, from Europe, Russia, and the United States, stated that they were working hard to make it happen.

An easy mix-up can be made with GEOS, which stands for *Geo-stationary Earth Orbit Systems*, which is not an organisation at all, but a network of geo-stationary satellites. Going further down the path, EOS jumps again back to *Earth Observing System*, a widely used abbreviation also referring to the NASA Earth monitoring program. More information on EOS can be found in [30].

The *Committee on Earth Observing Satellites* (CEOS) is a 20-year-old international organisa-

tion consisting of 24 members (mostly space agencies) and 21 associates (national/international organisations). The primary objectives of CEOS are to optimise benefits of spaceborne observations through co-operation, to be the focal point of international coordination, and to exchange information to encourage compatibility and complementarity of systems in the field of Earth observation [31]. For example, the highly useful *Earth Observation Handbook* mentioned in the end of the previous section has been put together by CEOS.

There are several other programs and organisations as well, such as the *Integrated Global Observing Strategy* (IGOS) of the *United Nations* (UN). In a smaller scale, space agencies also co-operate directly with each other.

Russia houses several research institutions in addition to the *Russian Federal Space Agency*[4] (ROSCOSMOS). *Khrunichev State Research and Production Space Center*[5], *Russian Federal Service on Hydrometeorology and Environmental Monitoring*[6], and *St. Petersburg Electrotechnical University*[7] can be mentioned as examples of institutes doing remote sensing -related research. There has been co-operation between the *Laboratory of Information Processing* at LUT and *St. Petersburg Electrotechnical University* in the past.

In Finland, the institutions participating in remote sensing research include, on the technical side, the *Laboratory of Space Technology* at *Helsinki University of Technology* (HUT), and the *Technical Research Centre of Finland* (VTT, Valtion Tieteellinen Tutkimuskeskus) as the most active public sector research institutes. In addition to algorithm development for data acquisition and interpretation, both work in the field of instrument development. Also the *National Technology Agency of Finland* (TEKES) should be mentioned, as it actively funds and participates in the research on remote sensing. Also other universities in Finland do research in the field. At least the *University of Helsinki*, the *University of Kuopio*, and *Lappeenranta University of Technology* are involved in remote sensing research. In addition, private companies, such as the *Jaakko Pöyry Group* and *Space Systems Finland*, contribute to the field. A major contributor in Finland is also the mostly state owned *Patria*, which has references to several ESA satellite systems, including Envisat and Aura, as well as the Mars Express spacecraft.

2.4 Data Acquisition

Research based on satellite data is often restricted by the availability of the kind of imagery that is needed. The upkeep and development of satellites is expensive, and thus the price of imagery is often quite high. There are companies specialising in the sales and distribution of remote sensing data. Usually, the better the spatial resolution of the imagery is, the higher the price is. However, in some cases data that is a few days old can be acquired even free of charge.

[4] `http://www.roscosmos.ru`
[5] `http://www.khrunichev.ru`
[6] `http://www.meteorf.ru`
[7] `http://www.eltech.ru`

Table 2 shows some examples of data sources and product prices. Archived data means data recorded by routine imaging, whereas programmed data means imaging of a certain location at the request of the customer. A scene is one image from an instrument, the width of which is the swath-width of the instrument.

Table 2: Sample prices of different satellite imagery scenes from different suppliers.

Source	Satellite+Instrument	Archive/Progr.	Spatial Res.	Price/Scene
SPOT Image	SPOT	Archive	5m	5400 e
		Programmed	5m	6200 e
Eurimage	QuickBird	Archive	0.61m/2.44m	5440 $
		Programmed (rush)	0.61m/2.44m	12240 $
USGS	EO-1 HYPERION	Archive	30	250 $
		Programmed	30	2500 $

Research institutes may be able to acquire images with less than the list price. Usually research activities, in contrast to operational use, do not require the data to be near real time, so archive data is just as usable. Russian researchers often use imagery from other nations' satellites, as getting access to data from Russian satellites seems to be difficult even for them. As an example of a foreign data source, SCANEX in St. Petersburg receives and distributes data from several satellites, including American, Indian and Russian satellites [32]. In addition, the MODIS instrument sends its data continuously for anyone with the right equipment to receive.

A new Russian federal space program (2006-2015) includes 7 new MONITOR-E series earth observing satellites. The primary users for the data created by these satellites will be the federal authorities of Russia, who are also the owners of the space program budget [23]. It remains to be seen whether the data will be available for at least Russian researchers at affordable prices and tolerable bureaucracy.

Even though it can be a major hindrance, the price is not the only factor to be considered when thinking of which satellite data to use. Naturally the abovementioned three resolutions (spatial, spectral and temporal) must be matched to the use of the data. Especially with temporal resolutions, one should also take into account the effect of the programming of the satellites. NASA satellites usually provide data in constant intervals, which is often a necessity for operational usage. On the other hand, ESA satellites like Envisat, as well as CNES SPOT, can be given programming requests. The price of data acquired by asking the satellite to image something not in its normal flight path is often higher[8] than normal, but can of course sometimes be handy if more frequent data is needed of a certain area. On the negative side, operational use becomes more difficult due to the possibility that a certain area is not imaged frequently due to programming requests by other parties [33].

[8]For example, 800 euros more for one scene with SPOT, plus extra if the image is needed quickly (`www.spotimage.fr`).

3 Water Areas

Altogether, water covers over 70% of the face of the Earth, and yet most of the monitoring applications are made for land. This is easy to accept, as humans mostly live on land, but the importance of water as a major component of the whole ecosystem can not be dismissed. This section will first discuss water area monitoring and regulations in general, followed by a more detailed discussion on activities in the Baltic sea, arctic regions and inland waters.

There are several different kinds of water environments in the world, all with at least partially different things to monitor. Here we will concentrate on areas in the Northern Dimension of the European Union, around and inside Finland, leaving oceans and other geographically distant areas for other studies. The monitoring activities and their nature in the target area are described.

In Finland, water resources are an important part of financial and recreational activities. Drinking water is monitored and cleaned more carefully than in central Europe [34], resulting in very clean tap water. Measurements of different water parameters in the Baltic Sea and lakes have been done for some time, but recently the *Water Framework Directive* [5] of the European Commission has introduced further monitoring requirements.

Gathering samples manually is a very laborious task, especially so if there is a high number of remote places to monitor, with no constant monitoring installations. The *Finnish Environment Institute* (SYKE, Suomen Ympäristökeskus) assesses the water quality of the lakes, rivers, and coastal areas periodically, with nationwide mapping taking several years [35]. Therefore satellite-based applications would be extremely helpful in easing the process of data acquisition.

In 2001, Östlund *et al.* [4] reported several problems in water area monitoring with satellites. They claim, as do other people, the existence of the following problems: (1) most algorithms are designed too specifically for a certain scene and type of data under study, (2) the influence of water depth is poorly investigated and unknown, and (3) satellite development tends to be oriented towards land applications, leaving too few and too wide spectral channels for water areas. Instruments created specifically for sea monitoring do exist (such as SeaWIFS), but they are mostly designed for use on open oceans, also known as case I waters. The problem of using these instruments for lake and coastal monitoring is mainly too low spatial resolution, while the high resolution satellites designed for land applications lack the correct spectral bands both in the sense of resolution and range.

In addition to the lack of dedicated instruments, water quality variables tend to have a high correlation with each other, increasing the complexity of interpretation [4]. Due to more simple optics of the open ocean, the methods there are more accurate and general than the ones created for all other water bodies, often called case II waters. However, usable results have been gained from several experiments in case II waters, which we will discuss here.

Some of the most common monitoring targets are algal rafts, both in oceans and other waters. Also sea surface temperature is a significant factor in water parameters. However, today the efforts with class II waters mostly seem to target the creation of algorithms for extracting the amount of chlorophyll-a in the water, as it is connected to the water quality classification. Other parameters, such as Zecchi depth, turbidity, and suspended matter concentration, are also studied, as they are related to defining the quality of water.

Chlorophyll-a, or chl-a in short, is usually the most important variable in the Finnish classification system [35]. It is always present in all algae groups in inland waters, and since the amount of algae is connected with the trophic state index, chl-a is thus connected to the quality of water. It has two distinct absorption bands, 440 nm (blue) and 678 nm (red). However, there are other substances with high absorption in the blue area of the spectrum, and thus using the reflectance peak at 705 nm and the absorption rate at 675 nm has proven to be more useful for determining chl-a concentration [36].

The main water monitoring institutions in Finland are SYKE and the *Finnish Institute of Marine Research* (FIMR). On more local scale, different *Water Protection Associations* contribute to the laborious job of field measurements.

Strong co-operation exists between the *Laboratory of Space Technology* at Helsinki University of Technology (HUT) and SYKE with regard to water monitoring. HUT Space Lab has supported SYKE with the development of algorithms and data acquisition, while SYKE offers the analysis of the meaning and distribution of information to the general public.

In the Russian Federation, things seem not to be very well coordinated. With the limited capability to search information provided in Russian, a single top institution for environmental monitoring could not be found. Several research institutes do engage in research of environmental monitoring done with remote sensing (see e.g. proceedings of ISRSE [21]), but no common source for information on operational activities could be found.

3.1 The Baltic Sea

Even though the Baltic Sea is a sea by name, it actually is the largest brackish water pool in the world, and hence not exactly a sea at all [37]. Due to little exchange of water with the Atlantic, and having a fairly large basin, the Baltic Sea has a strong resemblance with class II waters. Therefore algorithms developed for the oceans can not be applied there [37].

The 80 million people living in the basin of the Baltic Sea are continuously stressing the local ecosystem, resulting in strong eutrophication. This has resulted in yearly algal blooms that interfere with the recreational and the commercial use of the sea [38]. Eutrophication mainly results from nutrients released in the basin from farming, and earlier even environmental toxins were released into the sea [37].

The single largest source of nutrients and waste material in the Baltic Sea are the sewage wastes of St. Petersburg [39]. In 2001, two thirds of the waste waters of the city were processed, with one third dumped in the sea without any processing. This resulted in Russian Federation generating nearly 60 percent of the nitrogen and 80 percent of the phosphor load in the Gulf of Finland. For comparison, Finland and Estonia both measured close to 10 percent at the time [40]. However, things are currently proceeding in a better direction, as a new waste water treatment plant was opened in St. Petersburg in summer 2005.

Considering the state the Baltic Sea is in, it is no wonder that several of the countries bordering it have started some research in monitoring the quality of water. As such, the Baltic Sea represents a good example of an international environmental monitoring target. However, even though a lot has been done to protect the sea, Finland and Sweden have only recently been able to turn the growth of nutrient emissions downwards, with Baltic countries, Poland and Russia only approaching effective water purification processes [41]. An example of good international co-operation in the area is that of Finland and Sweden investing millions in water purification in St. Petersburg, as the gained value is much higher than investing the same money in national projects [39].

A lot of money has been invested in purification and improvement of emission control, but only small improvements in the quality of water are visible [41]. A study ordered by the Swedish government [42] presents two possible scenarios, the unfavourable one suggesting that the Baltic Sea could have gotten into such a state that more drastic measures than the ones currently done are needed to even start the healing process [43].

The "*Convention on the Protection of the Marine Environment of the Baltic Sea Area*", or the *Helsinki Convention*, is an agreement between Denmark, Estonia, the European Community, Finland, Germany, Latvia, Lithuania, Poland, Russia, and Sweden to work for the protection of the marine environment of the Baltic Sea [44]. The convention has created a need to measure certain parameters in the Baltic sea. In addition, the already mentioned *Water Framework Directive* of the European Commission will introduce further requirements for monitoring [5].

As described above, the use of static measuring stations is a necessity even when spaceborne and airborne remote sensing are used, but the static stations can not provide a good coverage of the area. However, it is not necessary to move up from the surface to get a decent coverage. FIMR has run a project called *Alg@line* since 1992 [45]. It is the first and largest research project in the Baltic Sea and in the world making use of a passenger and trading fleet in the collection of variables of the marine environment. There are a total of nine vessels carrying measuring equipment (SOOP - ship of opportunity) for the *Alg@line* system, including three coast guard vessels. The first vessel to get the on-board instruments back in 1992, Finnjet, measures the Baltic Sea Proper twice a week on its route between Helsinki and Travemünde, while the rest of the fleet covers areas near to southern Finland more closely [46]. The area covered by SOOP can thus be said to be fairly large, even though it consists of only thin slices. *Alg@line* is a part of the EU FERRYBOX project [45].

The SOOP measurement system is a fully automatic device, measuring chl-a, salinity, temperature, and turbidity of the surface water *in vivo*. A spatial resolution of 200 meters is used for chl-a fluorescence and turbidity measurements, with GPS defining the measurement point geographically. In addition to the flow-through system making the *in vivo* measurements possible, the SOOP system also collects 24 litres of water samples along the way into a refrigerated storage for *in vitro* analysis of inorganic nutrients, phytoplankton species analysis and validation of chl-a measurements [45].

The SOOP system aboard the fleet certainly offers more extensive coverage than mere static measurement points, but is still far from full coverage. However, one very important use of the system is to work as a valuable source of validation data for satellite image-based research and applications [45]. Strong co-operation exists with FIMR and SYKE, which publishes operational measurement data on the Baltic Sea based on satellites.

The operative measurement targets currently include surface water temperature (since 2000), thickness of surface algae blooms (since 2002), and turbidity (since 2005) [47][48][49]. Resulting from its location in the north, the Baltic Sea has a fairly large ice cover during the year, making the measurements reasonable only during the warm part of the year.

The surface water temperature of the Baltic Sea is calculated from data received from a NOAA-AVHRR instrument. More specifically, the AVHRR channel 3B measuring wavelengths between 10.30 - 11.30 in the TIR (Thermal InfraRed) area is used [50]. Two to four images are received daily by SYKE from the *Finnish Meteorology Institute* (FMI). The surface temperature is calculated daily from May to October, but due to cloudiness, the coverage of the mapping varies daily [51]. A sample of a sea surface temperature map is shown in Figure 4.

AVHRR has a fairly low spatial resolution of 1x1 km, but in mapping large water bodies this is not a problem. The temperature is calculated from emitted radiation instead of reflected one, and thus images taken at night time are used to minimise the effect of radiation from the sun [52]. In the Baltic Sea the error between the measured temperature from the AVHRR instrument and *in situ* validation measurements has been reported to be only 0.59°C, with standard deviation as low as 0.54°C [52].

The problem of blue algae in the Baltic Sea is most evident in the blooming season, starting from early May and lasting until late August [53]. SYKE maps the surface algae blooms during July and August. The data is taken from TERRA MODIS channels 1 and 2, with the resolution of 250 m [54]. The processing is done on all days that allow for some data to be shown, i.e the cloud cover does not obscure the whole scene. In Figure 5, two examples of surface algae maps are shown with a varying amount of clouds (clouds marked with white, non-water area with grey).

TERRA MODIS channel 1 is also used to map the turbidity of the Gulf of Finland in April, May, June, and September. July and August are left out, as algae blooms are monitored during those

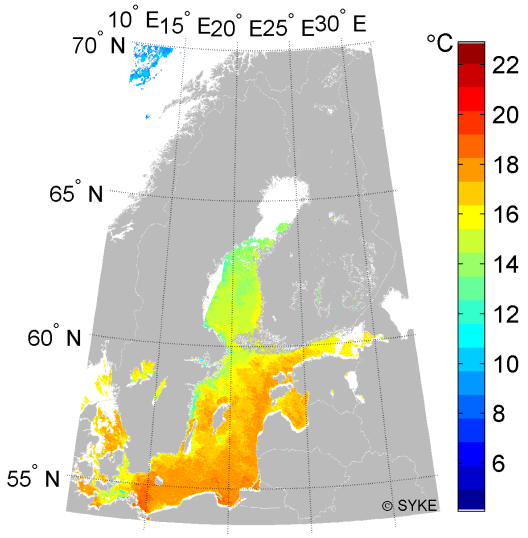

Figure 4: Sea Surface Temperature for the Baltic Sea on 07.09.2005. Image © SYKE Geoinformatics and Land Use Division. The image has been calculated using the NOAA AVHRR instrument [51].

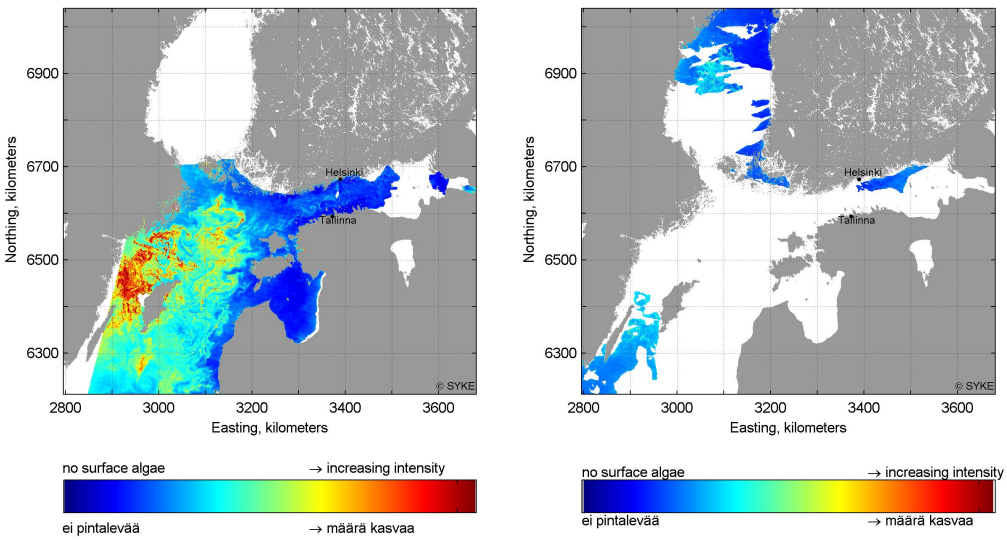

Figure 5: Maps of surface algae in the Baltic Sea: (a) Image with little cloud cover; (b) Image with an average amount of cloud cover. Image © SYKE Geoinformatics and Land Use Division. The images have been calculated from the NASA TERRA MODIS instrument channel 1 [54].

months. The unit that is used in the turbidity measurements is FNU (Formazine Nephelometric Units), which tells the amount of 'solid matter' in the water. The algorithm has been empirically developed in the Laboratory of Space Technology at HUT [55].

In addition to long term changes, monitoring is also done to improve disaster control. As the Baltic Sea has gained increased shipping activity, the risk of environmental problems in the form of oil spills has become more evident. To avoid waste taxes, ships have been known to spill oily waste to the sea on purpose [19]. However, the number of these incidents has decreased, most likely due to increased monitoring [56]. In addition, increased oil transportation has increased the risk of a major oil catastrophe. Successful application of remote sensing allows managing of pollution combat, continuous monitoring of small illegal discharges, archiving information, and compiling statistics on oil pollution [57].

The traditional way to monitor oil spills has been the use of SAR (Synthetic Aperture Radar). It was shown already in the 1970's that SAR provides good monitoring capability, regardless of weather, on open waters. However, during the time the Baltic Sea is covered with ice, radar based monitoring of oil is not feasible. To solve this, SYKE and the HUT Space Lab have developed an oil monitoring algorithm for imaging spectrometers [19]. Due to spatial, spectral or temporal resolution problems in the satellites, operational use has not yet been feasible, but SYKE hopes to make the service operational during 2005 [57].

The Russian Federation is the world's second largest producer of oil [58]. Due to environmental issues and direct loss of profit from the loss of oil, Russia has also actively developed methods to monitor oil spills. Some plans exist for building a monitoring centre for oil spill to *Arctic and Antarctic Research Institute* (AARI) together with *ScanEx* (a commercial supplier for remote sensing data) and *Institute of Remote Sensing Methods for Geology* (VNIIKAM) [59].

Another important factor on the seas in the north is ice. The Baltic Sea is the most heavily marine operated area in Europe where ice has a significant meaning [60]. Therefore it is essential to be able to determine the ice conditions during the time of ice cover, which might stretch to even half a year. Satellite monitoring of sea ice was started by Finland already in the end of the 1960's. Nowadays FIMR receives images from RADARSAT WideScanSAR, NOAA AVHRR and Envisat ASAR, which are used for analysis of routes and posted to Finnish and Swedish icebreakers [61].

3.2 Arctic Regions

The Russian Federation, having a major coastline in the arctic area, has also been productive in the field of ice monitoring. AARI generates ice maps for ships travelling along the northern sea route. An example is shown in Figure 6. Note that also ice thickness is estimated, making it possible to calculate the most cost effective route for the ships. The charts are created on the basis of data from several satellites, provided by ScanEX. At least NOAA, Meteor and Okean satellites are used [59][62].

Also Norway produces ice maps of the Arctic regions operationally, even on a daily basis [63]. Many kinds of other studies on the Arctic regions are also done, with attention to such matters as the well-being of fish species and glacier movements. For more information on remote sensing activities in the Arctic area, see [21] and [64].

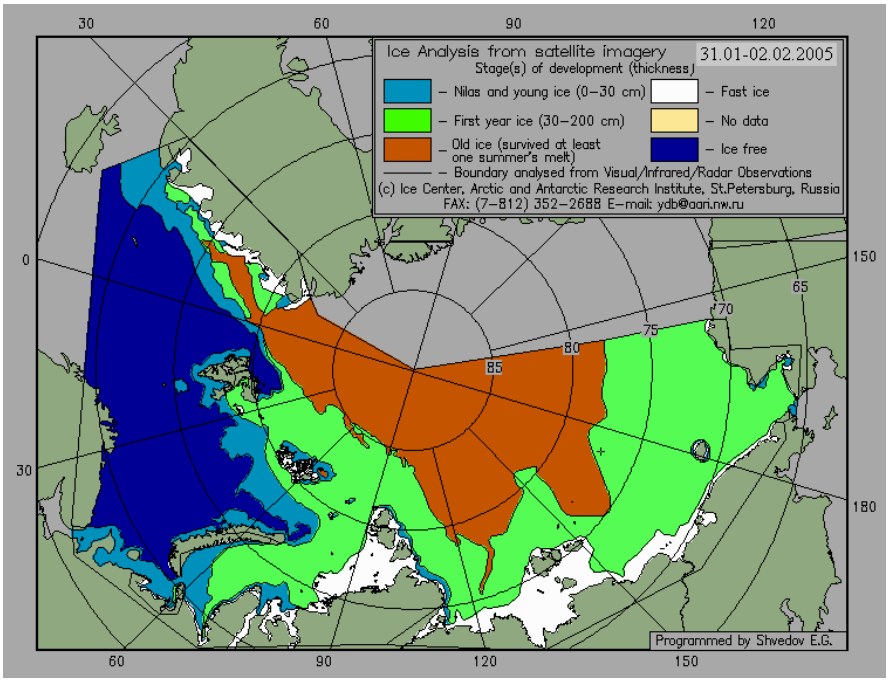

Figure 6: Ice chart of the Arctic [62]. Image © Center of Ice and Gydrometeorological Information, AARI.

3.3 Inland Waters

Finnish people traditionally refer to Finland as *"the land of a thousand lakes"*. In reality, approximately 10% of the whole area of Finland is covered by the 56 012 lakes with an area larger than 0.01 km^2, most of them eventually flowing into the Baltic Sea [65].

However, monitoring these nationally appreciated resources is not a simple task. SYKE and the HUT Laboratory of Space Technology have worked on creating algorithms for TERRA/AQUA MODIS (250 m resolution) and Envisat MERIS (300 m resolution) instruments for lake water classification. As mentioned, there are a lot of problems with class II waters in general when compared with oceans, and even further with lakes when compared with the Baltic Sea. In Finland, one of the major obstacles is the resolution (see Figure 3).

Even though lower resolution takes out peaks in the data, high resolution images are needed to get usable data on lakes. Finnish lakes are relatively small in size, and usually crowded with several islands. Using an instrument like MODIS with the resolution of 250 m, it is quite likely that most pixels contain also land areas. In addition, shallow coastal water interferes with the

measurements, as reflections would be received from the bottom of the water body. Therefore only 'clean' pixels with only water in them are usable. Figure 7 shows an aerial image of a part of a typical Finnish lake to demonstrate the fragmented structure of the lakes.

Two of the major components of lake ecosystems, DOM (Dissolved Organic Matter) and CDOM (Coloured Dissolved Organic Matter) present another problem. the high absorption of light by CDOM makes it difficult for satellite instruments to gain data on it. Especially in the boreal zone where Finland is located in, the amount of CDOM is so large that the sensitivity of satellite instruments tends not to be high enough [66]. The larger the spatial resolution, the stronger the signal. So while solving the problem with resolution, the problem with signal strength is increased and vice versa. The problems with lake monitoring are further increased by the fact that the lakes are not similar. Variations in optical properties due to different substances tend to make a good method for one lake useless for another [67].

Currently SYKE is doing some of the operative monitoring tasks on the largest lakes of Finland as it is doing on the Baltic Sea. Surface water temperature is mapped, and can also be seen in Figure 4 [51]. Turbidity measurements will later be applied to lakes as well [55].

A large international, partly EU-funded (4th RTD Work Program "Environment and Climate") project, *Satellite Remote Sensing for Lake Monitoring* (SALMON), ran from 1996 to 1998. More details of the project can be found in several publications in *the Science of the Total Environment* issue 268, and in the report for the *European Commission* (report EUR 18665 EN, 1999).

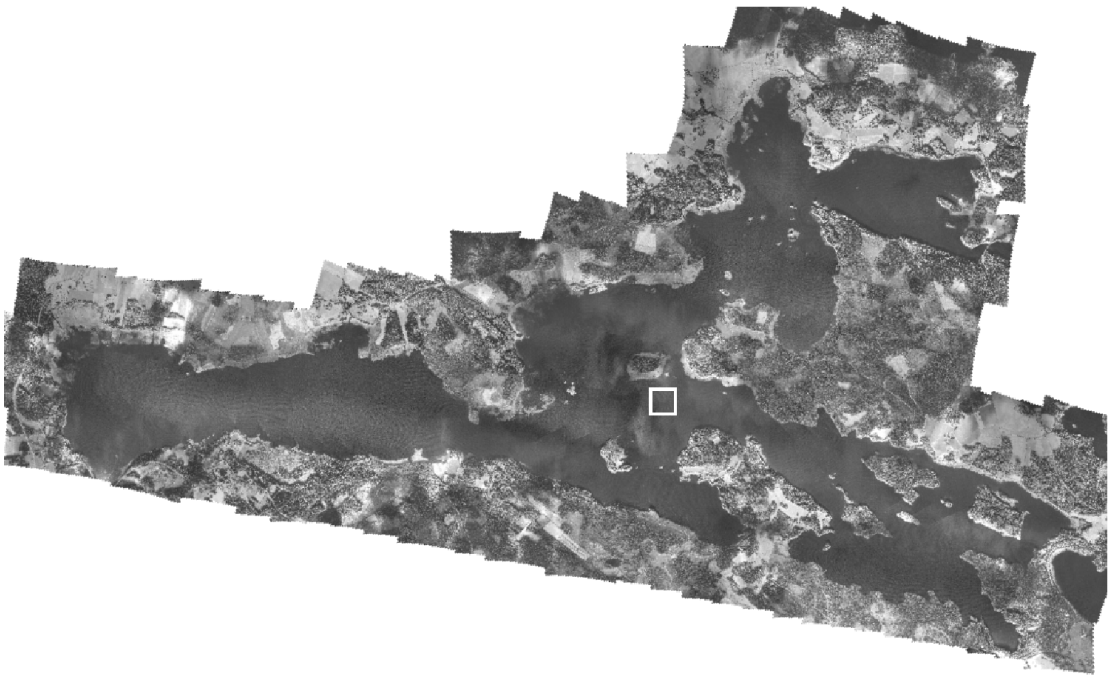

Figure 7: Example of an aerial false colour image of Maavesi area in Lake Saimaa [10]. The spatial resolution of the image is 10 m. Fitting in clean 250 m resolution pixels (white square) can be seen to be difficult in the more narrow areas of the lake.

In summer 2005 SYKE published a survey of user requirements for remote sensing products [68]. The information that was of most interest to users on the water side was the amount of chlorophyll on the water surface. Chlorophyll-a correlates strongly with the quality grading of lakes, and is often taken as the parameter to solve with remote sensing (see e.g. [69][70]). SYKE assesses the quality of rivers, lakes and coastal areas every 4 years, based on laboratory analysis. The last assessment included 5000 sampling stations, resulting in tremendous amount of laboratory work. Thus the interest in being able to map these variables with remote sensing is understandable.

The list of optically active variables that could perhaps be mapped with remote sensing in the future include chlorophyll-a, total suspended solids, turbidity, and Secchi depth [35]. As mentioned, of these only turbidity is mapped operationally, and only in the Gulf of Finland. As opposed to the current 4 year period, with remote sensing the quality of the lakes could be mapped several times a year [35].

The classification of lake quality is not the only reason to map lakes. The recognition of different aquatic macrophyte plant communities can be used to assist in preparations for plant biomass removal and monitoring. This has been studied e.g. in [10] with aerial photography. The fragmentariness of Lake Saimaa makes it a difficult target for low resolution satellite mapping.

LUT and *St. Petersburg Electrotechnical University* have co-operated on research on lake vegetation monitoring. The feasibility of using image analysis methods for monitoring vegetation changes has been studied on Lake Saimaa. The image data that was correlated to *in situ* measurements was acquired by aerial imaging. A correlation was found, and thus automating the monitoring when using satellite images should be feasible as well. For further details, see [10], [71], and [72].

3.4 Summary

Most of the Earth is covered with water. Therefore, water has a great effect on many environmental issues, and there is a large interest in monitoring water areas. In the oceans monitoring is easier, as it is possible to manage with and even benefit from a fairly low resolution. In inland waters, such as the fragmentary Finnish lakes, high resolution imagery is needed to avoid the interference of land.

The EU water framework directive makes the monitoring and reporting the water quality a necessary task for the member countries. To check the water quality, parameters such as chl-a, total suspended solids, turbidity and secchi depth can be monitored from satellites. Other potential applications of remote sensing include the tracking of the ice situation on the seas, as well as possible oil catastrophes and illegal discharges.

4 Forests

Forests are another important part of the nature in northern Europe. This is reflected even by the nickname for them, *green gold*. This section will offer an introduction to forest monitoring with satellites. First, the importance of forest monitoring is discussed. In the subsections, two major fields of forest monitoring, *stocktaking and mapping* and *hot spot detection*, are introduced.

Up to 86% of the land area of Finland is classified as forestry land, in Russia the corresponding figure is around 50%. The high percentage in Finland points out the importance of forests, but when absolute amounts are considered, Russia is number one. Compared with Finlands 26.3 Mha of forest land, the Russian Federation has an enormous amount of forest, 850 Mha, for the 50% of its area [73][74]. However, *Regions of Russia* by the Russian *Federal Service of State Statistics* decreases the total area of forest by 5% to 776 Mha. Seeing the difference, it can be said that these numbers are not as unambiguous as could be hoped for. In the end of the 1990's it was stated that the estimates vary from one source to the other, while most publications give no indication as to where the data originates from [75].

The Russian Federation houses a large part of forests on the northern hemisphere, a fact easily confirmed by a quick look at any map of the world displaying information on vegetation. Figure 8 is a simplified map of Russian forests. According to some statistics, Russia holds 22% of the forests in the whole world [76]. For comparison from the same set of statistics, Brazil has 16% and Canada 7% of the world's forests. Due to the amount, as well as (and maybe even more so) the fact that the ecosystems of Russian forests are quite fragile and currently the fastest changing ones in the world, the world in general has taken quite a large interest in them. Researchers from different countries and organisations have been developing methods for monitoring Russian forests with satellite imagery.

The Finnish Forest Research Institute (Metla) is one of the largest forest research institutes in Europe. It develops new methods for forest inventory, testing them first on Finnish forests and then exporting them to other countries. Especially the operative forest inventory methods developed in Finland have been considered ground-breaking also internationally [2].

Russian forests are mainly owned by the state, which deals with the permissions for logging and protecting the environment [74]. In Finland, the state owns part of the forests, but the main part is privately owned [73].

The most commonly used satellites for forest monitoring in 2003 were Landsat, SPOT, NOAA, IRS and IKONOS [77]. There are two viewpoints in forest monitoring. On one hand, the status of the forest can be monitored, such as the forest carbon sink and damages caused by natural phenomena such as fires. On the other hand, financial issues like logging management and stocktaking are in the interests of forestry companies.

Figure 8: Forests in Russia. Only part of the forests are usable financially, but should be controlled nevertheless. Image by the Forest Club of Russian non-governmental organisations [78].

4.1 Stocktaking and Mapping

Considering the area of forests, knowing what you have is quite essential. Therefore, from time to time the owners, whether government or private companies, need to assess the amount of forest they have. Doing this by field operations is a laborious task, considering for example the wide forest areas of Russia shown in Figure 8. In addition, information on the quantity of wood in the forest needs to be measured. Typical examples of measured quantities are the *number of stems*, *volume*, and *basal area* [77].

The stocktaking has been going on for a long time, so it needs to be considered what the advantages of new methods are. For the same reasons as with water, stocktaking is easier, faster, and cheaper with satellite images. Total statistics on Russian forests are published once every five years, if the five years is enough for all the activities involved (gathering the data, calculations etc.). The body responsible for creating the statistics in Russia is the All-Russian Research and Information Center for Forest Resources (VNIITSLesresurs) [79]. In Finland, the operation of gathering complete information on forests is done by the Finnish Forest Research Institute (Metla). Inventory of Finnish state forests has been done 10 times since 1921, with the old irregular periods being changed to a more regular approach [73].

Finnish forestry companies often make use of airborne imaging to acquire the parameters of the forests. There are companies specialised on aerial imaging of forests, producing the data for the forestry companies when needed. Aerial images can be taken with better spatial resolution than space images. However, aeroplane-based imaging methods tend to be more expensive compared to satellite imagery when price/m^2 is considered. Even though aerial methods can be used to acquire higher resolution images, there is motivation for space imaging of forest. [77].

Here we return to the question of spatial resolution. High-resolution satellite imagery that would allow mapping with almost the same degree of precision as aerial digital imagery, is expensive. In practise, the satellites providing such imagery are IKONOS and QuickBird [33][77]. However, if the user's needs are satisfied with lower resolution imagery, some satellite data might already be available for a clearly lower price than that of organising an aerial imaging project.

The imaging of forests is basically done on two resolution levels. If single trunks are desired to be mapped, high resolution is a necessity. Forest mapping can also be done just at wood-level resolution, with different textures and colours giving clues on what type of forest there is in a certain area. For example, in Sweden forests are classified into areas by the composition of tree species, age, and volume parameters using the k-NN method [80].

The methods of using the k-NN with satellite data on forest mapping originated in Finland with the first multi-source inventory done in 1990. It should be stated that in order to create a successful application for mapping, calibration data is needed. In addition to the Landsat ETM images (bands 3, 4, 5, and 7, see Table 1 for more details on the bands) used in Sweden, data from National Forest Inventory and maps to mask out non-forest parts of the images are needed [80].

Plain spectrometer imaging is often used in forest stocktaking and definition of species. Trusting an experts' opinion, it can be said that around 50% accuracy can be gained easily in measuring the volume of the forest [33][77] with a spectrometer, but getting better accuracy has proven to be difficult. Active remote sensing instruments are also often applied in forest inventories. Especially the *Synthetic Aperture Radar* (SAR) has proven usable, as it does not need a large antenna, and is thus easily taken into orbit aboard a satellite. However, the resolution of radars has not been high enough for acquiring detailed information [77]. A solution to the lack of precision has been the introduction of an additional scaling laser. With the laser, accuracy can be brought up to around 90%. This is even higher than with traditional mapping methods [33].

In addition to national interests in forest variables, an obligation to report some values to the *United Nations* (UN) creates additional motivation for managing the monitoring of forests in effective and affordable ways. Changes in the carbon storage of forests must be reported to the UN. Earlier, only the carbon bound to the trees was reported, but these days also the carbon bound to the ground in the forest should be reported [73].

4.2 Hot Spots of Forests

The so called 'hot spots' of forests can also be detected using satellite imagery. The term 'hot spot' refers to a relatively small area with high concentration of forest undergoing fast changes. These changes can result for example from clear cutting or forest fires, both of which are constantly going on in wide areas of Russian forests. The amount of fires and logging activities in the Russian area is actually increasing, resulting in a greater number of hot spots

around the country. The specific forestry management practises of Finland and Sweden result in practically no hot spots at all, but the forest cover remains fairly stable over the years [81].

Let us first consider the monitoring of logging activities. In a large area of forest, keeping track of where wood is logged and how aggressively, might be difficult. Using satellite imagery to detect these areas, certain kind of 'hot spots', would allow for continuous monitoring of logging activities.

Taking a look at illegal activity, in this case logging done without a permission, there are fairly reliable estimates of how much of it is going on in the Russian territory. The official statements claim illegal logging to be around 1% of the total annual amount, but other less personally involved parties like WWF and Greenpeace claim it to reach somewhere between 20 and 30 percent [82]. With frequent satellite images, the changes in the forest could be mapped against the given logging permits, and thus large illegal logging areas could be detected sooner than now.

It is difficult to say how the detection of illegal activities could be performed successfully. Currently the price of high-resolution satellites seems to be too high for operative monitoring in the field, especially since at least the Russian industry does not seem to see illegal logging as a problem [83]. *Achard et al.* [81] say that MODIS imagery (250 m spatial resolution) would be enough for the monitoring of clear cuts, as the normal size of a clear cut is larger than 15 ha. However, another research done by *Armas & Caetano* [84] shows that even the 250 m spatial resolution of MODIS is not enough to identify clear cuts and forest plantations. A point to consider is the location of the studies. The first one was done on a Russian area, while the latter one was carried out in Portugal.

Another type of hot spot are forest fires. In 2003, a total area of 24 Mha was affected by wildfires, causing severe damage to the nature [74]. On average, the amount of burnt forest area is around 7.5 Mha [81]. Studies on hot spots often analyse different types of changes in the forest area, and try to define the causes. Detection of fires among other types of hot spots has been presented in [81][84][85].

Detection of burnt areas has been stated to be easier than other hot spots, at least in the Portuguese environment due to the large size of affected areas [84]. This is mostly a matter of resolution, however, and thus not a general observation. Depending on what one wants to image, temporal resolution needs to be considered. If the detection target is a currently burning forest fire, then relatively good temporal resolution is required, as fires do not necessarily last very long. However, missing small fires is not a problem in long time statistics, as the number of forest fires is quite big. In case burnt areas need to be detected, changes in the NIR-spectrum can reveal the area where vegetation has drastically changed. However, to separate fires and clear cuts (random vs. organised change), methods like calculating the skeletons of the change area can be used [21].

4.3 Summary

Forests are an important part of the environment, as well as an important economical resource. The countries in the Northern Dimension have large areas of forest, which are difficult to monitor without using satellite or aeroplane-based methods. Through the use of satellite data, the monitoring can be done on a regular basis in a cost-effective way.

The stocktaking and mapping of forests is a crucial application for forestry companies and states. In the case of accounting for the forest, the most important characteristics of the sensor is spatial and spectral resolution. On the other hand, when locating hot spots is the goal, also temporal resolution gains in importance.

5 Atmosphere

The best known and most widely used application for satellite monitoring of the atmosphere is weather forecasting. International co-operation in the field is very strong, and large networks of equipment from sensors aboard aeroplanes to buoys in the oceans are used and shared in addition to satellite measurements. There exist several important research topics, as for instance storm prediction, in the field. However, in this study, weather forecasting is left out, as the emphasis is on environmental change monitoring. In this section, some atmospheric monitoring applications are introduced.

The *Finnish Meteorological Institute* (FMI) has other functions in the remote sensing field besides calculating weather forecasts. A lot of satellite imagery used by state organisations, such as SYKE, are distributed by FMI. They are also recognised as an Expert Support Laboratory of ESA with the GOMOS-instrument.

In addition to weather, there are numerous things in the atmosphere to detect. For example, FMI measures and predicts the amount of ultraviolet-radiation, issuing forecasts and possible warnings. Detecting UV-radiation is also related to tracking the amounts of ozone, and trying to find relationships between them [86].

With the metropolitan cities of today, also tracking of trace gases in the atmosphere has gained interest. Systems measuring trace gas concentrations above cities, such as the one described in [87], can be used to measure for example NO_x and O_3. In [87], the measuring equipment was installed in a city, to cover certain paths in the air. The measurements were typically done in wavelength regions between 295 nm and 375 nm [87]. Another experiment in the Russian area carried the instruments aboard a train, thus creating also a vertical profile of ozone and nitrogen dioxide concentrations. In addition to finding out local changes, these measurements can be applied as satellite calibration data much in the same way as *alg@line* measurements in the Baltic Sea [88].

O_3, or ozone, is a precious matter in the stratosphere (the middle layer of the atmosphere), protecting us from radiation from space. But as it reacts with nearly all other molecules, it is a poisonous substance for animals and plants to have in the troposphere (the lowest layer of the atmosphere) [89].

Getting measurement data from the upper layers of the atmosphere is quite difficult. A method called *star occultation* can be used for measuring the gas concentrations there. A satellite instrument, such as GOMOS (Global Ozone Monitoring by Occultation of Stars) measures the spectrum of a star when there is nothing interfering in between. Then, when the satellite proceeds further, the atmosphere comes to the field of view between the instrument and star. By observing the difference of recorded spectrum from these two locations, one can see what wavelengths were absorbed by the atmosphere, and thus determine the gas concentrations [90].

6 Ground

This section introduces some examples of remote sensing applications done on ground areas other than forests. The creation of maps is an important application for images taken from high altitudes in the visible region of the spectrum. Satellites like *Advanced Land Observing Satellite* (ALOS) can be used in cartography, to create and validate maps of areas around the world [91]. Even though maps are the kind of product that have a tendency to stay fairly stable over the years, there are factors that change. For a large country like Russia, using satellites to create up-to-date maps is very convenient, especially in the more distant regions.

CORINE Land Cover is a program for classifying *land cover usage*, that is what the land is used for. In contrast, *land cover* refers to the type of 'material' the ground is covered with. First initiated in 1985, classification of land cover usage was originally performed by marking areas on satellite images by hand. SYKE is developing semi-automatic methods for creating a CORINE database over Finland. Practically the whole Finland has been mapped using images from Landsat7 [92]. Also Russia has committed itself creating CORINE Land Cover data, but so far it has not been published [33]. CORINE data for Finland can be downloaded free of charge from the *European Environment Agency* website (`http://dataservice.eea.eu.int/dataservice/`).

Land cover usage information can be used for example in following city growth and urban planning. In Finland, land usage data has been used for example for designing mobile phone networks [2]. Also population growth can be monitored by remote sensing images, by estimating the amount of certain types of houses in an area [6].

Mineral detection can also be performed using remote sensing images from satellites. Especially multispectral imaging instruments have been useful to geologists, allowing them to analyse large sections of ground from a single image. Geophysical methods are still required to confirm the existence of deposits of minerals, but remote sensing imagery can be used to to find potential areas where such deposits might be found [6].

There are other, less obvious fields, such as archaeology, which make use of remote sensing images. Areas that have features of interest for archaeologists can be located, sometimes even if the features lie underground [6]. There are probably several other fields where remote sensing could be used, even if it is not obvious at first thought.

One of the more interesting ground area vegetation methods currently under development is the estimation of heavy metal pollution of vegetation using the visible light area of the spectrum. Some plant species, such as mosses and oats are sensitive to heavy metals, and their reflectance spectra is affected by pollution. There is an ongoing study in *St. Petersburg Electrotechnical University*, whose goal is to analyse the amount of pollution by imaging the spectrum of vegetation from space [93].

7 Summary and Conclusions

Environmental monitoring can benefit greatly from remote sensing techniques. In this document, the basics of remote sensing techniques have been described, as well as some commonly used satellite equipment, international co-operation, and some example applications of remote sensing in the Northern Dimension of the European Union.

Data on the environment can be acquired through many different channels, such as traditional *in situ* measurements, aerial measurements and space measurements. Different materials on the surface of the Earth reflect and absorb electromagnetic radiation in different ways, allowing us to infer characteristics of the material without physical contact. This action is referred to as remote sensing.

There are several satellites carrying instruments for measuring the characteristics of the Earth from the orbit. Different satellites have been designed for different purposes. Some carry instruments for imaging the oceans, some are focused on atmosphere monitoring and some, like Envisat, are multipurpose, having capability for a complete "planetary health check." In this document, examples of applications for water, forest, atmosphere and ground monitoring have been described.

Water bodies can be monitored for several different variables, such as sea surface temperature, suspended solids, and algal blooms. Due to the different nature of oceans from lakes, different algorithms must be applied. There is also a large difference in the spatial resolution requirement for the sensor, as the northern lakes tend to have several islands and irregular shapes. Monitoring of sea ice is a useful application for satellite data, as well as the tracking of oil spills from ships.

Countries in the north are often for a large part covered with forests. As forests are an important resource for the environment, as well as for the economy, there is a clear motivation for monitoring them. There is a long tradition of aerial imaging of forests. Values related to the type and amount of wood in forests can be measured, as well as the division of different tree types in the forest. The managing of logging permits and detection of natural phenomena, such as forest fires, are also possibilities for satellite monitoring.

Weather forecasting is a major application for satellite measurements, but information on the atmosphere is needed for other purposes as well. Information on clouds is useful in masking them out for surface area mapping, and concentrations of atmospheric trace gases, such as NO_x and O_3, can be estimated from satellite measurements. There are also monitoring applications for other ground areas in addition to forest monitoring. Satellite imagery can be used in urban planning and city growth monitoring. Spectral data can be used to locate promising mineral mining sites, and the amount of pollution bound to the soil can be estimated from the reflectance spectra of vegetation.

In comparison to traditional environmental monitoring methods, remote sensing often allows for

more cost-effective data gathering. Large areas can be mapped from satellites with information gained on the whole area, whereas gathering ground measurements would only give estimates on the state of the environment between sampling points. However, ground measurements are still necessary for calibration of the satellites.

The technical development has improved the possibilities of environmental monitoring by improving the spatial, spectral and temporal resolutions of the remote sensing satellites and instruments. Thus more precise data on the environment can be acquired more frequently, and monitoring applications can developed further to provide continuous operative data.

Remote sensing data can be acquired through several distribution companies. When selecting which satellites' data to use, attention should be paid to the attributes of the data. The spectral, temporal and spatial resolution should match the application they will be used for. The spatial and spectral resolution define what the satellite can see, but especially in operative monitoring, attention should be paid also to the temporal continuity of the data.

International co-operation is an essential issue in environmental questions. The problems of the environment are not restricted to only one nation, but will be spread to the neighbouring countries as well, perhaps even to the whole globe. Organisations and programs such as GEOSS attempt to create political and technical co-operation between different nations, to make remote sensing activities as optimal as possible. A lot of work remains to be done before data from different satellites is available for efficient use for everyone.

As a conclusion, it can be said that several promising possibilities for remote sensing of the environment exist. There are several areas of monitoring where spaceborne measurements already provide valuable information, but just as often there seems to be a need to improve the methods even further.

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