THE FUTURE OF VENICE

AND ITS LAGOON IN THE CONTEXT OF GLOBAL CHANGE

1.

Workshop Report

From Global to Regional: Local Sea Level Rise Scenarios

Focus on the Mediterranean Sea and the Adriatic Sea

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Published by United Nations Educational, Scientific and Cultural Organization (UNESCO)

Venice, Italy

Director of Publication: Engelbert Ruoss
Editorial Board: Lauren Bohatka, Philippe Pypaert, Mieke Van Molle
English language revision by: Lauren Bohatka
Graphic editing: Anne Ajoux
Graphic design: Anne Ajoux, SysCom Solutions

This workshop and report have been financially supported by the Italian Government.

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From Global to Regional: Local Sea Level Rise Scenarios Focus on the Mediterranean Sea and the Adriatic Sea

Workshop organized by UNESCO Venice Office and ISMAR-CNR

22-23 November 2010, Venice (Italy)

Contents

Foreword

The urban ecosystem of Venice and its Lagoon is among the most studied urban and environmental systems in the world. Acting as neutral broker and facilitator, UNESCO Venice Office has mobilized expertise in the interdisciplinary fields of science and culture to identify and discuss the scientific, environmental, cultural and socio-economic challenges faced by the World Heritage site of Venice and its Lagoon in the context of global change.

This document in your hands presents a summary of the results and discussions from the first of four thematic workshops that were held to gather the necessary expert inputs needed to evaluate the current situation of Venice and its Lagoon and to contribute to a shared sustainable vision for its future. The Workshop *From Global to Regional: Local Sea Level Rise Scenarios - Focus on the Mediterranean Sea and the Adriatic Sea*, was held 22-23 November 2010 at Palazzo Zorzi in Venice, Italy and was organized in partnership with ISMAR-CNR. The results from this international workshop will form a basis for a better understanding of the vulnerability of the Venice heritage site, since one of the key impacts of climate change identified for Venice and its Lagoon, as well as for the Adriatic Sea at large, is the dramatic increase of the sea level within the current century.

The results of the thematic workshops will be used by UNESCO to facilitate the vision, strategy and management plan for Venice and its Lagoon, and to prepare in collaboration with the local authorities a follow-up report to the one already elaborated by UNESCO in 1969 after the devastating *acqua alta* of 1966. This new report is intended to help guide sound decision-making and further enable sustainable management of not just the World Heritage Site of Venice and its Lagoon, but of urban coastal and lagoon systems worldwide that are facing challenges stemming from global change phenomena, and in particular those in the South-East European and the Mediterranean regions.

Prepared by the participants of the workshop, this report provides a shared overview of the main challenges that are being faced by the World Heritage site of Venice and its Lagoon and significantly contributes to the growing body of knowledge on the impacts of sea level rise on coastal and lagoon cities.

Engelbert Ruoss
Director, UNESCO Venice Office

Introduction

© KlausFoehl - Acqua alta flooding in St. Mark's Square

One of the key impacts of climate change identified for Venice and its Lagoon, as well as for the Adriatic Sea at large, is a dramatic increase of the sea level within the current century. In order to avoid potential disasters caused by "high water", the Italian authorities have authorized the construction of an underwater barrier system, referred to as the MOSE Project. This system should help Venice and its Lagoon avoid extreme flooding and high waters as soon as 2014. The continued existence of Venice and the preservation of its cultural heritage are highly connected to the *acqua alta* flooding phenomenon; however, other natural hazards as well as this artificial barrier will result in considerable changes within the Lagoon eco-system, all of which are highly unpredictable. The knowledge of these interactions within an urban Lagoon eco-system will enhance the chances for a series of coastal cities worldwide to be better prepared for natural hazards and a changed environment.

At the end of 2010 an international workshop was held on the topic of Climate Change Physical Knowledge and on the correlated Sea Level change in the northern Adriatic and the Venice Lagoon. The workshop was useful to discuss major controversial scientific issues on the topic and to evidence the scientific background. The Workshop tried to identify multiple plausible end-of-century sea level rise scenarios for the northern Adriatic Sea, and is considered to be useful for the local authorities responsible for the implementation of major mitigation interventions.

The global view

The last assessment report of the IPCC-Intergovernmental Panel on Climate Change (IPCC AR4, 2007) has given new sea level rise estimates that range between 18 and 59 cm up to the end of next century. This report corrected the previous one (IPCC TAR, 2001) which showed a higher uncertainty with a range of 9 to 88 cm. An average between the different models and scenarios can be set at about 40 cm of global sea level rise (Figure 1).

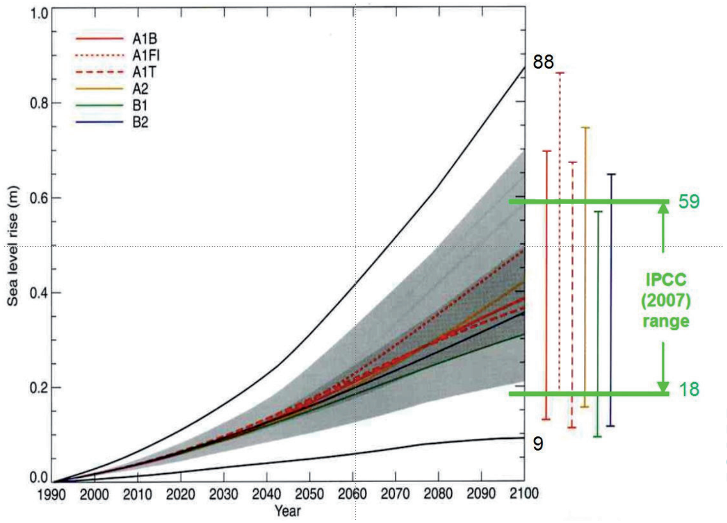

Figure 1:
Projections of accelerated sea-level rise underestimated? EOS, v.91, p.205-206 (from IPCC, 2001 with some modifications by Pirazzoli)

It is important to note that these estimates exclude the contribution of melting ice to the sea level rise. Basically, the estimates include only the steric component of the sea level rise due to the heating of the ocean waters and their consequent expansion. The numbers given by IPCC should therefore be considered as a lower limit of the expected sea level rise (Figure 2).

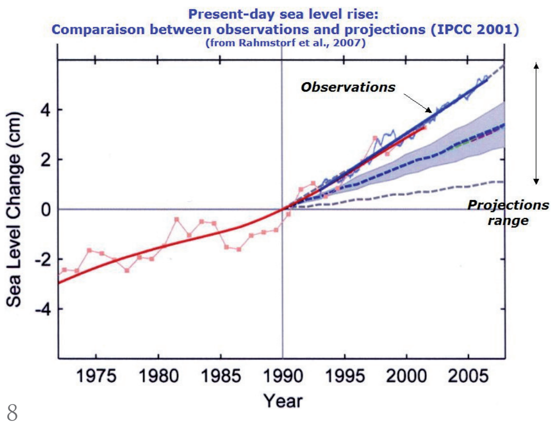

Figure 2:
Short term projections (IPCC, 2001) of sea level rise and observations (from Rahmstorf, 2007)

The uncertainties of the results are due largely to two factors. The first factor relates to the uncertainty of modeling the heat uptake of the oceans because the dynamics are not sufficiently understood. The second factor is due to the different scenarios of CO2 emission and the consequent heating of the atmosphere.

If the dynamics of the ocean heat uptake is not yet fully understood, the problem of sea level rise due to melting ice is even less known. It is basically for this reason that IPCC has excluded this contribution from the global estimates, since these changes could not be modeled. This is, e.g., seen in the fact that the observed sea level rise exceeded for the period 1961-2003 the model projections by 50% and by 80% for the years 1990-2008.

A possible solution to this problem is the inclusion of semi-empirical approaches to sea level rise projections. These models are based on using an observable parameter that climate models can predict with confidence, namely global mean temperature, and establish with the help of observational data how this parameter is linked to sea level.

New paleoclimatic data for the past two millennia show that 20th Century sea level rise is unprecedented during this period.

Since the AR4 assessment report, some recently published papers give new estimates on global sea level rise. All of these give much higher projections than those of the AR4 (Figure 3). Rahmstorf (2007) gives an estimate of 50-140 cm, later corrected to 75-190 cm (Vermeer and Rahmstorf, 2009). Horton et al. (2008) estimate 54-89 cm (acknowledging that this could be a lower limit), Grinsted et al. (2009) 72-160 cm or 96-215 cm, and Jevrejeva et al. (2010) estimate the sea level rise between 60 and 160 cm. It can be noticed that all estimates are substantially higher than the estimate of AR4. The Delta Committee (KNMI, 2006) estimated 55-110 cm (high end).

If one does not limit estimates to the end of this century, then two more estimates are to be considered. The Delta Committee (2008) gives a range of 1.5-3.5 m for the year 2200, and WBGU (2006) estimates a sea level rise of 2.5-5.1 m for 2300. This means that sea level rise will be governed in the coming centuries by a delayed response to 21st Century anthropogenic warming.

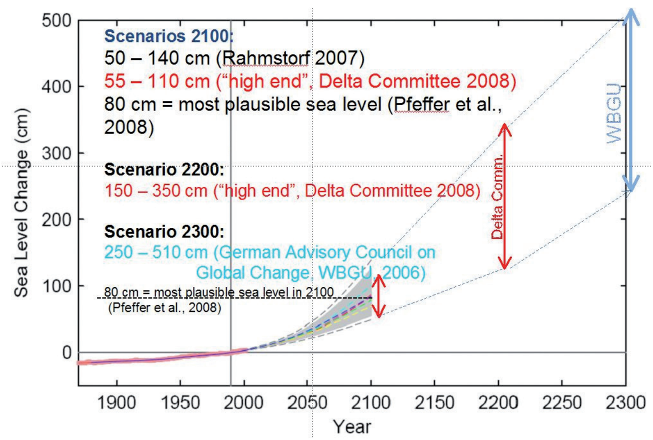

Figure 3:
Long term projections of sea level rise by various authors and committees (by Pirazzoli)

Even if short-term sea level response is dominated by thermal expansion and glacier melt, the long-term response is dominated by the ice-sheet volume reduction, which accounts for the largest sea level rise. A realistic maximum rate of sea level rise can be inferred from the analysis of past data (Rohling et al., 2008; Andersen et al., 2010; Stanford et al., 2010). During the Last Interglacial, sea level rose above the present level at a rate of 1.6 ± 1.0 m/century, which is 2-3 times the rate reported in IPCC AR4 (Rohling et al., 2008). A probabilistic global summary confirms 'jumps' of last interglacial sea-level rise of the order of 1-2 m/century (Kopp et al., 2009). Maximum values of sea level rise (with 95% confidence) can reach 2.5 m/century, but mean sea level rise is probably closer to 1 m/century for the next century (Siddall et al., 2003; Rohling et al., 2004). The current understanding of the ice dynamics allows modern rates of 0.8-2.0 m/century to be estimated (Pfeffer et al., 2008). Antarctica alone may account for up to 1.5 m/century (SCAR report, 2009).

Overall, past data seem to suggest that sea level rise for the next century is most likely to approach 1 m or more.

The Mediterranean

The sea level in the Mediterranean shows a strong variability over the last century. In any case, with a rate of approximately 1.2 mm/yr the observed rate of rise is significantly lower than the global average. Based on measurements of available tide-gauges the level increased until the 1960s and dropped a few cm between 1960 and 1993. Between 1993 and 2000, a quick sea level rise of 4-5 cm took place, after this there was no change.

One factor concerning regional sea level is atmospheric pressure forcing. A drop of 1 mbar is approximately equal to a rise of 1 cm in sea level. This forcing is responsible for the drop of sea level between 1960 and 1993 and can be linked to the North Atlantic Oscillation (NAO). The average change of sea level was a reduction of 0.6 mm/yr. Since climate models indicate that pressure could rise, a reduction of 2 cm (average -0.2 mm/yr) can be expected due to this forcing.

The other factor that controls sea level change is the steric effect. Due to a change in temperature and salinity, the volume of the Mediterranean (and therefore sea level) is changed. Higher temperature increases sea level, while higher salinity will lower it.

It is estimated that the total steric effect has contributed to a lower sea level in the Mediterranean Sea. This means that due to a rise in both temperature and salinity, the latter is dominating. However, results depend on the depth that these changes will propagate. If a depth of 300 m is used for integration, then a change of 0 to -2 ± 1 mm/yr can be computed.

© NASA - Satellite photo of the Strait of Gibraltar, entrance from the Atlantic Ocean to the Mediterranean Sea

Estimating trends for the future is even more complex. The thermosteric increase (due to a temperature increase) in water level of about 50 cm in the next century is opposed to a halosteric reduction (due to increasing salinity) of about equal size, making the estimates highly uncertain and problematic. This results in a sea level change that can be positive or negative, with a low confidence in the overall result.

Moreover, the Mediterranean is not a stand-alone basin, but is linked to the Atlantic Ocean. The resulting sea level will therefore only partially be governed by the regional change. One of the crucial uncertainties concerns the question of how exchanges through the Strait of Gibraltar will influence sea level in the Mediterranean.

These results are confirmed by the application of a global and regional model framework (CMCC-MED) which for the first time, allows for an accurate assessment of the role and feedback of the Mediterranean Sea in the global climate system, coupling a general circulation model with a high-resolution model of the Mediterranean Sea. Results obtained indicate for the end of this century an increase in temperature of 2.5-3 °C with respect to the past (1961-1990). Evaporation increase and reduced precipitation have an important impact on the density of the Mediterranean Sea. At the end of the century the sea level rise appears to be around 22 cm due to the steric effect of the Mediterranean.

Similar results have been obtained by another regional model consisting of the RegCM and the MITgcm. In these simulations the maximum steric sea level difference in the South Adriatic Sea ranges between 16 and 26 cm by the year 2050, depending on the applied scenario.

All models indicate the importance of the Strait of Gibraltar in controlling the changes between the Mediterranean and the Atlantic Sea. With increasing salinity difference across the Strait, the Strait becomes more and more hydraulically controlled and transport through the Strait tends to saturate. Depending on the degree of isolation of the Mediterranean basin, the scenarios discussed range from a possible sea level drop of -14 cm (Mediterranean completely isolated with halosteric effects dominating) to a sea level rise completely governed by the Atlantic and global ocean, and changes propagating undisturbed into the Mediterranean basin. In this case the sea level rise (as explained above) may vary between 20 and 200 cm.

In a recent study (Jorda et al., 2011), a conceptual model was developed for the mass exchange through the Gibraltar Strait. In this work the message is clear: sea level in the Mediterranean will basically follow the Atlantic Ocean. The time scales for the exchange will be in the order of months. There might be a sea level difference between the Mediterranean and the Atlantic, but in the range of not more than 5-10 cm over the next 100 years.

The Adriatic Sea

The Adriatic Sea is better connected to the rest of the Mediterranean than the Mediterranean to the Atlantic Ocean. It is therefore expected that variations in sea level will be much stronger related to the rest of the basin.

The most important feature of the sea level rise is a slowing down that has been recorded since the 1960's (Orlić and Pasarić, 2000; Tsimplis and Baker, 2000) and that now appears to have ceased. As mentioned before, this deceleration is partially due to a change in air pressure and wind forcing (Tsimplis et al., 2005), with the steric component as other factor.

Long-term trends in the Adriatic Sea are available for the Italian and Croatian coast. During the last century the mean sea level rise was approximately 1-2 mm/yr. During winter these values are quite coherent through the whole basin, but during summer, the behavior is more heterogeneous. The fluctuations of sea level during winter can mostly be ascribed to atmospheric pressure variations, particularly in the northern basin.

© NASA - Satellite photo of the Adriatic Sea

Analysis of tide gauge data between 1993 and 2005 shows a general rise in the Adriatic Sea that ranges from 2.9 to 5.7 cm during the 13-year period (only highly significant data have been used). When compared to satellite measurements of the Mediterranean mean (2.17 cm), the global mean (3.3 cm) and IPCC data (3.1 cm), these data indicate that the Adriatic Sea shows a higher rate of sea level rise in the period 1993 to 2005.

Concerning the storminess and the storm surges in the North Adriatic Sea, the data show large inter-annual variability and very few overall tendencies on a multi-decadal time scale (e.g., 11-year solar cycle). This suggests progressively milder storms during the second half of the 20th century (Lionello et al., 2010). There is a trend of higher storm surge frequency, but this can be explained by the increase of relative sea level. In the future, scenario simulations (Lionello et al., 2003) suggest higher frequency of intense storms for the B2 scenario, but not for the A2 (IPCC, 2007). Likely, these differences are not the effect of climate change, but of climate multi-decadal variability. Therefore, there is no convincing evidence for more stormy conditions in future scenarios and the Northern Adriatic storminess is not very sensitive to climate change. There is substantial agreement between present trends and the available climate change scenarios for storm surges and waves, suggesting that marine storm extremes will either not change or will become slightly milder in future climate conditions.

The Venice Lagoon

Measured data (ISPRA, the Italian Environmental Protection Agency, and French SONEL) indicate that mean sea level has risen during summer months about 10 cm in the last 3 years. This rise is strongly correlated with anomalies in atmospheric pressure observed in recent years. However, during winter months this mean sea level rise (observable in most of the stations throughout Italy) shows a relative increase of around 20 cm. This is again correlated with a drop in atmospheric pressure from 2020 to 2013 mbar in the last 3 years. It is doubtful that these trends will continue, but extreme variability of mean sea level in the Adriatic Sea and close to the Venice lagoon is likely.

The inlets have a strong hydraulic control on the water entering the Venice lagoon from the Adriatic Sea. Water masses entering the lagoon are slowed down by bottom friction. This effect has been controlled and altered by human interaction, especially around the year 1970, when the industrial channel that leads from the central inlet to the industrial port was built. During the period 1940-1965, 3128 events with fast rising water levels (defined as a growth higher than 20 cm/h) occurred in the Venice lagoon, compared to 13293 in Trieste, where sea level is not damped by strong hydraulic controls. But during the period 1970-1995, there were 6912 events in Venice and 13122 in Trieste. Therefore, in the two 25 year periods, the fraction of these cases between Venice and Trieste has risen from 0.235 to 0.527, showing an increase with a factor of more than 2.

© JøMa - Tourists visiting St. Mark's Square in times of flood

Even with this strong hydraulic control exerted by the inlets, the mean sea level is basically the same between the Adriatic Sea and the lagoon. This means that the slow water level variations occurring in the Adriatic Sea will propagate inside the lagoon with no reduction. It is generally acknowledged that a water level of 110 cm is the level where the city starts to be flooded. During the last century the lagoon has gradually been sinking due to natural activities (subsidence and sea level rise) and man-made activities (ground water extraction). Therefore, in the 1980's and 1990's the average water level was about 23 cm above the zero datum. More recent data show that the average water level is now closer to 30 cm above datum. This indicates that a sea level rise of 80 cm would bring the mean water level to the critical threshold of 110 cm. In this case, Venice would experience regular flooding twice a day, due to the tidal oscillation (tidal amplitude 40 cm during spring tide).

In the last years, major changes have occurred in the Venice inlets. One of these is the construction of the MOSE flood defence barrier system. One question that needs to be answered concerns for how long these mobile gates will be able to protect Venice from flooding. During the project planning phase, three sea level rise scenarios for the next century were considered. The most probable (Corila, 1999) gave an estimate of 16.4 cm, the prudent one (the one recommended for the MOSE project) 22 cm and the pessimistic one 31.4 cm. These estimates were clearly given at a time when climate change and sea level rise were still highly debated. It emerges however, that these numbers (even the pessimistic one) are now at the lower end of what is believed to be a realistic sea level rise scenario for the next century.

© Chris 73 - Aerial view of the Lido lagoon inlet with construction of the MOSE mobile barriers

In assessing potential economic damages that sea level rise could bring to Venice, two main aspects have to be considered. The first deals with damages to the historic buildings used for housing and economic activities. The estimates consider the increase in maintenance costs of building structures caused by periodic contact with salt water during flooding. The increase in damages (and subsequent annual maintenance costs) is estimated at about 50 % with respect to the damages experienced in the current situation.

The second aspect deals with the tourism sector. In 2030 the climatic attractiveness of the four local Venetian tourism centres (Jesolo-Eraclea, Chioggia, Bibione-Caorle and Venice) is expected to worsen as a result of the compounded effects of an increase in the number of Italian tourists and a decrease in foreign tourists. According to simulations, Venice in particular might lose 19 % of visitors in the trend scenario. However, losses are smaller when specific vulnerability is accounted for. The cultural and artistic appeal can partially compensate the lower climatic attractiveness, with projected losses to an average of 6%. In absolute terms, by 2030 Venice could lose between 105 and 415 million Euros a year due to a decline in tourist arrivals caused by a decrease in climate-attractiveness.

© Abxbay - Rising damp damage to brickwork and masonry. Rio de la Frescada

Conclusions

The future of Venice remains uncertain. In this report the potential impact of the sea level rise in this century has been investigated. Data and modeling have been used to come to an understanding of the changes in sea level that can be expected for the Venice lagoon.

The highest uncertainty we have to deal with is the global sea level rise. Estimates of the increase until the end of this century range from 18-59 cm (IPCC, 2007) to 215 cm (Grinsted et al., 2009). Results from IPCC only consider steric changes and do not consider ice melting. Models that give higher numbers are based on an empirical approach. However, data from satellites seem to indicate that sea level rise is already at its maximum with respect to the IPCC estimates. This evidence should point us to the possibility of a sea level rise higher than 60 cm. A rise of 100 cm should not be excluded.

It will still take some time to settle the question of how much the sea level in the Mediterranean and in the Atlantic can differ. However, latest findings indicate that the difference between both basins should not be higher than 10 cm, with an adjustment process that should not take longer than a few months. With these findings the sea level rise in the Mediterranean will be dominated by the global signal, even if some local differences might continue to exist. The fact that the steric change of the Mediterranean Sea could be much less (or even negative), simply indicates that the contribution of the Mediterranean to the global sea level rise will be much smaller than that of the other oceans. However, in the long run, the Mediterranean will follow the global ocean.

The same problem of how independently the single sub-basins react to sea level rise arises when dealing with the Adriatic Sea. However, in this case the connection with the rest of the Mediterranean is much less restricted as the one between the Mediterranean and the Atlantic Ocean. It is therefore conceivable that the Adriatic Sea should follow very closely the trends in the Mediterranean.

© Andrea Pattaro/AFP Photo/AFP/Getty Images - A view of St. Mark's Square and the Doge's Palace during extreme flooding in December 2008

Finally, the exchanges between the Adriatic Sea and the Venice lagoon will not allow any mean water level difference between both basins. Even if it has been demonstrated (Umgiesser, 1999 and 2004) that most of the storm surge peaks could be lowered by 20 cm if the section of the inlets would be (sometimes drastically) reduced, these interventions will not be able to change the mean water level between the interior and the exterior of the lagoon.

In conclusion, with the projections given in this report there should be no doubt that the sea level will eventually rise to a value that will not be sustainable for the lagoon and its historical city. The planned mobile barriers (MOSE) might be able to avoid flooding for the next few decades, but the sea will eventually rise to a level where even continuous closures will not be able to protect the city from flooding. The question is not if this will happen, but only when it will happen.

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Annex 1: Agenda

Sunday 21 November 2010

Arrival of participants

Day 1 - Monday 22 November 2010

09:00 - 09:30 Opening remarks & Welcome:
Engelbert Ruoss, Director, UNESCO Venice Office
Fabio Trincardi, Director, ISMAR-CNR, Venice
Overview of the activities of the ISMAR-CNR Institute of Marine Sciences of the National Research Council
Georg Umgiesser, Workshop Coordinator, ISMAR-CNR, Venice
Philippe Pypaert, Programme Specialist, Environment, UNESCO Venice Office

09:30 - 10:00 Stefan Rahmstorf
Global sea level projections since the IPCC AR4

10:00 - 10:30 John B. Anderson
Threshold response of low gradient coastal systems to accelerated sea-level rise: examples from the U.S. Gulf of Mexico

10:30 - 11:00 Eelco Rohling
A long-term perspective on potential sea-level rise due to ice-sheet reduction

11:00 - 11:30 *Coffee break*

11:30 - 12:00 Michael N. Tsimplis
Forcing of sea level variability in the Mediterranean Sea: The past and the future of direct atmospheric forcing and steric changes

12:00 - 12:30 Piero Lionello
Present and future of marine storminess in the Northern Adriatic Sea

12:30 - 13:00 Pier Vellinga and Natasha Marinova
Practical scenarios for sea-level-rise in Venice

13:00 - 14:30 *Lunch*

14:30 - 15.00 Vincenzo Artale
The sea level rise scenarios in the Mediterranean Sea for the XXI century from the new Regional Earth System Protheus

15:00 - 15:30 Silvio Gualdi
Climate change and sea level rise in the Mediterranean region from a high-resolution coupled AOGCM perspective

15:30 - 16:00 Mirko Orlić
Processes contributing to the Adriatic sea-level variability, with scales ranging from minutes to decades and beyond

16:00 - 16:30 *Coffee break*

16:30 - 17:00 Fabio Raicich
Sea level variations in the Mediterranean Sea since the late 19th century, with focus on the Adriatic Sea

17:00 - 17:30 Alberto Tomasin
Monitoring sea level at Venice by local and national Italian institutions

17:30 - 18:00 Closing session

20:00 *Social Dinner*

Day 2 - Tuesday 23 November 2010

09:00 - 09:30 Paolo Pirazzoli
Will the MoSE project be able to defend Venice and its lagoon against the predicted sea-level rise?

09:30 - 10:00 Margaretha Breil
Insights into economic impacts from climate change in Venice

10:00 - 10:30 *Coffee break*

10:30 Round table on the future of Venice

13:00 *End of workshop and lunch*

Annex 2: List of Participants

John B. ANDERSON
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Vincenzo ARTALE ENEA
National agency for new technologies, Energy and sustainable economic development, Rome, Italy

Margaretha BREIL
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THE FUTURE OF VENICE

AND ITS LAGOON IN THE CONTEXT OF GLOBAL CHANGE

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The urban ecosystem of Venice and its Lagoon is among the most studied urban and environmental systems in the world. Acting as neutral broker and facilitator, UNESCO Venice Office has mobilized expertise in the interdisciplinary fields of science and culture to identify and discuss the scientific, environmental, cultural and socio-economic challenges faced by the World Heritage site of Venice and its Lagoon in the context of global change.

This report presents a summary of the results and discussions from the first in a series of four workshops that were held to gather the necessary expert inputs needed to evaluate the current situation of Venice and its Lagoon and to contribute to a shared sustainable vision for its future. While providing a shared overview of the main challenges that are being faced by the Venice heritage site, the workshop report *From Global to Regional: Local Sea Level Rise Scenarios - Focus on the Mediterranean Sea and the Adriatic Sea* significantly contributes to the growing body of knowledge on the impacts of sea level rise on coastal and lagoon cities.

The results of the thematic workshops will be used by UNESCO to facilitate the vision, strategy and management plan for Venice and its Lagoon, and to prepare in collaboration with the local authorities a follow-up report to the one already elaborated by UNESCO in 1969 after the devastating *acqua alta* of 1966.

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