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CURRENT STATUS OF EXTREME GLOBAL CLIMATE PARAMETERS IN THE CONTEXT OF RISK EVALUATION AND GOVERNANCE

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Abstract: Increasing climate variability is also associated with more intense and frequent extremes, such as major large-scale hazards, e.g. droughts, heatwaves or floods, which could lead to the occurrence of natural disasters that are beyond our socio-economic planning levels. As expected, regional response capabilities could be stretched beyond their capacity, which could require new adaptation and preparedness strategies. In such cases, disaster prevention and preparedness should become a priority and rapid response capacities to climate change have to be associated with a disaster prevention strategy. The objective of this paper is to present a comprehensive description of extreme global climate parameters in the context of risk evaluation and governance for disaster reduction. This is associated with projections and trends of climate extremes under climate uncertainty and increasing climate variability. Risk evaluation and governance of climate extremes is then considered in association with vulnerability and risk transfer. Then, the basic difference between disaster risk management and adaptation to climate change is also considered based on the temporal and spatial dimension of their analysis.

Key words: climate extremes, risk evaluation and governance, adaptation to climate change, disaster reduction.

1. INTRODUCTION

Disasters are defined by the United Nations International Strategy for Disaster Risk Reduction (UNISDR, 2005) as “a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources”. Similarly, a hazard is defined as “a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation” (Smith, 2013). This event has a probability of occurrence within a specified period of time and within a given area, and has a given intensity (UNISDR, 2015). An extreme climate event is defined as the occurrence of a value of a climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable (Seneviratne *et al.* 2012). Long term observations of past decades suggest that characteristic recurrence frequencies, intensities and durations of certain extreme events have already increased (Hartmann *et al.*, 2013), posing risks for a wide range of social and natural systems.

The extreme events designate the initial and consequent physical phenomena, which include some that may have causal factors originating from human activity, in addition to factors related to climate. For certain classes of regional, long-duration weather extremes, it has proven possible to argue that the probability of such conditions has changed due to anthropogenic climate forces. However, single extreme events cannot be simply and directly attributed to anthropogenic climate change (Hegerl and Zwiers, 2011). The observed climate variations generally encompass both natural variations internal to the climate system and responses to external forces such as changes in radiation, human induced changes in greenhouse gases (GHG), and enhanced moisture content in the atmosphere.

Recent research findings suggest that variability of climate, if encompassing more intense and frequent extremes, such as major large-scale hazards like droughts, heatwaves or floods, results in the occurrence of natural disasters that are beyond our socio-economic planning levels. This is expected to stretch regional response capabilities beyond their capacity and will require new adaptation and preparedness strategies. Disaster prevention and preparedness should become a priority and rapid response capacities to climate change need to be accompanied by a strategy for disaster prevention. Nevertheless, each type of extreme events has its own particular climate, cultural and environmental setting, and mitigation activities must use these settings as a foundation of proactive management (IPCC, 2012). There is an urgent need to assess the forecasting skills for natural disasters affecting agriculture in order to determine those, where greater research is necessary. It is well known that lack of good forecast skill is a constraint to improve adaptation, management and mitigation.

In this paper, a comprehensive description of climate extremes is presented, along with their projections and trends. Then, the risk assessment and management framework of climate extremes is considered, along with vulnerability and risk transfer. Finally, adaptation to climate change is presented.

2. CLIMATE EXTREMES CONCEPTS, CAUSES AND EXPOSURE

In the following sections 2.1 to 2.6 the main causes of climate extremes are illustrated, as well as current features and characteristics of climate extreme events, namely intensity, frequency, and areal extent. Table 1 presents features of climate extremes, along with an attribution of observed changes of climate extremes (Dalezios (ed.), 2017).

2.1. Extreme Precipitation

On global level, the pattern of precipitation has changed. Observations and model simulations

Table 1
Attribution of Observed Changes of climate extremes (from Dalezios (ed.), 2017)

Parameters/Extremes	*Observed Changes (since 1950)*	*Attribution of Observed Changes*
Temperature	Very likely decrease in number of unusually cold days and nights at the global scale. Very likely increase in number of unusually warm days and nights at the global scale. Medium confidence in increase in length or number of warm spells or heat waves in many (but not all) regions. Low or medium confidence in trends in temperature extremes in some sub-regions due either to lack of observations or varying signal within sub-regions.	Likely anthropogenic influence on trends in warm/cold days/nights atthe global scale. No attribution of trends at a regional scale with a few exceptions.
Precipitation	Likely statistically significant increases in the number of heavy precipitation events (e.g., 95th percentile) in more regions than those with statistically significant decreases, but strong regional and sub-regional variations in the trends.	Medium confidence thatanthropogenic influences have contributed to intensification of extreme precipitation at global scale.
Winds	Low confidence in trends due to insufficient evidence	Low confidence in the causes of trends due to insufficient evidence.
Monsoons	Low confidence in trends because of insufficient evidence.	Low confidence due to insufficient evidence.
El Nino and other Modes ofVariability	Medium confidence in past trends toward more frequent central equatorial Pacific El Niño-Southern Oscillation (ENSO) events. Insufficient evidence for more specific statements on ENSO trends. Likely trends in Southern Annular Mode (SAM).	Likely anthropogenic influence on identified trends in SAM.1Anthropogenic influence on trends in North Atlantic Oscillation (NAO) are about as likely as not. No attribution of changes in ENSO.
Tropical Cyclones	Low confidence that any observed long-term (i.e., 40 years or more) increases in tropical cyclone activity are robust, after accounting for past changes in observing capabilities.	Low confidence in attribution ofany detectable changes in tropical cyclone activity to anthropogenic influences (due to uncertainties in historical tropical cyclones record, incomplete understanding of physical mechanisms, and degree of tropical cyclone variability).
Extratropical Cyclones	Likely poleward shift in extratropical cyclones. Low confidence in regional changes in intensity.	Medium confidence in anthropogenic influence on poleward shift.
Droughts	Medium confidence that some regions of the world have experienced more intense and longer droughts, in particular in southern Europe and West Africa, but opposite trends also exist.	Medium confidence that anthropogenic influence has contributed to some observed changes in drought patterns.Low confidence in attribution of changes in drought at the level of single regions due to inconsistent or insufficient evidence.

contd. table 1

Parameters/Extremes	*Observed Changes (since 1950)*	*Attribution of Observed Changes*
Floods	Limited to medium evidence available to assess climate-driven observed changes in magnitude and frequency of floods at regional scale. Also, there is low agreement in this evidence, and overall low confidence at the global scale regarding even the sign of these changes. High confidence in trend toward earlier occurrence of spring peak river flows in snowmelt- and glacier-fed Rivers.	Low confidence that anthropogenic warming has affected the magnitude or frequency of floods at a global scale. Medium confidence to high confidence in anthropogenic influence on changes in flood-affecting components of the water cycle (precipitation, snowmelt).

indicate that most regions have experienced an increase in the number of heavy precipitation events, whereas fewer regions have been subjected to a respective decrease of rainfall events. However, there are also wide sub-regional, regional and seasonal variations, and observed trends in many regions are not statistically reliable.

Specifically, a likely increase of heavy precipitation has been observed in many regions in North America, while regionally varying trends in extreme rainfall events have been recorded in Central and South America (Watterson, 2005).In Europe, the results are more controversial; in central-western Europe and in European Russia, extreme winter precipitation has increased, but the trend in summer precipitation has been weak or not regionally homogeneous. Uncertainties are larger overall in southern Europe and in the Mediterranean region. Both statistically significant increases and decreases in extreme precipitation have been found in China, Japan and India.

Mechanism: The change in the pattern of global precipitation is consistent with the theoretical understanding, related to the Clausius-Clapeyron equation (Trenberth *et al.*, 2005). The higher the global temperatures the more intensified the water cycle will be, increasing thus the average rainfall and/or rainfall intensity, and amplifying the net evaporation; wet regions become overall wetter and dry regions drier in a warming world (Held and Soden, 2006). But this explanation might be an oversimplification and effects are likely to manifest in unforeseen ways (Cook *et al.*, 2014). Why there have not been increases in precipitation extremes everywhere? Probably because changes in extreme rainfalls could be also be depended on changes in the moist adiabatic temperature lapse rate, in the upward velocity (Sugiyama *et al.*, 2010). Allen and Ingram (2002) suggest that while global annual mean precipitation is constrained by the energy budget of the troposphere, extreme precipitation is constrained by the atmospheric moisture content, though this constraint may be most robust in extra-tropical regions and seasons where the circulation’s fundamental dynamics are not driven by latent heat release (Meehl *et al.*, 2007). The increased intense of precipitation extremes is attributed with a medium confidence to anthropogenic activities (Min *et al.*, 2011), since 18% of the moderate daily precipitation extremes over land are attributable to the observed temperature increase (Fischer and Knutti, 2015), and the anthropogenic influence is the primary driver of global temperature alteration (Bindoff *et al.*, 2013).

2.2. Floods

Floods can be devastating disasters, which can affect people at almost any time. There are historical flood events, such as major floods in China, which have caused the death of almost 2 million people in 1887, about 4 million in 1931 and almost 1 million in 1938. More recently, the 1993 flood on the upper Mississippi river and the Midwest caused the death of only 47 people, but the economic loss was estimated between 15 to 20 billion dollars (US Department of Commerce, 1994). Hazards associated with flooding can be divided into primary hazards that occur due to contact with water, secondary effects that occur due to flooding, such as disruption of services, health impacts, such as famine and disease, and tertiary effects, such as changes in the position of river channels.

Flooding has been one of the most costly disasters in terms of both human casualties and property throughout the last century. Indeed, the frequency of major floods has increased substantially during the 20th century (Dalezios (ed.), 2017). I t is recognized that changes in floods are expected, due to the fact that they are affected by changes in a number of hydrometeorological parameters, such as precipitation, ice cover, snowmelt or soil moisture status, which in turn have been detected in several regions. Climate change has the potential to change river flood characteristics, as well as land cover and river engineering in terms of large dams.

Increased intensity of precipitation events imply greater risks of flooding at the regional scale, but the magnitude and frequency of floods have not been clarified from the scientific community primary because there is a limitation of data availability. However, during the twentieth century the frequency of great floods, with discharges exceeding 100-year levels from basins larger than 200,000 km^2, have increased substantially (Milly *et al.*, 2002). Many regions in Australia, United States of America and Asia have been subjected to severe flooding events, which may lead to extreme impacts to humans and social systems. For example, in the summer of 2010, Indus valley floods in Pakistan resulted in over 2,000 casualties, 4 million displacements, and a total of 20 million people affected directly or indirectly (Lau and Kim, 2011).

An examination of the relationship between change in flood magnitude and flood extent showed a strong dependency on local topographic conditions (Veijalainen *et al.*, 2010). Few evidences indicate that anthropogenic climate change have increased the risk of rainfall-dominated flood occurrence in South-East Europe and United Kingdom (Sippel and Otto, 2014). Changes in land cover, floodplain storage and the river engineering have the potential to change river flood characteristics. For instance, large dams have resulted in large-scale land use change and may have changed the effective rainfall in some regions (Hossain *et al.*, 2009).Recorded alterations in soil precipitation, snowmelt and moisture status can lead to changes in the physical characteristics of river floods (Bronstert *et al.*, 2007).

2.3. Extreme winds- storms

In 2005, hurricane Katrina made landfall along the Gulf Coast U.S. causing at least 1,836 deaths from sequential floods and displacement of thousands of people. $81 billion was the total damage cost from this extreme event, while the tropical storms in Yemen in 2008 caused damages and losses of about 1.6 billion USD. It was estimated that in some of the regions poverty rates increased from 28 to 51% (GFDRR, 2009).

Changes in wind extremes may arise from changes in the intensity or location of their associated phenomena such as tropical and extra-tropical cyclones.

Some studies have identified a recently high correlation between net hurricane power dissipation and tropical sea surface temperature over the Atlantic and elsewhere (Elsner and Jagger, 2010). From 1970 a large increase has been recorded in the number and proportion of hurricanes reaching categories 4 and 5, as in the North Pacific, Indian, and Southwest Pacific Oceans (Webster *et al.*, 2005). The largest increase in the intensity of the strongest hurricanes was found over the Caribbean Sea and the Gulf of Mexico. An increase in the intensity of pre-monsoon Arabian Sea tropical cyclones during the period 1979–2010 has been also reported, and this change in storm strength was attributed to a simultaneous upward trend in anthropogenic black carbon and sulphate emissions (Evan *et al.*, 2011). While the Inter-Tropical Convergence Zone moved southward, leading to weaker monsoons across Asia (Haug *et al.*, 2001), the Walker circulation strengthened and Southern Ocean westerlies moved northward and strengthened, affecting southern Australia, New Zealand, and southern South America (Shulmeister *et al.*, 2006). It is likely that there has been a poleward shift in the main Northern and Southern Hemisphere extra-tropical storm tracks, and currently there are few evidences for a change toward a lower Northern Atlantic Oscillation (NAO) (Wanner *et al.*, 2008). While the changes in the Northern Hemisphere can be attributed to changes in orbital forcing, those in the Southern Hemisphere are more complex, possibly reflecting the additional role on circulation of heat transport in the ocean. Solar variability and volcanic eruptions may also have contributed to decadal to multi-centennial fluctuations (Wanner *et al.*, 2008).

2.4. Extreme sea level rise

A likely increase in the trend of extreme sea levels worldwide is associated with the rise in mean sea level (Menendez and Woodworth, 2010) and variations in regional climate (Bindoff *et al.*, 2007). The relationship between mean sea level rise and extreme sea level rise has been confirmed also at the regional scale (e.g., Haigh *et al.*, 2014). Sustained mid-latitude winds can elevate coastal sea levels (e.g., McInnes *et al.*, 2009), while longer-term changes in prevailing wind direction can cause changes in wave climate and coastline stability (Pirazzoli and Tomasin, 2003). Changes in sea level have been recorded across the Pacific (Merrifield *et al.*, 2007), in the west coasts of Australia (Church *et al.*, 2006) and in the north coast of Canadian British Columbia (Abeysirigunawardena and Walker, 2008). Currently, there are insufficient evidences, that anthropogenic climate change has been a major cause of any changes in coastal erosion and inundation.

2.5. Heat waves and temperature extremes

Since the middle of the 20th century, a tendency toward warmer and more frequent warm days and nights or increased heat waves has been identified in large parts of Europe, Asia, Australia and North America, while the south-eastern United States and southern Greenland constitute exceptions (Alexander *et al.*, 2006). Changes in regional extreme temperatures display a rather linear scaling with the global mean temperature difference. The observed relationship typically implies a larger change of the former at more local scales. For instance, a 2 °C warming in hot extremes (annual warmest daytime temperature) takes place in the

Mediterranean for a change of 1.4 °C in global mean temperature change (Seneviratne *et al.*, 2016).

Human contribution to the occurrence of a few prominent heat waves has been demonstrated, such as for the 2004 European heat wave (Stott *et al.*, 2004) and the Australian heat wave in 2013 (Lewis and Karoly, 2013). It is likely that human influence has more than doubled the probability of occurrence of heat waves in some locations. A recent study concluded that the proportion of anthropogenic contribution to the moderate daily extremes of heat over land is larger when considering the rarest and most extreme events, such that human contribution increases nonlinearly with further warming (Fischer and Knutti, 2015).

Due to a variety of reasons including planned and unplanned urbanization, some cities are characterized by a recent trend in loss of green space (Rafiee *et al.*, 2009), which in turn, may increase exposure to extreme climate events in urban areas through decreasing runoff amelioration, alterations in biodiversity and exacerbating the urban heat island effects under heat wave conditions ((Dalezios *et al.* 2017b).

2.6. Droughts

Drought is a complex environmental impact. There is medium confidence that since the 1950s some regions of the world have experienced more intense and longer droughts, in particular in southern Europe and West Africa, but in some regions droughts have become less frequent, less intense, or shorter, for example, in central North America and north-western Australia.

In the past few years, major drought events have been recorded in Sub-Saharan African countries, Australia, United States, Middle East, and in southern Europe. In Syria the worst drought, lasting from 2007 to 2010 damaged the agriculture and forced about 1.5 million people to fled rural areas for suburbs. The exposure of Sub-Saharan African countries to drought and floods account for 80 % of loss of life and 70 % of economic losses (African Union, 2008) while there is a chance up to 50 % for a drought event to cause food security stresses (World Bank, 2011). Specifically, the estimated annual average response costs to droughts ranged $US 26 million and $US 319 million from 1983 to 2011 for Ethiopia, Kenya, Malawi, Mozambique, Niger and Senegal. On the other hand, the uninsured economic losses in the European Union for the agriculture sector were estimated at € 13 billion (Sénat, 2004).

Usually, the primary cause of drought is the lack or deficit of precipitation. However, increased evapotranspiration induced by the interaction of increased radiation, wind speed, or vapor pressure deficit (Orlowsky and Seneviratne, 2011) contributes to the deficit of soil moisture and negative anomalies in lake, streamflow, and groundwater levels (Heim Jr., 2002). Through this mechanism, droughts and heat waves may be inter-stimulated in transitional regions between dry and wet climates (Seneviratne *et al.*, 2010). Trends in average wind speed can influence potential evaporation and in turn water availability and droughts (McVicar *et al.*, 2008). Further, pre-event conditions of soil moisture, surface fluxes, and/or groundwater storage are important factors for drought genesis since they have predetermined response times to drought forcing (e.g., Begueria *et al.*, 2010; Fleig *et al.*, 2011). Human activities, like urbanization, and changes in vegetation cover and agriculture, stressing the water resources, may itself influence climate and possibly the drought conditions (Gedney *et al.*, 2006; Arneth, 2015).

3. PROJECTIONS AND TRENDS OF CLIMATE EXTREMES

The rate and scale of projected climate change and climate extreme changes in 21st century are expected to have profound impacts on the functioning of Earth's ecosystems (Garcia *et al.*, 2014). The following projections are the main outcomes evaluated by an ensemble of climate models (IPCC, 2014). Table 2 presents characteristics of climate extremes, along with projected changes of climate extremes (up to 2100) with respect to late 20th Century (Dalezios (ed.), 2017).

3.1. Heavy Precipitation

A robust projection is that the frequency and the fraction of rainfall falling in the form of heavy precipitation events will increase in many regions during the 21st century (Meehl *et al.*, 2007), especially in the high latitudes, the northern mid-latitudes, and the tropical regions, where mean precipitation increases. In this framework, wet extremes will become more severe in many areas where mean precipitation increases, and dry extremes will become more intense where the mean precipitation decreases (Barnett *et al.*, 2006).

Based on a range of emissions scenarios climate-model projections highlight that in a future, warmed climate due to increasing concentration of GHGs, the increase of precipitation extremes is greater than changes in mean precipitation (IPCC, 2007). There are regions of increased number of dry days between precipitation events in the subtropics and lower mid-latitudes, but a decreased number of consecutive dry days at higher mid-latitudes and high latitudes where mean precipitation increases. Since there are areas of both increases and decreases of consecutive dry days between precipitation events in the multi-model average, the global mean trends are smaller and less consistent across models.

3.2. Floods

There is medium confidence that projected increases in heavy rainfall would contribute to increases in local flooding in some catchments or regions, while there is low confidence in projections of changes in fluvial floods.By assessing the global flood risk for the end of this century Hirabayashi *et al.* (2013) stressed that there is high probability that Southeast Asia, Peninsular India, eastern Africa and the northern half of the Andes will experience increase in flood frequency. However, intense and heavy episodic rainfall events with high

Table 2
Projected Changes of climate extremes (up to 2100) with Respect to Late 20th Century (from Dalezios (ed.), 2017)

Parameters/ Extremes	*Observed Changes (since 1950)*	*Projected Changes (up to 2100) with Respect to Late 20th Century*
Temperature	Very likely decrease in number of unusually cold days and nights at the global scale. Very likely increase in number of unusually warm days and nights at the global scale. Medium confidence in increase in length or number of warm spells or heat waves in many (but not all) regions. Low or medium confidence in trends in temperature extremes in some sub-regions due either to lack of observations or varying signal within sub-regions.	Virtually certain decrease in frequency and magnitude of unusually cold days and nights at the global scale.Virtually certain increase in frequency and magnitude of unusually warm days and nights at the global scale. Very likely increase in length, frequency, and/or intensity of warm spells or heat waves over most land areas.
Precipitation	Likely statistically significant increases in the number of heavy precipitation events (e.g., 95th percentile) in more regions than those with statistically significant decreases, but strong regional and subregional variations in the trends.	Likely increase in frequency of heavy precipitation or increase in proportion of total rainfall from heavy falls in the high latitudes and tropical regions, and in winter in the northern mid-latitudes.
Winds	Low confidence in trends of extreme winds due to insufficient evidence	Low confidence in projections of winds (except in tropical cyclones).
Monsoons	Low confidence in trends because of insufficient evidence.	Low confidence in projected changes in monsoons.
El Nino and other Modes of Variability	Medium confidence in past trends toward more frequent central equatorial Pacific El Niño-Southern Oscillation (ENSO) events. Insufficient evidence for more specific statements on ENSO trends. Likely trends in Southern Annular Mode (SAM).	Low confidence in projections of changes in behavior of ENSO and other modes of variability because of insufficient agreement of model projections.
Tropical Cyclones	Low confidence that any observed long-term (i.e., 40 years or more) increases in tropical cyclone activity are robust, after accounting for past changes in observing capabilities.	Likely decrease or no change in frequency of tropical cyclones. Likely increase in mean maximumwind speed. Likely increase in heavy rainfallassociated with tropical cyclones.
Extratropical Cyclones	Likely poleward shift in extratropical cyclones. Low confidence in regional changes in intensity.	Likely impacts on regional cyclones. Low confidence in regional projections. Medium confidence in reduction in mid-latitude storms, and in poleward shift of mid-latitude storms.

contd. table 2

Parameters/ Extremes	*Observed Changes (since 1950)*	*Projected Changes (up to 2100) with Respect to Late 20th Century*
Droughts	Medium confidence that some regions of the world have experienced more intense and longer droughts, in particular in southern Europe and West Africa, but opposite trends also exist.	Medium confidence in projected increase in duration and intensity of droughts in some regions, including Mediterranean basin, central Europe, central North America, Central America, Mexico, northeast Brazil and southern Africa. Overall low confidence elsewhere because of insufficient agreement of projection.
Floods	Limited to medium evidence available to assess climate-driven observed changes in the magnitude and frequency of floods at regional scale. Furthermore, there is low agreement in this evidence, and thus overall low confidence at the global scale regarding even the sign of these changes. High confidence in trend toward earlier occurrence of spring peak river flows in snowmelt- and glacier-fed Rivers.	Low confidence in projections of changes in flood magnitude-frequency due to insufficient evidence. Medium confidence that projected increases in heavy precipitation would contribute to rain-generated local flooding. Very likely earlier spring peak flows in snowmelt- and glacier-fed rivers.

runoff amounts are interspersed with longer relatively dry periods with increased evapotranspiration, particularly in the subtropics (Beniston and Diaz, 2004; Christensen and Christensen, 2004).

3.3. Extreme winds –storms

When projections of changes in extreme winds are generally characterized with low confidence, an increased mean tropical cyclone maximum wind speed can be projected with high confidence. Future projections consistently indicate that global warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2–11% by 2100, while the globally averaged frequency of tropical cyclones, will be decreased by 6–34%. (Knutson *et al.*, 2010). Other studies, however, project increases in the frequency of the most intense cyclones.

The intensity and frequency of downscaled tropical cyclones display increases during the 21st century in most locations. Increases in tropical cyclone activity are most prominent in the western North Pacific, but are evident in other regions except for the south-western Pacific (Emanuel, 2013). There is a potentially large risk for tropical cyclone storm surge in the Persian Gulf, and larger-than-expected threats in Cairns, Australia, and Tampa, Florida. With climate change, tropical cyclones striking Tampa can generate storm surges with estimated annual exceedance probabilities of about 1/2,500 – 1/700 (Lin and Emanuel, 2016). Typical example is hurricane Ike (Sep 2008), which was a powerful tropical cyclone wreaking havoc on infrastructure and agriculture, especially in Cuba and Texas. Very recent examples are hurricanes Harvey (2017), Irma (2017) and Maria (2017), respectively. Specifically, hurricane Maria (Category 5) is regarded as the worst natural disaster on record in Dominica and Puerto Rico, the tenth-most intense Atlantic hurricane on record and the most intense tropical cyclone worldwide of 2017. These are indications of projected future storms in the context of human lives transforming events.

Despite these findings, at the present time, there is low confidence in the detailed geographical projections of mid-latitude cyclone activity. There is low confidence in projections of changes in monsoons, in NOA, Southern Annular Mode, Indian Ocean Dipole, ENSO variability and the frequency of El Nino episodes. However, most models project an increase in the relative frequency of central equatorial Pacific events. Also there is low confidence in projections of small-scale phenomena, such as tornadoes, because competing physical processes may affect future trends and because climate models do not simulate such phenomena.

3.4. Sea level rise

Sea level will continue to rise by an additional 0.18 to 0.59 meters by 2100 (Meehl *et al.*, 2007) and if the projections about continuous decrease of snow cover and sea ice extent (Zhang, 2010), are taken into account, the sea level would rise further by 0.10 to 0.20 m. Variations in the rate of sea level rise can be large relative to mean sea level (Yin *et al.*, 2010), and it is very likely that the mean sea level rise will contribute to upward trends in extreme coastal high water levels in the future. There is high confidence that locations currently experiencing adverse impacts such as coastal erosion and inundation will continue to do so in the future due to increasing sea levels. Debernard and Roed (2008) project an 8 to 10% sea level increase along the coastlines of the eastern North Sea and the northwest British Isles by 2071-2100 when compared to changes between 1961 and 1990. Wang *et al.* (2008) projected a significant increase in wintertime storm surges around Ireland, except the south Irish coast, over 2031-2060 relative to 1961-1990. Future negative or positive changes in significant wave height are likely to reflect future changes in storminess and associated patterns of wind change.

3.5. Heat waves and temperature extremes

The frequency and intensity of heat waves is projected to continue to increase over most land areas. This projection is considered robust, since a shift in the average value of a temperature distribution typically entails an increase in the frequency of extreme and unprecedented events (Meehl *et al.*, 2007). Climate models project substantial increases in the frequency and magnitude of warm daily temperature extremes globally, by the end of the 21st century. However, regional changes in temperature extremes will often differ from the mean global temperature change. Similarly, there is considerable confidence that the frequency of cold extremes will decrease and that the number of frost days will decline in the middle and high latitudes (USGCRP, 2009).

3.6. Drought

There is medium confidence that the duration and intensity of hydrological droughts will increase in the 21st century in some seasons and areas, due to reduced precipitation and/or increased evapotranspiration. However, other factors, like changes in agricultural land cover and upstream interventions may also contribute to a reduction in river flows or groundwater recharge. This projection applies to regions including southern Europe and the Mediterranean region, central Europe, central North America, Central America and Mexico, northeast Brazil, and southern Africa. In a future warmer climate the models simulate summer dryness in most parts of the northern subtropics (Pan and Wang, 2015) and midlatitudes (Wanner *et al.*, 2008), with an associated increased likelihood of drought (Rowell and Jones, 2006).

3.7. Abrupt Changes and Other Climate Surprises

Confounding all projections of future climate is the possibility that abrupt changes or other climate “surprises” may occur. Abrupt changes in the climate system can occur when (1) there is a rapid change in forcing or (2) thresholds for stability (or “tipping points”) are crossed, such that small changes in the climate state are reinforced and, thus, leading to rapid shifts until the climate enters another stable state and stability is restored. Since the Earth’s temperature is now demonstrably higher than it has been for at least 400 years (NRC, 2006), and GHG concentrations are now higher than they have been in many hundreds of thousands of years, it is possible that we may be nearing other stability thresholds (Schuur *et al.*, 2009). One example of a potential abrupt change mechanism is the possibility that huge amounts of carbon stored in permafrost across the Arctic could be released in large quantities in the form of CO2 and CH4 (Shakova *et al.*, 2010) as high-latitude warming continues. In a related example, if the Greenland ice sheet were to shrink substantially in a short period of time, the surface waters of the North Atlantic could release large amounts of heat to the atmosphere, thereby becoming sufficiently dense to sink and return southward, affecting the oceanic redistribution of heat from the tropics to the Northern Hemisphere (Haupt and Seidov, 2007).

4. MANAGEMENT OF CLIMATE EXTREMES

At the present time, most of the climate change scenarios focus on climatic change within the next 100 or 200 years, whereas often the projections of vulnerability just use present socioeconomic data. While an important segment of the adaptation literature focuses on social and economic sectors and macro ecosystems over large regional scales, the disaster risk management has emphasized on local and community based risk management in the framework of national management systems (Dalezios *et al.* 2017a). Figure 1 presents the main components of the risk management framework.

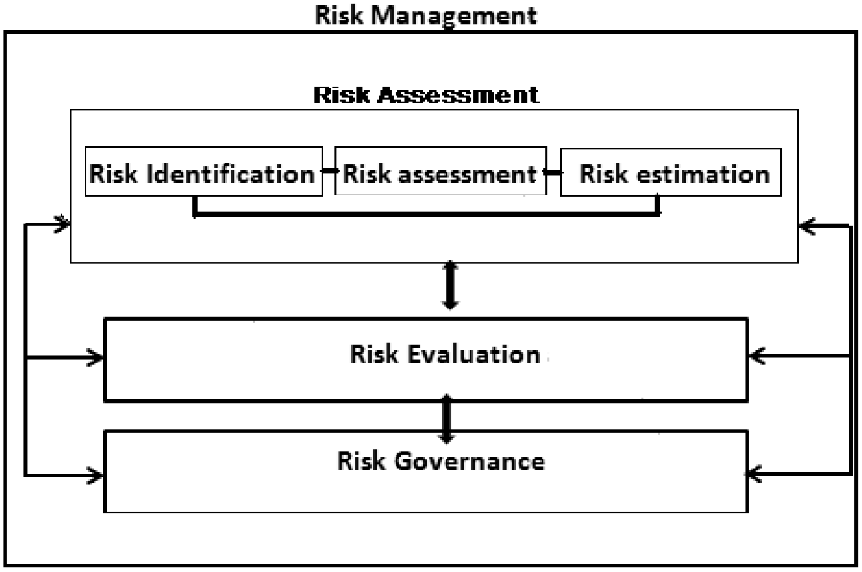

Figure 1: Main Components of the Risk Management Framework (from Dalezios and Eslamian, 2016)

4.1. Disaster Risk Management (DRM)

In some cases, the interaction of extreme events may have positive impacts to reduce disaster risk. For example, intense rainfall accompanying monsoons and hurricanes also brings great benefits to society and ecosystems; on many occasions it helps to fill reservoirs, sustain seasonal agriculture, and alleviate summer dry conditions in arid zones (Cavazos *et al.*, 2008). However, increases in disaster risk and the occurrence of disasters have been in evidence over the last five decades and may be enhanced in the future as a result of projected climate extremes. In addition, there is high confidence that climate change will affect disaster risk, not only through changes of some events, but also through indirect effects on vulnerability and exposure, through impacts on the number of people in poverty or suffering from food and water insecurity.

In this framework, disaster risk management can be utilized to increase human security, and support sustainability in social and economic development by designing and evaluating strategies and policies, which i) improve our understanding of disaster risk, ii) foster disaster risk reduction and transfer, and iii) promote adequate preparedness for disaster. In other words, risk reduction aims to reduce vulnerability and the probability of occurrence of some events, risk transfer aims to compensate losses suffered by those who directly experience an event, and disaster management aims to respond to the immediate consequences, facilitating reduction of longer-term consequences. Figure 2 presents the components of risk evaluation and governance.

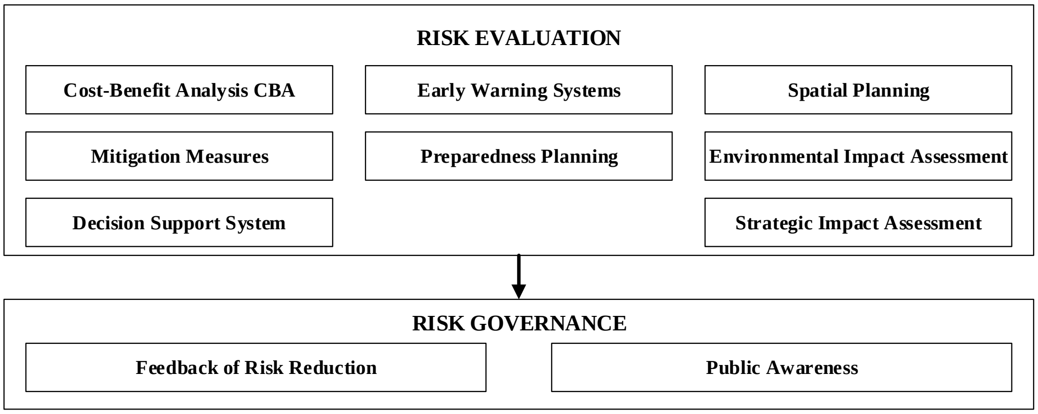

Figure 2. Components of Risk Evaluation and Governance (from Dalezios and Eslamian, 2016)

After identifying the level of exposure to current -and future- climate extreme events, the next step to design disaster risk management actions, is to identify the causes and trends of vulnerability to climate extreme events. It is possible to be exposed to an extreme event but not be vulnerable (Füssel and Klein, 2006). By performing vulnerability analysis we aim to evaluate the harm to populations, ecosystems, and resources that might result from changes in climatic conditions, and to provide useful information for the decision makers involved.

Thirdly, an effective disaster risk management should involve a portfolio of actions to reduce and transfer risk and to respond to events and disasters customized to specific local circumstances. Thus, availability of observational data is of central relevance for DRM. Successful strategies considering major sectors such as water, agriculture, health, improvements in urban land use, strengthening of rural livelihoods and reductions in the rate of ecosystem services depletion, would all include a combination of the so-called 'hard'(engineering) and 'soft'(social and administrative) technologies. Great advances have been made in hard technology around hazard identification. Communicating warnings through the 'soft' technology of institutional reform and communication networks has been less well developed.

In most cases, responses to climate extremes can be improved by addressing social vulnerability, rather than focusing exclusively on technological responses (NRC, 2010).

4.2. Vulnerability to Climate Extremes

Identification of spatial and temporal differences in vulnerability is a pivotal research issue. Potentially vulnerable natural systems are low-lying islands, coastal zones, and drylands which are exposed to hazards, like flooding and drought (Nicholls, 2004). But people are becoming vulnerable to extreme events by dynamic and multiscale interactions between societies and the environment. Thus, irrespective of the type of hazard, the levels of vulnerability can be aggregated by skewed development processes such as unplanned urbanization (Sánchez-Rodríguez *et al.,* 2005), corruption or mismanagement of governance, ecosystem services degradation, as well as the lack of livelihood options for the poor (Cannon, 2006). While a similar portion of population (11-15%) in both low and high human development countries may be exposed to hazards each year, the average numbers killed is about 53% and 1% respectively (Peduzzi, 2006).

''Warming will hit the poorest first''

For example, the degradation of ecosystem services in developing countries and countries in transition, where poorer rural communities often entirely depend on them, can contribute to an exacerbation of both the natural hazard context and the vulnerability of people (Confalonieri *et al.*, 2007). Deteriorating environmental conditions as a result of altered ecology, salinization, land clearing or dust generation (Tong *et al.*, 2017) can impact key ecosystem services and exacerbate climate sensitive disease incidence (e.g., diarrheal disease; Clasen *et al.*, 2007), particularly via deteriorating water quality and quantity. Globally, the pressure for urban areas to expand onto flood plains and coastal strips has resulted in increased exposure of populations to coastal flood risk (Nicholls *et al.*, 2011). For example, unplanned human settlements in flood-prone areas appear to have played a major role in increasing flood risk over the last few decades (Di Baldassarre *et al.*, 2010). Lagos, Nigeria (Adelekan, 2010) serves as clear example of where an upward trend in the area of slums increased the exposure to flooding.

Certain population groups are more vulnerable to various extreme events than other population groups. Perhaps the most vulnerable social group to climate extremes and climate change are economically and environmentally displaced persons. Research evidence emphasizes also the social construction of gendered vulnerability (Neumayer and Plümper, 2007) in which women and girls are often at greater risk of dying in disasters, typically marginalized from decision making fora (Sultana, 2010). For floods, children are at greater risk for transmission of fecal-oral diseases, and those with mobility and cognitive constraints can be at increased risk of injuries and deaths (Ahern *et al.*, 2005), while under heat wave conditions socially isolated elderly people and young children are vulnerable to heat-related health effects (Gosling *et al.*, 2009).

Immigrants, refugees, ethnic minorities, physically or mentally disabled people (Peek and Stough, 2010), poor households, the homeless (Wisner and Adams, 2002), children, and women-headed households (Morrow, 1999) are highly vulnerable social groups and national development plans and adaptation strategies should be transformed into actions targeting these vulnerable groups (UNISDR, 2011).

4.3. Risk Sharing and Transfer

The mechanisms of risk sharing and transfer are linked to disaster risk reduction and climate change adaptation by providing finance relief and reconstruction; reducing vulnerability; and providing knowledge for reducing risk. Risk transfer options such as insurance, micro-insurance, reinsurance, and national to global risk pools involving risk sharing; and new, innovative insurance mechanisms (World Bank, 2010), can provide much needed, immediate liquidity after a disaster. The limitations of the effectiveness of risk financing instruments, especially in high exposed and vulnerable countries should be acknowledged. Governments of these countries have limited ability ‘to compensate and provide support to the public and insurers while donor institutions provide only a small percentage of post-disaster capital (Becerra *et al*. 2012) and currently there is reluctance on the part of insurers to cover catastrophic events from climate-weather extremes (Nguyen, 2013). Traditional instruments, such as pre-disaster savings, post-disaster credit and informal reciprocal financial arrangements can be ineffective for catastrophic risks that affect savings and micro-finance institutions, households and regions (Linnerooth-Bayer and Hochrainer-Stigler, 2015). Traditional insurance can be directly linked to reducing risks and losses if premiums reward investments in risk, but can be costly especially at high level risks. Index-based micro-insurance targets the reduction of transaction costs and it can service low income markets since claims are independent of losses. Further, if forecasts are combined with index based insurance payouts, the clients can have the flexibility to take preventive measures to reduce damages. But these programs need the support of the governance/institutions when very poor communities are considered. Non-traditional risk financing instruments such as micro-risk transfer programs are too expensive and highly risk for low-income farmers, households and intermediaries. Instruments that transfer sovereign risk to the capital markets can enhance the flexibility of government and donor financing but they can be very costly for poor countries.

4.4. Disaster Risk Reduction

Low regrets measures are practices that may contribute to a reduction of the disaster risk (Kwadijk *et al.,* 2010), especially when the uncertainty of climate change and the future impacts of climate change or extreme events are high (Wilby and Dessai, 2010). Potentially effective low regrets measures are:

- Improvement of risk communication between decision-makers and local citizens (e.g., public campaigns) in order to inform and advice the social groups on what to do during extreme events. Improved forecasting capacity and implementation of early warning systems should be designed appropriately to reach particularly vulnerable groups.
- Improvements of water supply, irrigation and drainage systems, desalination facilities and water treatment infrastructure. Water demand management and improved irrigation efficiency measures, groundwater harvesting and storage systems can be considered to compensate droughts in the context of food security. Maintenance of drainage systems, sewerage improvements, and implementation of technologies to limit saltwater contamination of groundwater can all be serviceable to reduce the risk of floods.
- Ecosystem-based investments, including ecosystem conservation measures. Ecosystem conservation measures, like conservation of agriculture, crop rotation, livelihood diversification, watershed rehabilitation, and forest or mangrove landscape restorations, contribute to disaster risk reduction from floods, inundation events, landslides and drought, while they provide opportunities to increase carbon sequestration and energy savings, and enhance sustainability of ecosystem services in the long-term.
- Enforcement of building codes to design new, or reinforce existing, infrastructures against flash floods and storm surges, while effective thermo-isolation to buildings should be incorporated in building design to compensate heat waves and temperature extremes. Structural and engineering solutions can provide some protection from disasters but consideration need to be taken to ensure that these solutions will not increase the exposure of a system to disaster in the long-term.
- Health surveillance combined with climate-proofing of infrastructure, and awareness. Vulnerability-reducing measures, such as improved social services and protection, use of social care networks to reach vulnerable groups, could attain poverty reduction schemes.

5. ADAPTATION TO CLIMATE CHANGE

A basic difference among disaster risk management (DRM) and adaptation to climate change is the temporal and spatial dimension of their analyses. While climate change adaptation is concentrated to the long-term trends and stresses of hazard events based on climate change scenarios, the projections of vulnerability in DRM often are based on current socioeconomic data (Thomalla *et al.*, 2006). While DRM has emphasized in local and community based risk management within national management systems to reduce the adverse effects of experienced hazards, the respective segment of climate change adaptation focuses on socio-economic sector and macro ecosystems over regional scales.

Based on the literature of climate change adaptation, the main drivers of adaptive capacity to anticipate and transform functioning, structure or organization to better survive hazards, are: i) an integrated economy, ii) attention to human rights, iii) information technology, iv) access to insurance, v) access to public health facilities vi) existing warning and protection from natural hazards vii) strong international institutions and existing planning regulations at both national and local levels, viii) and institutional and decision making frameworks (Luís Bettencourt *et al.*, 2007).Consequently, many less-developed regions will have limited success in reducing vulnerability only by managing climate risk, because their status influences both vulnerability and adaptive capacity.

Climate change and its interactions with ecological, economic, and social systems can affect the so called ‘‘climate-related decisions’’ made by individuals or organizations (Dulal *et al.*, 2009). Therefore accuracy in regional climate predictions is necessary to form such decision rules. Others have suggested that decision rules could be based on the concept of robust adaptive policies, where in some cases relatively low cost, near-term actions and explicit plans to adjust those actions over time can significantly improve future ability to manage risk managing (Wilby and Dessai, 2011).

Another way to inform climate-related decisions, instead of using climate predictions, is to utilize the iterative risk management approach (Jones and Preston, 2011), which will be discussed in the following section. In either case, to develop robust adaptation strategies and set appropriate GHG emission reduction targets there is an increasing need to understand further the abrupt changes in the Earth system on multiple stresses, as well as their potential role in future climate shifts. Sustained observations, improving also model simulations would be serviceable for this purpose (NRC, 2010).

5.1. Adaptive Risk Management

Long-term perspectives on climate change adaptation, as well as short-term perspectives on disaster risk management aim to appropriately allocate efforts among disaster management, disaster risk reduction, and risk transfer, and both consider vulnerability reduction as the cornerstone to their efforts (IPCC, 2007).

As it was discussed earlier, there is a need to moderate the respective adverse effects of climate extremes and to achieve the composite agenda of disaster risk reduction and climate change adaptation, we have to implement corrective disaster risk management strategies that are adaptive. Closer integration of disaster risk management and climate change adaptation, into from local to international development policies and practices, could provide benefits at all scales.

Adaptive risk management is a tool that integrates the aforementioned practices to address and incorporate uncertainty and the expectation of surprises through adaptive management, anticipatory learning, and innovation (Renn, 2008). For instance, addressing social welfare, and incorporating a multi-hazards approach into planning and action for disasters in the short term, facilitates adaptation to climate extremes both at the local scale and in the longer term. The steps needed to develop adaptation and disaster risk management plans are:

Risk identification. Risk and vulnerability assessment systematize data and information to identify and evaluate different levels of risk and vulnerability of social groups, infrastructures and institutions. Vulnerability assessment gives the opportunity to identify priority areas for immediate intervention, when current climate-related risks or social factors that can exacerbate adverse effects of extreme events are not satisfactorily controlled. The basic probabilistic risk analysis, used by adaptive risk management regards risk as the product of the probability of an event multiplied by its consequence (Bedford and Cooke, 2001). However, extreme events are phenomena characterized by non-stationarity posing a particular set of challenges for implementing probabilistic approaches to estimate consequences that contribute to disaster risk (NRC, 2009). With risk assessment we can provide an effective mix of the costs of risk reduction, risk transfer, and disaster management activities in any case-study.

Assessment and evaluation of the responses to risk. The responses to risk should be assessed and evaluated by a range of stakeholders considering the impacts of allowing risks to go unmitigated, the costs of different risk-management strategies, and public perceptions and acceptability of risks and/or responses to those risks. The development of appropriate assessment indicators and evaluation criteria could be enhanced if respective integrative and consistent goals for vulnerability reduction and climate change adaptation could be defined for specific regions and the assessment is undertaken before, during, and after disasters occur.

Iterative decision making and deliberate learning. Earning knowledge from the information about the effectiveness of actions taken, decisions should be revisited, reassessed, and improved over time to evaluate them with regard to the allocation of resources and efforts between risk reduction, risk sharing, and disaster response and recovery efforts. Addressing knowledge gaps through enhanced observation and research is essential since actions taken for reducing or adapt disaster risk can be effective in the short term, but may increase vulnerability over the longer term (Birkmann, 2011). Learning is most effective when it engages a wide range of stakeholder groups, particularly affected communities (Tschakert and Dietrich, 2010).

5.2. Portfolio of Actions

Assessment, evaluation and the respective iterative process should engage possible and desirable futures and options for decision making. Thus, a portfolio of many types of risk reduction, risk transfer, and disaster management actions appropriately balanced in terms of resources applied over time, have to be employed.

In the framework of adaptive risk management a popular practice in national policies and plans is to incorporate measures that compensate the near-term climate risks and options that satisfy multiple synergies like sustainable carbon sequestration, energy and water-use efficiency, and food self-sufficiency. Multi-hazard risk management approaches based on structural and engineering strategies or on land and water use planning, are focused in reducing hazards in urban and rural environments. For example, a multi-hazard risk management approach in high urbanized areas would target a considerable reduction of greenhouse gas emissions by developing green cities that reinforce the behavior of less energy demand and use of fossil fuel for transportation and by replacing traditional fossil fuel-based energy systems in the industrial sector with technologies that emit fewer GHGs and aerosol concentrations (Ewing *et al.*, 2007). Science and hard and soft technologies provide valuable tools for development of a range of decision support tools (van de Walle and Turoff, 2007), for planning and climate risk management in business (Changnon and Changnon, 2010), food security and health (Degallier *et al.*, 2010).

Maximizing robustness. To enhance the robustness of decisions and implement the most equitable response strategies and policies, one should obtain more detailed information about the uncertainty in current and future trends of extreme events along with their socio-economical impacts, but should also identify drivers that limit locally the adaptive capacity of people to undertake necessary measures to protect themselves against climate extremes and disasters (e.g., lack of access to and mobilization of the resources of the human beings and their institutions to resources, or information gaps) (Pettengell, 2010).

Ensuring durability. Governance and institutions should design mechanisms that can ensure the long-term durability of policies, provide stability for investors and society. Without competent regulatory bodies that assure conditions for both insurers and clients, the market cannot provide sustainable insurance contracts (Linnerooth-Bayer and Hochrainer-Stigler, 2014). Some recommendations illustrate that financing mechanisms of disaster risk management and adaptation could be merged through development agencies and nongovernmental organizations or national and international organizations and institutions such as environmental ministries. Development ministries could be also coordinated to merge climate change adaptation and DRM strategies (Lavell, 2010).

Effective communication. An essential component of effective risk management is the communication of risks to all involved stakeholders. Since climate-related risks affect different regions, communities, and stakeholders in different ways and to different degrees, stakeholders should be also participating in the process of identifying risks and evaluating response options, as well as in risk communication (NRC, 2008h). Climate researchers and educators must recognize cultural diversity which leads to legitimate disagreements about the risks of climate change, making different social groups to be receptive to different types of interventions; thus, informative dialogue about value-laden choices should be supported. For example, environmental education programs among children and adults may have benefits for public understanding of risk from extreme events (Kuhar *et al.*, 2010) providing the opportunity to integrate diverse participatory processes in resource management (Krasny and Tidball, 2009).

5.3. Needs for further research: the case of risk management of water supply

In light of global water intensification, improve understanding of the frequency and intensity of precipitation combined with feedbacks of human water use and drivers on climate is essential (Conway *et al.*, 2015).

Enhancing water supplies, improving effluent treatment, and employing flood management measures would all lead to reductions in vulnerability in the water sector. In this framework, existing water infrastructure will need to be maintained and upgraded, considering the current and projected impacts of climate change and extremes. Improved physical observations are needed to monitor the impacts on water systems and to support model development, and improve short term hydrological forecasts. Improved regional-scale projections of changes in precipitation-runoff, soil moisture and groundwater availability on seasonal to multi-decadal time scales are needed, as well as projections of changes in the frequency and intensity of severe storms, floods, and droughts are critical both for water management planning and for adapting capacity of the systems. New technologies are needed to allow continuous high precision measurements of inventories and fluxes of water.

In addition to tools and models that expand the range of response options, managers and policy makers will need governance flexibility to increase adaptive capacity in water systems (Zimmerman *et al.*, 2008). An option to deal with these challenges are governance frameworks involving reforming broader institutional structures of water governance including decentralization, integration, collaborative management, and social learning. To improve decision making tools an insight about how governance structures affect human and institutional behavior will be effective on this purpose (Engle and Lemos, 2010). It is extremely important to engage from the outset natural sciences with behavioral science, sociology, legislation, financial risk and communication.

6. SUMMARY AND CONCLUSIONS

In this paper, a comprehensive consideration of extreme global climate parameters in the context of risk evaluation and governance has been presented. A thorough description of climate extremes, which have occurred mainly during the end of 20th century, has been presented, along with their future projections and trends. These climate extremes have included extreme precipitation, floods, extreme winds-storms, extreme sea level rise, heat waves and temperature extremes, as well as droughts. The expected increase in frequency and severity of climate extremes has been attributed to climate uncertainty and increasing climate variability.

The ultimate objective consists of reducing disaster risk and enhancing resilience to climate extremes through multidisciplinary multi-hazardous management, which is addressed in this paper in the context of risk evaluation and governance of climate extremes. However, the severity of disaster impacts is not only affected by the nature of a hazard, but also by the level of exposure and vulnerability of a system to a climate event, which determines whether an impact is extreme or not. Vulnerability and risk transfer have been described to be influenced by a wide range of factors, including anthropogenic, climate change and socioeconomic development. Moreover, disaster risk management has been considered and is associated with adaptation to climate change, where their basic difference consists of the temporal and spatial dimension of their analyses. Adaptation measures to climate change include also disaster prevention and preparedness, which may lead to disaster reduction. It has been stated that scientific progress supported by extended literature on climate adaptation and disaster risk management can provide valuable solutions to some of the challenges facing societies and natural systems. Specifically, national development plans and adaptation strategies must be primarily focused on vulnerable areas and groups and institutionally less-diversified countries. Furthermore, natural sciences should be integrated with behavioral sciences, sociology, economics, public policy management, and communication. The role people play in the determination of extreme impacts must be re-conceptualized in order to generate sustainable behavior.

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