



Implication of Climate Change on Droughts and Water Scarcity

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Abstract

Droughts and water scarcity are important issues related both with climate change and sustainability. Water quality deficiency can be a major cause of water scarcity. Water scarcity is also a matter of poverty. There are many regions in the world already experiencing severe droughts and under a water scarcity situation. Climate change will substantially increase the number of people under water scarcity. If climate change implies greater water scarcity in some regions relative to water demand, then, adaptation strategies should include ways that improve water use efficiency and management. Many developed and developing countries have conducted detailed studies on climate change impacts. Several are moving toward implementation of adaptation strategies. Adaptation to climate change should be at the core of the international poverty agenda. The poorest of the world will hardly escape from dangerous climate change. Current approaches to adaptation planning in many countries center on the idea of using a climate-proofing approach. Adaptation to climate change should reduce the risk of damage when taken in advance. There are many factors that contribute to limiting adaptation; those factors influence the adaptive capacity of water management systems. Adaptation and mitigation need to be viewed as complementary responses to climate change. The presentation aims to offer a comprehensive assessment of the current knowledge about the effect of climate change on droughts and water scarcity in dry regions and also its effects on sustainability. How climate change will impact the already existing problems. Why water scarcity is a climate and sustainable development issue. Impacts of climate change on droughts and adaptation responses and the regional implications of the relation between climate change and droughts.

Key words: Drought; water resources, extreme events, water scarcity.

1. Introduction

Water scarcity and droughts are important issues related both with climate change and sustainability. Extreme events as droughts have very important consequences on human

natural systems. Water quality deficiency can be a major cause of water scarcity. Water scarcity is also a matter of poverty. Estimates of population already living in severely water-stressed areas range from 1.4 billion to 2.3 billion. Globally, only 15% of people live in relative water abundance. There are many regions in the world already experiencing severe droughts and under a water scarcity situation. For example, drought events in the Mediterranean region have been more frequent after 1970. The North Atlantic Oscillation is widely recognized as the most important pattern to explain the climatic and hydrological variability of the Iberian Peninsula. Droughts in the western and central Mediterranean have also been connected to ENSO.

It is important to highlight that water scarcity is not only function of water availability but (e.g., in sub-Saharan Africa, a high degree of precipitation variability coupled with a severe lack of indispensable infrastructure have lead to extreme water scarcity in many places despite an indication of per capita water abundance in some studies). The level of water scarcity depends on the region. It is important to point out that water scarcity is not just a problem in arid regions; even in the fertile humid tropics of, for example, Costa Rica, some communities experience water scarcity due to deforestation and intensive agriculture. Water quickly becomes scarce when communities, industry, agriculture, and natural ecosystems all depend on the same source, potentially depleting natural water reservoirs.

Water scarcity is also a matter of poverty. Lack of sanitation and impure water is a common place for the poor across the world. Water quality deficiency can be a major cause of water scarcity. One in five people in the developing world lack access to sufficient clean water. For poor people is not only about low flow rivers or droughts. It is also about fairness and safe access to the water they need to support their lives and make their livelihoods safe. However, they are extremely sensitive to extreme events such as droughts.

Climate change will substantially increase the number of people under water scarcity by the year 2050 under the Intergovernmental Panel on Climate Change (IPCC) A2 and B2 scenarios. If climate change implies greater water scarcity in some regions relative to water demand, then, adaptation strategies should include ways that improve water use efficiency and management.

Droughts are creeping phenomena that causes tremendous impact in society. It is not a permanent condition which distinguishes it from the arid conditions that occur in different parts of the globe. They can persist for several years; however, short intense droughts can also cause major damage. Droughts generate substantial adverse impact on natural (e.g., ecosystems) and management systems (e.g., water resources, energy, agriculture and tourism) and society in general. In recent years, the economic impact of droughts in the European Union member States has been estimated to be in the order of billion of euros.

Droughts affected areas will likely increase during the 21st century with clear impact on agriculture, forestry, ecosystem, water resources and society. Prolonged droughts also have effects on the economic sector such as damaging crop yields and decreasing farmers' income. The social sector is also affected due to adverse effects on health. For the

Mediterranean region, under different emission scenarios, between 14 to 30% of the population would be living in water-stressed watershed.

Climate change and sustainable development policies have strong linkages. In many regions of the world, the impacts of climate change on droughts and water scarcity may affect sustainable development and put at risk the reduction of poverty. The MDGs are of vital importance in the context of sustainable development and constitute a framework for international cooperation. The MDGs could be jeopardized by climate change when it affects global and regional water resources.

2. Observed and projected changes in temperature and precipitation

Global mean surface temperatures have risen by $0.74\text{ }^{\circ}\text{C} \pm 0.18\text{ }^{\circ}\text{C}$ over the last 100 years (1906-2005). The heat wave over western and central Europe in the summer of 2003 is an example of an extraordinary contemporary extreme event. The 2003 summer was the hottest in records—about $1.4\text{ }^{\circ}\text{C}$ above the prior warmest in 1807. For the next two decades, a warming of about $0.2\text{ }^{\circ}\text{C}$ per decade is projected for a range of SRES. Even if the concentration of all GHGs and aerosols had been kept constant at year 2000 levels, a further warming of about $0.1\text{ }^{\circ}\text{C}$ per decade would be expected (Meehl *et al.*, 2007). Current projections indicate a global temperature increase of $1.1\text{ }^{\circ}\text{C}$ to $6.4\text{ }^{\circ}\text{C}$ (2.0°F to 11°F) around 2100.

Globally, precipitation has increased over the period 1900 to 2005 but downward trends dominated the tropics since the 1970s. From 10°N to 30°N precipitation increased appreciably from 1900 to the 1950s, but started declining around 1970. Some regions as the eastern part of North and South America, northern Europe, and northern-central Asia has become considerably wetter, while the Mediterranean region, the Sahel, southern Africa and part of southern Asia have become significantly drier. In Europe, direct links to global warming have been inferred through the extreme nature of high temperatures and heat waves accompanying recent droughts (Trenberth *et al.*, 2007). In particular in southern Italy, frequent droughts in the last 25 years have occurred. A prevalent decreasing trend of annual rainfall is observed from 1921 to 2001 over 97% of southern Italy. The decrease in rainfall is significant after 1980 for this region (Casarano *et al.*, 2006). Model simulations indicate that global mean precipitation increases with global warming. However, there are substantial spatial and seasonal variations (precipitation may increase in one season and decrease in another). Increases in precipitation at high latitudes in both seasons are very consistent in all models (Meehl *et al.*, 2007). There are significant increases in precipitation in some monsoon regimes (*e.g.*, South Asian monsoon in JJA) (Neelin *et al.*, 2006). Decreases in precipitation over many subtropical areas are clear in multi-model ensembles, and consistency in the sign of change among models is regularly high (Wang 2005). Substantial decrease, about 20%, is estimated to occur in the Mediterranean region and in the Caribbean/Central America region (Neelin *et al.*, 2006) for scenario A2 for period 2070-2099. As presented by Meehl *et al.* (2007), the agreement with respect to projected changes in precipitation is lower than with projected changes in temperature.

3. Observed and projected changes in evapotranspiration and runoff

Many of the currently water stressed semi-arid and arid areas are likely to suffer from decreasing water resources availability due to climate change, when both river flow and groundwater recharge decline. Also in semi-arid and arid areas, climate change is likely to increase salinization of shallow groundwater due to increased evapotranspiration. As runoff (streamflow) is likely to decrease in many semi-arid areas, salinity of rivers and estuaries will increase (Bates, 2008). By the year 2050, annual average river runoff and water availability are projected to decrease over some dry regions at mid-latitudes and in the dry tropics. Many areas such as the western United States, the Mediterranean Basin, southern Africa and north-eastern Brazil are projected to have a decrease of water resources due to climate change (Bates *et al.*, 2008).

4. Observed impacts of climate change on droughts

Quantification of droughts is difficult because, as previously pointed out in this report; there are many definitions for these extreme events. In dry regions, water in rivers, lakes and groundwater is usually very scarce, accounting for less than 10% of the overall water balance. With higher temperatures, the water holding capacity of the atmosphere increases as well as evaporation. This will favor climate variability with more droughts (Trenberth *et al.*, 2003).

There are evidence of intensified droughts in some drier regions since the 1970s: globally, very dry areas ($PSDI \leq -3.0$) have more than doubled due to a combination of ENSO events and surface warming, while very wet areas ($PSDI \geq +3.0$) have declined by about 5%. Temperature was a major contributing factor to droughts after the early 1980s (Dai *et al.*, 2004).

All rain-fed agriculture, in regions where irrigation is not prevalent, depends on the soil capacity to capture the usually little amount of rain that fall. Droughts affect rain-fed agricultural production as well as water supply for domestic, industrial, and agricultural purposes.

Some arid regions of the globe (*e.g.*, Australia, western and southwestern USA, southern Canada, the Sahel and the Mediterranean region), have suffered from more intense and multi-annual droughts. In Portugal, reservoirs significantly lowered during the 2004-2006 droughts. Moreover, in the southern province of Algarve, two major reservoirs – Funcho and Arade – ended to be totally empty (EC, 2007).

The terrestrial part of the water cycle is the balance between total precipitation, evaporation and runoff. In a warmer climate, changes in precipitation, but also in surface evaporation and in runoff will affect the distribution of freshwater resources. A decrease in summer precipitation, for example, in southern Europe together with an increase in temperatures

which enhance evaporative demand would lead to reduced summer soil moisture (Douville *et al.*, 2002) and therefore more frequent and more intense droughts (Kundzewicz *et al.*, 2007).

5. Projected impacts of climate change on droughts

The projected adverse consequence of climate change on regional droughts is well established by global and regional studies. Simulations using a regional climate model¹ for the period 2071-2100 revealed marked changes in the characteristic of daily precipitation in Europe due to the projected global warming. In winter, the frequency of wet days is enhanced over most of the European continent except, for example, in the Mediterranean region. In summer, in contrast, the frequency of wet days is estimated to decrease over most of Europe. Also, the distribution of wet days is projected to change in future. During summer, for example, both the frequency and the length of dry spells are largely increased over most of the European continent. Conversely, the frequency and the length of wet spells are usually reduced during summer and increased during winter with the exception of the Iberian Peninsula). All regional models tested in the PRUDENCE² project predict earlier and longer droughts in the Mediterranean region (Beniston *et al.*, 2007).

There is a tendency for summer drying of mid continental areas. Summer dryness indicates a great risk of droughts (Meehl *et al.*, 2007). Burke *et al.* (2006) projected, using the HadCM3 global model and the SRES A2 scenario for the 2090s, regions of strong wetting and drying with a net overall global drying trend. The proportion of land surface in *extreme drought*³ is projected to increase from 1% to 30% by the year 2100.

Will the occurrence and duration of extreme droughts increase by the end of the century?
In a future warmer climate (A2 scenario), the number of mean extreme droughts events for 100 years and mean droughts duration are likely to increase by a factor of two to six, by the end of the century (Burke *et al.*, 2006).

Can a single episode be identified as an extreme event associated to global warming?
Single extreme climate events cannot be directly attributed to human induced climate change, as there is always a possibility that the event might have happened naturally. However, when an extreme event can be associated with a pattern that persists for some period of time (*e.g.*, irregularities in the SSTs⁴ or changes in atmospheric circulation⁵) it may be classified as an extreme climate event due to global warming.

An episode in North America (1999-2004) could be considered as an example—the western USA, northwest Mexico and southern Canada experienced a persistent drought with dry

¹ HIRHAM model—a regional model of the Danish Meteorological Institute.

² PRUDENCE Project—European project on prediction of regional scenarios and uncertainties for defining European climate change risks and effects.

³ An *extreme drought* is defined in Burke's paper when limiting PDSI value is -4.3

⁴ Sea Surface Temperatures.

⁵ Linked to global warming.

condition starting as early as 1999 and continuing until the end of 2004. The period 2000-2004 was the first time of five consecutive years of below average flow in the Colorado River since 1922⁶ as reported by Pagano *et al.* (2004). This drought highlights both the extreme vulnerability of the semi-arid western United States to precipitation deficits and the need to better understand long term drought variability and its causes in North America (Cook *et al.*, 2004). The drought metric used in that study was the Palmer Drought Severity Index (PDSI). The PDSI rose above 20% in November 1999 and stayed above this level until October 2004. It reaches its peak on August 2002, affecting around 87% of the West. This drought has been associated to changes in atmospheric circulation linked with warming of the western tropical Pacific and Indian Oceans (Hoerling and Kumar, 2003) and to the confluence of both Pacific decadal and Atlantic multi-decadal fluctuations (McCabe *et al.*, 2004).

6. Impacts of droughts on natural and human systems

Droughts affected areas will *likely* increase in extent during the 21st century with clear impacts on agriculture (lower yields and crop damage), forestry (increase risk of wildfires), ecosystems, water resources (more widespread water stress) and society (water shortage for settlements, reduced hydropower generation).

Then, the impact of droughts is not only about water supply or in general about water resources (*e.g.*, lower levels in reservoirs or lakes) problems. Prolonged droughts has also effects on the economic sectors such as reduce crop production and damage crop quality, increase irrigation cost; decrease farmers' income, reduce milk production, affect recreational areas, damage hydroelectric infrastructure, degrade groundwater quality⁷, impair navigation and loss of aquatic organisms due to decreased flows.

The social sector is also affected due to adverse effects on health (*e.g.*, diminished sewage flows and increased pollutants concentration are both health related low flow problems, reduction in nutrition, increase respiratory illness and increase poverty in general).

Droughts also impact the environment through different forms, for example, reduce fish and wildlife habitat, increase stress to endangered species, loss of wetlands, changes in salinity levels and loss of biodiversity.

At the global and regional scale, increase in population and consumption alone will reduce water availability. Thus, changes in the provision of water affect humans directly and indirectly through the effects on other ecosystem services.

Schroeter *et al.* (2005) using several GCMs model and a macro-scale hydrological model, quantified the implication of water availability in Europe⁸ and, in particular, in the Iberian Peninsula. Table 1 shows the values of decreased changes in precipitation using the

⁶ Beginning of modern records.

⁷ Degradation as a result of aquifers overuse.

⁸ 15 pre 2004 European Union member States, plus Norway and Switzerland.

HadCM3 global model for four emission scenarios. The values are given for the summer (JJA) season; they range from -14 to 27%.

Table 1: *Changes in summer precipitation (%) for the Iberian Peninsula. Source: Schroeter et al., 2005.*

Scenario by 2080	Change^a in precipitation (%)	Population in Europe (million)	CO₂ concentration (ppm) for
B1	-17	376	518
B2	-14	346	567
A1FI	-27	376	779
A2	-22	419	709
(a) compared to 1990			354 (in 1990)

For the Mediterranean region, under scenarios B2, A1FI, A2 and B1, between 14 to 30% of the population would be living in water-stressed watersheds. In this region, water scarcity would likely be aggravated by higher extraction per capita for irrigation and tourism (Schroeter *et al.*, 2005).

7. Implications for policy and sustainable development

Climate change and sustainable development policies have strong linkages. However, sometimes their policies have evolved in parallel and furthermore sometimes they even have competed with one another.

One way to avoid that climate change might test sustainability is to use methods and tools, such as integrated modeling approach (Berry *et al.*, 2006), integration frameworks and scenario construction for transition management (Wiek *et al.*, 2006), in order to close the gap in our understanding of how climate change would affect sustainability.

In many regions of the world, the impacts of climate change on droughts may affect sustainable development and then put at risk the reduction of poverty and sometimes they could be a setback in already developed areas.

A set of adaptation measures can diminish the risk of climate change and improve the linkages with sustainability. Some examples for the water sector, and related to droughts are: expanded use of traditional rainwater harvesting, water conserving techniques, capacity building of local authorities, assistance to small subsistence farmers to increase crop production, drought early warning systems, adjustment of planting dates and crop variety (*e.g.*, inclusion of drought-resistant plants such as aloe and agave) and integration of rainwater harvesting systems in domestic and commercial buildings (Adger *et al.*, 2007).

Mitigation measures that reduce greenhouse gas emissions lessen the impact of climate change on water resources. The projected number of people which will be exposed to water scarcity and potentially affected is emission scenario-dependent. For example, stabilization of greenhouse gas concentration at 550 ppm, which can be considered the case of a temperature increase relative to pre-industrial of nearly 2 °C, reduces the number of people adversely affected by climate change by between 30-50% (Amell, 2006).

Climate change mitigation, through greenhouse gas emissions (GHG) reduction and sequestration is not a sufficient response. Adaptation will need to feature as a response strategy. Mitigation and adaptation need to be viewed as complementary responses to climate change in relation to the water and agricultural sectors. An example of the concept of complementarity of mitigation and adaptation is the case of hydropower construction as a policy to mitigate GHGs. Given the well-known concern over climate change and GHG emissions, hydropower generation is considered a clean source of energy, suggested prominently as a mitigation option for many developed and developing countries. However, research shows that construction of hydropower plants may in some situations provoke social and environmental consequences that contribute to global warming (Mata and Budhooram, 2007).

Many water management adaptation measures, particularly those involving pumping or treating water are very much energy intensive. Their implementation would intensify energy related greenhouse gas emissions (Kundzewicz *et al.*, 2007).

The MDGs are of vital importance in the context of sustainable development and constitute a framework for international cooperation.

Potentially, the most related goals to both water resources and climate change⁹ are goal 1 and goal 7. The first *emphasize eradication of extreme poverty and hunger* and it is linked directly to water resources since water is a factor in many production activities (*e.g.*, agriculture) and in the sustainable production of fish and other foods. Goal 7 address the issue of *ensure environmental sustainability* which is directly related to water through several aspects such as the need to improve water supply and sanitation services to poor communities, reduce wastewater discharge and improve environmental health, and reduce water consumption.

Climate change could jeopardize those two goals as it affects directly global and regional water resources and also might affect goal 8 which is related to creation of a global partnership for development.

8. Conclusions

Droughts and water scarcity are currently global problems. There are evidences of intensified droughts in some drier regions since the 1970s. Droughts generate adverse effects in multiple socio-economic sectors, for example, they affect rain-fed agricultural

⁹ Although climate change is not directly mentioned in the MDGs.

production as well as water supply for domestic, industrial, and agricultural purpose. Climate change will exacerbate these impacts. Some uncertainties still remain in future impacts of climate change on water scarcity and droughts. They are due to different reasons such as how the future will be in relation to scenarios of economic and technological development, demography, greenhouse gas emissions pathways, climate and hydrological modeling. Despite these uncertainties, important results are available on the impacts of climate change on droughts and water scarcity in dry regions.

- Droughts affected areas will likely increase during the 21st century with clear impacts on agriculture, forestry, ecosystems, water resources and society. In some sites as the Mediterranean region, between 14 to 30% of the population would be living in water stressed watershed.
- By the year 2050, annual average river runoff and water availability are projected to decrease over some dry regions at mid-latitudes and in the dry tropics. Many areas such as the western United States, the Mediterranean Basin, southern Africa and north-eastern Brazil are projected to have a decrease of water resources due to climate change.
- In semi-arid and arid areas, climate change is likely to increase salinization of shallow groundwater due to increased evapotranspiration. As runoff (streamflow) is likely to decrease in many semi-arid areas, salinity of rivers and estuaries will increase. For example, salinity levels in the Murray-Darling river basin in Australia are expected to increase by 13-19% by 2050.
- In regions where changes in runoff depend basically on changes in rainfall rather than in changes in temperatures, most studies agree that flow seasonality increase with higher flows in the peak flow season and either lower flow during the low flow season or extended dry periods.
- A decrease in summer precipitation, together with an increase in temperatures which enhance evaporative demand would lead to reduced summer soil moisture and therefore more frequent and more intense droughts (*e.g.*, southern Europe).
- Of all sectors related to water demands the irrigation sector, including rainfed agriculture, will be affected most strongly by climate change while the increase in household and industrial water demand due to climate change is likely to be about 5 % by 2050.
- Under a particular emission scenario—the IPCC A2 scenario—the number of extreme droughts events for 100 years as well as the mean droughts duration are likely to increase by a factor of two to six by the end of the century.
- As global population grows and development needs call for increased allocation of water, the competition for water resources also increase among the different sectors involved. This competition is expected to intensify as climate change affects precipitation and runoff patterns around the globe.
- For poor people is not only about low flow or less precipitation leading to droughts. It is also about fairness and safe access to the water they need to support their lives and make their livelihoods safe. However, they are extremely sensitive to droughts.
- Probably, it is in rural areas where water scarcity affects the majority of people. The poor people depend mainly on rainfall for food production. However, rainwater is not often incorporated into the countries water management strategies.

References

- Adger W.** and 8 co-authors: Assessment of adaptation practices, options, constraints and capacity. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the AR4*, [Parry, M.L. O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.)], Cambridge University Press, UK, 717-743
- Bates. B.**, and 38 co-authors., 2008: *Climate Change and Water. IPCC Technical Paper*, 240 pp.
- Berry, P.M.**, M.D.A. Rounsevell, P.A. Harrison and E. Audsley, 2006: Assessing the vulnerability of agricultural land use and species to climate change and the role of policy in facilitating adaptation. *Environ. Sci. Pol.*, **9**, 189-204.
- Burke, E. J.**, S. Brown, and N. Christidis, 2006: Modeling the recent evolution of global drought and projections for the Twenty-First Century with the Hadley Centre Climate Model. *J. of Hydrometeor.*, **7**, 1113-1125.
- Casarano, D.**, V. Dragone and M. Polemio, 2006: Drought spatial and temporal variability in Southern Italy (1821-2004): analysis of temperature and rainfall data. *Geophys. Res. Abstracts*, **8**.
- Cook, E.R.**, C.A. Woodhouse, C.M. Eakin, D.M. Meko and D.W. Stahle, 2004: Long-term aridity changes in the western United States. *Science*, **306**, 1015-1018.
- Dai, A.**, K. Trenberth and T. Qian, 2004: A global data set of Palmer Drought Severity Index for 1870-2002: relationship with soil moisture and effect of surface warming. *J. of Hydrometeor.* **5**, 1117-1130.
- Douville, H.**, F. Chauvin, S. Planton, J. F. Royer, D. Salas-Meliá and S. Tyteca, 2002: Sensitivity of the hydrological cycle to increasing amounts of greenhouse gases and aerosols. *Climate. Dyn.*, **20**, 45-68.
- EC**, 2007: *Water Scarcity and Droughts, Second Interim report*, page 47.
- Hoerling M. and A. Kumar, 2003: The Perfect Ocean for Drought. *Science*, **299**, 691-694.
- Kundzewicz Z.W.**, L.J.Mata, N.W. Arnell, P. Doll, P. Kabat, B. Jimenez, K. A. Miller, T. Oki, Z. Sen and I. A. Shiklomanov, 2007: Freshwater resources and their management. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Parry, M.L. O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK, 173-210.
- Mata, L. J.**, and J. Budhooram, 2007: Complementarity between mitigation and adaptation: the water sector. *Miti. Adapt. Strat. Glob. Change*, **12**, 799-807.
- Meehl, G.A.**, T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver and Z.-C. Zhao, 2007: Global Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 747-842.
- Neelin, J.D.**, M. Munnich, H. Su, J.E. Meyerson and E. Holloway, 2006: Tropical drying trends in global warming models and observations. *Proc. Natl. Acad. Sci. U.S.A.*, **103**, 6110-6115.

- Nicholson, S.**, 2005: On the question of the recovery of the rains in the West African Sahel. *J. Arid Environ.*, **63**, 615-641.
- Pagano, T.**, P. Pasternis, M. Dettinger, D. Cayan and K. Redmond, 2004: Water year 2004: Western water managers feel the heat. *EOS*, **85**, 385-400.
- Schroeter, D.**, and 34 co-authors, 2005: Ecosystem service supply and vulnerability to global change in Europe. *Science*, 310, 1333-1337.
- Trenberth, K.E.**, A. Dai, R. M. Rasmussen and D.B. Parsons, 2003: The changing character of precipitation. *Bull. Am. Meteorol. Soc.*, **84**, 1205-1217.
- Trenberth, K.E.**, P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, B. Soden and P. Zhai, 2007: Observations: Surface and Atmospheric Climate Change. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Wang, G.**, 2005: Agricultural drought in a future climate: Results from 15 global climate models participating in the IPCC 4th Assessment. *Climate Dyn.*, **25**, 739-753.
- Wiek A.**, C. Binder and R.W. Scholz, 2006: Functions of in transition processes. *Futures*, **38**, 740-766.