The European Sea Level Service (ESEAS): Assessment of the first three years

Hans-Peter Plag
Norwegian Mapping Authority,
Kartverksveien 21, N-3511 Hønefoss, Norway,
phone: +47-32118100, fax: +47-32118101, Email: plag@statkart.no

Contents

Abstract

In 2001, the European Sea Level Service (ESEAS) was established as one of the main results of the COST Action 40 "European Sea Level Observing System" (EOSS). The goal of ESEAS is to provide sea-level and sea-level related information for the European waters to scientific and non-scientific users. ESEAS aims to co-ordinate the long-term monitoring activities and data exchange as well as to enhance exploitation of sea-level data and related information.

Initially, the ESEAS was set up as a pilot projet for three years. In the frame of the ESEAS, the EU-funded ESEAS Research Infrastructure project (ESEAS-RI) started in November 2002, and this project helps to improve the sea level observational and research infrastructure associated with the ESEAS. As a result, both the quality of and access to the European sea level data basis have been improved. In combination, the ESEAS and the ESEAS-RI project have created a community representing sea level observation and research on a European level.

It is therefore recommended to establish the ESEAS as a permanent service. However, there are several critical and open issues that need consideration.

1 Introduction

Sea level is an environmental variable which is widely recognised as being important in many scientific and non-scientific applications. In the documents defining the Global Observing Systems and in related publications, sea level is listed as a relevant input variable for a range of research and operational activities (e.g. Prandle & Flemming, 1998). Sea level is also recognised by the *Group on Earth Observations* (GEO[1]) as an important quantity of the Earth system that requires continuous monitoring (see GEO, 2004).

In Europe, tide gauges have been operated at many coastal locations for a long time, some up to two hundred years, and the total data base of European costal relative sea level (RSL) observations is likely to exceed 10,000 station years by far. Presently, more than 450 coastal tide gauges are in operation at European Coasts. However, the organisational background is rather heterogeneous with more than 50 national authorities or institutes involved in the operation of gauges and the data being stored in an equal number of different data archives. The sampling is heterogeneous as well as the processing and quality control, resulting in variable data quality. Access to the various data archives is gouverned by variable data policies and until recently no European inventory of available data existed. A few years ago, national inventories were the exception, and most often such inventory were not easily accessible. Thus, the database valuable for many scientific and practical purposes was to a large extent inaccessible (for a more detailed documentation of this situation, see Plag et al., 2000).

[1] See http://earthobservations.org

The importance of sea level has led to an implementation plan for the Global Sea Level Observing System (GLOSS, see IOC, 1997) and requirements for a regional sub-system in Europe (e.g. Baker et al., 1997). However, access to, and scientific exploitation of European sea-level data from tide gauges has been hampered by the large differences in the national organisation of operational sea-level observations, data management, data policies, data quality and data quantity (Plag et al., 2000). The Permanent Service for Mean Sea Level (PSMSL) provides access to a subset of the available data (Spencer & Woodworth, 1993), but a comprehensive European sea-level data base does not exist and neither does a facility for Europe-wide access to national data bases. Furthermore, European sea-level observations currently do not meet the user requirements explicitly described in, for example, the GLOSS implementation plan, or the EuroGOOS science document (Prandle & Flemming, 1998). As a result, a full scientific or non-scientific exploitation of the available data has not been possible.

Moreover, newly evolving observing techniques require integration into a coherent methodology for observation of relative and absolute sea level variations, with the techniques including tide gauges, GPS, absolute gravity, and satellite altimetry. Thus, the development of a methodology for determination of vertical crustal motions using GPS has been carried out in a number of research activities, such as the International GPS Service for Geodynamics (Blewitt et al., 1997; International GPS Service, 2001) and the WEGENER project (Plag et al., 1998).

In 1996, the COST[2] Action 40 "European Sea Level Observing System" (EOSS[3]) was initiated, taking the unsatisfying situation described above as a starting point. A considerable number of national geodetic and hydrographic agencies in Europe contributed to this COST Action. One objective of the activities of EOSS was the development of a methodology for sea level monitoring taking into account the ongoing technological development and the required accuracy. Most results related to this objective are documented in Plag et al. (2000). The work reported in EOSS (2001) describes experiences based on or further developments of the methodology proposed by EOSS. The other main objective was the establishment of "an 'organism' that guarantees and coordinates the long-term monitoring activities and data exchange along the entire European coastline" (quoted from the EOSS Memorandum of Understanding; for full text see Plag et al., 2000). Working towards this objective, EOSS proposed the establishment of a European sea level service. After agreeing on draft Terms of Reference (ToR) for the ESEAS, EOSS in fact initiated the implementation of ESEAS with a Call for Participation in December 2000. In July 2001, the ESEAS Governing Board met for the first time and offically initiated the ESEAS as a pilot project limited for three years.

The ESEAS Pilot Project has made the initial step in bringing together the formerly scattered sea level research infrastructure in Europe. ESEAS has developed into a major research infrastructure for all aspects related to sea-level, be it in the field of climate change research, natural hazards and marine research.

The ESEAS community was able to attract funding for a three-years project under the European Commission *Fifth Framework Programme* (FP5) for improving the research infrastructure. The main goal of this "ESEAS Research Infrastructure" (ESEAS-RI) project, which started on 1 November 2002 [4], is to support the research infrastructure of ESEAS and to facilitate full scientifiic exploitation of European sea level observations.

This report attempts an assessment of the achievements of the ESEAS Pilot Project, taking into account the contributions of the ESEAS-RI project. The ESEAS Pilot Project has greatly benefited from the ESEAS-RI project, which made resources available for both the community building, the improvement of the infrastructure and actual research based on the ESEAS infrastructure. Therefore, the assessment of the ESEAS Pilot Project is not possible without considering the contributions of the ESEAS-RI project.

In the next section, we first review the objectives, tasks and products of the ESEAS. We then briefly review in Section 3 the organisational structure of the ESEAS, and summarise in Section 4 the current status of the ESEAS in terms of membership, activities and achievements. Section 5 is devoted to a description of the ESEAS-RI project focusing on the objectives, the participants, and the tasks. The integration of the ESEAS-RI project into the broader ESEAS community is crucial for the future of the ESEAS and is therefore addressed in Section 6. The ESEAS/ESEAS-RI has been widely accepted on European level and the relation between ESEAS/ESEAS-RI and various on-going European and global programmes is considered in Section 7. In Section 8 we review the critical aspects of the development of the time period of the ESEAS Pilot Project that may have hampered the development of the ESEAS into an even more successful organisation. The main contribution of the ESEAS and the ESEAS-RI project are summarised in Section 9 and the relevance of the issues addressed by the ESEAS for the society at large is pointed out in Section 10 before the open issues to be solved in the near future are identified in Section 11. Finally, in Section 12 we summarise the assessment of the ESEAS Pilot Project and give recommendations for the continuation of the ESEAS-RI.

[2]For a full description of the "European Cooperation in the field of Science and Technology (COST)" Programme, see the COST home page at http://cost.cordis.lu/

[3]The EOSS web page is still available under http://www.eseas.org/eoss/eoss_note.html

[4]For more information, see the ESEAS-RI web page on "http://eseas.org/eseas-ri/".

2 Objectives, tasks and products of the ESEAS

In the ToR[5], the ESEAS is described as "an international collaboration of governmental and non-governmental organisations operating tide gauges along European coasts or providing sea-level related information originating from other sources such as satellite altimetry, GPS and absolute gravity measurements at tide gauges." Cognizant of the growing need in Earth System Science as well as many societal areas for environmental information, the ESEAS focuses on sea-level as one variable relevant for many scientific studies and practical applications.

In the ToR, it is also stated that the major objective of the ESEAS is to enhance exploitation of sea-level and related databases both in scientific and non-scientific applications. In order to achieve this, the ESEAS strives to identify and promote user requirements as well as requests and wishes made by the users for specific products and to give access to quality-assured sea-level and sea-level related information for European waters. Moreover, the ESEAS coordinates sea-level observations along European coasts, sets standards for sea-level observations, promotes the analysis of the observations and the production of higher-level data products. And, not least, the ESEAS develops and maintains user-friendly interfaces to databases and stimulates research in order to improve observation and analysis methods. Thus, the ESEAS is developing into a source for comprehensive information on sea level as well as a broad spectrum of products for all types of users, from the layman to environmental managers, engineers and scientists.

It should also be mentioned here that the ESEAS is endorsed by the Global Sea-Level Observing System (GLOSS) Group of Experts as the regional densification of GLOSS and in this function contributes to the three Global Observing Systems (G3OS).

According to the ToR, the major tasks of the ESEAS are to ensure a sufficient quantity, guarantee the quality, and improve the accessibility of sea-level information. The ESEAS also aims to meet the requirements and specifications of a wide range of users. A tasks to be mentioned here is the integration of the ESEAS activities into the strategies of relevant on-going programmes or services such as GLOSS, MED-GLOSS, G3OS, EuroGOOS, IGS, and EUREF, and recently IGOS and GEO. Moreover, the ESEAS has the task to set and maintain standards for operation of tide gauges and other ancillary observation infrastructure, and to take appropriate measures to quality-assure all data, products and information provided to users through the ESEAS. Another task to be emphasised here is the establishment and maintenance of a comprehensive sea-level web site providing general information as well as access to sea-level data and products. This web pages is largely in place at "http://eseas.org/".

The ToR emphasise that the list of products to be developed and provided by the ESEAS has to be based on user requirements. The preliminary list in the ToR includes but is not limited to near real-time access to tide gauge data; hourly data from tide gauge sites including relative sea level and meteorological parameters, monthly mean values of relative sea level, extreme sea-level estimates, long-term statistics and possibly predictions of extremes, long-term trends and possibly predictions of means, routine maps of sea-surface topography over extended areas of the European coastal seas and adjacent deep ocean, crustal vertical motion at locations adjacent to tide gauges, and absolute gravity values from sites close to tide gauges. ESEAS intends to provide these products, wherever possible, in close cooperation and coordination with existing services such as PSMSL and EUREF. In addition, the ESEAS aims to provide general information on sea-level related topics, contact addresses, bibliographies, as well as links to other relevant information sources.

3 Organisational structure of the ESEAS

Organisationally, the ESEAS can be separated into a physical network of observation sites, an application network providing access to data and higher level data products as well as research results, and an institutional network of the authorities and institutes that own the physical and application networks and provide the required resources (see Figure 1). The physical network is largely in place, though scattered and with a high diversity in operational routines and quality assurance. Moreover, some geographical gaps still exist and required ancillary measurements (in particular, GPS) are not carried out satisfactorily at many stations. With respect to observations, cooperation between different authorities initially was on a low level. However, the ESEAS-RI project has improved the situation considerably (see Section 9).

The institutional network is represented through the Governing Board (GB), the Central Bureau (CB) and the Technical Committee (TEC). The institutional network of the ESEAS is based on a so-called "voluntary" or non-binding commitment. Such commitment is the basis for a number of rather successful services in the geodetic field (such as IERS, IGS, ILRS, IVS). It provides the necessary flexibility of organisations to join and contribute with best effort without being legally bound in case of future budgetary problems. But in the implementation of any activity it has to be kept in mind that this voluntary commitment also introduces a certain level of fluctuation in the membership and level of contribution.

The authorities, institutions and organisations contributing to the ESEAS have to provide the necessary funds both for running the physical network and setting up the application network. However, being part of the ESEAS in many

[5]The full ToR are available at the ESEAS home page at http://www.eseas.org/

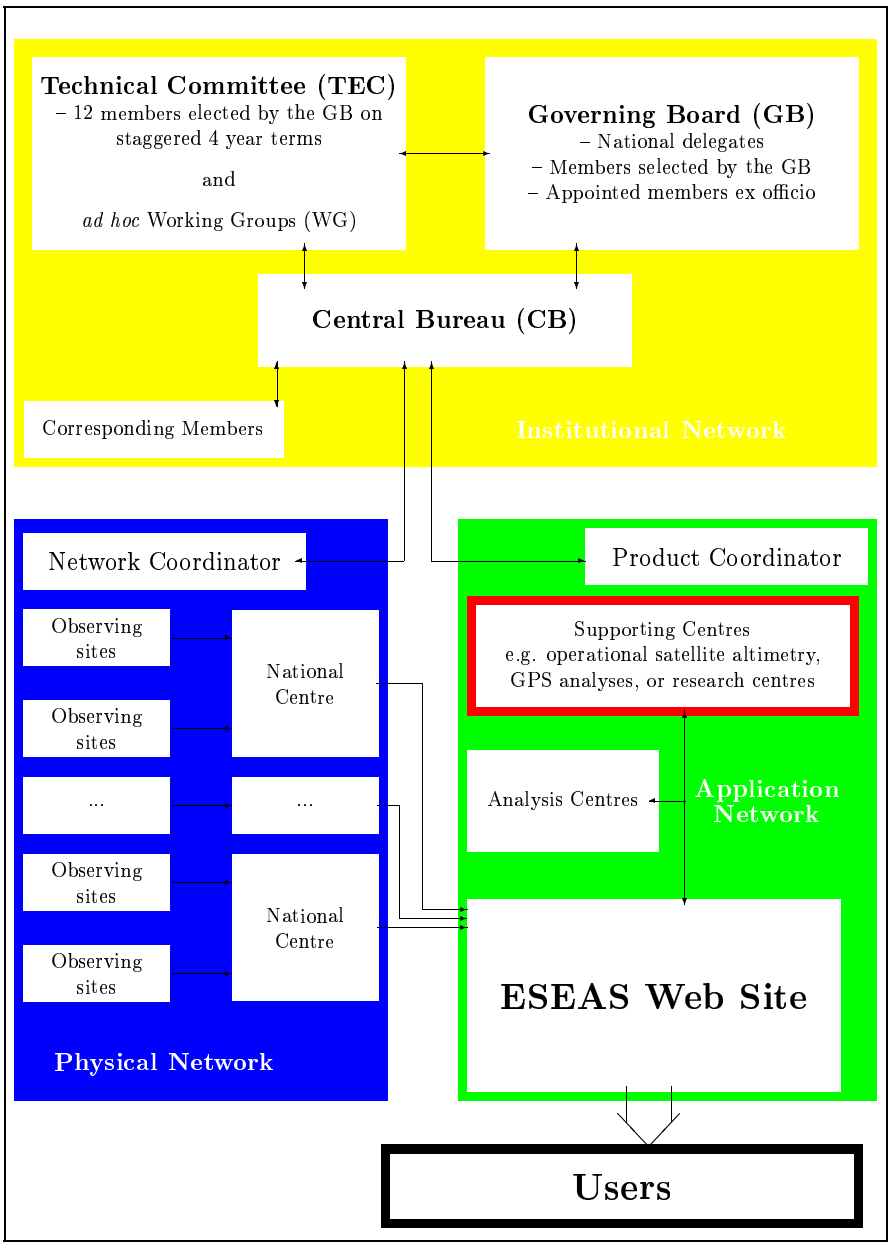

Figure 1: Organisational structure of the ESEAS.
The ESEAS structure is composed of a physical, application and institutional network (Plag, 1999).

cases eases to justify the necessary funds or even helps to open new doors for funding.

The application network of ESEAS brings together a number of research institutes in order to both provide higher level products and to carry out sea level research on a regional basis. A European application network for sea-level data and products was almost completely absent prior to the establishment of the ESEAS, thus leading to a poor exploitation of an extensive and highly valuable database. The application network currently being developed by the ESEAS and ESEAS-RI project uses the data from the physical network to produce products relevant for users of the ESEAS. The link between the application network and the users is primarily through the ESEAS web side.

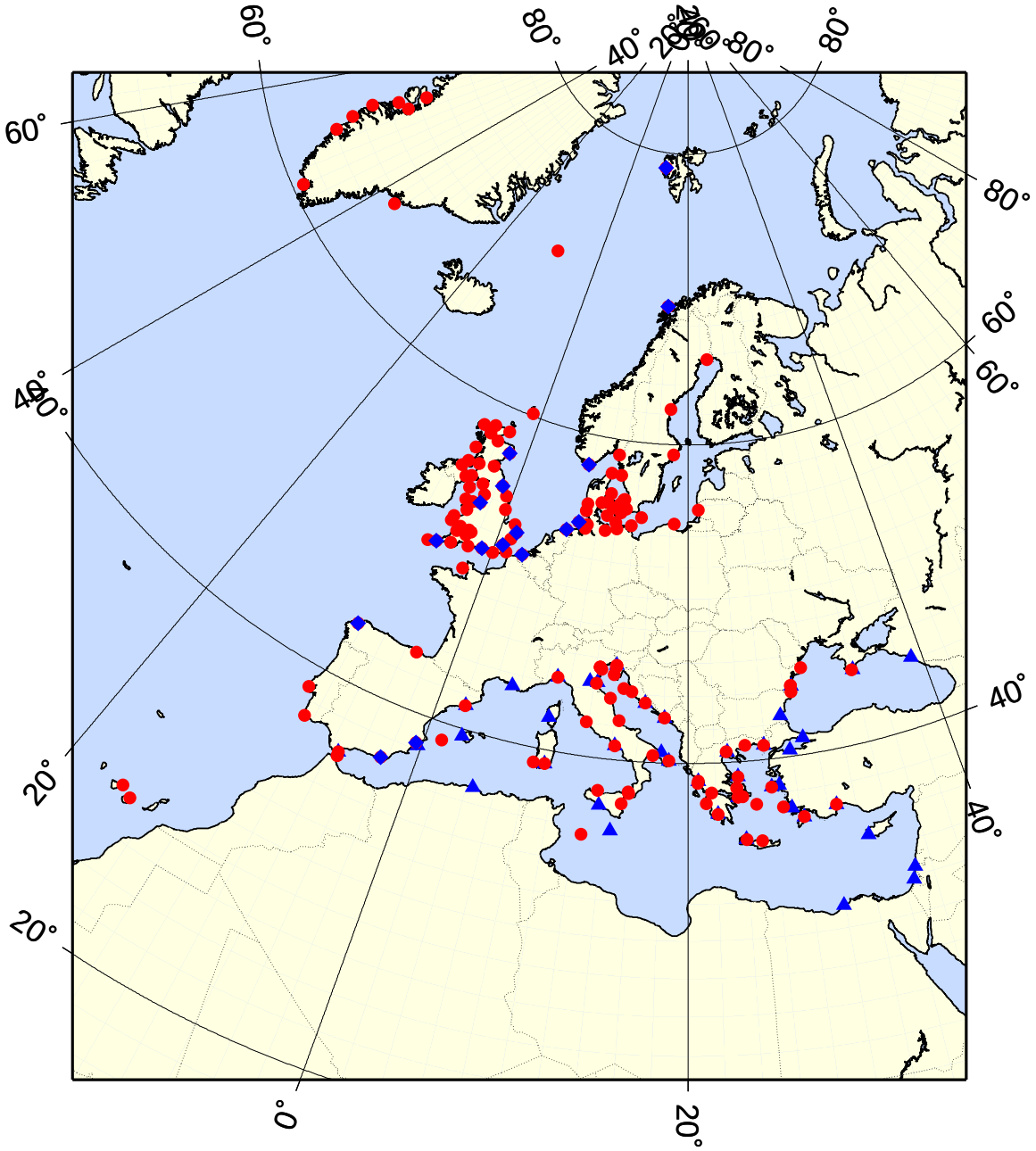

Figure 2: The ESEAS network of Observational Sites.
Circles are ESEAS Observing Sites consisting of a tide gauge; squares indicate Observing Sites with tide gauges and CGPS. Triangles are the MedGLOSS sites. Note that some overlap exists between the ESEAS and MedGLOSS sites.

4 Status of the ESEAS

The establishment of the ESEAS was initiated by the CfP distributed early in December 2000 to all relevant organisations in Europe. This CfP solicited nominations of Delegates to the ESEAS GB, as well as proposals for ESEAS Observing Sites, ESEAS National Centres, and the ESEAS Central Bureau. The CfP was asking for commitments for an initial test phase of three years, after which the concept of the ESEAS will be evaluated. In total, 22 countries responsed to the CfP, and 17 countries were actively participating from the start. Currently, the list of countries with institutes being members of the ESEAS includes Belgium, Croatia, Denmark, Germany, Greece, Italy, Lithuania, Norway, Poland, Portugal, Romania, Slovenia, Spain, Sweden, The Netherlands, Turkey, Ukraine, U.K, Cyprus, and Georgia. Moreover, an institution from Malta has applied for membership. In five more countries, namely France, Bulgaria, Estonia, Latvia and Russia, participation in ESEAS has been under discussion internally for some time without any definite decision being reached.

As a result of the first CfP, the ESEAS GB could be established. During its first meeting in July 2001 in Koblenz, Germany, the GB decided to implement the ESEAS initially as a Pilot Project limited to three years. During the first GB meeting, no chair for the GB was elected. The GB accepted the proposal by the Norwegian Mapping Authority to host the ESEAS Central Bureau, and Hans-Peter Plag was accepted as the Director of the CB.

After the first GB meeting, a second CfP was issued in July 2001, and this CfP asked for proposals for the ESEAS Analysis and Supporting Centres as well as the Network and Product Coordinators. As a result, a number of ESEAS Analysis and Supporting Centres were established during the second ESEAS GB meeting, which was held subsequent to the Final Workshop of the COST Action 40 in September 2001 in Dubrovnik, Croatia. Unfortunately, no proposals were received for the Network and Product coordinators. During this second ESEAS GB meeting, Stefano Corsini, Servizio Idrografico e Mareografico, Rome, Italy, was elected chair of the GB.

The ESEAS TEC, which is the scientific committee of the ESEAS with twelve experts covering all relevant fields, was established at the second ESEAS GB meeting. Richard Bingley, University of Nottingham, was elected chair of the TEC. The ESEAS TEC held two meetings in 2002 prior to the kick-off of the ESEAS-RI project (see next section). Afterwards, the TEC meetings were intended to be held in conjunction with the ESEAS-RI Project Team meetings. However, the TEC meetings were more or less replaced by the ESEAS-RI WP meetings and the ESEAS Project Team meetings. This development led to the restriction of most of the work to the ESEAS-RI community, while those TEC members not associated with an ESEAS-RI partner were mostly inactive.

Up to now, the ESEAS GB has met four times (see the ESEAS web page for the full information). The ESEAS Central Bureau is continuously provided by the Geodetic Institute of the Norwegian Mapping Authority. The main ESEAS web page is maintained by the ESEAS CB, while individual, topical sites are also operated by other member institutions.

In response to the first CfP, more than 150 tide gauges were proposed as ESEAS Observing Sites (see Figure 2). Some of the proposed tide gauges were co-located with GPS and more were upgraded in the frame of the ESEAS-RI project. The resulting network is still spatially inhomogeneous but, nevertheless, the ESEAS GB accepted all initially proposed sites. However, the task of classifying the sites was delegated to the ESEAS TEC.

The ESEAS has specified four main applications for these gauges (see Plag et al., 2000, for a full discussion), namely:

- 'Application A': obtain an accurate regional measure of the rate of change of absolute sea level in each of the basins around the continent. This requires stable long-term operation of the gauges and co-location with GPS.

- 'Application B': monitor the circulation around the European coasts for regional oceanography, water quality modelling etc.; such gauges may comprise pairs of gauges at straits, for example, at Gibraltar and Ceuta for Mediterranean inflow studies; between the central Mediterranean islands; at either end of the Turkish Straits; across the Straits of Dover; across the Skagerrak etc.

- 'Application C': provide calibration of satellite radar altimetry. The requirements are broadly the same as for Application A, however, the open ocean sites, and particularly islands, are clearly the most valuable once.

- 'Application D': storm surge warning and other practical applications. For this application, real-time and near real-time access to the observations is the main specification. As an example, such gauges are clearly required in the northern Adriatic, North and Irish Seas, where rapid relative sea-level changes are a main measurement quantity of interest.

Based on detailed requirements for the different applications initially defined by the ESEAS TEC and finalised within the ESEAS-RI project, the ESEAS Observing Sites were classified in the frame of the ESEAS-RI project, both with respect to their potential application and the actual situation. This classification helps to direct resources for necessary upgrading and data quality control.

As far as possible, ESEAS has been open for cooperation with existing activities. Therefore, focus has been on relations of ESEAS to on-going relevant activities. As a result, representatives of EuroGOOS, GLOSS, and MedGLOSS are members of the ESEAS GB while EUREF has nominated an

observer to the ESEAS GB. Also in the frame of the ESEAS-RI, focus has been on cooperation with other relevant organisations and group (see Section 7 for more details).

One of the main activities in the first year of the ESEAS was to coordinate the proposal for the ESEAS-RI project. The proposal was discussed during the first two meetings of the ESEAS GB and all ESEAS members were invited to participate in the project. However, several members choose not to join the proposal consortium. Moreover, several partners in the proposal were not members of the ESEAS but rather research groups joining only the proposal group. As a result, there is only partial overlap between the ESEAS and the ESEAS-RI consortium.

The proposal was submitted by the ESEAS CB in October 2001 and after successful reviewing and contract negotiation, the project could start with a Kick-Off Meeting (KOM) in November 2002. Initially, the project was coordinated by the ESEAS CB Director, Hans-Peter Plag.

In June 2004, Hans-Peter Plag left the position at the Geodetic Institute, Norwegian Mapping Authority, and consequently, he stepped down both as Director of the ESEAS CB and as coordinator of the ESEAS-RI project. In both these roles he was succeeded by Bente Lilja Bye also of the Geodetic Institute.

5 The ESEAS-RI project

The primary technological objective of the ESEAS-RI project is to support the ESEAS research infrastructure. The ESEAS-RI project facilitates the transnational coordination and supports the upgrading of the network of observing sites. The standardisation of the network, the operational routines, the databases and the quality-control have contributed to create a more uniform observing system as a prerequisite for a full scientific exploitation of the present and future sea level observations.

The primary scientific objective of the project is to study sea level variations at inter-annual to century time scales and to quantify potential future changes in mean sea level. In order to reach the objective, the following main steps are necessary, with each of these steps corresponding to a work package of the project (see Figure 3):

1. Quality control of the hourly tide gauge data accessible through the ESEAS

2. Determination of vertical land movements at tide gauges in order to decontaminate the relative sea level records for this bias

3. Determination of sea level variations on inter-decadal time scales in the North Atlantic and the semi-enclosed European seas as well as assessment of secular relative sea level trends for the European coasts

4. Improvement of the network of ESEAS Observing Sites through upgrading of selected tide gauges and co-location of gauges with continuous GPS.

The full Description of Work (DoW) for the project is available on the ESEAS-RI web page. Here, two aspects of the project are emphasised. With respect to the second bullet, it is worthwhile to mention that the determination of vertical land movements at the 1 mm/yr level or better is not a trivial but highly relevant task for sea level studies. Current analyses strategies for GPS do not provide such an accuracy with respect to the geocentre. The IGS pilot project "TIGA"[6] aims for a global solution. In the ESEAS-RI project, different strategies have been studied and an optimal methodolgy was developed.

The third bullet is related to interannual to decadal sea level variability. The IPCC assessments emphasise the role of sea level studies for global climate change assessment (Warrick et al., 1996; Church et al., 2001). The importance of interannual to inter-decadal variations in the climate system has been emphasised recently (see Houghton et al., 2001, for summary). Coupled atmosphere-ocean phenomena such as El Niño/Southern Oscillation and North Atlantic Oscillation (NAO) and Northern Hemisphere Annular Mode (NAM, see e.g. Wallace & Thompson, 2002, for a review) have typical time scales of years to decades (e.g. Philander, 1990; Hurrell, 1995; Hurrell & van Loon, 1997; Thompson & Wallace, 1998; Thompson et al., 2000; Thompson & Wallace, 2001). For the NAO, century scale variations have been described (e.g. Van Loon & Rogers, 1978).

The NAO exerts a dominant influence on the wintertime temperatures of the Northern Hemisphere. Surface air temperature and sea surface temperature in wide regions across the North Atlantic basin, in eastern North America, the Arctic, Eurasia and the Mediterranean, are significantly correlated with NAO variability. Changes in temperature over land (and related changes in rainfall and storminess) are of serious consequence to a wide range of human activities. It can be expected that the NAO strongly affects sea level at interannual to inter-decadal time scales. However, sea level research has largely concentrated on either shorter time scales (up to seasonal) or secular changes, with particular focus on a global average trend. Moreover, determination of the global average has been based on the global tide gauge database with records unevenly distributed in space and time. Little has been done to account for factors causing decadal to inter-decadal sea level variability such as ocean circulation changes, atmospheric effects and decadal scale mass exchange with other reservoirs in the hydrological cycle. The only factor accounted for in all recent studies is the present-day post-glacial rebound signal. If t ESEAS-RI project is successful in setting up an empirical sea-level model of decadal sea level variations, then more complete

[6] see http://igscb.jpl.nasa.gov/projects/tiga/tiga.html

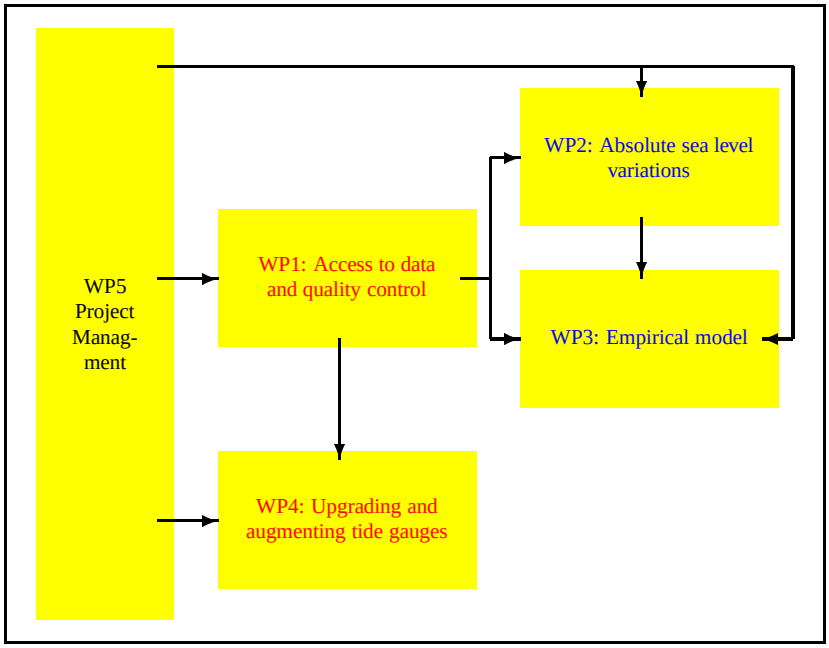

Figure 3: Interconnection of work packages.
All project management tasks are allocated in WP5, and this WP has a close link to all other WPs. WP1 and WP4 are related to the network of ESEAS Observing Sites, while WP2 and WP3 relate to the scientific objective of the proposal.

studies of the forcing factors will be possible on the basis of such a model.

It is expected that through ESEAS-RI, a quality-controlled database of hourly tide gauge data will be made accessible. Standard ESEAS quality control procedures have been set up and it is likely that these procedures will be used to quality control data before it is made available through the ESEAS Data Portal. This portal is currently under implementation and is expected to be operational soon.

The ESEAS observing network has been upgraded by the ESEAS-RI project in crucial regions. Moreover, the project has contributed to an major improvement of the research infrastructure comprised in the ESEAS, particularly through linking together a major part of the formerly scatter sea level community in Europe and by knowledge transfer between the different groups. The research carried out in the project will hoepfully result in an empirical model of sea level variations, which provides a unique basis for future studies of climate processes at decadal to inter-decadal time scales, particularly the NAO, as well as a coherent description of the occurrence of extreme sea levels. On the basis of the model and additional parameters, the causes for decadal to inter-decadal sea-level variations could be identified and quantitatively described. Potentially, an empirical relation between sea level variations at the European coasts and phenomena such as the NAO or NAM could be established.

The project has stimulated the integration of European sea level research community into a larger network and thus promoted coordinated research. The work in the project was also supposed to directly result in contributions to environmental assessment reports and to give information with respect to obstacles for the exploitation of existing multi-national databases in terms of e.g. technical, data quality and policy, legal and organisational issues. These results are of particular importance for GMES. However, these contributions are still open.

6 Links between ESEAS and ESEAS-RI

The main goal of the ESEAS-RI project is to develop and implement the infrastructure for the ESEAS. Therefore, it is of paramount importance that the activities in the ESEAS-RI project are very well integrated into the activities of the ESEAS. The ESEAS-RI proposal outlined several formal links between the ESEAS and the ESEAS-RI project, which partly were implemented after the ESEAS-RI KOM.

The ESEAS-RI consortium consists of 21 partners from 12 countries (Table 1, see the ESEAS-RI web page for more details). The consortium includes national authorities responsible for tide gauge operation and/or the geodetic control of tide gauges as well as research institutes involved in research and operational activities related to sea level. Additionally, through the ESEAS the consortium is closely linked with the national authorities for tide gauge operation in an ad-

Table 1: Institutions participating in the ESEAS-RI Project.

No.	Short	Full Name	City/Country
P1	NMA	Norwegian Mapping Authority (Statens kartverk)	Hønefoss, Norway
P2	KMS	National Survey and Cadastre (Kort- og Matrikelstyrelsen)	Copenhagen, Denmark
P3	NERC-POL	NERC Proudman Oceanographic Laboratory	Birkenhead, U.K.
P4	UNOTT	University of Nottingham, Institute of Engineering Surveying and Space Geodesy	Nottingham, U.K.
P5	IEO	Spanish Institute of Oceanography	Madrid, Spain
P6	PE	Puerto del Estado	Madrid, Spain
P7	ROA	Royal Naval Observatory of Spain	Cadiz, Spain
P8	UIB	Institut Mediterrani d'Estudis Avanóats	Esporles, Mallorca, Spain
P9	GCM	General Command of Mapping	Ankara/Turkey
P10	EARS	Environmental Agency of the Republic of Slovenia	Ljubljana, Slovenia
P11	IMGW	Institute of Meteorology and Water Management- Maritime Branch	Gdynia, Poland
P12	HHI	Hydrographic Institute of the Republic of Croatia	Split/Croatia
P13	PMF	Andrija Mohorovicic Geophysical Institute (AMGI), Faculty of Science, University of Zagreb	Zagreb, Croatia
P14	TUD	Institute of Physical Geodesy, University of Technology Darmstadt,	Darmstadt, Germany
P15	GI	Geodetic Institute of Vilnius Gediminas Technical University	Vilnius, Lithuania
P16	UPC	Universidad Politécnica de Cataluña	Barcelona, Spain
P17	HNHS	Oceanography Division of HNHS	Athens, Greece
P18	IOLR	Israel Oceanographic and Limnological Research	Haifa, Israel
P19	NERC	Southhampton Oceanography Centre, James Rennell Division	Southampton, UK
P20	SRC	Space Research centre, Polish Academy of Science	Warszawa, Poland
P21	CNR-ITT	CNR, Istituto Talassografico di Trieste	Trieste, Italy

ditional 8 countries. Moreover, in principle, the scientific experties provided by the ESEAS Technical Committee should be available to the ESEAS-RI project.

The project is managed by the Central Bureau of ESEAS, which is hosted by the Norwegian Mapping Authority. In order to ensure a strong link between the project and the ESEAS, the project's Steering Committee was supposed to be the ESEAS Governing Board (Figure 4). The GB was thought to continuously monitors the projects progress against the milestones and expected deliverables. Moreover, continuous scientific reviewing of progress as well as advice was to be provided by the ESEAS TEC. However, the ESEAS GB at its meeting following the ESEAS-RI KOM, held in Istanbul, Turkey, 11-13 November 2002, decided not to straight forward accept the role as Steering Committee. Formally, the ESEAS GB has up to today not accepted this role, thus leaving the relation between ESEAS-RI and ESEAS somewhat unclear.

During the ESEAS-RI KOM, leaders were assigned for the four WP, who are responsible for the technical progress in their respective WP. The Project coordinator and the WP leaders form the Project Team. Initially, it was also intended to include three external experts into the PT, which would provide external reviewing of the progress and complementary expertise where needed. However, the external experts could not be integrated satifactorily into the work of the PT.

Each WP comprises several separate task, and task responsible persons were also assigned during KOM. A full overview of the structure of the project including all individuals participating is available on the ESEAS-RI web page.

Progress in the ESEAS-RI has mostly followed the plan set out in the DoW. Two major deviations were and still persists in the implementation of the ESEAS Data Portal and the upgrading of the ESEAS observational network, where particularly the co-location of ESEAS Observing Sites with CGPS was considerably delayed.

During KOM, the ESEAS-RI WPs were opened for participation of members of the ESEAS. The ESEAS GB in its subsequent meeting formally established ESEAS WG corresponding to the four ESEAS-RI WPs. However, only very few ESEAS members not included in the ESEAS-RI project made use of the opportunity to join these WGs.

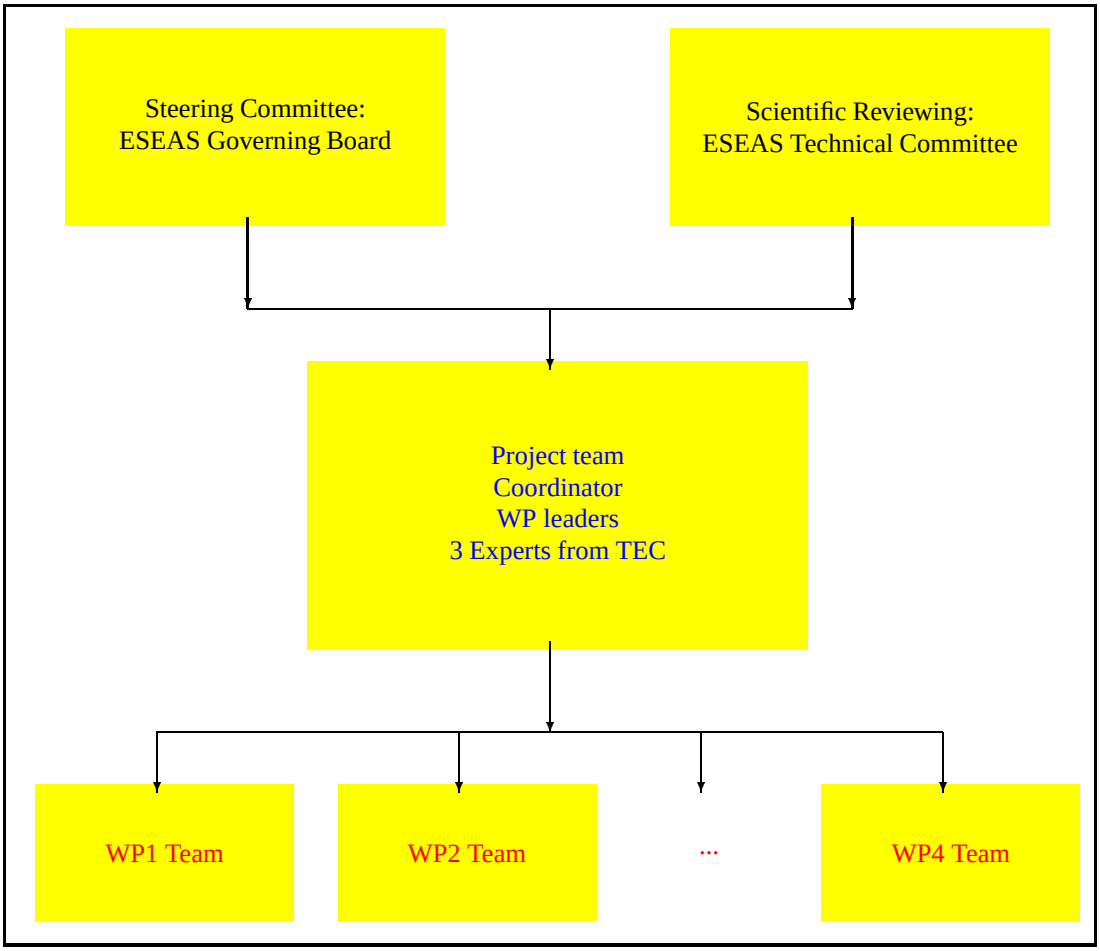

Figure 4: Project management structure.

7 Interrelation of the ESEAS and other relevant activities

The ESEAS and particularly the ESEAS-RI project has developed a number of relations to other relevant activities such as EuroGOOS, GLOSS, MedGLOSS, EUREF, GMES, and a number of EU-funded projects in the Operational Forecasting Cluster. The ESEAS is also recognised by organisations in neigbouring fields such as EPIGGOS. In most of these organisations, the ESEAS is considered to represent the European sea level monitoring and research community.

For GLOSS, the ESEAS approach appears to be a model for potential similar approaches to regional implementations of GLOSS, e.g. in parts of Africa, South-East Asia, South America, and the Caribbean. The IOC secretariat has been promoting the ESEAS approach at several opportunities in these regions.

In the frame of the first phase of the *Global Monitoring for Environment and Security* (GMES) programme, the European Commmission has taken the ESEAS into account as the non-governmental organisation representing the European "Sea Level Domain". As such, the ESEAS is the partner for addressing sea level related topics in the frame of GMES. In the operational phase, ESEAS is expected to contribute with several aspects, namely:

- Operational contribution to GMES with extreme sea level forecasting. This application requires real time or near-real time sea-level data in relevant areas.

- Assessment of risks with respect to long-term sea level changes. Here we point out that security has not only a near-real time component but also long-term, precautionary aspects. A question to be answered is whether the present sea level observing system has sufficient monitoring capacity for this application.

- Global monitoring. The ESEAS is the European implementation of GLOSS and as such contributes to GOOS.

- Capacity building. The ESEAS is actively involved in

support for sea level monitoring outside of Europe, particularly in the frame of GLOSS.

The ”best effort” principle, which is the basis for ESEAS contributions (outside the ESEAS-RI project) has allowed the ESEAS to circumvent long contractual negotiations, which are known to delay progress for some of the EuroGOSS activities. Unlike most of the other services, the ESEAS brings together institutes and experts from different disciplins in an environment making it easy to start cooperations in a fairly informal manner. In this respect, the ESEAS appears to have a model character also for other disciplins. It can be expected that the ESEAS model is going to influence the discussion of the implementation of the GEOSS plan (see GEO, 2004).

8 Critical points

The ESEAS appears rather successful and particularly the ESEAS-RI project has made the acronym ESEAS well known on European level. Both the COST Action 40 and the ESEAS are considered to be successful activities, and the ESEAS and/or the ESEAS-RI project are invited to many events organised by the European Commission. Nevertheless, it is worthwhile to focus on critical points having delayed the progress of the ESEAS or reduced it general acceptance.

Initially, the ESEAS would have needed persons fully devoted to their specific roles in the ESEAS. This applies in particular to the chair of the ESEAS GB, the director of the ESEAS CB, and the chair of the ESEAS TEC. Unfortunatetly, there were considerable difficulties in identifying a chair for the GB, particularly because it was assumed that the chair should come from an institution primarily operating tide gauges and not from an institution primarily involved in geodetic activities. The chair finally elected was not a member of the COST Action 40, and therefore rather new to the development that led to the establishment of the ESEAS. As a consequence, most of the external representation of the ESEAS and the intiative for implementation of the the ESEAS was left to the ESEAS CB.

Initially, the ESEAS started off with considerable energy and activities. This is documented by a high level of activity of the ESEAS CB and the ESEAS TEC, with the latter involving a number of highly active individuals. The chair of the TEC took an active role in the ESEAS building the TEC into a group of experts.

Very soon after the establishment of the ESEAS Pilot Project, the ESEAS CB set up a web page, which initially contained solely information about the ESEAS. Besides setting this web page, one of the main contributions of the ESEAS CB was the coordination of the ESEAS-RI proposal, the subsequent contract negotiations and the implementation of the project through the KOM in November 2002.

It has to be pointed out that the ESEAS CB was heavily loaded through the ESEAS-RI proposal and the subsequent coordination of the ESEAS-RI project. Seen in retrospect, it can be questioned whether it was appropriate to combine the ESEAS CB Director and the ESEAS-RI coordinator in one person. Particularly in a situation where the ESEAS GB chair was not agressively promoting the ESEAS to the broader society and leading the GB as a tool for the implementation of the ESEAS, the ESEAS CB director should have been freed to take a much greater share of the work load in implementing the ESEAS.

During KOM and the subsequent ESEAS GB meeting, it was decided to have the ESEAS TEC meetings together with the extended ESEAS-RI Project Team meetings. This decision concentrated the work loaded onto the ESEAS-RI consortium and deactivated the ESEAS members not included in the ESEAS-RI consortium to a large extent. Moreover, in effect it nearly eliminated the ESEAS TEC as a component of the ESEAS and reduced the number of TEC members actually participating in the work to those associated to the ESEAS-RI consortium. This development did not favour the independent progress of the ESEAS implementation and the creation of an ESEAS identity. In fact, there are indications of a splitting of the ESEAS community into a part of ESEAS-RI partners and contributors and the non-ESEAS-RI members. It can be expected that this development will create some problems at the end of the ESEAS-RI project.

It is questionable whether the ESEAS CB should coordinate ESEAS related projects. On the one hand, the ESEAS CB appears to be the organisational component most appropriate for such a role. On the other hand, the importance of such projects, particularly if they are of the size of the ESEAS-RI project, and the associated prestige easily lead to a down-prioretising of the ESEAS related activities in the ESEAS CB, if such projects are coordinated by the CB. This is nicely documented by the development of the ESEAS web pages, where the extent of the ESEAS-RI subset has constantly grown over the last two years, while the part directly related to the ESEAS has stagnated.

In any case, if the ESEAS CB is to coordinate further ESEAS related projects of significant extent, then this will require a better personnel basis, with a clear separation of those resources devoted to the ESEAS and those devoted to the management of the projects.

The ESEAS GB has not taken a very active role in the development of the ESEAS. This may be due to the composition of GB. The GB is composed of a number of ex-officio representatives of other relevant organisations and so-called national delegates, who represent the institutions in their country. Initially, the ToR allowed for one delegate per country, which was changed by the GB to open up for up to three delegates per country. The number of delegates varies from country to country, and there is considerable fluctuation of GB membership. The size of the ESEAS GB is quite large and varies between 30 and 35. The national delegates

are supposed to represent all institutions from their country that are active in the ESEAS. However, in some countries there seem to be tensions between institutions and delegates and some ESEAS members do not consider themselve well represented in the ESEAS GB.

Comparing the ESEAS GB composition to the Board membership of other services such as the IGS, the IVS, and ILRS, the main difference can be found in the national delegates. All of the other services have a Governing Board or Directing Board primarily consisting of members elected by the contributing member institutions. An exception is EUREF, where a large plenary group of national representatives is meeting annual, while a much smaller and rather effective Technical Working Group meets three to four times a year and carries most of the work load. In all other cases, the size of these institutional decision-making components is normally considerably smaller than that of the ESEAS GB. Moreover, elected members tend to be more devoted to the role and more active in the Board. Therefore, the ESEAS should reconsider the composition of the ESEAS GB, particularly if the ESEAS is going to be established as a permanent services. This would require an efficient and active Board, which the current GB does not appear to be. Since none of the ESEAS members has made a formal and binding commitment of resources, an IGS-like structure of the ESEAS GB would be fully appropriate and most likely lead to a far more active and efficient decision-making process.

Perhaps the most critical point in the development of the ESEAS so far is the absence of products delivered by the ESEAS. This lack of products is caused by several peculiarities of the ESEAS compared to other services:

- The ESEAS could not base itself on existing centres producing relevant products. Right from the start, services such as IGS, IVS and ILRS included institutions already involved in producing relevant products on a nearly routine basis. Having such a basis provided the background for an active discussion and development of routines, methodology, and standards. For the ESEAS, such centres needed to be set up in the frame of the ESEAS-RI project more or less from scratch. In the field of GPS analyses, the ESEAS-RI project was rather successful in activating six ESEAS Analysis Centres. In the field of sea level analyses, ESEAS-RI stimulated nine partners to participate in the analyses and the productions on scientific results, while routine sea level products are not yet available.

- Data policy has been a blocking aspect particular with respect to provision of real-time or near real time data from tide gauges.

- The lack of the Network and Product Coordinators has certainly been a handicap for the ESEAS. The coordinators would have been able to stimulate agreement on conventions and standards. Moreover, they would have been able to take a share of the work load and ensure that network development and product production were in line with the ESEAS rules and conventions.

- In mst services, a pro-active and constructive interaction of the chair of the respective Board and the Central or Coordinating Bureau allows for a concentration of the resource available to the Central or Coordinating Bureau on the day-to-day running of the service and the development of the tools required for the central interface between users and the service. In the case of the ESEAS, the ESEAS CB was overloaded with both the task of representing the ESEAS externally, promoting the growth of the ESEAS and running the day-to-day business of the ESEAS.

Finally, it is stressed that the voluntary commitment or the ”best effort principle” is not considered a critical point for the ESEAS. All other services including the IERS are based on this principle and they are rather successful. However, this requires a certain attitude of the members, i.e. the contributing institutions. It requires the insight that a return for the contribution does not come in form of direct funding through the organisation based on best effort contributions but rather through a recognition of the value of the contribution to the organisation at home and in regional funding sources. This comes as a result of a valuable service provided by the organisation, which depends crucially on the positive attitude and the active contributions of its members.

9 Summary of main contribution

In continuation of a processes started in the frame of the COST Action 40, the ESEAS and particularly the ESEAS-RI project achieved both a regional linking of the formerly scattered sea level monitoring and research community and the integration of two distinct disciplines into a highly interactive community. Thanks to the ESEAS, many of the institutes responsible for the operation of coastal tide gauges in Europe have now expert support for the additional task put upon them through the requirement to provide absolute sea level changes, namely the task to monitor the vertical land motion at the tide gauges. Thus, the ESEAS achieved an integration of the field of oceanography and geodesy normally not found in comparable activities such as GLOSS or TIGA.

In a relatively short time period of three years, the ESEAS managed to raise the funds to upgrade a number (more than ten) of tide gauges to modern digital gauges apt for real-time applications. Moreover, more than 15 tide gauges were co-located with CGPS and will soon provide high-quality estimates of absolute sea level changes in several oceanic regions where they currently are not available.

Based on the work done in the frame of GLOSS and IOC, the ESEAS has started to compile routines for operational procedures with particular emphasis on quality control.

Thus, the ESEAS is fostering the standardisation of operational routines.

The ESEAS has done considerable work to improve the data availability through a central European sea level data interface. In the process, a number of national institutes have invested in setting up own web pages, which give access to parts of their data archives. It is expected that the ESEAS in the near future will have a user interface giving access to a significant fracture of the European sea level database.

Within the frame of the ESEAS-RI project, significant knowlegde transfer has taken place both between geographical regions, individual institutes and between disciplins. This applies to operational routines as well as research methodology.

The ESEAS and the ESEAS-RI project have contributed to the GMES programme development as the partner representing the European sea level monitoring and research community. At several opportunities such as the EuroGOOS conferences and the Eurocean 2004 conference, the ESEAS has taken part actively in shaping the observational and research programme in the frame of GMES and the European framework programmes.

10 Relevance for Society

Sea level is an environmental variable important for studying climate processes in the coupled atmosphere-ocean system. Moreover, sea level data has a large market in both scientific and non-scientific applications. A considerable proportion of the population of Europe is concentrated near the coast, thus the provision of sea level data and products for assessment of risk and safety (extreme values, subsidence rates, increasing storminess) is of paramount importance. Having an unique access to a quality-controlled, European-wide database of tide gauge and ancilliary observations as well as derived products will ease many practical application requiring sea level information as well as scientific studies and coastal zone applications. In particular, the improved high-frequency European database will allow improved estimates of extreme sea levels, and further develop the techniques to predict them and their return frequency, and thus allow to assess better the economic cost of coastal development. Likewise, and in combination with observations of vertical land motion, this database will facilitate the improvement of estimates of local subsidence rates, and changing tidal conditions, leading to improved management of flooding hazard. In addition, the ESEAS data set will lead to improved products for climate change research allowing better assessments of long-term hazards to be undertaken.

The research carried out in the ESEAS-RI project is expected to result in an empirical model of sea level variations, which provides a important basis for future studies of climate processes at decadal to inter-decadal time scales, particularly the North Atlantic Oscillation, as well as a coherent description of the occurrence of extreme sea levels. Climate fluctuations on inter-annual time scales affect human activities at sea (such as fishery and off-shore ingeneering) as well as on land (such as agriculture). Having available an empirical model describing the sea level variations during the last hundred years will be valuable for validation of models for seasonal to inter-annual climate prediction, which may help to mitigate the effects of these climate variations on human activities.

Improvements of the sea level observation network contribute to better data availability in near-real time for operational oceanography as well as on the longer term for climate monitoring. This opens for contributions particularly to GMES.

The integration of a major part of the European sea level research community into a larger network promotes coordinated research. Moreover, the work in the project is resulting in contributions to environmental assessment reports and provides input to the development of the future GMES, particular with respect to obstacles for the exploitation of existing multi-national databases in terms of e.g. technical aspects, data quality and policy, legal and organisational issues.

11 Open issues

There are a number of open issues that need to be emphasised and addressed here. The list of issues includes but is not limited to the following:

- **Data quality information**: There is currently no clear concept of how data quality information is going to be made available to users together with the data. Initial ideas of quality flags are rather traditional and may easily prove to be insufficient. Here, the ESEAS should follow closely the discussion in the context of global Earth observations and integrate the methodology worked out there in the ESEAS products.
- **Digital Object Identifier (DOI)**: The ESEAS needs to consider how data sets and products can be associated with the originater in a unanimous way, thus easing the process of making data freely available to users. The DOI system[7] may be the appropriate tool to achieve this.
- **Copyright issues**: The ESEAS needs to consider copyright issues in a coherent and transparent approach. For most institutes, it will ease the step to make data and products available through the ESEAS if copyright issues are treated appropriately, and thus it is ensured that copyrights of the data or product originator are respected.
- **Data access policy**: The ESEAS needs to address more clearly the data access policy with its members and

[7] See http://www.doi.org for more information on DOI.

to ensure that the requirements for data access are respected.

- **Integration of ESEAS and ESEAS-RI**: Depending on the continuation of the ESEAS, the integration of the results of the ESEAS-RI project into the ESEAS will deserve considerable effort. It would be rather unfortunate if the future ESEAS would not be fully build on the achievements of the ESEAS-RI Project. The integration of ESEAS-RI partners, that are currently not ESEAS members, into the ESEAS also needs to be forster.

- **ESEAS and GMES**: The role of the ESEAS in the GMES needs to be addressed offensively on European level. A key issue will be whether the ESEAS as an organisation currently based on the best effort principle will be able to guarantee a contribution to GMES or whether such a contribution will require to base at least a part of the ESEAS on more formal and binding agreements.

12 Conclusion and Recommendations

The ESEAS Pilot Project, which was initiated by the COST Action 40, has resulted in considerable achievements in terms of community building, cross-disciplin knowledge transfer, improvement of the observational and application network, progress towards standardisation of operational routines as well as access to data and products. The ESEAS-RI project has provided funds for improvements of infrastructure and also for exploitation of the sea level data for research.

The ESEAS and the ESEAS-RI project have achieved a high level of recognition on European level. It is likely that the ESEAS will form one of the initial operational contributors to GMES. The organisational approach taken by the ESEAS is likely to influence other regional implementations of GLOSS and also activities in other areas of Earth observations.

It is therefore recommended that

- the ESEAS is established as a permanent service;

- the ESEAS continues to base its main activities on the ”best effort” principle, which opens the ESEAS for potential member institutions without first having to go through a tedious process of agreeing to binding contracts;

- the ESEAS reconsiders the composition of the ESEAS GB with the goal to achieve a more effective decision making component;

- the ESEAS reactivates the TEC in order to ensure continuity of work in post ESEAS-RI times;

- the ESEAS focuses on making available the full ESEAS sea level data base and sea level related products through the ESEAS web interface;

- the ESEAS establishes a firm commitment towards a service provision for the GMES.

It will be important for the ESEAS to meet in the near future the high expectations created on European level in the course of the ESEAS Pilot Project and the ESEAS-RI project. For that, an active chair of the GB, a highly qualified chair of the TEC and a supportive director of the CB are crucial but not sufficient. The ESEAS member institutions will have to take more responsibilities for specific tasks as ESEAS Analysis and Supporting Centres. In particular, it will also be necessary to support the GB and TEC chairs as well as the CB director through efficient Network and Product Coordinators.

References

Baker, T. F., Woodworth, P. L., Blewitt, G., Boucher, C., & Wöppelmann, G., 1997. A European network for sea level and coastal land level monitoring, *Journal of Marine Systems*, **13**, 163–171.

Blewitt, G., Davies, P., Gregorius, T., Kawar, R., & U., S., 1997. Sustainable geodetic monitoring of the natural environment using the igs, in *Proc. of the IGS-PSMSL Workshop on Methods for Monitoring Sea Level*, edited by R. E. Neilan, R. A. Van Scoy, & P. Woodworth, pp. 69–83, JPL Publication 97-17, Pasadena March 17-18, 1997.

Church, J. A., Gregory, J. M., Huybrechts, P., Kuhn, M., Lambeck, K., Nhuan, M. T., Qin, D., & Woodworth, P. L., 2001. Changes in sea level, in *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, edited by J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, & C. A. Johnson, p. 881, Cambridge University Press, Cambridge.

EOSS, 2001. *Book of Extended Abstracts, Final Workshop of COST Action 40*, Hydrographic Institute of the Republic of Croatia - Split.

GEO, 2004. Draft geoss 10-year implementation plan, Draft Reference Document 202-1, prepared by the *Ad hoc* Group on Earth Observations (GEO) Impementation Plan Task Team IPTT. Avaliable at http://earthobservations.org.

Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K., & Johnson, C. A., eds., 2001. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.

Hurrell, J. W., 1995. Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation, *Science*, **269**, 676–679.

Hurrell, J. W. & van Loon, H., 1997. Decadal variations in climate associated with the North Atlantic Oscillation, *Climatic Change*, **36**, 301–326.

International GPS Service, 2001. GPS Tide Gauge Benchmark Monitoring Pilot Project (TIGA - PP), Call for participation, International GPS Service, available at http://op.gfz-potsdam.de/staff/schoene/TIGA_CfP.pdf.

IOC, 1997. Global Sea Level Observing System (GLOSS) Implementation Plan - 1997, Tech. rep., Intergovernmental Oceanographic Commission, Technical Series, vol 50, 91 pp plus Annexes.

Philander, S. G. H., 1990. *El Niño, La Niña and the Southern Oscillation*, Academic Press, San Diego, CA.

Plag, H.-P., 1999. Network implications for global change monitoring, in *Proceed. IGS Network Systems Workshop*, edited by C. E. Noll, K. T. Gowey, & R. Neilan, pp. 69–76, IGS/JPL, Pasadena.

Plag, H.-P., Ambrosius, B., Baker, T. F., Beutler, G., Bianco, G., Blewitt, G., Boucher, C., Davis, J. L., Degnan, J. J., Johansson, J. M., Kahle, H.-G., Kumkova, I., Marson, I., Mueller, S., Pavlis, E. C., Pearlman, M. R., Richter, B., Spakman, W., Tatevian, S. K., Tomasi, P., Wilson, P., & Zerbini, S., 1998. Scientific objectives of current and future WEGENER activities, *Tectonophysics*, **294**, 177–223.

Plag, H.-P., Axe, P., Knudsen, P., Richter, B., & Verstraeten, J., eds., 2000. *European Sea Level Observing System (EOSS): Status and future developments*, vol. EUR 19682, Office for Official Publication of the European Communities, Luxembourg, 72 pages.

Prandle, D. & Flemming, N. C., eds., 1998. *The Science Base of EuroGOOS*, EuroGOOS Publication No. 6, Southampton Oceanography Centre, Southampton, ISBN 0-90417530-8.

Spencer, N. E. & Woodworth, P. L., 1993. Data holdings of the Permanent Service for Mean Sea Level, Tech. rep., Permanent Service for Mean Sea Level, Bidston, UK, 81pp.

Thompson, D. W. J. & Wallace, J. M., 1998. The arctic oscillation signature in the wintertime geopotential height and temperature fields, *Geophys. Res. Lett.*, **25**, 1297–1300.

Thompson, D. W. J. & Wallace, J. M., 2001. Regional climate impacts of the Northern Hemisphere annular mode and associated climate trends, *Science*, **293**, 85–89.

Thompson, D. W. J., Wallace, J. M., & Hegerl, G. C., 2000. Annular modes in the extratropical circulation. Part ii: Trends, *J. Climate*, **13**, 1018–1036.

Van Loon, H. & Rogers, J., 1978. The seesaw in winter temperatures between Greenland and northern Europe. Part I: General Description, *Mon. Wea. Rev.*, **106**, 296–310.

Wallace, J. M. & Thompson, D. W. J., 2002. Annular modes and climate prediction, *Physics Today*, **55**(2), 28–33.

Warrick, R. A., Provost, C. l., Meier, M. F., Oerlemans, J., & Woodworth, P. L., 1996. Changes in sea level, in *Climate Change 1995–The science of climate change*, edited by J. T. Houghton, L. G. Meira Filho, B. A. Callander, N. Harris, A. Kattenberg, & K. Maskell, pp. 359–405, Cambridge University Press, Cambridge, UK.