8 Climate Change and On-farm Conservation of Crop Landraces in Centres of Diversity

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8.1 Introduction

Global climate change will have important effects on the ways in which humanity feeds itself (Fischer *et al*., 2005; Lobell *et al*., 2008). Increasing temperatures, changing rainfall patterns and increases in frequency of extreme events, such as droughts, storms, floods and weather extremes, will present important challenges to agricultural and food systems (Ortiz, 2011; Vermeulen *et al*., 2012). Agricultural biodiversity in general, and plant genetic resources for food and agriculture in particular, will play a fundamental role in the capacity of agricultural and food systems to adapt and respond to climate change (Jarvis *et al*., 2010; Ortiz, 2011). The fundamental role of these resources still remains, however, relatively unacknowledged (Ortiz, 2011). This is changing, however, and there is increasing attention to the complex relationships between climate change and the use and conservation of agricultural biodiversity, of which this volume is a good example. The conservation of crop genetic diversity has been a worldwide concern for many decades, particularly owing to the worry that much of this diversity would disappear with agricultural and economic development, i.e. genetic erosion (Hawkes, 1983; Harlan, 1992). Although this has happened for certain crops and certain areas, considerable diversity is still grown in developing countries by smallholder farmers, particularly in centres of crop domestication and diversity (Brush, 2004; Jarvis *et al*., 2008). Efforts to conserve crop diversity by the scientific community have led to the collection and conservation of seeds in *ex situ* genebanks (Plucknett *et al*., 1987). In the past two decades, there has been a growing interest in on-farm conservation of landraces in centres of crop diversity (Bellon *et al*., 1997; Bretting and Duvick, 1997; Brush, 2004; Gepts, 2006). It refers to the management of landraces in farmers' fields and orchards where they originated, and aims at maintaining the processes of crop evolution (Brush, 1995). Landraces have been defined as dynamic populations of a cultivated plant with a historical origin, distinct identity, often genetically diverse and locally adapted, and associated with a set of farmers' practices of seed selection and field management as well as with a knowledge base (Camacho Villa *et al*., 2005). To function, on-farm conservation depends then on farmers' preferences, knowledge, management, practices and social organization. It contrasts with *ex situ* conservation, where the aim is to maintain the genes and genotypes contained in samples of seeds or planting material representative of the diversity of a particular crop without change over a long time. These two strategies are aimed at conserving different things. On-farm conservation is about maintaining processes, whereas *ex situ* conservation is about maintaining specific results of these processes (specific genes and genotypes sampled at a particular point in time). Both types of conservation can be treated as complementary (Bretting and Duvick, 1997; Brush, 2004).

Climate change is predicted to have major impacts on small-scale farmers in the developing world but these impacts are likely be complex, locally specific and hard to predict (Morton, 2007). Therefore, the climatic suitability for many crops will change with particularly negative consequences for crops in tropical areas of the world (Lane and Jarvis, 2007). Because many centres of crop diversity are located in those areas and the small-scale farmers there are key players in on-farm conservation, it is clear that climate change will have an important impact on the viability of on-farm conservation (Jarvis *et al*., 2010). The future of crop genetic resources maintained on-farm will depend on the responses of landraces – and the farmers who grow them – to climate change, particularly on the tolerance and adaptive capacity of landraces to the novel conditions climate change will bring about (Mercer and Perales, 2010). The sensitivity of landraces to climate variability and their capacity to evolve and adapt to these changes is central to assess both their fate and value under a changing climate. Changes may be of such magnitude and speed that the evolutionary potential of crop populations may be limited (Gepts, 2006) and novel climatic conditions may adversely affect currently adapted landraces. This will reduce their performance and increase the vulnerability of the associated farming systems, probably requiring the adoption of new crops or varieties, leading to further genetic erosion (Jarvis *et al*., 2010). Ecologists have, however, already documented rapid rates of evolution in response to climate change in several species (Davis *et al*., 2005; Reusch and Wood, 2007), a pattern observed also in crops (Vigouroux *et al*., 2011), which suggests that climate change can lead to the adaptation of landraces (Mercer and Perales, 2010) and provide options to farmers. These dynamics will depend not only on the inherent genetic and biological properties of the specific crop landraces in particular locations but also on the knowledge and management practices of the farmers who maintain them. In this chapter we review the potential impacts of climate change on on-farm conservation of crop diversity and on the contribution that on-farm conservation can make to agricultural adaptation to climate change, and ask two questions:

1. How might climate change affect the viability of on-farm conservation of landraces in centres of crop diversity?
2. How can on-farm conservation contribute to the adaptation of small-scale farmers to climate change?

8.2 What is On-farm Conservation?

On-farm conservation involves farmers' continued cultivation and management of a diverse set of crop populations in the agroecosystem where the crop evolved or in secondary centres of diversity. It depends on farmers' active participation based on their reasons and incentives for maintaining diversity (Bellon *et al*., 1997). Crop genetic diversity is unequally distributed around the world and is concentrated in centres of diversity that often coincide with centres of crop domestication (Gepts, 2006). In these locations, besides the broad genetic and phenotypic diversity present, there is a long history of co-evolution between humans and the crops (Brush, 2004; Zimmerer, 2010), reflected in:

- The cultivation of a diverse set of landraces with an associated knowledge base.
- The existence of multiple uses and preparations, usually linked with particular cultural preferences.
- Specific management practices such as intercropping or rotations, as well as seed selection and sharing.
- Matching specific landraces to particular environmental niches for optimizing production and managing risk.
- Social norms and organization that underpin all of these aspects.

The structure and dynamics of these landraces are the result of both natural and human selection. Even natural selection is influenced by human actions such as moving and planting crop species in particular locations and environments, thereby exposing the crops to different natural selection pressures such as climatic conditions, specific soils, pests and diseases. As indicated by Gepts (2006): 'Through farming practices (time of planting, thinning, and seed selection), farmers are able to keep landraces adapted to their growing conditions and socio-cultural preferences'.

The objective of on-farm conservation is therefore to maintain crop evolution in farmers' fields, farms and landscapes. The reason to maintain evolutionary processes in crops is 'to generate new potentially useful genetic variation, which in turn contributes to maintain the capacity of agricultural and food systems to adapt to change, particularly if it is unpredictable' (Bellon, 2009). Clearly this capacity involves many other dimensions but, given that crops are central to these systems, the crop dimension is of great importance. The outcome of on-farm conservation can be conceptualized as an 'evolutionary service' to agricultural and food systems, and, although it is implicit in the definitions and rationale for on-farm conservation, it has not been conceptualized explicitly as such. The idea of ecosystem services has gained recognition and value as a way to conceptualize how nature contributes to human well-being (Millennium Ecosystem Assessment, 2005), but it is only recently that the idea of evolutionary services is beginning to be explicitly recognized as a category in its own right. Evolutionary services have been defined as 'all of the uses or services to humans that are produced from the evolutionary process' (Faith *et al*., 2010) and include novel uses from known and from not-yet-known elements of biodiversity. These unknown uses are part of what economists call option values, which are to do with the idea that maintaining diversity keeps our options open to benefit from unanticipated future uses of biodiversity (Faith *et al*., 2010).

A crucial aspect of on-farm conservation is the seed systems that are associated with the maintenance and management of landraces in centres of crop diversity (Pautasso *et al*., 2012). A seed system refers to the interrelated set of participants, rules, interactions and infrastructure by which farmers obtain seed or planting material through time and space. Historically seed systems have been in the hands of farmers and communities, and are usually referred to as local, informal or traditional seed systems. In them, farmers rely mainly on themselves to obtain seed and these systems are still common in the developing world for a large number of crops (Pautasso *et al*., 2012), particularly in centres of crop diversity, such as maize in Mexico and Guatemala (van Etten and de Bruin, 2007; Dyer and Taylor, 2008; Bellon *et al*., 2011), potatoes in the Andes (Thiele, 1999; Zimmerer, 2003), durum wheat (Tsegaye and Berg, 2007) and sorghum (McGuire, 2008) in Ethiopia, and millet in India (Nagarajan and Smale, 2007). In these systems farmers typically save seed from one season to the next and may share seed with other farmers inside or outside their communities. Seed sourcing is embedded in well-structured traditional systems with rules and expectations based on family and local social networks and regulated by ideas of fairness, and of respect for the seed (Badstue *et al*., 2007), though farmers may also obtain seed – including commercial varieties – from strangers, in village markets and from the formal seed system through purchase or as aid (Lipper *et al*., 2010).

Traditional seed systems are not closed or static but open and dynamic with seed coming in and out of the systems, and with farmers experimenting and incorporating new seeds, while keeping and discarding others. They can be quite decentralized because farmers and communities make different and independent decisions in multiple locations, environments and situations. These systems, however, tend to be quite local with a limited spatial scope (Bellon *et al*., 2011), although they can include long distance seed flows (Van Etten and de Bruin, 2007). This contrasts with formal seed systems that are in the hands of plant breeders and seed companies that are driven by profits, specialization and economies of scale, mediated by commercial transactions of homogenized products, and can be global in their scope.

Seed systems influence which alleles and genotypes pass from one generation to the next, shaping the traits that are under human selection and, by influencing the movement of and location where a crop is planted, the specific natural selection pressures to which it is exposed. Depending on the reproductive system of the crop, sharing of seed and planting in close proximity can foster gene flow. Therefore, understanding the structure and functioning of seed systems is fundamental to maintain and influence the generation of new and useful genetic variation in agricultural systems and highlight the landscape nature of on-farm conservation. On-farm conservation does not depend then on just a few farmers managing diverse crop populations in one village or even a group of farmers in a few villages in a particular area. It is tied to broader social and ecological landscapes of many farmers and villages interlinked to various degrees, and distributed across different types of environments facing diverse selection pressures (both natural and human) leading to the generation of a broad array of genetic variation. Because conditions and environments change and some of those that are rare today may become common tomorrow – and vice versa – having a diversity of 'winning' (adaptive) combinations of genes and traits that are constantly being updated in response to changing situations and new knowledge should allow us to cope and adapt better to change. This is precisely the idea of the option value of the evolutionary services that on-farm conservation delivers (Bellon, 2009).

An important conceptual issue is that the socio-biological systems that maintain landraces in centres of crop diversity are producing two distinct types of benefits: private and public (Smale and Bellon, 1999). The private benefits refer to those that accrue and are captured directly by farmers who maintain these systems, such as the food and products they consume or sell (and associated income), the insurance they gain and the cultural values they fulfil. The public benefits refer to those that accrue to others besides the farmers themselves and that can happen at different scales. Pest control properties of planting varieties with different resistance genes by different farmers (occurring at the local or regional level; Rebaudo and Dangles, 2011) or the new potentially useful genetic variation generated by their management of landraces (the evolutionary services described above) and that can be available through seeds locally, regionally or globally to other farmers for direct use or to plant breeders for further crop improvement are good examples. The problem is that the resources needed to generate these benefits, such as land, labour, capital and knowledge, are limited, whereas public and private benefits can often diverge, creating trade-offs for individuals and society (Heal *et al*., 2004; Smale and Bellon, 1999). For example, the conventional explanation for crop genetic erosion is that farmers increasingly specialize and replace their diverse sets of landraces with a few scientifically bred varieties that provide them with higher yields and more income. Although farmers pursue their legitimate private interest (higher incomes), crop genetic diversity that may be central to ensure the adaptation of other farmers to changing conditions or the needs of future generations (public benefits) may be lost. Farmers as individuals may tend to underinvest in the conservation of landraces and associated genetic diversity relative to what might be considered optimal for society at large (Heal *et al*., 2004; Smale and Bellon, 1999).

This explanation underpins two important and related criticisms levelled at on-farm conservation. The first is that replacement of landraces by scientifically bred varieties is an inexorable process that sooner or later will take place everywhere, including centres of crop diversity. Hence on-farm conservation is not a viable and sustainable strategy in the long run. The second criticism is that on-farm conservation perpetuates poverty among farmers who maintain diverse landraces by promoting them at the expense of more productive scientifically bred varieties that would provide farmers with higher incomes and improved welfare (Brush, 1995; Bellon, 2009).

Research among small-scale farmers in centres of crop diversity over the past 20 years has shown that these two criticisms are not necessarily valid and involve more complex issues than appear at first sight (Brush, 2004). Many small-scale farmers still have strong private incentives to maintain a diversity of landraces. There are many species of regional and local importance where no breeding has taken place, and hence local landraces are still the mainstay for farmers who grow them (Gruere *et al.*, 2009; Padulosi *et al.*, 2011). Even for major crops, scientifically bred varieties are often inadequate for farmers' circumstances, seed may be unavailable, or they complement rather than replace landraces and hence both are grown together. Because it is common among small-scale farmers that production and consumption decisions are linked, profit maximization is not a main production objective, and therefore consumption preferences continue to influence their decisions. This can lead to very high willingness to pay for landraces in some systems, and shows that market prices only capture a fraction of the private value that farmers attach to their landraces (Smale and Bellon, 1999; Arslan and Taylor, 2009). This in turn means that cultural preferences play a role in their decision making, even when farmers can be quite commercially oriented (Bellon and Hellin, 2011). Landraces can perform well under improved management and can provide important commercial opportunities (e.g. maize; Perales *et al.*, 1998), particularly as new uses are discovered and products developed as knowledge progresses and new markets are created.

This does not mean that there are no challenges to on-farm conservation. Besides the substitution of a diverse set of landraces by a few scientifically bred varieties, other mechanisms that can lead to the loss of crop biological and genetic diversity in farming systems include: the replacement of a native crop with great diversity by another crop with little local diversity (e.g. sorghum by maize in some parts of sub-Saharan Africa); farmers abandoning agriculture altogether and shifting to other activities; or even migration. Maintaining crop diversity on-farm can entail important costs to farmers, but as long as they have private incentives to maintain landraces, there are opportunities for on-farm conservation to continue. Although on-farm conservation may continue on its own, as has already been documented extensively, in certain circumstances it needs to be supported by outside interventions (Bellon, 2004). The methods to target and prioritize systematically the specific areas and systems where these interventions should take place are still poorly developed, and this is an area for further research. Nevertheless, on the basis of the arguments presented above, these methods should be based on evolutionary and landscape approaches with a strong socioeconomic perspective, given that the processes and the socio-biological systems that generated them are what should be maintained.

In any case, in terms of outside interventions to support on-farm conservation there is already a wealth of knowledge at the farmer and community levels. In the past two decades there have been many projects worldwide to support on-farm conservation implemented by many different types of institutions such as national and international non-governmental organizations (NGOs), farmers' organizations, universities, international research organizations (Jarvis *et al.*, 2011). However, even though placed in centres of crop diversity, these projects usually tend to be ad hoc and opportunistic. Projects usually implement a series of interventions aimed at changing the way crop diversity is accessed, managed, used, consumed and/or marketed. Interventions can either influence the demand for crop diversity by aiming to increase the value of crop diversity for farmers or decreasing the opportunity costs of maintaining it, or its supply by aiming to decrease the costs of access to diversity (Bellon, 2004). A recent and extensive review by Jarvis *et al.* (2011) identified 59 different types of interventions for supporting on-farm conservation, which can also be conceptualized as influencing either the demand or supply of crop diversity. Unfortunately, there is still scant rigorous evidence that such interventions actually make a difference, an area in much need of further research and evidence. The challenge of any on-farm conservation project then is to identify, design and implement interventions that make the conservation of crop diversity on-farm compatible with improved livelihoods and well-being among the farmers who conserve it and to demonstrate that interventions work (Bellon, 2004). The basic principle is not to keep farmers poor, but to enable them to capture more benefits from the diversity they maintain, including the public benefits resulting from that conservation.

8.3 Changes in Climatic Suitability due to Climate Change for Selected Crops in their Centres of Diversity

The impact of climate change on crop productivity and land suitability depends not only on global climate trends but also on a range of local factors, such as soil characteristics, crop management, as well as specific adaptation measures taken by farmers. Also, it may be that extreme weather events are equally or even more important than shifts in average values (Trnka *et al*., 2011). Therefore, it is difficult to estimate climate change impact in a quantitative way. Simple, heuristic models work well to make broad comparisons and make it easier to assess shortcomings.

In order to assess how climate change can affect the land suitability for crops in their areas of origin and/or centre of diversity, the focus for on-farm conservation, we determined the future trends in land suitability for a small number of important crops in relevant areas (Table 8.1). We used a model that determines suitability on the basis of monthly averages in temperature and precipitation (Hijmans *et al*., 2012). The model has been shown to function reasonably well for a range of crops (Jarvis *et al*., 2012; Ramirez *et al*., 2013). Depending on crop-specific parameters, we determined the suitability based on current climate data and 19 general circulation models (GCMs). For each region, we took the 'majority vote' of the models, and in Table 8.1 we indicate whether ten or more models projected an increase (+) or decrease (–) in area. This analysis does not take into account inter-annual variability, even though this may increase in the future, with negative effects for land suitability.

The results are mixed. Rice, sorghum, pearl millet, cassava and *Musa* crops show a

Table 8.1. Climate change impact on land suitability for selected crops.

Crop	Geographical origin / centre of diversity	Trend in area suitable for this crop in this region, current to 2030s[a]
Wheat	West Asia	–
Maize	Mesoamerica	–
Asian rice	China	+
Barley	West Asia	–
Sorghum	North-east tropical Africa	+
Sorghum	Indian subcontinent	–
Pearl millet	Sahel	+
Potatoes	Andes	–
Cassava	Amazon Basin	+
Banana and plantains	Papuasia	+

[a]Change in arable land suitable for the crop under current climate conditions and land suitable in the 2030s. EcoCrop results of 'majority vote' of 19 general circulation models (down-scaled using delta-method, Ramirez and Jarvis, 2008), scenario A2, assuming rainfed conditions.

net expansion in the broad region around their centre of diversity. In broad terms, these crops may play an important role in climate change adaptation. The results for rice may not be fully representative because rainfed conditions were assumed (as for the other crops) but rice is predominantly an irrigated crop in its area of origin. Also, rice may suffer much from weather variability, given its sensitivity to high night temperatures during the flowering period (Jagadish *et al*., 2007; see Djanaguiraman and Prasad, Chapter 12, this volume). Interestingly, the suitability of sorghum will decrease on the Indian subcontinent, a secondary area of diversity for this crop. Wheat, maize, barley and potatoes tend to decrease their area of suitability in their centres of origin. Interestingly, these are crops that are widely grown in temperate as well as tropical climates. Potatoes are a highland crop in the tropics and suffer under higher temperatures. Although some high altitude environments will become more suitable for potato, their overall area is projected to decrease in the Andean region. Maize is an interesting case owing to its wide area of adaptation and large genetic diversity. Maize landraces in Mexico – a centre of origin and diversity for this crop – show remarkable diversity and climatic adaptability growing from arid to humid environments and from temperate to very hot environments (Ruiz Corral *et al*., 2008). Under climate change, the area of adaptation of some maize populations may expand, whereas others such as highland maize contract (Bellon *et al*., 2011; Ureta *et al*., 2011), but the great diversity present suggests that there is already enough to allow the crop to adapt to new conditions fostered by climate change (Mercer *et al*., 2011; Ureta *et al*., 2011). Nevertheless, some particular races may be threatened as well, such as those from the highlands (Mercer *et al*., 2008; Bellon *et al*., 2011), and because these are not well represented in genebanks, they should be a priority for further *ex situ* conservation efforts.

Clearly the implications of these results are variable. They depend on the crop and the environments in which it grows. There is no widespread threat for crops in their centres of diversity from climate change but there are some specific ones. Hence on-farm conservation may continue to be a viable strategy for some crops but not necessarily for others. This will depend on the capacity of these crops to evolve under climate change conditions. In particular for crops with a wide distribution, such as maize, the threat may be for specific populations. Obviously, this a simplistic analysis but it is useful as a first approximation, and to identify further areas of research such as additional analysis at the infraspecific level related to the ranges of adaptation of the crops in their centres of diversity and to prioritize additional *ex situ* conservation efforts.

8.4 On-farm Conservation as an Evolutionary Service in the Context of Climate Change

Predictions of the impact of climate change on the distribution and productivity of crops rely on models for identifying novel climates and to assess the potential response of crops to them. Although it is extremely useful to assess some of the challenges that agricultural and food systems may face with climate change, they provide only a partial picture because they do not take into account the potential that crops have for change and evolution, which can vary widely within and among populations of a species and depend on the presence of genetic variation in populations (Sgro *et al*., 2011). Due to genetic variation, climate change will affect populations differently throughout the species range and populations will vary in the rate of adaptation (Davis *et al*., 2005). Hence an evolutionary perspective is needed to assess how crops may respond to climate change and the extent that these responses can be useful for farmers to adapt (Mercer and Perales, 2010). In ecology, there is an increasing recognition of the importance of an evolutionary framework to assess species responses to climate change and for biodiversity conservation (Davis *et al*., 2005; Sgro *et al*., 2011). The assumption that species tolerance limits to climate remain stable over time is increasingly being challenged and there is evidence that selection under climate change conditions can lead to adaptive changes regardless of whether ranges shift or not (Davis *et al*., 2005). Although plant species, and hence crops, may evolve and adapt to new conditions, there are limits to this capacity as well. The capacity of plant species to evolve and adapt to climate change will depend not only on the genetic variation present in populations, but also on the magnitude, direction and speed of change that climate change will bring about.

Mercer and Perales (2010) have already used an evolutionary framework to explore the potential impacts of climate change on landraces in centres of crop domestication. These authors note that the future of crop genetic resources maintained on-farm will depend on the responses of landraces and the farmers who grow them, particularly on the tolerance and adaptive capacity of landraces to novel climate conditions. The issue is complex and they identify four potential responses of landraces to climate change: plasticity; evolution; gene flow; and extinction. Although the first three factors offer opportunities for landraces to adapt to the novel conditions induced by climate change, there are also limits on how far these can go and hence extinction is always a possibility. Particularly, the multiplicity of biophysical and socio-economic factors that can affect negatively the performance of landraces (stressors) associated with climate change, and the existence of negative correlations among traits that are adaptive to these stressors individually but which act antagonistically when stressors occur simultaneously or in close succession, can limit the capacity of landraces to adjust. These antagonistic correlations can be due to pleiotropy, when the effect of an allele on one trait enhances fitness but its effect on another reduces fitness, or to linkage disequilibrium, which is the association of alleles at different loci (Davis *et al*., 2005). Although local adaptation is seen as a positive feature of landraces and a reason for the great diversity observed in centres of crop diversity, it could cause difficulties for farmers who grow them under climate change by placing limits on their future plastic responses. Though the use of theory to explore these issues is very useful, as these authors also note, there is a need for empirical evidence on how landraces may respond to novel conditions associated with climate change. Although there is increasing understanding on how improved germplasm responds to changing conditions associated with climate change from multi-locational trials (Lobell *et al*., 2011), there is still limited empirical knowledge on how landraces may respond.

Two examples of the type of work needed to address this gap are reported by Mercer *et al*. (2008) and Vigouroux *et al*. (2011). Mercer *et al*. (2008) established two experimental gardens (referred to by the authors as ‘common gardens’) at two altitudes (1500 and 2150 m above sea level), planting a set of 21 maize landraces from three altitudinal ranges (lowland, mid-elevation and highland) collected in the Mexican state of Chiapas, and recorded their performance in terms of the likelihood of producing good quality seed and the total mass of good quality seed per plant. The results show that landraces are well adapted to the altitude where they were collected. When planted at different altitudes, however, they showed asymmetric local adaptation. Although mid-elevation and lowland landraces did not produce as well as highland ones in the highland site, they still produced about 80% of seeds per plant compared with the highland types. This was not the case with the highland landraces when planted in the mid-elevation site, which only produced 33% of the seeds per plant compared with what the mid-altitude types produced there; it appears that highland landraces do not express the necessary plasticity to sustain productivity under warmer conditions. Highland maize environments in Mexico are likely to show the most dramatic shifts in climate under climate change (Bellon *et al*., 2011), which suggests that highland Mexican races may be the most threatened by climate change due to their strong local adaptation, and therefore merit special attention from a genetic resources conservation perspective, particularly because of the high genetic diversity among New World maize races (Vigouroux *et al*., 2008).

Vigouroux *et al*. (2011) made agronomic and genetic comparisons of 136 paired varieties of pearl millet in Niger, a very dry country in West Africa, from 79 different communities distributed throughout the country collected in 1976 and 2003. Their results show no evidence of genetic erosion between the two periods, but significant changes in flowering time (shorter), plant height (smaller) and spike size (smaller) among the sampled pearl millet populations, showed a correlation between time to flowering and annual precipitation. They were also able to show that these changes were linked to changes in the locus PHYC associated with flowering time. In the context of climate change, a shorter flowering cycle allows flowering and seed production under drier conditions.

Another crucial aspect regarding on-farm conservation is the impact of climate change on farmer seed systems (Bellon *et al*., 2011). As indicated above, farmer seed systems are the backbone of the socio-biological systems that underpin on-farm conservation of landraces. Although historically these systems have worked very well, climate change may disrupt their functioning, not only as providers of actual seed but also as providers of valuable information about seeds, the traits they contain and the adaptation they show. These systems may not be able to provide small-scale farmers with adapted local varieties in the face of climate change because they may be ‘too local’ relative to the spatial scope of environmental shifts expected with climate change; climate change may render local information and knowledge about the performance of varieties less useful because it makes past and current crop performance an unreliable indicator for future one, making farmers’ decisions more difficult and riskier. Climate change destroys valuable agricultural information, especially informal knowledge of particular climates and their interaction with crops that farmers have acquired through experience over a long period of time (Quiggin and Horowitz, 2003).

An evolutionary perspective of on-farm conservation actually coincides with current developments in the conservation of biodiversity. For example, Sgro *et al*. (2011) argue that evolution should be taken into consideration in the management and planning for biodiversity conservation, in order to develop resilient landscapes where evolutionary potential of species and populations can be maintained. They introduced the concept of evolutionary resilience, defined as the ability of populations to persist in their current state and to undergo evolutionary adaptation in response to changing environmental conditions. This approach places an explicit emphasis on maintaining genetic diversity and the processes that support ongoing evolutionary processes (notice the parallel with on-farm conservation). There starts to be a convergence in the thinking about the conservation of wild and domesticated biodiversity as processes that maintain evolution *in situ* and that are particularly relevant under climate change.

8.5 Responses to Climate Change – Supporting On-farm Conservation

Supporting on-farm conservation of landraces as a means for farmers and society to adapt to climate change will require several interventions. The status quo is not enough. From the outset there is a need for a global information system that monitors changes in adaptation and evolution processes in selected landscapes or across environmental gradients, and enables scientists and farmers to identify new genes and genotypes that can be used in different places as needed. Such a global information system will require the development of a new set of tools and methods to monitor evolution and adaptation (and not only genetic erosion). This is one means by which on-farm conservation can generate global option values. This system will be challenged by issues related to farmers’ rights, economic incentives and cross-border access to germplasm.

At the community and farmer level there will be a need to:

1

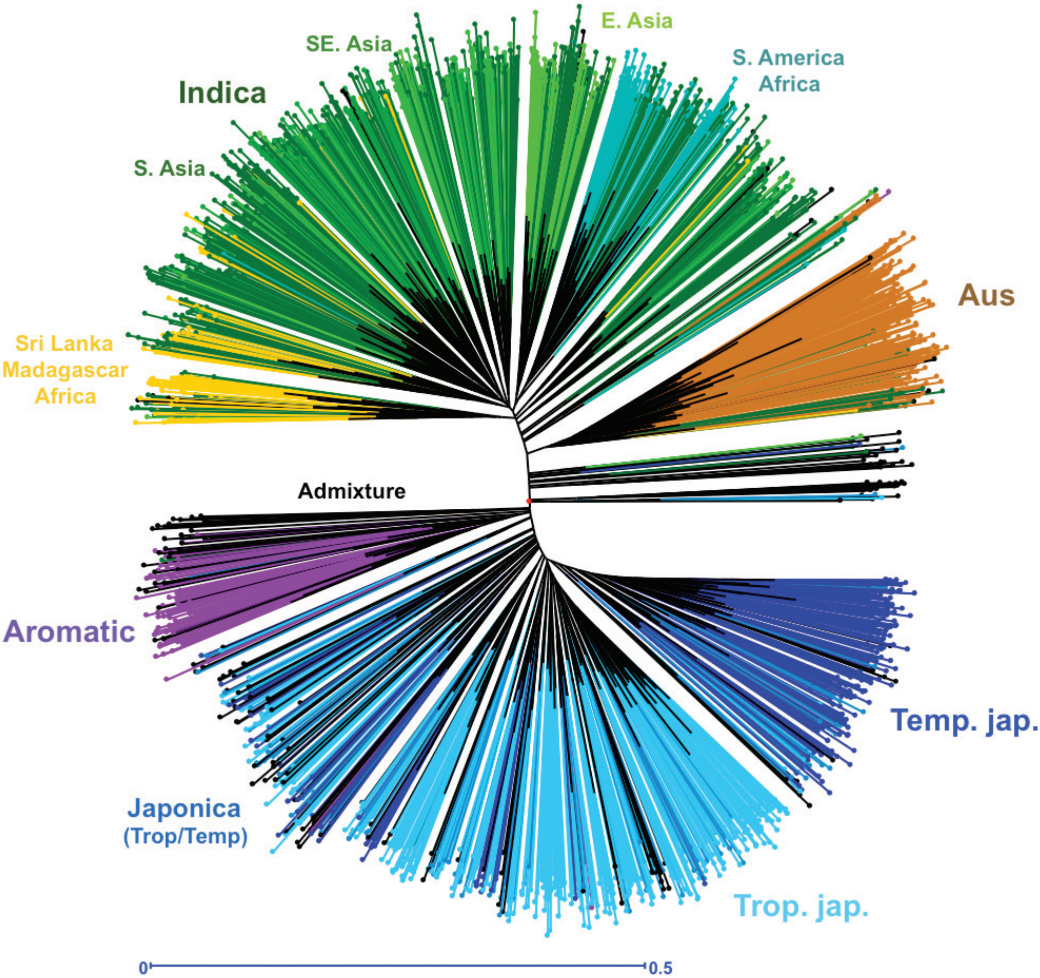

Plate 1. Population structure for *Oryza sativa* represented by a neighbour joining dendrogram showing the five variety groups (indica, aus, aromatic, tropical japonica and temperate japonica) and admixed types for 2252 rice accessions analysed using 45 SSR loci (built by IRRI's T.T. Chang, Genetic Resources Center, unpublished; based on Garris *et al.,* 2005).

2

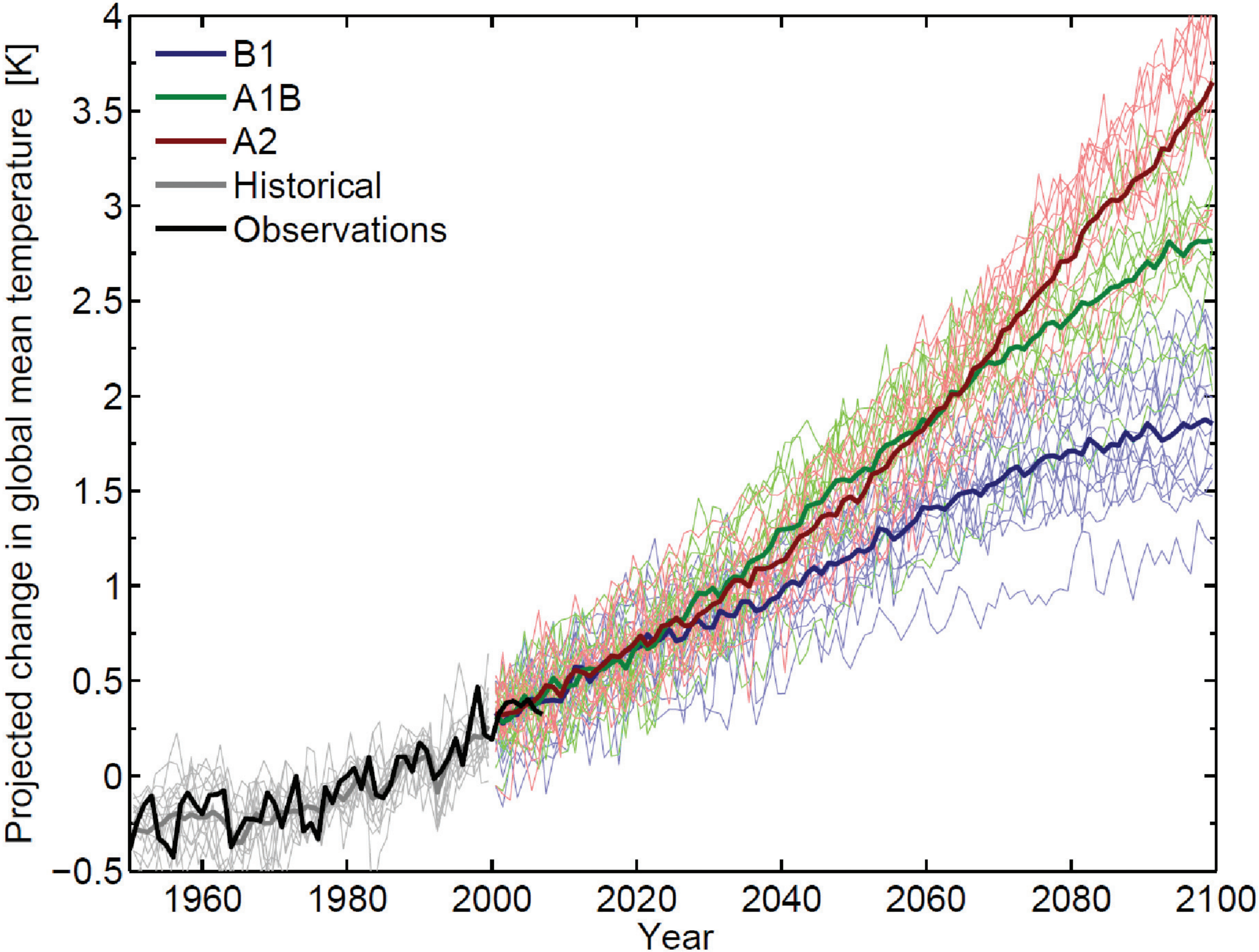

Plate 2. GCM projections of global mean temperature change for the A2, A1B and B1 scenarios from the 3rd Coupled Model Intercomparison Project (CMIP3) multi-model ensemble. Reproduced from Hawkins and Sutton (2009).

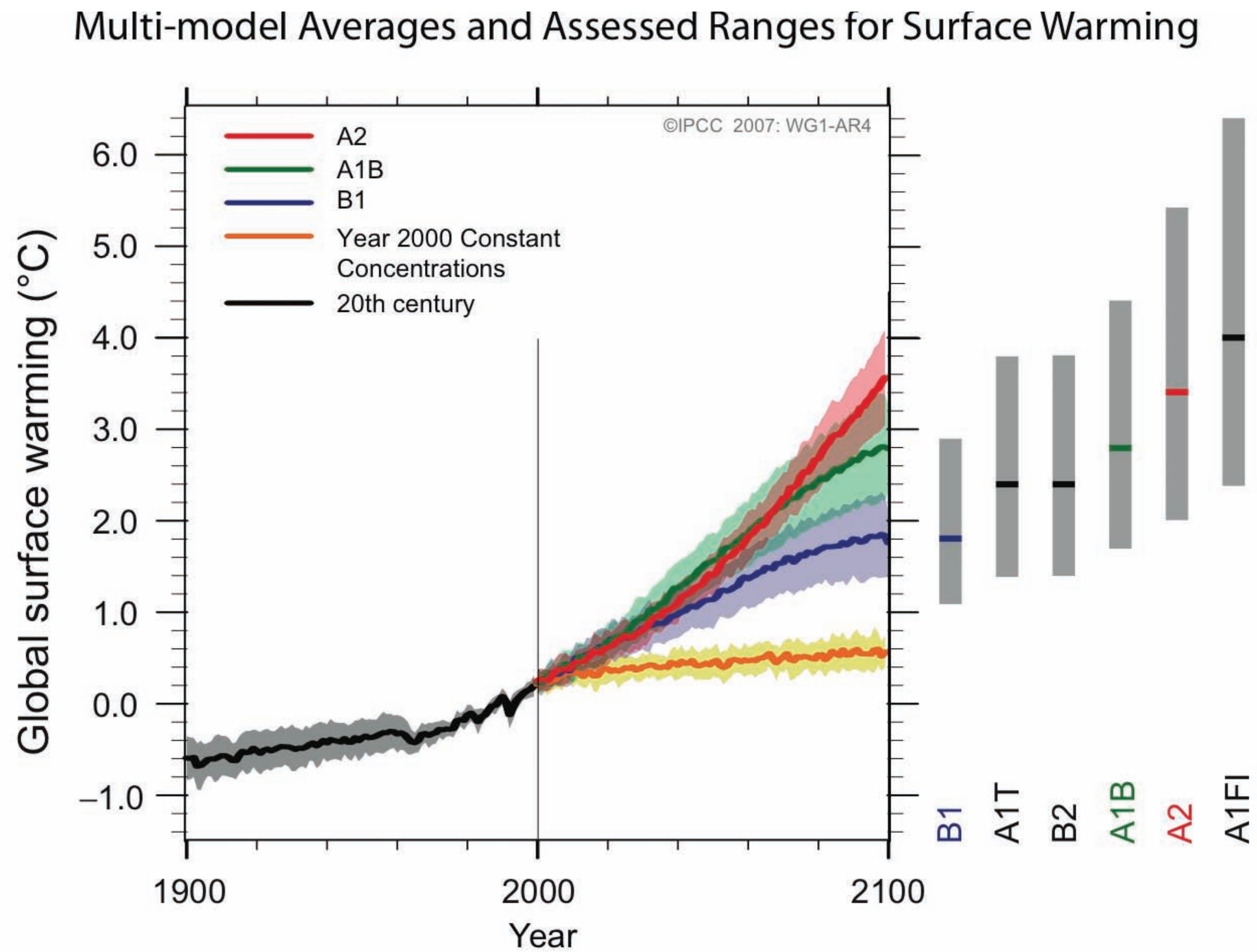

Plate 3. Projections of global mean temperature change for the A2, A1B and B1 scenarios from the CMIP3 multi-model ensemble (coloured curves) and uncertainty range for these and the A1FI, A1T and B2 scenarios from simple climate models (grey bars). Reproduced from IPCC (2007), copyright IPCC (2007).

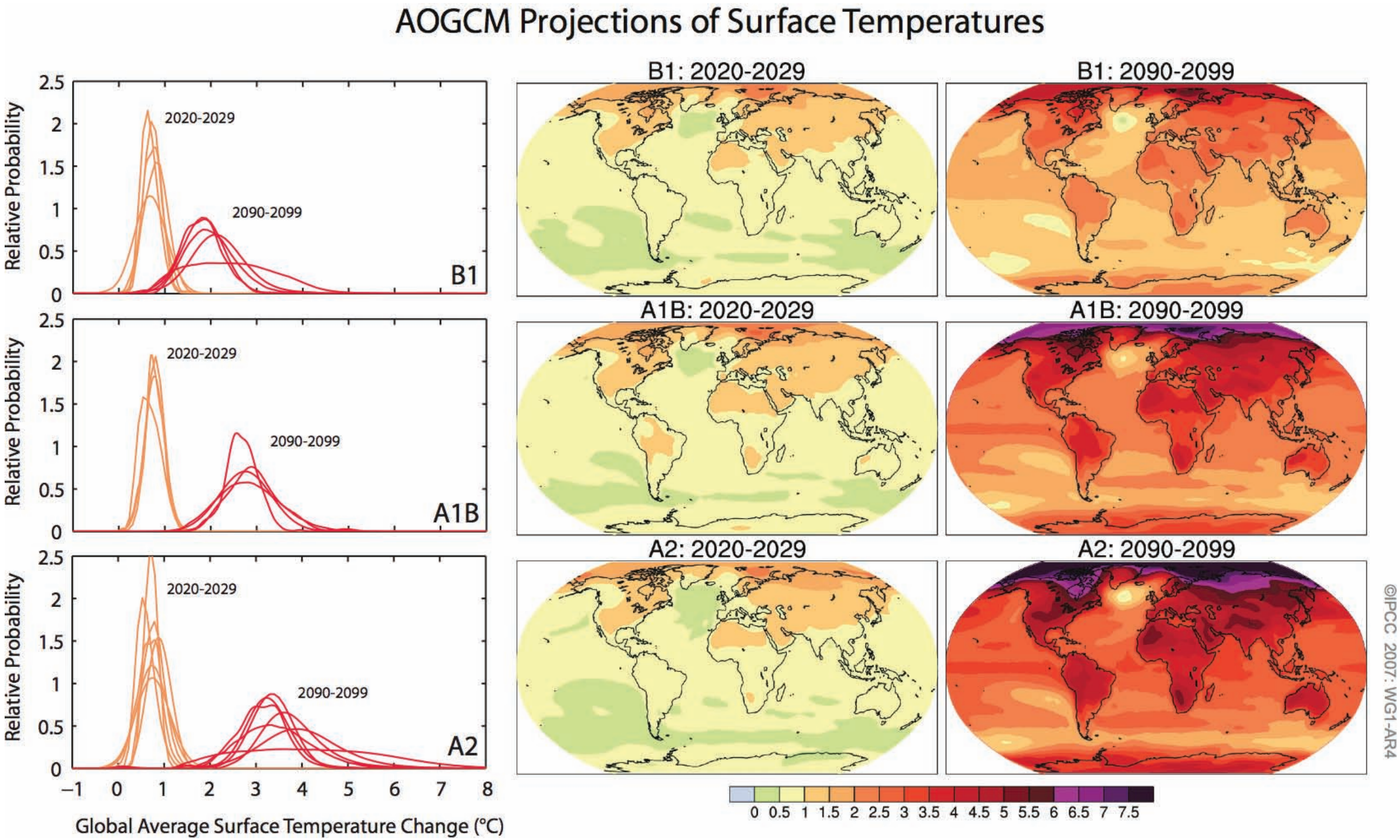

Plate 4. Annual mean temperature change projected by the CMIP3 multi-model ensemble for 2020–2029 and 2090–2099 relative to 1980–1999 under the A1B scenario; mean across all ensemble members.

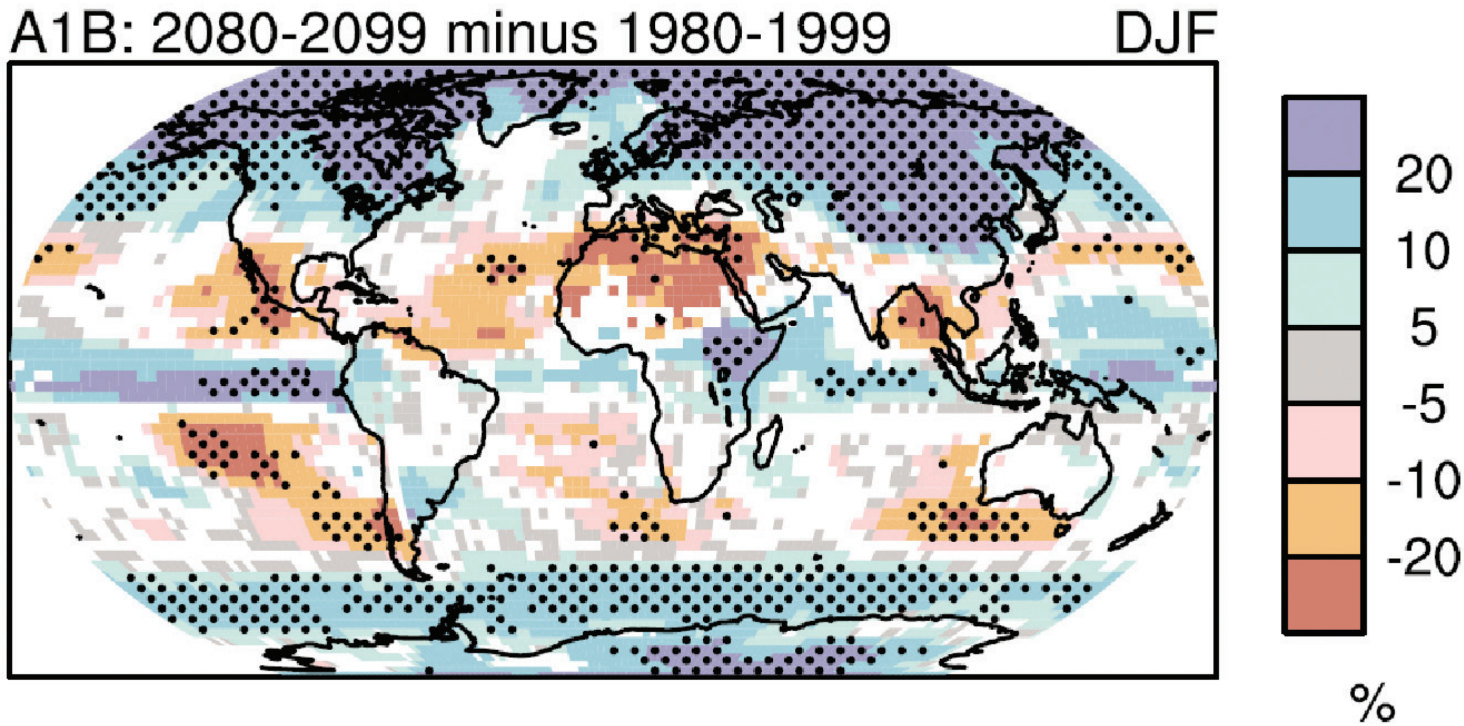

Plate 5. Mean percentage change in precipitation projected by the CMIP3 multi-model ensemble by 2080–2099 relative to 1980–1999 for the A1B scenario, for December–January–February. Colours are shown where 66% of the models agree on the sign of the change, black stipples where 90% of the models agree, as in standard IPCC AR4 method. Reproduced from Tebaldi *et al*. (2011).

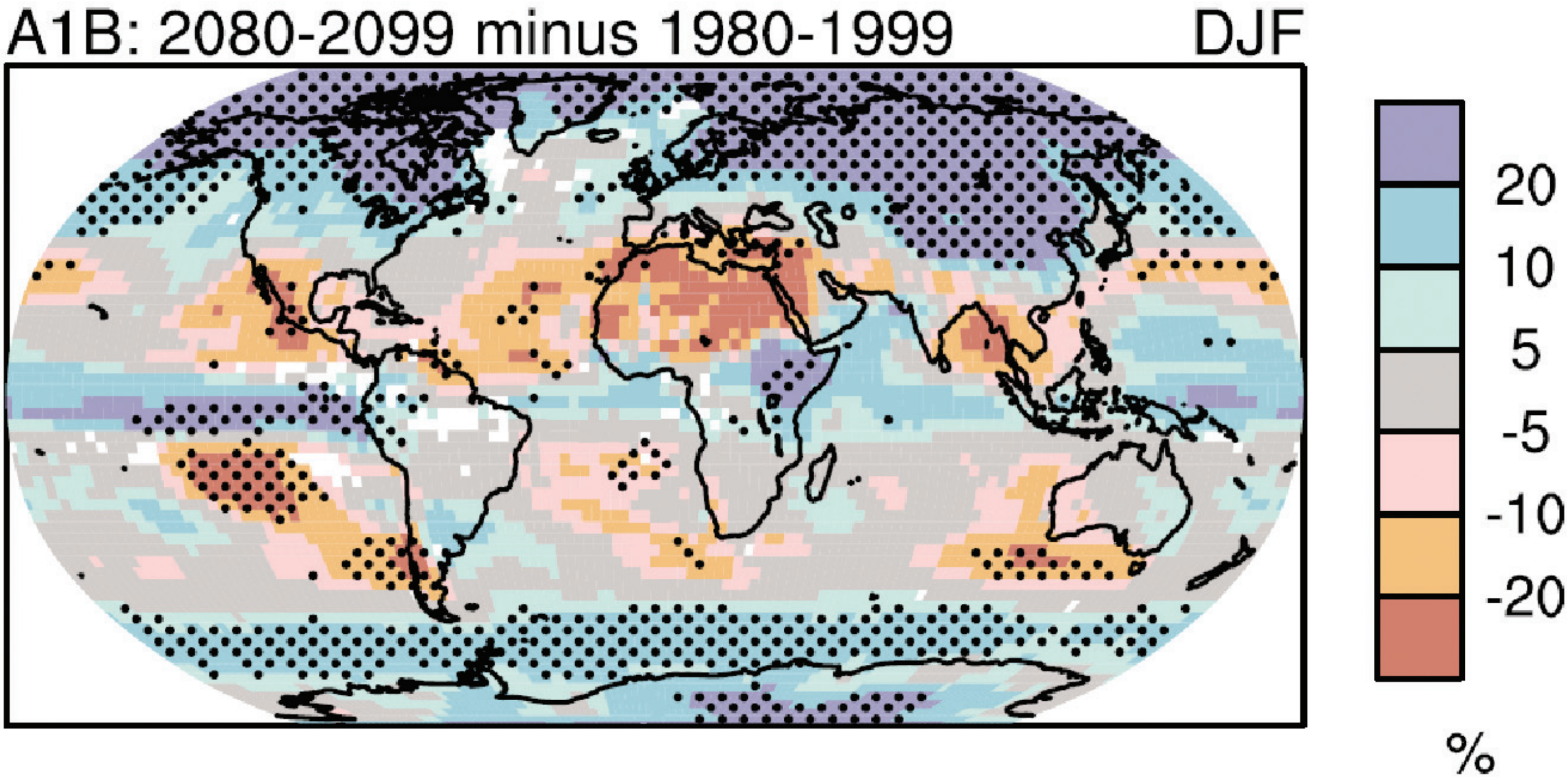

Plate 6. Mean percentage significant change in precipitation projected by the CMIP3 multi-model ensemble by 2080–2099 relative to 1980–1999 for the A1B scenario, for December–January–February. Colours within stipples indicate where less than 50% of models show significant change, white shows where more than 50% show significant change but less than 80% agree on sign of change, stipples show where more than 80% agree on sign of change. This allows areas of low signal to be distinguished from disagreements between models. Reproduced from Tebaldi *et al.* (2011).

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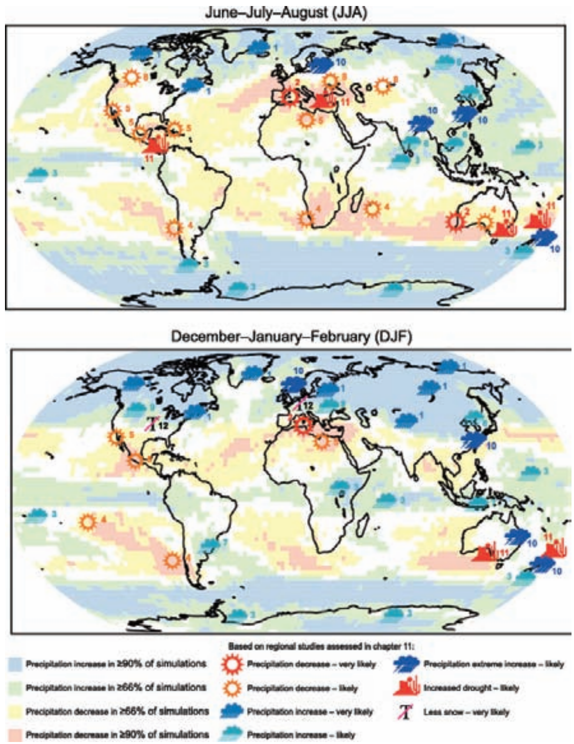

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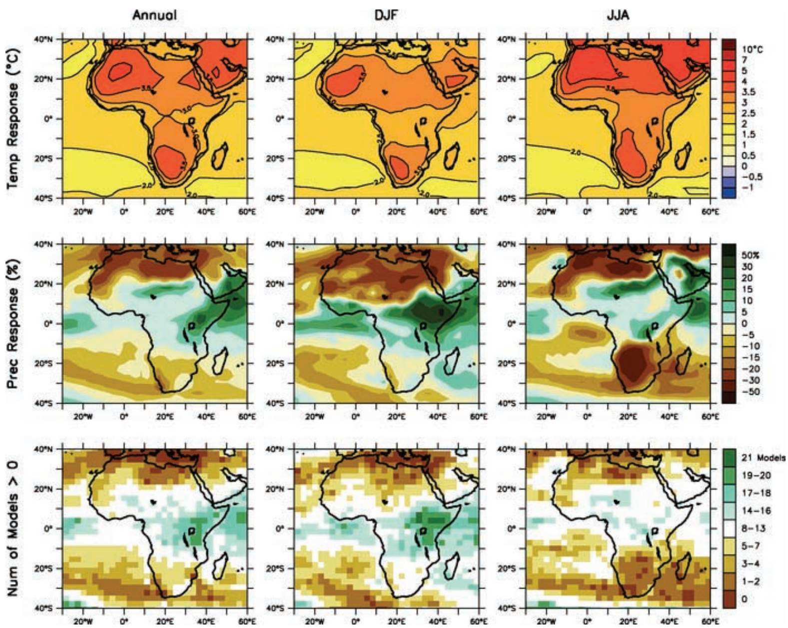

Plate 7. Changes in seasonal precipitation by 2080–2099 relative to 1980–1999, projected by the CMIP3 multi-model ensemble for the A1B scenario. Top: June–July–August; Bottom: December–January–February. Symbols indicate changes assessed as robust on the basis of inter-model agreement and physical understanding. Further details, including an explanation of the numbering associated with the symbols, are in the original publication. Reproduced from Christensen *et al.* (2007), copyright IPCC (2007).

Plate 8. Changes in precipitation projected for Africa by IPCC AR4 multi-model ensemble driven by the A1B scenario, by 2080–2099. Left column: annual mean. Centre column: December–January–February. Right column: June–July–August. Top row: multi-model mean percentage precipitation change. Bottom row: number of models projecting an increase in precipitation. Reproduced from Christensen *et al.* (2007), copyright IPCC (2007).

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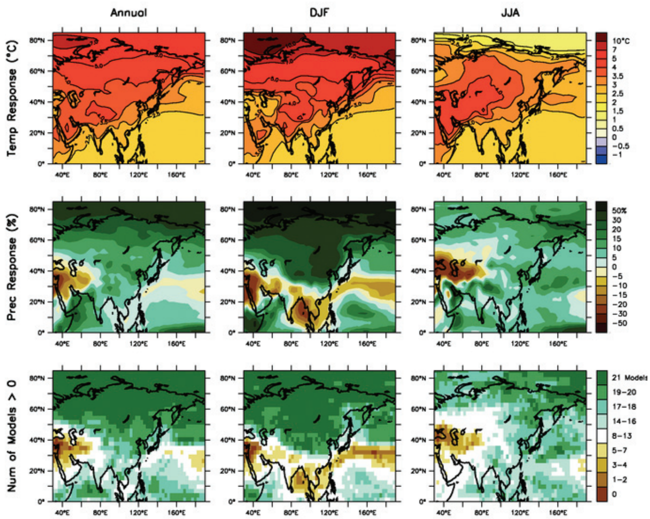

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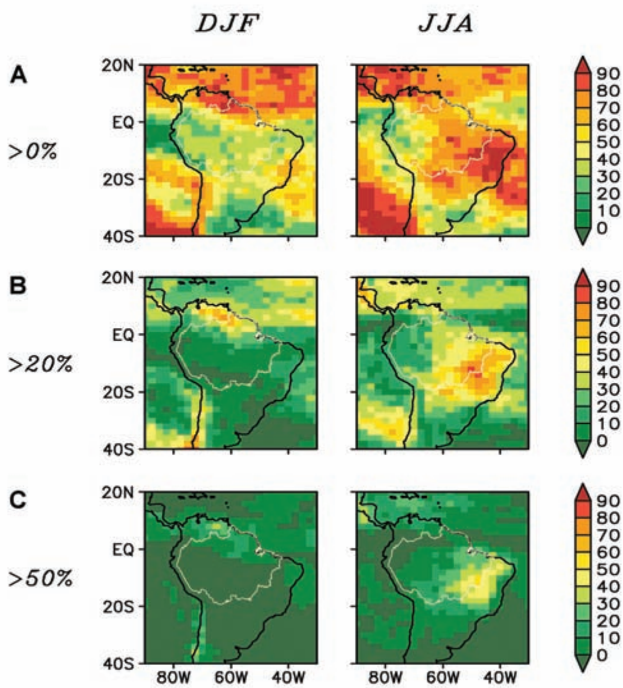

Plate 9. Changes in precipitation projected for Asia by IPCC AR4 multi-model ensemble driven by the A1B scenario, by 2080–2099. Left column: annual mean. Centre column: December–January–February. Right column: June–July–August. Top row: multi-model mean percentage precipitation change. Bottom row: number of models projecting an increase in precipitation. Reproduced from Christensen *et al*. (2007), copyright IPCC (2007).

Plate 10. Precipitation changes simulated by the IPCC AR4 multi-model ensemble driven by the A1B scenario by 2080–2099. Left column: December–January–February. Right column: June–July–August. Top row: percentage of models simulating any level of precipitation reduction. Middle row: percentage of models simulating at least a 20% precipitation reduction. Bottom row: percentage of models simulating at least a 50% precipitation reduction. Reproduced from Malhi *et al.* (2008).

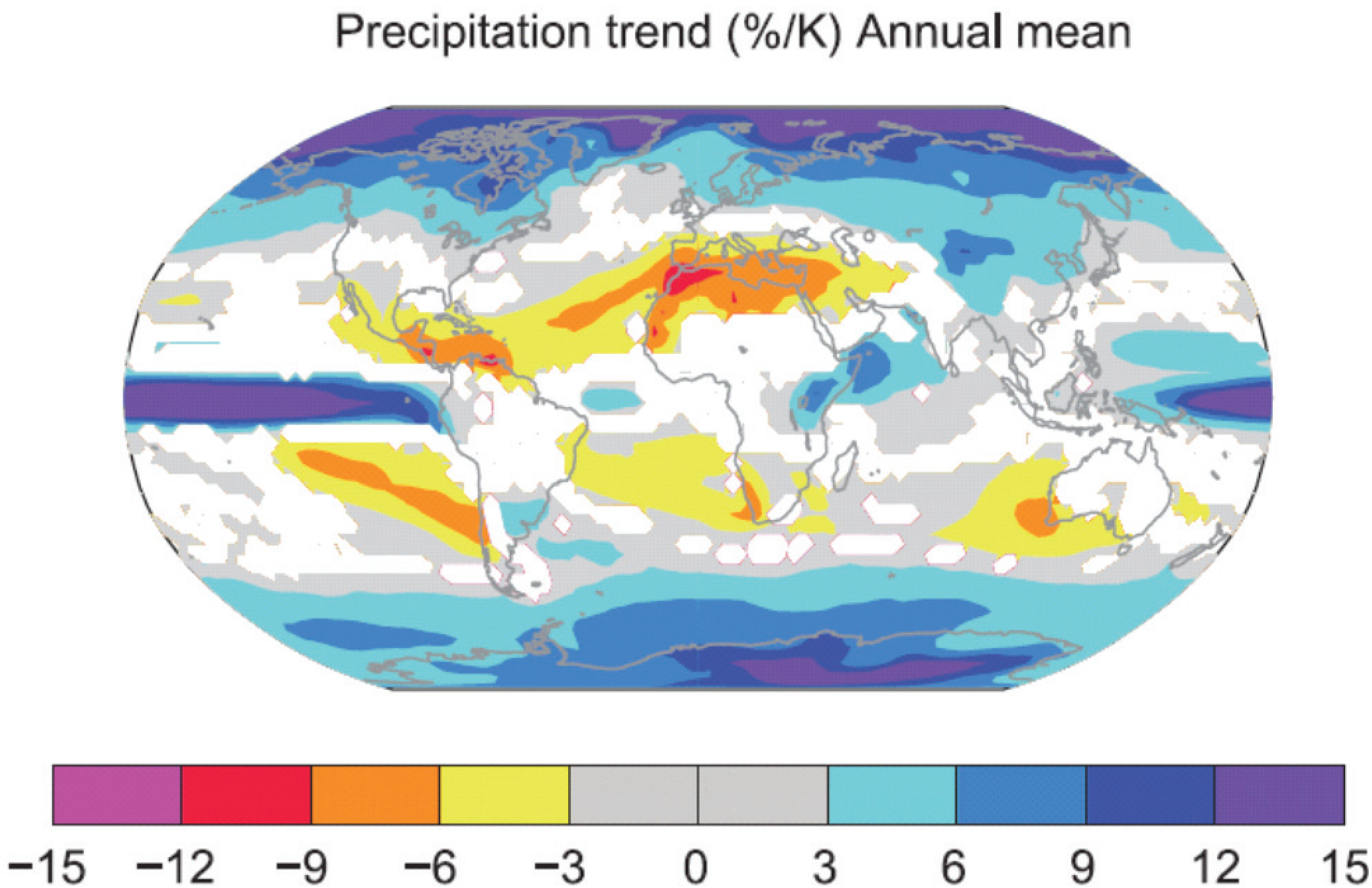

Plate 11. Percentage change in annual mean precipitation per K global warming; mean across CMIP3 multi-model ensemble projections for the A1B scenario. Reproduced from Knutti *et al.* (2010).

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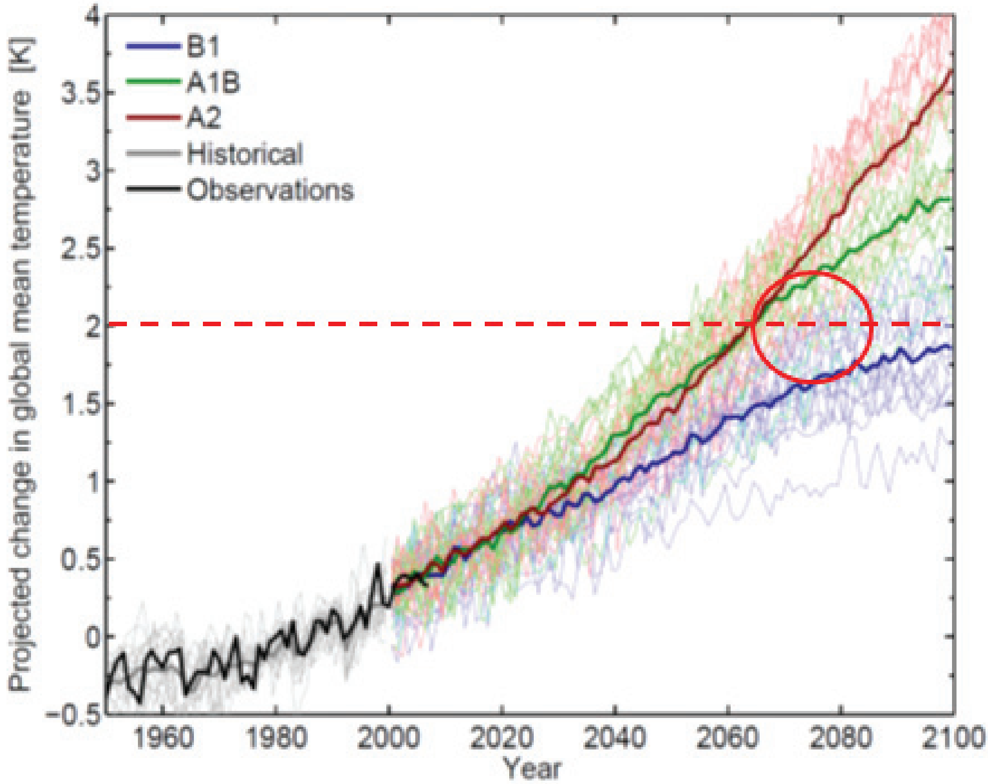

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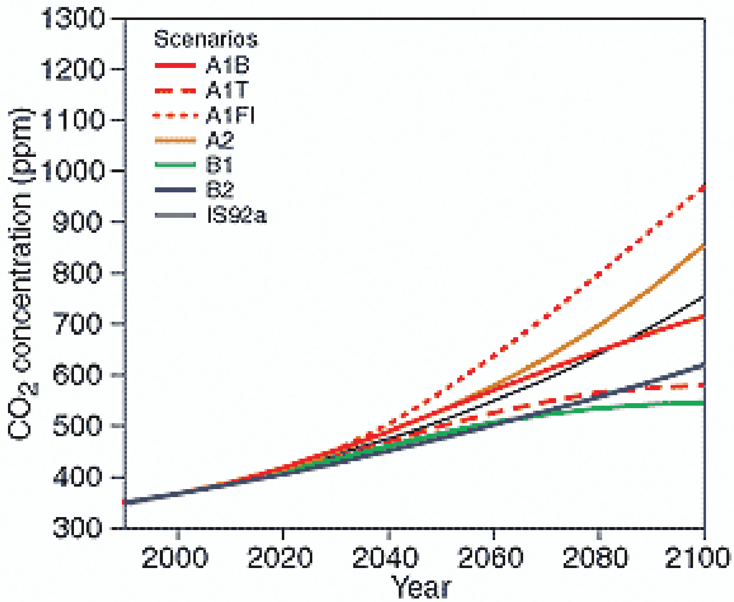

Plate 12. (a) Multi-model GCM projections of global mean temperature change relative to 1971–2000 for the A2, A1B and B1 scenarios, showing overlap of the ranges of the A2 and B1 projections at 2°C warming (red dashed line) in the 2070s (red circle). (b) CO_2 concentrations for all SRES marker scenarios, including the concentrations applied as input to the GCM used for the A2, A1B and B1 projections in (a). (a) Reproduced from Hawkins and Sutton, 2009. (b) Reproduced from IPCC (2001), copyright IPCC (2001).

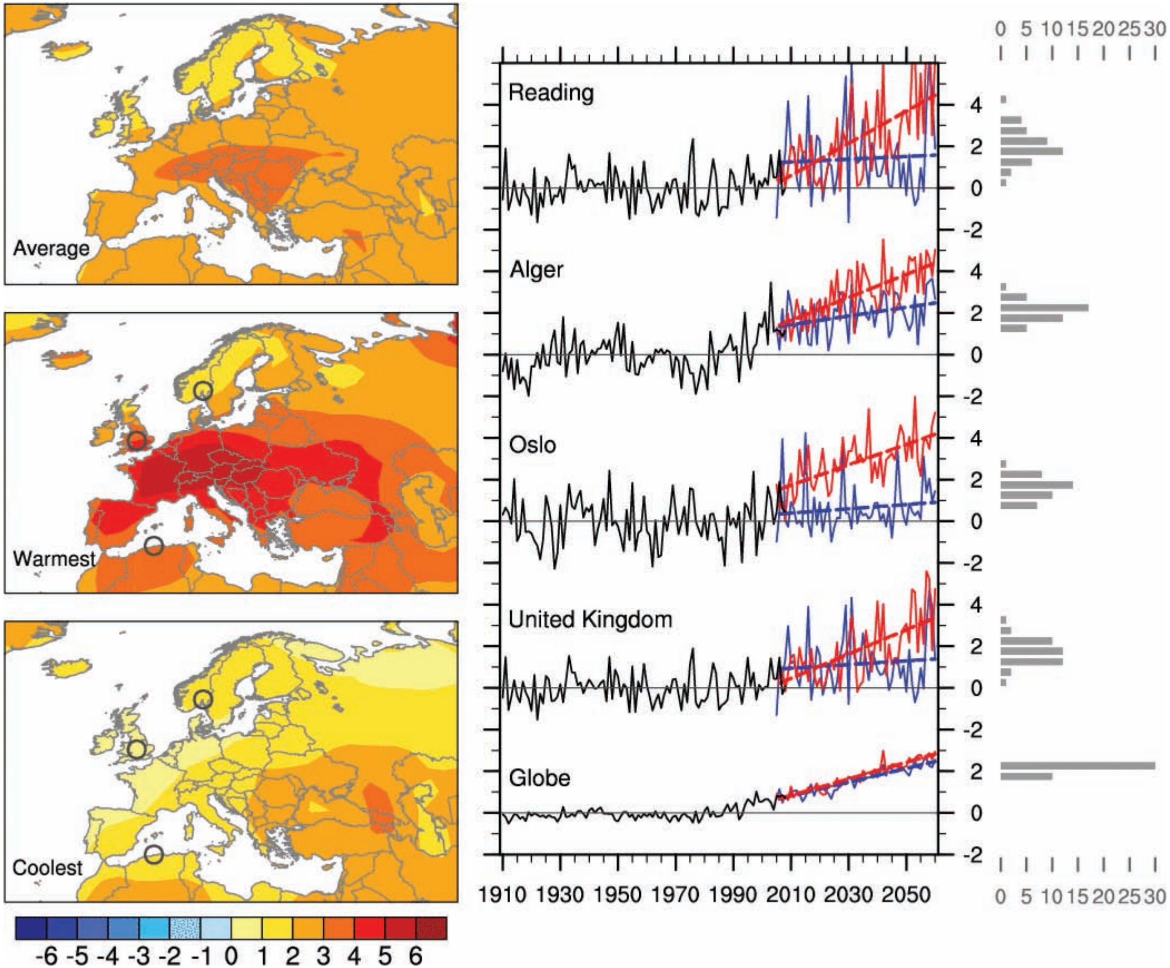

Plate 13. Change in June–July–August mean temperature projected for the A1B scenario by the CCSM3 GCM, with different projections starting from different initial conditions. The top map shows the average warming by 2060 across 40 simulations, the middle map shows the results from the simulation with the greatest warming over the UK, and the bottom shows the simulation with least UK warming. The time series on the right show observations (black) and the warmest (red) and coolest (blue) projections for each location or region, all under the same external forcing. Figure provided by C. Deser.

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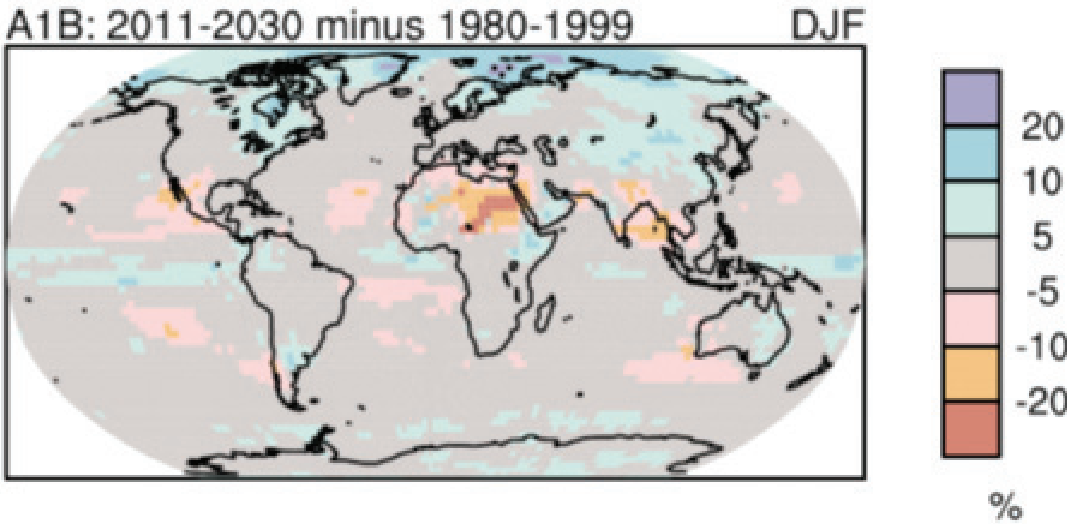

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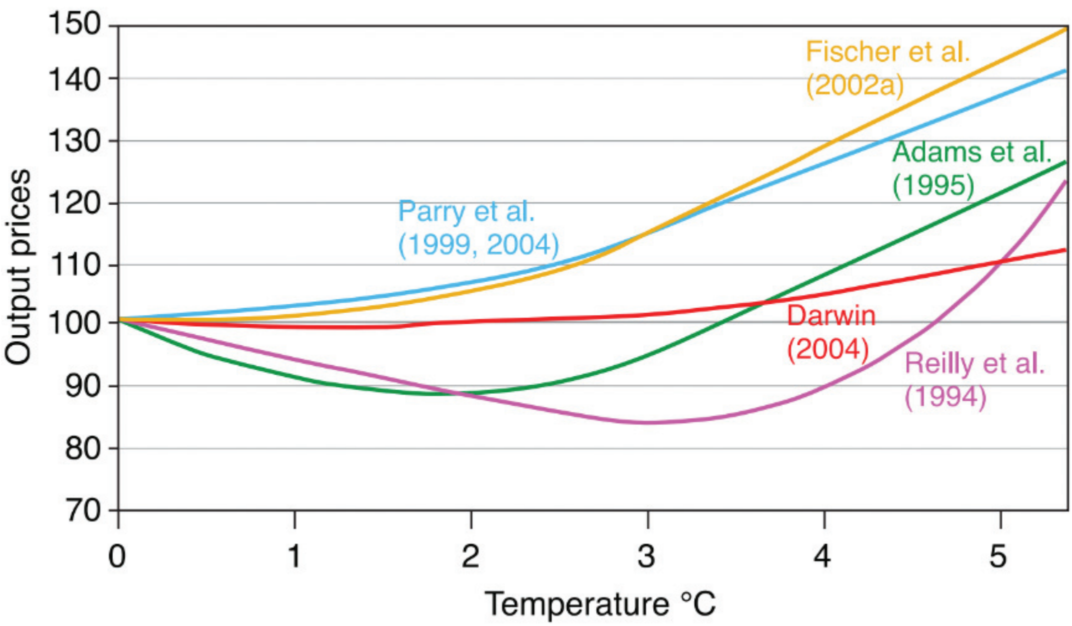

Plate 14. Projected changes in precipitation for December–January–February over 2011–2030 relative to 1980–1999, including consideration of signal-to-noise ratios (Tebaldi *et al.*, 2011).
Plate 15. Cereal prices (percentage of baseline) versus global mean temperature change for some modelling studies. Prices interpolated from point estimates of temperature effects (from Easterling and Aggarwal, 2007).

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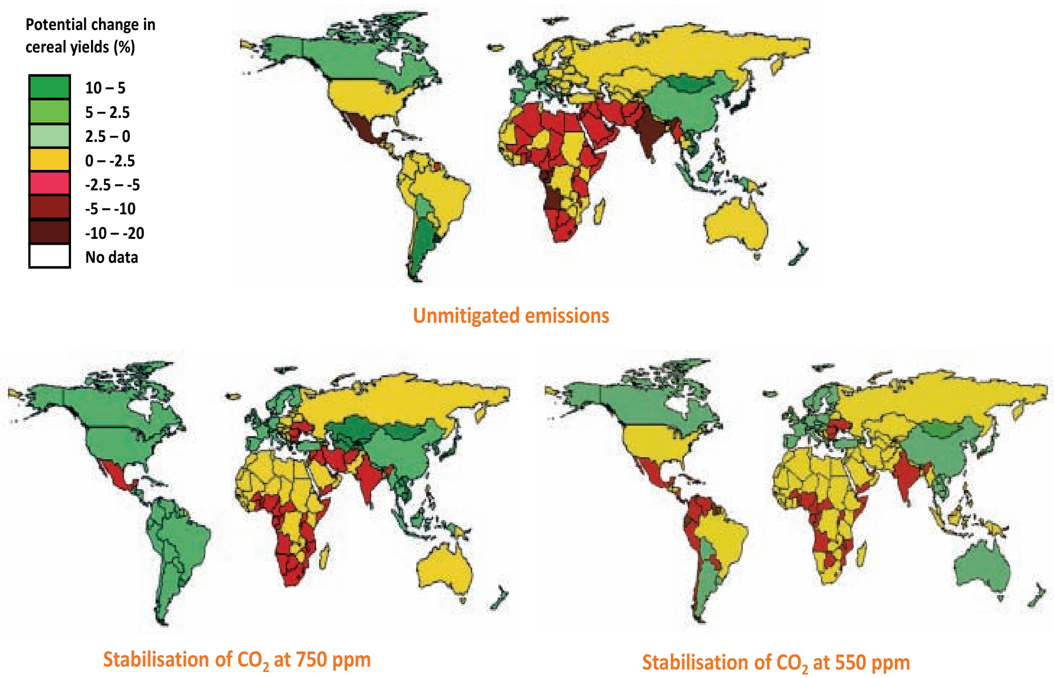

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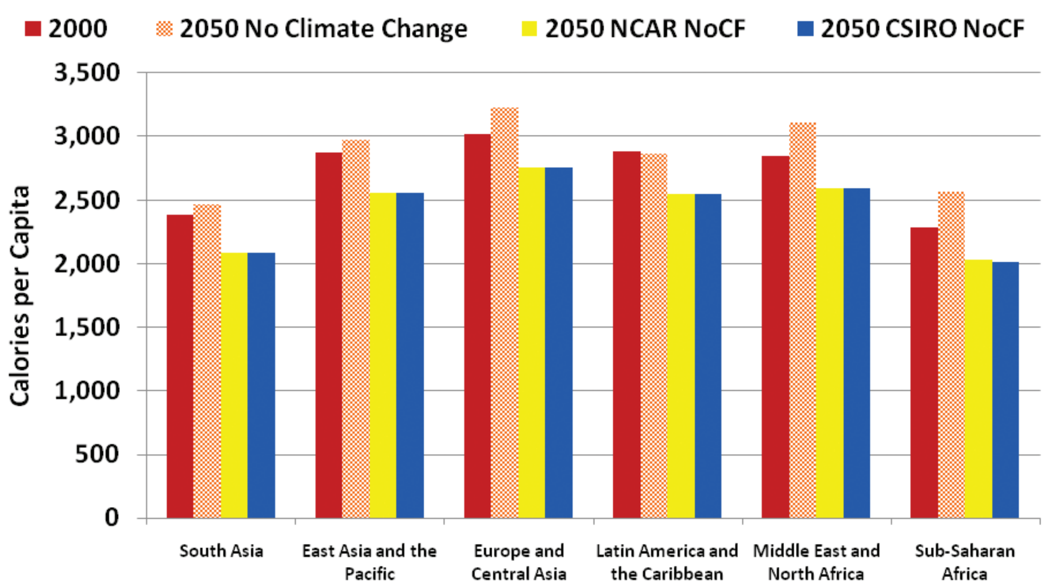

Plate 16. Changes in national cereal crop yields by the 2080s under three different emissions scenarios: unmitigated (IS92a: top map), S750 (bottom left map) and S550 (bottom right map) (from Arnell *et al.*, 2001).
Plate 17. Daily per capita calorie availability with and without climate change. No CF, no carbon fertilization (from Nelson *et al.*, 2009).

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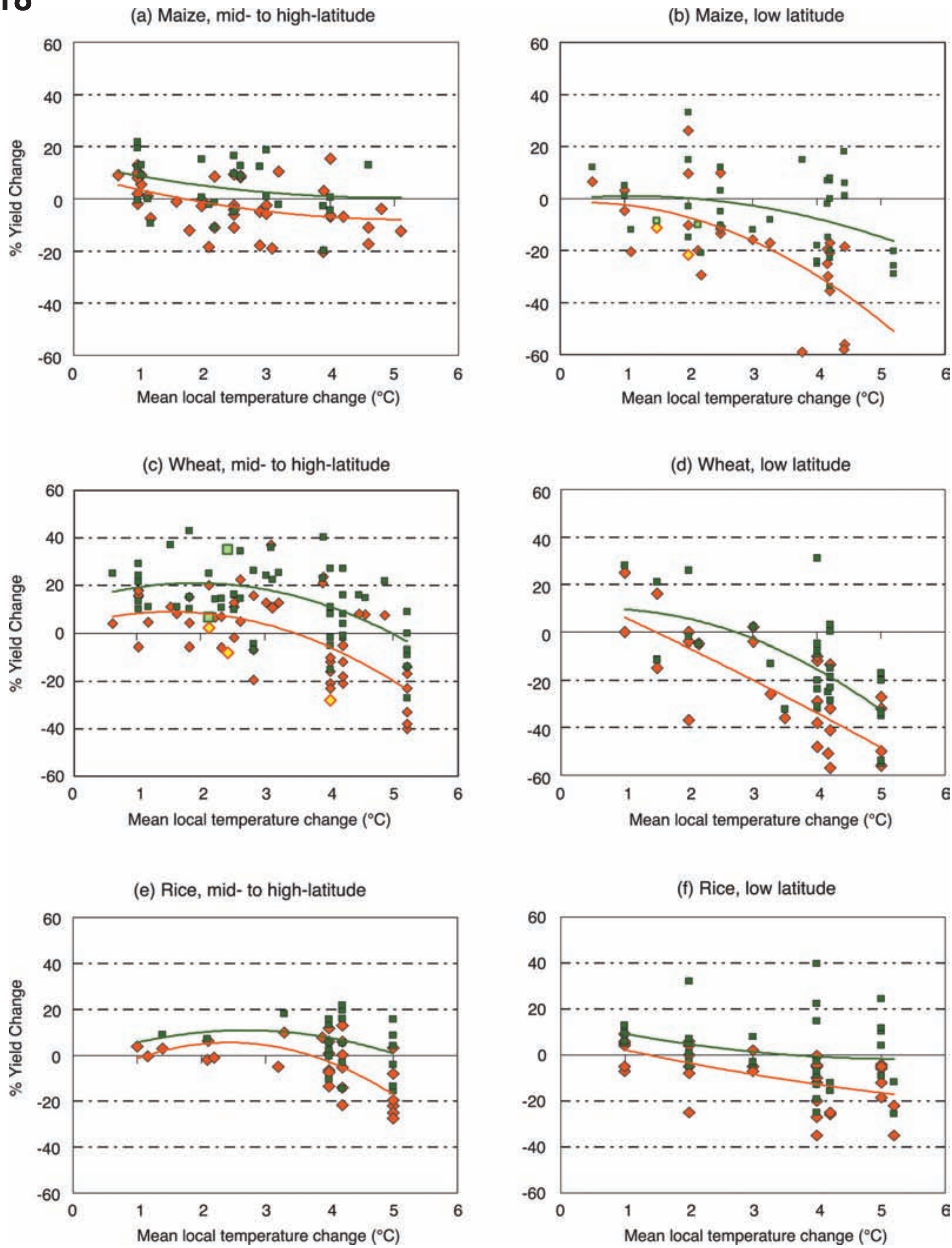

Plate 18. Sensitivity of cereal yield to climate change for maize (a,b), wheat (c,d) and rice (e,f), as derived from the results of 69 published studies at multiple simulation sites, against mean local temperature change used as a proxy to indicate magnitude of climate change in each study. Responses include cases without adaptation (red shapes) and with adaptation (dark green shapes). Adaptations+ represented in these studies include changes in planting, changes in cultivar, and shifts from rainfed to irrigated conditions. Lines are best-fit polynomials and are used here as a way to summarize results across studies rather than as a predictive tool. The studies span a range of precipitation changes and CO_2 concentrations, and vary in how they represent future changes in climate variability. For instance, lighter-coloured shapes in (b) and (c) represent responses of rainfed crops under climate scenarios with decreased precipitation. From Easterling *et al*. (2007).

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d

e

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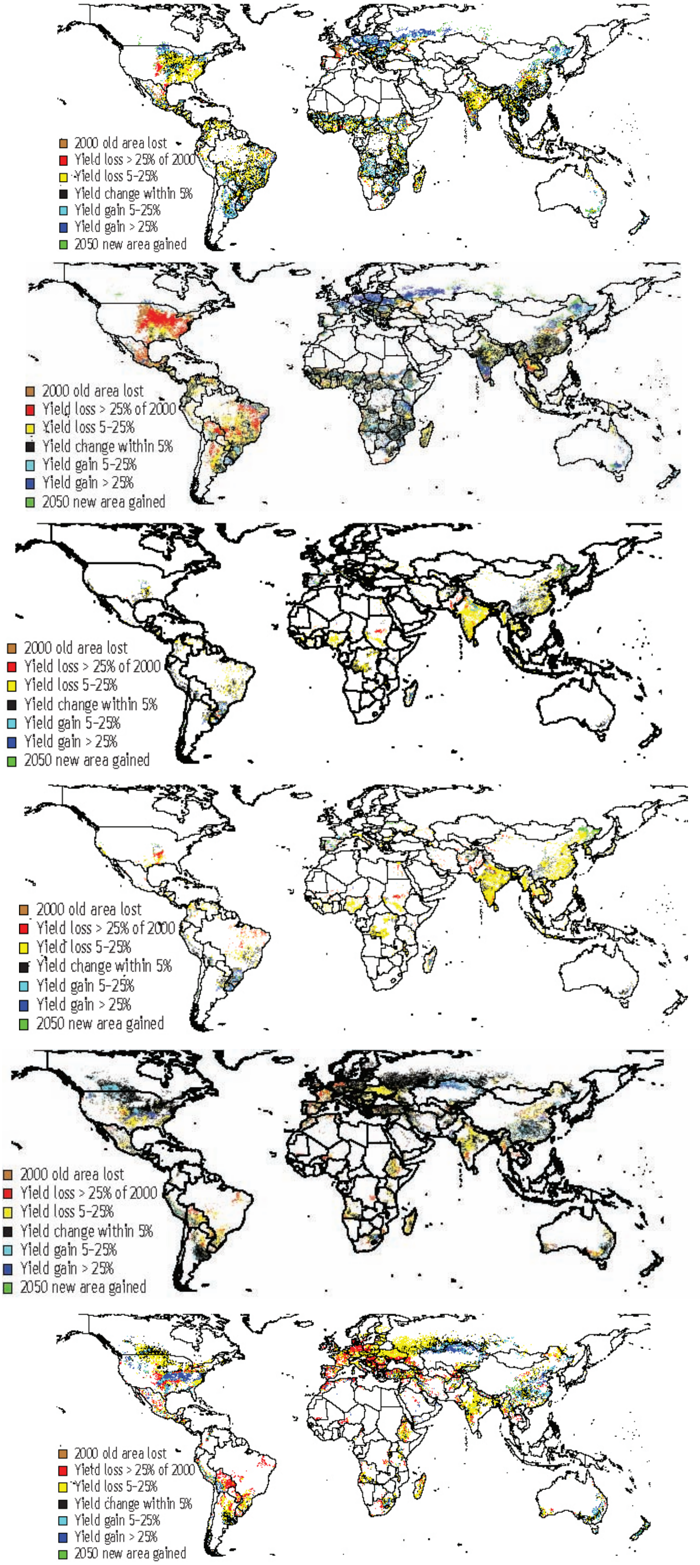

Plate 19. Modelled potential effect of climate change on yields of (a,b) rainfed maize, (c,d) irrigated rice and (e,f) rainfed wheat in a 2050 climate (from Nelson *et al.*, 2010, with permission from IFPRI).

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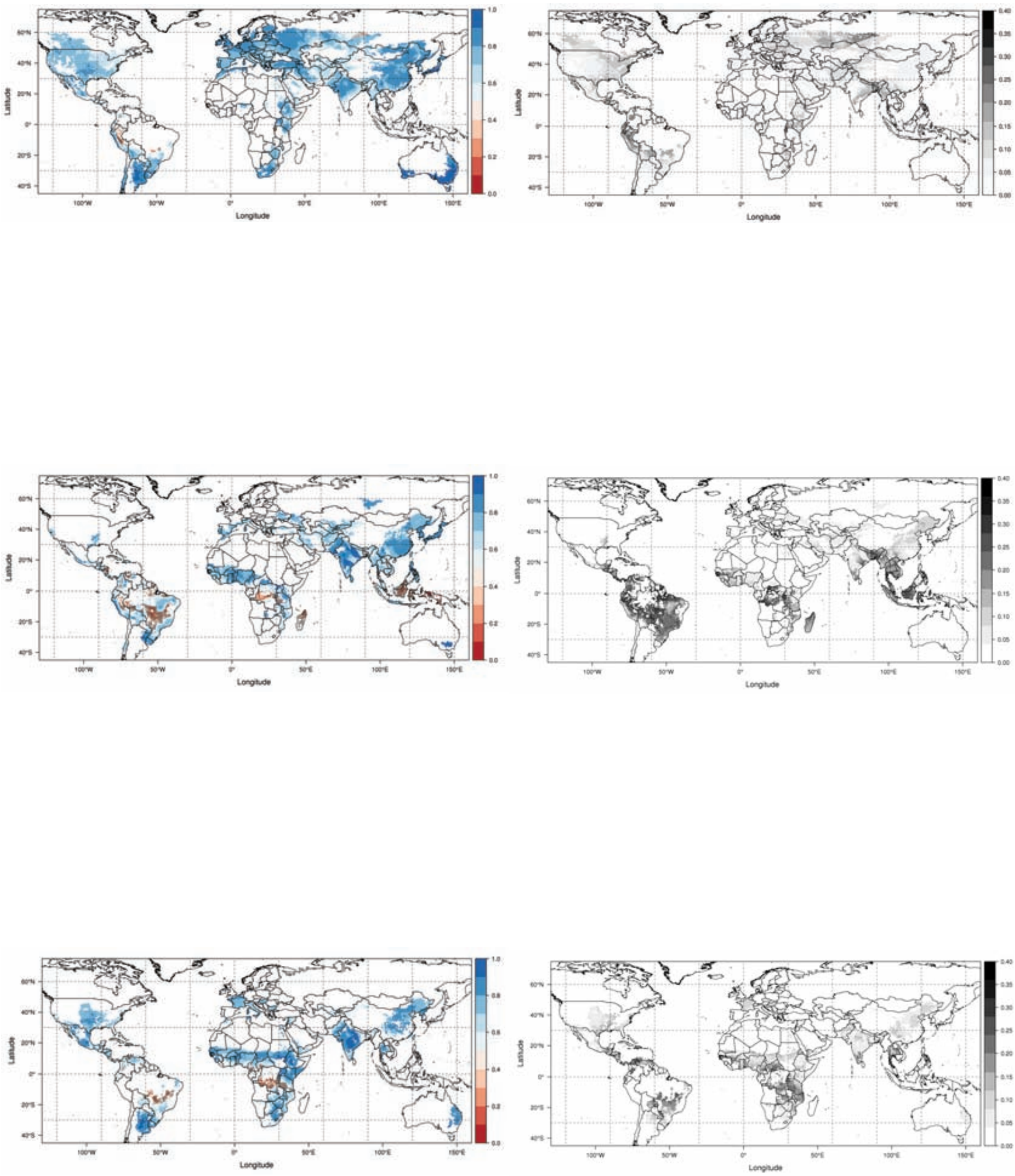

Plate 20. Self-overlap between historical (1966–2005) and future (1956–2095) climates as average (left) of ten individual GCMs for wheat (top), rice (middle) and sorghum (bottom). Uncertainties (right) are expressed as standard deviations of the ten GCMs. Hatched areas in the left panels indicate locations where self-overlap (as average of ten GCM) is below 50%, but where at least 75% of the novel climate exists in neighbouring areas (i.e. 250 km neighbourhood, country).

- Strengthen the capacity of farmers to store seeds of multiple varieties given that increases in extreme climatic events may increase the risk of field losses, reducing the capacity to save seed (as well as share it).
- Increase capacity to save seed for replanting from plants that survive under extreme conditions, and hence may have adaptive traits particularly by avoiding consumption or sale of seeds.
- Link farmers' seed systems to seed systems from areas that have the adapted types required under novel climatic conditions.

This will probably require the establishment of new relationships within farmer seed networks that go beyond their traditional spatial scopes so as to connect communities in current and future analogue climates. For example, in the case of maize in Mexico, this would entail farmers in the highland agroclimate environment linking with communities in the dry mid-altitude environment. In practice, broadening the geographical reach of farmers' seed networks could be achieved through: exchange visits; linking farmer groups in different locations; fostering the exchange of germplasm, knowledge and practices among them; and encouraging cross-community experimentation with local and introduced crop varieties.

Evolutionary plant breeding is beginning to be reconsidered as an option to deal with current and predicted threats to agriculture, even in countries with highly industrialized agriculture (Goldringer *et al*., 2001; Döring *et al*., 2011). Evolutionary plant breeding involves subjecting crop populations with high levels of genetic diversity to the forces of natural selection, leading to evolving populations that are in constant change responding to the strength and direction of environmental variables (Döring *et al*., 2011; see Ceccarelli, Chapter 13, this volume). It is not a new idea but goes back more than half a century (Suneson, 1956), with well documented research supporting it (Allard, 1988). The process has parallels with the management of landraces by farmers in developing countries (and hence is relevant to our discussion of on-farm conservation), but evolutionary plant breeding is usually based on purposefully created crop populations either through crosses or varietal mixtures from the outset. Although there may be trade-offs between overall performance, diversity and stability in an evolving population, a crucial advantage is that, under large environmental variance, evolving populations will maintain diversity, providing a buffer against environmental fluctuations through compensatory effects (Döring *et al*., 2011). This approach has limitations, however, particularly related to varietal and seed legislation and incentives to make it attractive to the private sector. For our purposes it illustrates and stresses again the importance of genetic diversity and evolution to cope with unpredictable change in agricultural systems, and hence the link between climate change and on-farm conservation. One can imagine some type of strategic evolutionary landrace breeding by which a diversity of landrace populations are purposefully located under different environments (targeting analogue climates) and are allowed to evolve, using the concepts presented by Döring *et al*., (2011), as well as replicating the experimental garden approach used by Mercer and Perales (2010) in a wider and strategic manner. This strategy may need an outside intervention because farmers themselves may not wish to apply it because of the risks involved. A similar approach has already being pioneered by French scientists for research purposes, indicating its potential viability (Goldringer *et al*., 2001, 2006).

Climate change may also have indirect effects on on-farm conservation, by prompting policies to support adaptation measures that have implications for crop diversity and on the incentives for on-farm conservation. For example, to manage climate risk, different forms of financial risk transfer, and specifically index-based insurance, have often been proposed and implemented to reduce income instability of smallholder farmers (Hansen *et al*., 2007). The need for risk management should become more acute as climate variability increases (Hansen *et* *al*., 2012). Improved access to financial risk management is, however, expected to lead to a reduced role for crop diversity as a natural insurance against risk (Baumgärtner and Quaas, 2009), reducing the incentives that farmers have to maintain crop diversity and thus to engage in on-farm conservation. For farmers growing crops in their centres of diversity, badly designed, over-subsidized insurance policies could therefore have a negative effect not only on farmers' welfare by allowing them to take more risk that would make sense economically (this will be true also for non centres of crop diversity), but also on public benefits such as the evolutionary services derived from on-farm conservation. It is worth noting that there is already some anecdotal evidence of this type of effect (though in a developed country and not a centre of diversity) where a representative of a private seed company commented, in the context of the 2012 drought in the USA, that the market demand for drought tolerance traits was fairly low, possibly due to the effect of crop insurance (Keim, 2012).

A key aspect in tackling climate change is global interdependence among nations with respect to plant genetic resources. This interdependence has always existed but it will be even more evident with climate change. For example, Burke *et al*. (2009) have studied the distribution of maize in current and future climates (in 2050) in sub-Saharan Africa, and included Mexico as a centre of diversity for this crop. The results show three types of situations:

1. Countries with a low overlap between current and future climates, but with many similar climates in other countries, hence the former may obtain genetic resources from the latter.
2. Countries with low overlap between current and future climates, but with few similar future climates in other countries, which puts them in a very difficult situation and a high vulnerability condition.
3. Countries where current climates are similar to those in other countries and therefore future climates are a source of crop varieties.

In this respect, the role of Mexico should be noted because its current climates are analogous to many future climates in Africa, thus underlining the global and future value of centres of crop diversity for climate change adaptation. Although this interdependence is increasingly being recognized, there are also increasing restrictions on farmer and breeder access to seeds and germplasm, locally and globally. Local constraints on access reflects national seed policies that favour the recognition of only scientifically bred varieties that are distinct, uniform and stable, discouraging the use of more heterogeneous, variable landraces. Global constraints on access result from asserting the sovereignty of countries over the plant genetic resources found within their national boundaries, coupled with the belief that there are major monetary benefits to be gained by restricting the access of other countries to these resources. Unfortunately, this largely mistaken perception has contributed to restrictions in the global flow of plant genetic resources (Falcon and Fowler, 2002). The problem has been identified but is only partially addressed for some crops by the International Treaty for Plant Genetic Resources for Food and Agriculture (see Moore and Hawtin, Chapter 6, this volume). This is a crucial area to address for the value of on-farm conservation to respond to climate change to be realized.

8.6 Conclusions

The impact of climate change on the viability of on-farm conservation of crops in their centres of origin and/or diversity and the potential contribution of on-farm conservation to climate adaptation strategies are complex. These impacts will vary by crop, and the environments and conditions present in its centre of diversity. Climate change can affect the viability of on-farm conservation of landraces by reducing the range of adaptation of a crop – changing the environmental conditions so much that growing a crop in its centre of diversity becomes non-viable – leading to its 'extinction' in particular regions or agroecosystems. At the same time, on-farm conservation can remain viable, depending on the sensitivity of landraces to climate variability and their capacity to evolve and adapt to these changes. The capacities depend not only on the genetic and biological characteristics of the crop, but also on the management, preferences and incentives of farmers that grow them. Depending on the evolutionary capacity of landraces, on-farm conservation can provide options to farmers and society to adapt to climate change. Although this still requires further analysis and action, recognizing this need and potential is fundamental to advance further.

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