Région et Développement
n° 46-2017
www. regionetdeveloppement.org

Ocean acidification in the Middle East and North African region

Nathalie HILMI[*], Alain SAFA[**], Victor PLANAS-BIELSA[*], Yasser KADMIRI[***], Mine CINAR[****]

Abstract - After examining the current state of knowledge about ocean acidification in Middle East and North African (MENA) countries, we model the socio-economic impacts of disasters, ocean acidification and ecological risk. We use Extreme Value Theory and Peak Over Threshold concept to define the critical threshold point for ocean pH value as an Ornstein-Uhlenbeck process, initially with Gaussian noise. We define the benchmark pH based on time series observations which exhibit moderate to large variations and use Monte Carlo simulations and also model non-Gaussian cases to examine the probability of disasters.

JEL Classification
C02, O13, Q54, Q56, Q58

Key-words
Ocean acidification
MENA countries
Environmental disasters
Stochastic processes

[*] Centre Scientifique de Monaco ; hilmi@centrescientifique.mc
[**] Skill Partners
[***] Université de Toulon
[****] Loyola University of Chicago

INTRODUCTION

Regional variations in ocean Ph levels can deviate from global averages and vary in the Mediterranean Sea capable of producing large effects on fishing, diets, environment and tourism, which is of crucial importance for 466 million people (2010) in the coastal countries. Population is expected to grow to 529 million by 2025 and three quarters of the people will be from countries living in the southern shores of Meditternean which are in North Africa (Grida, 2017). Defining extreme events and predicting the probability of such events is of crucial importance in a region already suffering from unemployment, poverty and political instability. In this research, we describe the phenomena of ocean acidification (OA) in Middle East and North African (MENA) countries and examine the probability of future disasters. Section 1 define OA and the literature review of OA in MENA, Section 2 builds a stochastic model of acidification disaster events assuming Gaussian and non-Gaussian noise, and section 3 gives policy actions as conclusions.

1. CONSIDERING OA IN THE MENA COUNTRIES

1.1. Ocean Acidification : the other CO2 issue

Ocean acidification is the process through which the balance of the global ocean chemistry is changing. It consists in a decrease of ocean pH resulting from the dissolution of additional CO2 (primarily due to humans' increasing need of energy and its production by burning fossil fuel) in seawater from the atmosphere. This process becomes significantly relevant in the context of biology and the effects that occur in living organisms. Some areas, such as upwelling waters, polar and subpolar regions, some coastal and estuarine waters, are natural « hot spots » for ocean acidification.

Ocean acidification may cause an alteration of the growth of the shells of molluscs and skeleton of corals. Concerning fish species, shellfish are deeply affected by ocean acidification, while the fate of some species like finfish is still uncertain. It is known that fishes will have psychological (due to neurotransmitter effects of exposure to high CO2 waters) or physiological issues compromising their natural process of reproduction. The study of the impacts of ocean acidification needs to include issues pertaining to altered food-webs as well. For example, key trophic links such as shelled pteropods are sensitive to CO2 levels in the highly productive Southern Ocean where there are upwelling zones naturally rich in CO2.

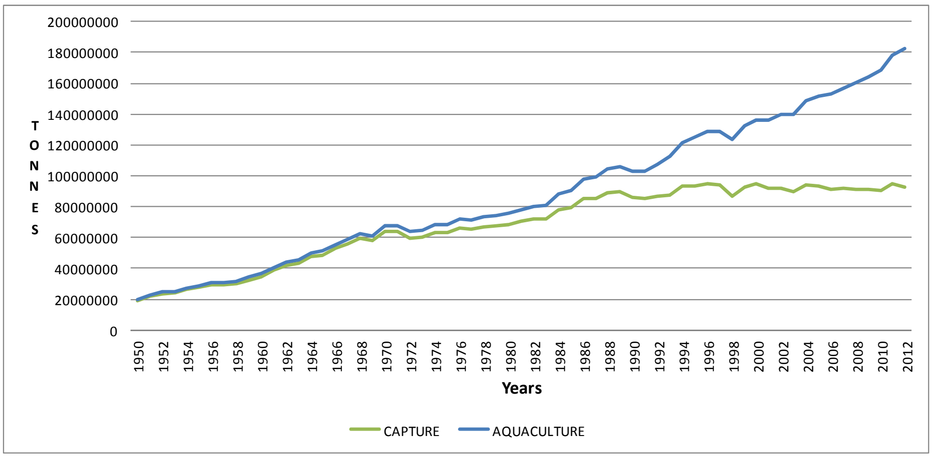
Ocean acidification will result in adverse economic impacts on employment, incomes, food security, trade and profits, and social and cultural impacts on well-being, poverty alleviation, social conflicts and population migration. Amongst the sectors that might endure dramatic social and economic downside are tourism, fisheries and aquaculture.

Fisheries and aquaculture are important components in food security and poverty alleviation. These sectors employ between 600 and 660 billion persons, directly and indirectly, about 10-12% of the world population (FAO, 2014).

The total fishery production (including both capture fisheries and marine aquaculture) has increased during the last few decades. World capture fisheries and aquaculture generated about US$ 18 billion in 2010 and provided 4,3 billion people with more than 15% of their animal protein, of which 90% live in developing countries. Over 95% of small-scale marine fishers live in developing countries (World Bank, 2012). This is why subsistence fisheries are so important for food security and poverty alleviation.

Disaggregating this production into capture fisheries and aquaculture portrays a different picture. Catches from wild stocks have stagnated while aquaculture production has increased substantially. The part of aquaculture in the world production has expanded twelve-fold during the last 30 years and represents nearly half of human seafood consumption (figure 1).

Figure 1: Capture and aquaculture world total production, by tonnes, 1950-2012



Source : FAO FishStat.

Predictions about the future biological effects of OA are of particular socio-economic significance because of the well-established importance of seafood in global food security and supply. They are also significant for the aquaculture industry that is positioning itself for a 'blue revolution', *i.e.* the aquatic analogue of the agricultural 'green revolution' that began in the 1960's, in order to fill much of the projected shortfall in food production from agriculture that will be needed to feed the world's population as it increases over the coming decades.

The research on ocean acidification is still in its early days. If the chemical effects are now recognized, the biological and ecological impacts have to be identified and documented. For instance, the knowledge of the effects of ocean acidification on fish is inadequate and the sensitivity of open ocean finfish fisheries to ocean acidification via physiological or food-web effects is not well understood. The effects of an ever-decreasing pH on fish eggs and larval development have to be studied in real environment conditions and not only in labs. The length of the incubation period experiments should be increased to investigate if the species can adapt to a more acidic environment. Other stressors should be concomitantly considered because a negative impact on a given parameter observed in the laboratory may not translate to a negative impact on the species fitness, and ecological interactions can modulate a species-level response. The aspects of biological pathways resulting from ocean acidification have not been thoroughly studied, e.g. very often, that part of the animal which has an economic value is its edible flesh, not the shell. If the calcification process is impacted by ocean acidification, that does not necessarily imply that the commercial value of the product would be affected should the gustative quality remain unaffected (Hilmi et al, 2012). It is necessary to fill in the gaps of knowledge through research, especially on finfish, high-value crustaceans (crab, lobster, shrimp) and early stages of sea-food species. Modelling may help to acquire relevant missing data, create adequate results, initiate the investigation of strategies and policies to mitigate the effects of ocean acidification. Yet the knowledge is still limited especially the biological uncertainties that need to be solved, so the socio-economic assessment is relatively undetermined. Case studies and best practices examples can serve as lessons. The interaction between natural and social sciences is crucial not only to develop the research, but also to propose relevant strategies to decision makers.

1.2. Socio-economic impacts of ocean acidification on MENA region

The health of the Mediterranean Sea is societally and economically important for more than the 400 million people living in 22 countries around its coasts (Ziveri, MedSeA consortium) and especially for the Middle East and North Africa countries since they're considered as less developed than their European neighbors.

Fisheries and aquaculture in the Mediterranean Sea represent 1% of world landings, and 2% in terms of economic value. While fish catches have remained quite stable since 1990's, aquaculture has quadrupled in production reaching 20% of production in 2011 (FAO, 2012). While aquaculture production is mainly supported by northern European countries, the fishery sector mainly comprises artisanal activities, being more common in southern Mediterranean countries. (Lacoue-Labarthe, 2016)

Due to the previsions of the ocean acidification impacts on the Mediterranean Sea and the communities' heavy dependence on marine resources in this region, they are more prone to experience changes in marine harvests. Nevertheless, few studies have reported ocean acidification responses of the most nutritionally or economically important species harvested in the Mediterranean. (Hilmi et al. 2013).

Hilmi et al. (2009) provide an analysis of the potential direct and indirect effects of the Mediterranean acidification on seafood. Concerning direct effects, there will be fatal effects on calcifiers such mollusks, sea urchins and crustaceans that inhibit shell growth and could even lead to shell dissolution in case of higher OA. A comparison and some experiments on species under the 2100 conditions' expectations present in the Mediterranean Sea show that OA doesn't affect all the marine species at the same level but there are OA tolerant ones. The paper shows also that even though fishes possess an internal medium with a naturally high CO2 concentration and appear tolerant to OA, its metabolism might be greatly altered in a small amount of time especially some commercial fishes such as dogfish and sea bass.

Indirect effects could be seen in some commercially high value marine creatures; finfish will be at risk because of the lack of some calcifying organisms such as crustacean zooplankton that will suffer from OA and that are very important to the diets to both adults and larval stages or alteration of some specific ecosystems like deep-sea corals that provide important socio-economical resources. The paper also gives an economic analysis where it underlines that it will take a macroeconomic approach in order to properly analyze the economic impacts of Mediterranean Sea acidification but it will be focused geographically in order to properly assess the specificities of the region using the FAO Fishstat database to provide summary conclusions. It concludes by giving directives about what should next research be based on like the necessity to focus more on the species that have been identified as of particular economic value for individual countries.

Another important aspect to the MENA countries studied by Hilmi et al. (2012) is coastal tourism since climate change will have inevitably a significant impact on global tourism. Climate actually controls the length and quality of tourism season, and it plays a major role in the choice of destination and tourist spending. The latter complicates the dynamics of how climate change will affect the global industry as tourism will continue to grow, but the patterns of travel will change and some destinations will benefit and others will be impacted negatively.

The paper offers figures about the evolution of tourism in the world from 1950 until 2011 and argues that “Arab Spring” affected very seriously the tourism in MENA countries. It has been an exceptional period that does not reflect the real potential of tourism in MENA countries as the arrivals decreased by 9% in the Middle East and by 15% in North Africa. It impacted not only the directly involved countries such Egypt, Syria… but also the European holidaymakers that were forced to stay away from the whole region. However, some other countries both inside and outside the region took benefit from the situation such as the Golf countries (except Bahrein), Turkey and destinations in southern and Mediterranean Europe in general. Up until 2010, the Middle East was the fastest growing region in 2010 (+14%).

Reef-related tourism in the region is most likely to be affected by ocean acidification as it encompasses a broad range of recreational activities including diving, snorkeling, free diving, education, cultural activities, fishing gleaning, kayaking, surfing, viewing from glass-bottomed boats, beach activities, and passive appreciation of beautiful coastal vistas (Cesar et al., 2003; Hoegh-Guldberg et al., 2000). Taking a very broad perspective, the values that people hold related to the existence of coral ecosystems unrelated to any direct use may also be considered. Reef related tourists and recreationists are diverse and can be from coastal communities living near reefs, other regions of the countries in which coral reefs are located (domestic tourists) or from distant countries (international tourists).

There are other micro-studies that give concrete examples of the importance of coral reef based tourism to coastal communities as around 2.5 million visitors a year enjoy the tropical coast area of Egypt of which 23% come specifically to dive and a further 33% participate in snorkeling activities (Cesar et al., 2003). In fact, the substantial growth of tourism activity is clear in the MENA region. The number of international arrivals shows an evolution from 18 million international arrivals in 1990 to an estimated 80 million in 2010. Therefore, we observe the same phenomenon with the rise in international tourist receipts increased from 1990 to 2010 (Hilmi et al., 2015).

Finally, ocean acidification will as well push people who depend on fisheries and crustaceans to leave their homes and migrate to other countries and other cities searching for job opportunities, which will create a concentration of poor people around the cities and will, in turn, influence the socioeconomic development of the country.

Another real threat is coral bleaching which directly affects tourism, especially since coral reefs are the first attraction for the tourists. The bleaching affects its beauty and they lose their shining colors for a white insipid color.

People depending on aquaculture see their production reduced because most of the species elevated find it hard to grow properly in an acidic environment.

We all know that acting on the reduction of anthropogenic carbon emissions is the solution either for ocean acidification problems or the climate changes in general. So, decision makers should take global measures in order to kill two birds with one stone.

In the developing destinations, it is difficult to keep under control the seaside model growth. At local level, tourism benefits are generally insufficient to finance fight against pollution and environmental nuisance. In emerging or potential destinations, the most beautiful coastal spots are coveted and are praise for investors who exert strong pressure to get and manage them. “Foreign enclaves” are developed and their benefits often completely elude the local populations. (Hilmi et al., 2012)

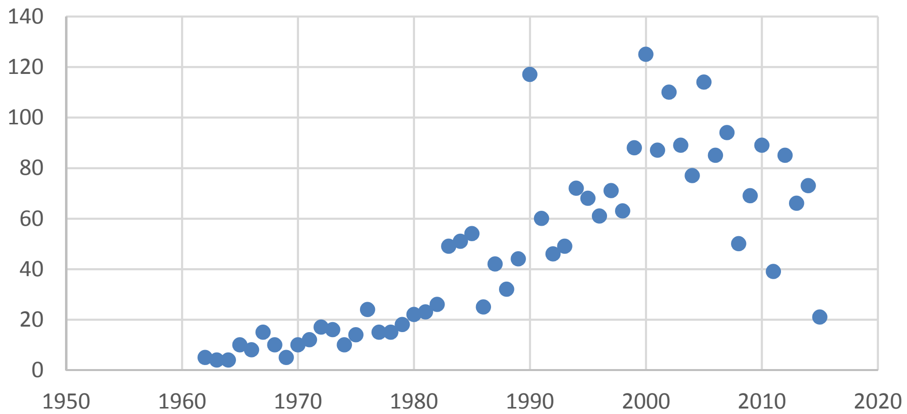
However, adapting to climate change does not necessary mean preparing for the worst. It can mean preparing to take advantage of new conditions. So exploring future positive as well as negative outcomes from climate change is important in developing climate adaptation strategies in tourism activities (Hilmi et al., 2012).

2. THE MODELISATION OF THE IMPACTS OF OCEAN ACIDIFICATION

2.1. Standard approach

Ocean Acidification is caused by cement production and the burning of fossil fuels. Those emit carbon dioxide into the air, and it builds in the atmosphere. Carbon dioxide is a greenhouse gas that causes global warming. And about a third of all that CO2 dissolves into the ocean, causing Ocean Acidification. It actually changes the chemistry of the water, and has negative effects on the organisms living in it. This absorption has as a consequence the decrease in the Ph of the ocean. The process is chemically well understood and there's no doubt that human emitted C02 has cause an increase of 30% in the acidification of the ocean (actually at a ph value of about 8.1 in average). Lower ph values may have consequences (to several degrees) in marine biodiversity. This change can also cause a socioeconomic impact in some areas where the economy is strongly linked to marine resources.

Figure 2: Reported disasters since 1960



Source : 'International Disaster Database'. http://www.emdat.be/database

Ph values are typically monitored as world averages. There are a number of studies trying to evaluate the impact of acidification in different marine species, especially those for which calcification is important. The results are mixed, thought there's no doubt that for some species, there are levels of acidification that will cause an increase in death rates, or a decrease in development rate. For other species, the effect is actually positive. The evaluation of the change in status quo of the local oceanic species distribution is an important topic of study.

Ocean Ph is a local measure with a high degree of variability around the globe. Though the global decrease of Ph has been well documented, local ph variations is actually of several orders of magnitude. There has already been localized episodes of temporary extreme acidification of coastal areas that have produced a localized equilibrium crisis, affecting both the biodiversity and the economic environment. We want to understand how a local 'ph-disaster' may affect the local economy.

Figure 2 shows that the number of reported disasters increases, in part due to increase exposure because of population growth, and also by increase number of weather related disasters, caused by global warming.

2.2. Statistical model to assess the impacts of disasters

As we want to also know how often and how big are the ecological disasters, standard deviation is a good description of variability only in 'normal' or 'central' conditions. Many natural phenomena have Fat Tails which means that extreme cases are more extreme than expected, and occur more often than expected (as extrapolated from central data). Analysis of peaks, and observations at the tails requires specific statistic tools. Extreme Value statistics is a crucial tool for risk assessment and risk management.

Global vs. Local impact of Ocean Acidification

Global average value of Ocean pH is 8.1 today, decreasing from a value of 8.3 during last glacial era. If the current CO_2 emission trends do not stop, the pH of the ocean is expected to reach 7.8 in year 2100 (Orr, 2011). However, global values have little meaning (if any) when analysing the consequences of acidification on ecosystems.

In general, global values are averaged in space and time. High frequency data for localised areas reveal that pH is a dynamic quantity whose range and variability depends greatly on local conditions, and in some areas one can observe variations of more than 1 unit of pH (Hofmann, 2011).

One of the reasons for this variability is that pH is determined by many other variables such as temperature, salinity, or aragonite saturations among others. Not all the oceanic areas have the same buffering capacity, and thus the variability of pH to changes in CO_2 differs greatly. For instance, the pH changes through the water column, and is typically lower at deep points (Rios 2015), and thus upwelling areas are more exposed to variability and temporal high acidification episodes.

Now, upwelling areas are not the only ones that could be labelled as 'at risk areas', and some specific locations may also have coincident factors that make them more exposed to raises in pCO_2. Arctic Ocean is potentially at risk for its own reasons; melting of ice due to global warming increases the intakes of fresh water, and making the Arctic ocean less effective in chemically neutralising the pCO2 acidifying effects (AMAP 2013).

Policy-makers are demanding for a shift from global climate studies toward more analysis of real and measurable impact on localised areas (Howes 2015, Parmesan et al. 2013). A local analysis cannot then stay focus on average values (that is the field of global climate studies) but on the dynamics and variations of the variables through time. However, some studies have proved that acidification episodes at time windows as smaller as 48 hours have a dramatic impact on bivalve larvae, if Ωar decreases below a certain threshold.

High temporal variability at the local level implies that certain ecosystems can be potentially exposed in a very near future, to pH levels that are only expected to be attained at the global level in 2100. To better understand which areas are locally more exposed to such a disaster risk, we need to apply statistical tool that go beyond the linear forecasting of mean values and that take into account variability in a more detailed manner that just by computing the standard deviation or the range of the values.

We can define a climate extreme event to a localised (temporally and geographically) quantifiable event that passes a given threshold. Some well-known cases are extreme rainfall, temperature extremes, annual frequency of typhoons in a given region, etc.

It has been shown that the number of extremes events linked to climate change has increased in the last decades, and there is strong evidence that at least part of this raise is linked to human influence. (Rahmstorf, 2011). Without entering in physical considerations, the increase in the number of extremes can be explained by a shift on the mean, or by a change in the shape of the probability density function that govern the underlying process (Coumou, 2011).

Extreme Value Theory (EVT) is the statistical tool that is used to model and describe the behaviour of extreme events (see Gumbel, 1958, Coles, 2001, or Beirlant, 2004, for instance). In EVT we are interested in describing and making inferences about the tail of the distribution. Two approaches can be taken: Block Maxima, and Peak Over Threshold (POT). In the first approach, the interest is to model the limiting behaviour of the maximum (or minimum) of a sequence of independent identically distributed (i.d.d.) random variables. The approach taken here is the POT. In this method, we fix a threshold and we consider only events that are beyond that value. It has been proved (Belkama, 1974, and Pickands, 1975) that for a very general class of systems, the resulting tail distribution follows a Generalised Pareto Distribution (GPD), that can be parametrised as follows:

$$P\left(x-t>y \mid x>t\right)=\left(1+\frac{\eta y}{\sigma_u}\right)^{\frac{-1}{\eta}}$$

where t is the threshold, σ is a scale parameter, and η is a shape parameter than gives information about how fat are the tails. It turns out that not only extreme events coming from physical and meteorological processes can be studied using POT, but also the large financial and economic losses that can result of those (see for instance Gilli, 2006, and references therein).

Montecarlo Simulation of POT statistics for shape shifting pH dynamics

Local dynamics of pH is very different depending on the location. High frequency pH data shows that variability can be strikingly different depending on the site (1), as it happens with many other climate related quantities. Open ocean measurements, for instance, tend to be more stable over time than coastal locations, where daily data may show variations of up to 1.4 pH units.

To understand how variations of the underlying probability distribution of coastal pH can modify the frequency of extreme events, specially at the most sensible areas, we introduce here the following two steps methodology.

First, we model the temporal evolution as a simple reasonable stochastic process for which an analytical solution is known if the uncertainty (noise) is normally distributed. This gaussian solution serves as benchmark to compare other types of uncertain behaviour. Then, we numerically simulate the evolution of the same model in the case in which the stochastic term has fat tails. We need to do this numerically as analytical expressions do not exists.

First, we will model the dynamic of the pH as an Ornstein-Uhlenbeck process with Gaussian noise:

$$dX_t=-\beta\left(X_t-\mu_t\right)dt+\sigma_t dW_t$$

where X_t is the pH, μ is the mean reverting parameter. σ is the standard deviation of the Gaussian process, and β is a parameter that refers to how strongly the process reverts to its mean. The solution to this stochastic equations when the parameters are stationary is well known, and the asymptotic probability distribution of the future values is again a Gaussian distribution with mean μ and variance $\sigma_X = \sigma^2/2\beta$.

It is well know that the process X_t has an exponentially decaying autocorrelation with exponent –β (see for instance Oksendal, 2003).

In order to calibrate the Ornstein-Uhlenbeck processes, several techniques are available, and the values will depend on each location. Thus, modelling of open ocean sites will have a stable mean reverting parameter and a low volatility, while coastal locations may fit better with a time dependent mean reverting parameter to account for daily oscillations that may be caused by physical changes, like temperature, buy also by changes in CO2 due to natural biological activity.

Our goal is not to calibrate our model to a specific site, but to illustrate the effect that the variation of the model parameters may have in the probability that a acidification *disaster* occurs, and point out that this risk may be underestimated with we do not consider factors such as the long term acidification trend, the increase of the volatility in the pH variation, or the effect of non Gaussian variations, in particular with positive excess of kurtosis.

To perform our analysis, we will define first a benchmark process with reasonable values for the parameters. We will then calculate the probability of having an extreme acidification episode in this setting. Finally, we will calculate how the probability of a pH disaster may increase dramatically, even for small variations of the model parameters.

The definition of disaster, or the level for which we can consider the pH to have reached an extreme value, is itself a parameter that will depend on the location. Not all species react or are impacted in the same way (Kristy, 2010) by the acidification, and depending on the ecosystem, the critical pH level; may be different. Again, for illustration purposes, we are going to consider as extreme episode, moment in which the pH decreases 4 standard deviations from its mean value. (We consider here 4 standard deviations of the asymptotic solution for the Ornstein-Uhlenbeck process, that is, the threshold t is defined as $pH_{threshold} = \mu - 4*\sigma_X$.

The benchmark is an Ornstein–Uhlenbeck process with mean pH μ = 8, β = 5, and $\sigma_X = 0.2$. These parameters are consistent with the order of magnitude that is found in pH time series for locations where variability is moderate to large (See Hofmann, 2011, for instance).

Downward trend for the mean pH

The first effect that we model is the linear decrease in mean pH value, which has been clearly documented in the literature (Broecker, 1966, and Feely, 2009). The decrease is slow enough to consider the process stationary at characteristic time-scale of the process. This time-scale depends on the mean reverting parameter β. The stronger it is the mean reverting component, the faster the system converges to its stationary solution.

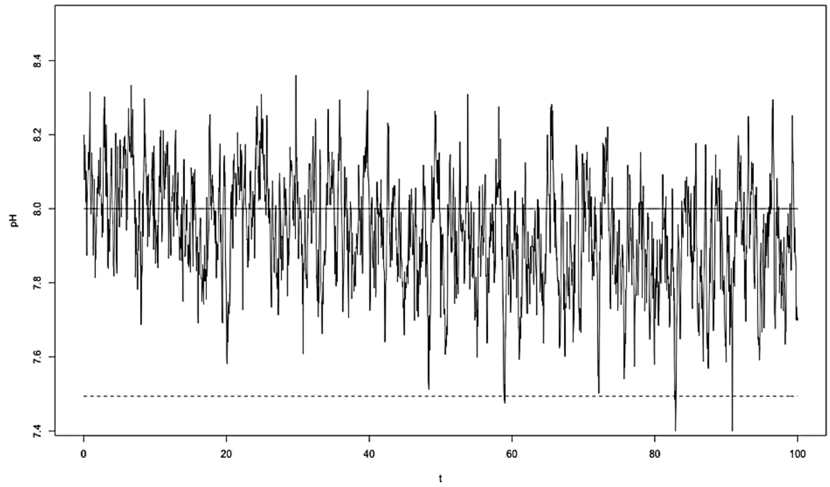
Figure 3 shows how our simulation of the benchmark process in which the mean is decreasing from 8 to 7.85 pH units. The solid line indicates the initial mean value μ = 8. The dashed line indicates the threshold value pHthreshold =7.47, for which a disaster occurs if the pH stays long enough beyond that point.

Something that we can easily compute in the Gaussian case is the percentage of days that the process is over the threshold, as a function of the mean value μ(t), and the pH volatility, σX(t).

$$P\left(X_t < pH_{\text{threshold}} \mid \mu(t), \sigma_X(t)\right)$$

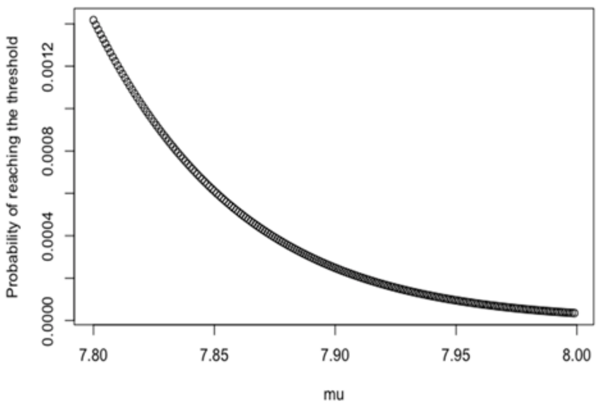
In Figure 4 we can see the impact of the downward drift in the mean pH value. The effect is highly non linear, and a change in pH value of 2.5% multiply for more than 40 times the chances to have a acidification disaster.

Figure 3. Simulation of stochastic pH evolution with slow downward trend



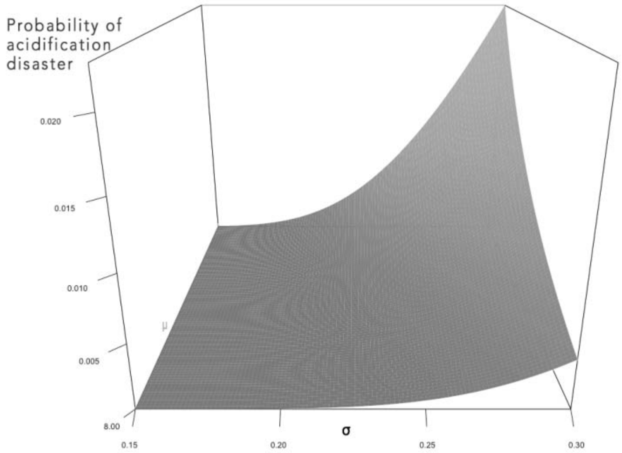
Changes in the volatility of the process also have a nonlinear impact on the probability of reaching the critical point. We can put together the two effects in a *risk map* as in figure 5. Each point in the 2D map corresponds to a pair of values (μ, σ_X). The bottom left corner corresponds to the benchmark process, and points toward the upper right corner correspond to process for which the mean value μ has decreased (increase of global acidification) and the variability has also increased.

Figure 4. Nonlinear relationship between average pH and probability of acidification disaster



Colours of the map correspond to different values for the acidification disaster risk, being warmer colours indicators of a high risk (Figure 5). The scale of the colour bar refers directly to the probability of being over the threshold limit.

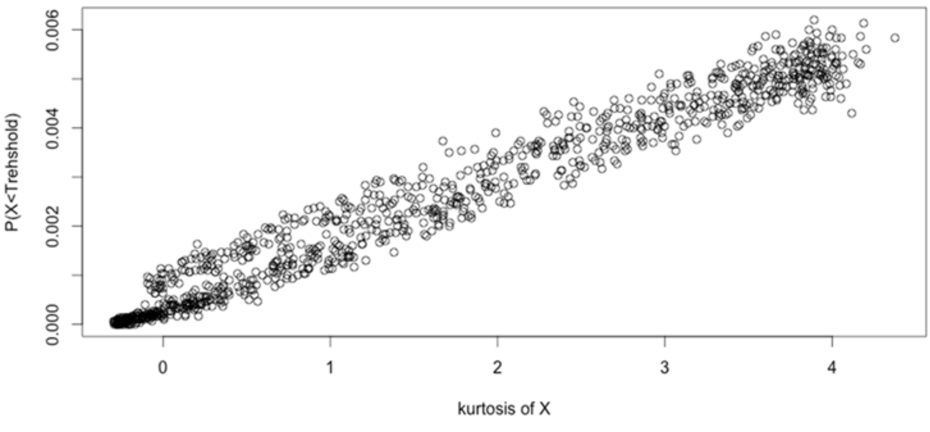
Figure 5. Risk map of acidification disaster



Non Gaussian Case

If the condition of Gaussian noise is drop from the model, we can no longer use the previous analytical results to easily calculate the effect of the parameter shifting. One option would be to substitute the Gaussian noise for a Levy driven stochastic term, for which some theoretical results exist. A simpler although more practical direction is to study numerically a discretized version of the Ornstein Uhlenbek process, and then modify the noise term from a distribution with different kurtosis values.

Figure 6. Relationship between departure from Gausian case and probability of acidification disaster (numerical simulation)



To do this, we generate a random variable whose distribution is a small deformation of the normal distribution. In particular, we generate the random variables as: $z=F^{-1} \circ (D \circ F(w))$, where D is a small polynomial deformation that does not modify the mean or the variance of the distribution, but ads a small kurtosis.

We then simulate a number of discrete Ornstein-Uhlenbeck processes (setting dt=0.01) to calculate the asymptotic probability distribution of X_t, from which we can easily calculate the probability of such values to be beyond the threshold.

By modifying the deformation parameter, we obtain different sample probability values depending, that we plot against the asymptotic probability distribution kurtosis, which is smaller than the kurtosis for underlying stochastic process. The results are shown in figure 6.

Deviations from the Gaussian hypothesis have a significant effect on the disaster risk, and thus this should be a parameter to consider in all statistical analysis of pH time series.

3. GENERAL CONCLUSIONS

Theoretically, a zero emission of CO2 would be the long-term solution to climate change and ocean acidification but this is a panacea and not economically viable on a worldwide scale. Thus, we believe that environmental issues should be addressed on a more regional level based on scientific data pertaining to the economy, culture or available natural resources. Nevertheless, a global mitigation approach is always valid and would most likely lead to sustainable outcomes. Furthermore, as economies are mostly driven by private sector, the latter must be considered as an important stakeholder for the process of determining adaptive solutions.

Ocean acidification can be included in global climate change negotiations in addition to increasing temperatures, pollution, sea level rise, overexploitation of resources and invasive species introduction. Scientists can determine the most tolerant species to ocean acidification to develop their culture because biodiversity is a natural capital and ecosystem services have non-monetary values too. So their protection and preservation in a healthy planet is a legacy to transmit to new generations.

To achieve rapid results in protecting the oceans, all the stakeholders should be involved. As we have noticed, developing countries are the most vulnerable to climate change and ocean acidification. No solution can be found without their participation in the negotiations. Also indigenous populations should be involved in the international negotiations because they are likely to be the most impacted communities.

To improve ecosystem and community resilience through better management options and to reduce the negative effects of other stressors (overfishing, destructions by divers, bad water quality), funding is necessary to undertake such actions, so financing solutions should be found. In addition to the Green Climate Fund, a Blue Ocean Fund could be raised.

When countries face economic crisis, the environmental issues become secondary. Governments seek to recover the economy thanks to an increase of growth domestic product (GDP), while ocean acidification potentially reduces all the components of the GDP : consumption, investment, governement spending, trade. That is why environmental options can be considered not only in structural policies, but also in cyclical policies and be inserted in monetary or budgetary policies. That is why environmental issues should be considered in both macroeconomic and microeconomic aspects.

Local mitigative actions should be developed, such as marine protected areas, in addition to human adaptation solutions. The private sector should be involved in environmental actions too. The firms can be environment friendly. As they imply investments, financial instruments should be implemented like taxes, insurances, loans and bonds, equities and derivatives… The biobanking scheme can complete the credit-trading scheme with biodiversity credits. In the Ecosystem Marketplace, natural capital is considered as important as other forms of capital. Nature is also a heritage for future generations. Industries and financial markets should be part of the solution at the same level as international organizations, governments and NGOs. Greening the financial system and the business, and including ocean-related issues would be part of mitigation and adaptation strategies. Public and private investments can be combined and oriented towards social, economic and environmental objectives.

Communication between the different stakeholders is crucial: scientists, policy makers, CEOs, businessmen, traders, bankers, international organisations and NGOs. As economists are a common components to all those parties, their language can be understood by most of them. Through education and training, the population can be informed and included in adaptative capacities. To convince people about climate change and ocean acidification risks, scientific facts may be presented with its advances and remaining questions. They have to know that the phenomena are amplifying year after year because the effects are cumulative and that it is really urgent to find mitigation and adaptation solutions. Even if there is no « one-fits-all » solution, some options are already locally applicable.

These attitudes toward resilience and/or increased adaptation are very important. The international community signed for a definitive agreement in 2015 in Paris about GHG emissions (greenhouse gases). The Kyoto Protocol will be extended and strengthened. The gap of "environmental" awareness between North and South will be bridged thanks to the establishment of an international climate green fund filled by countries with historical responsibility for carbon dioxide emission. This fund will support the developing countries' efforts after 2020. The MENA countries should be ready if they want to face the challenges thanks to the Green Fund for Climate.

REFERENCES

Beirlant J. Goegeburg Y., Teugels J. and Segers J. (2004), *Statistics of Extremes. Theory and Applications,* Wiley, England.

Belkama A. and De Haan L. (1974), "Residual life time at great age", *Annals of Probability,* 2, 792-804.

Bossell H. (ed.) (1999), Indicators for Sustainable Development: Theory, Method, Applications: A Report to the Balaton Group, Winnipeg, Canada: International Institute for Sustainable Development (IISD).

Broecker W.S. and Takahashi T. (1966), "Calcium carbonate precipitation on the Bahama Banks", *J. Geophys. Res*, 71, 6, 1575-1602.

Cesar H.S.J., Burke L., Pet-Soede L. (2003), The economics of worldwide coral reef degradation. Cesar Environmental Economics Consulting (CEEC), 6828GH Arnhem, The Netherlands.

Coles S. (2001), *An Introduction to Statistical Modeling of Extreme Values*, Springer– Verlag, London.

Common M., Perrings C. (1992), "Towards an Ecological Economics of Sustainability", *Ecological Economics,* 6, 7-34.

Constantin F. (2002), *Les biens publics mondiaux. Un mythe légitimateur pour l'action collective ?*, L'Harmattan, Paris.

Coumou D. and Rahmstorf S. (2012), "A decade of weather extremes", *Nature climate change*, 2, 7, 491-496.

Daly H.E. (1994), "Operationalizing Sustainable Development by Investing in Natural Capital", in AnnMari Jansson et al. (eds.), *Investing in Natural Capital: The Ecological Economics Approach to Sustainability,* Washington, D.C., Island Press.

Dixon J.A. and Fallon L.A. (1989), "The concept of sustainability: origins, extensions and usefulness for policy", *Society and Natural Resources*, 2, 73-84.

FAO (2014), The State of World Fisheries and Aquaculture. Rome: FAO Fisheries and Aquaculture Department.

Feely R.A., Doney S.C. and Cooley S. (2009), "Ocean acidification: present conditions and future changes in high-CO2 World", *Oceanography*, 22, 1490-1492.

Gabas J-J, Hugon P. (2001), « Les biens publics mondiaux et la coopération internationale », *Economie Politique*, 12.

Gilli M. and Këllezi E. (2006), "An application of extreme value theory for measuring financial risk", *Computational Economics*, 27, 2, 207-228.

Grida (2017), https://www.grida.no/resources/5900

Gumbel E. J. (1958), *Statistics of Extremes,* Columbia University Press, New York.

Hartwick J.M. (1977), "Intergenerational Equity and the Investing of Rents from Exhaustible Resources", *American Economic Review*, 66, 972-974.

Hilmi N., Allemand D., Cinar M., Cooley S., Hall-Spencer J. M., Haraldsson G., Hattam C., Jeffree R.A., Orr J.C., Rehdanz K., Reynaud S., Safa A., Dupont S., (2014), "Exposure of Mediterranean countries to ocean acidification", *Water*, 6, 1719-1744.

Hilmi N., Allemand D., Dupont S., Safa A., Haraldsson G., Nunes P.L.D., Moore C., Hattam C., Reynaud S., Hall-Spencer J.M., Fine M., Turley C., Jeffree R., Orr J., Munday P.L., Cooley S.R. (2012), "Towards improved socio-economic assessments of ocean acidification's impacts", *Marine Biology,* 160, 8, 1773-1787.

Hilmi N., Allemand D., Jeffree R.A., Orr J.C. (2009), Future economic impacts of ocean acidification on Mediterranean seafood: First assessment summary, Proc. 9th Int. Conf. on the Medit. Coastal Envir., Medcoast 09, E. Ozhan (Editor), 10-14 Nov., Sochi, Russia, 597-608.

Hilmi N., Safa A., Reynaud S., Allemand D. (2012), "Coral reefs and tourism in Egypt's Red Sea", *Topics in Middle Eastern and North African Economies*, 14.

Hilmi N., Safa A., Teisserenc B., Peridy N. (2015), "Sustainable tourism in some MENA countries", *Topics in Middle Eastern and North African Economies*, 17, 1.

Hoegh-Guldberg O. (2000), "Global Climate Change and the thermal tolerance of corals", *Galaxea, JCRS,* 2, 1.

Hofmann G.E., Smith J.E., Johnson K.S., Send U., Levin L.A., et al. (2011) "High-Frequency Dynamics of Ocean pH: A Multi-Ecosystem Comparison", *PLoS ONE*, 6, 12.

Howes E.L., Joos F., Eakin M., Gattuso J.-P. (2015), The Oceans 2015 Initiative, Part I: An updated synthesis of the observed and projected impacts of climate change on physical and biological processes in the oceans, Studies N°02/15, ID- DRI, Paris, France, 52 p.

Hyogo Framework for Action 2005-2015, Building the resilience of nations and communities to disasters, United Nations Office for Disaster Risk Reduction (UNISDR). http://www.unisdr.org/we/inform/publications/1217

Kroeker K.J., Kordas R.L., Crim R.N., and Singh G.G. (2010), "Meta-analysis reveals negative yet variable effects of ocean acidification on marine organisms", *Ecology Letters*, 13, 1419-1434.

Lacoue-Labarthe T., Nunes P.A.L.D., Ziveri P., Cinar M., Gazeau F., Hall-Spencer J.M., Hilmi N., Moschella P., Safa A., Sauzade D., Turley C. (2016), Impacts of ocean acidification in a warming Mediterranean Sea: an overview.

Mebratu D. (1998), "Sustainability and sustainable development: historical and conceptual review", *Environmental Impact Assessment Review*, 18, 493-520.

Ministère de l'environnement (2013) Rapport national de suivi sur la mise en œuvre du Cadre d'action de Hyogo (2011-2013).

Oksendal, B. (2003), *Stochastic Differential Equations. An Introduction with Applications*, Springer, Series : Universitext.

Orr J.C. (2011), Recent and future changes in ocean carbonate chemistry, In Gatusso J.-P & L. Hanson (Eds), *Ocean acidification*, Oxford University Press, Oxford.

Pickands J. (1975), "Statistical inference using extreme order statistics", *The Annals of Statistics*, 3, 119-131.

Rahmstorf S., Coumou D., (2011), "Increase of extreme events in a warming world", *PNAS*, 108, 44, 17905-17909.

Rios A.F. et al. (2015), "Decadal acidification in the water masses of the Atlantic Ocean", *PNAS,* 112, 32, 9950-9955.

Schiederig T., Tietze F., and Herstatt C. (2012), "Green innovation in technology and innovation management – an exploratory literature review", *R&D Management*, 42, 180-192.

Solow R.M. (1986), "On the Intertemporal Allocation of Natural Resources", *Scandinavian Journal of Economics,* 88, 141-149.

Stiglitz J. (1998), "More Instruments and Broader Goals: Moving Toward the Post Washington Consensus", WIDER Annual Lectures No. 2, Helsinki.

Tseng M-L., Wang R., Chiu A.S.F., Geng Y., and Lin Y.H. (2013), "Improving performance of green innovation practices under uncertainty", *Journal of Cleaner Production*, 40, 71-82.

UNWTO (2015), Yearbook of Tourism Statistics and Compendium of Tourism Statistics. http://statistics.unwto.org/content/yearbook-tourism-statistics.

Wacheux F. (1996), *Méthodes qualitatives et recherches en gestion*, édition Economica, Paris.

World Bank (2012), *Hidden Harvest: The Global Contribution of Capture Fisheries*. Washington DC.

Yin R. (1994), *Case Study Research, Design and Methods, Sage*, second edition revised (Première edition 1984).

Ziveri P., Institute of Environmental Science and Technology. Universitat Autonoma de Barcelona and the MedSeA consortium. Mediterranean Sea Acidification in a changing climate (MedSeA).

Acidification des océans dans la région Moyen-Orient et Afrique du Nord

Résumé - Après avoir examiné l'état actuel des connaissances sur l'acidification des océans dans les pays du Moyen-Orient et de l'Afrique du Nord (MENA), nous modélisons les impacts socio-économiques des catastrophes environnementales, de l'acidification des océans et des risques écologiques. Nous utilisons la théorie de la valeur extrême et du seuil maximal pour définir le point de seuil critique pour la valeur du pH de l'océan en tant que processus d'Ornstein-Uhlenbeck, initialement avec un bruit gaussien. Nous définissons ensuite le pH de référence sur la base d'observations de séries chronologiques qui présentent des variations modérées à importantes et utilisons des simulations Monte Carlo et des cas de modèles non gaussiens pour examiner la probabilité de catastrophes.

Mots-clés

Acidification des océans
Pays du Moyen-Orient et de l'Afrique du nord (MENA)
Catastrophes environnementales
Processus stochastiques