Collaborative Project

CLIM-RUN

Climate Local Information in the Mediterranean region Responding to User Needs

WP 1 – Climate Services Analysis and Support
Task 1.1 CLIM-RUN Protocol Development

D 1.3: Future Impacts at the Case Study Level

Project No. 265192– CLIM-RUN

Start date of project: 1st March 2011 Duration: 36 months

Organization name of lead contractor for this deliverable: PLAN BLEU

Due Date of Deliverable: Actual Submission Date: YYY

Authors: N. Rousset, S. Torresan, M. Davis, Christos Giannakopoulos, Ghislain Dubois
On the basis of WP5, WP6, WP7 and WP8 inputs

Table of Contents

1 - INTRODUCTION

The Mediterranean region is considered as a “hot spot” of climate change and is already highly vulnerable to climate variability. A better understanding of impacts of climate variability and change would be an essential input to promote sectoral adaptation strategies and planning at local and regional scales. The Clim-Run experience based on a strong involvement and communication with stakeholders has shown that the delivering of clear information on the potential impacts of climate variability and change is an important climate information need expressed by stakeholders. As a matter of fact,

The main objective of this deliverable is thus to describe, assess and analyze the potential impacts of climate variability and change at the case study level. An important effort has been made to use indicators and modalities of representation of the impacts useful for the stakeholders. In this way, the information delivered here are intended to support the implementation of adaptation measures at regional and local scales.

More precisely, the impacts of climate variability and change has been assessed for the coastal region of the Italian North Adriatic Sea (WP8), the forest fire risk in Greece (WP6), the wind energy sector at the Mediterranean level (WP7), and the tourism sector in Tunisia (WP5). The analysis of potential impacts of climate variability and change and the delivering of indicators are mainly based on results from the WPs Case Study (WP5, WP6, WP7 and WP8) and on the climate products produced to respond to expressed user needs at the case study level and developed jointly by the Climate Expert Team, the Stakeholder Expert Team and the WPs Case Studies Team. It should be noted that the methodology used as the indicators presented here are quite different from one case study to other ones, depending on the socio-economic sector at stake, on the stakeholder types involved in the process and information needs, but also on the scientific background of scientists involved in the WPs Case Studies Team, from social science to climate science.

In this way, the methods and tools used for the coastal region of the Italian North Adriatic Sea is based on the Regional Risk Assessment (RRA) methodology and the GIS based Decision support SYstem for COastal climate change impact assessment DSS DESYCO. The use of this methodology has permitted to develop impacts indicators for two main risks of climate variability and change in the North of the Adriatic sea : (i) pluvial flood inundation risk maps and statistics for urban areas, and (ii) sea level rise inundation risk maps and statistics.

The assessment of impacts and vulnerability of Greek forests to climate change is mainly based on the Forest Fire Weather Index (FWI) Model and on the conceptual framework of vulnerability developed on IPCC. This methodology has permitted to assess change in the exposure understood as the change in regional FWI following changes in temperature and precipitation indices, to provide an analysis of the sensitivity factor by creating fire hazard maps based on static information on the topography and vegetation, and finally to assess the level of vulnerability of each Greek region by taking into account relative adaptive capacities.

For the wind energy sector, wind forecast indicators have been developed at a seasonal timescale by using climate forecast system to generate wind predictions for the next season and their associated uncertainty, but also probabilistic future wind speed. Wind predictions have also been simulated at climate change timescales (2021-2050).

For the tourism in Tunisia, an analysis of climate-tourist environment on the present climate, but also the evolution under climate change condition has been developed by using TCI indicators. Moreover, as Tunisian tourism is essentially a seaside destination, seasonal forecast and long term changes (2021-2050) of sea surface temperature have also been simulated.

2 - ASSESSMENT OF FUTURE IMPACTS OF CLIMATE VARIABILITY AND CHANGE IN THE COASTAL ZONE OF THE NORTH ADRIATIC SEA (ITALY)

2.1 - Context

Coastal areas represent an irreplaceable and fragile ecological, economic and social resource highly threatened by potential impacts of climate-induced hazards such as more frequent inundation of low-lying areas, increased rates of coastal erosion, saltwater intrusion, accelerated sea level rise. Moreover, rapidly growing population, urbanization and associated land use changes in coastal areas would exacerbate these issues and could potentially increase the environmental and anthropogenic risks calling for new integrated management challenges and adaptation strategies.

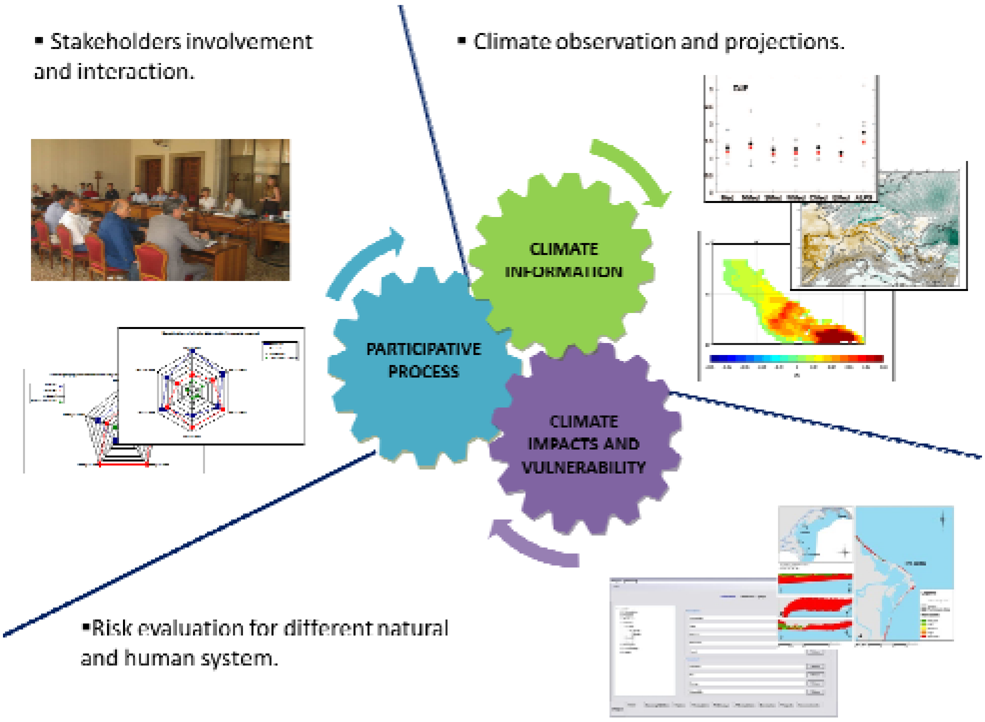
Coastal zones are considered key climate change hotspots worldwide and coastal systems are projected to be increasingly at risk over future decades (IPPC 2007, 2012). The major expected climate change impacts in coastal zones will include sea-level rise, coastal erosion, alteration in water quality and increase of flooding due to extreme events (e.g. heavy precipitations, storms) and will affect different natural and human systems and sectors including health, tourism, agriculture, industry, energy. As a result, new challenges are posed to coastal managers and policy makers that need an increasing amount of climate information in order to include climate change in the definition of Policies, Plans and Programs, ensuring a sustainable management of the coastal zone.

The interest for climate risk information in coastal areas is therefore rising due to the social and economic benefits that different stakeholders can achieve managing climate risks in order to ensure a sustainable integrated coastal zone management aimed at preserve coastal environments and socio-economic activities. The development of climate services transferring knowledge about climate-related risks to stakeholders and society is becoming a key step to communicate information about the expected impacts of climate change and mainstream climate change adaptation into local and regional planning.

The main objective of the Italian North Adriatic Sea Case Study (WP8) is to analyze the need of climate information and the effectiveness of climate services for the integrated assessment of climate change impacts in coastal zones at the regional to local scale. Research activities were organized according to three main tiers illustrated in Figure 1: (i) the participative process, aimed

at understanding needs and requests of the stakeholders for what concern climate impacts and risks; (ii) the climate information, aimed at providing forecasts and projections on future climate change scenarios; (iii) the climate impacts and vulnerability, integrating climate data and end-users requests in order to evaluate climate-related risks for different natural and human systems.

FIGURE 1: The three main tiers for the development of climate risk and adaptation services within the North Adriatic case study



For this purpose within the Italian North Adriatic Case study, climate risk and adaptation services answering coastal stakeholders needs were developed applying an integrated approach based on the involvement of different experts (i.e. Stakeholders, Climate and Risk Experts) working in synergy (see D8.4). Specifically, the Stakeholders Experts Team (SET) supported the stakeholders involvement and engagement; the Climate Experts Team (CET) developed tailored climate services and products relevant and usable by end-users (e.g. regional climate projections, seasonal forecasts, extreme event indices); finally, the Risk Experts Team (RET) used climate modeling information in order to analyze policy-relevant impacts on different natural

and human systems (e.g. impacts of sea level rise on low-lying coastal systems, impacts of precipitation extremes in urban areas) and transfer the results to decision-makers and practitioners in the area of climate adaptation.

Methods and tools applied to the North Adriatic coast by the RET in the third tier of the process in order to produce climate risk and adaptation indicators for stakeholders namely are describe in the next section. It concerns the Regional Risk Assessment (RRA) methodology and the GIS based Decision support SYstem for COastal climate change impact assessment DSS DESYCO.

2.2 - The Regional Risk Assessment (RRA) Methodology and the Decision support SYstem for COastal climate change impact assessment (DESYCO)

The Regional Risk Assessment (RRA) is a procedure aimed at providing a quantitative and systematic way to estimate and compare the impacts of environmental problems that affect large geographic areas considering multiple sources releasing a multiplicity of stressors impacting multiple endpoints (Hunsaker et al., 1990; Landis, 2005).

The RRA integrates Multi Criteria Decision Analysis (MCDA) techniques in order to (i) estimate the relative risk in the interested region, comparing different impacts and stressors; (ii) identify and prioritize targets and areas at risk (e.g. residential and commercial-industrial areas, beaches, infrastructures, wetlands, agricultural areas); (iii) select risks that should be investigated in more detail and localize priority areas where adaptations strategies could be required.

The RRA methodology was developed upon the three main pillars of risk defined by UNISDR (2009) and IPCC (2012) (i.e. hazard, exposure, and vulnerability) and is composed of four main steps:

- Hazard Assessment;
- Exposure Assessment;
- Environmental vulnerability Assessment;
- Relative Risk Assessment.

The **Hazard assessment** aims at defining hazard scenarios representing the physical phenomenon related to climate change (i.e. sea-level rise, heavy precipitations) that can cause damages to affected regions and targets. This step requires the definition of hazard metrics (e.g. intensity of precipitation, sea-level rise, water depth, flood extension) derived from climatic and/or dedicated impact models (e.g. hydrodynamic or hydrological models) or from statistical analysis of time series. The hazard assessment phase was performed using outputs of climate models, projections and observations developed within the CLIM-RUN Project (i.e. WP2 and WP3). Moreover, the identification of appropriate hazard metrics and stressors was performed trough a close collaboration with CET and taking into considerations stakeholders' requests.

The second step of RRA is the **Exposure assessment**, aimed at identifying and localizing the receptors (i.e. elements at risk) that can be subject to potential losses due to climate change impacts. This step requires the analysis of land use/land cover datasets for the localization of people, environmental resources, infrastructures, social, economic or cultural assets that could potentially be in contact with a given climate change hazard.

The **Environmental Vulnerability Assessment** is the third step of the RRA and is aimed at evaluating the degree to which the receptors could be affected by a climate change hazard. This step requires the analysis of vulnerability factors which determine the susceptibility of a receptor to different climate change hazards. Vulnerability factors are represented by geo-physical or ecological factors (e.g. geomorphology, slope, vegetation cover, land use) and are used to measure the degree to which a receptor is affected, either adversely or beneficially, by climate-related stimuli (IPCC, 2007).

Finally, the **Relative Risk Assessment** step is aimed at identifying and classifying areas, receptors and hotspots at risk in the considered region. This phase combines the information about the climate change hazard scenarios with the exposure and the environmental vulnerability assessment providing a relative evaluation of risks for each analyzed receptor.

In the North Adriatic case study the RRA was applied following a bottom up approach involving stakeholders early in the process with the support of the Decision support System for COastal climate change impact assessment (DESYCO) and GIS tools. DESYCO is a GIS-based Decision Support System (DSS) which implement the RRA in order to provide an integrated assessment of multiple climate change impacts (e.g. sea-level rise inundation, coastal erosion, water quality

variations) on vulnerable coastal systems (e.g. beaches, river deltas, estuaries and lagoons, wetlands, agricultural and urban areas).

The use of this methodology has permitted to develop impacts indicators for two main risks of climate variability and change in the North of the Adriatic sea : (i) pluvial flood inundation risk maps and statistics for urban areas, and (ii) sea level rise inundation risk maps and statistics.

2.3 - Impacts of Climate Variability and Change

According to preferences expressed by local stakeholders (see D8.2) the analysis was applied to the coastal zones depicted in Figure 2, including: (i). the Municipality of Venice (Italy), for the evaluation of pluvial risk in urban areas under future climate change scenarios; and (ii) the overall coastal area of Veneto and Friuli Venezia Giulia regions, for the evaluation of sea-level rise inundation in coastal zones under future climate change scenarios.

The issues tackled by the risk products were considered very important by local stakeholders because, in recent years, the North Adriatic coastal zone has been dealing with an increasing number of damaging flood events due to heavy precipitation events; moreover, the effect of sea level rise on storm surge is a prominent issue in relation with the high tide events affecting the city of Venice.

According to the overall need of local stakeholders for information on a mid-term timeframe (SEE D8.1), the analysis of climate-related risks was performed for the future decade 2041-2050. Moreover, for the sea level rise impact hazard maps were elaborated from the output of PROTHEUS/ENSEMBLES models forced by the A1B emission scenario in terms of sea-level rise scenarios (Dell'Aquila et al., 2013) coupled with topographic information from the Digital Elevation Model with a spatial resolution of 5m. For pluvial floods impact, hazard maps were elaborated from the output in terms of precipitation scenario of the RegCM4 model forced by the RCP 8.5 emission scenario (Giorgi et al., 2012), coupled with a comparison of total daily precipitation and the Maximum Pluvial threshold defined by ARPAV (Regional Agency for Environmental Protection of the Veneto) based on an analysis of the state of the soil (ARPA Piemonte, 2004).

Risk maps were produced by integrating hazard maps with exposure and vulnerability maps (representing information about physical, geographical and environmental features of the North

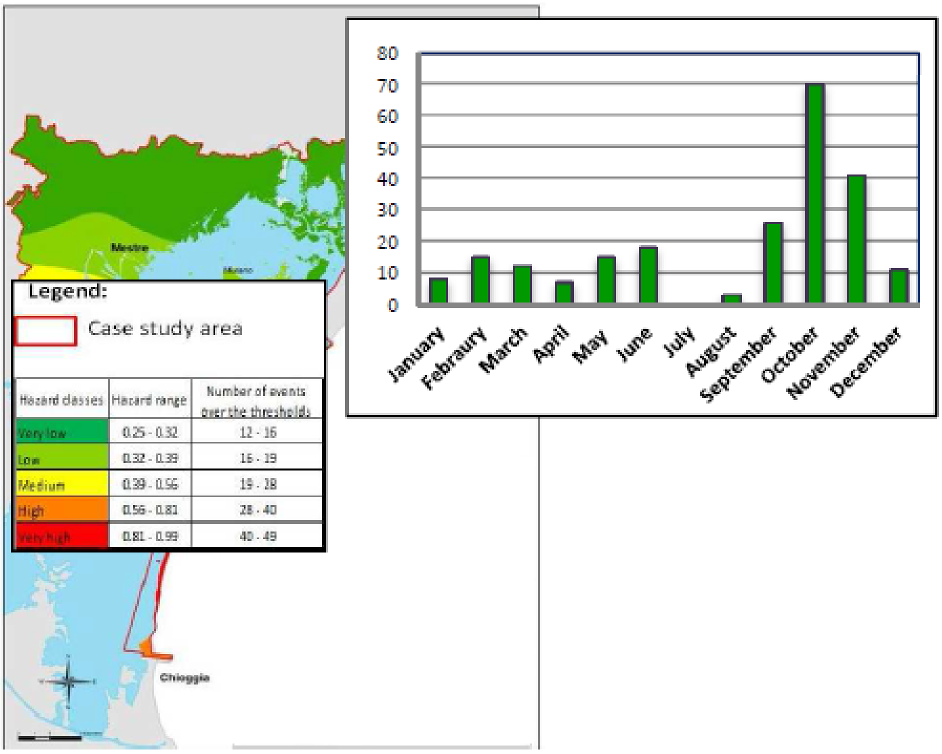
Adriatic region) in order to provide a relative classification of areas which are more likely to be affected by sea level rise and pluvial flood risk in the future decade 2041-2050.

FIGURE 2: North Adriatic case study (Italy)

The analysis for pluvial flood risks was performed analyzing commercial-industrial areas, residential areas and infrastructures receptors and producing maps with a spatial resolution of 5m.

Specifically, the hazard map obtained for the pluvial floods impact period allowed identifying the areas of the municipality of Venice that could be more interested by hydraulic emergencies in the 2041-2050 decade (Figure 3). Moreover, the hazard scenario of pluvial flood depicts that the major number of potential emergencies (i.e. from 26 to 70 potential emergencies) will take place in the autumn season (i.e. September, October, November).

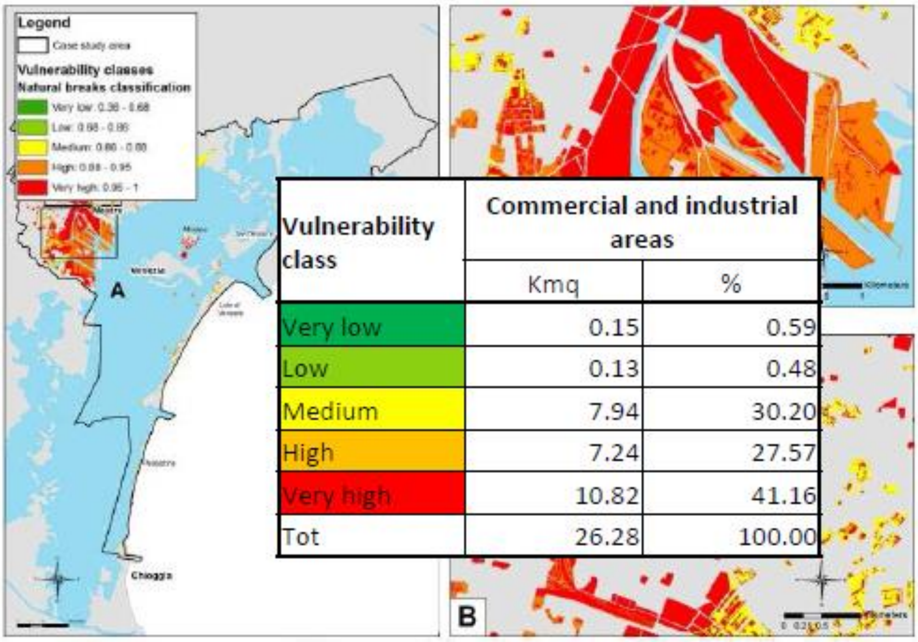
FIGURE 3: Hazard map representing the number of potential hydraulic emergencies in the 2041-2050 scenario and related statistics reporting the number of potential hydraulic emergency for each month of the 2041-2050



Vulnerability maps highlighted that all the receptors are highly vulnerable to pluvial floods with more than 60% of the territory in the high and very high vulnerability classes (Figure 4).

Despite of this, risk maps showed that all the receptors present few areas in the higher risk class (less than 0,54 km^2) and that the risk increases moving to south-east according with the spatial distribution of hazard classes.

FIGURE 4: Vulnerability map and related statistics showing the distribution of the percentage of surface associated with each vulnerability class for the receptor commercial and industrial areas



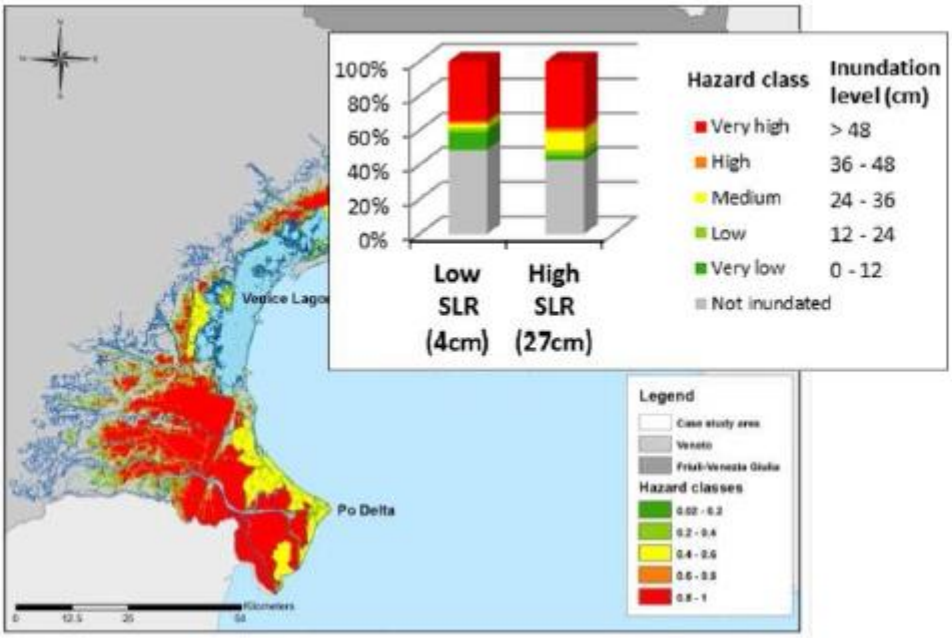
Vulnerability class	Commercial and industrial areas	
	Kmq	%
Very low	0.15	0.59
Low	0.13	0.48
Medium	7.94	30.20
High	7.24	27.57
Very high	10.82	41.16
Tot	26.28	100.00

As far as the sea level rise inundation risk is concerned, the analysis was performed considering multiple coastal receptors selected by local stakeholders (e.g. beaches, wetlands, protected areas, river mouths, agricultural areas, terrestrial biological systems and urban areas) and comparing different sea level rise scenarios (i.e. high, medium and low) considering different projected water levels (i.e. 4, 15 and 27 cm).

The evaluation of risk related to sea-level rise inundation in coastal areas was performed applying a simplified approach that projects the water height, related to the future sea-level rise scenarios, inland and inundates all land areas at an elevation below this level using the topographic information coming from the Digital Elevation Model (DEM), with a spatial resolution of 5m for the North Adriatic coastal areas.

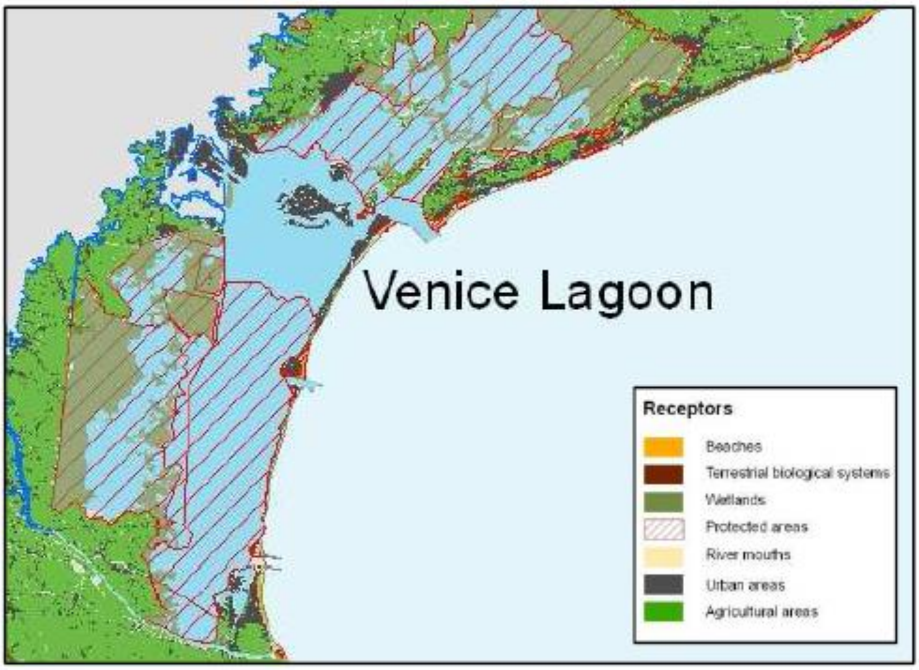
The results of the hazard maps (Figure 5) highlighted that more than 50% of the investigated area will be potentially inundated by a future sea-level rise inundation (2041-2050) for all the three SLR scenarios considered (4cm, 15cm and 27cm).

FIGURE 5: Hazard map for sea-level rise inundation impact (for projected water level of 27 cm) and related statistics showing the distribution of the percentage of surface associated with each hazard class



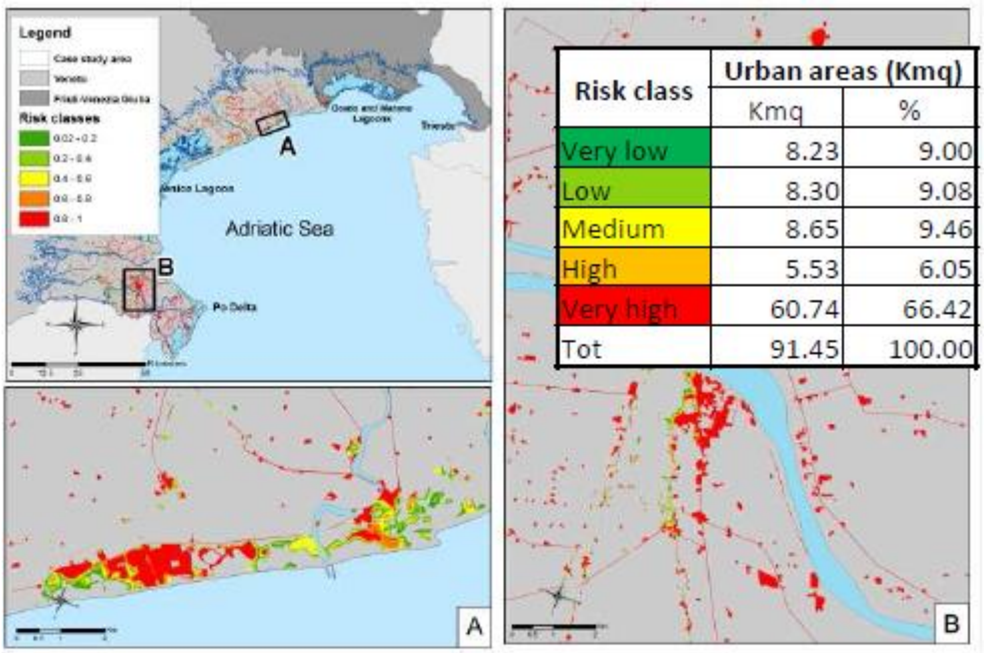
Exposure maps allowed to identify that the receptor most affected by a potential SLR inundation are agricultural areas, however, also terrestrial biological systems, urban areas and river mouths presented most of the surface areas characterized by high and very high risk scores in all the considered scenarios (Figure 6).

FIGURE 6: Exposure map for the receptor beaches, terrestrial biological systems, wetlands, protected areas, river mouths, agricultural areas and urban areas.



Risk maps highlighted for each receptor the areas at risk of inundation for each risk class. For example, urban areas are highly vulnerable to sea-level rise with more than 70% of the surface of urban areas in the high and very high vulnerability classes for a 27 cm sea-level rise scenario.

FIGURE 7: Risk map of urban areas for sea-level rise scenario (27 cm) and related statistics showing the distribution of the percentage of surface associated with each risk class.



Risk class	Urban areas (Kmq)	
	Kmq	%
Very low	8.23	9.00
Low	8.30	9.08
Medium	8.65	9.46
High	5.53	6.05
Very high	60.74	66.42
Tot	91.45	100.00

DESYCO and RRA proved to be useful tools to bridge the gap between climate experts and local stakeholders allowing to develop suitable indicators and maps to support decision making and coastal management in a wide range of situations (e.g. shoreline planning, land use management, flood risk reduction, strategic environmental assessment) (see D8.4).

Both sea-level rise and floods indicators and maps developed by RET were considered useful as first-pass assessment of critical vulnerabilities associated to climate change in the North Adriatic region. However, it was agreed that a more detailed analysis is necessary in order to respond to very specific needs of stakeholders (e.g. how to improve urban drainage systems, when and where plan the construction of protection barriers). For this purpose further developments should consider a more detailed parameterization of local processes (e.g. by means of hydraulic models) and a more precise spatial dataset (e.g. high resolution data obtained by Light Detection and Ranging techniques (LIDAR), information about the capacity, structure and localization of the urban drainage system; information about the height and level of protection of coastal defenses) in order to give a more precise assessment and localization of climate risks at the local scale.

2.4 - References

ARPA Piemonte, 2004. *Convenzione tra il dipartimento per la protezione civile e l'Arpa per l'assistenza alla gestione delle situazioni di rischio idrometeorologico sul territorio nazionale*. Soglie pluviometriche

Dell'Aquila A., Calmanti S., Ruti P., Struglia M., Pisacane G., Carillo A., Sannino G., 2012, Effects of seasonal cycle fluctuations in an A1B scenario over the Euro-Mediterranean region, *Climate Research,* 52, pp. 135–157.

Giannini V., Torresan S., Gallina V., Critto A., Giupponi C., Marcomini A., 2011, Deliverable 8.1 Workshop report: context and objectives, comparison of data supply and demand, simulation results, feedback and discussion. Integrated case study: Veneto and Friuli Venezia Giulia, Northern Adriatic Sea, Italy – CLIM-RUN project report.

Giannini V., Torresan S., Gallina V., Critto A., Marcomini A., 2013, Deliverable 8.2 - Workshop report: context and objectives, confrontation of data supply and demand, simulation results, feedback and discussion - CLIM-RUN project report.

Giorgi F., Coppola E., Solmon F., Mariotti L., Sylla M.B., Bi X., Elguindi N., Diro G.T., Nair V., Giuliani G., Turuncoglu U.U., Cozzini S., Güttler I., O'Brien T.A., Tawfik, A.B., Shalaby A., Zakey A.S., Steiner A.L., Stordal L.C., Brankovic C., 2012, RegCM4: model description and preliminary tests over multiple CORDEX domains, Climate Research, 52, pp. 7-29.

Hunsaker C.T., Graham R.L., Suter G.W., O'Neill R.V., Barnthouse L.W., Gardner R.H., 1990, Assessing ecological risk on a regional scale, *Environmental Management,* 14, pp. 325-332.

IPCC, 2007, Parry L., Canziani O.F., Palutikof J.P., van der Linden P.J., Hanson C.E. (Eds), *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 976 p.

IPCC, 2012, Field, C.B., Barros V., Stocker T.F., Qin D., Dokken D.J., Ebi K.L., Mastrandrea M.D., Mach K.J., Plattner G.-K., Allen S.K., Tignor M., Midgley P.M. (Eds.), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 582 p.

Landis W.G., 2005, Regional scale ecological risk assessment, In: Landis WG, (ed), *Using the relative risk model*, CRC Press.

UNISDR, 2009, *Global assessment report on disaster risk reduction – Risk and poverty in a changing climate*, United Nations, Geneva, Switzerland, 207 p.

Torresan S., Critto A., Rizzi J., Marcomini A., 2012, Assessment of coastal vulnerability to climate change hazards at the regional scale: the case study of the North Adriatic Sea, *Natural Hazards and Earth System Sciences*, 12, pp. 2347-2368.

Torresan S., Rizzi, J. Zabeo A., Critto A., Gallina V., Furlan E. and Marcomini A., 2013, *Assessing environmental impacts of climate change at the regional scale to provide adaptation services: the DEcision support SYstem for COastal climate change impact assessment (DESYCO)*, Proceedings of the first annual conference SISC on climate change and its implications on ecosystem and society, 23- 24 September 2013, Lecce, Italy, pp. 468-476.

3 - ASSESSMENT OF FUTURE IMPACTS OF CLIMATE VARIABILITY AND CHANGE FOR WILD FIRES RISK IN GREECE

3.1 - Context

Forest fires constitute a major environmental and socioeconomic issue in the Mediterranean. An average of 50,000 fires per year burn a range of 470,000 hectares annually causing, apart from ecological catastrophe, severe damages in infrastructures, economic costs, and, quite often, human casualties (Schmuck et al., 2011). Although forest fires have always been present in the Mediterranean and the Mediterranean climate-type forest areas are extremely fire prone, their destructive capacity is on the rise for the last few decades (Pausas and Vallejo, 1999), while an extension of the fire season has been reported (Flannigan et al., 2009; Dimitrakopoulos et al., 2011).

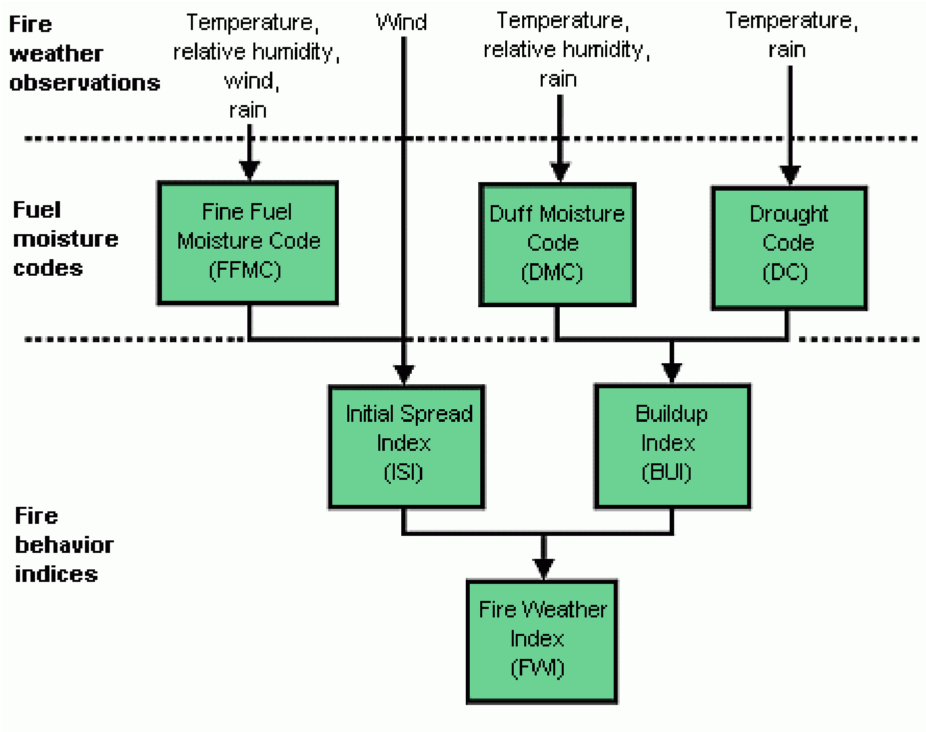
Forest fires are highly sensitive to climate change because fire behaviour responds immediately to fuel moisture (Weber and Flannigan, 1997, Stocks et al., 2001). Thus, the projected increase in temperature increases fuel dryness and reduces relative humidity and this effect worsens in those regions where rainfall decreases. These trends are expected to have a great impact on forest fire vulnerability in the Mediterranean region (Beniston, 2003).

3.2 - Methodology: The Forest Fire Weather Index (FWI) Model and the Vulnerability Assessment

The analysis of fire risks under climate change is based on the Forest Fire Weather Index. The Forest Weather Index (FWI) is a numerical rating of fire intensity based on physical processes, suitable for use as a general index of fire risk (Natural Resources Canada, 2008; van Wagner, 1987). The FWI model has been used at several locations, including the Mediterranean basin (Moriondo et al., 2006, Carvalho et al., 2008; Giannakopoulos et al., 2012). Furthermore, since 2007 the FWI has been adopted at the EU level by the European Forest Fire Information System (EFFIS) of the Joint Research Centre of the European Commission (http://forest.jrc.ec.europa.eu/effis). Thus, it seems a sensible choice for analysing the impacts of climate change on fire risk at the Mediterranean and Greek level.

The FWI System has six standard components (Figure 8) each measuring a different aspect of fire danger: three fuel moisture codes and three fire behaviour indices. Each component has its own scale of relative values, with a high number indicating more severe burning conditions.

FIGURE 8: Structure of the Fire Weather Index System



Source: Natural Resources Canada (2008)

The FWI System provides numerical ratings of relative fire potential based on weather observations. The meteorological inputs to the FWI System are daily noon values of temperature, relative humidity, 10m wind speed and precipitation during the previous 24 hours (van Wagner, 1987). It has been used to predict peak burning conditions expected to occur at around 16:00. FWI represents the frontal fire intensity and is used to estimate the difficulty of fire control.

The concept of vulnerability is defined by IPCC (2001) as “The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity”. Thus as per this definition, vulnerability has three components: exposure, sensitivity and adaptive

capacity. The first two components together represent the potential impact and adaptive capacity is the extent to which these impacts can be averted. Thus, under this conceptual framework,

Vulnerability = Impact-Adaptive capacity

Where

Impact= sensitivity * Exposure

The assessment of potential impacts and vulnerability methodology is based on three main steps:

1- **Exposure assessment**: A meteorological fire danger index is calculated at the case study level and its future evolution under climate change scenario is projected up to 2021-2050 and 2071-2100.

2- **Sensitivity assessment**: An analysis of the topography and the vegetation is conducted to create a fire hazard map and assess the sensitivity factor.

3- **Adaptive capacity assessment** has been conducted on the basis of discussions with local stakeholders.

3.3 - Assessment of climate change impacts on wild fire and vulnerability of Greek forests

In the context of climate change, the concept of "vulnerability" has been used to denote the extent of damage a region is expected to be affected by various factors influenced by climate change.

Following the IPCC Third Assessment Report definition, vulnerability is a combination of three components: exposure, sensitivity and adaptive capacity. Moreover, the first two components together (exposure and sensitivity) represent the potential impacts and adaptive capacity is the extent to which these impacts can be averted.

In the context of Greek forests, exposure is defined as the degree to which forests will be affected by climate change, sensitivity is the degree to which forests are exposed to land hazard that will be discussed later in detail, while the adaptive capacity is defined by the ability of forests to adapt to changing environmental conditions which is also enhanced by the measures implemented in the country, in order to mitigate the adverse impacts of climate change on this sector.

Exposure

For the Mediterranean-type ecosystems, fire occurrence strongly depends on the drought conditions that drastically increases flammability during summer period, on the temperature reached during this period as well as on the amount of fuel load (Mouillot et al., 2002).

Daily output data from three regional climate models (RCMs) developed at KNMI (Netherlands), ETHZ (Switzerland) and MPI (Germany) within the framework of the EU ENSEMBLES project have been used (www.ensembles-eu.org). All models have a horizontal resolution of 25 km × 25 km and use the A1B greenhouse gases emissions scenario (Nakicenovic et al., 2000). Present day simulations cover the period 1961-1990 and used here as reference for comparison with future projections for the periods 2021-2050 (near future) and 2071-2100 (distant future).

Changes in precipitation indices are of importance for fire risk. Among the climatic parameters with implications on fire risk, the maximum length of dry spell (amount of rainfall less than 1 mm) as well as the number of dry days have been examined as they can contribute to increases in fire risk and can influence forest species due to their sensitivity to soil moisture content.

As far as the maximum length of dry spell is concerned, the RCM ensemble mean results show an increase of 20-30 additional days with dry conditions for Greece in the distant future (2071-2100). In the near future (2021-2050), an increase of 10-15 days in Greece is depicted by the simulation. For this period, the increases may vary between 5-30 and 10-20 additional days per year in the eastern and western part of Greece, respectively. In the distant future, this increase will be up to 50 additional days for the eastern and up to 30 additional days per year for the western parts (Table 1).

The number of dry days, namely the days with daily total precipitation less than 1mm, ranges between 210 to 310 days for the control period. Higher values are depicted for Eastern lowlands and Eastern high elevation area. The number of dry days is expected to increase in the entire domain up to 15 and 30 days in the near and distant future, respectively. Maximum increases are expected for the eastern parts of Greece (Table 1).

TABLE 1: Value of precipitation indices with particular relevance to forest fire risk for Greece for the control period (1961-1990) and potential future change for near future (2031-2050) and distant future (2071-2100)

		Eastern lowlands	Eastern high elevation areas	Western lowlands	Westerm high elevation areas
Number of dry days (P<1mm)	Control period	290-310	270-310	250-270	210-250
	Near future	+5-15	+5-15	+5-10	+5-10
	Distant future	+15-20	+15-30	+12-15	+12-15
Max length of dry spell (days)	Control period	80-120	70-90	70-90	30-70
	Near future	+10-30	+5-30	+10-20	+10-20
	Distant future	+20-50	+15-30	+20-30	+15-25

The projected increase in temperature will increase fuel dryness and reduce relative humidity. This, in combination with reduced winter precipitation, is likely to increase the potential for larger and more destructive fires in the future.

The average summer maximum temperature is expected to increase up to 2.5°C in the near future for the entire domain (Table 2). At the end of the century this increase will reach 5.5°C in western and northern parts of Greece.

Moreover, the number of hot days (Tmax>35°C) is expected to increase by 5 to 25 days in Greece in the near future. In the distant future, the number of additional hot days would reach 40-60 days in the Western Lowlands and 35-60 additional hot days are expected in the Eastern Lowlands.

TABLE 2: Value of temperature indices with particular relevance to forest fire risk for Greece for the control period (1961-1990) and potential future change for near future (2031-2050) and distant future (2071-2100)

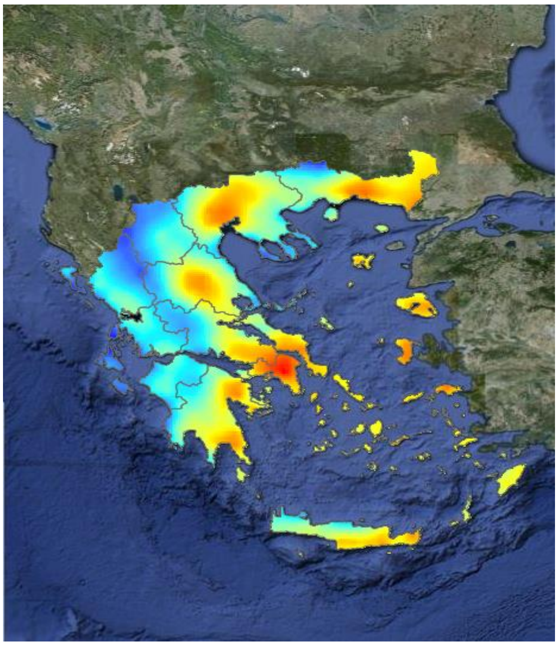
		Eastern lowlands	Eastern high elevation areas	Western lowlands	Westerm high elevation areas
Average summer Tmax (°C)	Control period	31-35	27-30	29-32	25-27
	Near future	+1.5-2.5	+1.5-2.5	+1.5-2.5	+1.5-2.5
	Distant future	+3.5-5.5	+4.5-5.5	+4.5-5.5	+4.5-5.5
Number of days with Tmax>35°C (days)	Control period	20-40	5-20	5-15	10
	Near future	+15-25	+5-15	+10-15	+5-10
	Distant future	+35-60	+25-40	+40-60	+25-35

The expected variations in precipitation and temperature indices led us to conduct an analysis of **future fire risk projections** for Greece based on the FWI model.

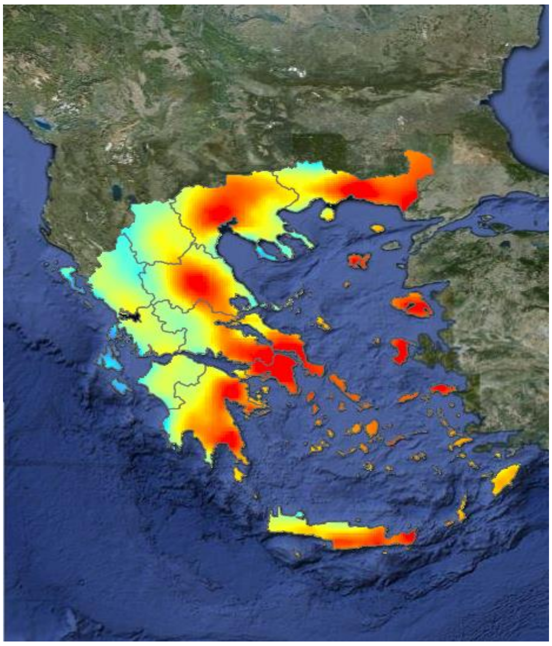
Previous research studies have shown that fire risk is low for FWI<15 and increase more rapidly for FWI>15 (Hanson and Palutikof, 2005 ; Good et al., 2008). In order to assess fire risk under climate change in Greece, a threshold of FWI>15 was selected as a measure of fire risk and FWI>30 was selected as a measure of elevated fire risk.

As shown in Figure 9, the days with elevated fire risk are expected to increase by 20 days in the entire country, for the near future. This increase is even greater for the distant future and would reach 30 days. The number of days with elevated fire risk is higher for the lowlands in the eastern part of Greece. The Greek domain can be divided into four sub-regions of fire risk behavior and exposure: the eastern lowlands and high elevation areas, as well as the western lowlands and high elevation areas. The eastern lowlands are more exposed to fire risk followed by eastern high elevation areas. They present a high number of days with elevated fire risk both for the control and future periods. The western lowlands and high elevation areas are the least exposed, both for the control and the future periods.

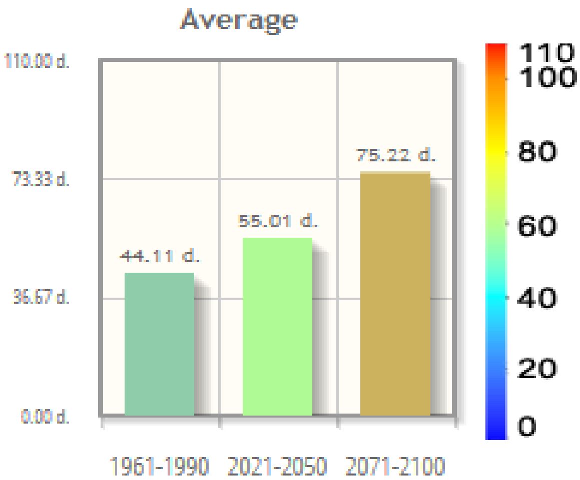
FIGURE 9: Mean number of days with elevated fire risk (FWI>30) in the near future (2021-2050) and in the distant future (2071-2100)



a) near future



b) distant future



Using historical data, a statistical relationship can be established between FWI and forest burned area. Once established this relationship can be applied to the expected FWI conditions under climate change conditions. Because of data limitations, WP4 use hypothetical coefficients derived by linear regressions on historical national average values (from 1951-2010) to establish a statistical relationship between FWI and burned areas. The coefficients applied here have very low statistical significance even if the final results are comparable to those found in other works. Then, this exercise has only illustrative purposes.

Historical observations as well as the results of the linear regression analysis are shown in the Table 3. Results indicate an increase of about 23% of the average annual burned area between the current period and the distant future (2070-2100) under climate change conditions. Thus, an average of 58,000 ha of burned area is expected for the distant future.

Nevertheless, assessment of impacts and then of vulnerability gained in quality when the sensitivity factors and the adaptive capacity are assessed.

TABLE 3: Projected average annual burned area (ha) in Greece for the period 2070-2100

	Current (1980-2010)	Projected (2070-2100)	Increase
Greece	47,309	58,016	+22.95%

Sensitivity

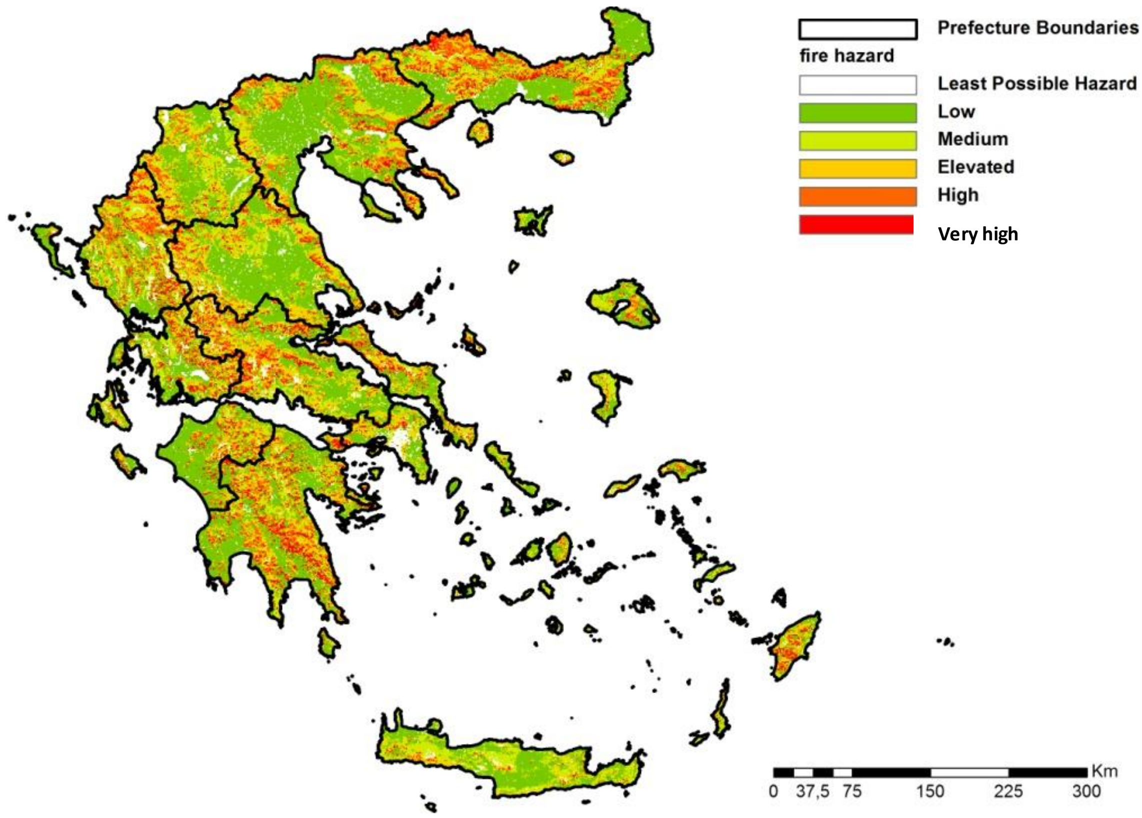
Impacts of climate change are understood as a combination of exposure and sensitivity. Sensitivity describes the human-environmental conditions that can worsen or ameliorate the hazard. For fire risk in Greece, two static information of importance have been taken into account to create a fire hazard map and assess the sensitivity factor: the topography and the vegetation.

For vegetation, a sensitivity map has been produced by categorizing vegetation according to 8 fuel type categories, denoting how much combustible material the vegetation would be able to provide in a possible fire event. Each category has been weighted according to their evaluated fuel load and combustibility. The higher weights were assigned to shrubs and sclerophyllous.

Topography, in terms of aspect and slope, also affects forest fires. Aspect generally refers to the horizontal direction to which a mountain slope faces. For example, south and west aspects are generally the hottest and the driest in Greece. This also affects the vegetation. Thus south facing slope vegetation is generally drier and more fire prone than north facing slopes.

The Fire Hazard map was constructed by combining the two information layers of landcover and aspect and by weighted each combination. South facing shrubs depict the higher weight. The final Fire Hazard Map (Figure 10) was categorized in six different classes, from the least possible one that is found inside cities, artificial construction and water bodies to the very high level of the south oriented vegetated areas. The figure shows that high elevation continental areas can be characterized as “high” fire hazard areas while the lowlands can be characterized as “low” and “medium fire hazard areas.

FIGURE 10: Fire hazard map for Greece



Assessment of vulnerability of Greek forest to forest fire

Vulnerability depends on potential impacts of climate change but also on adaptive capacity of Greek forest. The evaluation of adaptive capacity has been conducted on the basis of discussions with local stakeholders. It shows that when vegetation and changes in meteorological conditions due to climate change are combined, forests of northern and western Greece are expected to be more adaptive than their eastern counterparts. That is mainly due to the fact that the aforementioned areas receive greater amounts of precipitation, together with less human activities due to lower population density, compared to southern and eastern areas of Greece.

From this adaptive capacity analysis, it can be said that Eastern Greece has low adaptive capacity and Western Greece has medium adaptive capacity.

The combination of the results regarding the exposure, the sensitivity and the adaptive capacity of Greek forest to fire risk under climate change conditions shows that the higher level of vulnerability are found in the Eastern Greece (Table 4).

TABLE 4: Overall vulnerability assessment to climate change of Greek forests

	Eastern Greece		Western Greece	
	Lowlands	**High elevation areas**	**Lowlands**	**High elevation areas**
Sensitivity	Medium	High	Medium	High
Exposure	Very High	High	Elevated	Elevated
Adaptive Capacity	Low	Low	Medium	Medium
Vulnerability	Medium	Medium	Least	Low

3.4 - References

Beniston, M., 2003, Climatic change in mountain regions: a review of possible impacts, *Climatic Change,* 59, pp. 5–31.

Carvalho, A., Flannigan, M. D., Logan, K., Miranda, A. I., and Borrego, C., 2008, Fire activity in Portugal and its relationship to weather and the Canadian Fire Weather Index System, *International Journal of Wildland Fire*, 17, pp. 328–338.

Dimitrakopoulos, A.P., Bemmerzouk, A.M., Mitsopoulos, I.D., 2011, Evaluation of the Canadian fire weather index system in an eastern Mediterranean environment. *Meteorological Applications*, 18, pp. 83–93.

Flannigan, M. D., Stocks, J. B., Wotton, M. B., 2000, Climate change and forest fires, *Science of the Total Environmental*, 262, pp. 221–229.

Giannakopoulos, C., LeSager, P., Moriondo M., Bindi M., Karali A., Hatzaki M. and Kostopoulou E., 2012, Comparison of fire danger indices in the Mediterranean for present day conditions, *iForest*, 5, pp. 197-203

Moriondo, M., Good, P., Durao, R., Bindi, M., Giannakopoulos, C., Corte-Real, J., 2006, Potential impact of climate change on fire risk in the Mediterranean area, *Climate Research*, 31, pp. 85–95.

Natural Resources Canada, 2008. *Canadian Wildland Fire Information System*. Extract from web page, accessed 07/02/2014. http://cwfis.cfs.nrcan.gc.ca/background/summary/fwi

Pausas, J. G., Vallejo, R., 1999, The role of fire in European Mediterranean ecosystems, In: Chuvieco, E. (ed.) *Remote sensing of large wildfires in the European Mediterranean basin*, Springer-Verlag, Berlin, pp. 3-16.

Schmuck, G., Ayanz, J.S.M, Camia, A., Durrant, T., Oliveira, S.S., Boca, R., Whitmore, C., Giovando, C., Libertà, G., Corti, P., Schulte, E., 2011, *Forest Fires in Europe 2010. Joint Research Centre – Institute for Environment and Sustainability*, Report No 11, Land Management and Natural Hazards Unit, Publications Office of the EU, Luxembourg, pp. 8-11.

Stocks, B.J., Wotton, B.M., Flannigan, M.D., Fosberg, M.A., Cahoon, D.R. Goldammer, J.G., 2001, Boreal forest fire regimes and climate change, In: Beniston M, Verstraete MM (eds), *Remote Sensing and Climate Modeling: Synergies and Limitations, Advances in Global Change Research*, Kluwer Academic Publishers, Dordrecht and Boston

Van Wagner, C.E., 1987, *Development and structure of the Canadian Forest Fire Weather Index System*, Canadian Forestry Service, Ottawa, Ontario, 37p.

Weber, M.G. and Flannigan, M.D., 1997, Canadian boreal forest ecosystem structure and function in a changing climate: impact on fire regimes, *Environmental Review*, 5, pp. 145-166.

4 - IMPACTS OF CLIMATE VARIABILITY AND CHANGE ON THE WIND ENERGY SECTOR AT THE MEDITERRANEAN LEVEL

4.1 - Context

The wind energy sector has an important capacity development potential, particularly in the context of climate change mitigation policies. In 2012, installed wind power capacity in the European Union totaled 105,000 megawatt (MW), meeting 7% of the EU's energy supply (EWEA, 2012). Moreover, 11,895 MW of wind power was installed in 2012, representing 11.4% of new European power capacity. The EU wind industry has had an average annual growth of 15.6% between 1995 and 2011 (EWEA, 2011). The wind energy capacities are growing rapidly, and this figure will still stay true in the coming decade. The EWEA estimates that 230 and 400 gigawatts (GW) of wind capacity will be installed in Europe by 2020, consisting of 190 GW onshore and 40 GW offshore. This would produce between 14 and 17% of the EU's electricity supply, avoiding 333 million tons of CO_2 per year and saving €28 billion a year in avoided fuel costs. In 2030, installed wind capacity will reach 400 GW, produce between 26 and 35% of the EU'S electricity, and avoid 600 million tons of CO_2 per year (EWEA, 2011, 2012).

Wind energy sector investment decisions regarding location and size, but also operation and management decisions at the utility level depends directly on wind resources as they directly impact energy yield of a wind farm. Thus it is of importance for the sector to have reliable knowledge and data on wind patterns.

Natural inter-seasonal and inter-annual climate variability directly impacts wind energy production and potential. Moreover, global climate change may alter the geographic distribution and/or the inter-annual, intra-annual and inter-decadal variability of the wind speeds, and/or the quality of the wind resource, and/or the prevalence of extreme weather events that may impact wind turbine design and operation but also investment location and size and management operation at the wind farm and the grid network levels (IPCC SRREN, 2011).

At climate change timescales, potential changes in wind speeds can create a risk to the security of the energy network because total energy supply will be lower than required if wind power does not continue to generate what it is expected to over the lifetime of a wind farm project (approximately 20 years). This can also create a risk to the investment in wind energy. At seasonal timescales, wind variability can create a risk to the balance of the energy system because if wind power does not generate what it is expected to, or if it is highly variable, the grid

network can become unstable. Short-term wind variability can also create a risk to operational and maintenance plans of a wind farm, which should be managed in a optimal manner to exploit low/high wind power generation periods.

4.2 - Methodology for wind energy forecasting, wind seasonal forecast and climate change impacts assessment

Wind energy model

The impact indicators of climate variability and change on the wind energy sector are for wind speed, which impact directly on wind power generation. Wind energy can be evaluated using this industry standard methodology (Grogg, 2005)

$$E = \frac{1}{2}mv^2 = \frac{1}{2}(Avt\rho)v^2 = \frac{1}{2}At\rho v^3,$$

where *ρ* is the density of air; *v* is the wind speed; *Avt* is the volume of air passing through *A* (which is considered perpendicular to the direction of the wind). *Avtρ* is therefore the mass *m* passing per unit time. One can note that ½ *ρv2* is the kinetic energy of the moving air per unit volume.

Power is energy per unit time, so the wind power incident on *A* (e.g. equal to the rotor area of a wind turbine) is:

$$P = \frac{E}{t} = \frac{1}{2}A\rho v^3.$$

Wind power in an open air stream is thus *proportional* to the *third power* of the wind speed. In other words, the available power increases eightfold when the wind speed doubles. Wind turbines for grid electricity therefore need to be especially efficient at greater wind speeds.

Seasonal Wind Forecast Methodology

Long-term wind energy resource estimates are currently inferred from archives of global weather forecasts and in-situ observations of, e.g., the past 10 years, and reanalysis data of e.g. the past 30 years, when no direct observations are available. The statistical components (moving means etc.) of this data enables wind speeds to be forecast for weeks or months ahead, although with inherently large uncertainty. Seasonal climate forecasts can help to reduce this uncertainty i.e. to improve a longer-term forecast above the current observational estimate used. It achieves this by looking beyond the trend of the statistical components and assessing the variability of the climate means over past timescales.

Seasonal wind forecasts are divided into two stages:

First, a climate forecast system produces seasonal wind predictions (3 months for each season) for as many cases in the past as possible (typically using a baseline period of 1981-2012). These predictions are based on the monthly means and include an estimate of their uncertainty, depending upon the spread of the forecast ensemble members and their ability to reproduce the observations. This measure of uncertainty is used to assess the forecast quality of the system. This stage is performed using climate forecast system ECMWF S4 and the ERAINterim reanalysis “observations”.

Second, probabilistic future 10m wind speed for the three next month information is produced as an operational tool that shows the distribution of the forecast ensemble members over three categories: above normal, below normal and normal wind speeds, and the probability of the event to happen, based upon the number of forecast members within each of the categories.

Climate Change Impacts on Wind Speed Methodology

Regional Climate Models (RCMs) produce high-resolution (about 20 km) climate scenarios over selected areas by taking the input at the lateral boundaries from coarser resolution (about 100 km) Global Climate Models (GCMs). RCMs enhance the quality of climate projections with respect to GCMs, especially in the presence of complex orography (Artale et al., 2010) and in the proximity of coastal areas (Feser et al., 2011). In CLIMRUN, we have evaluated wind modelling over the Euro-Mediterranean area using what is currently the largest and most consolidated

ensemble of RCM simulations - produced during the EUFP6 project ENSEMBLES (van der Linden and Mitchell, 2009).

The Table 5 shows in blue the GCMs-RCMs combinations that have been extracted from the ENSEMBLES archive to develop regional long-term wind speed scenarios.

TABLE 5: GCMs-RCMs combinations extracted from the ENSEMBLES project to develop regional long-term wind speed scenarios

Regional Model	Global Model: HadCM3Q16	ARPEGE	BCM	ECHAM5-MPIOM r3	MIROC3.2 hires	HadCM3Q0
C4IRCA3	■					
CNRM-RM4.5		■				
DMI-HIRAM5		■	■	■		
ETHZ-CLM						■
ICTP-RegCM3				■		
KNMI-RACMO2				■	■	
METNO-HIRAM			■			■
METO-HC HadRM3Q0						■
MPI-M-REMO				■		
SMHIRCA			■	■		
UCLM-PROMES						■

Simulations of mean change in surface wind speed have been projected for winter (December, January, February) for 2021-2050 with respect to 1961-1990 using the A1B greenhouse gas emission scenario.

4.3 - Seasonal Forecast results and relevance for the wind energy sector

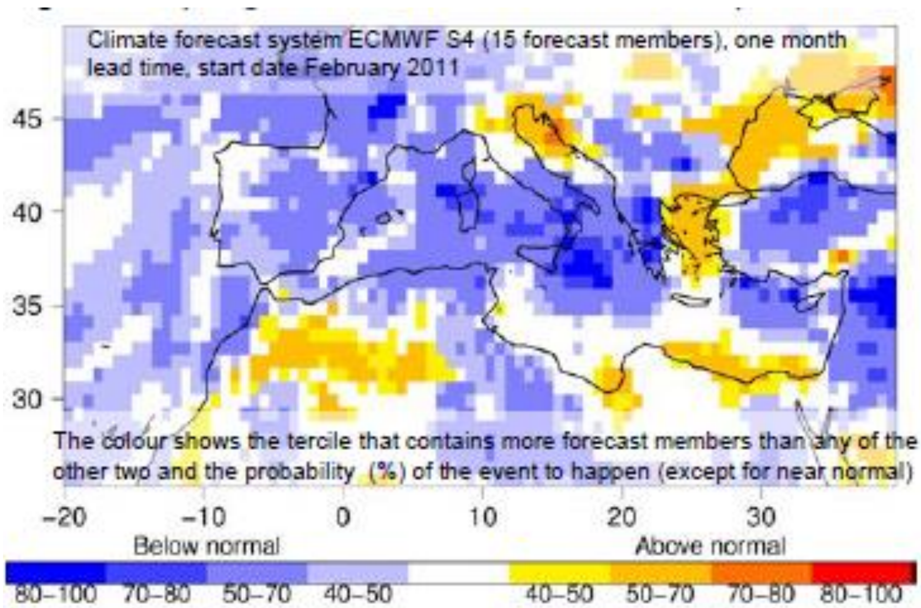
The variability of wind resources is directly linked to the energy yield of a wind farm. Throughout a wind energy project's life, it is currently unknown how much the wind resources could vary from

one season to the next. The assumption is therefore made that long-term wind resource availability is constant; that future wind resource will reflect the past and its variability is consistent across all timescales. The potential risk that future wind resources could be significantly different over space and time is currently not assessed, nor have tools been made available to deal with this risk. This creates an uncertainty that affects investment and operations for wind projects and the grid network.

In order to support decision-making at the seasonal scale of the wind energy sector, a wind speed forecasting over seasonal timescale, here for the 2011 spring season (March, April, May), has been produced. An estimate of the climate forecast system quality has been delivered, and then, operational predictions that provide probabilistic future wind information at the regional and at site specific level have been issued.

The results of this exercise show for example (Figure 11) that below normal winds was generally predicted in the Western Europe for spring 2011, with a probability of 70% and higher. On the contrary, above normal winds was predicted in the region of North Adriatic Sea.

FIGURE 11: Spring 2011 forecast for 10m wind speed



The skill of the climate forecast system to be able to predict winds speed in certain geographical regions and temporal seasons suggests that an operational, probabilistic seasonal forecast contains some useful information for risk management when planning and operating wind energy projects. With a skilful prediction of wind speeds, the corresponding impact to the wind power generation can be evaluated using the industry standard approach described in the wind energy model (Grogg, 2005).

By having a better understanding of the expected wind power output over the coming season, specific end-users can mitigate possible risks using a range of methodologies depending on the decision being made i.e. clustering assets from different sites or seeking insurance for poor cash flow for investors, hedging power generation risk or buying alternative energy resources for energy traders, adapting management strategies of hydropower resources to cover wind power deficits etc.

4.4 - Climate change impacts results and relevance for the wind energy sector

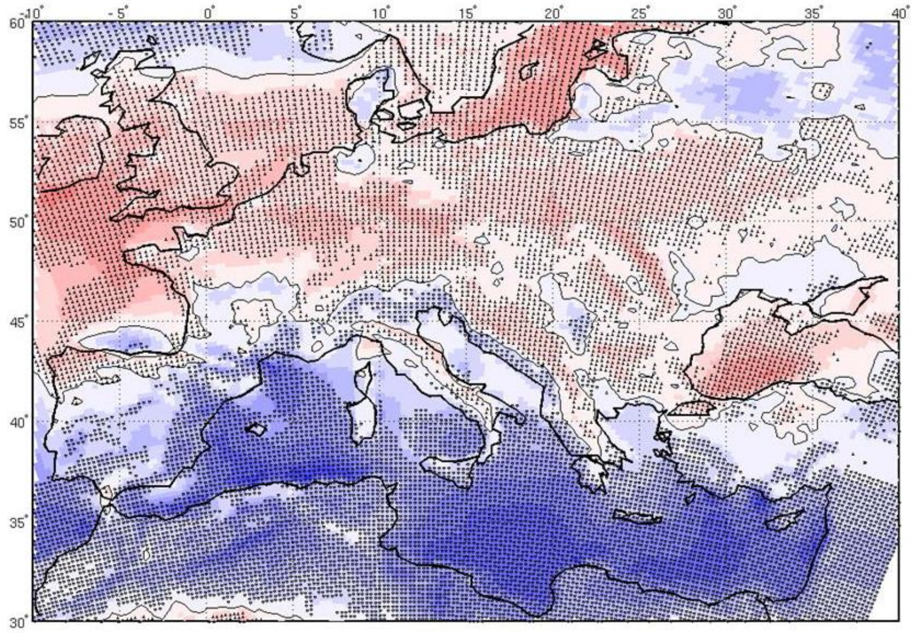
Most of the interest concerning wind modelling focuses on the very short-range (nowcasting) and on seasonal forecasts, because the largest part of the manageable risk is concentrated on these timescales.

However, the interaction of WP7 with stakeholders, especially in the energy sector, has highlighted the need for more in-depth understanding of wind modelling capacities at a longer time scale, which may contribute to both site evaluation and to the assessment of risks that may affect the return on investments on longer time scales.

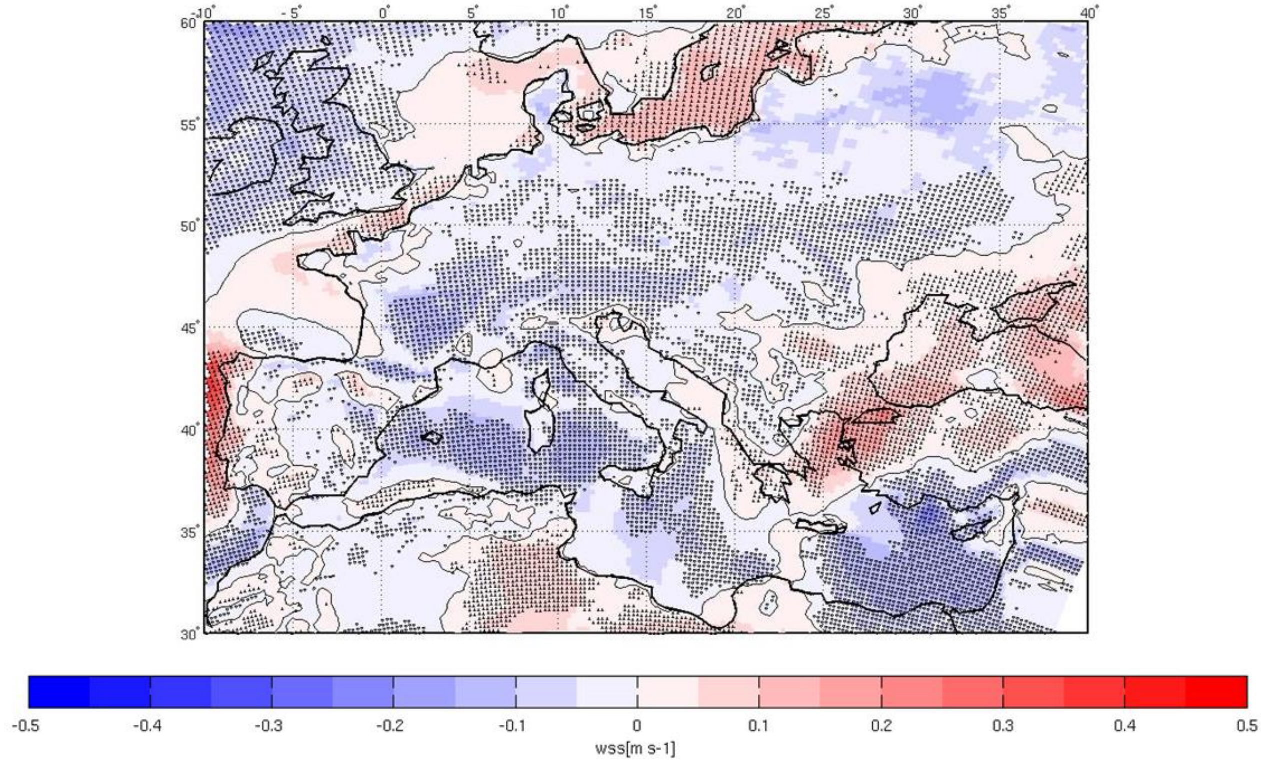
These simulations show (Figure 12) that wind speeds under climate change are expected to decrease in average in the winter seasons of 2021-2050 compared to 1961-1990 around the Mediterranean and increase in the inland areas of the South of Europe and in most of the North of Europe. For summer periods, climate change is expected to reduce slightly or to have no impact on wind capacities across most part of Europe.

FIGURE 12: A1B RCMs wind speed changes for 2021-2050 compared to 1961-1990 in winter and summer seasons

a) Winter (December, January, February)



b) Summer (June, July, August)



4.5 - References

Artale V., Calmanti S., Carillo A., Dell'Aquilla A., Herrmann M., Pisacane G., Ruti P.M., Sannino G., Struglia M.V., Giorgi F., Bi X., Pal J.S., Rauscher S., 2010, An atmosphere-ocean regional climate model for the Mediterranean area: assessment of a present climate simulation, *Climate Dynamics,* 35(5), pp. 721-740.

EWEA, 2013, Wind in power: 2012 European statistics, February 2013, 14 p.

EWEA, 2012, Wind in power: 2011 European statistics, February 2012, 11 p.

Feser F., Rockel B., von Storch H., 2011, Regional climate models add value to global model data, *Bulletin of the American Meteorological Society*, 92, pp. 1181-1192.

Grogg K, 2005, Harvesting the wind: The physics of wind turbines, Physics and Astronomy Comps Paper, Carleton College, 42 p.

IPCC, 2011, *Special Report on Renewable Energy Sources and Climate Chang Mitigation*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1075 p.

van der Linden P., Mitchell J.F.B., 2009, ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre, FitzRoy Road, Exeter EX1 3PB, UK, 160 p.

5 - IMPACTS OF CLIMATE CHANGE ON TOURISM SECTOR IN TUNISIA

5.1 - Context and approach

Tourist destinations and more generally the tourism sector are sensitive to the climate, its variability, its changes, and its future development. The climate has directs impacts on the level of climate-touristic comfort environment, but also indirect impacts on the tourism sector as it affects the availability of water resources, the ecosystems, the sea-level, and the beaches. The climate is also involved at certain components of accommodation management such as air-conditioning.

The current climate of Tunisia which is rather favorable to outdoor tourist activities would be affected by climate change as its effects on air and sea temperature, precipitations and sea-level rise will generate direct and indirect impacts on the Tunisian tourism sector. In summary, the tourism sector would be probably negatively affected by climate change in the summer season as it will become more and more uncomfortable, and positively impacted in intermediary season as the length of the bathing season and of favorable temperature conditions will increase.

5.2 - Analysis of present climate-tourist environment

Tourism sector is of importance for Tunisia. This country is classified among the top 50 world tourist destination, and one of the major tourist destinations in the Southern Mediterranean. With 5 to 7 million tourists a year (from 2005 to 2009) and 34,62 million overnight stays in 2009, tourism activity is a major economic sector for the country and represent 7% of GDP, generating 18-20% of foreign exchange earning a year and contribute to around 12% of total job creation. Furthermore it has an important knock-on effect on other economic sectors as transportation, construction, and agriculture.

The tourism sector expansion was fostered by three main factors, namely a climate characterized by a significant sunshine duration, 1,300 km of sandy beaches, and a geographically situation close to Europe. Tunisian tourism is an almost standardized tourism which is essentially based on two natural determinants, the sun and the sea (Hénia and Alouane, 2007). The coastline accounts for 95% of tourism investments and functional beds, and seaside resorts represents 93% of night stays. The high season that runs from April to October records 73% of arrivals of non-resident tourists.

In order to support adaptation to climate variability and change of the Tunisian sector actors, it seems important to deliver indicators which allow them to better understand the relationship between climate parameters and tourist comfort and expectations. This has been done by creating a Climate Tourist Comfort Index (Mieczkowski, 1985) at spatial and seasonal scales for Tunisia.

ICT relies on tourist expectations in terms of climate, and assess the relative importance of each climate parameters in the perception of climate comfort by tourists, but also the importance of personal factors of tourists (country of origin, age, gender). The ICT for Tunisia has been developed on the basis of a questionnaire survey among tourists during their stay in Tunisia. The ICT is the sum of five climatic indices determinant of climate-tourist atmosphere, where T represents temperature, H humidity, S sunshine duration, V wind speed and sand wind duration, and P precipitation:

$$\mathbf{ICT = iT + iH = iS = iV + iP}$$

The results show that the sunlight, humidity and wind come almost equally with temperature in the determination of climate comfort for tourists, even if thresholds for assessing the effects of different climate parameters vary substantially according the nationality of the tourist.

The Figure 13 shows that Tunisia presents a dominance of favorable and very favorable days during the year for outdoor activities with shades between regions. Gafsa, Kairouan and Jerba appear to be to most favorable ones. For example, in average 85% of the days are favorable to very favorable in terms of tourist climate comfort in Jerba each year. The Figure 14 shows that comfort prevailing also across Tunisia on nocturnal climatic atmosphere.

FIGURE 13: Annual frequency of days par ICT class (% of days per year)

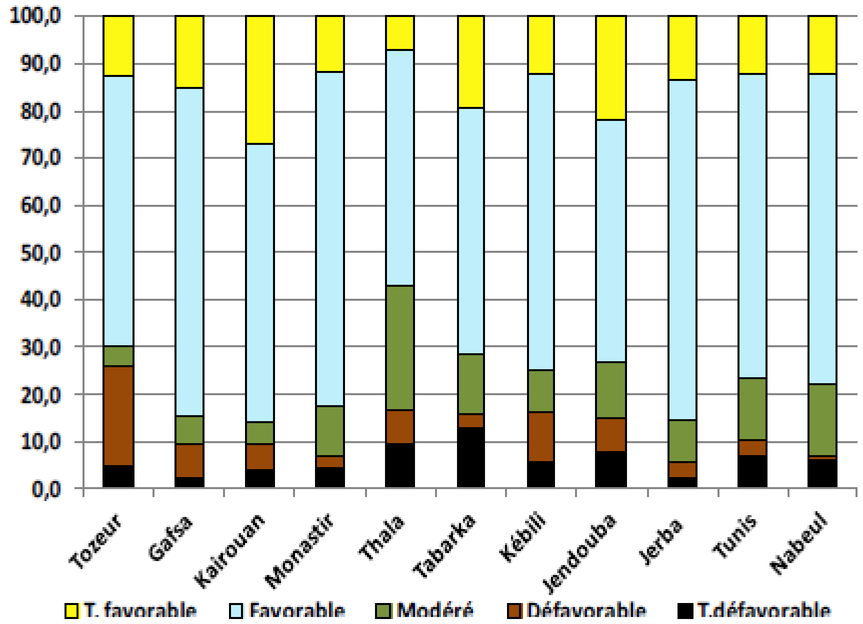
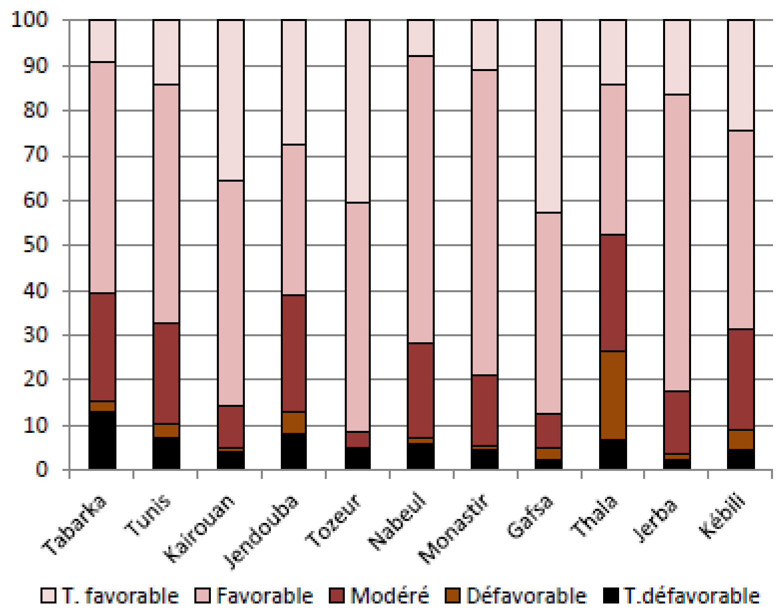


FIGURE 14: Annual frequency of nights per ICT class (% of nights per year)



These indicators are intended to allow developers, investors and policy-makers to have a better understanding of tourist comfort relationship to climate at the spatial and seasonal scales, but also to make a better use of the climate potential of the country and a diversification of tourism products.

5.3 - Analysis of future climate-tourist environment

As temperature and humidity are major components of climate related comfort of tourists in Tunisia, the expected evolution of these climate parameters under climate change is of importance for the future potential of the tourism sector in this country.

Climate change scenarios for Tunisia have been developed on the basis of the results of the EU FP6 ENSEMBLES project that allows adapting the results of global climate models at regional scales by using downscaling methodologies and tools.

Regional Climate Models (RCMs) have been forced with the IPCC A1B scenario and provide results in terms of foreseen changes in seasonal temperature and precipitation for 2041-2050 compared to 1971-1980. The results show that most of ENSEMBLES models predict an increase of air surface temperature between the two periods of 2.9-3.8°C in summer (Figure 15), but also in winter (Figure 16). On the other side, average precipitations are expected to decrease by 0.05 to 0.1 mm per day in summer (Figure 15) and by 0.1 to 0.3 mm per day in winter (Figure 16).

FIGURE 15: Foreseen changes in summer air mean surface temperature (left) and precipitation (right) for 2041-2050 against 1971-1980 in IPCC A1B scenario.

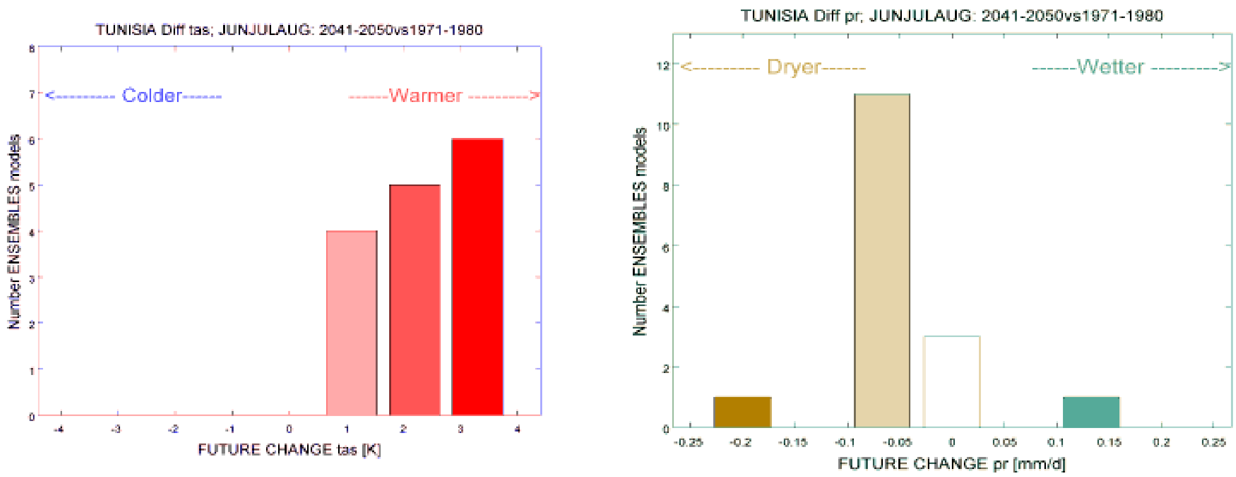
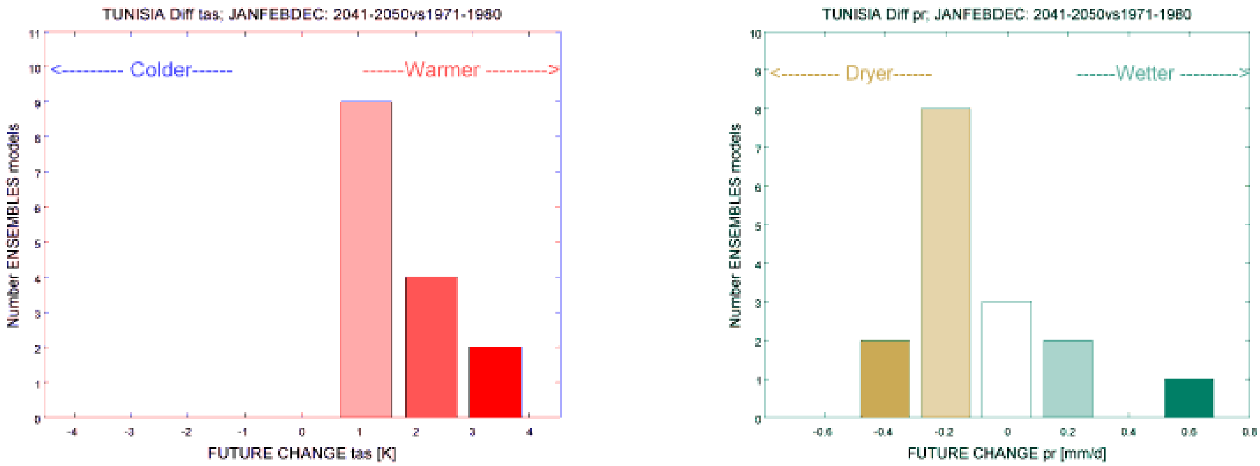


FIGURE 16: Foreseen changes in winter air mean surface temperature (left) and precipitation (right) for 2041-2050 against 1971-1980 in IPCC A1B scenario.

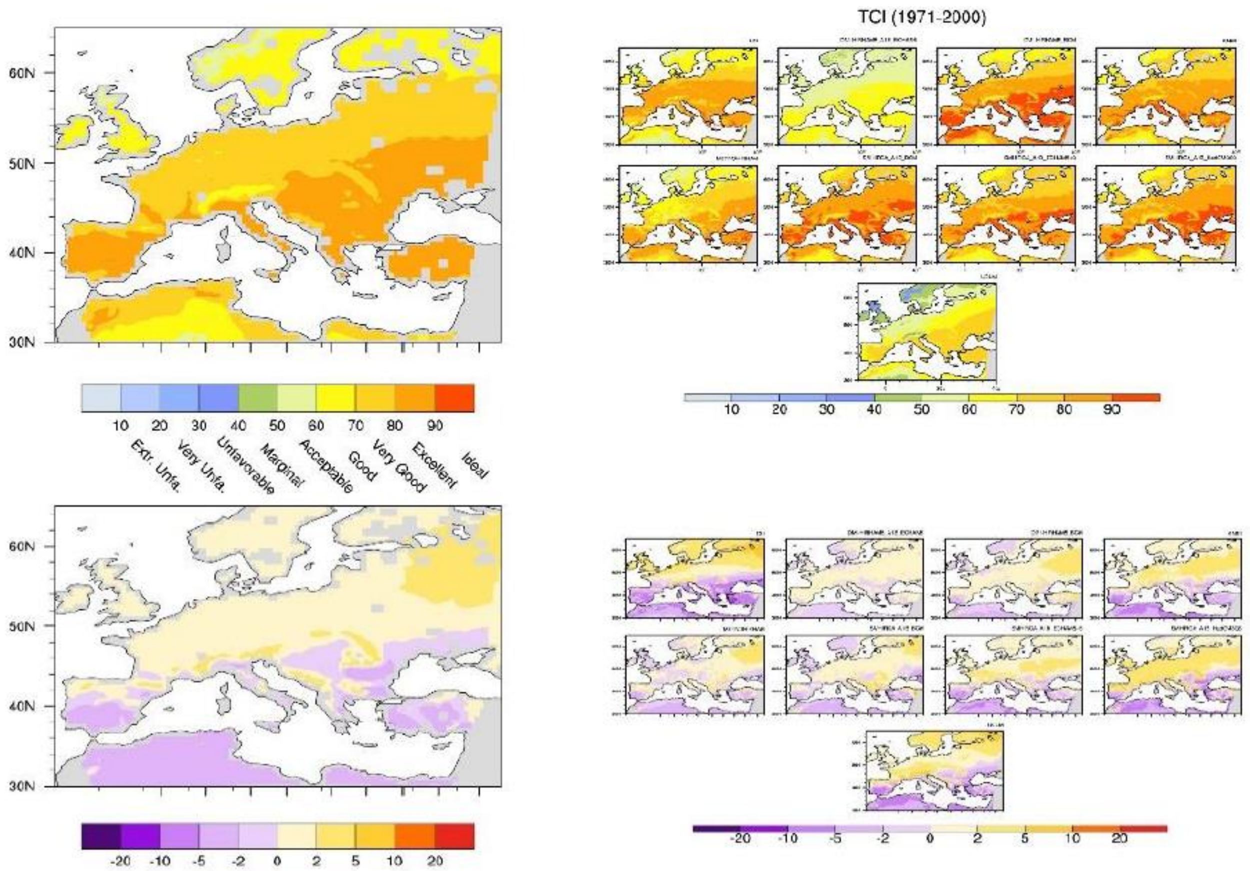


These foreseen evolutions of climate parameters would have an important impact on the TCI on Tunisia but also on the Mediterranean region. A regional simulation of the evolution of suitable climate conditions for tourism activities has been carried out at the regional level. The evolutions of TCI of Tunisia, but also of the Mediterranean region are of interest for the Tunisian tourism sector as the TCI of the destination and of the emitters' country are important for the destination

choice but also because the Tunisian destination is in concurrence with other destination across the Mediterranean region.

High resolution simulation over the Mediterranean region has been used to represent the local and diverse orography over the region. 9 atmospheric regional climate models of climate change simulations have been carried out within the EU FP6 ENSEMBLES project. Thus, only a limited number of models have been used to calculate the TCI as many variables are needed to calculate it. The simulations are at 25km horizontal resolution and follow the A1B emission scenarios.

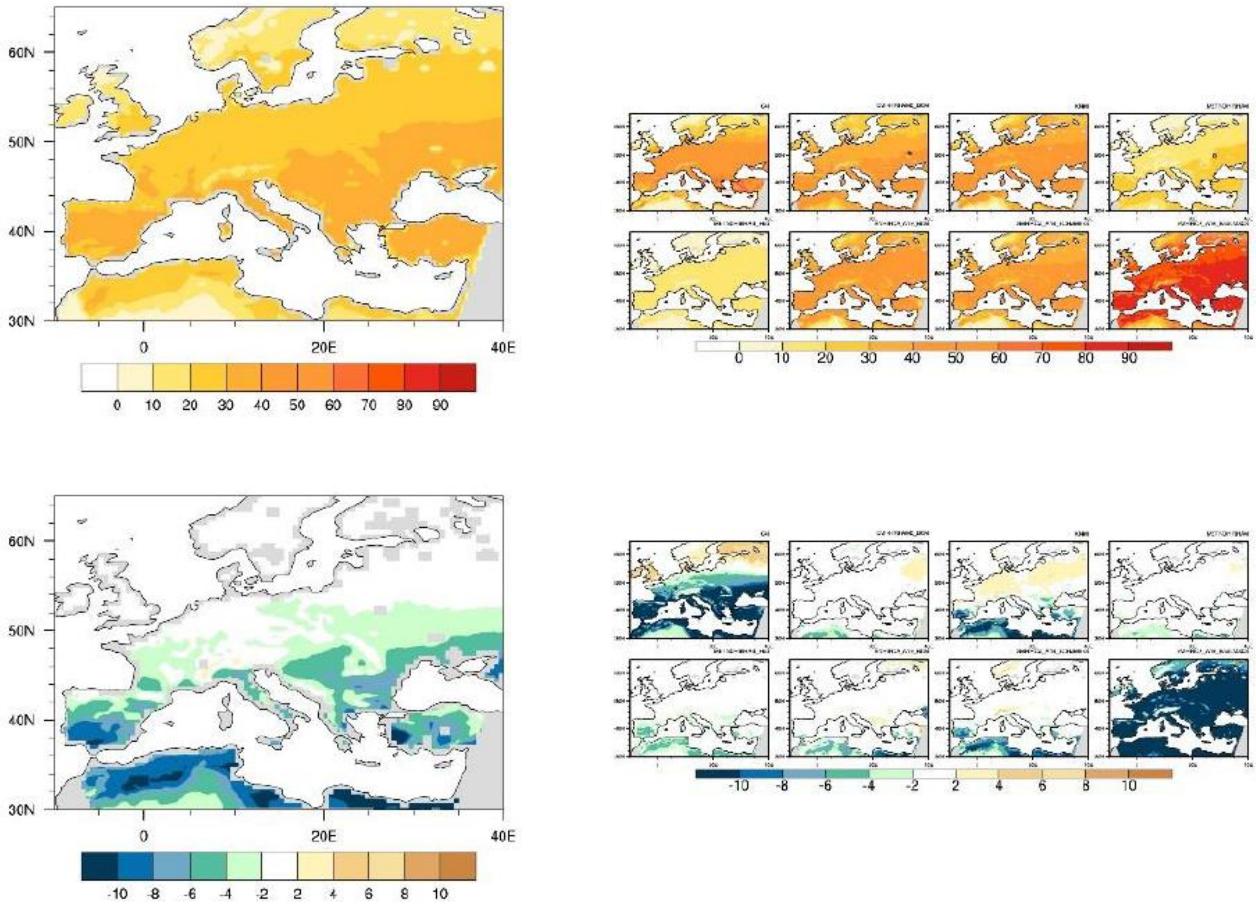
FIGURE 17: Summer TCI in 1971-2000 (top) and changes over 2021-2050 (bottom) simulated by the ensemble mean (left) and individuals models (right) under the A1B emission scenario.



The evolution of the summer TCI over the period 2021-2050 show a decrease of the TCI around the Mediterranean basin in the future, which will be more important in the south Mediterranean countries as Tunisia. The spatial structure of the evolution is quite similar for each individual model simulation with a decrease in the TCI around the basin, accentuated in the South rim, and an increase in Northern and inland Europe (see Figure 17).

Moreover, the number of days with TCI greater than 70 in present climate (1971-2000) and its evolution over 2021-2050 have been calculated for 8 different models. Results of the simulations show an important decrease of the number of days with TCI greater than 70 around the Mediterranean basin. Here again, South Mediterranean regions depict the higher decreases.

FIGURE 18: Number of days with TCI greater than 70 in 1971-2000 (top) and changes over 2021-2050 (bottom) simulated by the ensemble mean (left) and individuals models (right) under the A1B emission scenario



5.4 - Sea surface temperature and bathing conditions

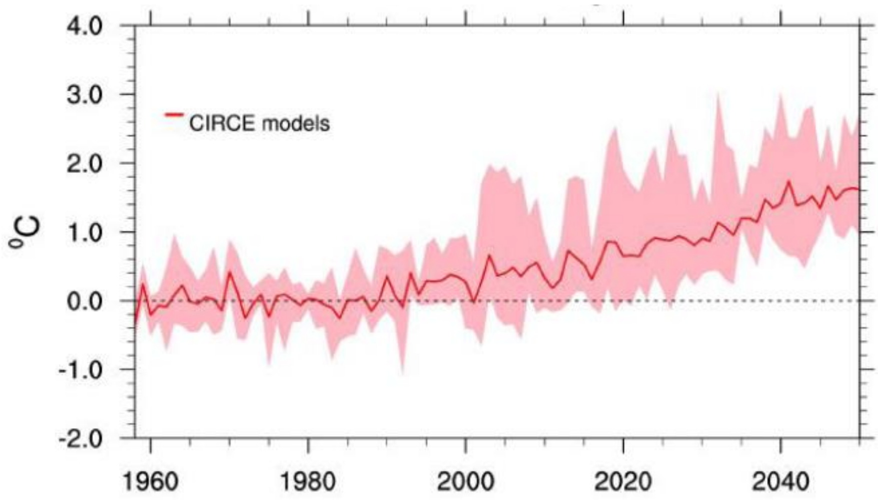
As mentioned before, Tunisian tourism is largely dominated by seaside tourism and bathing related activities. In this context, the delivering of indicators of changes in sea-surface temperature under climate change but also of seasonal forecast of the bathing season can provide useful information to tourism institutions and seaside tour operators to adapt the tourism products supply.

Under climate change, bathing conditions are expected to change. Those changes would have positive impacts on bathing activities as they will led to an extend of the bathing season, but also negatives ones taking into consideration the possible proliferation of jellyfish.

A high spatial resolution of the Mediterranean Sea is required to represent the complex local bathymetry over the Mediterranean coast. Simulations of five coupled atmosphere-ocean models carried out within the EU FP7 CIRCE project have been used to illustrate the possible evolution of sea surface temperature from 1950 to 2050 with respect to the reference period 1961-1990 under A1B emission scenarios.

Results show that sea-surface temperature is expected to increase in all bathing sites around the Mediterranean. As depicted in the Figure 19, in the Tunisian Gulf of Gabès sea-surface temperature would increase by 1 to 2°C in 2050 compared to 1961-1990. This would potentially have important consequences for the tourism sector as the bathing period would increase the length of the Tunisian bathing season over large period of spring and autumn.

FIGURE 19: Sea surface temperature anomalies in Golf of Gabes from 1961-1990 average



In the same way, seasonal forecasts of bathing conditions have raised the interest of Tunisian sector stakeholders. The intra-annual variability of sea surface temperatures largely determines the length of the Tunisian summer bathing season. It is currently unknown how much the sea surface temperatures could vary from one summer season to the next. The assumption is therefore made that long-term intra-annual sea surface temperatures is constant and therefore that future bathing season length will reflect the past. However, if the lengths of future bathing seasons are significantly different over space and time, the tourism sector could adapt to exploit the opportunity of a longer season, or manage the risk of a shorter season.

Seasonal sea surface temperatures estimates are currently inferred from archives of global weather forecasts and in-situ observations of, e.g., the past 10 years, and reanalysis data of e.g. the past 30 years, when no direct observations are available. The statistical components of this data enable sea surface temperatures to be forecast for weeks or months ahead, although with inherently large uncertainty. Seasonal climate forecasts can help to reduce this uncertainty i.e. to improve a longer-term forecast above the current observational estimate used. It achieves this by looking beyond the trend of the statistical components and assessing the variability of the climate means over past timescales.

Seasonal sea surface temperatures forecasts are divided into two stages.

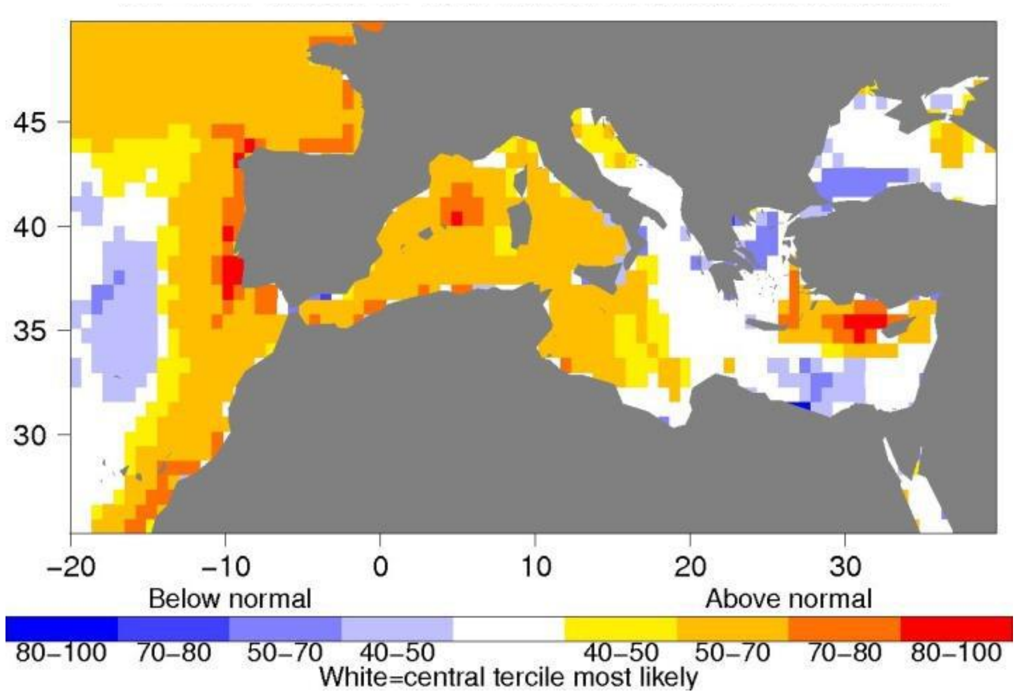
First, a climate forecast system produces seasonal sea surface temperatures predictions (3 months for each season) for as many cases in the past as possible (typically using a baseline

period of 1981-2012). These predictions are based on the monthly means and include an estimate of their uncertainty, depending upon the spread of the forecast ensemble members and their ability to reproduce the observations. This measure of uncertainty is used to assess the forecast quality of the system. This stage is performed by using climate forecast system ECMWF S4 and the HadISST reanalysis "observations".

Second, probabilistic future sea surface temperatures information for the next three months is produced as an operational tool that shows the distribution of the forecast ensemble members over three categories: above normal, below normal and normal sea surface temperatures, and the probability of the event to happen, based upon the number of forecast members within each of the categories.

In order to support decision-making at the seasonal scale of the Tunisian tourism sector, a sea surface temperature forecasting exercise over seasonal timescale, here for the 2011 summer season (June, July, August) has been produced. An estimate of the climate forecast system quality has been delivered, and then, operational predictions that provide probabilistic future sea surface temperature information at the regional and at site specific scale have been issued.

FIGURE 20: Summer 2011 forecasts for Sea surface temperature



The exercise shows the probability forecast of sea surface temperature most likely tercile for the next season. Results of this exercise (Figure 20) show that above normal sea surface temperatures were predicted around the Tunisian coast for summer 2011, with a probability of 50-70%. One can conclude that the length of the 2011 bathing season would be more long that normal ones.

5.5 - References

Hénia L., Alouane A., 2007, *Le Potentiel climato-touristique de la Tunisie*, actes du XX ème colloque de l'AIC, Tunis Carthage, p. 27-33.

Hénia L., Alouane A., 2008, *Impacts potentiels du réchauffement global sur les ressources climatiques et non climatiques du tourisme balnéaire en Tunisie*, communication orale au congrès de l'Union Géographique Internationale (UGI), Tunis, 2008.

MEDD/GTZ/TEC, 2010, *Tourisme et changement climatique en Tunisie : évaluation des impacts et élaboration de la stratégie nationale d'adaptation du secteur*, 148 p.

Mieczkowski Z., 1985, The Tourism Climatic Index: A method of evaluating world climates for tourism, *The Canadian Geographer,* 29(3), pp. 220-233

LIST OF ILLUSTRATIONS

5.6 - List of Tables

5.7 - List of Figures

