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EuroGOOS
European Global Ocean
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Abstracts

The following are the abstracts of presentations submitted to the Sea Level Futures conference, hosted at the National Oceanography Centre and Liverpool University, Liverpool, UK 2-4 July 2018. These abstracts were selected for presentation, but otherwise have not been subject to peer-review. For further information, please contact the authors directly.

A probabilistic framework for the assessment of coastal impacts

Authors: Alexandra Toimil, Paula Camus, Melisa Menendez, Inigo Losada

Presenter: Alexandra Toimil

The increasing flood risk and the acceleration of beach erosion due to the effects of climate change are both main threats to coastal areas worldwide. Coastal damages are consequently expected to be intensified over the course of this century as sea level rise and so does the socio-economic development. Within this context, and according to the IPCC (2014), risk results from the interaction of hazard, characterized by coastal dynamics, exposure, associated to the physical and socioeconomic environment, and vulnerability, linked to the susceptibility of the system to be damaged.

Coastal flood and erosion hazards depend on waves, storm surge, astronomical tide, and mean sea level rise. While much research focuses on the analysis of flood risks owing to sea levels, few studies included the effect of waves, even despite having been responsible for serious damage on the coast. In connection with how climate change is introduced in the coastal assessments, changes in storminess are not usually considered and adding sea level rise to present extreme water level climate has become a common practice. Besides, little effort has been made to include waves and storm surge regional projections.

Regarding the characterization of exposure (e.g. number of people, residential and industrial buildings, critical infrastructures), local data is essential. However, obtaining such a detailed information is still an open challenge, which causes that many studies describe sectors or economic activities through land use data instead of socioeconomic indicators. While there is a generalized agreement on the definition of exposure, the way vulnerability is addressed widely differs among methodologies. In either case, vulnerability is complex, and depends on the sector exposed, the impact considered, and the geographic location where the latter takes place.

Here, a regional approach for the assessment of flood and erosion risks triggered by climate-related extreme events and sea level rise is presented. The framework is applied over the Asturian coast, a 345 km coastline on the Cantabrian Sea, where the risk of loss of beach recreation is estimated in probabilistic terms, and the flood risk consequences are evaluated for a number of sectors and finally integrated. To that end, multiple simulations of a process-based approach that combines cross section–based equilibrium models and long-shore sinks allowed the reconstruction of thousands of potential shoreline evolutions over the 21st century. In the case of coastal flooding, the RFSM-EDA hydraulic model is applied to obtain inundation maps that account for the key topographic features derived from a high-resolution digital terrain model and the local roughness with high efficiency and speed.

Tectonic influences on late Holocene relative sea levels from the central-eastern Adriatic coast of Croatia

Authors: Timothy A. Shaw, Andrew J. Plater, Jason R. Kirby, Simon Holgate, Keven Roy, Pero Tutman, Niamh Cahill, Benjamin P. Horton

Presenter: Andrew J. Plater

Differential tectonic activity is a key factor responsible for variable relative sea level (RSL) changes during the late Holocene in the Adriatic. Here, we compare reconstructions of RSL from the central-eastern Adriatic coast of Croatia with ICE-7G_NA (VM7) glacial-isostatic model RSL predictions to assess underlying driving mechanisms of RSL change during the past ~ 2700 years. Local standardized published sea-level index points (SLIPS) (n = 23) were combined with a new salt-marsh RSL reconstruction and tide-gauge measurements. We enumerated fossil foraminifera from a short salt-marsh sediment core constrained vertically by modern foraminiferal distributions (+ 0.12 m), and temporally by radiometric analyses providing sub-century resolution within a Bayesian age-depth framework. We modelled changes in RSL using an Errors-In-Variables Integrated-Gaussian-Process (EIV-IGP) model with full consideration of uncertainty. Previously established SLIPS show RSL rising from -1.48 m at 715 BCE to -1.05 m by ~ 100 CE at ~ 0.52 mm/yr. between ~ 500 and ~ 1000 CE, RSL was -0.7 m below present rising to -0.25 m at ~ 1700 CE. A minimum rate of RSL is recorded at 1500 CE decreasing to 0.13 mm/yr. The salt-marsh record shows RSL rose ~ 0.28 m since the early 18th century at an average rate of 0.95 mm/yr. Magnitudes and rates of RSL change during the twentieth century are concurrent with long-term tide-gauge measurements, evidencing a rise of ~ 1.1 mm/yr. Furthermore, a constant but subtle increase in the rate of RSL change supports previous findings for the lack of a significant modern sea-level acceleration in the Adriatic and wider Mediterranean. Predictions of RSL from the glacial-isostatic model are consistently higher than the reconstruction during the Late Holocene (-0.25 m at 715 BCE) suggesting a rate of tectonic subsidence of 0.45 mm/yr. The new salt-marsh reconstruction and regional SLIPS coupled with glacial-isostatic and statistical models estimate the presence and rate of the Anthropocene transition and vertical land motion caused by the Adriatic tectonic framework.

Improving the Validation Technique for Coastal Sea Level Rates from Tide Gauge and Satellite Altimetry Observations

Authors: Andrew Shaw, Francisco Mir Calafat, Nadim Dayoub, Jérôme Benveniste

Presenter: Andrew Shaw

The development of the altimeter retrackers such as the Adaptive Leading-Edge SubWaveform (ALES) have led to retrieval of more useable altimetry data closer to the coast. Validation of these data against in-situ tide gauge measurements is a crucial part of verifying the altimetric sea level observations. However, an issue arises when tide gauge data are influenced by coastal processes with small cross-shelf length scales that may not necessary be captured by altimetry measurements taken at a certain distance from the coast. Therefore, improved validation techniques are needed for assessing the quality of coastal altimetry products. As a technique to address this limitation, we identify tide gauge locations where processes relevant to sea level have longer length scales. As part of a study conducted within the framework of the ESA Sea Level Climate Change Initiative (SL_cci) project, we identify tide gauge locations of long length scales based on the high-resolution NEMO (1/12 degree) global ocean model and use only these tide gauges for the validation of the altimetry products. The technique and the results of our work will be presented.

Making sea level data FAIR

Authors: Andy Matthews, Elizabeth Bradshaw

Presenter: Andy Matthews

Sea level records are some of the longest ocean observations available, with the earliest continuous time series beginning in the 18th Century. The length of data available makes creating one complete findable, accessible, interoperable and reusable (FAIR) record a challenge.

Are the data findable?

Data can be made findable through creating standalone discovery metadata records, such as European Directory of Marine Environmental Data (EDMED) or NASA's Global Change Master Directory entries. Alternatively, discovery metadata can be attached to the actual data file, such as in a netCDF file implementing the Attribute Convention for Data Discovery (ACDD). We can also make sea level data more accessible by assigning persistent and unique identifiers such as Digital Object Identifiers (DOIs). Sea level discovery metadata should make use of controlled vocabularies, ontologies and taxonomies, and we describe those in common use and areas for development.

How do we make the data accessible?

Global sea level data are relatively accessible compared to other Essential Ocean Variables as they are deposited in the long established international data centres such as PSMSL. Data in all the GLOSS data centres are freely available and organisations comply with the obligations for GLOSS members.

How can we make data interoperable?

Currently the GLOSS data centres each deliver data in their own format, but we are looking to use a common standard format such as CF netCDF and/or common data models to deliver data. We are also looking at increasing the granularity of our usage metadata. We are developing systems that will use Sensor Web Enablement (SWE) standards to help fully describe how we transform an observable property (such as the length of a piece of wire, the return time of a radar pulse, or the electric charge generated by a crystal under pressure) into a sea level measurement. This will improve the description of a time series where the sensor and platform changes many times.

We also need to ensure that we are using standard vocabularies for simple properties, such as time (ISO 8601) and country names (ISO 3166-1), although for long time series, even these can be complex: for example, the operating country may have changed.

How do we make sea level data reusable?

By storing sea level data in one of the global sea level data centres, we ensure that the data remain useable for the foreseeable future. By keeping comprehensive usage and lineage metadata alongside a dataset, we will increase the reuse of the data, but also ensure that proper credit for the creation and preservation of a dataset is given.

Letting a user know what the quality of the data are and the level to which they have been screened will give confidence in the reuse of the data. Unique identifiers for data sets will help in the transparency and replicability of studies.

Tailoring Tide Gauge Technology to Developing Economies

Authors: Angela Hibbert, Jeff Pugh, Dave Jones, Simon Williams, Kevin Horsburgh, Francisco Calafat, Alan Evans, Neil Milliken, Chris Pearce, Geoff Shannon, Phil Woodworth

Presenter: Angela Hibbert

The National Oceanography Centre (NOC) has a long history of installing and maintaining tide gauge networks in the UK and overseas, providing diverse and often bespoke technology solutions to meet the challenges presented by monitoring in hostile environments. Since 2016, NOC has been one of three partners appointed by the UK Government to deliver the Commonwealth Marine Economies (CME) Programme, which is a ~£23 million package of measures to help small islands and developing states (SIDS) develop their marine economies. Caribbean SIDS require low budget, high quality technology solutions that have minimal running costs, but will withstand hurricane events. As the area is prone to seismic activity, high frequency sampling is also needed to expedite the identification of tsunamis and dissemination of warnings around the region.

Through this programme, NOC has installed bespoke sea level monitoring instrumentation in St Lucia, Belize and Dominica, to facilitate mitigation of coastal hazards such as tsunamis, storm surges and for predicting tides.

NOC is collaborating with the regional tsunami warning body (ICG/Caribe-EWS) and local agencies to embed this technology in their operational forecasting systems, by jointly delivering regional training courses for sea level operators.

The 25-yr-long sea level record from satellite altimetry: Lessons learned, remaining gaps, new scientific questions

Authors: Anny Cazenave and Benoit Meyssignac

Presenter: Anny Cazenave

Sea level, one of the best indicators of climate change, is routinely monitored since 25 years at global and regional scales by a series of high-precision altimetry missions. These observations have shown that the global mean sea level is presently rising, and even accelerating, in response to ocean warming and land ice melt. Satellite altimetry has also revealed strong regional variability in the rates of sea level change, mostly driven by redistribution of heat and fresh water by the ocean circulation in response to internal climate variability. More generally, the altimetry record has been invaluable to address questions such as: can we close the sea level budget over the altimetry era?, what is the deep ocean contribution to sea level rise and its role in the current Earth's energy imbalance?, what are the causes of the regional and interannual sea level variability?, can we already detect the anthropogenic forcing signature in the sea level signal and separate it from the internal/natural climate variability?, etc. While it is extremely important to ensure sustained and ever more accurate observations of global and regional sea level variations from space, new scientific questions are now emerging that also deserve new research investments. Among these, accurate monitoring from space of sea level changes at the coast, highly under-sampled by tide gauges, must be given top priority. Indeed, sea level rise at the coast remains almost unknown globally, although it is a major concern for populations living in low-lying coastal regions (about 25% of human beings). In addition to direct negative impacts (e.g., temporary and permanent inundation, shoreline erosion, wetland loss, saltwater intrusion in surface water bodies and aquifers, rising water tables, etc.), sea level rise may amplify other negative factors of natural and/or anthropogenic origin, such as ground subsidence due to sediment loading, and ground water pumping and hydrocarbon extraction. Continuous and improved monitoring of sea level variations from space, from global to local scales, is absolutely essential to estimate how fast sea level is rising, understand physical processes at work and develop strategies of coastal adaptation to the numerous societal impacts of climate change.

Connecting the Open Ocean and coastal sea level along western boundaries, why bathymetry matters.

Authors: Anthony Wise, Chris W. Hughes, Jeff Polton, John Huthnance, Jason Holt.

Presenter: Anthony Wise

The role of ocean dynamics as a driver of coastal sea level is a fundamental question. What determines the degree to which coastal sea level deviates from the adjacent ocean sea level? Classic linear circulation theory with vertical sidewalls along the boundaries suggests that oceanic gyres result in frictional western boundary layers, which, in terms of sea level, should result in an equatorward displacement and attenuation of sea level at the coast. This coastal sea level is related to the open ocean via an integral of the ocean sea level between poleward and equatorward latitudes. This relation sits favourably alongside results describing a correlation in dynamic sea level between the North Atlantic subpolar gyre and the North American eastern shelf. An important exclusion however, is the role of the continental shelf and slope, and it will be shown that this hides the role that depth, bottom friction and bathymetric width scales play as the controlling parameters determining the extent to which coastal sea level is attenuated and displaced relative to the oceanic sea level. Here we extend the linear theory to include more realistic bathymetry and explain the importance of these parameters, in doing so we suggest that the representation and resolution of friction and bathymetry should be important to the predictions of numerical models.

Challenges of present day tide gauge observing systems

Author: Begoña Pérez Gómez

Presenter: Begoña Pérez Gómez

Coastal sea level has been measured since the end of XIX century by means of tide gauges operated by national institutions and harbor authorities. The launch of the first altimetry missions in the 90's enhanced significantly our knowledge of sea level variations with near-global measurements in the open ocean. Both space and in-situ measurements complement each other due to their different spatial and temporal resolution, however, spatial changes and high-frequency oscillations along the coastlines, where this variable becomes most important for the population, can only be monitored by tide gauges.

The Permanent Service for Mean Sea Level (PSMSL, http://www.psmsl.org/) and GLOSS (Global Sea Level Observing System, http://www.gloss-sealevel.org/) are the main international programs responsible for the compilation and availability of long-term high-quality tide gauge data. The occurrence of several recent coastal disasters and the uncertainties in the knowledge of the regional impacts of global mean sea level rise, has yielded to an increasing demand for tide gauge data and to the installation of new stations. Therefore, nowadays, thousands of tide gauges operate in the world, many of them integrated in new sea level hazards warning systems (tsunamis and storm surges) via new real-time data exchange channels. At the same time, new general-purpose data portals are also distributing tide gauge data in the framework of other international initiatives such as CMEMS (Copernicus Marine Environment Monitoring System, http://marine.copernicus.eu/).

The multi-purpose character and new technical requirements of existing tide gauge networks demand an enhancement of international collaboration and a review of the priorities and main challenges that the tide gauge community should face in the future: impact of the upgrade to new technologies (e.g. radar sensors), influence of new data sampling and latency in the standard data process and quality control, study of high frequency phenomena and adequate management of the increasing volume of raw high-frequency data, assessment of the impact of waves, convenience of adopting new standards, availability of absolute reference and vertical land motion information, etc. In Europe, all these challenges have yielded the establishment in 2015 of the EuroGOOS Tide Gauge Task Team (EuroGOOS TGTT: http://www.eurogoos.eu/tide-gauge-task-team/), that has the role of bringing together the European and adjacent seas tide gauge community, with experts from GLOSS, CMEMS, universities and hydrographic offices. Very recently, this task team launched a questionnaire to evaluate the type of problems the existing national tide gauge networks may have to survive during next years. One of the most important conclusions of this survey was that the most immediate problem we have to face is the sustainability of the system as more than half of the institutions and near 30% of the tide gauge stations in Europe and adjacent coasts would be facing problems of funding in some way. Therefore, raising awareness of the policy-makers and stakeholders about the importance of the network has become an urgent objective.

Exploring broad usage of Sea-Level data provided by the Puerto Rico Seismic Network as a Natural Laboratory

Authors: Benjamín Colón Rodríguez, Gisela Báez Sanchez, Víctor Huérfano Moreno, Elizabeth Vanacore, Javier Santiago

Presenter: Benjamín Colón Rodríguez

The Puerto Rico Seismic Network (PRSN) has installed over 15 tide gauges in different locations of the Caribbean Region including Puerto Rico, the US and British Virgin Islands, the East coast of the Dominican Republic and Haiti. The primary purpose of these stations is to provide real time sea-level data as part of the region's tsunami monitoring system and provide data to duty geophysical data analysts in the case of a tsunami protocol. The sea level data is available in real-time through the PRSN, UNESCSO IOC, and NOAA via web-interfaces or by request directly to the PRSN. This data may provide valuable insight into topics of current interest including meteotsunamis and storm surges. Here we present observations of meteotsunamis that are routinely observed in the Puerto Rico region as well as discuss the impact and observations of hurricanes and storm surges in the region. The variety of phenomena recorded on the PRSN tide gauge network demonstrate that it is in a prime location to act as a natural laboratory to observe and analyze sea level changes related to storm, atmospheric and tsunami events.

Climate model simulations of the 20th century sea-level changes compared to observations.

Author: Benoit Meyssignac

Presenter: Benoit Meyssignac

Tide gauge records and satellite observations show that sea level has risen during the 20th century and that this rise has not been spatially uniform. Climate model projections indicate that global mean sea level will almost certainly accelerate through the 21st century in response to Greenhouse Gas (GHG) emissions and associated global warming. Irrespective of the GHG emission scenario, this global rise will be accompanied by regional variations of mostly up to ±30% of the global rise. However, the magnitude of the sea level rise and its spatial variations remain uncertain because of uncertainties in GHG emissions and in model representation of climate change and because of inherent uncertainty associated to the chaotic nature of the climate variability. This is an important issue, as coastal communities need reliable projections to prepare adaptation plans for future sea-level rise.

The reliability and uncertainty of climate model projections depends on the ability of climate models to simulate sea-level changes. This ability can be assessed by comparing climate model simulations of the 20th century sea-level changes with observations from tide gauge records and satellite altimetry. The comparison is not straightforward as variations in sea level are driven by a combination of internal climate variability and external forcings (including forcings from both natural origins and anthropogenic origin). Various comparison strategies have been developed ranging from simple direct comparisons to sophisticated optimal regressions. Recent comparisons show a fairly good agreement between climate simulations and observations of the 20th century sea level changes at both global and regional scale (except in the south of Greenland during the 1930s). They reveal that sea level rise has been dominated by the thermal expansion of the ocean and glaciers ice melt during the 20th century while the ice sheet contribution has been small and started to contribute significantly only after 1990. They also show that anthropogenic GHG emissions are responsible for most of the thermal expansion and glaciers ice melt since the 1950s.

The recent ability of climate models to reproduce the 20th century sea level changes due to thermal expansion and glacier mass loss gives some confidence in climate models to project future changes of these contributors to sea level. Since 1990 the ice sheet dynamics contribution has increased but it remains relatively small up to present and the comparison of climate models simulations with sea level observations do not test the reliability of ice-sheet models in simulating rapid ice sheet dynamical changes. This is an important limitation for projecting sea level rise as this contribution may become dominant in the future.

Drivers and trends of coastal sea level variability along the east and south of South Africa

Authors: Bernardino Nhantumbo, Jan Even Nilsen, Björn Backeberg, Chris Reason and Frank Shillington

Presenter: Bernardino Nhantumbo

Sea level rise and variability is of great concern in the coastal areas where a significant part of the global population is settled. Therefore, understanding regional and local long-term sea level variability as well as its trend is critical. On the other hand, understanding how the sea level has varied on different timescales and why is critical for understanding sea level changes, and crucial for improving future global, region, and local projections. In this study, monthly mean sea level records of seven individual tide gauges, from the south and east coast of South Africa were used to analyse the embedded timescales of variability. The data sets were obtained from the Permanent Service for Mean Sea Level (PSMSL, http://www.psmsl.org/). After optimising the data, filling the gaps as best as possible, the oscillatory timescales of variability were separated using the Empirical Mode Decomposition (EMD) method. This is the first time that the method has been applied to southern African tide gauge records. However, identifying a single driver for each separated timescale is challenging due to our limited knowledge of how sea level is linked to the various forcing mechanisms. Therefore, the timescales of sea level variability extracted using the EMD were grouped into sub-annual and interannual timescales, and their relationship to possible driving mechanisms was investigated. The sub-annual timescale indicates how sea level responds to the mesoscale and synoptic weather systems in the annual cycle, including seasonal and annual large-scale wind and atmospheric pressure pattern changes. The interannual timescale indicates an association with the climate indices including El Niño-Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) and Southern Annular Mode (SAM) through large-scale sea surface temperature patterns and large-scale pressure and wind patterns. In addition, the results have suggested that the studied coastal SL has an association with the Agulhas Current at both sub-annual and interannual timescale through an association with the upper Indian Ocean heat content. The remaining EMD mode, which is considered as the trend, showed that along the study region sea level is rising at all sites mainly from the 1990s onwards, at a pattern similar to the global mean increase.

Late Holocene Sea-level change in the Dysynni Valley, Wales

Author: Caitlin Nagle

Presenter: Caitlin Nagle

Understanding past sea-level change is essential to comprehend the future impacts of sea level change, especially on vulnerable coastal communities. The aim of this project is to determine how past communities responded to changing sea levels by reconstructing sea level through the Holocene and comparing the results to the archaeological record.

Northwest Wales is characterised by estuaries with rich archaeological records dating to the Holocene, as well as sediments suitable for sea level research. The project focusses on a case study based in the Dysynni Valley, which was chosen, as there are well-preserved clastic sediments as well a history of human occupation throughout the Holocene. Palaeoenvironmental analysis will help better understand the interaction between past populations and their landscape.

Sampling sites in the Dysynni Valley have been located using evidence from mapping and field observations. Stratigraphic analysis, combined with radiocarbon sting and diatom analysis is used to reconstruct changes in salinity through time. These data will be used to calculate sea-level index points. A diachronic model of past coastal changes will be produced from these data, which will be compared to known archaeological sites in GIS software in order to propose scenarios for how sea level change impacted on past human populations.

Flood hazard assessment for a hyper-tidal estuary and river as a function of tide-surge-morphology interaction

Authors: Charlotte Lyddon, Jenny M. Brown, Nicoletta Leonardi, Andrew J. Plater

Presenter: Charlotte Lyddon

In heavily populated and industrialized estuaries, accurate prediction of extreme water level and its timing is essential for storm hazard mitigation. Such prediction requires accurate understanding of the interaction between tide and surge, how this varies as a function of the timing and shape of the storm surge relative to high water, and how such interaction changes due to estuary morphology. This is especially critical in hyper-tidal estuaries and rivers where the consequences of tide and storm surge concurrence can be catastrophic. Delft3D-FLOW is used to assess up-estuary variability in extreme water levels for a range of historical events of different severity within the River Severn estuary, southwest England. The influence of the following on flood hazard is investigated: i) event severity, ii) timing of the peak of a storm surge relative to tidal high water and iii) the temporal distribution of the storm surge component (here in termed the surge skewness). Results show when modelling a local area event severity is most important control on flood hazard. Tide-surge concurrence increases flood hazard throughout the tidal domain and influences the nature of saltwater penetration. Positive surge skewness can result in a greater variability of extreme water levels, the effects of which are magnified up-estuary by geometry to exacerbate flood hazard. When viewed in the context of the Source-Pathway-Receptor-Consequence model, these results help to identify the combined effect of factors, which contribute to extreme water levels for local scale, flood hazard management. The severity of an extreme water level event and the timing of the storm surge are identified as sources to flood hazard. The morphological form of a hyper-tidal estuary and river is a ‘source’ or ‘pathway’ in itself, influencing how floodwaters are conveyed through the system. The concepts and methodology presented can be applied to other estuaries worldwide.

Out of the Freezer: Scientific Altimetry Studies using CryoSat-2 in the Global Ocean

Authors: Chris Banks, Francisco Mir Calafat, Helen Snaith, Christine Gommenginger, Nadim Dayoub ,Andrew Shaw, Jérôme Bouffard, Pierre Féménias, Paolo Cipollini

Presenter: Chris Banks

CryoSat-2 is Europe's first ice mission and features an advanced radar altimeter specifically designed to monitor the most dynamic sections of Earth's cryosphere. CryoSat-2 acquires data over all surfaces, including the global ocean where the altimeter operates mainly in conventional low-resolution-mode (LRM) but also in SAR (synthetic aperture radar) mode over a few regions. A dedicated operational ocean processor has existed for CryoSat-2 since April 2014. In addition, the same processing chain has recently been used to provide data for the full-length of CryoSat-2 operations (from November 2010 onwards). An improved version of the processor has been in operation from November 2017 onwards.

Within the ESA funded CryOcean-QCV project, the UK's National Oceanography Centre (NOC) is responsible for routine quality control and validation of CryoSat Ocean Products. Activities include daily and monthly reports providing global assessments and quality control of Sea Surface Height Anomaly (SSHA), Significant Wave Height (SWH), backscatter coefficient (Sigma0) and wind speed, as well as a suite of validation protocols involving in situ data, model output and data from other satellite altimeter missions.

This presentation provides details of some of the metrics and results obtained for CryoSat Ocean Products for SSHA, SWH and wind speed using data tide gauges, wind and wave buoys, WaveWatch III wave model output, HF radar surface current data and comparisons with Jason-2 and Jason-3. In addition, the utility of the data from CryoSat-2 for oceanographic studies will be demonstrated using Rossby-type wave propagation in the Indian Ocean.

The global coastal mean dynamic topography from tide gauges

Authors: Chris W Hughes, Mederic Gravelle, Rory Bingham, Philip Woodworth, Luciana Fenoglio-Marc, Ole Andersen

Presenter: Chris Hughes

Using GPS-derived coordinates at 301 tide gauges, and recent high-resolution geoids, we calculate a 5-year mean coastal dynamic topography. Comparisons with numerical models and a comparable dynamic topography from satellite altimetry demonstrate that the tide gauge values are consistent with these other estimates with a typical (1-sigma equivalent) error of 9 cm. We also find that the distribution of errors is highly non-Gaussian, which we attribute to the special nature of the geoid at the coast. This level of agreement is sufficient to rule out major roles for processes (such as tides and wave setup) which are not present in the model simulations, though such processes may still be important at the sub-decimeter level, or higher in some locations. These results highlight the importance of further determination of GNSS ties to tide gauges, and of fine resolution geoid information to reduce errors.

The AdriSC modelling suite: operational and research modes in reproducing meteotsunamis

Authors: Cléa Denamiel, Ivica Vilibić, Jadranka Šepić

Presenter: Cléa Denamiel

Destructive meteotsunamis – intense long ocean waves in a tsunami frequency band - are known to occur along the eastern Adriatic coastal areas and islands (Vilibić and Šepić, 2009). The temporal lag between the offshore generation of meteotsunamis due to specific atmospheric conditions and the arrival of a dangerous nearshore propagating wave at known locations is of the order of tens of minutes to a couple of hours. In the Adriatic Sea the amplitude of such local high-frequency sea-level oscillations can exceed other phenomena, like tides and storm surges. It is thus important to better understand their effects.

The Adriatic Sea and Coast (AdriSC) modelling suite uses high-resolution atmospheric and ocean models in order to represent many ocean phenomena, including both the generation of meteotsunamis offshore and their propagation and impact in the nearshore areas. A modified version of the coupled atmosphere-ocean COAWST model (Warner et al., 2010) is used to reproduce/forecast and project the generation of meteotsunamis with a resolution of 1km for the ocean and 3km for the atmosphere while the nearshore barotropic propagation of the meteotsunami waves is obtained with the ADCIRC model (Luettich and Westerink, 1991) forced by 1km pressure and wind fields.

With the aim to better understand the generation and the impact of meteotsunami waves, the “climate” component of the AdriSC modelling system is currently used to produce a 30 year-long historical run. Furthermore, in the next few years, the model will also run for the RCP8.5/4.5 scenarios in order to project the recurrence and impact of the future meteotsunami events.

Meanwhile, the operational version of the AdriSC modelling system is already running and has been evaluated for well documented meteotsunami events which were recorded along the Croatian Adriatic coast area.

Sea Level Variability in Pemba, North of Mozambique

Authors: Clousa Maueua, Sinibaldo Canhanga

Presenter: Clousa Maueua

Monthly Mean Sea Level (MSL) values from 1970 to 2015, with some years missing in between, are used to analyze sea level variability in Pemba Bay, in north Mozambique. The data used are in a metric and where not adjusted in “revised local reference”. Results shown that the sea level is not the same every year. Within the 3 months of 1971 (October, November, December) the trend has been increased to +10mm from October to November and then decreased in -10mm from November to December. Whereas within the short time window of 2007 there is a trend to +1.3mm/month. From 2007 to 2009 there is a decrease trend of -7mm. High monthly MSL in Pemba usually occur in February- March (months of high rain and highest air temperature) whereas low monthly MSL occur in September- October.

Application of satellite altimetry as a tool for managing coastal risk in Mozambique, Madagascar and South Africa

Authors: David Cotton, Amani Becker, Val Byfield, Francisco Calafat, Nadim Dayoub

Presenter: David Cotton

It is well established that global sea-level is increasing and that large-scale weather patterns are changing, however, across large parts of the world, there is a lack of observational data from in-situ instrumentation available on which to implement evidence-based approaches to coastal adaptation. Mozambique, Madagascar and South Africa have large coastal populations whose lives and economic security are vulnerable to the consequences of climate variability and change.

In the past it has been difficult to retrieve satellite altimeter data close to the coast, due to land contamination of the return waveform. Using an innovative coastal processor, developed by the NOC, UK, a new satellite altimeter sea-level dataset for the South West African coastline has been generated. These data are now being validated against available tide gauge data and analysed for regional characteristics in sea-level variability, including long-term sea-level trends.

These data are being provided through C-RISe, a Coastal Risk Information Service, to partner organisations in South Africa, Mozambique and Madagascar to inform decision-making and reduce the impact of coastal inundation and increasingly variable weather patterns.

A key objective of C-RISe is to support the development of local capacity to access, process and apply satellite sea-level data. This is achieved through case studies which will evaluate the C-RISe service in different application areas. Local users are also being trained in the use of marine satellite data to quantify coastal hazards and incorporate this information into ongoing programmes.

This presentation will introduce the project, present some early results on the characteristics of sea level variability in the SW Indian Ocean region, and provide an overview of the use cases.

C-RISe is funded by the UK Space Agency under the International Partnership Programme

A unified analysis of Great Britain Sea Mean Sea Levels, from 1830 to 2105.

Author: David Pugh

Presenter: David Pugh

Historic sea level data is valuable in estimating future flooding risks and in understanding the impacts of climate change. This data archaeology, compares present PSMSL average sea levels around Great Britain with data from the nineteenth century, and up to 1960. The main sources are the hitherto un-published and un-accessed ledgers of the Hydrographic Department of the Admiralty, and publications of the Ordnance Survey. Some early academic data sources are also included.

Data are analysed in 26 local clusters, each with a current PSMSL Station as a core control. Adjustments are made for changes from Ordnance Datum Liverpool to Ordnance Datum Newlyn in the early 20th Century; for mean Tide Level to Mean Sea Level; and for seasonal bias of short periods of observations. Cluster trends are computed and compare, paying detailed attention to sampling and levelling uncertainties, and making corrections for vertical crustal movements.

Confidence in long-term trends is improved, on average, by factor of three. If the adjusted mean sea level trend for each cluster is regarded as a separate independent estimate of a Great Britain Mean Sea Level increase, then the average weighted trend for Great Britain is 1.523 millimetres per year, with a standard deviation of 0.629 mm/year, and a standard error of 0.12 mm/year. There is a significant acceleration of 0.0094 mm per year, in the rate of rise over the period 1830 to 2015.

The UK Admiralty archives, and other hydrographic sources, may be used to improve trend estimates for many other regions globally.

Developing the Irish National Tide Gauge Network for 21st Century Challenges

Authors: Guy Westbrook, Eleanor O'Rourke, Kieran Lyons, Deirdre Fitzhenry

Presenter: Eleanor O'Rourke

The Irish National Tide Gauge Network (INTGN) was established in 2004 in response to an acute flooding vulnerability in the greater Dublin area and a specific flooding event in February 2002. The case for a national network providing operational flood monitoring support was strengthened by a need to provide an open and free public service tidal prediction facility as well as monitoring to establish levels for a range of purposes, not least informing coastal engineering, though a centrally managed national infrastructure.

However, demands on the network are evolving. During 2017, a number of challenging periods of severe weather highlighted the value of the real time data dissemination with information obtained every 5 minutes relayed to users such as ports, local authorities, and the general public. Further the need for developing the network and capacity in sea level analysis has grown with the implementation of national climate adaptation planning legislation.

This presentation will highlight the current status of the network and future plans and potential opportunities including GLOSS standard gauges, ensuring the network is meeting evolving stakeholder needs, and building the national capacity in sea level science in collaboration with Higher Education Institutes.

Impact of the large-scale atmospheric circulation on the sea level variability over the Northern European continental shelf

Authors: Fabio Mangini, Jan Even Øie Nilsen, Léon Chafik, Camille Li, Erica Madonna

Presenter: Fabio Mangini

This PhD focuses on the drivers and the mechanisms of sea level variability in the North Sea and along the Norwegian coast. Here, attention is on the atmospheric contribution and, more precisely, on the impact of the North Atlantic large-scale atmospheric variability. This topic has been analysed in the past (e.g., Chafik et al., 2017). However, this work differs from the previous ones. Here, the jet clusters perspective is adopted to describe the large-scale atmospheric circulation. Four jet clusters are used, with each jet cluster representing a recurrent atmospheric pattern over the North Atlantic. With respect to the methods previously used (e.g. the leading modes of atmospheric variability), the jet clusters have the advantage of being more closely related to the 2D structure of the jet stream and more easily associated to the wind pattern over the North Atlantic.

Here an attempt is made to find a relationship between each jet cluster persistence and the sea level variability. The aim is to understand how each jet cluster individually affects the sea level variability in our region of interest.

Sea level impact of the Northers in the Mexican Pacific

Authors: Felipe Hernández-Maguey, Jorge Zavala-Hidalgo, Rosario Romero-Centeno

Presenter: Felipe Hernández Maguey

Strong winds crosses the Gulf of Tehuantepec during Norther events that occur between 30 and 50 times every year. The northers are caused by high pressure systems that reach the Gulf of Mexico coming from the Rocky Mountains in the United States with an associated cold front that reduces the temperature, precipitation and strong winds. The impact of the Northers also affect the Gulf of Tehuantepc when the pressure difference between the Gulf of Mexico and the Gulf of Tehuantepec causes strong gap winds that crosses Mexico through isthmus of Tehuantepec reaching the Gulf of Tehuantepec. It has been studied that these winds cause a decrease in the surface temperature and generate eddies but its impact in the sea level has not been studied. Here, based on coastal sea level observations from the UNAM tide gauge network, the impact of these events is presented showing that.

Historical sea level data rescue to assess long-term sea level evolution. Example of Saint-Nazaire (France)

Authors: Yann Ferret, Vincent Donato, Nicolas Pouvreau

Presenter: Yann Ferret

In coastal areas, the characterisation of sea-level rise and variations of sea level due to extreme weather events (e.g. storm surges) remains a strong societal concern. The analysis of long historical water level records proved to be an ideal way to provide relevant arguments regarding the observed long-term sea-level evolution. In France, many systematic sea level observations performed by mechanical tide gauge have taken place since the mid-1800s. Despite this rich history, long water-level data sets digitally available are still scarce. Currently, only the time series of Brest, Marseille span periods longer than a century and are available (SONEL, PSMSL databases) to be taken into account in studies dealing with long term sea-level evolution.

In this context, an extensive work in sea level data rescuing is undertaken at Shom (French Hydrographic & Oceanographic Office) within the SONEL framework. This task aims to rescue the numerous existing historical data, still preserved in paper form, in the Shom Archives Centre. These old tide measurements mainly concern French ports and also locations around the world (although those generally span shorter time periods). This initiative responds to the recommendations of the Global Sea Level Observing System program (GLOSS) on the recovery of forgotten sea level measurements.

Data rescue performed at Shom implies to inventory documents related to water level measurement (marigrams, ledgers), to scan and digitise those, and finally to quality control the newly digitised sea-level data. This is a time-demanding effort, and the work is still in progress. The final purpose is to recovery the French scientific and cultural heritage on sea level observations, and to provide to researcher community new datasets to analyse.

A focus on the historical (1863 – today) sea level reconstruction for Saint-Nazaire (outer Loire estuary, France) will be presented. Through this example, all the different steps necessary to rescue these data will be detailed: from paper documents to the assessment of long-term sea-level evolution.

In addition, sea level reconstruction allows identifying historical storm surges, non-quantified up to now. These extreme values enable the improvement of estimation and prediction of extreme coastal water levels.

Characterization and prediction of seiches in small-scale harbours

Authors: Gael Andre, Fabien Leckler, Florian Bellafont

Presenter: Gael Andre

Coastal seiches may have dramatic coastal impacts and represent a significant hazard for population safety and economic activities. Harbours are particularly vulnerable to these phenomena, which can seriously affect operations and cause severe and expensive damages to harbour facilities and moored ships. Large water level oscillations are associated to strong horizontal currents that also induce substantial sediment transport and may modify the harbour bathymetry. The aim of our work is to characterize the main forcings that drive harbour oscillations and to provide an early warning system able to predict harbour seiche to harbour authorities in order to prevent damages and secure harbour procedures.

Semi-enclosed basins and harbours have natural resonant periods ranging from a few tens of seconds to a few hours. The amplitude of small oscillations coming from the open ocean may be strongly increased by resonant processes. The most common mechanisms driving seiches in harbours are related to atmospheric disturbances and infragravity waves (IG). For small-scale basins with resonant periods of a few minutes, seiches are mainly forced by IG waves, with frequencies between 0.004 and 0.04 Hz.

In order to illustrate this phenomenon, we focus here on the case study of Port-Tudy harbour, located on Groix Island on the Western Coast of France. Strong seiches regularly develop in this harbour, with some of the highest amplitudes observed along the French metropolitan coast. The development of seiches in the harbour results from the amplification by resonance of IG waves released around the island and propagated to the harbour entrance. This hypothesis is verified using process-based models capable of simulating coastal IG waves and in-situ measurements collected during an extensive field campaign that was carried out during winter 2017-2018.

Vulnerability of Dublin Bay to Extreme High Water Levels

Authors: A. Greene, D. Clarke, D. Smyth, G. D. McCarthy, P. W. Thorne

Presenter: Gerard McCarthy

Direct coastal flooding is an issue in Dublin, Ireland. A notable event occurred in February 2002 where over 1000 homes were flooded by high sea levels. The subsequent reaction, notably the initial raising and subsequent planned lowering of the Clontarf Sea Wall, has proved controversial. The key factor for making information-based decisions is good quality data. Dublin has tide gauge records dating from 1920. However, a number of issues exist with the data. In particular, Dublin has a number of unresolved reference level issues, meaning that current observations of Irish sea level (provided by the National Tide Gauge Network since 2007) have little long term context. Were the data at Dublin to be believed as they currently stand in the PSMSL archive, a jump of 20 cm would have occurred in 2002. This magnitude of sea level rise would typically transform a 1 in 50 year high-water event to more frequent than 1 in 5 years. There is sufficient doubt surrounding this jump to warrant further investigation.

Paper and digital images of the original mareographs do exist and offer an opportunity to reconcile existing issues. Here we rescue and analyse a timeseries of daily high tide data from Dublin Port stretching back almost continuously to the late 1960s. These data are compared to retrospective tidal predictions, and global sea-level observations removed, to yield a timeseries of local residuals which are then modelled statistically to assess long term changes in high tide levels at Dublin.

Projecting sea-level rise changes out to 2300 for Paris Agreement commitments

Authors: Ivan D. Haigh, Phil Goodwin, Sally Brown and Robert Nicholls

Presenter: Ivan Haigh

Sea-level rise is one of the most certain and costliest impacts of climate change. The Paris Agreement committed signatories to 'Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels recognizing that this would significantly reduce the risks and impacts of climate change'. However, while reducing human emissions of greenhouse gases will stabilise temperature and other climate factors, sea-level rise will continue for many centuries. This is due to the long timescale of cryospheric adjustment to elevated air temperatures (especially the large ice sheets), and the long timescale of the deep ocean temperature warming to surface warming.

Here we present a new novel hybrid approach to projecting sea-level rise out to 2300 to accurately assess our 'commitment to sea-level rise'. This new approach combines a mechanistic representation of thermosteric sea-level rise with a semi-empirical representation of the ice volume component of sea-level rise, embedded within an efficient conceptual Earth System Model. We use the Warming Acidification and Sea-level Projector (WASP) Earth system model. WASP is an efficient 8-box representation of the atmosphere-ocean and terrestrial carbon system. It calculates surface temperature changes due to cumulative carbon emissions and additional terms to take account of radiative forcing. WASP is very computationally efficient and therefore can be run 10 million times with random perturbations to multiple parameters, allowing us to calculate a probabilistic projected range. Future projections are made only from the simulations that are historically consistent. The projections from our hybrid approach are found to be consistent with the dominant process-based global sea-level projections out to 2100 from the Climate Model Intercomparison Project phase 5 (CMIP5) ensemble.

We then use a novel Adaptive Mitigation Pathway (AMP) approach to restrict future warming to policy-driven targets, in which future emissions reductions are not fully determined now but respond to future surface warming each decade in an adaptive manner. A large ensemble of Earth system model simulations demonstrates our adaptive mitigation approach for a range of climate stabilization targets ranging from 1.5 to 4.5°C, and generates AMP scenarios up to year 2300 for global mean sea level.

Our AMP ensemble restricting temperatures to 1.5°C results in a median global sea-level rise of 0.4m and 0.99m by 2100 and 2300, respectively. For our AMP to 2.0°C ensemble we predict a median global sea-level rise of 0.46m and 1.26m by 2100 and 2300, respectively. For a comparison with a policy of stringent climate change mitigation, a high emissions scenario (RCP8.5) was generated assuming policies of no climate change mitigation. For RCP8.5 our ensemble results in a median global sea-level rise of 0.78m by the year 2100 and 4.5m by 2300.

In conclusion, we show that Paris Agreement commitments will reduce global sea-level rise by around 20cm by 2100, but targets will avoid up to 4m of sea-level rise by year 2300 relative to a high-end (RCP8.5) scenario.

High-frequency sea level oscillations: relevance, predictability, climate and projections

Authors: Ivica Vilibic, Jadranka Sepic, Natalija Dunic, Florence Sevault, Sebastian Monserrat, Gabriel Jorda

Presenter: Ivica Vilibic

Sea level extremes are a consequence of contributions acting on different time scales. Upper tail of frequency distribution of extremes, i.e. high-frequency sea level oscillations (HFSLO), which appear at periods lower than ca. 2 hours, has been only sporadically assessed. This is due to both: (i) unavailability of measurements of sufficiently small time step - with global tide gauge measurements at a minute time scale initiated only during last decade; (ii) non-recognition of importance of these oscillations by scientific community. We show that HFSLO may surpass one metre in mid-latitudes and may be a dominant contributor to sea level extremes in low-tidal basins. In the Mediterranean HFSLO can contribute to extremes by 40% in range. It has been shown that the Mediterranean HFSLO extremes can be related to specific synoptic patterns. Thus, a related quantitative synoptic index, linking sea level oscillations to synoptic variables, has been constructed. This index is correlated to HFSLO at a 0.01 significance level, allowing for its use in weekly HFSLO forecasts. The index has been further reconstructed for the present climate by using ERA Interim data. It has also been estimated from climate models, allowing for proxy-based HFSLO assessment for future climates. An initial assessment obtained using regional climate models indicates that the index and thus the HFSLO will not change through the 21st century under RCP2.6 and RCP4.5 climate projections, but will substantially increase under RCP8.5 projection. In combination with the projected mean sea level rise and a decrease in storminess in the Mediterranean, projected HFSLO should be used for the assessment of future sea level extremes. This methodology might be transferred to other ocean basins, provided that a statistically significant relation between synoptic patterns and HFSLO can be estimated.

Sea Level Variability on Interannual, Decadal and Longer Time Scales along the Tropical Atlantic

Authors: Kemgang Ghomsi, Franck Eitel, Jan Even Øie Nilsen, Nouayou Robert, Nguiya Sévérin, Ola M. Johannessen

Presenter: Jan Even Øie Nilsen

Long-term trends, the interannual and decadal variability of sea level in the Tropical Atlantic and along the Cameroonian coast, have been studied over the period 1993–2016.

This region has a sparse and few dense networks of tide gauges, and non-frequent hydrographic measurements in the surrounding area. We have focused on the few documented coastal areas east of 8° E and 5°N including Bioko Island and Inter Cameroon-Bioko corridor (ICBC). Sea level rise variability in this region has been few evaluated.

Monthly data of Sea Surface Height Anomaly (SSHA) at 0.25˚X0.25˚ computed from merged data by Archiving, Validation, and Interpretation of Satellite Oceanographic data (AVISO) is available at https://www.aviso.altimetry.fr/en/my-aviso.html. This data is derived using up-to-date datasets with up to four satellites at a given time, from Jason-2/Jason- 1/Envisat/Topex/Poseidon/GFO. We have used AVISO monthly SSHA data for the period 1993 to 2016 in this study. In the open ocean surface, geostrophic currents are caused by the variability of sea surface elevation.

We have extensively studied the decadal and interannual variability and find out that the Sea Level Pressure and winds stress are tightly correlated to the Sea Level Anomaly with a predominant peak from JJA during the predominance of the Equatorial upwelling and the onset of the West African Monsoon. A strong coastal upwelling has been identified along the northern part of the Gulf of Guinea with a delay of 15 days after the Equatorial upwelling onset accompanying with a deep slope of the SLA. This fits with the theory of longshore wind forcing along the eastern boundary of the Tropical Atlantic specifically along the Cameroonian coastline causing coastally trapped waves to propagate over thousands of kilometers along the continental slope. According to these findings, we have found out that the removal of known variability helps us to characterize more accurately the estimation of the linear trends and have highlighted possible fluctuations due to some possible anthropogenic climate change in the Gulf of Guinea. Local authorities need to know as early as possible how much Sea Level Rise is likely to be expected over the next decades in order to prevent coastal flooding and establish coastal planning and safety management.

The effect of decadal variability on the extreme sea levels on the west coast of Norway

Authors: Ulpu Leijala, Jan Even Øie Nilsen, Oda Ravndal, and Hilde Sande

Presenter: Jan Even Øie Nilsen

The highest sea levels are often a result of combined events. At the Norwegian coast, extreme water levels are mainly caused by astronomical tides and storm surges. Despite the fact that Norway in many places has a strong land uplift, in the long-run climate change driven mean sea level rise will make coastal flooding situations in the Norwegian coastal communities more frequent and severe. The highest and rarest flooding events are the most hazardous ones and evaluation of their origin and risk is crucial.

Normally, extreme value analysis (EVA) on the Norwegian coast is performed using the observed records of the sea level maxima at the tide gauges, taking into account the astronomical tides that vary significantly within different regions. However, in addition to the short-term phenomena, there are processes unrelated to these special events, that make mean sea level (MSL) vary on seasonal to decadal time scales. These are not necessarily random processes, and they may even be predictable some years ahead. In particular, slow variations in heat content, overturning circulation, wind forcing and ocean currents, create decadal variability along the Norwegian coast.

In this study, we investigate how interannual and decadal sea-level variability affects to the extreme sea-level analysis, focusing on the Bergen region located on the west coast of Norway. During the last decades (from 1980 forward) the amount of sea flooding situations with 20 year return water level (RWL) or higher have increased compared to the period of 1958-1980. At the same time we see that several of the highest extremes have occurred during years with specially high MSL. The aim of this study is to evaluate the magnitude of the interannual MSL variability and investigate how removing such a long-term variability from the records before executing EVA analysis, affects the results.

Coastal Flood Boundary update 2018

Author: Jennifer Hornsby

Presenter: Jennifer Hornsby

In 2008, the Environment Agency commissioned the Coastal Flood Boundary project - a national project to produce consistently derived extreme sea level estimates around the coastlines of England, Scotland and Wales. Extreme sea levels were estimated at 44 Class A gauge sites using joint probability analysis of skew surge and predicted tide levels. The approach overcomes the need to take account of surge-tide dependence and enables much more data points from the recorded water level series to be used in extremes analysis than previous methods applied, such as AMAX GEV. It also reduces uncertainty as the predicted tide in most areas along the coast forms, by far, the largest component of the extreme sea level and its distribution is also “known” (within the accuracy of tidal prediction).

Ten years later, the Coastal Flood Boundary project had been updated this year with new available data and science improvements providing a test of the original approach. Up to ten years of additional recorded water level data is available for extremes analysis at Class A tide gauges, many having experienced significant storm and surge activity within the time period. At some locations, the increase in recorded data provides ~50% increases in record length. Science improvements include those in tidal prediction, de-trending, determination of the shape parameter, extremal index and uncertainty in extreme sea level estimates.

The update has shown that the skew surge joint probability method for extreme sea level estimation is relatively robust, with estimates largely remaining unchanged despite additions of data containing large storm and surge events. Testing and science improvements have indicated some of the changes observed are sensitive to de-trending improved tidal predictions. Uncertainty has been better taken into account considering some of these factors. Despite improvements and increased data availability, issues at some Class A sites still remain and indicates further challenges to resolve in future updates.

WireWall – a new approach to measure coastal wave hazard

Authors: J.M. Brown, M.J. Yelland, R.W. Pascal, T. Pullen, C.L. Cardwell, E. Silva

Presenter: Jenny Brown

The impact of rising sea level on the flood hazard from sea defence overtopping means new coastal schemes need to remain resistant to changing wave and water levels over the next 100 years. The design of new coastal flood defences and the setting of tolerable hazard thresholds requires site-specific information of wave overtopping during storms of varying severity, which are combined with future projections in sea level. By converting an existing wave measurement technology into an overtopping monitoring system "WireWall", field observations of wave-by-wave overtopping velocity and volumes will be made at our case study site Crosby, in the North West of England. The new system will collect observations that will provide site-specific data to:

•perform calibration of overtopping tools, e.g., EurOtop;

•perform validation of flood forecasting systems and overtopping models; and,

•develop site-specific safety tolerances to inform flood risk response plans.

Recent advances in technology mean existing wave height sensors can now measure at the high frequencies (a few 100 Hz) required to obtain overtopping data, making this the ideal time to initiate a step-change in coastal hazard monitoring capabilities. At Crosby a business case for a new sea wall is underway. Deployments at this site will provide the Coastal Group with the site-specific data and calibrated overtopping tools that they need to design a new, cost-effective seawall. The deployment of WireWall at Crosby will be the first step towards the development of an overtopping monitoring system that could ultimately be integrated into new coastal schemes as part of the UK's regional coastal monitoring programmes. Such data would enable long-term trend analysis of the changing flood hazard as a consequence of climate change and sea level rise at the coast.

Addressing ambiguity in probabilistic assessments of future marine flooding using possibility distributions

Authors: Jeremy ROHMER, Gonéri LE COZANNET, Jean-Charles MANCEAU

Presenter: Jeremy Rohmer

Today, decision making in the area of coastal adaptation is facing a major challenge due to the deep uncertainties of sea level projections. These deep uncertainties (aka ambiguity or epistemic uncertainties), reflect the intrinsically imprecise nature of global sea level rise (GSLR) due to the lack of knowledge regarding the melting of ice, particularly in Antarctica. Possibility distributions are one of the mathematical tools enabling to overcome the ambiguity in the selection a unique probability laws by bounding all the plausible ones. By adopting this new mathematical tool, we aim at evaluating how GSLR uncertainties accumulate with other sources of uncertainties, namely: the

choice in Representative Concentration Pathway (RCP) scenario, the ranking of high-end scenarios, the regional bias, the contributions of extremes and wave effects. The case study corresponds to a local low-lying coastal urban area exposed to storm surge and waves in the north-western Mediterranean coast. We focus on the probability of

future flooding by 2100 defined as the probability of exceeding a critical threshold corresponding to the height of coastal defences. The joint sensitivity analysis of the probabilistic, possibilistic and scenario-like sources of uncertainty enables to highlight the key role of deep uncertainties of GSLR, of the statistical uncertainty related

to extremes and to a lesser extent of the choice in the RCP scenario. These results heavily depend on the decision maker's attitude to risk (neutral, averse), which suggests the importance of entering into a loop of interactions with users, in order to collect their requirements and feedbacks, and involves research at the interface between

behavioural and decision analytics, climate and coastal science as well as applied statistics.

ESA's Earth Observation in Support of the Marine Environment

Author: Jérôme Benveniste

Presenter: Jérôme Benveniste

ESA's Earth Observation Programme and its contribution to the Marine Environment, in particular the measurement of sea level from space is the focus of this presentation. ESA's Earth observation missions are grouped into three categories: 1) The Sentinel satellites in the context of the European Copernicus Programme, 2) the scientific Earth Explorers and 3) the meteorological missions. The most important satellite missions for the subject of this workshop will be described and the applications of their data products and derived scientific results will be addressed, as well as the strategies for future oceanographic missions. A special focus will be put on the Earth Explorers, who form the science and research element of ESA's Living Planet Programme with an emphasis on the hydrosphere and geodesy. In addition the operational Sentinel satellites have a huge potential for operationally monitoring the oceans, their variability and their trends.

Owing to 25 years of continuous measurements, Radar Altimetry plays a major role in the ocean observing system. Thanks to the Sea Level Essential Climate Variable produced by the 6-year long Climate Change Initiative Sea Level Project, this tool can now be used to also accurately monitor trends in sea level and study the response of the ocean to anthropogenic perturbations to the natural Earth processes, which was not envisaged as possible at the beginning of the satellite era. Indeed, all the parameters involved in the radar equation from sending pulses, collecting echoes and converting these raw data into geophysical variables have to be mastered with high precision to reach the required centimetric accuracy, as well as any drift of each of these parameters to reach a global mean sea level trend accuracy of a few tenth of mm/yr. Recent progress enables the study of the 2nd derivative of sea level: acceleration. The positive sign of this acceleration entrains negative prospects for humanity, unless these measurements trigger rapidly a pro-active reaction by the dwellers of this unique Planet.

The European Space Agency is continuously collecting science requirements to design its future Earth observation missions and we expect a precious feedback from this workshop.

Assembling historical tide gauge records to a novel Baltic mean sea level data base

Authors: Jessica Kelln, Sönke Dangendorf, Justus Patzke, Jürgen Jensen

Presenter: Jessica Kelln

In this presentation we introduce a novel monthly mean sea level (MSL) dataset from 140 tide gauge records in the Baltic Sea covering a period from 1777 to 2015. The dataset has been produced within the BMBF project “AMSeL Baltic Sea” in which we collected high resolution tide gauge data and digitized historical sea level records of varying temporal resolution and tried to merge the corresponding monthly MSL records with existing records from the PSMSL database. The comparison to PSMSL records uncovered several significant differences (both jumps in the mean as well as differences in the variance) at individual stations, particularly along the German coastlines. Here we show that the differences result from tidal biases introduced by an inconsistent handling of historical data of varying temporal resolution at individual PSMSL sites. Using our comprehensive database of hourly records we demonstrate that especially in the southwestern part of the basin sea level time series exhibit a significant daily tidal cycle. This tidal cycle introduces biases in MSL estimates as soon as the data resolution falls below a few readings per day thus necessitating a tidal correction. Our assessment reveals that existing German PSMSL records often represent merged products with periods where such tidal corrections have been neglected so far. After introducing a new empirical tidal correction we update those records and demonstrate its impact on long-term trends and variability.

Storm surge forecasting procedures: errors arising from the double-counting of radiational tides.

Authors: Joanne Williams, Maialen Irazoqui Apecechea, Andrew Saulter, Kevin J. Horsburgh

Presenter: Joanne Williams

Tide predictions from observations are not just the astronomical tides, they also contain radiational tides - periodic sea level changes due to atmospheric conditions and solar forcing. Tidal models are usually either run as tide-only, with astronomic forcing alone; or tide-and-surge, forced additionally by surface winds and pressure. This poses a problem of double-counting for operational forecasts of total water level during storm surges, which add local tidal predictions to "non-tidal residuals", the difference between these two configurations. We use the Global Tide and Surge Model based on Delft-FM to investigate this in the UK and elsewhere, quantifying the weather-related tides that may be double-counted

in operational forecasts. We show that the global S2 atmospheric tide is captured by the tide-surge model and quantify the extent to which the "Highest Astronomical Tide", which is derived from tide predictions based on observations, may also contain weather-related components.

The land ice contribution to sea level during the satellite era

Authors: Jonathan Bamber, Richard Westaway, Bert Wouters, Ben Marzeion

Presenter: Jonathan Bamber

During the satellite era, when radar altimeters have provided unprecedented detail on the spatio-temporal variability in sea level rise (SLR), there has also been a revolution in our ability to resolve and quantify the land ice contribution to SLR. This began with the launch of ERS-1 in 1991 and has evolved as new sensors and missions were placed in orbit such as ICESat and GRACE in 2003 and 2002, respectively. Each mission has provided unique, but sometimes conflicting, insights into the mass trends of glaciers and ice sheets and each has its strengths and weaknesses. Over the last decade, over fifty estimates have been published, providing a confusing and often inconsistent picture of land ice trends. The IPCC Fifth Assessment Report (AR5) attempted to synthesise the estimates published up to early 2013. Since then, considerable advances have been made in understanding the origin of the inconsistencies, reducing uncertainties in estimates and extending time series.

Here, we update and synthesise the most recent results, primarily, since the AR5, with the aim of establishing a consistent and comprehensive estimate of the land ice contribution to SLR during the satellite era (1993 to 2016). We do this by taking a holistic approach: considering and combining observations from multiple missions, sensors and approaches including the use of regional climate models and statistical modelling. Our resulting synthesis of land ice contribution is both consistent and rigorous, drawing on expert assessment of the literature and methods used. We combine this with a novel analysis of Arctic glacier and ice cap trends and glacier mass balance modelling for other other regions. Finally, we examine our solution for land ice in relation to independent estimates of the changing mass of the oceans. Our time-mean estimate for 1993-2016 is 1.25+-0.3 mm/yr. Our trends are significantly less than the AR5 and slightly below the WCRP Sea Level Budget assessment (by ~0.2 mm/yr). They are, however, consistent with a GRACE and altimetry-based assessment of ocean mass change for the overlapping periods. Our results are resolved with annual time step and separately for the Greenland, East Antarctic, West Antarctic Ice Sheets and glaciers and ice caps.

REVIEWING THE SEASONAL SEA LEVEL VARIABILITY OF THE GULF OF MEXICO

Authors: Jorge Zavala-Hidalgo, Rosario Romero-Centeno, Jose Ochoa, Raúl González-Santamaría, Felipe Hernández-Maguey, Ma. Elena Osorio-Tai, Alin Calva-Chavez, Angélica Pedraza-Díaz

Presenter: Jorge Zavala-Hidalgo

The low frequency variability of the sea level (SL) in the Gulf of Mexico (GoM) is revisited based on tide gauge observations, altimetry data and numerical modeling. Here, the contribution to the SL variability of the currents, isostasy and remote forcing is quantified. During the altimetry period there is a global trend of 3.6 mm/year but local measurement differ from this value being the residuals computed discussed. On the seasonal scale, there is an amplitude of 0.145 m with a maximum during early October and a minimum during early March but with a lead in the northern GoM and a delay in the western and southern GoM. In the western GoM, during the transition from summer to autumn, there is a change from a stratified to a homogeneous shelf. It is shown that in addition to the impact in the vicinity of the landing area of tropical storms and hurricanes, they cause changes in the stratification and sea level in the western GoM by piling up warm water near shore, and changing the coastal circulation.

Investigation of the dynamic sea level changes in the Polish coastal zone

Authors: Katarzyna Pajak, Joanna Kuczynska-Siehien, Kamil Kowalczyk

Presenter: Katarzyna Pajak

Many of people living in coastal area are vulnerable to the effect of storm surges, seasonal and interannual sea level anomalies, and long-term sea level rise. Coastal seasonal-to-interannual sea level anomalies are strongly affected by climate phenomena.

In this paper we compare sea level trends observed at a few selected tide gauges and from satellite altimetry in the period from January 1993 to December 2015. The monthly time series of sea level were used to estimate the sea level change along the Baltic Sea coast. The time series of satellite altimetry and tide gauge data show almost similar behaviour in the sea level change. A trend and annual and semi-annual seasonal signals were determined using harmonic analysis.

Moreover, we used the statistical analysis of chronological series, which shall be based on a system of indicators that characterize many quantitative relations of the inside of series and at the period to which data is referring. The index method is using to numerically determine the rate and intensity of sea level changes in time, i.e. it presents the dynamics of sea level changes. We calculated the absolute, relative and average indicators which characterize the development of sea level changes. For each year, we determined the direction, the rate and the intensity of changes over time in the sea level. The values obtained by the indices investigation show that in the case of indices with fixed base and with the chain base values are relatively similar. We have encountered a similar situation in relation to the rate of growth of sea level rise in the period 1993-2015 from two different data sets.

A stochastic storm surge model for the German Baltic Sea coast

Authors: Leigh Richard MacPherson, Arne Arns, Sönke Dangendorf, Jürgen Jensen

Presenter: Leigh Richard MacPherson

Exposure of coastal populations and assets to extreme sea levels is expected to increase throughout the 21st century due to combinations of rising mean sea levels, potential changes in storminess, population growth, economic development and urbanisation. This is particularly true for the densely populated German Baltic Sea coast whose micro-tidal environment and limited coastal protection makes it especially susceptible to changes in sea level. Despite this, extreme sea level dynamics, their socioeconomic impacts and required adaptation responses in the region are poorly understood. In order to plan adequate coastal defences and adaptation pathways, robust return water level estimates for current and future conditions are required. Traditional analyses of extreme water level events are generally univariate, focussing entirely on peak water level. However, the temporal evolution of storm surge curves can also be a major factor in terms of coastal structure durability and flood impacts.

In this study, a stochastic storm surge model has been developed for the German Baltic Sea, capable of generating large numbers of extreme water level events for flood risk analyses. The model is driven by tide gauge measurements with hourly samples of total water level and has been applied at 45 locations in the region. Extreme water level events within the tide gauge data sets are identified and parameterised. Artificial storm surge curves can then be generated through Monte-Carlo-Simulations which rely on parametric distribution functions and a Gaussian copula fitted to the extracted parameters. Each storm surge generated by the model is a time series of total water level. The model is computationally cheap and allows for multivariate analysis of extreme water levels, based on peak water level and storm surge duration.

Assessing 20th century tidal range changes in the North Sea

Authors: Leon Jänicke, Sönke Dangendorf, Arne Arns, Jürgen Jensen

Presenter: Leon Jänicke

Tide gauges from the North Sea show significant changes in the local tidal regime since the middle of the 20th century. While some national assessments have been undertaken over the last decades, there is no comprehensive basin-wide evaluation available so far. For instance, it is well known, that the high tides in the German Bight have been rising significantly faster than mean sea level, while the low tides show smaller or even negative trends. The result of these opposing trends are an increase in tidal range of up to 10 % since 1955. The magnitude of the observed increase is a globally unique phenomenon which cannot be explained physically until today. These changes have direct impacts on coastal protection, because they have the potential to amplify coastal erosion or land losses.

Within the DFG (German Research Foundation) funded project TIDEDYN we assess temporal changes in tides along the North Sea coastline and try to explain their physical origin with high-resolution and three-dimensional numerical model experiments. There we will focus on the assessment of observed changes from tide gauges, aiming at seperating local from basin wide phenomena. We apply (i) nonlinear trend approaches (such as singular system analysis (SSA)) and Bayesian change point analyses to individual tide gauge records to identify the timing of the observed changes and (ii) a Gaussian Process Regression (Kriging) to spatially map these changes along the coastline. As a preliminary result we find, for instance, that the ongoing increase in the tidal range along the southeastern coastline of the North Sea is accompanied by a simultaneous decrease along the eastern UK coastline leading to a longitudinal shift of the major amphidromic point. However, these changes are not always spatially homogeneous and partially counteracted or amplified by local phenomena. For example, along a small coastal strip from Cuxhaven to Husum the observed changes in tidal range appear to be much smaller than in the surrounding areas. We hypothesize that this is related to the embankment of the Meldorf Bight in 1978, but this effect needs to be further assessed in numerical model simulations.

Changes in wave contribution to total sea-level in response to high-end climate scenarios.

Authors: Lucy Bricheno, Judith Wolf

Presenter: Lucy Bricheno

What will happen to the nearshore surface wave climate in the future? Rises in mean sea-level will drive extreme waves closer to the coast. Combined with changes in atmospheric conditions, this will change the probability of damaging storms impacting the coast.

Long period waves, with large significant wave height are the most damaging, yet many future predictions are based around changes in mean wave climate. We present new projections of coastal wave impacts under high-end climate change (RCP4.5 and RCP8.5), using CMIP5 climate model from the present day out to 2100. The novelty is a focus on the extreme waves (95th / 99th percentile), and mean annual maximum, which have a rather different signal to the mean wave climate.

Downscaled wind forcing at ~11km resolution are combined with a nested high-resolution spectral wave model, in order to draw conclusions directly applicable to coastal sites. We will also discuss if and where the dynamical downscaling has added value to predictions of extreme waves at the coast.

There are still uncertainties in the North Atlantic storms generated in the latest climate models. Though storminess is 'noisy', surface waves act to integrate the changing energetics, allowing a climate-change signal to emerge.

The downscaled wave forecasts from this regional model, will then be put into context of eight global wave models. This multi-model ensemble approach will investigate the robustness of future change signals in mean and extreme wave climate.

The impact of ice sheet interdependence upon probabilistic projections of sea-level change.

Authors: Luke P. Jackson, Andrew Martinez, Felix Pretis, Katarina Juselius

Presenter: Luke Jackson

Sources of sea-level rise uncertainty are numerous, however the continental ice sheets constitute both a potentially large contribution to future sea-level and physical mechanisms that are difficult to model (e.g. ice melt ponding, submarine melting, basal lubrication, ocean melting/interaction, ice cliff failure and ice sheet fracturing). In addition to this uncertainty, one must also consider possible interconnectivity between the ice sheets (East Antarctica, West Antarctica and Greenland): whether changes in an ice sheet drive changes in another and visa-versa. Clearly external drivers impact all ice sheets (e.g. temperature and precipitation) but not in the same way and underlying causal relations between ice sheets will either reflect these or other mechanisms. We analyse satellite derived mass-balance estimates, whose signal combines SMB and rapid dynamics, using a statistical methodology called vector-auto regression. We find that a twice integrated auto-regressive model, which is composed of two linear relationships (Greenland, West Antarctica and an external linear trend, and West and East Antarctica) is successful in estimating the mass-balance observations. This result points to present-day ice sheet mass evolution, and its first derivative being a non-stationary process. We show that these relationships can be easily implemented into probabilistic sea-level projections with clear differences from projections following the assumption of independent sea-level components.

Subsidence of the Ganges-Brahmaputra Delta induced by sediment loading

Authors: M. Karpytchev, V. Ballu, Y. Krien, M. Becker, S. Goodbred, G. Spada, S. Calmant, C.K. Shum and Z. Khan

Presenter: M. Karpytchev

Impact of subsidence on relative sea-level rise in the Ganges-Brahmaputra delta (GBD) is largely unknown and may considerably enhance exposure of the Bengal basin populations to sea level rise and storm surges. This study focused on estimating the present-day subsidence induced by Holocene sediment in the Bengal basin and by oceanic loading due to eustatic sea level rise over the past 18 kyr. Using a viscoelastic Earth model and sediment deposition history based on in-situ measurements, results suggest that massive sediment influx initiated in the early Holocene may have contributed significantly to the present-day subsidence of the GBD. We estimate that the Holocene loading generates up to 1.6 mm/yr of the present-day subsidence along the GBD coast, depending on the rheological model of the Earth. This rate is close to the 20th century global mean sea level rise (1.1-1.7 mm/yr).

In-situ adaptation can enable relocation

Authors: Ma. Laurice P. Jamero, Miguel Esteban, Motoharu Onuki, Christopher Chadwick

Presenter: Ma. Laurice Preciado Jamero

Although mass migration has often been referred to as a "last resort" solution to the problem of sea level rise in small islands, in reality many scholars and policy-makers as well as the general public have come to consider it as the ultimate solution – as evidenced by alarmist scientific studies and media articles that tend to ignore the demonstrated capacity of island and coastal communities to adapt to changing environmental conditions throughout history. This alarmist view also pre-supposes that in-situ adaptation and mass migration are mutually exclusive approaches, and that investment in the earlier is a waste of resources in the face of inevitable island abandonment.

In this study, we challenge this notion using field survey experiences from small island communities in Tubigon, Philippines that have suffered severe land subsidence due to the 2013 Bohol Earthquake. As a result of this earthquake, the communities are currently flooded at normal high tides, and the local government has (unsuccessfully) launched a relocation program.

Vulnerability drives mass migration. However, vulnerability also negatively impacts the chances of successful relocation. Previous studies have shown that, without sufficient resources, migrants face a great risk of impoverishment in their new location, or may not even be able to move in the first place despite wanting to (i.e. concept of “trapped population”). Nonetheless, this study argues that in-situ adaptation can help enable relocation by reducing the vulnerability of communities, allowing them to better manage if, when and where they will relocate. Coastal protection and ecosystem-based adaptation can increase a community’s resilience against natural hazards, which are an otherwise common driver of unplanned and involuntary movement. “No regrets” adaptation strategies also help address the socio-economic drivers of vulnerability, empowering communities to adapt to sea level rise as they see fit for their own needs. By reducing overall vulnerability, in-situ adaptation transforms mass migration into a choice, rather than an inevitability.

Better understanding the complementary relationship of in-situ adaptation and mass migration, the Municipal Government of Tubigon has also begun to take a fresh approach towards encouraging relocation. It now views the education of younger generation residents (a “no regrets” adaptation strategy) as an integral component of its relocation program. It has decided to prioritize qualified school children from the islands in its scholarship program, which aims to equip its beneficiaries with university degrees or vocational skills that would enable them to find job opportunities in the mainland. With this, the government hopes that the education of young children would lead to the natural depopulation of the islands in the near future.

Global modelling of future extreme sea-levels using a high-resolution Global Tide and Surge Model

Authors: Maialen Irazoqui Apecechea, Martin Verlaan, Sanne Muis, Joao de Lima Rego

Presenter: Maialen Irazoqui Apecechea

The increasing sea-level and meteorological changes associated with climate change increase the flood risk in coastal cities and low lying areas. Understanding the magnitude and impact of such changes is vital to design adaptive strategies and create awareness. Such risk predictions are possible with the use of hydrodynamic models that are coupled to climate models.

In the context of the CoDEC project (Coastal Dataset for Evaluation of Climate impact), we compute the climate change induced changes on future sea-level, storm-surge, tides and waves, and the associated impacts on coastal flood risk for Europe from present date to 2100. We consider the 4.5 and 8.5 Representative Concentration Pathways (RCP), and produce extreme value statistics representing mi-century and end of century conditions. For the waterlevels, we use the Global Tide and Surge Model v3.0 (GTSMv3.0), a high resolution hydrodynamic model with global coverage. The model has a coastal resolution of 2.5km globally and 1.25km in Europe, and incorporates dynamically sea-level rise, tides and surge, and therefore calculates the non-linear interaction between them. For the meteorological forcing, we use the global EC-Earth climate model together with a European-wide high resolution climate model from the CORDEX archive. In order to assess the changes relative to present and past conditions, we perform a reanalysis of extreme sea levels using the newly available high resolution ERA5 forcing. Based on the relative changes, we design a number of indicators that provide useful information about the possible impacts of climate change globally. For Europe, a number of user cases are defined in which different industries use such indicators and global model outputs to downscale and assess impacts at a regional/local scale.

We produce output for not only global coastlines at a high resolution, but also at organized nesting points covering the global ocean which can be used for regional downscaling anywhere in the globe.

Sea-level rise along the Emilia-Romagna coast (Northern Italy) in 2100: scenarios and impacts

Authors: Marco Olivieri, Luisa Perini, Lorenzo Calabrese, Paolo Luciani, Gaia Galassi, Giorgio Spada

Presenter: Marco Olivieri

In consequence of climate change and land subsidence, coastal zones are directly impacted by sea-level rise.

In some particular areas, the effects on the ecosystem and urbanisation are particularly enhanced. We focus on the EmiliaRomagna (E-R) coastal plain in Northern Italy. The plain is ~130 km long, bounded by the Po river mouth and by the Apennines, and it is characterised by wide areas below mean sea level, in part made up of reclaimed wetlands. During next decades, the combined effects of land subsidence and of the sea-level rise as a result of climate change are expected to enhance the shoreline instability, leading to further retreat. The consequent loss of beaches would impact the economy of the region, which is tightly connected with tourism infrastructures. Furthermore, the loss of wetlands and dunes would threaten the ecosystem, which is crucial for the preservation of life and the environment. These specific conditions show the importance of a precise definition of the possible local impacts of the ongoing and future climate variations.

The aim of this work is the characterisation of vulnerability in different sectors of the coastal plain and the recognition of the areas in which human intervention is urgently required. The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) sea-level scenarios are merged with new high-resolution terrain models, current data for local subsidence and predictions of the flooding model “in_CoastFlood” in order to develop different scenarios for the impact of sea-level rise projected to year 2100. First, the potential land loss due to the combined effect of subsidence and sea-level rise is extrapolated. Second, the increase in floodable areas as a result of storm surges is quantitatively determined. The results are expected to support the regional mitigation and adaptation strategies designed in response to climate change.

GNSS REFLECTOMETRY APPLIED TO MEXICO TIDE GAUGE SITES

Authors: María Elena Osorio-Tai, Simon D. P. Williams, Jorge Zavala-Hidalgo, José Antonio Santiago, Vladimir Kostoglodov

Presenter: María Elena Osorio-Tai

Here it is presented an evaluation of geodetic GNSS in Mexican tide gauges to measure sea level variability. Universidad Nacional Autónoma de México (UNAM) has been installing permanent GNSS receivers in order to have a better vertical control at the tide gauge station. Currently UNAM operates 28 stations around Mexico and 15 of them have GNSS receivers: 10 sites along the Pacific coast and 5 in the Gulf of Mexico and the Caribbean Sea. When the receivers were installed it was not considered the option to obtain sea level data with GNSS reflectometry, but since most of them are located in the same shelter it is possible to validate the estimation of sea level with direct observations from tide gauge (radar or float) and is expected that some of them may be useful for it. In addition, it is qualitatively evaluated, which sites may be useful for estimating sea level variability, considering the position of the GNSS receiver and the potential reflection sources.

Subseasonal to seasonal forecasts of coastal sea level

Author: Mark Merrifield

Presenter: Mark Merrifield

Short-term forecasts of extreme high, or low, sea level anomalies are becoming more common with advancements in dynamical and statistical modeling. Here we examine the state of sea level forecasting on subseasonal to seasonal time scales using tide gauge observations from US continental and island coastlines. Dynamical ocean processes that promote skillful forecasts will be examined in various regions. Strategies for downscaling sea level forecasts from low-resolution models will be discussed. In addition, we will consider the value of incorporating wave model forecasts in addition to sea level anomalies for providing advanced warning of coastal flooding.

Global Sea Level Budget and Ocean Mass Budget Assessment: Preliminary Results From ESA's CCI Sea Level Budget Closure Project

Authors: Martin Horwath, Anny Cazenave, Hindumathi Kulaiappan Palanisamy, Ben Marzeion, Frank Paul, Raymond Le Bris, Anna Hogg, Inès Otosaka, Andrew Shepherd, Petra Döll, Denise Cáceres, Hannes Müller Schmied, Johnny A. Johannessen, Jan Even Øie Nilsen, Roshin P. Raj, Rene Forsberg, Louise Sandberg Sørensen, Valentina R. Barletta, Per Knudsen, Ole Baltazar Andersen, Heidi Ranndal, Christopher John Merchant, Claire Rachel MacIntosh, Christopher Old, Karina von Schuckmann, Benjamin Gutknecht, Kristin Novotny, Andreas Groh, Jérôme Benveniste

Presenter: Martin Horwath

Studies of the sea level budget are a means of assessing and understanding how sea level is changing and what are the causes. Closure of the total sea level budget implies that the observed changes of global mean sea level as determined from satellite altimetry equal the sum of observed (or otherwise assessed) contributions, namely changes in ocean mass and ocean thermal expansion and haline contraction. Here, ocean mass changes can be either derived from GRACE satellite gravimetry (since 2002) or from assessments of the individual contributions from glaciers, ice sheets, land water storage, snow pack and atmospheric water content. Estimates of thermosteric sea level are obtained from ocean in situ measurements with additional plans for the inclusion of satellite derived Sea Surface Temperature information. Misclosure of the sea level budget indicates errors in some of the components or contributions from missing or unassessed elements in the budget.

ESA's Climate Change Initiative (CCI) has conducted a number of projects related to sea level. Among those projects, the Sea Level CCI project, the Greenland and Antarctic Ice Sheet CCI projects and the Glaciers CCI project directly benefit from satellite altimetry data. The Glaciers CCI project and the Sea Surface Temperature CCI project provide additional insights into phenomena related to sea level change.

The aim of the ongoing CCI Sea Level Budget Closure project is to use the CCI data products, together with further data products provided by the project partners to re-assess the sea level budget. Specifically, the project further develops and analyzes products based on the CCI projects mentioned above in conjunction with in situ data for ocean thermal expansion (e.g., Argo), GRACE-based ocean mass change assessments, and model-based data for glaciers and land hydrology. The work benefits from directly involving the expertise on the product generation for all the involved sea level contributions.

The presentation will report on preliminary assessments of global sea level budget closure and of global ocean mass budget closure. We focus on two periods: 1993-2015 (the altimetry period) and 2003-2015 (the GRACE / Argo period). We consider the budget of the long-term trends as well as the budget of the overlaid interannual variations. A special focus is on the account for uncertainties of the individual contributions, building on the expertise of all project partners.

Sea Level Monitoring in the South Atlantic Coast: Preliminary results for 3 tide gauges operating for 817 days in South Brazil

Authors: Boll, M.G, Vanz, A., Garbossa, L.H.P., Araujo, C.E.S. and Vieira, H.J.

Presenter: Matias G Boll

Brazil's coastal line (7,367 km), starts approximately at Lat 5o 00' N and extends up to Lat 33o 00' S, in the Subtropical South Atlantic. Santa Catarina, it's second Southernmost state (Lat 25o 57' to 29o 24' S), occupies 1.1% of Brazil´s surface area but encompasses 7.2% (561 km) of the country's coast line. The 37 municipalities located at the state's coastal zone, have 2.7 million inhabitants (41% of the state's population), generate 30% of its GDP, and occupy just 9% of the state´s land area.

Based on more than 30 years of meteorological monitoring experience, state agency Epagri expanded its activities to Santa Catarina´s coastal area. Over the last 5 years, 2 meteorological stations (MS) and 9 tide gauges (TG) were installed to form a new coastal monitoring network. This presentation reports the main results for sea level data analysis of 3 tide gauges (2901, Ilha da Paz; 2951, Florianopolis; and 2963, Imbituba). Data selected for the analysis represent monitoring activity of 643, 817 and 817 days (Jan/16 to Mar/18), respectively. Sea level data collection was performed through the use of radar sensors operating at local levelling (navigation purpose), using a 0.25 h sampling rate. Harmonic analysis was executed using TASK Windows Ed 2.1.0 software package, using 62 harmonic constants in every TG sea level data analysis.

From North to South (2901 -> 2951 -> 2963; 225 km total distance), the following statistics were recorded: maximum sea level, 2.125, 1.750, and 1.570 m, respectively; minimum sea level: -0.577, -0.620, and -0.660 m, respectively; mean sea level: 0.845, 0.550 and 0.4659 m, respectively. Following North to South data analysis, the difference between the highest and lowest record was: 2.702, 2.370, and 2.230 m; sampling failure was 0.34, 0.64 and 0.98% out of 15,431, 19,631, 19,631 reading possibilities; and residual means were 0.0001, 0.0000, and 0.0000 for TGs 2901, 2951 and 2963, respectively. Residual's maximum values were 1.167, 1.077 and 1,142 m , which is about 138%, 196% and 245% larger than TG's 2901, 2951 and 2963 mean sea level values, respectively. Finally, the equation that defines the tide type (O1+K1)/(M2 + S2) presented the following results for TGs 2901, 2951 and 2963: 0.324, 0.538, and 0.673, respectively, characterizing a mixed, mainly semidiurnal, tide type.

Results show an interesting pattern in sea level from North to South in South Brazil, e.g., tides tending from a mixed semidiurnal type to a mixed tide type. Furthermore, results indicate that meteorological tides have a significant importance in the region, showing the importance of tide predictions services. We expect that in the near future these stations will operate in the GLOSS pattern of quality, increasing the number of tide gauges monitoring sea level in the South Atlantic.

Drivers of the sea level response to common flux perturbations

Authors: Matthew Couldrey, Jonathan Gregory

Presenter: Matthew Couldrey

Coupled atmosphere-ocean general circulation models (AOGCMs) are useful tools to predict patterns of future sea level that result from climate change, but the large spread in projections is a considerable uncertainty. In particular, gaps in our understanding of ocean heat uptake make it difficult to determine which projections are more likely to be robust. Using a suite of Coupled Model Intercomparison Project (CMIP) models from the previous (CMIP5) and current (CMIP6) generations, the roles of physical processes in causing patterns of sea level change be quantified directly. The new Flux-Anomaly-Forced Intercomparison Project (FAFMIP) aims to reduce the uncertainty in projections of future sea level by comparing the oceanic response of several different models to a set of common perturbations to the atmosphere-ocean fluxes of momentum, heat, and freshwater. The FAFMIP framework allows for the effects of separate physical processes (such as residual mean advection, eddy advection, and diapycnal diffusion) in causing sea level change to be quantified. Refined projections of sea level change can then be produced by discounting those simulations found to be unreliable.

Can the coastal return sea levels be estimated when there is no local information?

Authors: Melisa Menendez, Hector Lobeto

Presenter: Melisa Menendez

The estimation of extreme water level values on coastal areas is a requirement for a wide range of engineering and coastal management applications. There are many coastal locations however where long in-situ records are not available. Simulations through numerical models are an alternative, nevertheless the models require also of local information, such as coastal bathymetry, that is often neither available. Here a novel study is presented to estimate the extreme 'non-tidal-residual' sea level component by using altimeter data.

A methodology has been developed by using a multi-mission and inter-calibrated along track satellite data. The methodology consists of: (i) the selection of a coastal maxima sample from the satellite data source; (ii) a time-dependent extreme statistical model from monthly maxima values, and (iii) definition of an extreme scale factor. The extreme scale factor depends on two weighted factors: the exposure degree of the target coastal location (e.g. within an estuary, on an open island, etc.) and the wide of the continental shelf.

Return level plots from this approach at several coastal locations are compared against estimated return sea levels from tide-gauge records. The approach is able to estimate extreme values associated to high return periods (e.g. 20,50 100 years) and confidence intervals in a similar way that when local records are available. Likewise, climate interannual variations on extreme sea level events due to circulation pattern fluctuations and decadal trends are provided from this approach in coastal regions.

Modelling the impacts of climate change and tidal stream energy extraction in a shelf sea.

Authors: Michela De Dominicis, Judith Wolf, Rory O'Hara Murray

Presenter: Michela De Dominicis

This study presents a plausible projection of how the hydrodynamic conditions on the NW European continental shelf might respond to climate change and to tidal stream energy extraction.

We numerically simulated changes on the physical marine environment of a shelf sea, induced by both the "business as usual" future climate scenario (RCP8.5) and by hypothetical very large tidal stream arrays in Scottish Waters (UK), able to provide 3.8 GW for electricity generation. This is about 10% of the UK present average instantaneous electricity consumption.

The Scottish Shelf Model, an unstructured grid three-dimensional ocean model, has been used to reproduce the present and the future state of the NW European continental shelf. A typical annual cycle of the present hydrodynamics was modelled, and compared with output for the same period of time perturbed by very large-scale tidal stream energy extraction developments. In order to determine if the latter may ameliorate or exacerbate the effects of future climate change on the marine system, the hydrodynamic conditions representative of the projected future climate in 2050 were modelled, including two scenarios, one without tidal energy extraction devices and a second with plausible very large scale tidal stream array layouts. This allows us to evaluate the potential effect of climate change on the hydrodynamics and compare it with the future state of the seas modified by large scale energy extraction.

It is found that where tidal range is reduced of by few cm by tidal stream energy extraction, it can help to counter extreme water levels associated with future sea level rise. Indeed, we found that rising mean sea level will increase tidal range along the UK coast. Sea level rise will affect also tidal currents: increased water depth, and consequent reduced friction, will lead to stronger tidal currents. Instead, tidal velocities, and consequently tidal mixing, are overall reduced by the action of the tidal turbine arrays. A key finding of this study is that climate change and tidal energy extraction both act in the same direction, in terms of increasing stratification due to warming and reduced mixing, however, the effect of climate change is an order of magnitude larger.

How to adapt to sea level rise: Lessons from cities and islands experiencing land subsidence

Authors: Miguel Esteban, Hiroshi Takagi, Laurice Jamero, Christopher Chadwick, Dyah Fatma, Erick Avelino, Takahito Mikami, Motoharu Onuki

Presenter: Miguel Esteban

There are currently a number of alarmist climate change discourses that have expressed a fear that many coastal communities would be forced to relocate in the face of rising water levels. Essentially, as a consequence of the warming climate the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) projects that by the year 2100 the global mean sea-level will rise by between 0.28m and 0.98m. However, there is little actual evidence of any actual mass relocation taking place, despite a number of past examples of relative sea level rise due to earthquake induced subsidence or groundwater extraction. To take advantage of the lessons that could be derived from such case studies, the authors analysed the effects of four instances of land subsidence that have taken place in the 20th and early 21st century, including the cases of Tokyo and Jakarta, and the experience of islands on the Danajon bank in the Philippines, and Kepulauan Seribu close to Jakarta. In all of these case studies local residents remain in place, despite the challenge of living with higher water levels. Human societies attempt to adapt through a five phase process, starting with the construction of weak seawalls, followed by the placement of pumps to drain water. Eventually, as the economic and technical capacities of coastal settlements improve better seawalls are built, leading to the reclamation of new areas and the elevation of entire districts or the construction of super levees. Hence, while it is clear that sea level rise will pose an additional financial strain on urbanised coastal areas, the authors found no evidence that any major coastal settlements will retreat, given the range of adaptation options available. Rather, the authors found evidence for the opposite, with new lines of defence being built further into the water, effectively meaning that humans will probably encroach on the sea.

Reasons to combine operational and long-term measurements of sea level

Authors: Robert Proctor, Mike Osborne

Presenter: Mike Osborne

Most ports and harbours have a requirement to measure sea level on an operational basis. They have a vested interest in ensuring that the data is available in real time for use in vessel traffic services (VTS), in combination with bathymetry to assist pilots when manoeuvring draught restricted vessels, and during capital and maintenance dredging, and in support of hydrographic surveys. They often make the data available to vessels at sea and recreational users via AIS and/or via public facing websites. They also use the data to support long-term planning, environmental assessment, and in design and engineering. Sea level is often measured in combination with other environmental parameters, such as weather, waves and water quality thus providing a useful aggregated dataset. This presentation postulates why sea level data from ports and harbours is not used more widely by the scientific community and discusses the obstacles to this - on both sides - and suggests a way forward to encourage the greater sharing of data and ultimately resources for mutual benefit.

Contribution of internal variability to the dynamic sea level changes in the tropical Pacific during the recent decades

Authors: Mohammad Hadi Bordbar, Thomas Martin, Wonsun Park, Mojib Latif

Presenter: Mohammad Hadi Bordbar

The spatial pattern of dynamic sea level change features a heterogeneous structure over the last decades. In particular, large zonal asymmetry is observed over the tropical Pacific. In the western part, sea level rise has been three times faster than the global average rise, whereas sea level slightly declined in the eastern part. It is still under debate what the relative roles anthropogenic forcing and long-term internal variability may have played in these spatial differences. Using preindustrial control integrations of climate models participating in the Coupled Model Intercomparison Project Phase 5 (CMIP5), we investigate the level of internal dynamic sea level variability and the possibility to detect anthropogenic signals in the presence of the former. The CMIP5 models simulate a high level of long-term variability in the zonal sea level gradient across the tropical Pacific, which is connected to the adiabatic redistribution of ocean heat content forced by variability in the Pacific trade winds. The models well reproduce the overall spatial pattern of dynamic sea level change observed during the recent decades. The observed decadal-scale change in the sea level gradient across the tropical Pacific is within the range of internal variability simulated by the CMIP5 models. These results suggest that the recent decadal dynamic sea level changes in the tropical Pacific could be of natural origin. The detection of anthropogenic signals in tropical Pacific dynamic sea level in the future is strongly hindered by the pronounced internal variability.

Measuring sea surface height with a GNSS Wave Glider

Authors: Nigel Penna, Miguel Morales Maqueda, Ian Martin, Jing Guo, Peter Foden

Presenter: Nigel Penna

Sea level measurements have traditionally been determined from coastline-based tide gauges, which provide high temporal resolution but coarse spatial resolution, or satellite altimetry measurements, which have near-global coverage, but coarse temporal resolution and only 10-100 km spatial resolution (they can also suffer from land contamination in the coastal zone). GPS systems have been deployed on buoys and ships, but the former only provide pointwise measurements and the latter are limited by pre-defined shipping routes and the ship's variable draught. The Wave Glider unmanned surface vehicle, equipped with a geodetic GNSS receiver, provides a means to bridge the gap between the aforementioned sensors, by providing high-rate centimetric precision sea surface height measurement over user-defined routes anywhere worldwide. We demonstrate this from a 13-day deployment in the North Sea, during which the glider traversed a track of about 600 km. Ellipsoidal heights were estimated at 5 Hz using GPS+GLONASS kinematic precise point positioning and, after correcting for tides using the FES2014b ocean tide model and for the geoid using EGM2008, hourly dynamic ocean topography measurements agreed with those from the UK Met Office FOAM-AAM7 model to 6.1 cm standard deviation. Similarly, after correcting the ellipsoidal heights for the tides and dynamic topography, agreement with the EGM2008 geoid at its 5 km North Sea spatial resolution was 5.1 cm. Hourly measurements of significant wave height agreed with the WAVEWATCH III model and WaveNet buoy observations to 17 cm and 24 cm, respectively, and dominant wave periods to 1.4 s. These precisions were obtained in winds gusting up to 20 m/s.

Tsunami-like occurrence detection and characterization: a comparison between time-frequency analysis methods

Authors: Paola Picco, Luca Repetti, Silvio Incardone, Maurizio Demarte, Elisabetta Schiano, Sara Pensieri, Roberto Bozzano

Presenter: Paola Picco

Tsunami-like waves having periods of about 30 minutes are often detected in the Gulf of Genoa and account for a relevant part of the coastal sea-level variability. In some of the cases, their amplitude is comparable or even higher than the local tides. Eight years of sea-level data were analyzed with the aim of assessing their occurrence, intensity and generation mechanism. Data were sorted on annual basis to infer about possible seasonality. Spectral characterization in the “tsunami-band” shows a bimodal oscillation centered on 26.7 and 30.1 minute period common to each year sub-set. A time-frequency analysis based on FFT allowed identifying the occurrences of the most relevant events, while wavelet analysis demonstrated to be a more appropriate tool for the characterization of those which presented relevant differences in terms of intensity, duration, time-frequency response.

Improving our understanding of sea level rise, acceleration and variability. Finding and assimilating new old data.

Author: Peter Hogarth

Presenter: Peter Hogarth

Sea level relative to local land based vertical datums has been recorded using observations from tide gauges for over two centuries, although records of this length survive from only a few sites. Increasing the length of existing records has proved a useful way of reducing the uncertainty in estimates of sea level rise through the industrial period. These records give valuable clues about the physical processes driving sea level variations, and thus about future sea level changes. There has therefore been interest in recovering tidal data from old documents, in the form of marigrams, tidal registers, and old publications such as town records and civil engineering reports. This effort has resulted in decades of additional sea level data being recovered from almost every continental coastline, greatly increasing our knowledge of temporal and spatial variations of relative sea level at the ocean margins. More recently, overlapping satellite altimetry missions have given georeferenced estimates of sea level, with global coverage and relatively high spatial resolution. This study focusses on the recovery of new old sea level data, the critical re-assessment of existing data and vertical references and the use of altimetry to augment the continual assimilation of new data into the existing PSMSL records. The project aims to deliver a new global database of sea level records where datum connections can be recovered, datum steps can be identified and objectively addressed, and the data has been systematically adjusted using best estimates of vertical land motion and meteorological influence. This will be extremely useful for improving and refining estimates of global and regional sea level rise as well as assessing low order non-linear trends such as acceleration or deceleration, which is the ultimate aim of this study. The ongoing work of validating and processing this data will be described, and some early results will be presented using examples from different regions.

Tidal Level Measurements for Coastal Resilience and Survey

Authors: Phil Knight, Andy Plater

Presenter: Phil Knight

The acquisition of Radar-based coastal survey data (using Marine X-Band Radar) requires local data on tidal level to ensure high accuracy monitoring of coastal morphology and coastal morphological change over timescales from days to years. Through this data coupling, beaches and tidal flats can be characterized in terms of their instantaneous and long-term behaviours.

Monitoring the health of beaches over the long term and in response to storms provides the essential evidence base for strategic beach maintenance. In addition, tidal observations provide local authorities and environmental regulators with a means for tracking changes in the frequency of damaging extreme water levels, and port authorities and shipping companies with data on safe access.

The research direction has evolved during this first year of investigation into three separate elements:

(1)To quantify tidal level differences around an X-band radar deployment at Crosby (near to Liverpool) using tidal data from nearby locations, and comparing the resulting ground-truth corrected radar derived beach elevations with Terrestrial LiDAR derived profiles. To report on progress with this analysis.

(2)To explore the use of alternative ways to measure tidal levels when traditional methods are not applicable, and/or there are no existing local tide gauge stations nearby. To report on results from the first experiments using a low cost GPS unit to measure sea surface elevations.

(3)To investigate and develop techniques to make use of the resulting spatial/temporal beach elevation data to gain a better understanding of beach morphology (Previous research has been restricted by only having limited numbers of LiDAR images, and/or a times series of single beach profiles).

Sea Level Change in Great Britain between 1859 and the Present

Author: Philip L. Woodworth

Presenter: Philip L. Woodworth

Short records of sea level measurements by the Ordnance Survey at 31 locations in 1859-60, together with recent Mean Sea Level (MSL) information from the UK tide gauge network, have been used to estimate the average rates of sea level change around the coast of Great Britain since the mid-19th century. Rates are found to be approximately 1 mm/year in excess of those expected for the present day based on geological information, providing evidence for a climate-change related component of the increase in UK sea level. In turn, the rates of change of MSL for the past 60 years are estimated to be ~1 mm/year in excess of the long-term rates since 1859, suggesting an acceleration in the rate of sea level rise between the 19th and 20th/21st centuries. Although the historical records are very short (approximately a fortnight), this exercise in 'data archaeology' shows how valuable to research even the shortest records can be, as long as the measurements were made by competent people and the datums of the measurements were fully documented.

The tidal measurements of James Cook during the voyage of the Endeavour

Authors: Philip L. Woodworth, Glen H. Rowe

Presenter: Philip L. Woodworth

The main priority of the first of James Cook's famous voyages of discovery was the observation of the transit of Venus at Tahiti. Following that, he was ordered to embark on a search for new lands in the southern ocean. Cook had instructions to record as many aspects of the environment as possible at each place that he visited, including the character of the tide. This paper makes an assessment of the quality of Cook's tidal observations using modern knowledge of the tide, and with an assumption that no major tidal changes have taken place during the past two and half centuries. We conclude that Cook's tidal measurements were accurate in general to about 0.5 ft in height and 0.5 hour in time. Those of his findings which are less consistent with modern insight can be explained by the short stays of the Endeavour at some places. Cook's measurements were good enough (or unique enough) to be included in global compilations of tidal information in the 18th century, and were used in the 19th century in the construction of the first worldwide tidal atlases. In most cases, they support Cook's reputation as a good observer of the environment.

Interannual sea level variability in the tropical Pacific from 1961-2014 derived using a multi-mode linear model system

Authors: Richard J. Greatbatch, Xiaoting Zhu, Martin Claus

Presenter: Richard J. Greatbatch

In the 1970's, Jim O'Brien's group at Florida State University made early advances in our understanding of the dynamics of El Nino/Southern Oscillation using linear reduced gravity models for the tropical Pacific Ocean driven by estimates for the time series of observed wind stress anomalies. At that time, only the very limited tide gauge measurements were available to verify the models. Here, we take advantage of satellite altimeter data to revisit the use of linear models to hindcast tropical Pacific sea level variability. Using wind stress from ERA-Interim to drive a linear multi-mode model, the weighting given to the different modes is determined by fitting the model-computed sea level at the equator to the AVISO satellite data. We find that it is possible to extract the first five baroclinic modes from the altimeter data and show that the model has skill not only at the equator itself, but also at off-equatorial tropical latitudes. A feature of the model results is a pivot point on the equator about which both the model and AVISO sea level tip up and down as in a see-saw. We show that the westward displacement of the pivot point from the center of the basin is strongly influenced by the fact that most of the wind stress variance is found in the western part of the basin. Using the same model driven by wind stress from ERA-40, before the satellite era, shows excellent agreement between the model-computed sea level variability and the available tide gauge data. We present evidence that the pivot point was further west during the period 1993–2014 than during the period 1961–2002 and attribute this to a persistent upward trend in the zonal wind stress variance along the equator west of 160 W throughout the period 1961–2014. We suggest that both the increase in zonal wind stress variance and westward shift of the pivot point are part of a positive feedback mechanism related to the emergence of Central Pacific Nino's following the 1976/77 climate shift. It follows that Central Pacific Nino's may be part of the natural variability of the climate system and that their recent emergence need not be due to anthropogenic climate change.

Steric sea-level trends in the Argo epoch: First results from an integrated, spatial sea-level budget assessment

Authors: Zhe Sha, Sam Royston, Jonathan Bamber, Jonathan Rougier, Rory Bingham, William Llovel, Maike Schumacher

Presenter: Sam Royston

Correctly separating the sources of sea level rise is crucial for understanding recent sea-level change and improving future predictions. Traditionally, changes in each component of the sea-level budget have been treated in isolation with inconsistent treatment of observational and systematic uncertainties. To address these issues, the European Research Council has funded the five-year 'GlobalMass' project (www.globalmass.eu). The project adopts a Bayesian Hierarchical Model (BHM) framework to produce a physically-based and data-driven attribution of global sea-level rise to its component parts that is consistent with the full suite of observations, prior knowledge and fundamental geophysical constraints. The goal of the project is to produce simultaneous, consistent, statistically-rigorous estimates of GIA, land ice mass, land hydrology and sea level trends with global spatial coverage for a common epoch. The approach will then be used to re-examine the 20th Century sea-level record.

We have developed a BHM framework that determines the posterior probability distribution of steric sea-level trends from 2005—2015 (when there is comprehensive Argo coverage) from independent total sea-level and mass trend data. The BHM uses observations and prior knowledge about changes in sea surface height (SSH) from altimetry, GIA from the ICE-6G forward model and ocean mass from GRACE. We compare our steric sea-level trend probability distribution from the BHM with four established gridded data sets of observed steric sea-level trend (Scripps, JAMSTEC, IFREMER ISAS15 and UKMO EN4). We use our solution to assess uncertainties in the observational data sets, focusing particularly on basin-scale trends and under-sampled parts of the (upper) ocean, such as in polar regions.

Variability in sea-level trends from open ocean to the coast: An Australian case-study

Authors: S. Royston, C. Watson, M. Passaro, B. Legresy, M. King

Presenter: Sam Royston

There are often differences in sea-level variability characteristics between tide gauge and nearby satellite altimetry observations. These differences occur on varied timescales and are due to differences in both the processing of observations (e.g. reference frame; geophysical corrections) and oceanographic dynamics across the continental slope and shelf to the coast. Understanding these differences is important for reconstructions of historical sea level which relate spatial basis functions from satellite altimetry to time series from tide gauge data. It is also necessary to understand local cross-shelf sea-level variability as short- and medium-term sea-level forecasts at the coast may be based on open ocean sea-level trends.

We use recent improvements in coastal altimetry (improved waveform retracking, tidal and wet tropospheric corrections) to investigate the variability in sea-level trends within 50 km of the Australian coastline. Australia's coastal regions are highly varied, with wide shallow shelf seas, coral reefs, narrow shelves and open ocean islands. We compare variability in sea-level trend with oceanographic variables and physical characteristics, such as distance from the coast and bathymetry, in an attempt to elucidate relationships in different regions. However, we find that the slope and variability of sea-level trend between the open ocean and coast is within the observation uncertainty, particularly when accounting for the uncertainty in the altimetry processing such as tides in shallow seas.

VULNERABILITY ASSESSMENTS OF WEST AFRICAN COAST TO SEA-LEVEL CHANGES USING RADAR AND GEOSAPTIAL TECHNIQUES

Author: Samuel Olumide Akande

Presenter: Samuel Olumide Akande

Coastal ecosystems are considered to be sensitive to different environmental forcings, particularly sea-level rise and an increase in storm intensity. The Gulf of Guinea (GOG) coastal region is within the Northern Atlantic Ocean, and stretches from the Senegal in the West to Gabon to the South-Eastern part of Africa. It is home to a large number people and economic activities with over 50 million of the African population. In order to ensure the preservation of preserving natural resources and ecological features, a modified methodological approached was developed to evaluate risk of coastal inundation from sea level rise and storm surge at specific sites, areas of importance for natural, and infrastructural resources. In this research, suitable geospatial tools, models, and data sets to conduct the coastal inundation risk assessments were used from using real-time kinematic global positioning system (RTK GPS) technology. The derived elevation data from Light detection and ranging (LiDAR), high spatial resolution multispectral imagery and spatial modelling, that in combination with historical estuary evolution and field observation was applied for effective management and conservation the ecosystem features of the area. This inundation risk assessment methodology can be applied to other coastal areas and to the same coastal regions at different times as more accurate elevation data sets and updated sea level rise projections become available. The tools were developed using the ArcGIS 10.6 and Idrisi Terrset software to enable users conduct risk analyses of coastlines by classifying vulnerable areas, and also to produce outputs for further analysis. The recommendations from this research thus enhance the capacity and knowledge of governments and other policy makers in the region to prepare for, and adapt to climate change and its extreme events. A coastal spatial planning designed and then the Integrated Coastal Zone Management framework for West Africa and the African continent was developed.

Progress in reconstructing global and regional sea level changes

Author: Sönke Dangendorf

Presenter: Sönke Dangendorf

Sea-level rise is one of the most certain and costly consequences of a warming world with potentially hazardous impacts on coastal infrastructure, property, and the livelihoods of coastal communities. Since 1992, radar altimeters on board of satellites have been continuously monitoring sea-level changes with high accuracy and nearly global coverage, providing essential information on the behavior of regional and (near-) global mean sea level (GMSL). However, placing this valuable record into historical context is challenging, since estimates of GMSL before the altimetry era rely on a spatially and temporally sparse set of tide gauge records along the coast. In addition, these in-situ records are affected by regionally varying geoid and solid earth processes such as vertical land motion (VLM) caused by glacial isostatic adjustment (GIA) or other local processes, which may mask the global information in the records. Uncertainties in geoid and solid earth corrections in combination with different processing schemes (manifesting itself in a different weighting of the tide gauges) cause current estimates of 20th century GMSL change based on tide gauges to vary widely between ~1 and 2 mm/yr (Church and White, 2011; Jevrejeva et al., 2014; Hay et al., 2015; Dangendorf et al., 2017). However, over the recent years much progress has been made within the different sea level related sub-disciplines in measuring and modelling historical changes of individual sea level components over the 20th century. This now provides the unique possibility of better placing local sea level changes into a global context and reconstructing sea level changes in space and time with increasing accuracy. In this presentation I will discuss challenges in reconstructing historical global and regional sea level changes and show examples of how advances in different data syntheses as well as mathematical and numerical modelling may help to constrain estimates over the entire 20th century.

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Coastal Sea level monitoring using satellite radar altimetry: a decade of progress and beyond

Authors: Stefano Vignudelli, Jérôme Benveniste

Presenter: Stefano Vignudelli

Satellite altimetry experts worldwide have put considerable efforts in the last 15 years to recover more and better observations of sea level closer to the coasts from radar altimetry measurements. Those efforts have marked the initiation and development of a new discipline, Coastal Altimetry. In the coastal zone, the quality of altimeter data is expected to be degraded with respect to the open ocean due to the effects of land returns and heterogeneities in ocean surface backscatter within the altimeter radar footprint. These issues make waveform processing more complicated and add difficulties with some of the corrections needed to achieve acceptable sea level measurement accuracy. As a result, until the early 2000s most of the data in the coastal band used to be flagged as bad and discarded. However, a number of scientists started to believe that most of those coastal data could be recovered and used for applications. The newly formed coastal altimetry community started gathering around regular international workshops and has already held ten of them, all well attended by both altimeter experts and coastal oceanographers. (see http://www.coastalt.eu).

A number of studies have demonstrated that conventional (i.e. 'pulse-limited') altimeter measurements, if reprocessed with specialized waveform re-trackers and optimized corrections, can provide reliable data down to 3–4 km to the coastline. Another step forward has been achieved with the advent of new technologies such as Ka-band altimetry or SAR and SARin mode altimetry. A case in point is the Sentinel-3 altimeter, operating in SAR mode over the global ocean, semi-enclosed and inland seas and lakes, which can be considered the first operational coastal altimetry mission. Its narrow along-track resolution cell (around 300 m) permits less contaminated measurements to be obtained much closer to the coast than for pulse-limited missions. This finer along-track resolution, combined with the enhanced signal-to-noise ratio, can capture the spatial complexity of the coastal zone much better than what is possible with only pointwise in situ observations.

Coastal altimetry is now an important component of coastal observing systems and has potential to support a wide range of applications, from monitoring storm surges and the rate of sea level change at the coast, to quantifying the natural variability in coastal sea level and sea state, information that can then be assimilated in coastal models to improve predictions and forecasting skills, all contributing to the WCRP Grand Challenge on Regional Sea-Level Change and Coastal Impacts.

The present contribution gives an update of the technical advances, challenges and difficulties, emerging applications, the favourable prospects deriving from a full exploitation of the information in SAR-mode altimetry data and the new generation of instruments using radar interferometry technology (e.g., SWOT).

Extreme sea level in the Danish coastal area as part of a new national climate service

Authors: Steffen M. Olsen, Kristine S. Madsen, Jacob L. Høyer, Jian Su, Torben Schmith, Peter L. Langen

Presenter: Steffen M. Olsen

The regional fingerprints of projected global sea-level rise combined with local changes in winds challenge our present knowledge of extreme storm surges in the Danish coastal area. In a new initiative the Danish Meteorological Institute will investigate changes in the extreme statistics of sea-level in the 21st century. The study will make use of IPCC scenarios RCP4.5 and 8.5 and use RCM simulations to drive a high resolution storm surge model for the North Sea and Baltic Sea area. This will be combined with at thorough evaluation of global sea-level changes and their imprint on the North Western European Shelf Seas.

An authoritative source of quality climate information is important for the Danish Municipalities to ensure coherent and timely adaptation measures. Main priorities of our geographical area are extreme precipitation and storm surges. This new Danish initiative will actively seek cooperation with similar initiatives in our region.

Changes in global extreme sea levels by 2100

Authors: Svetlana Jevrejeva, Michalis I. Vousdoukas, Lorenzo Mentaschi, Evangelos Voukouvalas, Martin Verlaan, Luke P. Jackson, Luc Feyen

Presenter: Svetlana Jevrejeva

Global warming is expected to drive increasing extreme sea levels (ESLs) and flood risk along the world's coastlines. In this work we present probabilistic projections of ESLs for the present century taking into consideration changes in mean sea level (MSL), tides, wind-waves and storm surges. Between the year 2000 and 2100 we project a very likely (90% probability) increase of the global average 100-year ESL of 34-76 cm under a moderate-emission-mitigation-policy scenario, and of 58- 172 cm under a business as usual scenario. For the latter a likely (67% probability) increase of at least 75 cm is projected along the Americas, Australia, South Pacific and South-East Asia. Rising ESLs are mostly driven by thermal expansion, followed by contributions from ice mass-loss from glaciers and ice-sheets in Greenland, and Antarctica. Changes in extreme weather show small contributions in the increase in global ESLs, but leave an important footprint at regional-and-below scales. For example, they contribute to the highest regional ESL increase; projected along the Southern Ocean with a median circa 1 m.

Under both emission scenarios (RCP4.5 and RCP8.5) from 2050 onwards, the intensification in ESLs can render a large part of the tropics exposed annually to the present-day 100-year event. By the end of this century this applies to most coastlines around the world. This implies unprecedented flood risk levels unless timely adaptation measures are taken.

Influence of sea level rise on highest water levels during storm surges in the Ems estuary

Authors: Tabea Brodhagen, Elisabeth Rudolph

Presenter: Tabea Brodhagen

Storm tides in the North Sea represent a major environmental threat. At sea, wind drags water masses towards the coasts, where the water levels may become dangerously high, overwhelm coastal defenses, and inundate low-lying coastal areas. Although recent storm surges may cause new record water levels (e.g. Allerheiligenflut 2006), the new record heights caused no severe damages due to significantly improved coastal protection. Due to the latter, public perception of storm tide vulnerability and risk has decreased in recent years. However, the risk is still present and may further increase in the expected course of anthropogenic climate change.

The project EXTREMENESS aims at identifying extreme events that are highly unlikely but still physically possible and plausible and which may cause extreme damages or have extreme con-sequences (so called “black swan events”). Within EXTREMENESS, conditions which are causing extreme storm surges and bear the potential for further amplification due to climate change will be studied. This is based on high resolution numerical modelling of the German Bight taking plausible future developments such as accelerated sea level rise or an increase in river runoff into account.

It is the task of the BAW within this project to analyze the possibility of further amplification of extreme storm surge events and model the respective water levels within the German estuaries. Within the framework of this project, the influence of the sea level rise and the river runoff on water levels within the Ems estuary is investigated. To do so, a hydrodynamical numerical model of the German Bight including the estuaries of the rivers Ems, Elbe and Weser is used. Several case studies featuring different river runoff scenarios and possible sea level rises are modelled to study their impact on highest water levels during storm surges and to identify areas of impact in the Ems estuary. Furthermore, the influence of applying the sea level rise at different places within the modelled area is investigated, i.e. in one case the sea level rise is applied to the boundary of the North Sea Model that provided boundary water levels for the German Bight model, respectively, and in another case the sea level rise is applied directly to the boundary of the German Bight model.

The results of this investigation will be used to determine the most extreme storm surge events and model their respective water levels which will then be given to another partner within the project. Then, the response of the dike near the region around Emden (Ems) to these extreme water levels will be studied.

Regional variability in the relative importance of surge and wave forecasting around the English coastline

Authors: Thomas Dhoop, Travis Mason

Presenter: Thomas Dhoop

Coastal zones and communities are expected to be increasingly threatened by changing sea-levels, particularly during times of storm surges and high waves which can cause overtopping or overwashing, leading to beach erosion, damage to coastal structures and defences and flooding. Although waves are commonly regarded as significant contributors to extreme sea levels, coastal forecasting and analysis in the UK is arguably still weighted towards the prediction of tidal surges, particularly in view of the notable extreme water levels recorded during the North Sea storm surge event of 31 January 1953 and more recently 5 December 2013.

This poster compares three datasets to bring attention to regional variability in the importance of waves and tides to forecasting efforts:

- The maximum surge measured around the English coastline since 2004 using both the Class A tide gauges and those operated by the Regional Coastal Monitoring Programmes (RCMP);

- The maximum significant wave height measured by the network of shallow water wave buoys operated by RCMP;

- The median duration of extreme waves measured at those same wave buoy sites (Dhoop & Mason 2018).

For the south coast and the southern Celtic Sea, tidal surges exceeding ~ 1 m are uncommon and serious risks to property and life tend to be associated with high wave action spanning High Water as the primary factor, rather than or supplemented by extreme water levels generated by surges. Even along the North Sea coast, wave action can be shown to be of similar importance as extreme water levels, in particularly in light of the long duration of extreme wave events (especially north of the Humber), with high chances of spanning High Water.

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Relocatable storm surge forecasting for predicting extreme sea levels in coastal areas

Author: Thomas Prime

Presenter: Thomas Prime

The marine environment represents a large and important resource for coastal communities around the world. However, the marine environment increasingly presents hazards that can have a large negative impact. One important marine hazard results from storms and their accompanying surges. This can lead to coastal flooding, particularly when surge and astronomical high tides align, with resultant impacts such as destruction of property, saline degradation of agricultural land and coastal erosion.

Where tide and storm surge information are provided and accessed in a timely, accurate and understandable way, the data can be harnessed to feed into an early warning system. Where short term forecasts of storm surge provide early warnings to coastal communities, enabling them to take actions to withstand extreme sea levels that can occur during a storm surge. Examples of actions include deploying flood prevention measures or mobilizing emergency response teams. However, to provide a forecast at high spatial and temporal resolution a dynamic ocean model is used. Over recent decades the National Oceanography Centre has been a world leading in developing coastal ocean models.

In addition to a numerical model, observations from the region are also important to help build confidence and validate any numerical models that are used in an early warning system. To this end ingesting available data regarding sea level height provided from various in-situ observations such as tide gauges and remote observations such as satellite altimetry is very important to ensure the model provides useful information to the coastal communities that will use it.

This presentation will present our progress on a current project to develop an information system for the Madagascan Met Office. The project, C-RISC, being executed in partnership with Sea Level Research Ltd, is translating the current modelling capability of NOC in storm surge forecasting and tidal prediction into a system that will provide information that can be easily transferred to other regions and is scalable to include other hazard types The outcome, an operational high-resolution storm surge warning system that is easy to relocate, will directly benefit coastal communities, giving them information they need to make effective decisions before and during extreme sea level events such as storm surges.

Survival of coastal wetland under rising water levels

Authors: Xiaorong Li, Nicoletta Leonardi, Andy Plater

Presenter: Xiaorong Li

This research will investigate changes in the salinity of brackish wetlands in response to water level increase linked to coastal storms and breaching of the coastal protection system; focus will be given to the exceedance of threshold criteria necessary for local vegetation die-back. The study site of this research is the RSPB Minsmere Nature Reserve, UK, a low-lying coastline characterized by a complex mosaic of reedbeds, sand dunes, drainage systems, and surface ponding. The potential of utilizing continuous and targeted fresh water discharge to mitigate disruption on wetland water salinity and habitat stability will also be investigated.

Sea-level rise and variability in China

Authors: Ying Qu, Svetlana Jevrejeva, John Moore

Presenter: Ying Qu

In this study we analyze the sea-level rise and variability along the Chinese coast using 26 tide gauge records since 1950s. The main difficulties to estimate sea level rise for the period since 1950 is a lack of information about the vertical land movement at the location of tide gauges. In our study the vertical land movement is estimated from the difference between tide gauge records and satellite altimetry. The results show that for many tide gauge location (mainly cities) there is a large subsidence due to the groundwater extraction. Variability in tide gauge records is mainly due to seasonal cycle, link to ENSO and local changes. For each tide gauge record we estimate sea level budget and identify the main source for sea level rise along the Chinese coast. Sea-level rise for future scenarios are also studied here, it is found that steric effects is the main contributor for both RCP4.5 and RCP8.5 scenarios at all probabilities except at 95% probability for RCP8.5, when Antarctic ice sheet makes the greatest contribution for all stations in China.

Future Sea Level Projections over the Seas around Korea peninsular

Authors: Kyung-On Boo, Young-Hwa Byun

Presenter: Youngmi Kim

Increases of carbon dioxide concentration in atmosphere has not only raised the global mean temperature but also caused ocean warming. Rising sea level caused by ocean warming will have a negative impact on the lives of millions of people living in coastal zones. Regional sea level changes differs from region to region (IPCC AR5). The Korean peninsula is surrounded by the sea on three sides, and there are many people living in coastal region. Tide-gauge data in Korean coastal shows quickly rising sea level in recent decade. This study analyzed observed and projected sea level changes over the Korean peninsula at three coastal regions based on CSIRO and icdc.zmaw.de. Commonwealth Scientific and Industrial Research Organization (CSIRO) data in 23 years shows that mean rate of sea level changes over the Korean peninsula is similar to global mean and interannual variability is greater than the global mean. The mean rate of sea level changes around the Yellow Sea is high relative to the other coastal seas. At the end of 21st century, sea level changes over the Korean peninsula are projected to rise 37.8, 48.1, 47.7, 65.0 cm under RCP2.6, RCP4.5, RCP6.0 and RCP8.5 scenario, respectively. The results exhibit similar tendency with the global mean sea level rise with small difference. The southern sea of Korea is expected to rise larger than the other coastal seas.