Paper published in *Poutanen, M. and Suurmäki, H. (eds.): Proceedings of the 14th General Meeting of the Nordic Geodetic Commission, Espoo, Finland, 1-5 October 2002*, Finish Geodetic Institute, Finland, pages 80-88.

European Sea Level Service (ESEAS): Status and Plans

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

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. In November 2002, the EU-funded ESEAS Research Infrastructure project (ESEAS-RI) started, and this project is expected to improve both the quality of and access to the European sea level data.

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).

In Europe, tide gauges have been operated at many coastal locations for a long time (up to two hundred years) and the total data base of European relative sea level 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 no European inventory of available data exists. Despite a positive trend over the last few years, national inventories are still the exception, and most often not easily accessible. Thus, the database valuable for many scientific and practical purposes is to a large extent inaccessible (for a more detailed documentation of the present situation, see Plag et al., 2000).

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 do not currently 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[1] Action 40 "European Sea Level Observing System" (EOSS[2]) was initiated, taking the unsatisfying situation as a starting point. Most 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 on-going 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

[1] 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/

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

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.

The ESEAS has made the initial step in bringing together the formerly scattered sea level research infrastructure in Europe. Presently, ESEAS is developing 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. In the frame of the ESEAS, the EU-funded project "ESEAS Research Infrastructure" (ESEAS-RI) started on 1 November 2002 [3]. This project has the goal to support the research infrastructure of ESEAS and to facilitate full scientifiic exploitaiton of European sea level observations.

2 Objectives, tasks and products of the ESEAS

In the ToR[4], 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 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. 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 user through the ESEAS. Another task to be emphasised here is the establishment and maintainance 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://www.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

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

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

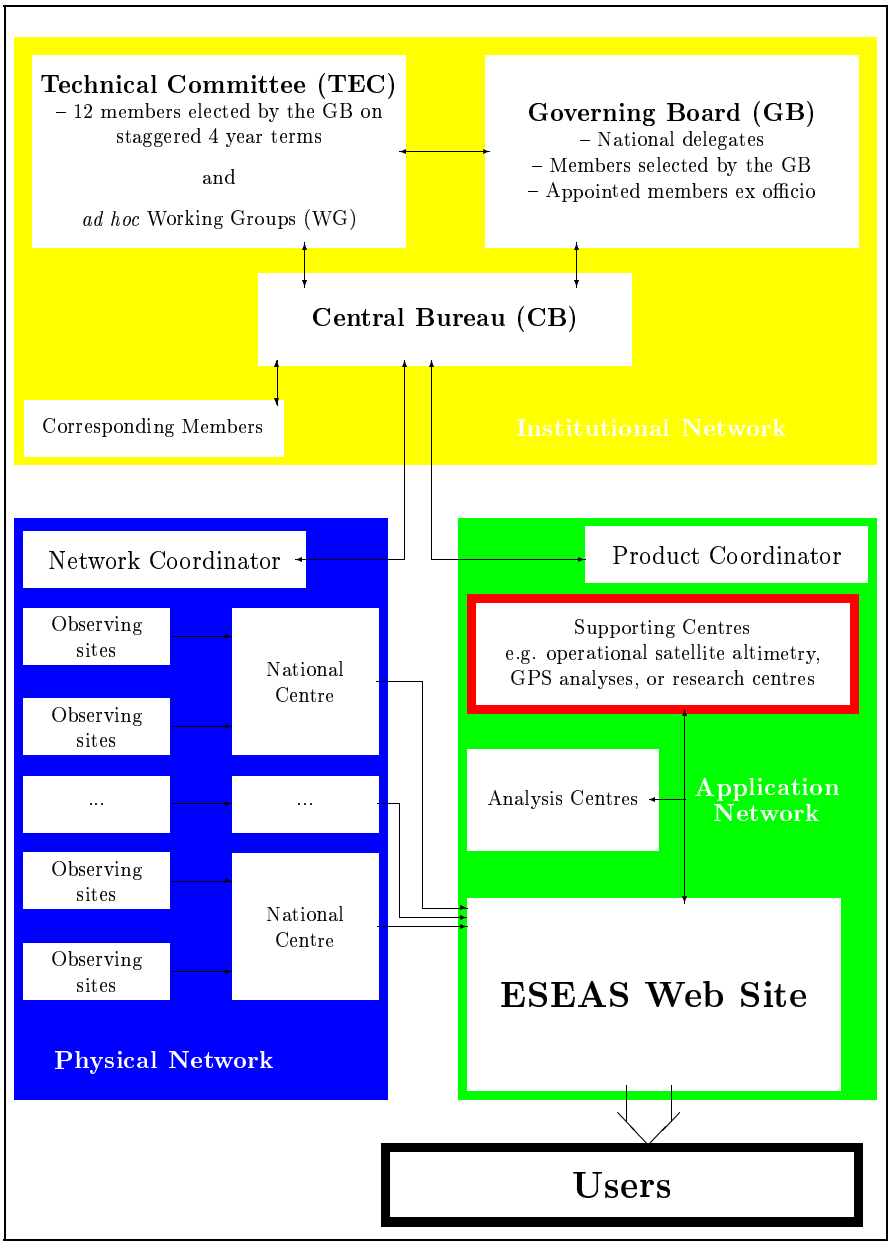

Figure 1: Organisational structure of the ESEAS.
The ESEAS structure is composed of a physical, application and institutional network (Plag, 1999).

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 currently is on a low level and will be promoted through the ESEAS-RI project.

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 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 have to provide the necessary funds both for running the physical network and setting up the application network. The institutional network is represented through the Governing Board (GB), the Central Bureau (CB) and the Technical Committee (TEC).

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.

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 18 countries are actively participating, namely Belgium, Croatia, Denmark, Germany, Greece, Italy, Lithuania, Norway, Poland, Portugal, Romania, Slovenia, Spain, Sweden, The Netherlands, Turkey, Ukraine, U.K. In five countries, namely France, Bulgaria, Estonia, Latvia and Russia, participation in ESEAS is under discussion internally. A second CfP was issued in July 2002, and this CfP asked for proposals for the ESEAS Analysis and Supporting Centres as well as the Network and Product Coordinators.

Up to now, the ESEAS GB has met three times (see the ESEAS web page for the full information). The ESEAS Central Bureau is 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 participants.

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.

In response to the first CfP, more than 150 tide gauges were proposed as ESEAS Observing sites (see Figure 2). Many of the proposed tide gauges are already co-located with GPS and more are planned to be co-located in the near future. The resulting network is spatially inhomogeous but, nevertheless, the GB accepted all proposed sites.

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, the sites of the tide gauges committed to the ESEAS are currently classified by the ESEAS TEC both with respect to their potential application and the actual situation. This classification will help to direct resources for necessary upgrading and data quality control.

As far as possible, ESEAS intends to cooperate and build on 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.

5 The ESEAS-RI project

The primary technological objective of the ESEAS-RI project is to support the ESEAS research infrastructure. ESEAS-RI will facilitate the transnational coordination and support the upgrading of the network of observing sites. The standardisation of the network, the operational routines, the databases and the quality-control will 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

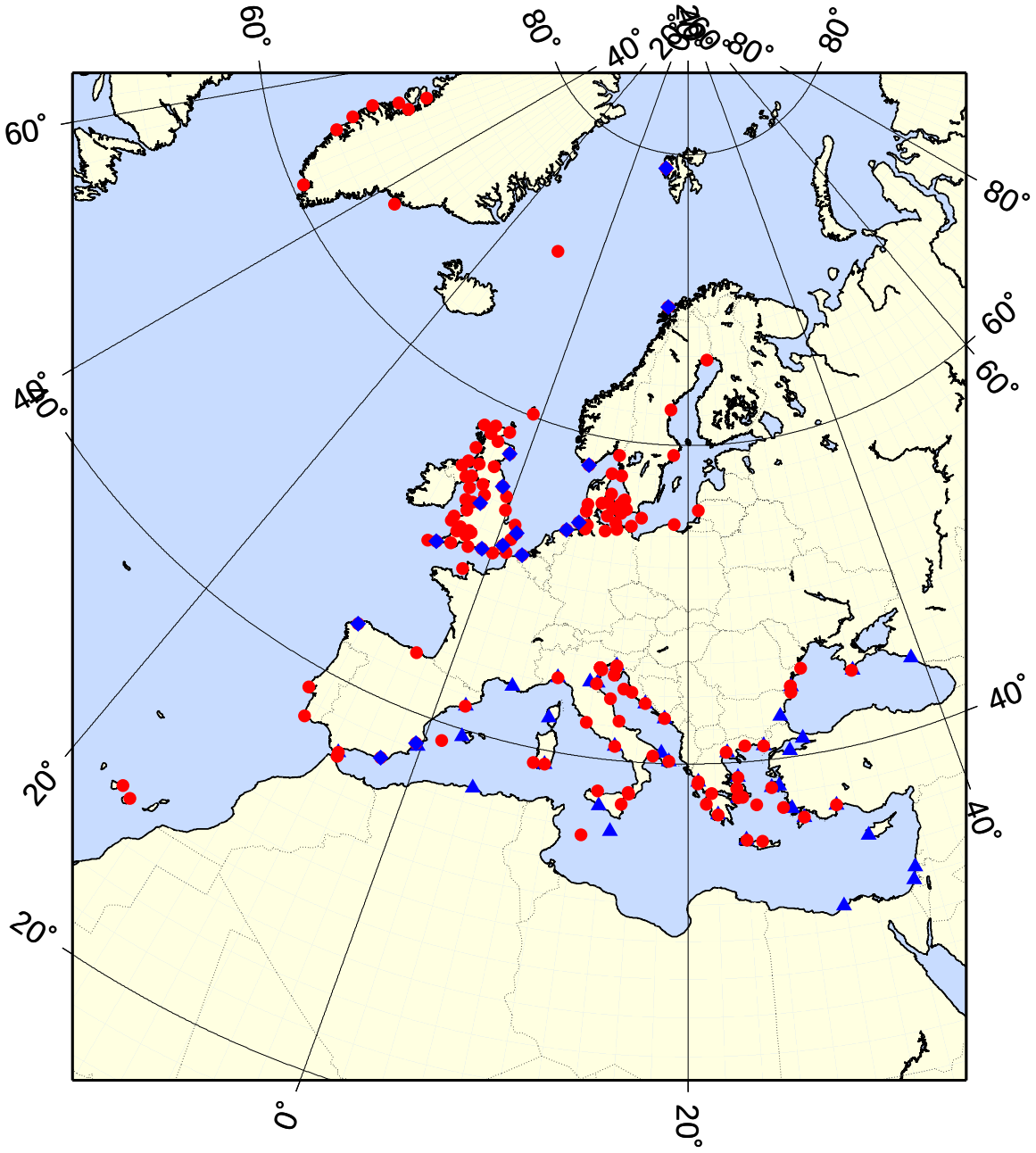

Figure 2: The ESEAS network of Observational Sites.
Circles are ESEAS Observing Sites consisting of a tide gauge; squares indicate Observing Sites with tide gauges and CGPS. Triangles are the MedGLOSS sites. Note that some overlap exists between the ESEAS and MedGLOSS sites.

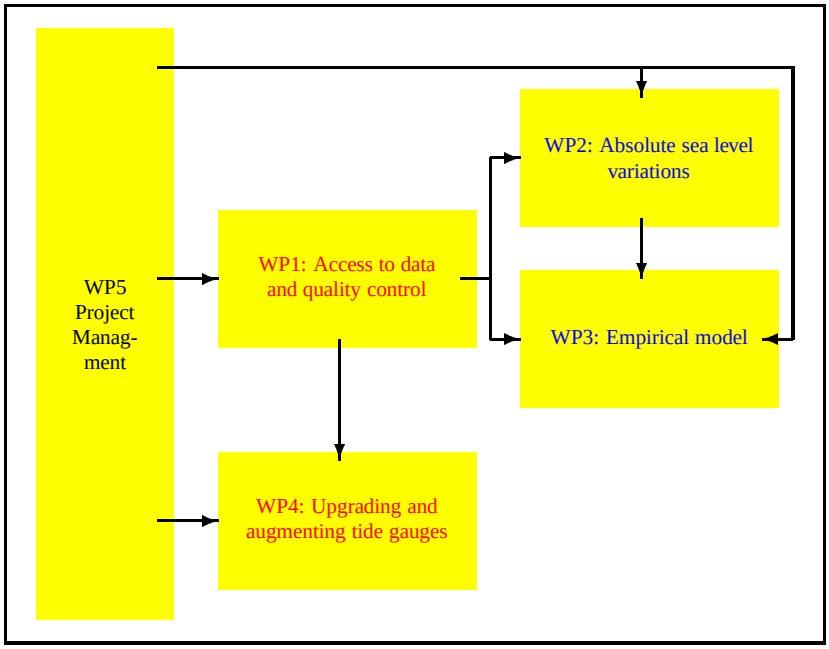

Figure 3: Interconnection of work packages.
All project management tasks are allocated in WP5, and this WP has a close link to all other WPs. WP1 and WP4 are related to the network of ESEAS Observing Sites, while WP2 and WP3 relate to the scientific objective of the proposal.

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 for the project is available on the ESEAS-RI web page. Here, two aspects of the project are emphaised. 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 trival but higly 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"[5] aims for a global solution. In the ESEAS-RI project, different strategies will be studied and an optimal methodolgy 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

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

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

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. Based on the empirical sea-level model produced in the ESEAS-RI project, more complete studies of the forcing factors will be possible.

It is expected that through ESEAS-RI, a quality-controlled database of hourly tide gauge data will be made accessible and the ESEAS observing network will be upgraded in crucial regiona. Moreover, the project is expected to result in an major improvement of the research infrastructure comprised in the ESEAS. The research carried out in the project will 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 will stimulate the integration of European sea level research community into a larger network and thus promote coordinated research. The work in the project will directly result in contributions to environmental assessment reports and will also 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.

6 Links between ESEAS and ESEAS-RI

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

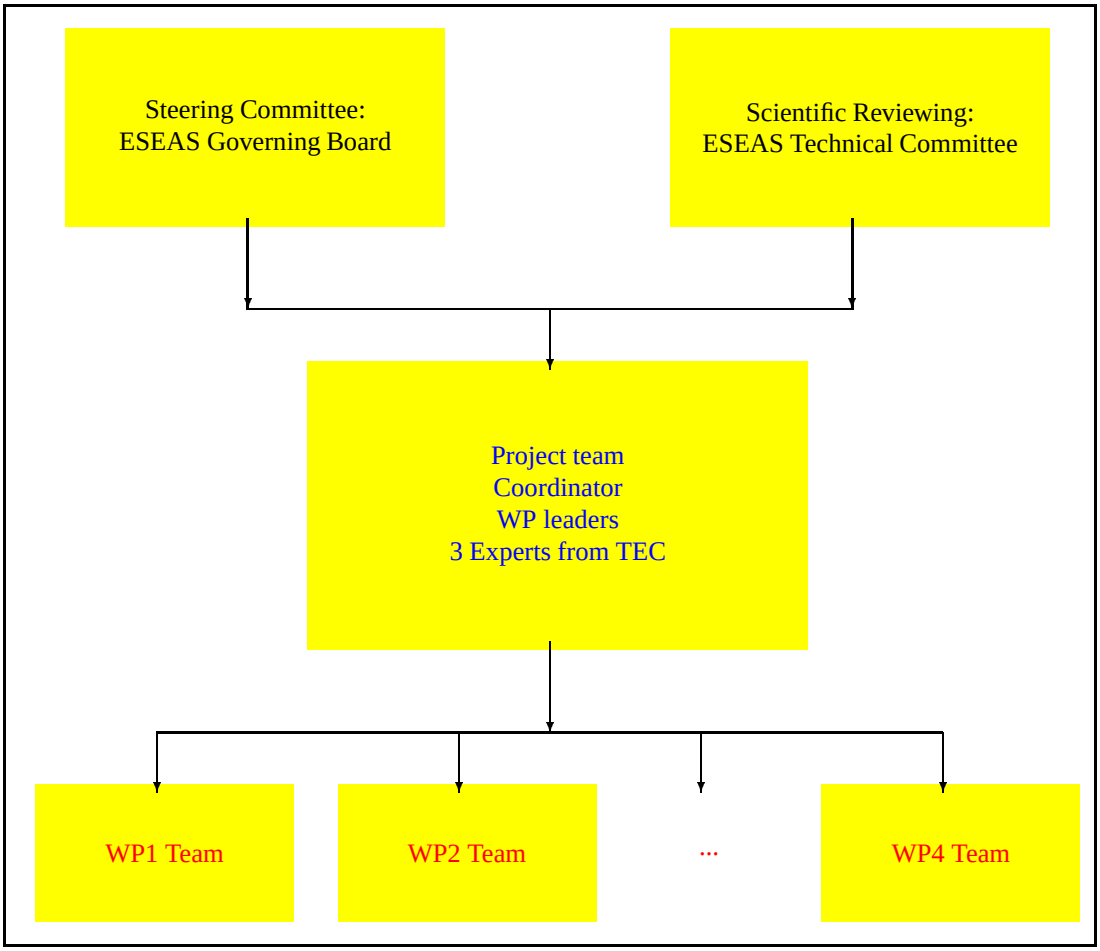

Figure 4: Project management structure.

and operational activities related to sea level. Additonally, through the ESEAS, the consortium is closely linked with the national authorities for tide gauge operation in additional 8 countries as well as the scientific experties provided by the ESEAS Technical Committee.

The project is be managed by the Central Bureau of ESEAS, which is hosted at the Norwegian Mapping Authority, and the author is the coordinator. In order to ensure a strong link between the project and the ESEAS, the project Steering Committee is the ESEAS Governing Board (Figure 4). The GB continuously monitors the projects progress against the milestones and expected deliverables. Moreover, continuous scientific reviewing of progress as well as advice is provided by the ESEAS TEC,

At the kick-off meeting of the ESEAS-RI project, held in Istanbul, Turkey, 11-13 November 2002, for each WP, a WP leader has been assigned, who is responsible for the technical progress. The Project coordinator, the WP leaders, and three additional external experts form the Project Team. Each WP comprises several separate task, and task responsible persons were also assigned. A full overview of the structure of the project including all individuals participating is available on the ESEAS-RI web page.

The three external experts to be included in the project team have the task to provide advice on important issues and to review the progress. These experts, which are currently being identified, will cover the fields of sea level studies, geodesy, and oceanography.

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.

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.