A proposal for a meteorological index of climate change impact*

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Abstract: *In the last decades worldwide marked signals of climatic anomalies, observed at both global and local scale, have been recognized by several scientific studies. In such a framework, the weather events, as well as the intrinsic variability of the atmospheric phenomena, seem to converge towards medium and long-term trends that differ from the average climatic reference. The aim of this paper was to analyze at Italian level the trend of selected meteorological variables (temperature and precipitation) in order to provide a composite index of climate change. In particular, we focused our study on Tmin, Tmax and total amount of rainfall data. Through statistical methods based on the elaboration of long-term climatic series, we derived a short-term scenario and computed the deviation of each abovementioned variable from the climatic reference period (1961-1990). By means of a Standardized Climate Change Index (SSCI), we quantifies the variability related to temperature and precipitation both singularly and jointly. Results are discussed in the light of improvement in land management and mitigation actions to face the effects of the actual climate variability.*
Keywors: *Climate change, Trend, Standardized index, Climatic variability, Italy*

Riassunto: *Le evidenze scientifiche concordano sul significato dei segnali di atipicità climatica occorsi negli ultimi decenni sia a scala globale che locale. In un tale quadro, le manifestazioni meteorologiche, così come la naturale variabilità degli stessi eventi atmosferici, sembrano convergere verso tendenze di medio-lungo periodo che prospettano scenari anche molto diversi dai parametri climatici medi di riferimento. Lo scopo di questo lavoro è quello di analizzare il trend del cambiamento climatico in Italia e quantificare la variazione delle principali variabili meteorologiche (Temperatura minima e massima, precipitazioni). A tal fine, ipotizzando uno scenario di breve periodo, determinato con metodi statistici a partire dalle serie storiche del passato, sono stati calcolati gli scostamenti di ciascuna variabile dal periodo di riferimento climatico (1961-1990). Attraverso un Indice Standardizzato di Cambiamento Climatico (SCCI), è stata infine quantificata la variazione climatica delle singole grandezze e quella complessiva. I risultati sono letti in un'ottica di gestione del territorio e di supporto alla definizione di misure di adattamento/mitigazione.*
Parole chiave: *Cambiamenti climatici, Tendenza, Indice standardizzato, Variabilità climatica, Italia*

INTRODUCTION

Scientific evidences confirm atypical climate signals at global and local scale during the past few decades. In such framework, the meteorological events and the weather variability converge on long-term trends prefiguring future scenarios very different from the current reference climatic parameters. The phenomenon is mainly characterized by a significant increase in temperature (global warming) often associated with a decrease of precipitation and/or serious alteration of the rainfall regimes. The average surface temperature has increased by 0.74°C over the last 100 years, mainly due to the contribution of the years between 1995 and 2007 which proved to be the warmest since 1850 to present. In consideration of further temperature rises, that according to IPCC should be equal to 0.2°C for each of the next two decades, it is possible to assume that temperature will increase, between 1.8°C and 4.0°C, up to 6.4°C, at the end of the century (IPCC, 2007).

Over the past 2000 years the climate has experienced alternating phases of "cold" and "hot", with deep effects on ecosystems and society equilibrium (Naurzbaev and Vaganov, 2000). According to other studies, the temperature trend over the last 2000 years was characterized by an uninterrupted downward trend until the middle of the twentieth century when there was a reversal remarked in the four decades between 1950 and 2000,the warmest of the whole period (Kaufman et al., 2009).

Signals of climate change have been highlighted in the early years of last century in North America (Huntington Vishera and Sargent, 1922), while the first research on the historical changes of the Italian climate is dated back decades ago and regarded the study of the scope of the main rivers (Melicchia, 1939) subsequently followed by other several studies (e.g., Piervitali et al. 1997; Schönwiese and Rapp, 1997; Ambrosetti and Barbanti, 1999; Brunetti et al., 2000; Brunetti et al., 2001; Simolo et al., 2010).

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Compared to the past, however, the connotation mostly distinguishing the current climate trends is represented by an unusually fast change as witnessed, in particular, by the increase in temperature.
Climate change and some of its consequences are more pronounced in marginal areas where the environmental equilibrium is fragile and the demographic pressure is high. According to official estimates provided by the United Nations High Commissioner for Refugees, the "climate refugees", or people forced to leave their places due to floods, droughts and other environmental factors, currently amount to about 24 million, but are likely to increase up to 200 million according to estimates projected to 2050 (UNHCR, 2002).
Beyond the consequences, sometimes catastrophic, on the natural environment and/or on the socio-economic structures of the several Countries (Imeson and Emmer, 1992; Kirschbaum and Fischlin, 1996; UNEP, 2002; Baric and Gasparovic, 1992; Few et al., 2004; Myers N., 1993; Rosenzweig et al., 1993), climate change is evident throughout the Mediterranean basin and also in Italy with clear implications related to heat waves, heavy rains, floods, landslides, long drought periods, etc. (Allen et al., 2010; Allen and Diaz, 1996; Aru, 1984; Hollis et al., 1992; Kirschbaum and Fischlin, 1996; MEDALUS II, 1996; Myers, 1993; WCED, 1987).
Regarding the agricultural-forestry sector, the particularity of the Italian vulnerability mainly depends on the production addressed to specialized and typical crops, of highest quality and strongly related to the territory. In order to be economically convenient, this kind of production, requires optimal climatic conditions and massive investments in terms of economic, technological and natural resources (Rogers and Dahlman, 1993; Rosenzweig and Hillel, 1993; Rosenzweig et al., 1993; Rosenzwieg and Tubiello, 1997; Reilly, 1996; FAO, 2003). In this way, beyond the risks due to bad weather events, it is very easy to exceed the thresholds of sustainability and generate an environmental pressure able to trigger land degradation processes. The immediate and future consequences of climate changes are not easy to predict because there are several scaling factors and not well defined interrelationships between each climatic variables and the climatic factors (landscape, topography, vegetation, latitude, etc.). Probably, if the current rainfall and temperature trends will continue, alterations of the hydrological cycle will be likely to occur, with destabilization of the ecosystem equilibrium and reduced availability of water for the human needs (Kaczmarek, 1996; Carter et al., 1994; Bolin et al., 1986; Baric and Gasparovic, 1992). Also, the frequencies of extreme events (floods, droughts, hurricanes, heat waves, heavy rain) will increase, while the rise of sea levels (due in large part to the melting of glaciers) will determine the salinization of coastal aquifers (EPA, 1989; FEMA, 1991; Milliman, 1992; Milliman et al., 1992; Titus, 1998; FEMA, 2000; IPCC, 2007).
Considered the nonlinearity of the environmental dynamics phenomena, the climate change measurement can help to better understand the extent of its impact and to mitigate its effects. The aim of this study is therefore to propose a procedure for a quantitative assessment of the impact of climate change in Italy at the local level and on a national scale detail, using temperature and precipitation as variables. The results of this study will be discussed by several point of view: ecological, geographical and territorial.

MATERIALS AND METHODS

The main difficulties regarding the climate change analysis and related consequences is the prediction of future climate change scenarios (CCS). In this study in order to outline a likely future climate, we used a projection of the observed data: this assumption is based on the probability, at least for the near future, that climate change is inherently described by the variability of past. The meteorological database was built starting from daily series of temperature and precipitations data (1961-2007) of about 3000 weather stations collected by the National Agricultural Information System (SIAN). Final data derived from geostatistical procedures of spatialization (Perini et al., 2007) and are related to 544 points regularly scattered all over the Country (grid 30 x 30 Km) . Starting from the evidences of climate change from the thermo-precipitation trends, we classified each year of the historical series (1961-2007) on the basis of average annual temperature and total annual precipitation.
The method refers to a statistical multivariate analysis known as cluster analysis which allows to recognize and to classify objectively the elements of a universe or a statistically significant sample (Rizzi, 1985; Arabie et al., 1996). From available information, we obtained a partition of the years in five groups climatically homogeneous in order to select the one with highest average temperatures and with lower annual precipitations (Perini et al., 2007).
Using the period 1961-1990 as climatic reference, among the five cluster identified, we considered the one characterized by the most relevant thermal deviation (+0.8°C). This selected cluster includes almost all the most recent years and has been used to represent the condition of stronger heating of the Italian territory (Tab. 1).
We repeated the cluster analysis using the total annual precipitation as discriminating variable. In this case, the aggregation of driest years showed (at national level) a

Annual mean temperature

years	distance from centroid	minimum value (°C)	maximum value (°C)	mean value (°C)	standard deviation
1961	0.28	0.5	19.0	13.8	4.2
1988	0.26	0.4	19.7	13.8	4.3
1990	0.21	0.7	19.8	14.0	4.3
1992	0.28	0.5	19.3	13.8	4.3
1994	0.43	0.8	20.1	14.3	4.3
1997	0.26	0.9	19.1	13.9	4.2
1998	0.34	0.6	19.2	13.7	4.2
1999	0.27	0.2	19.7	13.8	4.5
2000	0.21	0.8	19.6	14.1	4.3
2001	0.26	1.0	19.9	14.0	4.4
2002	0.25	0.6	19.2	13.8	4.2
2003	0.72	1.5	20.0	14.5	4.1

Tab. 1 - Descriptive statistics of the warmest years cluster.
Tab. 1 – Statistiche descrittive relative al cluster degli anni più caldi.

mean annual precipitation equal to 645 mm, about 175 mm less than the reference climatology 1961-1990. Results demonstrated a substantial consistency between the two different classifications of the years: the driest years coincide almost entirely (over than 80%) with the warmest years.
According to the results of the cluster analysis, we drew the Italian climatic scenario (CCS) for the near future (next 15-20 years) through a climatology calculated on the basis of the group of years identified by the temperature-based analysis and listed in Tab. 1. Furthermore, we calculated the absolute deviations from the climatic reference (1961-1990) values. However, for an heterogeneous and complex environment as the Italian territory, the absolute climate variation could not give an exact perception of the actual change, especially at local scale or when it is necessary to compare several zones each other. For example, a climatic decrease of 200 mm/year is a macroscopic change, but it could have a low enviromental impact (or social impact) where precipitations continue to exceed the ecological (or human) needs. In other circumstances (e.g. in arid or semi arid zones), just a lack of few millimeters can lead to disastrous effects. Undoubtedly, the cumulate impacts from two or more variables (e.g., temperatures and precipitation) are more difficult to predict due to their non-linear effects.
In order to solve such difficulties, the values of changes of temperature (estimated in degree Centigrade) and precipitation (estimated in millimeters) were standardized on a scale of values between 0 and 1 according to the following algorithm:

$$SCCI = [(x - min) / (max - min)]$$

where:
– SCCI = Standardized Climate Change Index;
– x = deviation value of the considered variable;
– min = minimum deviation of the considered variable;
– max = maximum deviation of the considered variable.

For each grid node we calculated the Standardized Index for temperature (SCCIt) and the Standardized Index for precipitation (SCCIp).
The above-mentioned indices allow to quantify the relative magnitude of climate change at local level through a relative comparison among the different Italian regions. In order to build a composite index (SCCItp), we combined the previous indices using the geometric mean method which allows to combine variables with non-linear or not proportional cumulative effects.
The calculation of the indices for each grid node and GIS tools allowed to draw thematic maps according to geographical partitions (Northwest, Northeast, South, Central and Islands) and elevation belts (inland mountain, coastal mountains, inland hills, coastal hills, plains).

RESULTS

The results confirmed the empirical evidence about the correlation between hot years and dry years. Despite some outliers, a negative and statistically significant relationship (p <0.001) was found between temperature and precipitation, as clearly shown by Fig. 1.
At national level, the short-term climate change scenario (CCS) is characterized by an annual mean temperature (about 14.0°C) that is almost 1°C higher than the conventional reference climate (IPCC, 2007). This scenario fits very well the global warming phenomenon. Analysing the intrinsic meaning of these results it is possible to dare some suppositions about the complex interactions among the various climatic variables, their seasonal trends and, in general, their interrelation with environment.
Regarding minimum temperature (Tab. 2), the increase appears higher than the maximum temperature one. In

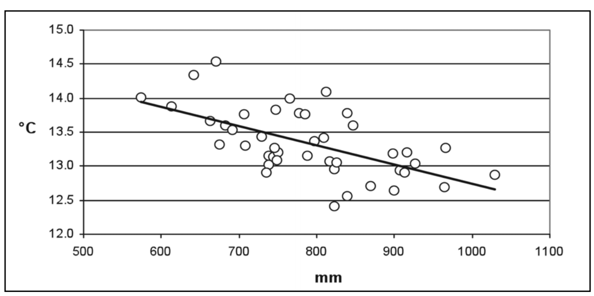

Fig. 1 - Relationship between mean annual precipitation (mm) and mean annual temperature (°C) in Italy (T_{med} = -0.003 + 15.572; R^2 = 0,35; p <0.001).
Fig.1 - Relazione fra il totale delle precipitazioni anno (mm) e la media delle temperature (°C) in Italia (T_{med} = -0.003 + 15.572; R^2 = 0,35; p <0.001).

Italian zones	minimum temperature (°C)							
	winter		spring		summer		autumn	
	climate	CCs	climate	CCs	climate	CCs	climate	CCs
Northern	-2.4	-1.1	3.8	4.6	12.1	13.1	5.8	6.1
Central	2.3	3.8	6.8	7.5	15.3	16.3	9.8	10.4
Southern	5.7	7.2	9.4	9.9	18.2	19.2	13.0	13.5
Islands	7.1	8.5	9.9	10.4	18.5	19.3	14.3	14.8

Tab. 2 – Mean minimum temperature of climate reference period (1961-1990) and Climate Change scenario (CCs) by geographical area.
Tab. 2 - Temperatura minima media della climatologia di riferimento (1961-1990) e dello scenario di cambiamento climatico (CCs) per partizione geografica.

Italian zones	maximum temperature (°C)							
	winter		spring		summer		autumn	
	climate	CCs	climate	CCs	climate	CCs	climate	CCs
Northern	4.6	5.8	13.2	14.8	22.8	24.0	14.5	14.6
Central	10.0	11.6	16.8	18.0	27.1	28.4	19.3	19.7
Southern	12.7	14.5	18.2	19.2	28.3	29.7	21.4	22.1
Islands	14.1	15.8	18.7	19.9	28.7	30.1	22.5	23.3

Tab. 3 – Mean maximum temperature of climate reference period (1961-1990) and Climate Change scenario (CCs) per geographical partition.
Tab. 3 - Temperatura massima media della climatologia di riferimento (1961-1990) e dello scenario di cambiamento climatico (CCs) per partizione geografica.

particular, winter is the season with the most striking changes, especially in the Northern and Central zones of Italy where winter temperatures increase up to +1.5°C respect to the reference climate (1961-1990). Also in the remaining parts of Italy the scenario values for the minimum winter temperature show a considerable growth, but with different intensity; for instance, in the Islands (Sicily and Sardinia) the deviation from the reference climate is about +1.4°C. Also in summer, Northern and Central Italy appear quite affected by sensible increases, while for the other seasons (spring and autumn), the minimum temperature increases are generally less important.
As for the maximum temperatures (Tab. 3), the widest changes involve mainly the winter season and, secondly, summer, spring and autumn. The highest climatic deviations are mainly found in the Southern Italy (up to 1.8°C during winter), but in Northern Italy we can observe the highest values (+1.2°C).
With regard to precipitation, the results highlight a general decrease at national level. Also this feedback is consistent with the global warming trends (Tab. 4). At the national level, the mean annual loss of precipitations amounts to about 130 mm. The most involved seasons are winter and spring, that regard the typical Mediterranean climate, generally represent the most rainy period in the year. As an example, in spring time, the largest reductions of precipitation occur both in

Italian zones	precipitation (mm)							
	winter		spring		summer		autumn	
	climate	CCs	climate	CCs	climate	CCs	climate	CCs
Northern	220	179	264	184	263	204	282	267
Central	278	239	199	163	140	96	282	269
Southern	286	237	166	119	78	47	248	203
Islands	232	219	129	90	34	22	193	180

Tab. 4 – Mean total precipitation of climate reference period (1961-1990) and Climate Change scenario (CCs).
Tab. 4 - Precipitazioni medie totali della climatologia di riferimento (1961-1990) e dello scenario di cambiamento climatico (CCs).

Northern and Southern Italy (-30% and -27% respectively), while in summer time, although the percentage values appear higher (-38% in the Southern Italy; -35% in the Islands), the absolute leak of precipitation is quantified by few millimeters only.
As concerns the elaboration of the Standardized Climatic Change Index (SCCI), we aggregated the values of the index for altitudinal belts and Italian macro zones. As for temperature, the highest scores of climate changes, as shown by Tab. 5, were found in the Islands (Sicily and Sardinia) where SCCIt is generally higher than other zones, with values between 0.62 (mountain) and 0.65 (hill). Other important increases regard mountains in Northern Italy (0.60), hills (0.58) and lowlands (0.64) in Southern Italy, and plains (0.54) in Central Italy.
Lowlands and hills in the Northern Italy appear to be less involved by temperature changes that other regions, and are characterized by the lowest SCCIt scores (≤ 0.40).
As for precipitation, the highest values of standardized index (SCCIp) were found generally in the mountainous areas with scores between 0.37 and 0.20. Concerning the geographical zones, the results show a more considerable reduction of precipitation in Northern Italy, followed by Central Italy, Southern Italy and Islands. Overall, the SCCIp spreads around the Country and the most common values range mainly

Italian Zones \ elevation belts	mountain			hill			plain		
	SICCt	SICCp	SICCtp	SICCt	SICCp	SICCtp	SICCt	SICCp	SICCtp
Northern	0.60	0.37	0.47	0.40	0.34	0.37	0.35	0.26	0.30
Central	0.54	0.37	0.45	0.48	0.26	0.35	0.54	0.32	0.42
Southern	0.55	0.31	0.41	0.58	0.30	0.42	0.64	0.29	0.43
Islands	0.62	0.20	0.35	0.65	0.19	0.35	0.63	0.21	0.36

Tab. 5 - Standardized Climatic Change Index (SCCI) by geographical partition and altitudinal belts (SICCt = for temperature; SICCp = for precipitation; SICCtp = for both temperature and precipitation).
Tab. 5 – Indice Standardizzato di Cambiamento Climatico (SCCI) per ripartizione geografica e fasce altitudinali (SICCt = per temperatura; SICCp = per precipitazione; SICCtp = per temperatura e precipitazioni).

between 0.2 and 0.4. The analysis, however, show that the strongest reductions in annual precipitation (SCCIp between 0.4 and 0.8) hit around 9% of the Northern Italy territory and 5% of the Southern Italy regions.
Finally, considering the cumulate index (SCCItp), it is possible to observe important climate change signals in mountain areas then in lowlands; while, by the geographical point of view, the most affected regions are, in order: Southern Italy, Central Italy, Northern Italy, Islands. In general, at national level, the most frequent values of the SCCItp range between 0.2 and 0.4. In the Southern, almost 25% of the area denotes SCCItp values between 0.4 and 0.6. The largest changes (SCCItp between 0.8 and 1.0) involve negligible fraction of the territory, also in the Northern and in the Central Italy.

DISCUSSION AND CONCLUSIONS

The climate change as predicted by the IPCC (2007), draws different scenarios at the regional level. At medium latitudes, where the Mediterranean basin is located, the most important signals include increasing temperatures, reduced rainfall, increased intensity and frequency of extreme events (Carter et al., 1994; Corre, 1992; Hollis et al., 1992; Imeson and Emmer, 1992; IPCC, 2007; Few et al., 2004; Magrin et al., 2007; Nicholls et al., 2005; Oxfam International, 2007; Thomas et al., 2004; UNEP, 2002; UNFCCC, 2006a,b,c,d; UNFCCC, 2007a,b,c,d,e; Houghton, 1997).
Some consequences of such phenomena are mainly related to reduced water availability, increasing risk of flooding, increase in intensity and duration of drought, deterioration of soil quality, increasing frequency of fires, acceleration of the processes of erosion and loss of wetlands in coastal areas. These effects could lead to serious unbalances both for the natural ecosystems and the traditional socio-economic organizations.
In the global context of climatic changes, the results of this study confirm the general climatic trends of Italy both in terms of reduction of precipitation and increase of temperature. As regards the short term evaluations, the comparison with the reference climate scenario (period 1961-1990) showed a considerable spatial and seasonal heterogeneity that match with the complexity and variety of the Italian environments. The main evidences raised from this study are: (i) a substantial increase in winter temperature especially in Northern and Central Italy; (ii) a strong decrease in winter and spring precipitation in Northern and Southern Italy, and in summer, particularly in Southern Italy and in the Islands; (iii) the concentration of the most significant climatic changes, as concerns temperature, in both the lowlands of Southern Italy and the uplands from Northern Italy.
However, absolute climatic change values do not express the different meanings that such variations assume in different environment conditions.
In fact, for instance, same absolute values of temperature increase may have variable impacts if we consider agro-ecosystems adapted to low or high temperatures. The mentioned increase of 1.5°C in northern Italy, where mean winter minimum temperature corresponds to -2.4°C, strongly alters the equilibrium of natural and semi-natural local biocenosis; the same increase in southern Italy, where mean winter minimum temperature corresponds to 5.7°C, will have a weaker impact on local well-adapted agro-ecosystems.
To overcome such limits, the proposed methodology relativizes the absolute climatic change values (both for temperature and precipitations), producing an index able to provide site-specific measures and suitable for regional comparisons.
Furthermore, the use of a normalized index, independent from the different variables units measure, allows to cumulate the effects of more than one climatic variable, synthesizing the climate change impacts.
The climatic shift toward warmer and drier conditions may have substantial consequences for the natural environment, human life conditions and economic activities. For instance, through a natural resilience, ecosystems may react to changing conditions and find new equilibrium that, in extreme, may affect the species distribution and, for example, modify the areal distribution of species and/or introduce alien species. When ecosystems are forced to be driven by human aims, such as in agriculture, man itself has the responsibility to find solutions for adaptation in order to preserve natural resources (water, soil, biodiversity, etc.) and to reconcile economic and production needs. In agriculture, higher temperatures than in the past can promote biological processes of growth and the development of crop producing good yields. This represents a positive aspect of climate change, also coupled with lower incidence of cold temperatures and frost. Regarding these events, especially in spring time, the probability of frost occurrences has almost halved in 50 years (Ranuzzi and Perini, 2002).
Higher temperatures, due to a most favourable thermal regime, could determine an early start and a quick conclusion of the growing crop cycles. However, this could represent a serious hazard for the potential risk of spring frosts, that, though less frequent than in the past, may affect the vegetation during the most vulnerable phenological stages (e.g., flowering and early vegetative) with consequences on the final crop yields (Perini et al., 2007). These risks are particularly real in the Northern Italy where agriculture is an activity derived by a long

adaptation to past environmental conditions, which are significantly different from those envisaged for the near future in this study. Regarding precipitation, the reduction in winter-spring rains particularly affects the recharge of water resources leading to a strict limitation for the next growing seasons. In addition, the non-linear combination of reduced rainfall and increasing temperatures emphasizes the individual effects of each variable, with particularly serious consequences in Southern Italy where the exasperation of the normal hot-dry climatic conditions, especially in summer, promotes degradation and soil erosion, ignition and propagation of fires, and lack of water resources both for the vegetation and human utilisation. Furthermore, it is important to consider that the temperature and precipitation changes may modify the environmental conditions necessary for some typical Italian productions, with all the socio-economic consequences related to such modifications.

In conclusion, the quantification and standardization of the anomalies resulting from climate change provide a better understanding of its consequences, allowing to assess their impacts and to compare the different territorial situations at regional and local scale. In addition, a more analytical knowledge of climatic change, may be useful in planning adaptation/mitigation measures, especially at the local scale, in order to preserve both natural resources and economic priorities. It is therefore important to focus attention and efforts on the most critical consequences for Italy, which could increase the territorial vulnerability in terms of water resources, hydro-geological risk, land degradation processes and biodiversity loss.

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