ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

1st NATIONAL WORKSHOP ON CLIMATE CHANGE AND SEA LEVEL RISE IN THE MEDITERRANEAN SEA

Rome, 5-6 july 2018 - ENEA, Lungotevere Thaon di Revel, 76

COMPENDIUM OF ABSTRACTS

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INDEX

Session IV : Sea level change and Coastal zone management

Climate Changes and Maritime Spatial Planning: a challenge in the challenge
Andrea Barbanti

Analysis of long-term sea level variation in the North Adriatic Sea and Seasonality
Sara Morucci, Franco Crosato, Marco Cordella, Maurizio Ferla, Antonio Rusconi

Sea-level changes in the Adriatic from tide-gauge data
Fabio Raicich

Assessing the impact of climate change in Italian coastal areas: tools and methods of risk and vulnerability assessment.
Silvia Torresan, Elisa Furlan, Petra dalla Pozza, Diana Derepasko, Andrea Critto, Melania Michetti, Mattia Amadio, Jaroslav Mysiak, Antonio Marcomini

Sea storm risk in Emilia-Romagna and future scenarios
Luisa Perini, Lorenzo Calabrese, Paolo Luciani

Coastal risk: strategic decision making for sustainable development
Barbara Zanuttigh

Sea level rise, coastal hazard and people awareness in the Mediterranean: new insights from the SAVEMEDCOASTS project
Marco Anzidei and SAVEMEDCOASTS Team

Dune reconstruction on rapidly eroding coasts as a tool of counteract impact of storms in a changed sea-levels scenario
Paolo Ciavola, Tomas Fernandez-Montblanc, Enrico Duo

Multidisciplinary assessment and prediction tools addressing coastal vulnerability to erosion and sea level rise. Lessons learnt from the RITMARE Project
Davide Bonaldo and RITMARE Team

Sea-level rise and potential drowning of the Italian coastal plains: flooding risk scenarios for 2100
Valeria Lo Presti, RITMARE 1 team, RITMARE 2 team, CLIMTOUR-COPERNICUS team

Coastal change drivers in the Mediterranean Sea: waves, storm surges, sea level rise and their interactions with the morphology and the use of the coastline
Piero Lionello

Poster

A Wavelet Analysis of sea level height in the Gulf of Naples (2002-2017): preliminary results
Berardino Buonocore, Vincenzo Capozzi, Giovanni Zambardino, Giorgio Budillon

Sea Level Rising: Perspectives from an Expanding Globe
Giancarlo Scalera

Sand dunes and marine litter: fragile ecosystems to preserve from pollution for the challenge of rising sea level
Federica Tommasi

Sea-level jumps during Early Holocene in Adriatic: evidence and open questions

ALESSANDRO FONTANA, LIVIO RONCHI

University of Padova – Department of Geosciences
Via Gradenigo 6, 35131, Padova, Italy
alessandro.fontana@unipd.it, livio.ronchi@gmail.com

ANNAMARIA CORREGGIARI

CNR-ISMAR Institute of Marine Sciences in Bologna
Via Gobetti 101, 40129, Bologna, Italy
anna.correggiari@bo.ismar.cnr.it

STEFANO FURLANI

University of Trieste - Department of Mathematics and Geosciences
Via Weiss 2, 34128, Trieste, Italy
Stefano.furlani@units.it

MLADEN JURAČIĆ, IGOR FELJA

University of Zagreb - Faculty of Science, Department of Geology
Horvatovac 102a, 10000, Zagreb, Croatia
mjuracic@geol.pmf.hr, igorfelja@geol.pmf.hr

In the last years strong efforts have been done by the scientific community to reconstruct the post-LGM transgression and describe it through geophysical models that could match with the observed field data. Notwithstanding, the eustatic curve is still largely unconstrained before 8 ka BP because of the few available data. Northern Adriatic is one of the very few places in the Mediterranean Basin where the sea-level variations occurred between Lateglacial and Early Holocene are recorded. These changes are documented by sediments and landforms, thanks to the gentle slope of the continental shelf and the occurrence of lagoon and paralic environments, which are strongly sensitive even to subtle variations of the sea level. This research considered the large database of CHIRP-Sonar profiles and stratigraphic cores collected by CNR-ISMAR of Bologna, especially through the oceanographic missions carried out on-board of the research vessel Urania.

A major issue is the recognition and characterization of the periods of rapid increase of the sea level, which punctuated some phases during the Lateglacial and the first part of Holocene, which caused the abrupt submersion of large sectors of the coast.

In the study area the remnants of a large barrier-island system formed during Younger Dryas and drowned in place soon after are present. Moreover, important information about a sea-level jump occurred around 9.5-9.2 ka BP have been recently documented in the deltaic plain of Po River and in the submerged shelf. This phase of transgression led the Adriatic to enter in the Gulf of Trieste, dramatically transforming the area between Istria and the coast of Friuli.

Some key questions, still partly unsolved, are related to the main indexes allowing the identifications of sea-level jumps and the possible occurrence of sea-level stillstands or the apparent decrease of the marine rise because of the increase in sediment supply.

Keywords: transgressive deposits, lagoon environments, submarine landforms

New altimetric data in the Mediterranean sea: from MIS 5.5 fossil-tidal notches to the Roman age fishtanks

FABRIZIO ANTONIOLI , FOSSIL TIDAL NOTCH GROUP AND FISHTANK GROUP

ENEA, Centro Ricerche Casaccia – Laboratorio Modellistica Climatica e Impatti
via Anguillarese 301, 00123 Rome, Italy
fabrizio.antonioli@enea.it

We investigated MIS 5.5 fossil tidal notches located in tectonically stable coasts of the central Mediterranean. In these stable areas, the elevation of the base of the MIS 5.5 notch ranges from 2.09 to 12.48 m, with a mean of 5.7 m. Such variability, although limited, indicates that small land movements, deriving from slow crustal processes, may have occurred in stable areas. This elevation has been compared against glacial isostatic adjustment (GIA) predictions drawn from a suite of ice-sheet models (ICE-G5, ICE-G6 and ANICE-SELEN) that are used in combination with the same solid Earth model and mantle viscosity parameters. Results indicate that the GIA signal is not the main cause of the observed highstand variability and that other mechanisms are needed. The GIA simulations show that, even within the Mediterranean Basin, the maximum highstand is reached at different times according to the geographical location. Our work shows that, besides GIA, even in areas considered tectonically stable, additional vertical tectonic movements may occur with a magnitude that is significantly larger than the GIA. Following the pioneering work of Schmiedt on establishing the level of the Tyrrhenian Sea in Antiquity, a number of studies have examined this evidence from Roman Period fish tanks but with significantly different outcomes due primarily to different interpretations of the functional level of these pools at the time of their construction. As part of a longer-term project to understand the causes of sea level change around the Italian coast we have re-examined and resurveyed 30 well-documented fish tanks, all based on the same construction principles, in Mediterranena sea for which it can be established that they were in open contact with the sea at the time of operation. The structural features that tidally control the exchange of water used to define the ancient local sea level are identified as the channel thresholds, the sluice gate and sliding post positions, and the lowest-level crepido. These are consistent for all the tanks examined, permitting the local sea level change over the past 2000 years to be established at each location with a precision of ±20 cm and against which other coastal archaeological features can be calibrated. We conclude that published local sea levels that are based on the present-day elevations of the foundations of protective walls constructed around the tanks and lie ~50 cm above our inferred levels are inconsistent with the successful functioning of the water exchange and have to be rejected The individual estimates for the observed local sea levels (in Tyrrhenian sea) rangefrom -0.9 to -1.5m with a mean value of -1.22±0.20 m indicating that the spatial variability of the local levels is small, consistent with model-inferences of the glacio-isostatic process that indicate near-constant contributions for this section of coast and with tectonic inference from the elevations of the Last Interglacial shoreline.

FOSSIL TIDAL NOTCH GROUP: ANTONIOLI F. [1], FERRANTI L. [2], STOCCHI P. [3], DEIANA G. [4], LO PRESTI V. [1], FURLANI S. [5], MARINO C. [2] · ORRU P. [4] SCICCHITANO G. [6], TRAINITO E. [7], ANZIDEI M. [8], BONAMINI M. [9], SANSÒ P. [10], MASTRONUZZI G. [11]

[1] *ENEA, Laboratory Climate Modelling and Impacts, Roma, Italy.*
[2] *Dipartimento di Scienze della Terra, delle Risorse e dell'Ambiente, Università Federico II, Napoli, Italy.*
[3] *NIOZ - Royal Netherlands Institute for Sea Research, Department of Coastal Systems (TX), and Utrecht University, P.O. Box 59, 1790 AB, Den Burg, Texel, The Netherlands.*
[4] *Dipartimento di Scienze Chimiche e Geologiche - Università degli Studi di Cagliari, Italy.*
[5] *Department of Mathematics and Geosciences, University of Trieste, Italy.*
[6] *Studio Geologi Associati T.S.T. Misterbianco, Catania Italy.*
[7] *Villaggio i Fari, Loiri Porto San Paolo, Italy.*
[8] *Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy.*
[9] *Marco Bonamini Palermo via Trinacria 4, Palermo, Italy*
[10] *Dipartimento di Scienze e Tecnologie Biologiche e Ambientali, Università del Salento Ecotekne, Lecce, Italy.*
[11] *Dipartimento di Scienze della Terra e Geoambientali, Università degli Studi di Bari "Aldo Moro", Bari, Italy*

FISHTANK GROUP: KURT LAMBECK [1], MARCO ANZIDEI [2], FABRIZIO ANTONIOLI [3], ALESSANDRA BENINI [4], STEFANO FURLANI [5]

[1] *Research School of Earth Sciences, The Australian National University, Canberra 0200, Australia*
[2] *Istituto Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata 605, 00143 Rome, Italy*
[3] *ENEA, via Anguillarese 301, S. Maria di Galeria,*
[4] *Archeologist, Roma, Italy*
[5] *Department of Mathematics and Geosciences, University of Trieste, Italy*

The Geoswim approach: a tool for studying sea level changes on rocky coasts

STEFANO FURLANI, VALERIA VACCHER, SARA BIOLCHI

Department of Mathematics and Geosciences, University of Trieste
Via Weiss 2, 34128, Trieste, Italy
sfurlani@units.it, valeria.vaccher@gmail.com, sbiolchi@gmail.com

FABRIZIO ANTONIOLI

ENEA – Centro Ricerche Casaccia – Laboratorio Modellistica CLimatica e Impatti
Via Anguillarese 301, 00123, Rome, Italy
fabrizio.antonioli@enea.it

We present and discuss the recent advances in scientific swim-surveys applied to the studies regarding sea level changes in the Mediterranean area. Data were collected in several campaigns between 2012 and 2017 along a route of 544 km carried out within the Geoswim program.
The availability of very detailed remote data both in the subaerial and underwater environment, such as respectively LiDAR and Multibeam data, cannot satisfactorily contribute to describe the intertidal zone, its peculiar landforms, such as tidal notches, its biological zonation, and the horizontal variations of these parameters. The high slope of sea cliffs and the occurrence of the water interface between the sea and the air prevent the acquisition of remote data, making swimming a potentially useful approach for photogrammetric surveys, visual observations and rough measures of morphometric data.
The swim survey method, here described, allow detailed geomorphological, biological, and hydrogeological observations. These data can be used for several aims, including the studies on sea level changes. Regarding the first two parameters, the method allows rough observations and image acquisitions of morphological and ecological horizontal variability along wide sectors of rocky coasts. The latter are tightly localized in time, or the surveying time, but wide in space, or the whole coastal perimeter of surveying.
This Geoswim approach allows to collect large amount of geomorphological, biological and hydrological data along rocky coasts in sheltered basins, mainly from the tidal zone. Data collected can be improved by rough field observations, or subsequent detailed observations. The field campaigns give the chance to produce large database of landforms and other parameters, such as sea caves, tidal notches, etc.
Published and new results from field data collected during the swimming expeditions are discussed with the aim of illustrating data collected along wide sectors of rocky coasts, with particular attention to the tidal zone.

Keywords: Sea level markers, coastal geomorphology, swim surveys, Mediterranean

Expanding the western Mediterranean Holocene relative sea-level records: new data from Balearic, Corsica and Sardinia Islands

MATTEO VACCHI

Geography, College of Life and Environmental Sciences (University of Exeter)
EX4 4RJ, Exeter, UK
matteo.vacchi@gmail.com

Our understanding of current rates of sea-level rise from tide gauges or satellite data requires correction for Glacio and hydro-Isostatic Adjustment (GIA) effects that can be quantified using observations of former Holocene (i.e. the last 12.0 ka BP) relative sea-levels (RSL).
According to published geophysical models, GIA-related deformation in the Western Mediterranean is mainly controlled by water loading, which has resulted in widespread subsidence throughout much of the basin. Balearic, Corsica and Sardinia Islands are located in the middle of the western Mediterranean basin, where GIA models predict a maximum isostatic contribution. However, the RSL records in these regions were poor (Corsica and Baleares) or mainly restricted to the late-Holocene (Sardinia). In order to expand the spatio-temporal RSL reconstructions in these coastal sectors, a series of new cores in salt-marshes and brackish lagoons was performed in these Islands.
The newly produced RSL record, based on 90 radiocarbon dates, has engendered a significant improvement in the assessment of the RSL histories of the Western Mediterranean. The isostatic pattern defined from newly assembled records shows significant discrepancy with respect to those predicted by the available GIA models. In particular, the new data outline a non-coherent isostatic response of the central portion of the western Mediterranean, with the Balearic Islands manifesting significant departures from the RSL evolution recorded in Corsica, Sardinia and, more generally, along most of the western European Mediterranean coast. These data provide then new insights on the on-going GIA-related vertical motions which represent a key parameter to better assess any possible post-industrial acceleration in RSL rise and to define future scenarios of coastal inundation in the context of global change.

Keywords: GIA, Western Mediterranean

Sea level rise in the Adriatic Sea and its impact on the Venice Lagoon

DEBORA BELLAFIORE, GEORG UMGIESSER [1], [2], MARCO BAJO, CHRISTIAN FERRARIN, FRANCESCA DE PASCALIS, MICHOL GHEZZO

[1] CNR-ISMAR (National Research Council – Institute of Marine Sciences)
Castello 2737/F, Venice, Italy
debora.bellafiore@ismar.cnr.it, georg.umgiesser@ismar.cnr.it, marco.bajo@ismar.cnr.it, c.ferrarin@ismar.cnr.it, francesca.depascalis@ve.ismar.cnr.it, michol.ghezzo@ve.ismar.cnr.it

[2] Marine Research Institute, Klaipeda University
H. Manto 84, Klaipeda, Lithuania
georg.umgiesser@ismar.cnr.it

The Northern Adriatic Sea experiences frequent storm surges, due to its shape, bathymetry, the bordering orography and the wind climate. While the whole coast is affected, the international attention is focused on the consequent flooding of Venice, due to its historical and artistic relevance. With a spring tidal excursion of around one meter any positive variation of the undisturbed sea level creates the conditions for a flooding. Granted that the possibility of a severe flooding existed also in the past (order of 100 years), the situation has worsened mainly because of the sinking of the town, due to natural (3 cm) and anthropogenic (9 cm) subsidence in the 20th century, and the sea level rise (SLR, estimated in the 20th century at 11-13 cm , Tsimplis et al., 2011).
In the last years the works for the mobile barriers have been started that should protect the city of Venice from flooding. Their planned closure at a safeguarding level of 110 cm would have led to around 10-20 closing per year in the last years. A precise water level forecast will be crucial for the correct operation of the mobile barriers. With the new estimates of SLR, this closing frequency will change, reaching a number of closures between 300 and 400 per year, with a SRL of 50 cm (Umgiesser and Matticchio, 2006).
Climate change strongly affects coastal areas and the status of transitional areas like lagoons. In a comparison study of the response of 10 Mediterranean lagoons to climate change by means of numerical models, our results suggest that Mediterranean lagoons amplify the salinity and temperature changes expected for the open sea and there will be a general loss of intra-lagoon and inter-lagoon variability of their physical properties. Therefore, climate change would lead to a homogenization of the physical characteristics with a tendency toward marinization and a subsequent loss of "hydrodiversity" for the Mediterranean lagoons.
The Venice Lagoon's saltmarshes will be affected as well by this increase in salinity and sea level, with a general decrease of these areas, up to a total extinction for the most extreme scenario. Modeling results showed how in saltmarshes the halophyte more resilient to these changes (Salicornia veneta) would be the only one present in the future. The presence of mobile barriers, would just delay the extinction of some species to a later date.

Keywords: transitional environment, finite element modeling, SLR effects

Isostatic contributions to present and future sea level in the Mediterranean Sea

GIORGIO SPADA, GAIA GALASSI

Dipartimento di Scienze Pure e Applicate (DiSPEa)
Università di Urbino
Via Santa Chiara 27
giorgio.spada@uniurb.it, gaia.galassi@gmail.com

Glacial Isostatic Adjustment (GIA) is affecting significantly the sea-level variations across the Mediterranean Sea, and is also a major cause of regional subsidence on millennium and century time scales. Indeed, GIA stems from the combination of various contributions reflecting physical interactions between solid Earth, the cryosphere and the oceans, associated with deformational, gravitational and rotational effects acting in different ways at different wavelengths. Local and global contribution from the evolving cryosphere are both important across the Mediterranean Sea; similarly hydro and glacio isostasy are of comparable amplitude at some locations. The multi scale and temporally variable manifestations of GIA is described by the so-called "Sea Level Equation" first introduced in geophysical modelling by Farrell and Clark in the seventies. In my talk I shall mainly focus on the regional pattern of the GIA "fingerprints" for relative sea-level, absolute sea level and vertical displacement across the Mediterranean Sea, which are characterised by a peculiar geometry and a distinctly different pattern compared to that observed in the polar regions that were deeply covered by ice at the Last Glacial Maximum ~21,000 years ago. The contribution to GIA associated with the melting of past ice sheets shows maximum rates in the bulk of the basin; at the same time, the rate of absolute sea-level change is fairly uniform across the basin, and a spatially variable subsidence is strongly anti-correlated with relative sea-level change. A completely different geometry is expected for the contributions to GIA from the future melting of the continental ice sheets according to various IPCC scenarios.

Keywords: Glacial Isostatic Adjustment, Sea Level Change, Mediterranean Sea.

Future sea level estimates for the Mediterranean Sea: ocean circulation contribution

GIANMARIA SANNINO, FABRIZIO ANTONIOLI , ADRIANA CARILLO, GIOVANNA PISACANE, MARIA VITTORIA STRUGLIA

ENEA – Centro Ricerche Casaccia – Laboratorio Modellistica CLimatica e Impatti
Via Anguillarese 301, 00123, Rome, Italy
gianmaria.sannino@enea.it, fabrizio.antonioli@enea.it, adriana.carillo@enea.it, giovanna.pisacane@enea.it, mariavittoria.struglia@enea.it

GAIA GALASSI , GIORGIO SPADA

Dipartimento di Scienze Pure e Applicate (DiSPEa) - Università di Urbino
Via Santa Chiara 27
giorgio.spada@uniurb.it, gaia.galassi@gmail.com

PAOLA MALANOTTE-RIZZOLI

Department of Earth, Atmospheric and Planetary Sciences - Massachusetts Institute of Technology
77 Massachusetts Avenue, 54-1416, Cambridge, MA 02139
rizzoli@mit.edu

Climate change-induced variations in local sea level are expected to expose coastal areas to increased risks of flooding and erosion, threatening the health and wellbeing of inhabitants and damaging coastal ecosystems. Predicting relative sea level rise at the local level is a complex task, as such process is the result of a variety of interacting factors occurring on a wide range of scales. Furthermore, actual impacts on coastal areas crucially depend on the occasional superposition of long-period trends, transitory fluctuations or exceptional extreme events, whose frequency and relative contribution are hard to project under muted climate conditions. The Mediterranean Sea is expected to be particularly vulnerable to future sea level rise, also in view of the high population density along its coasts. Its geography and physical characteristics demand specific treatment of local, high-resolution features, while its connection with the Atlantic Ocean correlate local responses to the global scale. Future sea levels in the Mediterranean Sea are affected by long-term vertical tectonic movement, glacial isostatic adjustment (GIA) and by the elastic contribution of present melting (PM) of ice sheets, glaciers and ice caps. In addition, rising water temperatures and altered salinity are expected to induce steric variations in water volumes, a major component of sea level projections in the Mediterranean. In this work, GIA and PM have been modelled numerically by an updated version of the code SELEN, accounting for rotational feedbacks on sea level, migration of shorelines and time variations of the ocean function. The information needed to compute the high-resolution steric component is provided by the regional ocean model MedMIT16 (MITgcm at 1/16° resolution, with 1/200° resolution at Gibraltar, and explicitly accounting for tides). The regional impact of the incoming Atlantic flow through the Gibraltar Strait is also accounted for. An ensemble of MedMIT16 simulations has been created by driving the ocean model with the state-of-the-art regional atmospheric climate scenarios available through the EURO-CORDEX Program, and by imposing the lateral boundary conditions derived from the corresponding CMIP5 global scenario.

Keywords: ocean circulation, GIA, ice melt

Sea Level change and regional budget of the Mediterranean Sea from space observations

FENOGLIO LUCIANA

Institute of geodesy and Geo information (University of Bonn)
Nussallee, Bonn, Germany
fenoglio@geod.uni-bonn.de

Satellite altimetry measures the total sea level since 1993. The altimeter total sea level can be compared locally to tide gauge records corrected for the vertical motion of the Earth crust and to ocean models, provided that the model includes all components of sea level variability within a realistic error bar. Skills of ocean models are improved by assimilation of altimeter data.
Satellite gravity mission and ARGO floats measure the part of sea level change due to changes in mass and in volume. The interval 2002-2017 is the longest time span where space-based measurements from altimetry, GRACE and ARGO are simultaneously available. Although gravimetry data provide valuable constraints on mass driven sea surface height changes, these data are rarely assimilated in ocean simulations and reanalysis runs.
One crucial challenge for the ocean models are the unrealistic boundary conditions at the Gibraltar and Dardanelli and Bosphorus straits and the uncertainties in the air-sea freshwater fluxes and river-runoff, which are often related to the inability of the model to represent geometry and circulation of the strait. Challenge for the satellite observations is the small dimension of the basins and the contamination by land effects in the mass change observed from satellite. The evaluation of ocean model simulations and reanalysis using geodetic data remains challenging, particularly in semi-enclosed ocean basins, due to model assumptions and limitation of satellite-based data in coastal zone.
Both satellite altimetry and gravimetry are important component of the ocean observing system and provide new data sets to study the sea level budget and improve the skill of ocean models. This study derives sea level trends in the Mediterranean Sea and in the Black Sea from the various observables and from regional ocean models. For each component of the sea level budget equation we discuss associated errors and provides trend estimates for the two periods 1993-2015 and 2002-2015.
The Mediterranean Sea ocean models differ mostly in annual amplitude and in the halosteric trend. The basin averaged trend of altimetry, 2.2 +/- 0.5 mm/yr in the interval 1993-2016, compares well with the trend of elevation plus thermo-steric sea level component for three ocean simulation and reanalysis. Instead, the accounting for the halosteric trend introduces large difference between model and observations. In the Black Sea, the trend of thermo-steric component is small over 1993-2016 (0.45 ± 0.01 mm/yr) and the halosteric component highly inaccurate, due to model freshwater forcing and scarcity of salinity data. We further address the basin averaged sea level budget derived from the various data and models.

Keywords: satellite altimetry, satellite gravimetry, sea level change

The contribution of crustal vertical movements to relative sea-level rise: the case of Lipari (Aeolian Islands, Southern Tyrrhenian Sea)

CLAUDIA ROMAGNOLI

Università di Bologna (Dip. Scienze Biologiche, Geologiche e Ambientali)
P.zza Porta S. Donato 1, Bologna, Italy
claudia.romagnoli@unibo.it

DANIELE CASALBORE , FRANCESCO LATINO CHIOCCI

Università di Roma "Sapienza" (Dip. Scienze della Terra)
P.le Aldo Moro 5, Roma, Italy
daniele.casalbore@uniroma1.it, francesco.chiocci@uniroma1.it

MARCO ANZIDEI

Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Roma 1, Italy,
Via di Vigna Murata 605, Roma, Italy
marco.anzidei@ingv.it

ALESSANDRO BOSMAN

IGAG-CNR, Istituto di Geologia Ambientale e Geoingegneria, Area della Ricerca di Roma 1
Via Salaria Km 29,300, Monterotondo Stazione, Roma, Italy
alessandro.bosman@cnr.it

Relative sea-level changes include the contributions from various processes interacting at different spatial and temporal scales. The determination of their relative role and rate is the base for a correct understanding of the current trends in sea level. In the Mediterranean, due to active tectonics displacing the coastal tracts, the crustal component to relative sea-level plays a crucial role. This is particularly evident in volcanic areas, where alternating, opposite vertical displacements commonly occur.
Geological researches carried out in the central sector of the Aeolian Arc (Southern Tyrrhenian Sea) allowed to recognize geological paleo-sea level markers both on the emerged and submerged flanks of the islands, indicating the occurrence of alternating, opposite vertical movements acting at different temporal scales, from the Late Quaternary to the present-day. At Lipari, while raised marine terraces witness a long-term uplift active in the last 125 ka, a localized submergence trend appears to affect some sectors of the eastern coast, where most of the historical settlements are located. Here the partial drowning of buildings and docks over the last century indicates a fast rise in the relative sea-level, which is probably related to local neo- and/or volcano-tectonic processes. Based on GPS data and the finding of presently submerged archeological remains, a subsidence rate of 6 mm per year if averaged at the last two millennia and up to 10 mm per year in the last decades/centuries, has been estimated for the eastern part of Lipari, with significant implication for the potential flooding of these coastal areas, also exposed to sea-level rise due to climate change. Anthropogenic effects overlap on natural coastal dynamics in reducing the sediment input to the eastern Lipari coast, as evidenced by the beach retreat. Furthermore, the eastern Lipari submarine flank is affected by several canyons, whose headwall cut back up to 5 meters water depth, few tens of meters far from the coast. Because of the proximity of these canyon heads to the coast, the potential hazard related to retrogressive (landward) erosion processes and to mass-wasting is also very high in this coastal area, being the most anthrophized and touristically exploited part of the island.

Keywords: relative sea level rise, coastal flooding, subsidence

The interplay between driving geodynamic processes, coastal tectonics and sea-level changes at different space and time scales in Italy

LUIGI FERRANTI

DiSTAR - Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse
Università di Napoli "Federico II"
Complesso Universitario Monte Sant'Angelo, Via Cinzia 21, 80126 Napoli.
lferrant@unina.it

Vertical tectonic displacements in Italy at the last 125 to 1 kyr are drawn from relative sea-level (RSL) history studies at coastal or shelf sites. Our review of the extensive work carried out since long at these sites aims at establishing the appropriate spatial extent, rate and duration of vertical tectonic motion within individual crustal segments. In addition, we seek to placing constraints on the contribution to displacements coming from regional (deep) and local (shallow-crustal) sources. Analysis reveals that the central and northern Tyrrhenian Sea and the Ligurian Sea margins show stability at the 101 to the 105 timescale, except for subsidence in coastal basins and uplift at fault-controlled coasts and at volcanic provinces. In volcanic areas such as the Phlegrean Fields, vertical tectonic rates are one order of magnitude higher than in tectonically controlled areas. The sustained, large magnitude uplift of Calabria and northeastern Sicily embeds a deep-seated contribution, highlighted by the spatial coincidence of the uplifting province with a NW-subducted lithospheric slab, and a contribution from local faults and folds. Holocene uplift was higher than uplift recorded by Middle-Late Pleistocene markers, and the rate of change tuned among all coastal sites. The recent increase in uplift rate, detected also in the instrumental record, relates to clustering of fault strain release, possibly triggered by the isostatic response to deglaciation. A weak deformation signal is recorded on the central Adriatic coastline, and may record slow Apennines thrust belt migration. In the northern Adriatic Sea, vertical tectonic motions result from opposite displacements in the Southern Alps, internal Dinarids and Northern Apennines, but flexure of the Adriatic (micro-)plate beneath the Northern Apennines appears the dominating contributor. Here, rate and spatial extent of displacements are steady over different time-scales, highlighting the control exercised by the Adriatic slab retreat and sinking.

Keywords: Coastal deformation, RSL changes, Italy

Holocene RSL changes based on using high-resolution seismic profiles in a sector of fast vertical ground deformation: the offshore Campi Flegrei resurgent caldera in the Pozzuoli Bay.

CAMILLA MARINO , LUIGI FERRANTI , JACOPO NATALE

Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse (DISTAR), Università degli Studi di Napoli "Federico II", Napoli, Italy.
Via Cupa Nuova Cintia 26, (80126), Napoli, Italy
camillamarino9@gmail.com ; lferrant@unina.it ; jacopoknatale@gmail.com

MARCO SACCHI, FLAVIA MOLISSO

Istituto per l'Ambiente Marino Costiero (IAMC), Consiglio Nazionale delle Ricerche (CNR), Napoli, Italy
Calata Porta di Massa, (80133), Napoli, Italy
marco.sacchi@iamc.cnr.it ; flavia.molisso@iamc.cnr.it

A new seismic stratigraphic analysis of very high-resolution single-channel reflection seismic profiles provided insights into the last ~10 ka vertical deformation pattern in the submerged part of the Campi Flegrei resurgent caldera, off the Pozzuoli Bay. The collapse of the central part of the Campi Flegrei is associated with the eruption of the Neapolitan Yellow Tuff (NYT) at ~15 ka BP and was followed by discrete phases of intra-caldera volcanic activity and resurgence. Only in recent years the southern part of the caldera, presently submerged off the Pozzuoli Bay, has been explored using marine geophysical data. Interpretation of the high-resolution seismic reflection dataset acquired during the Cruise SEISTEC_2013, calibrated by marine gravity cores, allowed us to identify key horizons between the 1538 AD M. Nuovo and the ~3.9 ka Capo Miseno eruption. Chronostratigraphy of the older part of the caldera infill was inferred through tentative correlation with the most significant known eruptive events.
In addition to this intense volcano-tectonic events, the depositional environment has also been significantly affected by sea-level variations. Seismic stratigraphic interpretation reveals the occurrence during the last ~10 ka of at least four generations of Prograding Wedges that were likely associated with corresponding periods of relative sea-level stands and volcanological known epochs.
Correction of the observed depth of each sea-level indicator for the paleo-bathymetric estimate and for the glacio-isostatic sea-level change occurred since its formation, allowed to reconstruct differential RSL curves for the western, central and eastern sector.
Preliminary results indicate that the periods of relative sea-level and accommodation space stability were attained when uplift occurred at a rate comparable to the rate of sea-level rise allowing the onset of retrograding or prograding wedges. These periods ostensibly correspond to known different phases of volcanic unrest, suggesting that, not only volcanism but also ground deformation were temporally clustered. Furthermore, when resurgence-related uplift exceeded the rate of sea-level rise, erosional surfaces developed. At the end of an unrest, a prograding/aggrading wedge phase prevails. Subsidence occurs during periods of volcanic quiescence and a pure aggrading phase takes place.

Keywords: RSL, Volcanic unrest episodes, Pozzuoli Bay, Sea-floor deformation, High-resolution seismic profiles

Climate Changes and Maritime Spatial Planning: a challenge in the challenge

ANDREA BARBANTI

CNR-ISMAR
Arsenale, Tesa 104 - Castello 2737/F - 30122 Venice – Italy
andrea.barbanti@ismar.cnr.it

Maritime Spatial Planning (MSP) is a practical way to create and establish a more rational organization of the use of marine space and the interactions between its uses, to balance demands for development with the need to protect marine ecosystems, and to achieve social and economic objectives in an open and planned way (Ehler & Douvere, 2009). As such, MSP is a key enabling factor for a sustainable development of sea economy (OECD, 2016; UNESCO-IOC/EC-DG MARE, 2016).
EU Directive 2014/89/EU "establishes a framework for maritime spatial planning aimed at promoting the sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources". In its premises, the MSP Directive clearly states and shows how MSP will contribute, inter alia, to achieving the aims of many other Directives, therefore highlighting the strong need for coordination and harmonization among policies and legislation. Each Member State shall establish and implement maritime spatial planning in its marine waters (sensu MSFD) by 2021, taking into account land-sea interaction (i.e. coordination between MSP and ICZM), organizing and sharing the use of the best available data necessary for maritime spatial plans, trans-boundary cooperating among Member States and with Third Countries, establishing public participation processes and ensuring the cooperation between national authorities and stakeholders. In order to promote the sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources, maritime spatial planning should apply an ecosystem-based approach as referred to in Article 1(3) of Directive 2008/56/EC.
Italy adopted the EU Directive on MSP through the Legislative Decree n. 201 of the 17 October 2016. This Decree foresees to adopt maritime spatial plans within the marine waters and seabed on which Italy has jurisdiction by December 2020. The preparation of the maritime spatial plans will offer the opportunity to Italy, as to all other Mediterranean countries, to rethink and improve its strategy on sea economy, as sectoral and as integrated strategies, encouraging multi-purpose uses, and to develop a vision for the future.
Directive 2014/89/EU recognizes the need that planning processes take into consideration long-term changes due to climate change and resilience to climate change impacts.
A synthetic conceptualization and some examples of the interaction between the planning process and climate change effects on sea uses will be presented. Moreover, examples on how these interactions are being taken into account explicitly or implicitly in different countries will be shown.
Finally, some discussion points will be raised, highlighting key factors and perspectives for the MSP implementation process and its linkages with climate change.

Analysis of long-term sea level variation in the North Adriatic Sea and Seasonality

SARA MORUCCI, FRANCO CROSATO, MARCO CORDELLA, MAURIZIO FERLA

Italian National Institute for Environmental Protection and Research (ISPRA)
Via Vitaliano Brancati, 48, Rome, Italy
sara.morucci@isprambiente.it, franco.crosato@isprambiente.it, marco.cordella@isprambiente.it, maurizio.ferla@isprambiente.it

ANTONIO RUSCONI

Venice International University IUAV
Venice, Italy
arusconi@iuav.it

In order to investigate mean sea level variations in the North Adriatic Sea the almost secular time series of sea level recorded at Venice (ISPRA) and Trieste (CNR) have been considered. To deeply investigate the phenomenon inside the Venice lagoon, the statistical method has also been applied to sea level data recorded at Chioggia, Burano, Porto Caleri and Grado; these tide gauges belong to the Sea Level Measurement Network in the North Adriatic Sea (RMLV), managed by ISPRA. The STL method (Seasonal Trend decomposition using Loess) has been applied to carry out the analysis. This is one of the most advanced statistical methods, widely used to decompose a signal in its components such as periodic one and trend and it is based on the locally weighted regression smoothing technique (Loess). Consecutive applications of the Loess smoother with different moving windows allow the separation of different frequencies present in the time series such as seasonality (St), trend (Tt), and residuals (Rt).

$$Yt = Tt + St + Rt$$

The trend component consists of the underlying long-term aperiodic rises in sea level over time. The results highlight a sea level rise during the last 92 years (1924-2015) and show the growth rate behaviour in Venice and Trieste. The growth rate in Venice, higher than in Trieste, could be related with a local effect of subsidence also due to strong groundwater extractions for industrial purposes in the area of Marghera harbour.
Different locations show similar behaviours, and even though the reason is still an open matter of investigation, the findings are consistent with a global sea level rise associated with climate changes.
In order to achieve more explications of possible climate changes impact on sea level variation, seasonal analysis have been carried out and an 'indicator' of seasonal variability has been defined. First of all the annual mean value of each season has been evaluated, hence a moving average (11 years moving window) has been applied to smooth the seasonal trend.
These results show a strong mean sea level variation and a seasonality changing over the whole period of investigation, probably due to climate changes effects, and lead to a further investigation as concerning the assessment and the management of flood risks (Directive 2007/60/EC) as well as to manage the protection at lagoon inlets.

Keywords: Mean Sea Level Variation, Climate Changes, North Adriatic Sea

Sea-level changes in the Adriatic from tide-gauge data

FABIO RAICICH

CNR, Institute for Marine Sciences
AREA Science Park, Q2 bldg., SS14, km 163.5, Basovizza, 34149 Trieste, Italy
fabio.raicich@ts.ismar.cnr.it

Tide-gauges represent the most effective source of information on sea-level before the early 1990's and continue to play a crucial role also in the altimetry era. Starting from about the mid-19th century several tide gauges have been operational in the Adriatic Sea, although with significant gaps in the spatial and time coverages. The earliest tide-gauges were installed in Trieste (1859), Venice (1871) and Porto Corsini, now Marina di Ravenna (1873).

In the context of the current climate change key issues are represented by the mean sea level changes and the variability of the frequency and intensity of sea-level extreme events. The availability of long and homogeneous sea-level time series is, therefore, essential, to describe and understand those phenomena, that have already produced a significant impact particularly on the northern Adriatic coasts, locally enhanced by ground subsidence.

A review of some recent studies is here presented as examples of the Adriatic tide-gauge data exploitation.

Relative sea levels for over a century have been used in conjunction with geodetic data (benchmark levelling, GPS) to model local subsidence at Venice and Porto Corsini/Marina di Ravenna. From the late 19th century to the early 21st, the corrected time series exhibit trends around 1.2 mm/yr, that are consistent with those of Trieste and Genoa, where the ground can be assumed free of significant vertical motion.

The sea-level records of Venice and Trieste allowed to quantify the frequency and intensity of storm surges along the northern Adriatic coast. Besides multidecadal fluctuations no evident trends of such extreme events can be detected during over a century. The same conclusion was drawn in the framework of a study on the risk of coastal floods along the coast of Friuli Venezia Giulia as a consequence of the changing climate. According to various climate simulations in different scenarios produced in the framework of EURO-CORDEX, no significant changes are expected in the frequency and intensity of the synoptic meteorological patterns favourable to storm surges in the Adriatic.

The relative mean-sea-level rise is, therefore, the main factor responsible for the increasing impact of storm surges on the coastal areas, that has been observed in the 20th century and is expected during the 21st century. Locally, the impact is going to be enhanced by ground subsidence.

Keywords: tide gauges, mean sea level, storm surges

Assessing the impact of climate change in Italian coastal areas: tools and methods of risk and vulnerability assessment

SILVIA TORRESAN, ELISA FURLAN, PETRA DALLA POZZA, DIANA DEREPASKO, ANDREA CRITTO, MELANIA MICHETTI, MATTIA AMADIO, JAROSLAV MYSIAK AND ANTONIO MARCOMINI

University Ca' Foscari Venice, Department of Environmental Sciences, Informatics & Statistics
via Torino 155, 30172 Mestre (VE), Italy
marcom@unive.it, critto@unive.it
and
Fondazione Centro-Euro Mediterraneo sui Cambiamenti Climatici (CMCC)
Via Augusto Imperatore 16, 73100 Lecce, Italy
silvia.torresan@cmcc.it, jaroslav.mysiak@cmcc.it

Gradually increasing sea levels and extreme events related to changing climate conditions are causing serious threats to coastal areas, affecting both natural and human systems. Moreover, there is growing evidence that socio-economic dynamics (e.g. unplanned urbanization, land use and demographic changes) would increase coastal flood risk in the next decades. Understanding how natural and human-induced drivers concur to determine exposure, vulnerability and risks in coastal areas is of paramount importance for mainstreaming effective climate adaptation and risk reduction policies into coastal zone management.
In the frame of the SAVEMEDCOASTS project (www.savemedcoasts.eu), a risk assessment methodology was developed to provide guidance and operative criteria for exposure, vulnerability and risk assessment under changing climate and land-use scenarios. The overall aim of the methodology is to identify, map and prioritize natural and human targets at higher risk from climate-related hazards (sea level rise inundation and storm surge flooding) in vulnerable (flood-prone) coastal areas, providing a knowledge base for national-scale adaptation planning and disaster risk management. The method combines (i) hazard-prone areas potentially inundated by sea level rise and extreme water levels in future RCP4.5 and RCP8.5 scenarios; (ii) exposure, including a classification of ecosystem services supplied by coastal areas (provisioning, regulation and maintenance, cultural) and indicators of economic, social and manufactured capitals; (iii) vulnerability, represented by indicators of geomorphic susceptibility to flooding and adaptive capacity. The results obtained for the Italian coast include a range of spatial risk and vulnerability indicators and statistics including, the estimate of population, infrastructures, urbanized and agricultural areas at risk for different administrative units. The main steps of the methodology and the applicability of results for decision-makers and risk practitioners are here presented and discussed.

Keywords: coastal hazards, land use change, climate change, risk mapping, adaptation strategies

Sea storm risk in Emilia-Romagna and future scenarios

LUISA PERINI, LORENZO CALABRESE, PAOLO LUCIANI

Geological, Seismic and Soil service, Emilia-Romagna Region
Viale della Fiera 8, Bologna, Italy
luisa.perini@regione.emilia-romagna.it

Emilia-Romagna faces the northern Adriatic Sea for 130 km, from the Goro Po mouth to the Gabicce headland, with a low, sandy coastal plain. The area is very important for regional economy, as it hosts one of the most important tourism department in Europe, other than hystorical heritages and natural protected zones. Over the past sixty years, intensive urban sprawl (< 400%), beachfront bathing, ports, wharfs and coastal defence systems alterated the morphological and morphodynamic characteristics of the beaches, which need to be adeguatly managed in order to gurantee present and future use. From a geological poin of view the E-R coastal plain is characterized by a sequence of alluvial and marine deposits that testify the interplay between sea-level fluctuation and river activity. The fine grained deposits induce, significant natural and anthropogenic subsidence rates up to 15-20 mm/y. From a morphological point of view the area is characterized by large areas below mean sea-level (up to -4.5 m), estensively reclaimed or weatlands. The coastal plain is consequently vulnerable to sea-storms that impact seasonally both natural areas and human infrastructures. Emilia-Romagna Region has defined the main risk indicator and developed dedicated tools and databases to monitor the damages by present sea-storms (beach erosion, sea flood, etc.) and of coastal dynamic.
In this context, the analysis of future scenarios due to the sea level rise, as effect of climate change , becomes essential for the management of this territory, both to understand the possible consequence on coastal and marine ecosystems and to determine the possibly increase of risk for populations and their assets.
For this purpose, simulations taking into account the combined effect of subsidence, sea level rise and sea storm to the 2100 have been elaborated. Afterwards, future scenarios have been compared with hazard maps related to sea flood, processed according to EU DIR 2007/60. This exercise, carried out in cooperation with Urbino University and INGV, has provided very interesting results on the most critical coastal stretches in order to better define the most suitable risk reduction measures in the second step of the floods directive.

Keywords: coastal risk, low-land, subsidence, sea-level rise

Coastal risk: strategic decision making for sustainable development

BARBARA ZANUTTIGH

Università di Bologna
DICAM, Viale Risorgimento 2, 40136-Bologna
barbara.zanuttigh@unibo.it

Large stretches of the European coasts, which are highly populated and economically essential, are threatened by coastal erosion and flooding, whose frequency and severity is increased by climate change and sea-level rise. Responding to disasters and enhancing resilience to extreme events needs a holistic, participatory and inter-disciplinary approach that should focus on how to operationalize the concept of resilience by the analysis, advance, development, testing and integration of a wide range of complementary adaptation and disaster risk mitigation measures.

Coastal adaptation consists of a cluster of solutions that can be combined to reduce the hazard or the exposure and to face the same or different hazards. The adaptation solution/s must be "tailored" to the local context through an inclusive process that matches development goals with the climate change issues and the technical capabilities and the capacity of the institutions and community stakeholders.

Risk assessment and planning management strategies, across a range of spatial and temporal scales, can be performed through scenarios analyses or qualitative assessments by means of tools to support the decision making process. This contribution focuses specifically on the tools proposed by the FP7 project THESEUS (www.theseusproject.eu) and by the ongoing H2020 project BRIGAID (www.brigaid.eu) to address different users of the coastal areas.

The open-source GIS-based Spatial Decision Support System developed within the THESEUS Project allows the users (coastal managers, public authorities, consultants) to perform an integrated quali-quantitative coastal risk assessment, to analyse the effects of different combinations of engineering, social, economic and ecologically based mitigation options, across short, medium and long term scenarios, taking into account physical and non-physical drivers, such as climate change, population and economic growth.

The Technological Innovation Framework and the Innovation Cluster Assessment developed within the H2020 BRIGAID project can be used by the users (designers, innovators) to qualitatively assess the TRL of each adaptation measures and the sectoral impacts of clusters.

Keywords: Coastal Risk, Risk Assessment, Decision Making, Sustainability, Innovation, Climate Change

Sea level rise, coastal hazard and people awareness in the Mediterranean: new insights from the SAVEMEDCOASTS project

MARCO ANZIDEI [1], PETROS PATIAS [2], CHARALAMPOS GEORGIADIS [2], FAWZI DOUMAZ [1], DIMITRIOS KAIMARIS [2], CHRISTOS PIKRIDAS [2], CARLO ALBERTO BRUNORI [1], XENIA I. LOIZIDOU [3], MELANIA MICHETTI [4], DEMETRA PETSA [3], DEMETRA ORTHODOXOU [3], SILVIA TORRESAN [4], ELISA FURLAN [4], MARIA LUCIA TRIVIGNO [5], MICHELE GRECO [5,6], ENRICO SERPELLONI [1], ANTONIO VECCHIO [7], STEFANO LORITO [1] AND LUCA PIZZIMENTI [1]

[1] *Istituto Nazionale di Geofisica e Vulcanologia INGV, CNT, Roma, Italy (marco.anzidei@ingv.it),*
[2] *Aristotle University of Thessaloniki, Greece,*
[3] *ISOTECH LTD Environmental Research and Consultancy, Cyprus,*
[4] *Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici, Italy,*
[5] *Centro di Geomorfologia Integrata per l'Area del Mediterraneo,*
[6] *Engineering School, University of Basilicata, Potenza, Italy,*
[7] *Lesia Observatoire de Paris, Section de Meudon 5, France*

Sea level rise is one of the main global threats caused by climate change. Recent independent studies and the IPCC reports show that global sea levels could rise even more than 0.8-1.0 m by 2100. When in combination with vertical land movements for natural or anthropogenic causes, changes in relative sea levels are particularly crucial in subsiding coasts, accelerating land flooding.
Here we show results from the SAVEMEDCOASTS Project (Sea Level Rise Scenarios along the Mediterranean Coasts – www.savemedcoasts.eu), funded by the European Commission ECHO A.5. The project aims to respond to the need for people and assets prevention from natural disasters in Mediterranean coastal zones placed at less than 2 m above sea level, which are vulnerable to the expected sea level rise. We use available high resolution DTM and bathymetric data, rates of vertical land motion and the IPCC projections RCP4.5 and RCP8.5 of climate change scenarios for sea level rise, to identify the areas of the Mediterranean region most prone to marine flooding for 2100 AD. We provide a focus on the main coastal plains, the deltas of the Nile and Po rivers, the coasts of SW Turkey, part of Greece and the north Adriatic Sea, besides other densely inhabited coastal areas. Detailed scenario are given for the three Italian UNESCO sites of the Venice lagoon, Lipari island and Cinque Terre and the Island of Lefkada (Greece), which are highly exposed to relative sea level rise, storm surges and tsunami, that all represent critical issues for the local population and coastal infrastructures. Through the implementation of a dedicated and structured method, local key actors become aware both of the extent and of the different aspects of the problem and are engaged in a process to identify solutions. Based on gaps/needs and perceptions analysis, policy tools targeting civil protection are produced. The hazard implications for the population living along the shore are considered to push land planners and decision makers to take into account scenarios similar to that here reported for cognizant coastal management. SAVEMEDCOAST is contributing to improve governance and raising community awareness towards coastal hazard, fostering the cooperation amongst science, affected communities and civil protection organizations for some high economic and environmental value zones of the Mediterranean coasts.

Keywords: sea level rise, coastal hazard, Mediterranean

Dune reconstruction on rapidly eroding coasts as a tool of counteract impact of storms in a changed sea-levels scenario

PAOLO CIAVOLA, TOMAS FERNANDEZ-MONTBLANC, ENRICO DUO

Dipartimento di Fisica e Scienze della Terra - Università di Ferrara
Via Saragat 1, Ferrara, Italy
cvp@unife.it, frntms@unife.it, enrico.duo@unife.it

In the current scenario of climate change, high water levels during storms threaten coastal landscapes that have a low elevation. In the current scenario of sea-level rise and increased mean sea-level may result in an increased impact of storm surges and/or in a change of the return period of these events.
Naturally coastal dunes and their vegetation provide the first line of protection. At eroding coastlines their reconstruction offers the opportunity to build dynamic coastal defences.
Numerical tests using the hydro-morphodynamic model XBeach were undertaken to design and evaluate the effectiveness of dune reconstruction and revegetation as a Disaster Risk Reduction (DRR) measure at a rapidly eroding coastline in Bellocchio (Northern Adriatic sea). The dune was built mimicking the current dune, enlarging it and increasing its crest according to the typical dune systems present in the region. The dune revegetation encompasses different species accounting for their distribution in the local dune systems. Two indicators were chosen to assess performance, respectively the Maximum Water Volume (MWV) for flooding and the sediment volume variation (SVV) for erosion.
Simulations were undertaken under the current sea-level as well as recent local scenarios. The indicators highlight the high efficiency of the dune system in controlling flood extent. The results show a reduction of inundation with the reconstructed dune, which is still breached and overtopped at some points. If the vegetation is reconstructed on the dune there is a considerable decrease of inundation. Minimum changes are observed between normal and high density of vegetation for the reduction of MWV. The high-density vegetation set-up provides instead the most efficient solution for SVV reduction.

Keywords coastal dunes, storm surges dune reconstruction

Multidisciplinary assessment and prediction tools addressing coastal vulnerability to erosion and sea level rise. Lessons learnt from the RITMARE Project.

DAVIDE BONALDO AND RITMARE TEAM

Institute of Marine Sciences, National Research Council (ISMAR-CNR)
Venice, Italy
davide.bonaldo@ve.ismar.cnr.it

Natural processes and human activities are strongly connected, and sometimes conflicting, in the evolution of coastal and transitional environments. The strong anthropic pressure on coastal regions, together with the effects of a changing climate, demands nowadays more pressingly for efficient tools to characterise and predict the behaviour of such systems in order to define appropriate response strategies. This requires a deep understanding of the connections among different drivers and different scales, a multidisciplinary challenge in which heterogeneous data, approaches and scales need to be framed within a consistent dynamical description.
To this aim, a specific research line was dedicated to "Coastal Vulnerability to Erosion and Sea Level Rise" within the RITMARE Project, supported by the Italian Ministry of University and Research with the purpose of integrating the Italian Marine community in shared research fields in the period 2012-2017. The activities carried out in this framework have been moving along interconnected branches tackling the themes related with sea level rise, ocean modelling, and geomorphological assessment in present conditions and in different climate change scenarios, with an eye on the exploitation of marine sand as a strategic resource.
In this contribution we review the main outcomes of this multidisciplinary and coordinated research. Besides discussing the advances and the possibilities from state-of-the art technologies and methodologies, we point out that a coordinated use of the described tools should be promoted in the design of survey and monitoring activities, as well as in the exploitation of already collected data. Expected outcomes of this strategy include the implementation of improved policies and infrastructures for coastal protection, flanked by reliable short-term forecasting systems and efficient rapid response protocols, in the framework of an integrated coastal planning at the multi-decadal scale.

Keywords: Coastal Monitoring, Multi-Scale Modelling, Climate Change

RITMARE TEAM
DAVIDE BONALDO [1], SANDRO CARNIEL [1], ANTONIO RICCHI [1], FABRIZIO ANTONIOLI [2], RENATA ARCHETTI [3], MARIA G. GAETA [3], ACHILLEAS G. SAMARAS [3], ANNELORE BEZZI [4], GIORGIO FONTOLAN [4], STEFANO FURLANI [4], SIMONE PILLON [4], ANNAMARIA CORREGGIARI [5], SILVIO DAVOLIO [6], MAURIZIO FANTINI [6], PAOLO STOCCHI [6], GIOVANNI DE FALCO [7], GABRIELE LEONI [8], VALERIA LO PRESTI [9], GIUSEPPE A. MASTRONUZZI [10], GIOVANNI SCICCHITANO [11]

[1] Institute of Marine Sciences, National Research Council (ISMAR-CNR), [2] ENEA, [3] Università degli Studi di Bologna, [4] Università degli Studi di Trieste, [5] ISMAR-CNR, [6] ISAC-CNR, [7] IAMC-CNR, [8] ISPRA, [9] Università La Sapienza Roma, [10] Università "Aldo Moro" Bari, [11] Studio Geologi Associati T.S.T. Catania

Sea-level rise and potential drowning of the Italian coastal plains: flooding risk scenarios for 2100

VALERIA LO PRESTI, RITMARE 1 TEAM, RITMARE 2 TEAM, CLIMTOUR-COPERNICUS TEAM
Geologist
Rome, Italy
valeria.lopresti@gmail.com

We depict the relative sea-level rise scenarios for the year 2100 from eight areas of the Italian peninsula. Our estimates are based on the Rahmstorf (2007) and IPCC-AR5 reports 2013 for the RCP-8.5 scenarios (www.ipcc.ch) of climate change, adjusted for the rates of vertical land movements (isostasy and tectonics). These latter are inferred from the elevation of MIS 5.5 deposits and from late Holocene sea-level indicators, matched against sea-level predictions for the same periods using the glacio-hydro-isostatic model of Lambeck et al. (2011). We focus on a variety of tectonic settings: the subsiding North Adriatic coast (including the Venice lagoon), three tectonically stable in Sardinia coastal plains (Oristano, Colledonia and Cagliari coastal plain), Marche (Tronto), Abruzzo (Pescara and Sangro coastal areas), Apulia (Lesina), Granelli (Sicily), and Marina di Campo (Tuscany) and the slightly uplifting Taranto coastal plain. Maps of flooding scenarios are shown on high-resolution Digital Terrain Models mostly based on Lidar data. The expected relative sea-level rise by 2100 will change dramatically the present-day morphology, potentially flooding up to about 6000 km2 of coastal plains at elevations close to present-day sea level. The subsequent loss of land will impact the environment and local infrastructures, suggesting land planners and decision makers to take into account these scenarios for a cognizant coastal management. Our method developed for the Italian coast can be applied worldwide in other coastal areas expected to be affected by marine ingression due to global climate change.

Keywords: flooding risk, IPCC

RITMARE1 TEAM

V. LO PRESTI, F. ANTONIOLI [1], M. ANZIDEI [2], A. AMOROSI [3], G. MASTRONUZZI [4],L, G. DEIANA [6],L, G. DE FALCO [6], A. FONTANA [7,10], G. FONTOLAN [8,10], S. LISCO [4,9], A. MARSICO [4,10], M. MORETTI [4,10], P.E. ORRÙ [5,10],G.M. SANNINO [1], E. SERPELLONI [2], A. VECCHIO [1]

[1] *ENEA,*
[2] *INGV Roma,*
[3] *University of Bologna,*
[4] *University "Aldo Moro" Bari,*
[5] *University of Cagliari,*
[6] *AMC-CNR,*
[7] *University of Padova,*
[8] *University of Trieste,*
[9] *Lesia Observatoire de Paris, Section de Meudon 5, France,*
[10] *CONISMA*

RITMARE 2 AND CLIMTOUR-COPERNICUS TEAM

ANTONIOLI F. [1], DE FALCO [7 2], BONALDO D. [3], CARNIEL S. [3], FURLANI S. [4, 7], MASTRONUZZI M. *e,g* , MORETTI L. [1], PETITTA M. [1], SCICCHITANO G. [6]

[1] *ENEA*
[2] *IAMC-CNR*
[3] *ISMAR-CNR*
[4] *University of Trieste*
[5] *University "Aldo Moro" Bari,*
[6] *Studio Geologi Associati T.S.T. Misterbianco, Catania*
[7] *CONISMA*

Coastal change drivers in the Mediterranean Sea: waves, storm surges, sea level rise and their interactions with the morphology and the use of the coastline

PIERO LIONELLO

Università del Salento e CMCC
Centro Ecotekne Pal. M-S.P. 6, Lecce - Monteroni - LECCE (LE)
piero.lionello@unisalento.it

This contribution discusses the data availability for coastal risk assessment at Mediterranean scale in the context of climate change. It describes as a new dataset containing information on exposure and vulnerability for the Mediterranean Basin, which can be combined with projections of future changes of hazards (sea level extremes, wave height and direction, sea level) to evaluate risks. This datatset hasbeen produced by a recently completed project (RISES-AM). It contains information on coastal morphology, human settlements and administrative boundaries, with 160 parameters describing the characteristics of the natural and socio-economic subsystems, such as vertical land movement and number of people exposed to sea-level rise and extreme sea levels.For the assessment of hazards, the analysis of a set of multi-decadal regional projections is available and allows to estimate the likely future changes of regional marine storminess and their uncertainty, depending on emission scenario, climate model and inter-decadal variability. Results show that future increase of sea level will be the major hazard for the Mediterranean coast, while a widespread and progressive future reduction of marine storminess in the Mediterranean Sea is expected. A tentative superposition of hazard level changes, morphology and exposure is here discussed.

A Wavelet Analysis of sea level height in the Gulf of Naples (2002-2017): preliminary results

BERARDINO BUONOCORE, VINCENZO CAPOZZI, GIOVANNI ZAMABRADINO, GIORGIO BUDILLON

Department of Science and Technology, University of Naples "Parthenope"
Centro Direzionale di Napoli – Isola C4, Italy
berardino.buonocore@uniparthenope.it, vincenzo.capozzi@uniparthenope.it, giorgio.budillon@uniparthenope.it, giovanni.zambardino@uniparthenope.it

This study analyses a sea level height time series measured in the Naples Gulf and its relationships with meteorological forcing. The investigated records have been collected by a tide-gauge located in Ischia (40°44'45.5" N, 13°56'26.2" E), belonging to the environmental monitoring network managed by the University of Naples "Parthenope", and span about 16 years (from 01/04/2002 to 31/12/2017). From the raw measurements, gathered with a time interval of five minutes, a high-quality hourly time series has been obtained using a Pugh filter, designed to remove the high frequency variability.
The non-tidal residuals (i.e. sea-level variability without the astronomical tide) have been examined through the Wavelet Analysis, which is a valuable tool for the detection of the non-stationary processes within a geophysical time series. According to the Continuous Wavelet Transform (CWT), the sea level signal exhibited some oscillations along the entire investigated period in the 500-1500 hours band. The most significant discontinuities have been found between 2002 and 2005 and between 2008 and 2010: in the first time interval, two areas of strong energy have been detected on a period of about 800 hours, whereas in the second one a relevant fluctuation over a period of about 1500 hours has been identified. A preliminary assessment of the atmospheric influence on the observed variability has been performed by analysing, for the 2002-2017 period, the hourly surface pressure measurements collected by an automatic weather station located in Naples urban area (which is 30 km far from the tide-gauge site). The CWT of atmospheric pressure signal reveals areas of strong energy in 2002-2005 and in 2014-2016 time intervals on a period of about 800 hours. Some relevant oscillations also occurred in 2008-2010 and 2012-2015 time intervals on periods ranging from 500 to 1500 hours. In order to measure the correlation in time-frequency space between sea level and atmospheric pressure time series, a Wavelet Coherence Analysis (WTC) has been performed. Preliminary results highlight that meteorological forcing mainly controls the irregular variability of sea level residuals. The WTC, in fact, shows a strong negative correlation between the two signals on a wide range of periods, varying between 256 and 4000 hours.

Keywords: sea level, meteorological forcing, wavelet analysis

Sea Level Rising: Perspectives from an Expanding Globe

GIANCARLO SCALERA
INGV – Istituto Nazionale di Geofisica e Vulcanologia
Via di Vigna Murata 605, Rome, Italy
Giancarlo.scalera@ingv.it

In the expanding Earth framework it is possible to find additional phenomena that could contribute in a proper way to the water balance and general tectonic eustatism involved in the sea level rising. Recent compilations seems to leave unexplained up to 12 cm/century of sea rising (Munk, 2002), and possible solutions invoking a polar ice shells melting near to the upper limit of the error bars reveal in conflict with the consequent expected decreasing of the Earth angular velocity. It is shown that taking into account possible effects of an expanding Earth, the problem can be initiated towards an appropriate solution: major effects on sea-level could come from ongoing relaxation of curvature variations that are peculiar for an expanding globe. While the global curvature of the Earth's surface must decrease with an increasing radius, the regional curvatures of continents and their fragments tend to be conserved.
The consequent increasing elevation of the regional bulges – that contemporaneously are slowly destroyed by erosion and dissipated by isostasy – provides an additional load on the continents and a resulting apparent sea level increase.
No claim is advanced to provide a detailed quantitative account of the effects caused by the Earth's curvature change on sea-level, and the aims are limited to scrutinize the involved magnitude orders and to compare them with the already recognized physical processes – like thermal expansion – that are cause of sea-level change.
The existence of unaccounted global geophysical processes linked to an expanding Earth can produce discrepancies in main-stream theories of sea level rise, and, as a matter of facts, this is the situation of the present day comparison between theory and observations. These discrepancies will presumably found a way toward their solution if new research lines will start that take into account the global isostatic and emissive phenomena of an expanding planet.

Keywords: Sea level rising, Expanding Earth, Lithospheric curvature variations, Global water balance

Sand dunes and marine litter: fragile ecosystems to preserve from pollution for the challenge of rising sea level

FEDERICA TOMMASI
EcoHealth Unit, Dept. Environment and Health, Italian National Institute of Health
Viale Regina Elena, 299 - 00161, Roma, Italia
federica.tommasi@iss.it

Mediterranean coastal dunes are heterogeneous, complex and dynamic ecosystems with an high rate of ecosystemic services. They represent the residual part of the natural configuration of the Mediterranean coasts that are still untouched by the anthropic invasion. For this reason they also represent the natural battlefront to coastal erosion, in the presence of beaches, due to climate changes and the related extreme events as well as to the rise of the average level of the seas. Currently, constantly increasing marine pollution represents a threat to the dune ecosystems of the Mediterranean Sea on more than one case, one of which, the most common is represented by marine debris. Sandy shores represented important sinks for marine litter coming from both sides: directly from the beach front and from inhabited inland areas that are the source of mismanaged waste. The effect is a growing accumulation of debris, many of which are objects mishandled in plastic materials. Climate change with rising sea levels and the increase in extreme weather events will cause, together with the combined increase of marine waste, mainly composed of plastic waste, the increase and storage in coastal dunes of not only waste guided by the impetus of the currents but also of all those that are able to float due to the lower density of sea waters in periods of climatic calm. Currently the methods of removal of waste of various sizes from the coastal areas of the dunes are mainly of two types: with the aid of mechanical means and done manually. The presence of waste could represent a serious threat to life in the sand dunes and mechanical seal of the dunes, mainly due to the cleaning activities carried out through mechanical equipment. It is certain that the waste must be removed regularly. the manual removal activities are the most desired because they allow the continuous monitoring of the dunes, the activities of control of beached waste and conveyed on both sides of the coastal dunes, the possibility of developing with the research new methods of removal and control. The periodic campaigns carried out on our coasts, often on the voluntary initiative of environmental associations, represent the most effective and least invasive method, which can also be associated with the collection of scientific data, as well as raising citizens' awareness of the problem of marine litter.

Keywords: Marine litter, Mediterranean sand dunes, coastal ecosystems