



Global and Mediterranean climate change: a short summary

Virginia Ciardini¹, Gian Marco Contessa², Rosaria Falsaperla³, José Luis Gómez-Amo⁴, Daniela Meloni¹, Francesco Monteleone⁵, Giandomenico Pace¹, Salvatore Piacentino⁵, Damiano Sferlazzo⁶ and Alcide di Sarra¹

¹Laboratorio di Osservazione ed Analisi della Terra e del Clima, Agenzia Nazionale per le Nuove Tecnologie, l'Energia, e lo Sviluppo Economico Sostenibile (ENEA), Rome, Italy

²Laboratorio Radioprotezione per Impianti Fusione Nucleare e Grandi Acceleratori, Agenzia Nazionale per le Nuove Tecnologie, l'Energia, e lo Sviluppo Economico Sostenibile (ENEA), Rome, Italy

³Dipartimento di Medicina, Epidemiologia, Igiene del Lavoro e Ambientale (DiMEILA), Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro, Monte Porzio Catone (Rome), Italy

⁴Departament de Física de la Terra y Termodinàmica, Universitat de València, València, Spain

⁵Laboratorio di Osservazione ed Analisi della Terra e del Clima, Agenzia Nazionale per le Nuove Tecnologie, l'Energia, e lo Sviluppo Economico Sostenibile (ENEA), Palermo, Italy

⁶Laboratorio di Osservazione ed Analisi della Terra e del Clima, Agenzia Nazionale per le Nuove Tecnologie, l'Energia, e lo Sviluppo Economico Sostenibile (ENEA), Lampedusa, Italy

Abstract

Observed changes at the global scale. An increase of the annual mean global temperature and changes of other climate parameters have been observed in the last century. The global temperature and the atmospheric concentration of greenhouse gases are changing at a very fast pace compared to those found in palaeoclimate records.

Changes in the Mediterranean. Variations of some climate change indicators can be much larger at the local than at the global scale, and the Mediterranean has been indicated among the regions most sensitive to climate change, also due to the increasing anthropogenic pressure. Model projections for the Mediterranean foresee further warming, droughts, and long-lasting modifications.

Impacts. Regional climate changes impact health and ecosystems, creating new risks, determined not only by weather events, but also by changing exposures and vulnerabilities. These issues, and in particular those regarding occupational safety, have not been sufficiently addressed to date.

Key words

- climate change
- global warming
- occupational health

INTRODUCTION

Climate describes the long-term behaviour of the Earth, on a time scale which starts from decadal and extends to billion years. As seen from space, the Earth climate is essentially determined by the amount of electromagnetic radiation exchange with space. At the equilibrium, the energy associated with the absorbed solar radiation is balanced by the one associated with infrared emitted radiation, and the Earth climate is basically linked to its capability of absorbing solar radiation.

Globally, Earth absorbs about 70% of the incoming solar radiation [1]; this ratio is determined by a number of factors, which are related to the transfer and redistribution of the electromagnetic radiation in the atmosphere, at the surface, and in the ocean. The Earth diffuse reflectivity (albedo) depends on the properties of the surface as well as on properties and distribution of

clouds, and of atmospheric constituents (gases and particles). At the local and regional scales, and with time, albedo varies largely.

The way in which infrared (IR) radiation exits from the Earth depends, in its turn, on the surface temperature and properties (emissivity), and on the atmospheric vertical distribution and amounts of gases which display absorption bands in the IR (the so called greenhouse gases, GHGs) and, in particular, on the occurrence and characteristics of clouds.

Within the surface-atmosphere system, energy is transferred through different other processes in addition to electromagnetic radiation exchanges. These processes are linked to evaporation and condensation of water, sensible heat exchange, and dynamical processes (in the atmosphere, the ocean, the cryosphere, and, over very long time scales, in the geosphere). The climate at the

different scales, from local to global, within the system is the result of the combination of all matter and energy exchanges, and their equilibrium; these exchanges involve the different components of the system (land, atmosphere, ocean, ice, and biosphere) through complex and interconnected mechanisms. The resulting equilibrium determines also the system capability to absorb solar radiation, and the global Earth radiation budget.

Terrestrial and marine vegetation also play an important role, contributing to exchange of energy, mass, and participating in important cycles favouring redistribution and transformation of different chemical species.

The climate at the surface of the Earth and in its atmosphere thus also depends on the amount and distribution of atmospheric greenhouse gases (primarily water vapour, but also CO_2 , CH_4 , N_2O and other species), and of clouds, which play a large role in determining the intensity of the greenhouse effect. This effect, known since almost 200 years [2], is the result of the balance between the infrared radiation absorbed and emitted at the surface, and the one absorbed and emitted by the atmosphere. The atmospheric opacity in the infrared spectral range produces an infrared radiation surplus in the lowest atmospheric layer, leading to an additional surface warming with respect to the warming that would occur without IR absorbing species. The IR radiation surplus associated with the greenhouse effect is evident by comparing the global annual mean outgoing IR radiation at the top of the atmosphere, of about 240 W m^{-2} , with the global annual mean IR radiation emitted (about 400 W m^{-2}) and absorbed (about 340 W m^{-2}) at the Earth surface [1].

The amount of atmospheric GHGs directly influences the intensity of the greenhouse effect. The quantification of this direct influence, and of the role of the many indirect effects, is often expressed as climate sensitivity (*i.e.*, the thermal response with respect to a radiative perturbation, or to a doubling of the atmospheric CO_2). Its determination is a very complex task, due to the high degree of interconnection and the existence of many feedback mechanisms acting on different time scales [3]. The feedback mechanisms lead to an amplification or a reduction of the direct effects. As an example, a perturbation in the surface properties, or in the atmospheric composition, is expected to affect the overall Earth albedo, thus possibly impacting the amount of absorbed solar radiation and also the global radiation budget at the top of the atmosphere.

Due to this complexity, many processes are still poorly understood. The role of aerosols and clouds, in particular, and the relevance of some key feedback mechanisms are still poorly constrained [3].

Very fast, large anthropic perturbations to the atmospheric composition have been observed in the last decades. Atmospheric CO_2 has increased by almost 40%, due to anthropic emissions (essentially the use of fossil fuels and the cement production), in the last 250 years, while CH_4 increased by more than 130%. Although it is difficult to quantitatively assess the changes in climate produced by these perturbations, various indications strongly support the fact that the global warming observed in the last 100 years may be attributed to the

anthropic modifications of the atmospheric composition, as well as other observed climate modifications. As stated, the effect of the GHGs increase vary at the regional scale. For instance, a very intense warming has been observed in the Arctic region during the last decades, which has been defined as Arctic amplification [4], and over the Sahara desert [5]. Various complex feedback mechanisms which involve radiation budget, sea and land ice, clouds, are involved in the Arctic amplification. The small available humidity at the surface, and the reduced role of latent heat, are expected to produce larger temperature increases in dry areas, like the Sahara.

The radiative perturbation produced by the addition or variation of a specific compound in the atmosphere is defined as radiative forcing. Its value is obtained as the difference between the net irradiance at a specific level with and without the specific compound.

The investigation of occurring changes and a robust identification of the causes require long-term dedicated measurements, with a high degree of comparability on the global scale, and high accuracy. In parallel, a large effort is also required both through dedicated experiments and modeling development to better understand processes whose knowledge is still incomplete, and in particular feedback mechanisms.

Although many uncertainties in the understanding of various processes exist, modelling analyses agree in suggesting significant changes for the next century, also depending on the implementation of policies for the reduction of GHGs emissions. The observed changes, and those expected for the future, impact many sectors. As an example, it has been suggested that climate change (CC) impacts on health may be viewed as a form of involuntary exposure, which is already mainly affecting populations least responsible for increased greenhouse gas emissions [6]. This aspect has also important ethical implications regarding equity.

Changes in environmental conditions and hazards, which are expected to be acting and vary on the regional scale, are expected to affect also, through different mechanisms, occupational safety and workers. These impacts have not been sufficiently studied to date. This issue addresses several different aspects of occupational health and safety (OHS) within this context, with a special focus on the Mediterranean, which is one of the regions particularly sensitive to CC [7].

Occupational health and safety aspects related with heat stress [8, 9], radiation [10], changing weather conditions [11], use of pesticides [12], radiation protection practices [13], vector-borne diseases [14], occupational allergies [15], and new professions in the green labour market [16] are discussed.

This paper gives a short overview of the present knowledge on CC, with emphasis on the Mediterranean region, to provide background information on the occurring and expected changes.

OBSERVED CHANGES AT THE GLOBAL SCALE

Evidences for changes of the Earth climate are based on the analysis of the long-term variability of the dif-

ferent components of the climate system (atmosphere, ocean, cryosphere, land, and vegetation), which are strongly interconnected. Long-term datasets are based on palaeoclimate archives and on *in situ* and remote sensing observations, often integrated by means of numerical model simulations and reconstructions.

Available observations of the atmosphere, the ocean, and the surface have shown evidence of occurring changes on decadal time scale related to CC, and it is now unequivocal that the planet has been warming since the 19th century [17].

Figure 1 shows the evolution of the anomaly (difference with respect to the average over years 1901-2000) of the annual mean global temperature over the period 1880-2015, as derived from the NOAA global temperature (land+ocean) dataset (version 3.3.0 Global Historical Climatology Network-Monthly data set and International Comprehensive Ocean-Atmosphere Data Set; www.ncdc.noaa.gov/sotc/global/201513).

The global annual average surface air temperature has risen since late 19th century, with a particularly marked increase since 1970 [e.g., 18, 19]; the surface temperature increase is estimated to be 0.85 °C over the period 1880-2012, and about 0.72 °C over the period 1951-2012. A possible slowdown of the warming has been suggested to occur during the last 15 years [e.g., 20], and different possible causes have been investigated. However, Rajaratnam *et al.* [21] recently found a non statistically significant difference in trends in the last 15-20 years through statistical analyses of the global temperature record. More recent data show that the global temperature reached the two highest values on record in 2014 and 2015; the very high temperature anomaly (+0.9 °C) for 2015 is expected to be largely influenced by the strong El Niño.

Observations show evidences that the Arctic sea ice and snow cover are shrinking, and that melting of ice sheets is increasing. The Arctic sea ice extent reduction is estimated in -3.8 ± 0.3 % per decade, with a notable

decrease in thickness and volume [22]. The annual ice mass loss is estimated to be increased from 34 Gt yr⁻¹ in the period 1992-2001 to 215 Gt yr⁻¹ in 2002-2011 for Greenland, and from 30 Gt yr⁻¹ in 1992-2001 to 147 Gt yr⁻¹ in 2002-2011 for Antarctica.

Global sea level has been observed to increase by about 0.19 m since 1901 [e.g., 23]. The increase is primarily due to the thermal expansion of the ocean and to the land-based ice discharge. The estimated sea level equivalent of the mass loss from the Greenland ice sheets over the period 1993-2010 is about 5.9 mm (considering also 1.7 mm from Greenland's glaciers), while is 4.8 mm for Antarctic ice sheets. In the same period, tide gauge and satellite altimeter observations show a global mean sea level increase by about 54 mm [24].

Significant increases in the heat content of the ocean, the atmosphere, and the cryosphere have also been observed; the increase in the ocean heat content appears one order of magnitude larger than in the other components [25].

An increase of the atmospheric water vapour has been reported [26], which may impact extreme events, as severe rainstorms or droughts.

Changes in extreme events have been registered since 1950; globally, rising trends in occurrences of heavy precipitation [27], heat extremes and decreasing trends in extreme cold events have been associated with the observed changes in average conditions; the frequency of heat waves has increased in large parts of Europe, Asia and Australia, while the frequency of intense precipitation events has likely increased in North America and Europe [18].

Changes in the precipitation regimes, droughts, and water availability have also been observed in different regions [e.g., 28].

These changes are expected to largely impact agriculture, coastal zones, mountain regions, etc. Most of these changes are also expected to produce indirect effects on the climate itself, as a consequence of modifications of surface albedo, vegetation distribution, evaporation, cloud properties, chemical cycles, etc. Many of these indirect effects involve complex feedback mechanisms [29].

EVOLUTION OF GREENHOUSE GASES

Among the different atmospheric compounds with a direct impact on climate, greenhouse gases are those that underwent the largest increase due to anthropic activity.

Among long-lived GHGs, carbon dioxide and methane are the most relevant contributors to the radiative forcing. Ice-core data show that during the last 800 kyr, until the pre-industrial times, CO₂ concentration ranged approximately between 180 and 300 ppm [30, 31]. The CO₂ mixing ratio exceeded 400 ppm at many sites around the globe already in 2014. Thus, the present atmospheric CO₂ is the highest of the last 800 kyr, and is more than 30% larger than in the pre-industrial period. The CO₂ growth rate ranges from 0.6 ppm yr⁻¹ at the beginning of the 1960s to more than 2.0 ppm yr⁻¹ in the recent years, although with a large interannual variability [32].

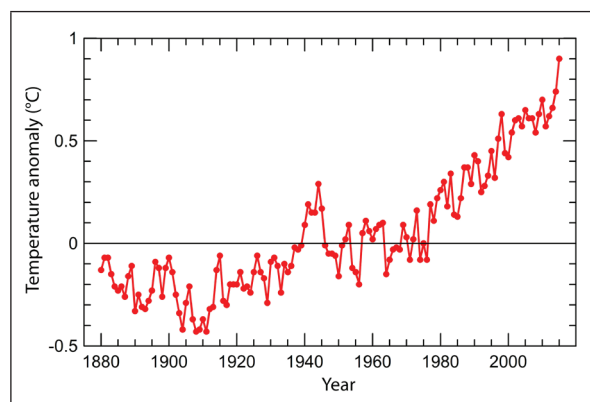


Figure 1

Time series of the annual mean global (land + ocean) temperature anomaly (difference with respect to the average over years 1901-2000, dataset from NOAA, Global Historical Climatology Network-Monthly data set, version 3.3.0, and International Comprehensive Ocean-Atmosphere Data Set; <http://www.ncdc.noaa.gov/sotc/global/201513>).

Since about 1750, about 374 billion metric tonnes of CO₂ have been released mainly from fossil fuels combustion and cement production. Half of the total CO₂ emitted from fossil fuel combustion has been registered since 1980s [33]. CO₂ emissions from fossil fuel use have continued to increase during recent years, reaching 9.9 GtC yr⁻¹ in 2013 [34]. In the same year, estimated CO₂ emissions from land-use changes are 0.9 GtC yr⁻¹, for a total of anthropic emissions of 10.8 GtC yr⁻¹. Fifty percent of the emitted CO₂ has remained in the atmosphere, as determined from the observed atmospheric CO₂; about 23% of the emitted anthropic CO₂ has been absorbed by vegetation, and about 27% by the ocean. The total CO₂ anthropic emissions since 1750 are estimated to correspond to about 580 ppm in the atmosphere [34].

CH₄ concentrations over the past 650 kyr, during glacial and interglacial periods, have ranged between 350 and 800 ppb [35] reaching a present value of about 1800 ppb [18]. Starting from 1750, changes in methane concentrations have led to an alteration of the radiative budget by about 0.5 W m⁻²; an additional forcing of ~0.3 W m⁻² has been attributed to the formation of tropospheric O₃ and stratospheric H₂O from CH₄ [36]. Sixty percent of the total atmospheric methane emissions are due to anthropogenic sources such as agriculture, biomass burning, extraction, and combustion of fossil fuels etc. Around 20% of the warming due to the long-lived GHGs is attributed to methane [37].

Beside carbon dioxide and methane, a growth of other greenhouse gases such as nitrous oxide (N₂O), and halocarbons has also been observed as a consequence of the human activities, N₂O, the third major atmospheric constituent influencing the IR radiative budget, shows a growth rate of 0.75 ppb yr⁻¹ since 1970s [18]. Emissions of the major GHGs peaked in 2014 [32].

The radiative forcing produced by the GHG increase occurred in the last 250 yr is estimated in about 2.94 W m⁻², 36% higher than 25 years ago [32].

It must be pointed out that the CO₂ increase occurred in the last 200 years is of the same magnitude, about 100 ppm, of the glacial-interglacial (about 100 kyr) CO₂ difference; however, the observed recent change is occurring on a very fast time scale, with possible complex impacts, partly still not well understood, also on the carbon cycle itself [38, 39]. Among the different implications, the ocean acidification due to increased oceanic dissolved CO₂ is expected to produce very large effects on the stability of the external calcium carbonate skeletons of key marine organisms and on the ocean capability to absorb CO₂ [40].

CHANGES IN THE MEDITERRANEAN

The Mediterranean is a semi-closed deep ocean basin surrounded by continents with different orographic and land use characteristics. The meteorology of the Mediterranean is strongly influenced by the ocean-land interactions, and by the complex orography. Large scale meteorological processes also affect the basin, which is influenced by the descending branch of the Hadley circulation on the Southern side, and by the mid-latitude disturbances in the North. This complex-

ity affects, among different aspects, its regional climate, with impacts on the thermal regime and hydrological cycles. In addition, the Mediterranean is characterized by a strong anthropic pressure, with about 400 million inhabitants distributed mainly in its coastal regions, and with significant anthropic impacts on emissions, land use, hydrology, etc. Due to this complex conditions, and the strong sensitivity to CC, the Mediterranean has been indicated among the main climatic hot-spots [7], *i.e.* the regions which are most vulnerable to CC.

Significant changes in various climate indicators have been observed also in the Mediterranean. Various studies suggest that the temperature increase measured in the coastal regions during the last decades is somewhat larger than at the global scale, although with remarkable seasonal and sub-regional differences [41, 42].

Long-term changes are also observed in the sea surface temperature. Satellite observations made in the period 1982-2012 indicate an average increase at a rate of 0.035 °C yr⁻¹, with seasonal and sub-basin differences; the rate varies between 0.017 °C yr⁻¹ (sub-western Ionian sub-basin), and 0.05 °C yr⁻¹ (north-east Levantine sub-basin) [43]. Long-term changes are apparent also in the deep water temperature and salinity [44].

Direct measurements also show an increase of the sea level, by about 1.1-1.8 mm yr⁻¹ [45]; this increase is significantly smaller than the one observed at the global scale (about 3 mm yr⁻¹ between 1993 and 2009) [24].

Changes in the occurrence of temperature extremes, and particularly heat waves [46], and precipitation [28] have been found in the Mediterranean. A progressive drying has been observed in the central and eastern Mediterranean in the period 1988-2005; in the same period humidity has increased in the western basin [47].

Extraordinary heat waves have been observed in the past two decades. In particular, a very intense heat wave occurred in summer in central-western Europe in 2003 [46], with large impacts on the whole basin [*i.e.*, 48], and in 2010 in Russia. High temperatures have been also observed in summer 2012 and 2013. The heat waves may be coupled with droughts [49].

Figure 2 shows the evolution of monthly means of temperature and other atmospheric parameters measured at the Station for Climate Observations on the island of Lampedusa (35.5°N, 12.6°E), in the Southern sector of the central Mediterranean.

Lampedusa is a small island, far from large pollution sources, and more than 100 km from continental areas. Thus, the local temperature is representative of the central Mediterranean, and the evolution of the atmospheric constituents is representative of the regional background [*e.g.*, 50].

A significant interannual variability is apparent in the temperature record, started in 1999, with particularly warm summers in 2003, 2009, 2012, and 2015. Similarly, warm winters occurred particularly in 2006-2007 and 2009-2010. The most evident long-term increases occur for CO₂, N₂O, and CH₄. CO₂ increased by more than 40 ppm over 23 years. A large interannual variability in the growth and in the seasonal amplitude is evident, as an effect of global phenomena, like El Niño [51], and synoptic configurations [52].

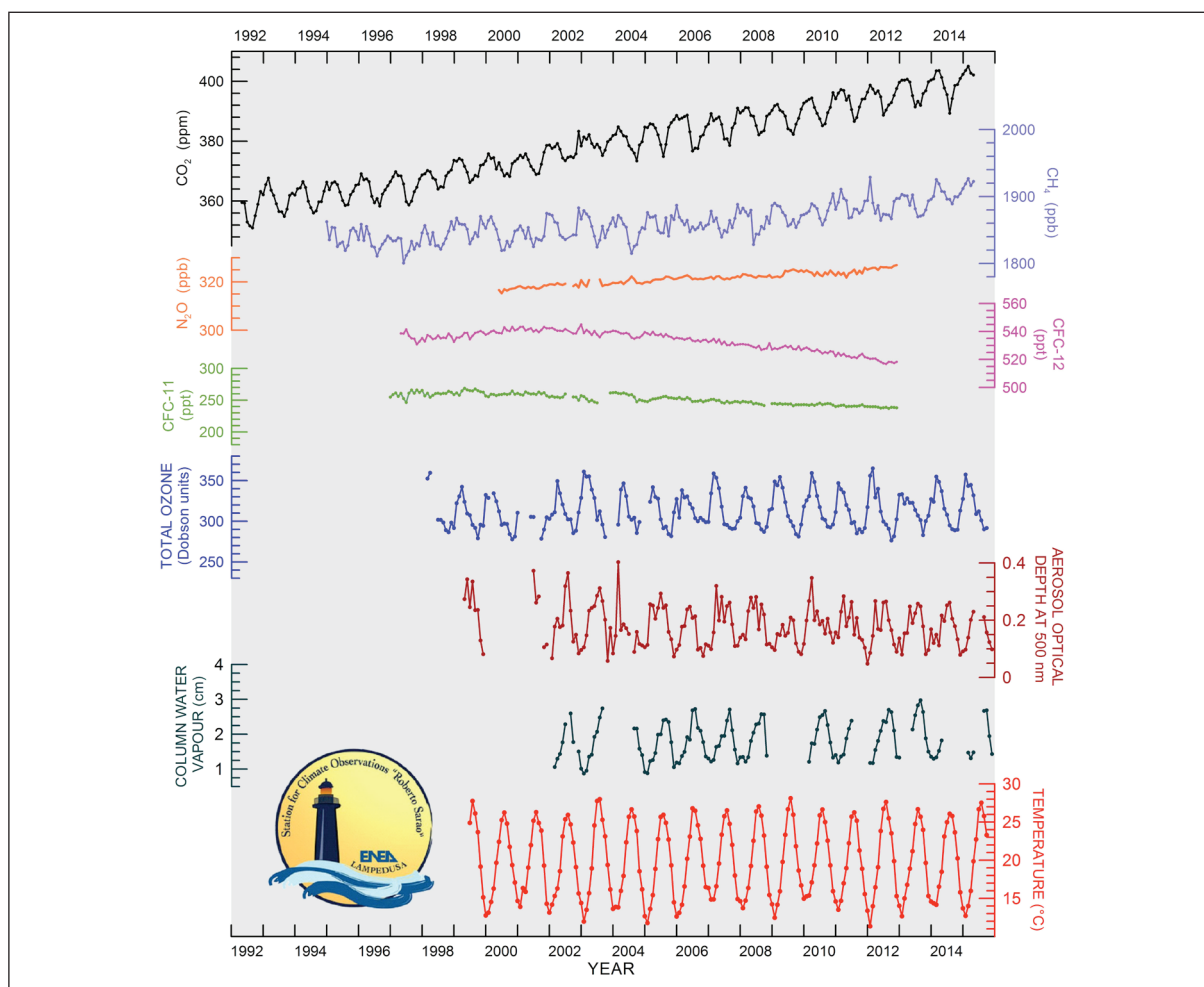


Figure 2

Monthly mean time series of (from bottom to top): temperature, column water vapour, aerosol optical depth, total ozone, and mixing ratio of CFC-11, CFC-12, N_2O , CH_4 , CO_2 , as measured at the Station for Climate Observations on the island of Lampedusa, in the central Mediterranean.

The monthly CO_2 record has been fitted with the following function:

$$f(t) = A + B t + C \sin(2\pi t + \phi)$$

where t is time. The derived average annual CO_2 growth rate, B , is 1.87 ppm yr^{-1} .

By applying the same fit to the CH_4 series [53], an annual growth rate of 3.3 ppb yr^{-1} is derived; data display a significant interannual variability, with a possible acceleration during the last years.

N_2O also displays a fast growth, of the order of 0.7 ppb yr^{-1} , while an evident decline appears for CFC-11 and CFC-12 [see also 54], following their reduction after the Montreal protocol.

Ozone, aerosol, and water vapour are other important parameters capable of affecting the radiative budget and climate. Total ozone measurements, made with a Brewer spectrophotometer [55], display the typical annual cycle for these latitudes, with a maximum in spring and a minimum in autumn. The aerosol optical depth also shows a strong seasonal cycle, and a large interan-

nual variability. The aerosol seasonal cycle is mainly determined by the processes associated with transport of Saharan dust [56, 57], which is most intense in spring and summer in the central Mediterranean. A small, non statistically significant downward trend in the aerosol optical depth has been derived in the period 2002–2013 [58]. An upward trend of the column water vapour, derived from sun-photometric observations [59], appears in Figure 2; however, water vapour data have not been verified for their long-term consistency and a reliable trend estimate is not possible.

The variability of each specific components is the results of many different factors, including the component lifetime in the atmosphere, influence of natural and anthropic sources, sinks, and dynamical processes. It must be noted that column water vapour seasonally changes by a factor of about 2, while the aerosol optical depth changes by a factor of about three. Relative changes of the other constituents on the seasonal scale and on the interannual scale are much smaller.

Clouds, GHGs, ozone, water vapour, and aerosols are the main atmospheric constituents which regulate the

radiation budget at the surface, in the atmosphere, and at the top of the atmosphere. Information on clouds is not included in Figure 2.

Aerosols interact with solar (e.g., [60, 61]) and, to a smaller extent, with IR radiation [62, 63]. The daily average radiative perturbation produced by aerosols at the top of the atmosphere in the solar spectrum in the Mediterranean is about -8 W m^{-2} [61]; a smaller forcing, of opposite sign, partly compensating the solar forcing, is produced by dust particles in the IR [62, 63].

Water vapour has absorption bands in the solar and in the IR spectrum, and plays a fundamental role in regulating the Earth climate and in amplifying the warming produced by long-lived GHGs, through a strong positive feedback mechanism [64]. Water vapour is responsible for about 50% of the Earth greenhouse effect; in addition, it participates in many processes, including significant energy exchanges through evaporation and condensation, and its behaviour largely affects clouds. Clouds produce very large radiative effects, both in the solar and in the IR spectrum.

Ozone displays an intense absorption band in the IR and contributes to the greenhouse warming; at the same time, it largely absorbs ultraviolet radiation and, to a smaller extent, solar radiation. The radiative forcing produced by the ozone changes is however small [65, 66].

The radiative effects produced by cloud and aerosol seasonal changes are thus much larger than the one produced by seasonal changes of GHGs, and is comparable or larger than the overall effect produced by GHGs over 250 years. Due to the clouds and aerosols short lifetime, their radiative effect is strongly variable at the regional scale, and is modulated by solar radiation. Thus, small changes in the long-term behaviour (amount, properties) of aerosol and clouds may add or compete with the effect of GHGs. Lack of detailed knowledge on the past variability of aerosol and clouds do not permit to constrain the determination of the climate sensitivity [67]. The simultaneous variability of these parameters, also considering their mutual interconnections, makes the understanding of the regional climate complex, especially in the Mediterranean.

ATTRIBUTION TO NATURAL AND ANTHROPIC CAUSES

Climate variability has natural external and internal forcings and feedbacks occurring at different spatial and temporal scales, whose effects can be superimposed to those deriving from anthropogenic forcings. Drivers of CC are defined as natural or anthropogenic components or as processes that can alter the Earth's radiative budget. The unequivocal attribution of CC to each forcing agent involves analysing observations and model simulations to explain all the involved processes and their interactions.

The successive reports of the Intergovernmental Panel on Climate Change (IPCC) assess with increasing confidence the dominant role of human-induced greenhouse gas emissions in causing increasing global near-surface temperatures [68]. The last report states that "It is extremely likely that more than half of the observed increase in global average surface temperature

from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period".

However, despite the high level of confidence in assessing the role of anthropogenic influence, uncertainties still remain in quantifying the attribution statement more precisely. These uncertainties are associated with observations (for example bias in the datasets or gaps in the global coverage) and with models (for example errors in model formulation, deficiencies in model resolution, and inadequacies in the way external climate forcings are specified). Coupled atmosphere-ocean general circulation models attempt to simulate all the most important physical processes in the climate system that lead to a model's response to a particular forcing.

The attribution study uses various ensemble of climate models. The last available ensemble of climate models, CMIP5, has sophisticated treatments of forcings, including aerosols and land use changes. It also includes ensembles of simulations with both anthropogenic and natural forcings, as well as alternative ensembles which just include natural forcings, and ensembles which include just changes in well-mixed greenhouse gases.

As shown by several authors [69, 70], model estimates, based on the natural internal forcing only or palaeoclimate reconstruction of the last 1000 years, can not explain the warming observed during the last century. Starting from the industrial revolution, anthropic factors have been influencing the climate and currently are considered the main responsible for the recent CC, and are expected to produce a large impact in the future.

Jones *et al.* [71] have explored the causes of changes in near-surface temperatures occurred from 1860 to 2010 using the CMIP5 ensemble. Simulations that incorporate both anthropogenic and natural factors reproduce the changes in observed temperatures, while simulations including only natural factors do not reproduce the recent warming. Calculations support previous conclusions that human-induced greenhouse gases dominate the observed global warming since mid-20th century. The estimated range of temperature increase between the period 1951-2010 and 1880-1919 (the most robust result found by [71]) due to GHGs is $0.6\text{--}1.2^\circ\text{C}$. This warming is balanced by a counteracting cooling from other anthropogenic forcings (direct and indirect effects of tropospheric aerosols mainly) between 0 and -0.5°C . The resultant contributions are very close to the observed warming of approximately 0.6°C over this period. Moreover, natural forcings alone can not explain the observed temperature variations, while a too high warming is obtained by including only the GHGs. This behavior is observed also at regional level for Europe and the Mediterranean Sea. Additional studies considered only the direct effects of sulfate aerosols, and both the direct and the indirect effects in the simulations. The weighted mean of the models incorporating only aerosol direct effects warms up considerably more than the models that also include aerosol indirect effects.

Recently, the first direct observations of the radiative forcing produced by the CO_2 increase occurred

between 2000 and 2010 (22 ppm) at the surface were shown [72]. The evidence comes from the observation of downwelling IR radiation spectra, which make unequivocal the attribution of the forcing to CO₂ thanks to the identification of its spectral features in clear sky conditions.

Various other changes, in addition to the increment of the lower atmosphere and near surface temperatures, are induced by the anthropogenic GHG increase. Observations indicate that most of the atmospheric heat trapped by GHGs is transported into the oceans [73]. The warming signal observed since 1970 in the first 700 m of depth, although varying from ocean to ocean in its vertical structure, can not be explained by natural forcings alone, but can be very likely attributed to anthropogenic forcings (emission of GHGs and sulphate aerosols) [74].

Similarly, an additional footprint leading to the attribution of the observed changes to the GHGs is given by the time and space evolution of the atmospheric thermal structure. The vertical and latitudinal distribution of the warming occurring in the atmosphere, as produced by climate models which include the GHG increase, mimics that observed in the atmosphere [75]. It must be emphasized that different mechanisms would be expected to produce a different spatial change of the temperature profile.

Differently from what already said for changes in temperature, it is difficult to determine the magnitude of the human contribution to the observed changes in precipitation. Major uncertainties arise because in situ land observational records are incomplete and with many gaps, particularly in the tropics and subtropics, and because the satellite record is short compared to decadal climate variability and affected by calibration uncertainties [76]. On the other hand, climate models lack in describing all the complexity of the large-scale water cycle. Similarly, although they include a treatment of clouds and, in some cases, aerosols and their mutual interactions, a detailed representation and quantification of these processes is still lacking.

IPCC attributes with medium confidence to human influence the changes in the water vapour amount and in the precipitation patterns [68]. IPCC also states that human activities have very likely impacted the ocean surface salinity as a consequence of the increase of E-P (evaporation minus precipitation) over the oceans since 1950's. Moreover, it is likely that the decrease in snow precipitation since 1970's has an anthropogenic component.

The intensification of precipitation extremes over the Northern Hemisphere land over 1951-2005 (+3.3% of the average daily precipitation) has been attributed with >90% confidence level to human influence [77]; these changes can not be explained by internal climate variability or natural forcing. Similarly, it has been suggested that the detected increase of 0.41 kg m⁻² per decade in the total atmospheric moisture content can be attributed to the increase in GHG, and can not be due to climate noise alone [78]. Moreover, a significant global-scale increase in surface specific humidity, attributable mainly to human influence, has been found [79].

Some evidences of the human influence on the pre-

cipitation patterns have been found at the local and regional scales. Changes in the precipitation regimes in western Mediterranean regions very sensitive to variations in near surface temperature and moisture have been reported [80]. These near surface variations have been mainly associated with land-use perturbations historically accumulated (*e.g.* progressive desertification, and reduced evaporation) and the combined radiative impact of the increasing levels of aerosols and air pollutants that may produce additional greenhouse heating. As a result, the perturbations on the hydrological cycle are amplified, changing the type and regime of precipitations.

IMPACTS

As discussed above, changes in global temperature, sea level, ice extent, water cycle, carbon cycle, and in other aspects of climate affect various planetary equilibria and human life. Strong interactions connect CC, ecosystems, biodiversity, human life, and various sectors of human economical activities.

Thus CC, through direct and indirect processes, may produce impacts at the global, regional, and local scale, depending on the specific conditions of the area. The severity of the impacts depends on vulnerability and exposure of each specific target: following the IPCC definition, vulnerability is the predisposition to be adversely affected, while exposure can be described as the presence of human and ecosystem tangible and intangible assets and activities (including services) in areas affected by climate extremes [81].

The health effects associated with the gradual warming of the planet are considered by the World Health Organization (WHO) among the most important health problems to be faced in the coming decades [82].

CC impacts human health through different complex pathways, acting on different time scales. Heatwaves impact cardiovascular and respiratory health; adverse health effects are associated with floods, storms, and wildfires; in addition, CC may indirectly impact health through decreasing food and water quality and availability, reduced air quality, increased allergic and vector borne diseases [83, 84], and a general deterioration of sanitary conditions.

In particular, decreased water availability and quality produce impacts on different sectors. Moreover, water stress is one of the most limiting factors constraining vegetation productivity. A reduction of crop productivity (maize and wheat) has been observed between 1980 and 2008, and has been attributed to the effects of the global temperature increase [85]. Changes in crop production associated with CC display a large spatial inhomogeneity, with regions also displaying an increase in productivity. Under warming climate, persistent drought and increasing water demand is expected to challenge food production, and may put global food security at risk [86].

CC impacts are expected to affect primarily people living in poverty and poor countries [81]. With this respect, the relationship between large global emitters and poor countries has also been investigated in the context of the global justice and inequalities [6, 87].

Links between CC and migrations and, in some cases, wars have also been suggested, highlighting possible impacts on global and regional security [88].

In addition to agriculture and fishing [89], other economic sectors are expected to be affected by CC, in particular those sectors which rely on environmental conditions. It has been suggested that changes in energy demand and production from some renewable energy sources [90, 91], and tourism [92], may occur as a consequence of CC.

Various mechanisms linking CC and air quality have been also suggested, with a possible degradation of air quality in some regions due to changes of meteorology, of dilution and removal processes, and of chemical interactions [93].

The Mediterranean area, due to the combined effects of anthropogenic stress and geomorphological features, is a region of high exposure and vulnerability, where CC is expected to impact many different sectors at the same time.

FUTURE PROJECTIONS

Projections of CC and impacts are made using climate models of different level of complexity, at the global (Earth system models) and at the regional scale. Simulations are based on a set of scenarios of anthropogenic forcings.

Model projections predict a further increase of the global surface temperature over the 21st century, between 1 and 3.7 °C, and an increase of the global mean sea level by 0.4-0.63 m by 2100, the range of values depending on the adopted emission scenario [68]. Such a rise in sea level would significantly impact coastal areas (flooding and erosion of coastal and low lying areas).

The increase in atmospheric CO₂ is expected to largely affect the global carbon budget through different feedback mechanisms; among the different effects, the increased CO₂ is expected to produce a reduction of the capability of natural sinks (oceans and vegetation) to absorb CO₂, with a subsequent faster growth of atmospheric CO₂ [38, 68]. Ocean acidification is one of the key processes which is expected to produce a large impact on the marine ecosystems and their capability to absorb CO₂.

In the Mediterranean various projections suggest an increase in the frequency of heat waves [94]. Heavy rain and other extreme weather events are expected to become more frequent in some regions, in particular in the Alpine sectors. In the central Mediterranean a very strong aridification is projected; the Mediterranean drying appears as a robust result of different models, which display a similar pattern [95]. Future scenarios prospect a drying and warming of the overall region mainly in summer (except for the northern sectors), with a reduction of precipitation of around 25-30% and an increase in temperature by 4-5 °C (years 2071-2100 compared to 1961-1990, for an emission scenario reaching 700 ppm of CO₂ in 2100) [96]. These changes, associated with an increase of the sea level, would imply severe effects on the coastal regions and, among other effects, a higher vulnerability to wildfires [97].

Future impacts largely depend on the emission sce-

narios. Thus, strategies to both mitigate (*i.e.*, limiting the magnitude of CC) and adapt (*i.e.*, develop measures aimed at preventing or minimising damage) to CC are necessary.

A first global agreement on the reduction of emissions has been achieved recently in Paris, at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC). This agreement is aimed at avoiding a global temperature increase by more than 2 °C compared to the pre-industrial time, and at pursuing efforts to limit warming to 1.5 °C. As discussed above, there are still many aspects of the complex climate system that require a better understanding; in particular, the role of factors that may have partly offset the warming produced by increased greenhouse gases in the past (primarily aerosol and clouds) needs to be better investigated. Small changes in the properties and evolution of aerosol and clouds may have influenced and may largely influence the future evolution of climate; a possible reduction of their compensation role might produce a warming even larger than projected [67]. For this reason, a continuous monitoring of the evolution of the climate, and an effort to understand those processes and complex interconnections which are still poorly understood are needed.

IMPACTS ON OCCUPATIONAL HEALTH AND SAFETY

Climate change leads to an increased likelihood, distribution, and severity of several known occupational risks [98] and may potentially lead to new risks, some of which are already known in other fields (*i.e.*, those related to new technologies, as in the case of “green jobs”). Although a significant effort has been dedicated to study the effect of heat and elevated temperatures, the combined effect of different exposures under varying conditions [*e.g.*, 99], and the occurrence of new risks have been only partly investigated [*e.g.*, 100].

The impact of CC on occupational health and safety can be either direct or indirect: in the first case the effect derives from a direct interaction of the new environmental conditions with the exposed subject, as in the case of heat strokes. In the second case, CC introduces modifications in the work environment that negatively impact workers health and safety. Changes in the number and distribution of disease biological vectors, or modifications of airborne pollutants concentration (such as those induced by an increase in ultraviolet radiation) and composition belong to this case.

Adaptation actions should however take into account different aspects: for example, working shifts could be moved at dawn and at dusk to reduce the risks of heat strokes; in the same time slots, however, the amount of disease-carrying insects is greater. Moreover, extreme weather events can affect workers involved in emergency operations, connected to the more frequent floods, landslides, storms, droughts, and wildfires, for example in nuclear and radiological emergencies.

CONCLUSIONS

The purposes of the monographic section that contains this paper are to provide an overview of the main

OHS issues related to CC, to highlight the research needs, and to promote a change of safety at work rules in order to reduce vulnerability and increase adaptation. In particular, the papers of this issue discuss the OHS inferences of heat waves and heat fatigue, UV radiation and related cataract, skin and eye cancer, microclimate conditions for indoor and outdoor workers, increased air pollution and related respiratory and cardiovascular diseases, vector-borne diseases, nuclear and radiological emergencies in the field of work with ionizing radiations. It will be also considered the CC impacts on the new technologies of “green jobs”, that are expected to involve a reduction of GHGs emissions and a better adaptation to climate change.

In the case of CC, adaptation means anticipating the adverse effects and taking appropriate actions to prevent or minimise the potential damage. It is clear that the new measures to be taken will follow in part the common guidelines, worldwide valid, but they will be mostly linked to local conditions and risks.

In the field of OHS, adaptation responses involve administrative (*i.e.* work organization) and technical (*i.e.* use of personal protection devices) interventions. As always, a relevant aspect will be the development of proper information and training of both workers and employers, in order to rise risks awareness in the short and long term.

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Conflict of interest statement

There are no potential conflicts of interest or any financial or personal relationships with other people or organizations that could inappropriately bias conduct and findings of this study.

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