Intergovernmental Oceanographic Commission
Workshop Report No. 180

Abstracts of Presentations at Workshops during the 7th Session of the IOC Group of Experts on the Global Sea Level Observing System (GLOSS)

Organized in co-operation with the
University of Hawaii Sea Level Centre

Honolulu, Hawaii, USA
23-27 April 2001

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INTRODUCTION

This report contains abstracts of presentations at several scientific workshops held during the week of 23-27 April 2001 at the University of Hawaii, as part of the discussions of the 7th session of the Intergovernmental Oceanographic Commission (IOC) Global Sea Level Observing System Group of Experts (GLOSS GE7). These workshops included:

(1) A one-day workshop (spanning 23-24 April) in honour of Professor Klaus Wyrtki which addressed sea level and oceanographic topics in the Pacific and Indian Oceans;

(2) A one-day workshop (spanning 23-24 April) which focused on research activities conducted under the sea level component within the Asia-Pacific Space Geodynamics (APSG) Programme;

(3) A working group meeting (also spanning 23-24 April) of the International Association of Geodesy (IAG) Section II project on GPS-Water Level Measurements;

(4) A workshop (25 April) on the use of GPS for the monitoring of tide gauge benchmarks held under the auspices of the International GPS Service (IGS), Permanent Service for Mean Sea Level (PSMSL), International Association for the Physical Sciences of the Ocean (IAPSO), IAG and GLOSS.

Details of the workshops held at the University of Hawaii during GE7 can be found in the meeting report published by (IOC/GE-GLOSS-VII/3). The present report can be considered as an extension to that document, by providing an additional record of the presentations made.

The presentations of Emery et al., Gordon, Merrifield, Meyers, Mitchum, Patzert, Woodworth and Aarup were given as part of workshop 1. Those contributed to workshops 2-4 was found to overlap to some extent with the themes of other workshops. Consequently, for simplicity, we have combined in the present report all the abstracts available from the 'Hawaii week' in first-author alphabetical order, making no distinction between oral and poster presentations.

T. Aarup, IOC/GLOSS Technical Secretary
M. Merrifield, University of Hawaii Local Organizer
C.K. Shum, Co-Chair APSG Sea Level Group
P.L. Woodworth, Chair IOC/GLOSS Group of Experts

ABSTRACTS

GPS and Absolute Gravity Measurements at UK Tide Gauges

T. F. Baker [1], R.M. Bingley [2], A.H. Dodson [2], F.N. Teferle [2] and S.D.P. Williams [1]

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Continuous GPS (CGPS) stations have now been installed at the seven UK tide gauges with the longest mean sea level records, with the aim of separating the vertical crustal movements from the climate related changes in mean sea levels. Episodic GPS measurements are also being made at a further 10 UK tide gauges. In addition, in 1995 a programme of absolute gravity measurements began at the UK GLOSS tide gauges at Newlyn and Lerwick. The measurement of vertical land movements by two independent techniques will allow an assessment of systematic errors affecting the measurements. In this presentation, the GPS and absolute gravity results will be discussed and the measured vertical rates will be compared with the predicted rates from post-glacial rebound models.

Radar Altimeter Calibration using a GPS-Buoy in Corsica

Pascal Bonnefond, Pierre Exertier, Yves Ménard, CNES, Avenue Edouard Belin, Toulouse, France

The Absolute calibration site of Corsica is working operationally for calibrating TOPEX/Poseidon altimeters, in preparation to Jason, using comparisons with tide gauges data. Taking the advantage of this site, a new experiment has been performed to calibrate T/P altimeters: it uses kinematic GPS technique to monitor sea level heights. A reference receiver is placed at a geodetic point (near the lighthouse) while the other is on the sea. Since February 2000, for each T/P over flight (during day) a GPS buoy is placed under the ground track about 10 km offshore. GPS and altimetric sea heights are then compared to deduce altimeter biases. Systematic controls are also performed using measurements above the three tide gauges before and after the over flight. Preliminary results are presented.

Levelling the Sea Surface using a GPS Catamaran

Pascal Bonnefond, Pierre Exertier, Yves Ménard, CNES, Avenue Edouard Belin, Toulouse, France

In 1998 a probatory experiment had been conducted at Corsica absolute calibration site (Senetosa) in order to determine the local marine geoid slope using GPS buoys. The very good results obtained during this campaign have encouraged us to extend the covered area (May 1999). This was necessary to insure the calibration process by using more 10 Hz altimeter data and above all data far from the shore which are of better quality. However, the GPS buoys technique is too long to cover a large area and we have then decided to build a Catamaran with two GPS antennas (Turbo-rogue/Sercel) on board. Tracked with a boat at a constant speed (between 3 to 3.7 m/s) this permitted to cover an area of about 20 km long and

7 km wide centered on the TOPEX/Poseidon ground track No. 85. Results show a very good consistency between GPS receivers: filtered sea height differences give a mean of -0.2 cm with 1.2 cm standard deviation. Moreover, crossover differences between GPS filtered sea heights have been performed in order to control the quality of the process. No systematism or distortions have been evidenced and statistic results of crossover differences give a mean of 0.2 cm with standard deviation of 2.7 cm. However, comparisons with tide gauges data show a bias of 1.9 cm with a standard deviation of less than 0.5 cm. Even if this bias does not affect the geoid slope determination, which is used in the altimeter calibration process, it needs further investigation in the framework of vertical reference studies. Results in term of altimeter calibration show an improvement of more than 1.5 cm rms by using the new geoid slopes.

Low Frequency Sea Level Variations in The North Atlantic

W. Bosch, Deutsches Geodätisches Forschungsinstitut, (DGFI) Marstallplatz 8, D-80539 München, Germany (email: bosch@dgfi.badw.de)

Long period sea level variations are taken as an indicator of global change. While global sea level rise is difficult to prove with satellite altimetry, regional sea level variations can be significantly identified. The paper analyses eight years of TOPEX/Poseidon altimeter data in order to identify long periodic anomalous sea level changes in the North Atlantic. Annual oscillations as well as alias effects from imperfect ocean tide corrections are estimated by harmonic analysis and are subtracted from the sea level heights. Principal Component Analysis of the residuals identifies a dominant mode that shows a low frequency variation with duration of approximately seven years. The sea level time series is compared with the North Atlantic Oscillation (NAO) index and the results of comparable analysis of sea surface temperature and sea level pressure. Correlations between these data sets are investigated.

Comparison of Altimetric Sea Level Time Series and Tide Gauge Registrations

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To extrapolate altimetric sea level observations from multi-mission altimetry to a near-by tide gauge station a surface approach is used that estimates surface slopes, residual ocean tide corrections and a combined sea level time series to be correlated with the tide gauge registration. The approach implies the capability to verify relative range biases between different missions and to perform absolute comparisons in case the benchmark has been tied by GPS positioning and the height difference to the tide gauge zero point is known. The approach is applied to several tide gauges in the North Atlantic and the correlation between sea level time series and tide gauge registrations are shown.

GPS Estimates of Vertical Crustal Movements for Sites around the North Atlantic Ocean

W. Bosch, P. Häfele, K. Kaniuth, Deutsches Geodätisches Forschungsinstitut (DGFI), Marstallplatz 8, D-80539 München, Germany (email: bosch@dgfi.badw.de)

Tide gauge registrations monitor sea level relative to the Earth's crust. In order to distinguish apparent and true sea level variations the vertical crustal movement at the tide gauge must be known. There are several permanent GPS stations at or close to tide gauges along the North Atlantic coastlines. For these sites we have processed several one-week data sets distributed between 1994 and 1999. The estimated vertical crustal movements will be discussed and compared with estimates for the actual postglacial rebound.

Geocentric Sea Level Rise Estimations from ITRF2000 Results at Relevant Tide Gauge Sites

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Tide gauge records analysis show significant interannual and interdecadal sea level variability. Therefore, time series spanning over at least 40 years are required to filter out this variability and to derive sea level trends, which might be related to recent climatic changes. However, the long-term signal inferred from the tide gauge records is ambiguous: it includes eustatic sea level change as well as land level motion.

Space geodetic techniques have already been recommended by several national and international group of experts to monitor crustal vertical motions at tide gauge sites in a well defined and maintained geocentric reference system like the ITRS (International Terrestrial Reference System).

The recent ITRF2000 solution shows unprecedented accurate position and velocity results. The first part of the presentation will review the ITRF2000 results and explain the factors that have led to such improvements. Then, we will focus on the synergy of tide gauge and ITRF2000 results at specific sites where both tide gauge and space geodetic techniques are collocated. Results obtained from each technique are discussed and merged under certain assumptions in order to derive absolute (geocentric) mean sea level trends.

Improved Design of the National Ocean Service (NOS) GPS Buoy System

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M. Chin, S. Cofer, D. Crump, and G. Mader, National Geodetic Survey, National Ocean Service, NOAA, Silver Spring, MD, USA

Frank Aikman, Coast Survey Development Laboratory, National Ocean Service, NOAA, Silver Spring, MD, USA

Precise orbits, improved antenna and receiver design, antenna phase centre models, and more robust kinematic software all contribute to obtaining centimetre-level precision in the vertical component of GPS measurements from floating platforms. This new high level of precision makes it possible to obtain GPS-derived water level time series suitable for the determination of tidal datums, mapping sea surface topography, satellite altimeter calibration, and the determination of boundary conditions for numerical models and model verification.

The authors describe improvements to the NOS GPS Buoy System designed specifically to improve the open ocean boundary conditions for the NOS Chesapeake Bay Operational Forecast System and for evaluation and verification of the NWS Coastal Ocean Forecast System.

ENSO Variability in the Indian and Pacific Oceans from Tide Gauge Data and TOPEX/Poseidon Empirical Orthogonal Functions

Don P. Chambers, Christopher A. Mehlhaff, Timothy J. Urban, Daisuke Fujii, Byron D. Tapley, Centre for Space Research, The University of Texas at Austin, USA

Tide gauge data and empirical orthogonal functions (EOFs) from TOPEX/Poseidon sea level measurements are combined using the process of EOF reconstruction to compute a regular grid of sea level anomalies in the tropical Indian and Pacific Ocean basins from 1950 to the present. The accuracy of the reconstructed grids is assessed by comparing with grids determined from full altimeter data from 1993 to the present. The accuracy of earlier grids based on modern EOFs is assessed using the longer time series of global sea surface temperature grids. Results indicate accuracy of 3-4 cm RMS in high variability regions, which is similar to the RMS of T/P sea level compared directly with tide gauges. The reconstructed grids are used to study El Niño/Southern Oscillation (ENSO) variations from 1950 to the present. In particular, correlations between the Indian Ocean and Pacific Ocean are examined, and the volume changes associated with ENSO warm and cool phases are estimated.

Absolute Altimeter Verification Activities in Bass Strait, Australia

Richard Coleman [1,2] , Chris Watson [1] , Neil White [2,3] , John Church [2,3] , Ramesh Govind [4]

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A tide gauge site at Burnie, Tasmania was established in June 1992 as part of a calibration/verification activity for the TOPEX/Poseidon satellite altimeter mission. A permanent GPS receiver was collocated with the Burnie tide gauge in May 1999 and since then has been collecting daily observations. During 1999, a one-month GPS campaign was carried out to connect a number of tide gauge sites around Tasmania, including Burnie and Port Arthur.

The primary focus of the Burnie site is to estimate the absolute bias and bias drift of T/P, Jason-1, ERS and ENVISAT satellite altimeters. The verification activities include measurements from permanent GPS receivers, GPS buoy deployments during altimeter over flights, deployment of a current meter array under the satellite ground track to allow estimation of oceanographic (apart from tidal) contributions to the sea-surface height at the comparison point, and meteorological measurements.

Preliminary results from our verification activities will be presented together with results from our ongoing studies of GPS/tide gauge measurements.

Towards a Global Tide Gauges - Space Geodesy Collocated Network

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In the past decade the study of the global mean sea level has become a valuable issue of oceanography. Continuous measurements of global sea level changes are therefore of primary importance. Tide gauges have provided historical records but are inadequately distributed and measure sea level relative to the Earth crust. High precision satellite altimetry have provided since the beginning of the 90s a well distributed absolute sea level measurements in a geocentric reference frame, but suffers from instrumental drifts.

It emphasizes the need to calibrate the onboard altimeters with tide gauges data. While satellite altimetry measure absolute sea level change, and tide gauges provide sea level data relative to the land, it is needed to correct these latest data from vertical crustal movements. The space geodetic techniques allow to consider now direct determination of these land movements, which would give the possibility to determine their contribution to the sea level variations recorded at coastal tide gauges, and deduce the oceanic signal. DORIS and GPS are now mature space geodetic techniques that have the potential to contribute to this effort. The aim of this presentation is to give first the status of the DORIS and GPS networks located near tide gauges stations, and their expected evolution in terms of densification of collocations with tide gauges stations.

50 Years of Sea Level Change in Hong Kong from Tide Gauge Records

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Nearly five decades of tide gauge records and levelling measurements collected at two tide gauge stations in Hong Kong are analyzed to study the tendency and the frequency features in the sea level changes in this region. The results from the research show that there has been a long-term rise of 1.9±0.4 mm per year in the sea level and a downward trend of 4.85±0.16 and 4.18±0.26 mm per year, respectively, in the vertical ground movement at the two tide gauge stations. The variations in the sea level from seasonal through to decadal time scales are also detected by using the time-frequency spectrum of wavelet transform. The annual, semiannual and the 18.6-year variations are most significant and exhibit stable periodicity. The local atmospheric pressure variations mainly influence the annual sea level change and the effect amounts to 30% of the magnitude calculated before the inverted barometer corrections are applied. It is also projected from the extrapolation of the current trends of seal level rise and ground subsidence that the absolute and relative mean sea levels in Hong Kong may further rise 10 and 30 cm respectively by the middle of the next century. The possible maximum relative mean sea level change when considering the various temporal variations can be as high as 50 cm in the next half century.

Absolute Calibration of TOPEX/Poseidon and Jason-1 Using UK Tide Gauges, GPS and a Local Precise Geoid Model

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This presentation will describe the use of UK tide gauges, the sea level data from which can be located using GPS in the same geocentric reference frame as altimeter data from TOPEX, to provide an ongoing absolute calibration of the altimeter bias. The method is an extension of that of Murphy et al. (JGR, 101(C6), 14191-14200). However, in this analysis, no *a priori* tide or surge model corrections have been required between gauge and altimeter measurement points, the tide-gauge corrections being derivable from the data themselves. In addition, the analysis has benefited from the continuing improvements in precise local geoid models (e.g., EGG97) with which one can compute the necessary gauge-altimeter sea surface height differences. The research complements that in Australia (Coleman et al., this conference) and elsewhere and can, in principle, be applied at any other location for which a precise local geoid model is available. The relatively sparser Poseidon data set has been used as a test of our ability to perform an absolute calibration of upcoming Jason-1 altimetry as soon as possible after launch.

Mapping Temporal Changes of the Mesocale Circulation in the East Australian Current Region using Sequential Infrared Surface Temperature Imagery and Satellite Altimetry

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A five-year time series of infrared sea surface temperature images and satellite altimetry are used to compute surface currents in the region of southeastern Australia. Surface currents are computed from the infrared images using the Maximum Cross Correlation (MCC) technique while the altimeter data are used to compute geostrophic surface currents. An optimum interpolation scheme is used to combine these two independent measures of the surface current field. The MCC currents represent well the mean current and the near shore currents that are absent or affected by errors in the satellite altimetry. At the same time the altimeter derived geostrophic currents provide stable and accurate currents in the open ocean regions. This unique combination of surface current mappings exhibits some very interesting features in this region not previously known from the analysis of traditional oceanographic data. Time and length scales representative of this region will be derived from an analysis of this surface current time series.

What We Know about the Indonesian Throughflow

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Building on Wyrtki's Indonesian research papers of 1957, 1961 and 1987, the community in the last decade has further developed many aspects of the Indonesian Throughflow (ITF). The ITF represents a major transfer of mass, heat and freshwater from the Pacific Ocean to the Indian Ocean. The primary inflow route from the Pacific Ocean is through Makassar Strait, with a smaller contribution by pathways east of Sulawesi. The combined ITF is exported to the Indian Ocean through the channels of the Lesser Sunda Island.

The three main exit passages for the ITF into the eastern Indian Ocean are: Ombai Strait, Lombok Strait, and Timor Passage. Within the thermo cline layer the ITF is predominately derived from the North Pacific subtropics. Lower thermo cline water and deeper water of direct South Pacific origin are introduced by the eastern route and by spillover of dense water at the Lifamatola Passage. The Indonesian Seas are not a passive channel linking the two oceans. Within the seas the ITF thermal and salinity stratification and the SST are significantly modified by tidally and wind-induced mixing and by sea-air fluxes. The Pacific water masses composing the ITF are altered, so that the thermohaline (and perhaps transport) profiles of waters entering the Indian Ocean are quite different from their Pacific parents. Observational and model studies suggest the ITF transport varies with ENSO: larger transport during La Niña condition, smaller transport during El Niño. Most of the remaining variance of ITF transport once ENSO effect is removed is explained by the annual cycle, with a June-August maximum and December-February minimum, and by intraseasonal events (Indian Kelvin Waves, Pacific Rossby Waves). Best guess of the ITF transport? 10-15 Sv.

Determination of Global Parameters For Modern Reference Frames

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At present, different types of global reference systems, such as IGS, ITRF, WGS 84, GRS 80, are being used in geodesy. Most of them are, more or less, interrelated. In theory, a Somigliana-Pizzetti system, such as GRS 80, should consist of four independent parameters. The ideal case would be for these parameters to be observable, in the sense that they can be directly observed. This is not the case in modern geodesy. Another deficiency is the fact that, even though attempts have been made or, at least considered, those global systems would be related to a global vertical (unified) datum. Moreover, the temporal changes of those fundamental parameters are not yet sufficiently taken into account. Models of horizontal variations prevail. Discrete point fields related to standard tectonic plate models, assuming more or less continuous (with time) motion, are dominating.

As far as the global shape of the earth is concerned, polyhedron type models are being used which do not sufficiently cover oceanic areas. Meanwhile the number of altimetric satellites is so large that, together with repeat GPS-controlled global tide gauge systems and substantially improved models for tidal and similar reductions, sufficient accuracy is achieved in deriving fundamental global parameters and their temporal variations. Whether or not ITRF should thus be related to a global vertical datum or an absolute geoid, GRS 80 should be replaced by an improved Somigliana-Pizzetti model etc., is a matter of practical relevance. However, first attempts in that direction by Rapp, Bursa, Grafarend indicate the possibility to derive substantially new global models as soon as results from new gravimetric satellite missions (Champ, Grace, Goce) are available. The details, which should be applied to make optimal models available, have to be discussed.

Global change and related variations are primarily and best evaluated from large and heterogeneous global data sets, which need to be referred to precise reference frames and systems. Recent progress in that respect is such that a new generation of parameters can be derived, where global fundamental parameters are superior to discrete sets of regional or local data in view of their integrated global information.

Continuous GPS Monitoring of Tide Gauges at the Harvest Oil Platform: Geodetic Results from 1992-2001

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The Arguello Inc. Harvest Oil Platform is located about 10 km off the coast of central California near Point Conception. Attached to the sea floor, the platform sits in about 200 m of water near the western entrance to the Santa Barbara Channel. In addition to its primary mission to drill for oil, Harvest has served since 1992 as a calibration site for the TOPEX/Poseidon (T/P) mission. The T/P repeat ground track passes within +/-1 km of the platform, and the satellite passes directly overhead every 10 days while tracing out its global pattern of sea-level measurements. The Jason-1 mission (planned summer 2001 launch) will follow the same ground track, implying that Harvest will continue to serve a vital role in validating data from precise space borne radar altimeter systems.

In its capacity as a T/P calibration site, Harvest has hosted a GPS receiver and tide gauges since 1992. In this paper, we review results from nearly a decade of continuous monitoring of the platform vertical motion and local sea level. Current GPS results suggest that the platform structure is subsiding at a rate approaching 1 cm/yr, a likely consequence of the ongoing extraction of oil from the underlying Arguello deposit. The time series of GPS vertical position estimates also shows evidence of annual and longer-term systematic variations. We will discuss potential sources of these signals, including various loading and thermal effects as well as manifestations of GPS measurement errors. Included in our characterization of the latter will be the effects of water vapour delays, and the impact of equipment swaps (e.g., receiver and random changes). Finally, we will present the latest Harvest calibration time series for T/P. Combining the GPS, tide gauge and altimeter measurements, this time series serves as a vital performance record for the T/P mission. Particular emphasis will be placed on the assignment of realistic errors to the time series based on evaluation of the systematic errors in the GPS and tide-gauge measurements.

Use of The Satellite Altimetry Technique to Monitor The Sea Level Changes

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With space sampling resolving power from several kilometers to scores of kilometers and overlay power on the whole earth and time sampling interval from several to ten more days, satellite altimetry data, which offer us an abundance of information about sea level change and that of the global fine structure of mean sea level and space-time change of the ocean flow field, can meet our requirement in tide observation of the wide area ocean far from the coast.

The present accuracy of altimetry of T/P and ERS-2 satellite comes to centimetre order with the support of satellite load GPS and up to date JGM-3 and EGM global gravity field model, so the satellite altimetry technique has already been one of the important means to monitor the sea level change. Using T/P satellite altimetry data during 1993-1999 to calculate 11 tide harmonic constants of East China sea, its precision is higher than 4 cm; Using T/P satellite altimetry data to monitor the process of 1997-1998 El Niño in Pacific with precision better than 7 cm; Using T/P data to study the seasonal sea level changes.

There is a falling trend in the sea level near China Sea in the first and the forth season, a rising trend in the second and third season. The global seasonal sea level change is on the contrary. Recently, $2.5' \times 2.5'$ mean sea level height model of Chinese sea and its near sea area is established using several generations of satellite altimetry data. Compared with other three global mean sea level height models, the precision of this one is higher than 0.1 m.

The Historic Tidal Benchmark at Port Arthur, Tasmania, Australia: Is Sea Level Changing?

John Hunter (Antarctic CRC, University of Tasmania, Hobart, Tasmania, Australia), Richard Coleman (School of Geography & Environmental Studies, University of Tasmania, Hobart, Tasmania, Australia & CSIRO Marine Research, Hobart, Tasmania), David Pugh (Southampton Oceanography Centre, Southampton, U.K.), Chris Watson (School of Geography & Environmental Studies, University of Tasmania, Hobart, Tasmania, Australia)

On 1 July 1841, Thomas Lempriere installed a tidal benchmark on the shores of the Isle of the Dead, Port Arthur, Tasmania, Australia. We believe that it is one of the first such marks placed anywhere in the world for the scientific study of sea level. He also collected several years of sea level data, which were related to the benchmark. An Aquatrak acoustic tide gauge was established at Port Arthur during 1998/99 and became fully operational in August 1999. Using a combination of levelling, GPS buoy and static GPS observations we have established a connection between the 1841-42 benchmark and the current operational tide gauge. These observations, over the 158-year period, have been used to estimate mean sea level changes in southern Tasmania. The estimated rise of 0.82 +/- 0.19 mm/yr has been provisionally corrected for local vertical land movement (geological and post-glacial rebound). Our results will be discussed in the context of rates of global sea level rise estimated by the Intergovernmental Panel on Climate Change (IPCC).

An Operational Realization of a Global Vertical Datum for MSL Studies using VLBI Baselines and its Stability

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We used VLBI baselines generated by the GSFC VLBI Solution GLB1122 - June 1999 for an operational realization of a global vertical datum for the mean sea level studies. We first derived three-dimensional coordinates for three different fundamental tetrahedrons, formed by the combination of Fortleza-Kokee-NRAO20-Wettzell, Gilcreek-Hartrao-Matera-Westford, and Gilcreek-Kokee-NRAO20-Wettzell, VLBI stations. In this process, we used a series of free network solutions referenced to a common set of initially adopted nominal coordinates for VLBI stations. The adjusted coordinates at different epochs for three tetrahedrons were used to examine the global deformations of fundamental tetrahedrons as well as to establish time series of height information variations at each station. We examined the first order differences of heights to establish a vertical datum, and their n^{th} order differences to assess their potential stability over time for three fundamental tetrahedrons.

Altimeter Calibration in the Southern Baltic Sea

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In the last two decades the satellite altimetry became more and more important for investigations of global secular sea-level changes. These long-term investigations have to rely on a careful evaluation of possible systematic influences on the altimetric sea-level heights of different satellite altimeter missions. In this investigation we have compared measurements of two tide gauges in the southern Baltic Sea with sea-surface heights obtained by altimeter measurements of the satellites GEOSAT, ERS-1, ERS-2 and TOPEX. Both kinds of sea-level heights will be compared in an absolute sense. Methods, results and the error budget will be discussed in detail.

GPS Buoys Technology Applied to the Absolute Calibration of Space Radar Altimeters and to the Regional Mapping of the Sea Surface Topography

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The application of the GPS buoys technology to the absolute calibration of radar altimeters on-board is the main purpose of this work. Also the application of this relative new technology to validate other geophysical data as the significant wave height, derived from the altimeter measurements, is performed. A potential use of this kind of buoys to state a reference absolute sea surface in small areas is discussed. The mapping of the sea surface can become a useful tool for the estimation for biases and drifts for any altimeter mission that traverses the studied area.

The combination of space altimeter, GPS buoys and tide gauge observations is needed for the three guidelines pointed before, which are the core of the work developed in several campaigns conducted offshore the Spanish NW-Mediterranean coast in March 1999 and in July 2000. In principle, these campaigns were oriented to prepare the direct absolute calibration of the Poseidon-2 altimeter, on-board the Jason-1 mission, in the Spanish territory.

The centimetre accuracy estimation of the sea surface heights derived from the GPS buoys observations and the long-term tide gauge measurements (8-year time series) nearby the buoys locations are the terrestrial sources considered for the monitoring of the sea level.

An overview of the results of the last two-year calibration campaigns conducted in this region will be presented as well as the future scientist guidelines in the topic.

Sea Level and Currents at the Hawaiian Ridge

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Various processes affecting sea level and currents along the Hawaiian Ridge are examined including internal tides, wind-driven island-trapped waves, and low frequency signals related to ENSO.

On the Regression X Correlation Plots of Sea Level Geophysical Series

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There are several ways of producing data representation of geophysical series. Time series, isoplets, space x time plots are amongst the most used ways of displaying data for analysis. In time series analysis, plotting the regression values of a set of sea level series (PSMSL), against their correlation values, is shown to be an interesting tool in the description of an earth's global property that arises from the whole set of data.

The correlation coefficients, taken as a measure of co linearity, are shown to depend on the ratio of two regression coefficients and then independent on the inclination of the straight line relative to the coordinated axes. Also independent of the regression coefficients are the mean distances of data points, taken as a measure of proximity, to the regression lines. Plots of these variables, produced from the above mentioned geophysical sea level series, suggest that the overall rate of relative sea level has a negative value and that the products of the mean distances, to the correlation values of each port, has an overall mean value and are displaced along a not normal distribution, that seems to be a characteristic plot of the global PSMSL series, which all the ports of the world must follow.

From Java Upwelling to Indian Ocean Dipole

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Klaus Wyrtki first identified upwelling in the Indonesian region whilst he was working in Indonesia and Australia. We will first take a look at some of the early results, and a general overview of the winds and currents in the region. The Java upwelling is not as well known as the other eastern boundary upwelling regions (California, Peru etc.), partly because it is more highly variable in time, with intraseasonal, monsoonal and interannual time scales. Also, the Indonesian through flow feeds warm water into the region, which may sometimes mask the expression of upwelling in sea surface temperature.

In modern times (TOGA, WOCE), systematic, routine observations were established in the Indonesian Seas. We can now look at the regional phenomena in time-sequence and get a better understanding of their dynamics. The Java upwelling in particular is now recognized as an important dynamical aspect of the Indonesian through flow and the Indian Ocean Dipole, both critical phenomena in modern climate research.

On Providing a "Datum" for Altimetric Sea Surface Heights

Gary T. Mitchum, College of Marine Science, University of South Florida, St. Petersburg, FL 33701, USA

Klaus Wyrtki recognized very early on the importance of maintaining the stability of altimetric sea surface height time series if these data were to be useful for studies of low frequency variations, and he published this idea (with an application to the GEOSAT data) more than 10 years ago. This idea has resulted in a great deal of effort, and hopeful progress, in the time since, and this work will be reviewed. The present state of the art will be described, and potential directions for future improvement will be outlined.

Observations of Sea Level Change using Satellite Altimetry

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Satellite altimetry measurements from the TOPEX/Poseidon (T/P) mission now provide a precise record of sea level change covering late 1992 to the present. As the satellite record lengthens, we can begin to use the record to test models of current sea level change. We will review the observations of long-term sea level change made by T/P, including the changes observed during the 1997-98 ENSO event. Measurements of long-term sea level change using satellite altimetry must also be accompanied by an independent calibration of the instrument performance. We will review the recent results using tide gauges to calibrate the T/P instruments, and discuss the need for monitoring the position of the tide gauges using geodetic techniques, including suggestions for which tide gauges should be made a priority for geodetic monitoring. We will also address the question of when satellite altimetry will be able to make quantitative contributions to climate change science. Finally, we will present estimates of vertical crustal motion we have made using altimeter minus tide gauge sea level differences.

Wyrtki's Role in the Sea Level from Space Business

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In the past two decades sea level researchers have been given a revolutionary new tool, satellite altimetry. The very precise, TOPEX/Poseidon mission data have changed our view of the global sea level. Sea level signals ranging from long-term change, to interannual variability (El Niño, La Nina and Pacific Decadal Oscillations), to ocean tides are now globally sampled with precision. Wyrtki's early advocacy of TOPEX/Poseidon and highlights of the past decade's successes will be discussed.

SEAL: A German Programme for Quantifying Sea Level Changes

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SEAL is a large-scale strategic programme of the German Helmholtz Association aiming at an integrated approach for quantifying sea level on various space and time scales. The project is based on new observing techniques and recent high-resolution models of the processes governing the system ocean-ice-solid earth and covers the following interdisciplinary tasks.

Observation: The accurate determination of sea level is based on a combination of satellite and surface techniques. The focus is on multi-mission altimetry, with the aim of constructing homogeneous time series extending back to 1985. Basic requirements are the development of uniform calibration methods based on GPS buoys, the employment of high accuracy gravity field models as resulting from the CHAMP and GRACE missions and the GPS control of tide gauges.

Ice mass transfer: For long-term predictions of sea level change, reliable estimates of the mass balance of the Greenland and Antarctic ice sheets are required. For this purpose, field campaigns are planned for selected drainage basins. Combined with improved atmospheric boundary conditions, this information serves as input for high-resolution dynamic ice sheet models. On shorter time scales, the mass balance of mountain glaciers is dominant. Their contribution during the period 1860 to 2100 is assessed in a supplementary study.

Ocean modelling: The new observational techniques of monitoring sea level are complemented by dynamic ocean models. To improve computational efficiency, a hierarchy of global, single basin and regional models is employed. The study uses data provided by altimetry and satellite missions and incorporates the freshwater influx from Greenland determined by mass balance studies. Newly developed data assimilation techniques and observational models link the dynamic models with tide gauge records.

Glacial isostasy: Since GPS control of tide gauges is both rare and recent, a computation of their vertical motions due to glacial isostatic adjustment becomes necessary. For this purpose, a dynamic model of the Pleistocene ice sheets is developed and coupled with an earth model with laterally heterogeneous viscosity. Using paleo-strandline data and recent geodetic measurements, the coupled model yields an improved estimate of the viscosity distribution, which enters into the computation of vertical motion at tide gauges.

The presentation will describe the project goals and results achieved so far.

GPS Buoys for Calibrating Radar Altimeters for the SEAL Project

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SEAL is a large-scale strategic programme of the German Helmholtz Association aiming at an integrated approach for quantifying sea level on various space and time scales. The project is based on different observing techniques and recent high-resolution models of the processes governing the system ocean-ice-earth.

Sea level and its changes measured by radar altimeters are a central part of this study. Measurements taken by ERS-1/2, TOPEX/Poseidon, GEOSAT and the upcoming ENVISAT and Jason-1 missions will be used to construct homogeneous time series. Beside a homogenization of orbits and geophysical correction models used, a major problem will be the estimation of the biases between and possible drifts of the individual altimeters.

A ruggedized GPS equipped buoy will be developed and deployed in the North Sea. A toroid buoy was already selected and tested. This surface rider type of buoy will not only permit the observation of the instantaneous sea level during the satellite pass, but also an estimation of the significant wave height will be performed. In addition, the buoy will be equipped with supplementary sensors, like wind speed, humidity and air pressure sensors, allowing a broader use for calibration, e.g. of the backscatter / wind speed relationship.

The buoy will be deployed at a crossover location of ERS-2 (and ENVISAT). A nearby crossover with TOPEX and GFO (less than 5 km) makes this site even more suitable for multi-mission calibration. In addition, up to three bottoms mounted tide gauges will be deployed to account for the sea surface slope between the crossovers. The lifetime of the buoy is expected to be several years, therefore, a long-term calibration, drift monitoring and inter-calibration of different missions will be possible.

The presentation will describe the project goals and the technical design in more detail.

Continuous Monitoring of Tide Gauge Benchmarks with GPS in the SEAL Project

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During the last century, tide gauges were the most important tool for measuring and quantifying sea level changes. Due to their inhomogeneous geographical distribution, the derived quantities are of limited use. Moreover, distinguishing between natural and anthropogenic effects as well as between relative and absolute changes in sea level is almost impossible. Today, with the help of GPS at least an absolute determination of sea level changes might be possible.

Within the SEAL project, the use of tide gauge records is two-folded. Firstly they will be used to monitor and calibrate the radar altimeters of current and future space missions, like e.g. ERS-2 and ENVISAT. On the other hand tide gauge data will be used to measure absolute sea level changes. Both tasks need tide gauge records related to a common global reference frame. This will be accomplished by using only tide gauges which are equipped with long-term continuous GPS stations, contributing to the IGS network.

A sub-set of GPS stations near tide gauges is selected and daily solutions will be computed routinely. Whenever possible, also GPS data from the IGS database from recent years will be recomputed in order to extend the record and to have better constraints on the vertical motion of the benchmarks. This will permit not only the determination of an absolute sea level but also, by subtracting vertical motions of the benchmark (e.g. from post-glacial uplift modelling), a quantification of environmental and climatic impacts on sea level change.

This project is also part of a proposal for a pilot project on “Continuous GPS monitoring of Tide Gauge Stations” submitted to IGS. While the SEAL project has its focus on the northern hemisphere, the pilot study will also address stations distributed worldwide. To meet the requirements of the IGS, additional points will be included into the routine.

The presentation will describe the project goals and results achieved so far.

The Global Sea Level Observing System (GLOSS)

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In the mid-1980s, Klaus Wyrtki and David Pugh proposed to the Intergovernmental Oceanographic Commission (IOC) that a programme called GLOSS should be established, to put on a firmer (intergovernmental) basis the measurement of sea level changes worldwide. The GLOSS acronym seems to have been chosen at an early stage, corresponding to 'Global Level Of the Sea Surface', and was retained even when the programme name became 'Global Sea Level Observing System'. (GLOSS is not an acronym of 'Global Sea Level Observing System' in some obscure language as some people think).

A Task Team was formed which met on two occasions, the second time at the University of Hawaii in 1987. Thereafter, once the programme was approved by the IOC Assembly, a Group of Experts was established, a Technical Secretary was appointed (Albert Tolkatchev), and many of the activities with which we are now familiar were started (regular Experts meetings, training courses, workshops, reports etc.).

The GLOSS network (what is now called the GLOSS Core Network) of approximately 300 tide gauge stations around the world were chosen to provide a approximately-uniform coverage of global-coastal sea level changes, along continental coastlines and in all island groups. The choice was based on the extensive experience of Klaus (in programmes leading up to TOGA) and David (PSMSL). In 1990, a somewhat-delayed Implementation Plan was published, which technical developments (altimetry, GPS etc.) rendered out-of-date a few years later, requiring a new Implementation Plan in 1997. Wyrtki and Pugh, together with a number of others involved at that time, are still active in the field, if somewhat greyer. (New recruits can apply now). This presentation will attempt to describe some of the history behind GLOSS, and summarize the present status of the programme.

Constructing Land-Level and Sea-Level Time Series from GPS and Tide Gauge Observations at some French sites

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France has a long history of sea level observation. Early observations were carried out by the astronomers La Hire and Picard in 1679 at Brest. Since then, the sea level observing activity has been highly encouraged and supported by famous scientists and respectable institutions in France. The activity grew considerably in the beginning of the 19th century and led to numerous sea level observatories along the French coasts that observed for many decades. Unfortunately, very few long records have been recovered from ancient manuscripts and tidal curves.

Brest and Marseille are the longest French sea level tide gauge records available in France, specially Brest which may have contributed to almost all studies carried out to derive a global sea level trend estimation. Following the group of experts' recommendations, Brest and Marseille were equipped with permanent GPS receivers in 1998. The objective is to monitor the vertical crustal motion that affect each tide gauge in order to derive long term absolute sea level trends that might be related to recent secular climate changes.

After an overview of the sea level gauge time series of Brest and Marseille, this presentation will focus on the permanent GPS stations that have been installed at various French coastal tide gauges. Different objectives are aimed at long-term sea level trend studies (Brest, Marseille), satellite altimetry calibration (Ajaccio) and ocean circulation monitoring (Kerguelen).

For each case, we will discuss how the scientific, technical and environmental constraints were managed. We will then present the current state of land level time series constructions and conclude the presentation with results expressed in the latest ITRF solution.

Sea Level Change in Hong Kong and ENSO

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Tide gauge records in Hong Kong and data sets of sea surface temperature in the eastern Pacific and of southern oscillation index over 1954 and 2001 are analyzed to find the possible links between the sea level changes in Hong Kong and ENSO events. The results from the study indicate that the interannual variations in the sea level of Hong Kong are related to El Niño and La Niña events that occur frequently in the tropical Pacific. The sea level rises in this region when a La Niña event occurs, while it drops when an El Niño is present. For example, the last strong La Niña event induced an interannual variation of about 10 cm in the sea level.

Based on this study and data sets on earth rotation and atmospheric angular momentum obtained from global measurements of space geodesy and meteorology, signals of the next El Niño event are studied. It is projected that the peak period of the new El Niño will appear around the end of 2001.