ISSN 2521-7259

Food and Agriculture
Organization of the
United Nations

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The impact of climate variability and extremes on agriculture and food security

An analysis of the evidence and case studies

Background paper for *The State of Food Security and Nutrition in the World 2018*

FAO AGRICULTURAL DEVELOPMENT ECONOMICS TECHNICAL STUDY

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The impact of climate variability and extremes on agriculture and food security

An analysis of the evidence and case studies

Background paper for *The State of Food Security and Nutrition in the World 2018*

By

Cindy Holleman
Senior Economist, Agrifood Economics Division, FAO

Felix Rembold
Scientific Officer, Directorate D - Sustainable Resources, Joint Research Centre, European Commission

Olivier Crespo
Research Officer, Climate Systems Analysis Group, Department of Environmental and Geographical Science, University of Cape Town

Valentina Conti
Economist, Agrifood Economics Division, FAO

Food and Agriculture Organization of the United Nations
Rome, 2020

Required citation:

Holleman, C., Rembold, F., Crespo, O. & Conti, V. 2020. *The impact of climate variability and extremes on agriculture and food security – An analysis of the evidence and case studies. Background paper for The State of Food Security and Nutrition in the World 2018.* FAO Agricultural Development Economics Technical Study No. 4. Rome, FAO. https://doi.org/10.4060/cb2415en

ISSN 2521-7240 [Print]

ISSN 2521-7259 [Online]

ISBN ISBN 978-92-5-133718-9

Cover photo: ©FAO/Fahad Kaizer

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Preface

There is unequivocal evidence of global climate change in the form of increasing air and sea surface temperatures, receding glaciers, increases in the number of extreme climate events, and changes in sea levels. The accelerated warming of the planet has and continues to lead to modification of ecosystem processes, increasing climate variability and the occurrence of extreme climate-related events across the globe, including extreme temperatures (cold and hot spells) and rainfall (floods and droughts).

At the same time, there is very strong evidence that increasing climate variability and extremes are already negatively impacting on agriculture and food security and will make the challenge of ending hunger and malnutrition even more difficult. *The State of Food Security and Nutrition in the World 2017* raised alarm bells as estimates of world hunger reversed course and began to increase in 2015 for the first time in more than 15 years. This reversal in the downward trend is significant, as it followed a period of significant achievement in reducing global hunger.

The rise in hunger was attributed to a number of factors, but there were indications that one of the drivers behind this increase could be related to climate shocks and stressors. New information from country Food Balance Sheets pointed to reductions in food availability and food price increases in regions affected by the recent 2015–2016 El Niño climate-related phenomena. The El Niño event resulted in large climatic deviations and anomalies as compared to historical norms and was a large climatic driver experienced differently and more intensely in various parts of the world. Drought conditions predominated across much of the globe, aggravated further by the El Niño.

The increases in world hunger, occurring consecutively for the last three years after more than two decades of decline, brought increased urgency to the question on the role of climate variability and extremes in this observed reversal of world hunger. This prompted FAO, IFAD, UNICEF, WFP and WHO to focus the thematic part of *The State of Food Security and Nutrition in the World 2018* on the impact of recent climate variability and extremes on agriculture and food security. The present study was developed as a background study for this report. The study provides an in-depth analysis of recent changes in climate over agricultural areas around the world. Using this climate analysis, it then explores empirically the link between recent occurrences in climate variability and extremes and the observed uptick in world hunger. The study aims to provide new evidence to enhance the understanding of the role of recent changes in climate impacts on agriculture, food access and food security, with recommendations for policy and programming.

Acknowledgements

This technical study was prepared to provide background analysis on the nexus between climate variability and extremes and food security, in support of the thematic part of *The State of Food Security and Nutrition in the World 2018* – a joint publication of the Food and Agriculture Organization of the United Nations (FAO), the International Fund for Agricultural Development (IFAD), the United Nations Children's Fund (UNICEF), the World Food Programme (WFP) and the World Health Organization (WHO). As such, most of the substance and all of the key messages of the present study coincide with those of the flagship publication. This study also provides additional evidence and analysis, including more in-depth analyses to show the patterns of climate hazards in different world regions and countries. It presents case studies and other evidence of how different types of climate extremes impact on agriculture and food security. The authors have compiled and integrated a broad range of input from numerous contributors, as well as a wealth of information obtained from the literature, cross-country assessments, country case studies, and original narratives on the issues covered in the study.

This study was prepared by Cindy Holleman and Valentina Conti (FAO); Felix Rembold, Michele Meroni, Andrea Toreti, Matteo Zampieri and Frank Dentener (European Commission Joint Research Centre [EC-JRC]); and Olivier Crespo, Bruce Hewitson, Christopher Jack, Pierre Kloppers and Mark Tadross (University of Cape Town [UCT]). Important background material and maps were prepared by Oscar Rojas (FAO) for the case study on the Central American Dry Corridor. Important conflict and food crisis data input was provided by Aurelien Mellin (FAO); and climate data input from Khadra Ghedi Alasow, Luleka Dlamini, Fatima Mohamed, Koketso Molepo and Tichaona Mukunga (UCT). The authors further acknowledge input from Giovanni Carrasco Azzini (FAO).

The authors acknowledge all technical input and comments received for the version of the analysis used in the thematic part of The State of Food Security and Nutrition in the World 2018, including those of Kostas Stamoulis, Marco V. Sánchez and *The State of Food Security and Nutrition in the World* 2018 Writing Team.

The authors thank Andrew Park for copy-editing and Daniela Verona for the design and publishing coordination.

Acronyms

AfDB	African Development Bank
ASAP	Anomaly Hotspots of Agriculture Production
ASIS	Agricultural Stress Index System (FAO)
CH	*Cadre Harmonisé* (harmonized framework)
CHIRPS	Climate Hazards Group Infrared Precipitation with Stations
CSAG	Climate System Analysis Group, University of Cape Town
CSI	Combined Stress Index
DES	Dietary energy supply
DRRM	Disaster risk reduction and management
EC-JRC	European Commission Joint Research Centre
ECMWF	European Centre for Medium-Range Weather Forecasts
EM-DAT	Emergency Events Database
ENSO	El Niño–Southern Oscillation
FAO	Food and Agriculture Organization of the United Nations
FEWS NET	Famine Early Warning System Network
FSIN	Food Security Information Network
FSNAU	Food Security and Nutrition Assessment Unit
GIEWS	Global Information and Early Warning System on Food and Agriculture
GSL	Growing season length
IFAD	International Fund for Agricultural Development
IPC	Integrated Food Security Phase Classification
IPCC	Intergovernmental Panel on Climate Change
KLIP	Kenya Livestock Insurance Programme
MENA	Middle East and North Africa
MVAC	Malawi Vulnerability Assessment Committee
NDVI	Normalized difference vegetation index
PoU	Prevalence of undernourishment
SADC	Southern Africa Development Community
SD	Standard deviation

UCT	University of Cape Town
UNICEF	United Nations Children's Fund
WFP	World Food Programme
WHO	World Health Organization

Executive summary

In *The State of Food Security and Nutrition in the World 2017*, alarm bells were raised as world hunger appeared to begin to rise from 2015 after a period of prolonged decline. Conflict and weather-related events – in part linked to climate change – were flagged to be among the possible main reasons behind this new uptick in hunger. The report also made reference to new information from country Food Balance Sheets pointing to recent reductions in food availability and increases in food prices in regions affected by El Niño–Southern Oscillation phenomena. Furthermore, there was some evidence that drought conditions and other climate shocks were damaging livelihoods, resulting in an increase in populations affected by food crises.

The objective of this study is to examine evidence and provide new analysis on whether climate is negatively affecting agriculture and food security, by analysing evidence on recent climate variability and extremes over agriculture areas and the impact of these on agriculture and food security.

New evidence from this study points to a clear role of climate variability and extremes in the yield and production variance of major cereal crops globally, regionally and subregionally. Increasing climate variability and extremes are a matter of concern for agriculture because yields and production in many countries show a high degree of vulnerability to climate factors, as shown by the variance in national cereal yield or production that is explained by climate factors.

Evidence is also unequivocal that the Earth's climate is changing. Global climate studies demonstrate that not only are temperatures increasing and precipitation levels becoming more varied, all projections indicate these trends will continue. It is therefore imperative that we understand changes in climate over agriculture areas and their impacts on food security. Are these changes already affecting agriculture and hunger, and are they driving or contributing to the observed uptick in hunger? What is the evidence? The aim of this study is to explore these questions empirically.

In order to draw robust conclusions about the possible influence of climate variability and extremes on food security it is first necessary to generate country-averaged climate anomaly data over agriculture areas. To evaluate recent short-term climate variations, two recent periods are analysed. The first, 2011–2016, broadly aligns with the period in which there was a rise in hunger, measured by the prevalence of undernourishment (PoU). The second period, 2015–2016, covers the most recent El Niño event which was one of the strongest in recent history and demonstrates the typical impact of short-term climate variations due to natural climate variability.

A number of important findings emerges from the analysis of climate variability and extremes over agriculture areas during these two periods. Although past decades have been increasingly warmer, 2011–2016 was the hottest period on record. Not only was there an increase in the mean temperatures over agricultural areas, but hot days were more frequent and the hottest days were hotter. Moreover, much of the world experienced below-normal rainfall levels over agricultural areas, especially during the 2015–2016 period, resulting in widespread severe drought conditions in many countries. Another important finding is that changes in seasonality, not only through lower rainfall intensity but fewer days of rainfall, featured prominently over agriculture areas in the 2011–2016 period in many countries.

The study findings show that not only are more countries exposed to climate shocks, but both the frequency (number of years exposed in a five-year period) and intensity (number of types of climate extremes in a five-year period) of exposure have increased. Of growing concern is the finding that in low- and middle-income countries, where most of the world's undernourished population live, exposure to climate extremes has increased significantly in recent years, both in terms of frequency and the multiple types of climate extremes.

The strongest direct impacts from increasing climate variability and extremes are felt in agriculture, given the sensitivity of agriculture production to climate and the primary role of the sector as a source of food and livelihoods for the rural poor. However, the overall fallout is far more complex and greater than loss of productivity alone. Increased climate variability and extremes are inflicting high levels of economic loss in agriculture and often trigger changes in agricultural trade flows, leading to increased import expenditures and reduced export revenues for a number of countries.

Importantly, food access is also significantly undermined. Many people whose livelihoods depend on agriculture and natural resources lose important sources of their livelihoods and hence their ability to access food. Studies also show that spikes in food prices and increased food price volatility follow climate extremes and extend well beyond the actual climatic event. Net buyers of food, especially the urban and rural poor, are the hardest hit by price spikes. Price volatility and the uncertainty it creates negatively affect both food buyers and small-scale food producers.

Simple correlation results from the analysis of this study show that higher levels of undernourishment are found in countries with high levels of exposure to climate shocks. Although it is difficult to establish a direct causal relationship between climate variability and extremes and undernourishment, due to the way in which the undernourishment indicator (PoU) is computed and smoothed over time, it is possible to examine whether change points in undernourishment correspond temporally to occurrences of extreme climate events. The results of this analysis indicate that for almost 36 percent of the countries that experienced a rise in hunger, as measured by the PoU in the last ten years, this uptick is associated with the occurrence of extreme drought. Most striking is the significant increase in the number of change points related to high drought stress during 2014–2015. More than two-thirds of change points occur during this period and are linked to severe droughts driven by the 2015–2016 El Niño.

Finally, four cases studies are presented that provide a sobering integrated picture of how increasing climate variability and extremes are negatively affecting agriculture, resulting in destructive secondary impacts on livelihoods, income, food prices and coping capacities, and ultimately increasing food insecurity. Two of these case studies also show that it is not only increasing extreme climate events such as severe droughts and floods that are negatively affecting agriculture and leading to food insecurity, but also changing seasonal patterns.

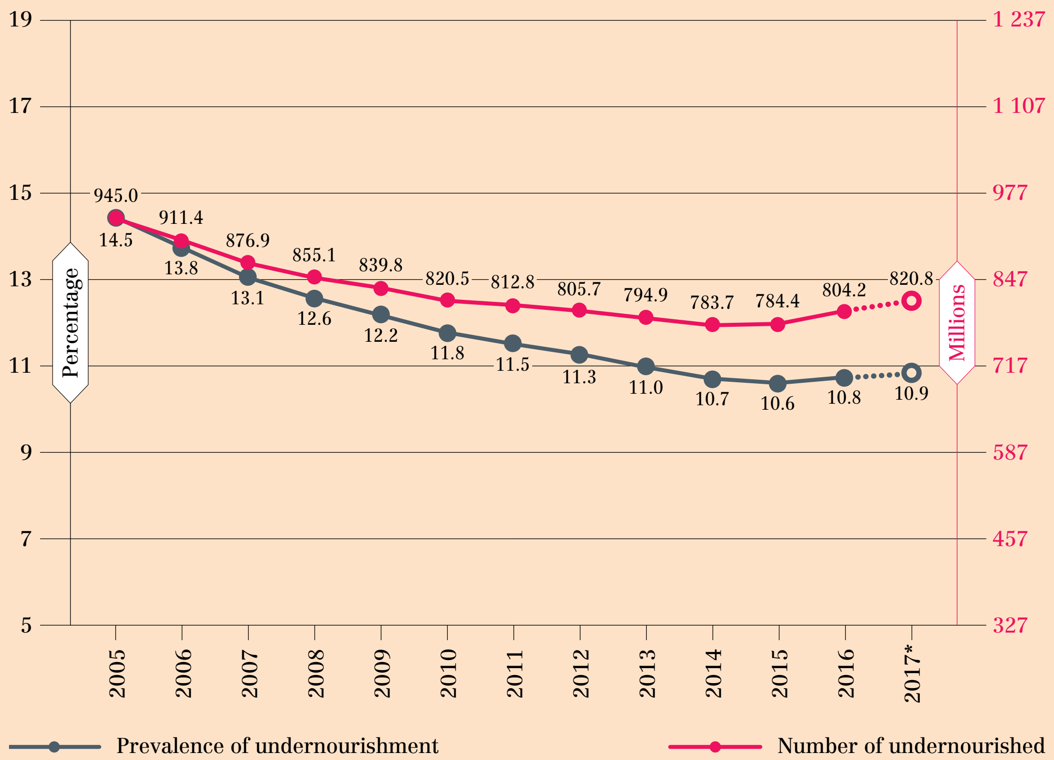
The 2015–2016 El Niño also features prominently in the cases studies, which document the devastating impact this event had on agriculture and food security in several countries, with a clear association between severe drought events and a steep increase in both chronic hunger (PoU) and emergency levels of acute food insecurity (Integrated Food Security Phase Classification – IPC). Recurrent and more frequent occurrence of extreme climate conditions and changes in seasonality are having a cumulative effect on agriculture and food security in many countries, undermining people's coping capacity and leading to more severe forms of food insecurity.

The findings of this study are compelling and bring urgency to the fact that climate variability and extremes are proliferating and intensifying and are more than ever contributing to a rise in global hunger. The world's 2.5 billion small-scale farmers, herders, fishers and forest-dependent people, who derive their food and income from renewable natural resources, are most at risk and affected. Actions to strengthen the resilience of livelihoods and food systems to climate variability and extremes urgently need to be scaled up and accelerated. The good news is that we have the knowledge and tools needed to begin to address this problem. We also have the experience and evidence pointing to the cross-cutting factors that lead to successful policies and practices to address climate risks. The study concludes with an outline of these.

1 Introduction

For a third year in a row, there has been a rise in world hunger (FAO, IFAD, UNICEF, WFP and WHO, 2017, 2018). The absolute number of undernourished people, i.e. those facing chronic food deprivation, has increased to nearly 821 million in 2017 from around 784 million in 2014 (Figure 1). This is an alarming situation given the world has made continuous and impressive reductions in world hunger, year after year, for the last two decades – even in the face of a rapidly increasing global population. This trend reversal has effectively set the world back to levels of hunger of almost a decade ago. Given the erosion in the gains made in ending hunger it is critical to better understand the drivers behind this renewed rise, so targeted actions can be made to reverse this trend and put the world back on track to ending world hunger.

FIGURE 1 Number of undernourished people in the world



Note: Projected values are illustrated by dotted lines and empty circles.

Source: Authors' elaborations based on data from FAO.

Although there are several drivers contributing to this rise in hunger,[1] including conflict and economic downturns, there is mounting evidence that the increase in climate variability and extremes is an important factor. For several countries that recently experienced a rise in hunger, information from country Food Balance Sheets points to reductions in food availability

[1] *The State of Food Security and Nutrition in the World 2017* signalled a rise in world hunger after a prolonged decline. The worsening food security in several countries were observed to be related to three factors: conflict, economic downturns and climate.

and price increases in regions affected by the 2015–2016 El Niño. This event resulted in large climatic deviations and anomalies compared to historical norms, affecting various parts of the world in different ways and at different levels of intensity: aggravating droughts in Africa, spurring typhoons in Asia and the Pacific and propagating extreme heat waves throughout the world. In tropical and subtropical regions, where many people rely on agriculture for their livelihoods and food security, drought conditions were intensified by the 2015–2016 El Niño.

The 2015–2016 El Niño, one of the strongest on record, affected over 60 million people worldwide, resulting in 23 countries appealing for over USD 5 billion of international humanitarian assistance (FAO, 2018a). El Niño events typically occur every few years, but climate change is influencing the traditional dynamics and frequencies of these events, as well as their impacts (WMO, 2018). People are still recovering from the devastating effects of the 2015–2016 El Niño, and already there are early warnings out for another one in 2018–2019.

Climate variability and exposure to more complex, frequent and intense climate extremes constitute a key force affecting agriculture and food security. Even outside large-scale global climate events like El Niño, temperatures are generally increasing and becoming more variable. Very hot days are becoming more frequent, and the hottest days are becoming hotter. At the same time, rainfall is becoming less predictable with large spatial variability; the nature of rainy seasons is also changing, in terms of both onset of the season and the duration and intensity of the rainfall itself.

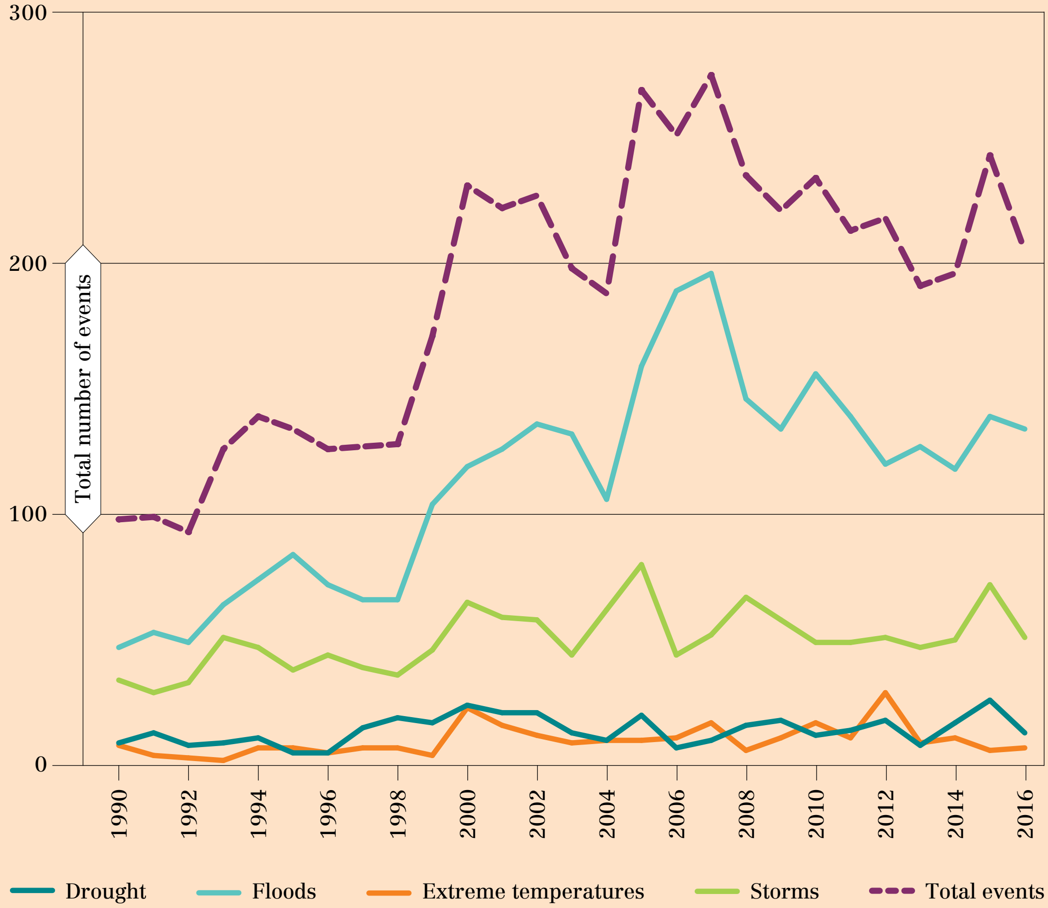
The strongest direct impacts of increasing climate variability and extremes are felt in agriculture and crop production, given the sensitivity of agriculture to climate and the primary role of the sector as a source of food and livelihoods for the rural poor. However, the overall fallout is far more complex and greater than lost productivity alone. Food access is significantly undermined too. Evidence shows that spikes in food prices and increased food price volatility follow climate extremes and extend well beyond the actual climatic event. Net buyers of food, especially the urban and rural poor, are the hardest hit by price spikes. Price volatility and the uncertainty it creates negatively affect both food buyers and small-scale food producers. As a result of climate variability and extremes many people whose livelihoods depend on agriculture and natural resources lose important sources of their livelihoods and hence their ability to access food.

Strong evidence points to the fact that climate change is already affecting agriculture and food security, which will make the goal of ending hunger, achieving food security, improving nutrition and promoting sustainable agriculture more difficult to achieve. Although climate change occurs over a period of decades or centuries, climate variability (e.g. in temperature and rainfall) and extremes (which can lead to drought, floods, storms, etc.) occur on shorter time scales (days to years) and may be associated with periodic or intermittent changes related to different natural phenomena (such as El Niño, La Niña, volcanic eruptions or other changes in the Earth's climate system). These shorter-term climate variations are nearly always never wholly attributable to climate change, though the chance of them occurring is often modified (or made more likely) due to climate change. The science of attribution of climate variations and extremes to climate change is, however, complex, and the required modelling is beyond the scope of this study.

This study focuses not on climate change *per se*, but on climate variations and extremes and is prompted by three considerations. First, climate extremes have increased in number and intensity. The number of extreme events, including extreme heat, droughts, floods and storms, has doubled since the early 1990s, with an average of 213 of these events occurring every year during the period 1990–2016 (Figure 2). Second, while climate change occurs over a period of decades or centuries, what people experience in their daily life is climate variability and climate extremes superimposed on the ongoing climate change.

Third, unsurprisingly, all dimensions of food security and nutrition, including food availability, access, utilization and stability, are potentially affected even in the short term by climate variability and climate extremes.

FIGURE 2 **Total number of climate-related medium- and large-scale disasters (1990–2017)**



Notes: Total number of natural disasters that occurred in low- and middle-income countries by region during the period 1990–2016. Disasters are defined as medium- and large-scale disasters that exceed the thresholds set for registration on the Emergency Events Database (EM-DAT). See Annex 3 for the full definition of EM-DAT disasters.

Source: FAO elaboration based on data from CRED. 2017. EM-DAT – the international disasters database. In: *Centre for Research on the Epidemiology of Disasters (CRED)* [online]. [Cited 2 October 2020]. https://www.emdat.be

This study presents new analysis on the impact of climate on agriculture and food security, by examining evidence on recent climate variability and extremes in agriculture areas and the impact of these on agriculture and food security. Section 2 sets the stage by examining how changes in climate can impact on agriculture, and the historical evidence that the climate is indeed changing. In order to be able to draw robust conclusions about the possible influence of climate variability and extremes on food security, it is first necessary to generate country-averaged climate anomaly data over agriculture areas. Section 3 presents new analysis of recent trends in temperature and rainfall anomalies over agricultural areas, as well as looking at evidence on changing seasonality and more severe climate-related events including severe drought, storms and floods. Section 4 takes this analysis a step further and explores the impact that the increasing climate variability and extremes are having on agriculture and food security. To provide a more nuanced understanding of how climate is affecting agriculture and food security, three case studies are then presented in Section 5, followed by a discussion on the policy implications of the results.

2 Are changes in climate variability and extremes a concern for agriculture?

KEY MESSAGES

- Increasing climate variability and extremes are of great concern for agriculture because yields and production show a high degree of variance due to changes in temperature and precipitation.
- Climate is the single most important determinant of agricultural yield, and variability in temperature and rainfall is estimated to explain 30–50 percent of the global interannual variability in cereal yields.
- While the relationship between climate factors and national cereal production is more nuanced due to the diversity and complexity of agricultural systems, national cereal production in many countries still shows a high degree of variability attributed to climate factors.
- Not only are temperatures increasing and precipitation is becoming more varied, all projections indicate these trends will continue.

2.1 Changing climate variability and extremes are of great concern

Increasing climate variability and extremes matter greatly for agriculture because yields and production in many countries show a high degree of vulnerability to climate factors, as shown by the variance in national cereal yield or production that can be attributed to these factors. This is important, because it means that even despite current levels of agrotechnology, climate still plays a significant role in determining differences in outcomes for agriculture yields and production levels.

There is ample evidence that climate is the single most important determinant of agricultural productivity globally, through its effects on temperature and water availability (Kang, Khan and Ma, 2009; Lai, 2004; Oram, 1989). Crop yields in many countries have suffered from changes in temperature and precipitation, which have affected global aggregate wheat and maize yields (Porter *et al.*, 2014). Globally, estimates indicate that climate variability accounts for roughly one-third (~32–39 percent) of the observed yield variability (maize, rice, wheat and soybean) (Ray *et al.*, 2015). A newly developed index, the Combined Stress Index (CSI),[2] which combines heat and water stress during the crops'

2 The CSI is defined as a linear superposition of the Standardized Precipitation Evapotranspiration Index (Vicente-Serrano, Beguería and López-Moreno, 2010) and the Heat Magnitude Day (this study).

more sensitive phenological periods, is able to capture a larger amount of variability, confirming and strengthening previous findings on the effects of climate on yields (Figure 3). For wheat this CSI captures 42 percent of global interannual variability (Zampieri *et al.*, 2017). For maize it captures 50 percent of the global variability.[3]

From 1982 to 2010, year-to-year variations in yields of maize, soybean, rice and wheat significantly decreased in 19–33 percent of the global harvested area varying extent of area by crop). However, in some regions of the world (9–22 percent of harvested area), yields have become more unstable (significant increase in yield variability was detected). On a global scale, over 21 percent of the yield variability change could be explained by the change in variability of the agro-climatic index. Examples of relatively food-insecure countries with increased yield variability due increased climate variability are Kenya and the United Republic of Tanzania (maize), and Bangladesh and Myanmar (rice) (Figure 3a). Extending the analysis of maize to the more recent period of 2015–2017 shows that the years with largest stress for maize were indeed the last ones for food-insecure countries in sub-Saharan Africa (Figure 3b). There is also strong evidence that climate variability driven by major El Niño–Southern Oscillation (ENSO) events plays a key role in decreasing crop yields (Hansen *et al.*, 2011; Iizumi *et al.*, 2014).

Climate variations and extremes influence not only yields but all components of crop production, including cropping area (area planted or harvested) and cropping intensity (number of crops grown within a year). Unlike yields, however, there is no global overview of increased climate variability effects on area planted and cropping intensity, due to limited data. Nevertheless, there is evidence from a number of case studies on the relationship between climate variability and cropping intensity. Variations in the timing of seasonal wet and dry seasons and extreme weather events are shown in a number of cases studies to be one of the changes that is negatively impacting on area planted and cropping intensity.

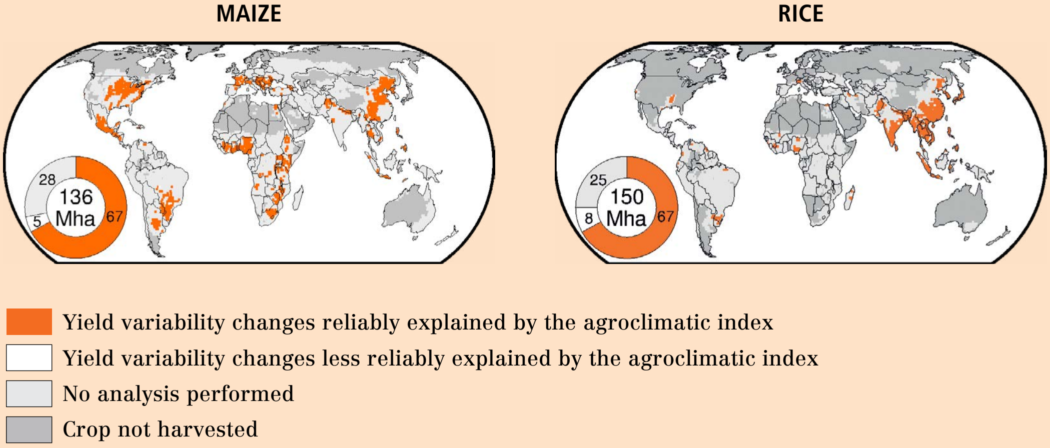
For example, in the Viet Nam Mekong Delta, where a triple rice cropping system is used, the annual number of completed cropping cycles is affected by variations in the timing and extent of flooding in the wet season as well as those of salinity intrusion in the dry season (Iizumi and Ramankutty, 2015; Kotera *et al.*, 2014; Sakamoto *et al.*, 2006). Due to the severe floods in 2000, the second-season rice (planted in the middle of the dry season and harvested before the onset of the wet season) grown in the upstream area of this region that year was fully and continuously submerged immediately after the flooding leading to crop failure except for the floating rice varieties. In contrast, the below-normal seasonal rainfall in 2004 reduced water availability for irrigation due to high salinity, and as a result the dry-season rice in that year could not be harvested (Kotera *et al.*, 2014).

The evidence of the relationship between climate variability and extremes and agriculture production is more nuanced and varied. Differences in overall aggregate impacts on national food production arise not only due to the variations in type and geographical distribution of climate variability and extremes, but also due to the diversity and complexity of agricultural systems, including differences in crops, cropping patterns, farming technology (e.g. rainfed vs irrigated, high and low input ratios, nomadic pastoral vs intensive livestock production) and agriculture management systems.

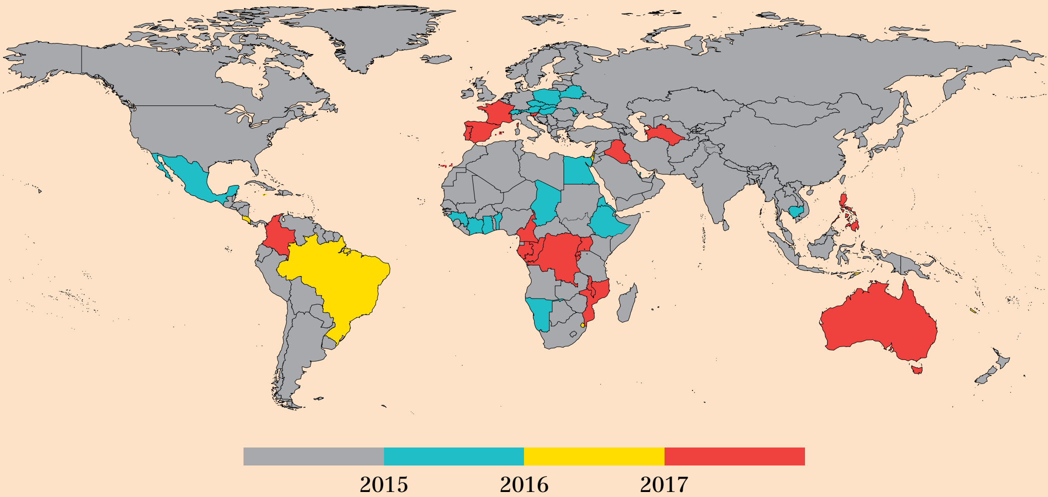
[3] The variation of several growing season climates was shown to have changed significantly during the last 50 years. The use of empirical relationships between crop yield and climate identified several countries, in particular Indonesia (maize) and India (rice), where significant changes in climate variability have led to the observed reductions in yield variability.

FIGURE 3 Yield variability explained by climate variability and extremes

A. 1981–2010



B. 2015–2017 COMPARED TO 1988–2017



Notes: a) Locations where the major characteristics of yield variability change could be reliably explained by the agroclimatic index. The pie diagrams indicate the percentage of harvested areas in the coloured areas, normalized to the world harvest area in 2000; b) Combined Stress Index (CSI) is computed based on ERA-Interim data for the updated period 1988–2017, showing the year of the maximum if occurring after 2015. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. Final status of the Abyei area is not yet determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

Source: a) Iizumi, T. & Ramankutty, N. 2016. Changes in yield variability of major crops for 1981–2010 explained by climate change. *Environmental Research Letters*, 11(3): 034003; b) authors' elaboration based on ERA-Interim data for the Combined Stress Index (CSI). Conforms to Map No. 4170 Rev. 19 UNITED NATIONS October 2020.

Despite these nuanced and varied elements, there is evidence that for many countries at least part of their national cereal production variance is explained by climate factors. Figure 4 shows countries where there is a high and statistically significant association between production and climate or biophysical indicators, specifically temperature, rainfall and vegetation growth. The analysis shows there is a strong cereal production sensitivity to climate variability, a generally positive correlation with climate or biophysical indicators (e.g. rainfall or normalized difference vegetation index [NDVI]) and a negative relationship with temperatures. In countries in semiarid climate regions, such as in Central Asia and in Middle East and North Africa (MENA) countries, the correlation is especially strong, and it is not uncommon to have 80 percent or more of the production variability explained by climate variability. Conversely, in a portion of the tropical belt, high annual rainfall with consequent water excess or possible floods can be a limiting factor to production. The relationship with temperature is also significant in most countries but can be either positive or negative, depending for example on altitude (e.g. the relationship is positive for the Ethiopian highlands, but negative in Somalia) (Figure 4a).

Although for a large number of countries globally it is common for production to be influenced by climate, the relationship is strongest but also most complex in the African continent. There, each country shows a different mix of sensitivity to climate variability both in terms of strength and sign of the correlation. In contrast, in many Asian countries there is no significant correlation with single climate indicators, but there is with biophysical indicators such as NDVI, that provides and integrated response to temperature and preicpitation but also to any other factors affecting vegetation growth. This includes countries such as China, India and Kazakhstan, partly due to the effects of climate variability on agricultural vegetation.

Drought is one of the most extreme climatic events that has shown to have a negative impact on production. For many countries there is a high negative correlation between drought indicators and food production (i.e. high level of drought stress for low production) (Figure 4b). The highest correlations occur in semi-arid countries or drought-prone continental climates (e.g. central Asia), while in many tropical areas there is no correlation between drought indicators and production (Central Africa, Central America and Central Asia).

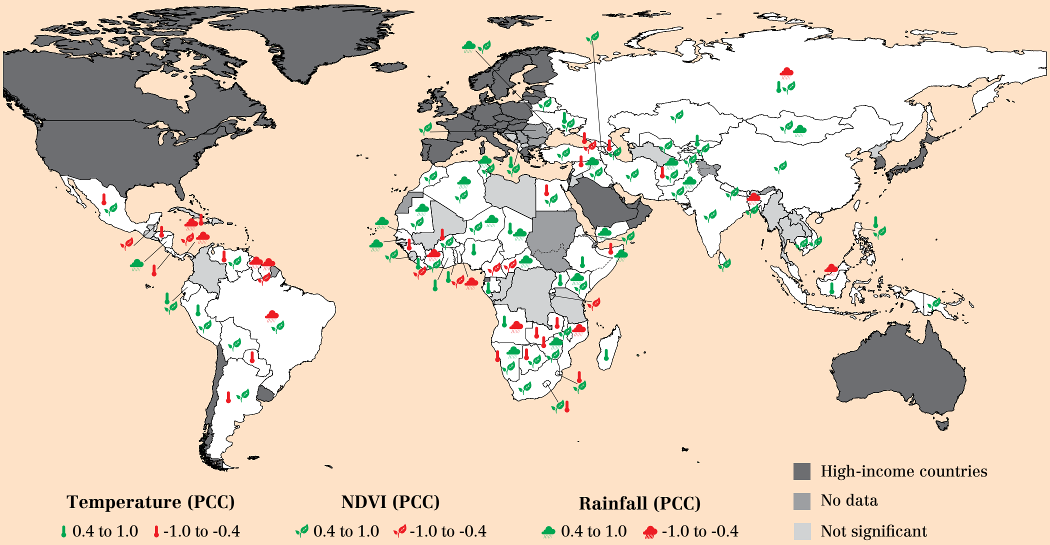
Even when national food production is stable or increasing, climate variability and extremes in certain subnational areas – particularly in more marginal agriculture areas – can result in significant losses that lead to high levels of food insecurity and increased risks of malnutrition. In these cases, although food production might be increasing on a national scale, local food production does not necessarily follow suit.

When climate shocks hit major cereal producers and regions, impacts can extend beyond the national scale to affect food availability and food prices globally. Figure 5 provides evidence of global impacts on the specific maize supply attributable to heat waves, drought and water access at the global, national and subnational scales. An analysis of major producers of wheat shows a similar relationship between the impact of climate shocks on the global wheat supply (Zampieri *et al.*, 2017).

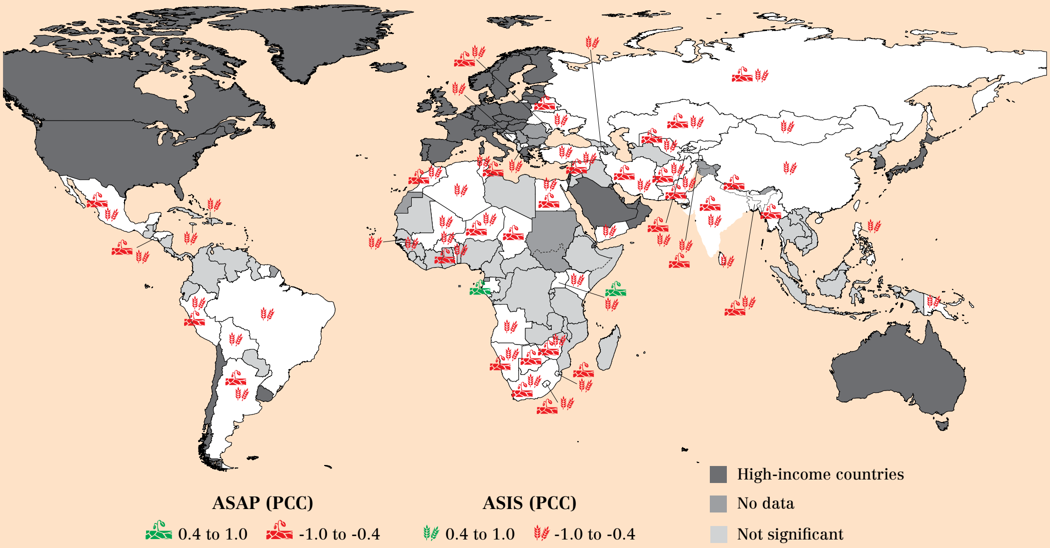
Thus, there is a clear role of climate variability and extremes in the yield and production variance of major cereal crops globally, regionally and subregionally. Increasing climate variability and extremes are therefore matters of concern for agriculture.

FIGURE 4 Relationship between climate variability and drought on national cereal production (2001–2017)

A. RELATIONSHIP BETWEEN CEREAL PRODUCTION AND VARIABILITY IN TEMPERATURE, RAINFALL AND VEGETATIVE GROWTH



B. RELATIONSHIP BETWEEN CEREAL PRODUCTION AND MEASURES OF DROUGHT (ASAP AND ASIS)

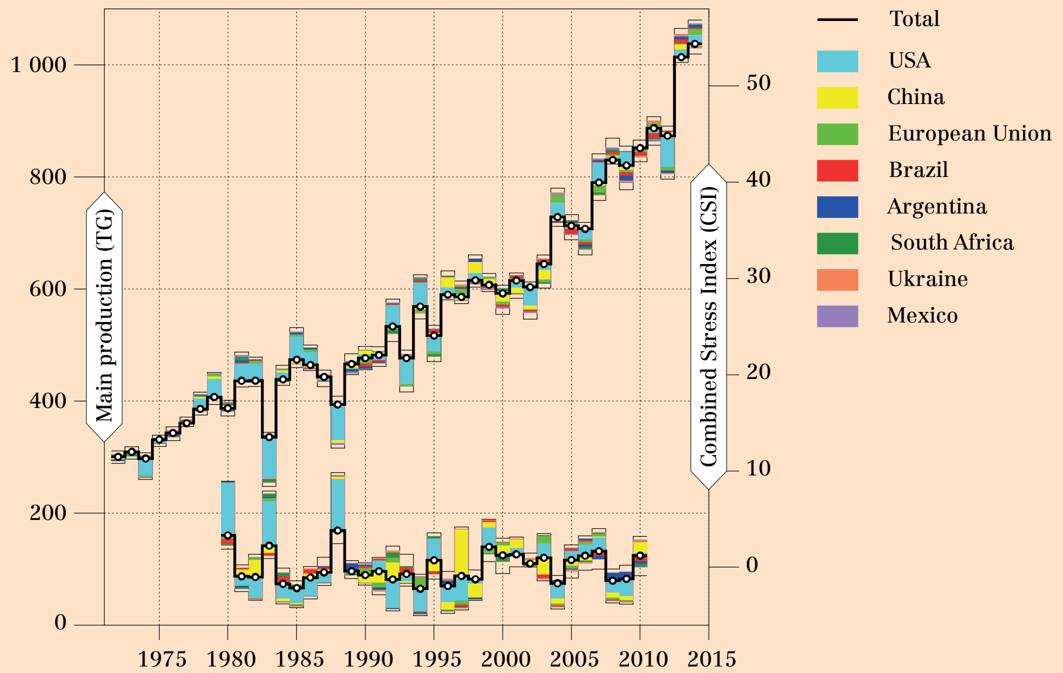


Notes: Figure shows where part of cereal production variability in low- and middle-income countries is explained by a) mean annual temperature, cumulative normalized difference vegetation index (NDVI) over the growing season and cumulative annual rainfall; and b) two climate indicators that measure drought: Anomaly Hotspots of Agriculture Production (ASAP) and Agricultural Stress Index System (ASIS). Colours of the symbols reflect the sign of the correlation (green = positive, red = negative), as provided by the Pearson coefficient of correlation (PCC). See Annex 3 for data sources and methodology. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. Final status of the Abyei area is not yet determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

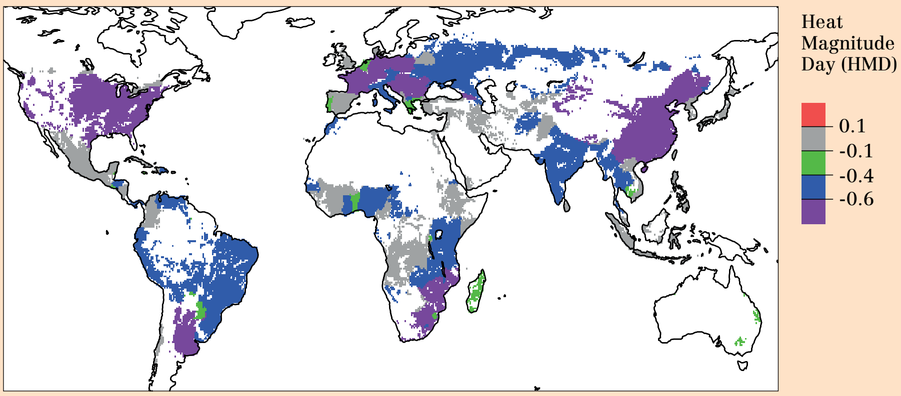
Source: Authors' elaborations based on data from FAO GIEWS Cereal Balance Sheets for cereal production; FAO for the Agriculture Stress Index System (ASIS); Crespo *et al.* (2018) for temperature and precipitation data; European Commission for the Normalized Difference Vegetation Index (NDVI). Conforms to Map No. 4170 Rev. 19 UNITED NATIONS October 2020.

FIGURE 5 Maize production and yield explained by changes in climate variability and extremes

A. TOTAL MAIZE PRODUCTION AND ANOMALIES DUE TO THE MAJOR PRODUCER



B. CORRELATION OF CSI WITH NATIONAL YIELD DATA



C. FRACTION OF VARIABILITY EXPLAINED BY HEAT VS WATER STRESS

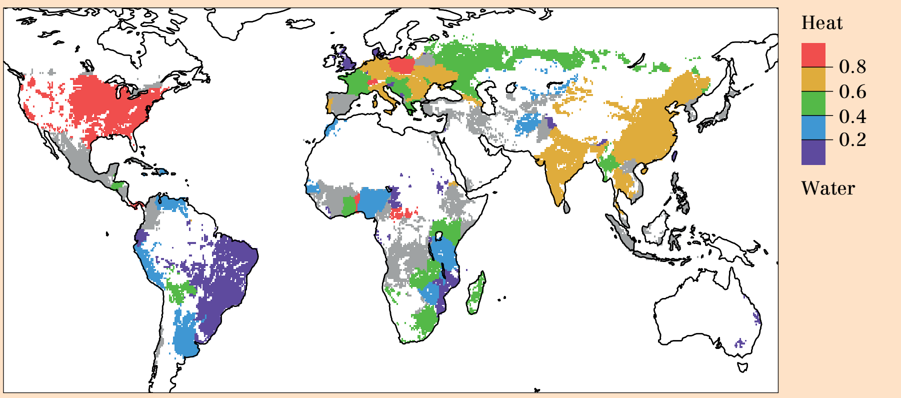
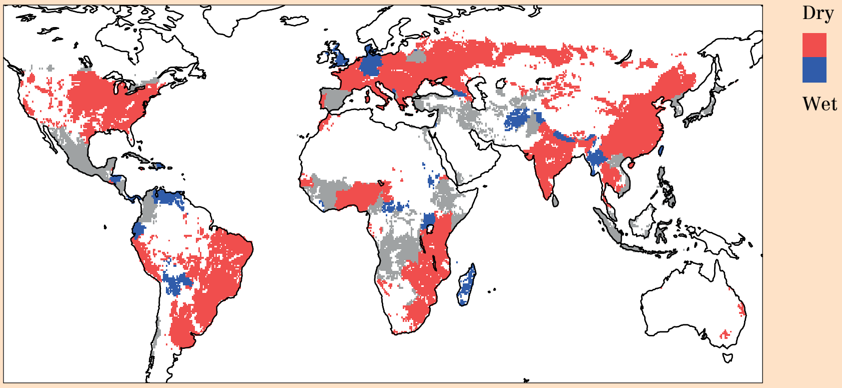


FIGURE 5 Maize production and yield explained by changes in climate variability and extremes (cont.)

D. SENSIVITY TO DROUGHT OR TO WATER EXCESS



Notes: a) Time series of global maize production (FAOSTAT data) and Combined Stress Index (CSI). In both time series the sum of all the negative and positive country-scale anomalies is shown; the proportions attributed to the eight major producing regions are highlighted in colour. b) Linear correlations between the combined stress indicator and the national yield data over wheat-planted areas; regions with small correlations, or not passing a 10 percent two-sided correlation test, are displayed in grey. c) Portion of variability explained by heat anomalies alone (i.e. the heat sensitivity parameter). d) Role of water stress as accounted for in the combined model (i.e. the sign of the soil moisture sensitivity parameter). Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. Final status of the Abyei area is not yet determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

Source: Zampieri *et al.*, 2017.

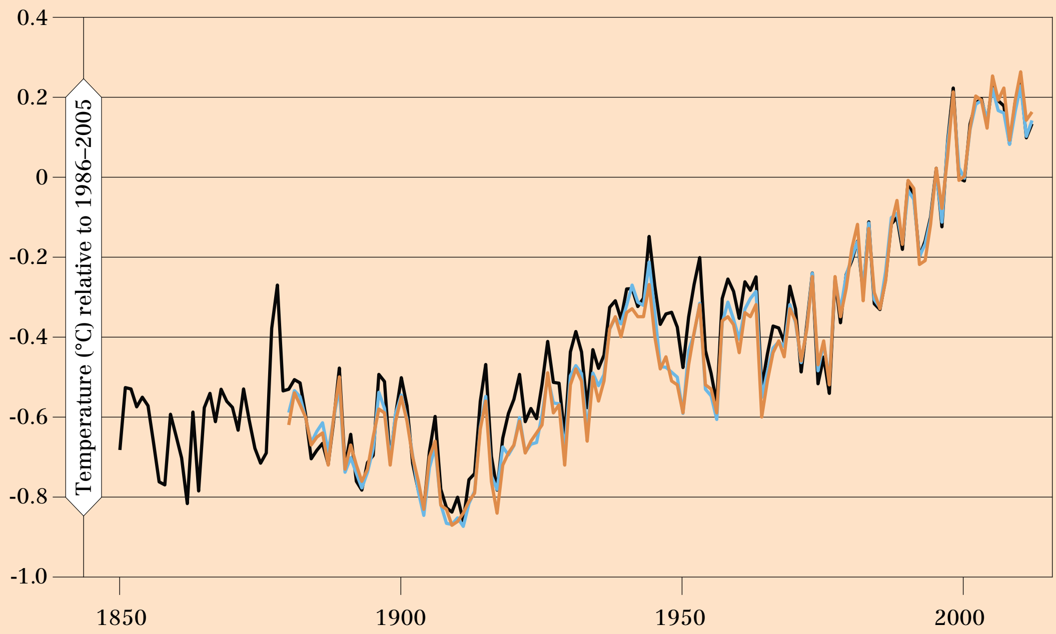
2.2 A changing climate: now and continuing into the future

There is strong evidence of global climate change in the form of increasing air and sea surface temperatures, receding glaciers, changes and shifts in climate regimes, increases in the number of extreme events, and changes in sea levels (IPCC, 2014; Porter *et al.*, 2014). Global changes in climate are well-established and undeniable, as revealed through historical data analyses supported by such international organizations as International Council of Science (ICSU), the Intergovernmental Panel on Climate Change (IPCC) and the World Meteorological Association (WMO). The accelerated warming of the planet has and continues to lead to modification of ecosystem processes, increasing climate variability and the frequency of extreme climate-related events across the globe, including extreme temperatures and rainfall (floods and droughts).

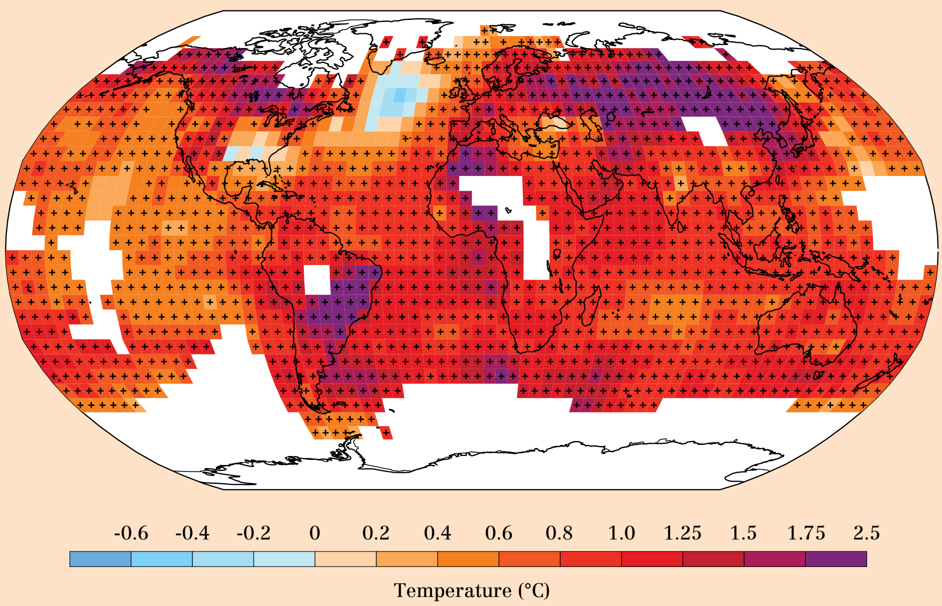
The Earth's climate has experienced rapid warming of approximately 0.85 °C since the pre-industrial period and continuing through the twentieth century. Based on historical temperature observations, there is a clear trend at the global scale of an overall increase in warm days and nights and a reduction in cold days and nights. Considering the 1961–1990 period as reference period, Figure 6a plots more than a century of records of averaged temperature anomalies globally, showing a clear increase over time, including an acceleration of temperature increases in the last few decades. While short periods of cooling have occurred, for example in the 1950s and 1960s (related to volcanic eruptions), each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850.

FIGURE 6 Historical temperature trends and anomalies (1850–2012)

A. OBSERVED GLOBAL ANNUAL MEAN COMBINED LAND AND OCEAN SURFACE TEMPERATURE ANOMALIES (1850–2012)



B. OBSERVED CHANGE IN SURFACE TEMPERATURE (1901–2012)



Notes: Figure 6a shows observed global annual mean combined land and ocean surface temperature anomalies, from 1850 to 2012, using three different datasets (denoted by three colors) with anomalies relative to the mean 1986-2005. Figure 6b shows observed surface temperature change from 1901 to 2012 derived from temperature trends determined by linear regression from one of the three datasets (the orange line in Figure 6a).

Source: IPCC. 2014. *Climate Change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea & L.L. White, eds. Cambridge, UK and New York, USA, Cambridge University Press.

An increase in global mean temperature by 1.5 °C or 2 °C implies substantial increases in the occurrence and/or intensity of some extreme events for many regions (Chevuturi *et al.*, 2018; Fischer and Knutti, 2015; Karmalkar and Bradley, 2017; King and Karoly, 2017). In the presence of progressive increases in global temperatures, limiting warming to 1.5 °C has been declared to be important for the future of agricultural production (Allen *et al.*, 2018; Hoegh-Guldberg *et al.*, 2018). Each increase in temperature corresponds to a reduction in maize crop yield: a 1.5 °C increase yields a 10 percent reduction, an increase of 1.5–2 °C yields a 15 percent crop reduction, and a 3 °C increase yields an alarming 20 percent reduction in yield. Approximately 20 to 40 percent of the global human population live in regions that have already experienced warming of more than 1.5 °C above pre-industrial levels in at least one season during 2006–2015 (Allen *et al.*, 2018). The extent to which warming greater than 1.5 °C can be avoided depends on future rates of emission reductions.

While average global temperatures are increasing, year-to-year variations and variations between regions – often the result of large-scale modes of climate variability (e.g. ENSO; North Atlantic Oscillation – are superimposed on these long-term trends. Even so, the only regions that have experienced any cooling are small areas of the north Atlantic (related to changes in ocean currents and sea surface temperatures) and southern United States of America (Figure 6b).

Trends in average temperature are often reflected in trends in one or more measures of extreme temperatures (e.g. hot/cold days and hot/cold nights). For instance, over Southern Africa, Northern, Central, Eastern and Western Asia, and Australia, there likely (or very likely) have been increases in hot days and hot nights, with similar increases in hot nights over Northern, Central and Western Asia and Australia. Nevertheless, a few subregions have demonstrated varying warming and cooling trends spatially (e.g. Eastern Africa, the west coast and south-eastern region of South America, central Northern America and eastern United States of America, with decreases in hot nights in north-east Canada). Overall, in the Northern Hemisphere, 1983–2012 was the warmest 30-year period of the last 1 400 years. (IPCC, 2013).

Historical trends in annual precipitation, while far more diverse and uncertain (both positive and negative, depending on the region), point to changes in regimes and intensification of extremes.

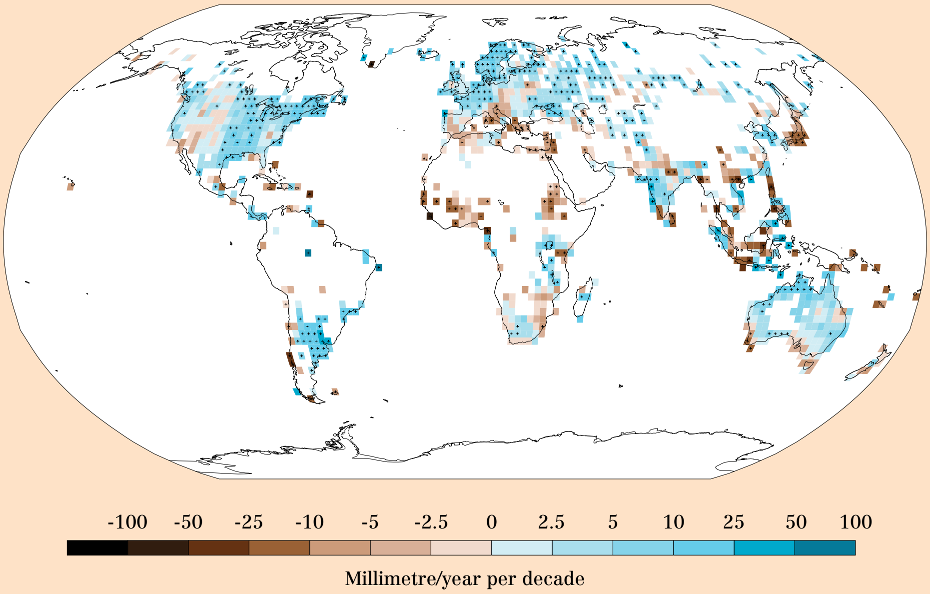
Comparing precipitation trends for the two periods 1901–2010 and 1951–2010 (Figure 7), the spatial variability of these trends is reasonably consistent, with noticeable areas of significantly decreasing and increasing precipitation. While these trends are spatially consistent, they are greater (both negative and positive), spatially more extensive, and more significant during the latter 1951–2010 period.

Not only is the evidence unequivocal that the Earth's climate is changing, we also know that these climate trends will continue. Climate models project these trends forward into the future, based on varying assumptions. All of them, even under different degrees of climate change mitigation, point to a continuation of these trends. For example, two future temperature and precipitation projections based on climate change scenarios at either end of the range cited by IPCC (2014) foresee both to keep increasing (Annex 1). At either end of the climate change scenario range, temperatures are projected to keep increasing, though the magnitude varies with location or pathway. For precipitation, although the spatial variability is relatively consistent through future climate scenarios, the changes depend on location.

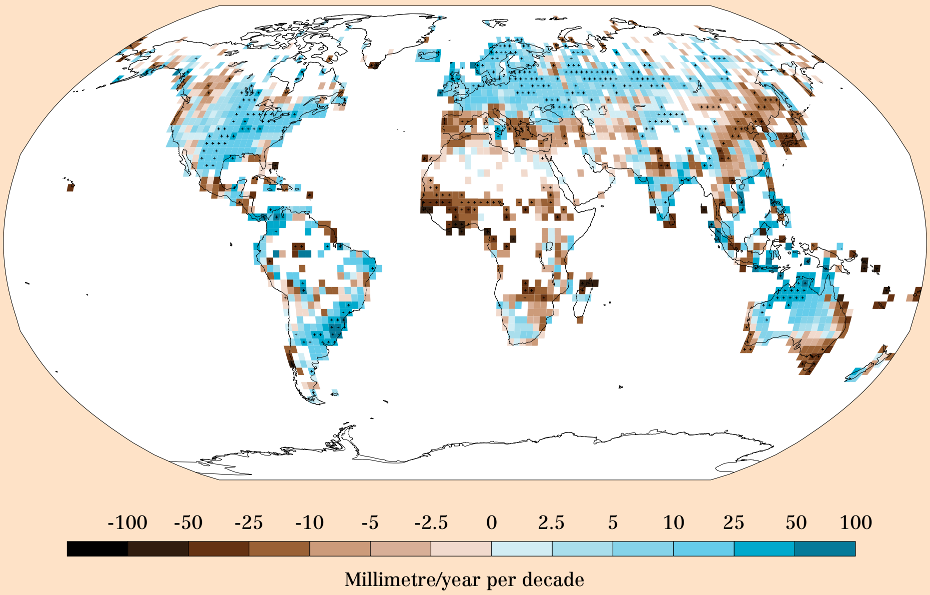
Thus, it is clear from evidence that the world is experiencing increasing trends in climate variability and extremes, and that these trends will continue. It is therefore imperative that we understand changes in climate over agriculture areas and how these impact on food security. Are these changes already affecting agriculture and hunger, and are they driving or contributing to the observed uptick in hunger? What is the evidence? The following sections explore these questions.

FIGURE 7 Historical precipitation trends (1901–2010 and 1951–2010)

A. 1901–2010



B. 1951–2010



Notes: Maps of observed precipitation change from 1901 to 2010 and from 1951 to 2010 from one data set. Dots indicate locations where the observed trends are statistically significant (i.e. where a zero trend lies outside the 90 percent confidence interval).

Source: IPCC. 2014. *Climate Change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea & L.L. White, eds. Cambridge, UK and New York, USA, Cambridge University Press.

3 Recent impacts of climate variability and extremes over agriculture areas

KEY MESSAGES

- To evaluate the recent impact of climate variability and extremes on agriculture and food security, it is necessary to first measure the degree and occurrence of climate variability and extremes over agricultural areas.
- Although past decades have been increasingly warmer, 2011–2016 was the hottest period on record. Not only was there an increase in mean temperature over agricultural areas, but hot days were more frequent and the hottest days were hotter.
- Much of the globe experienced below-normal rainfall levels over agricultural areas during the 2015–2016 period, resulting in widespread severe drought conditions.
- Changes in seasonality, not only through lower intensity but fewer days of rainfall, feature prominently over agriculture areas in the 2011–2016 period in many countries.
- Not only are more countries exposed to climate extremes, but both the frequency (number of years exposed in a five-year period) and intensity (number of types of climate extremes in a five-year period) of exposure have increased.
- Low- and middle-income countries' exposure to climate extremes has increased significantly in recent years, both in terms of frequency and the multiple types of climate extremes.

3.1 Methods and selection of climate indicators

In order to evaluate recent climate variability and extremes in agriculture areas, it was first necessary to identify suitable climate indices that capture the climate attributes over months and years, representing both rainfall and temperature extremes, and their variability and seasonality. The subset of chosen climate indices for this study are from Crespo *et al.* (2018) and their description are outlined in Annex 2.

Second, in order to be able to draw robust conclusions about the possible influence of climate anomalies on country-level food security, specifically the PoU (see Chapter 4), crop-masked averages of climate anomalies at the country level were also produced. The maps and analysis presented below represent the country-averaged climate anomalies over areas with significant agricultural activities. This is important, as it allows us in the next chapter to avoid falsely identifying a link between a climate anomaly and country PoU indicators where the climate anomaly occurs in a subregion where there is little or no agriculture. Cropland and rangeland masks[4] are hybrid masks obtained merging multiple land cover products, including areas over both cropping and pastoral areas, together to produce an integrated product that represents the best characterization of cropland or land cover at a particular location.

To evaluate recent climate variations, we analyse two recent periods. The first is the 2011–2016 period which broadly aligns with the period in which a rise in hunger, measured by the PoU (FAO, IFAD, UNICEF, WFP and WHO, 2017), has been observed in a number of countries. The second period (2015–2016) covers the most recent El Niño event which was one of the strongest in recent history and demonstrates the typical impact of short-term climate variations due to natural climate variability. Both periods are compared to the longer-term averages for the period 1981–2016, in order to identify anomalies or differences from the longer trend (see Annex 2 for further details on methods).

The section below summarizes the outcome of the above analysis, presenting the recent evidence on climate variability and extremes over both crop and pastoral areas. The time period is relevant to the recent uptick in hunger, as it a) is long enough to approximate the historical averages, and b) gives an understanding of the changes in climate during a period of rising hunger.

3.2 Higher temperatures, with increasing frequency

Although past decades have been increasingly warmer as seen from the above historical climate trends, 2011–2015 was the hottest period on record, and the year 2015 – with the contribution of El Niño – was the hottest since modern observations began in the late 1800s (WMO, 2016). (See Box 1 for an explanation of these ENSO-related events).

Important results emerge from the analysis of recent climate anomalies over agricultural areas using the sub-decadal period of 2011–2016 and a short-term period of 2015–2016 that covers the most recent El Niño event – one of the strongest in the recent history, and a key driver of the most significant recent climate anomalies worldwide.[5]

First, temperatures have generally been warmer in the recent past than in the reference period (1981–2016), for both the periods considered (Figure 8). Second, the 2015–2016 El Niño was a significant source of regional temperature anomalies, contributing to both warmer and cooler conditions depending on the spatial location. For example, Chad and the Sudan experienced warmer temperatures during both periods, whereas Kenya and part of Western Africa experienced lower temperatures. In Southern Africa strong temperature anomalies during the El Niño were observed, with worrisome effects on agriculture cropping areas. In fact, 32 million people were estimated to be food-insecure, leading to the declaration of a regional drought disaster. The situation was further exacerbated by a mid-season dry period in the 2017–2018 cropping season, with most countries reporting below-average cereal harvests that aggravated current food insecurity conditions (FAO, 2018a).

4 These crop masks are a product of the EC-JRC.

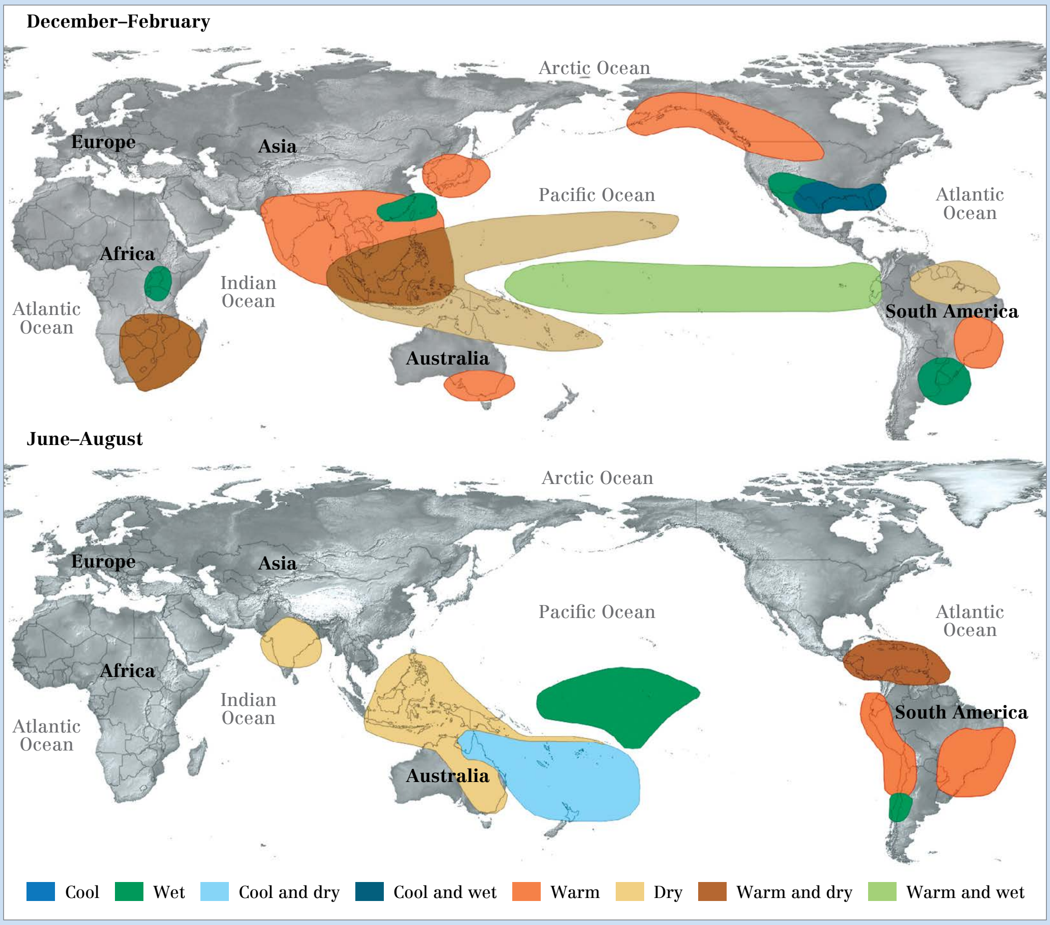
5 The recent sub-decadal period of 2011–2016 was chosen as it aligns with the period when PoU has increased in a number of countries after systematic declines over previous decades. This allows us to identify areas and countries that have experienced anomalous climatic conditions in 2011–2016, and the potential links with increasing PoU during the same period.

BOX 1 Relationship between climate variability and the El Niño–Southern Oscillation

Climate variability describes the year-to-year and decade-to-decade variations in climate at a particular location or for a particular region. It is the product of drivers at the global, regional and local scale, as well as effects owing to the stochastic nature of weather.

Local climate is determined by a combination of large-scale drivers (e.g. the El Niño–Southern Oscillation, North Atlantic Oscillation, and Indian Ocean Dipole) that influence regional atmospheric circulation patterns; regional-scale drivers such as regional Sea Surface Temperatures (SST); local drivers such as soil moisture conditions; and local stochastic effects such as the random location and track of a thunderstorm/cyclone over a region.

EL NIÑO CLIMATE IMPACTS

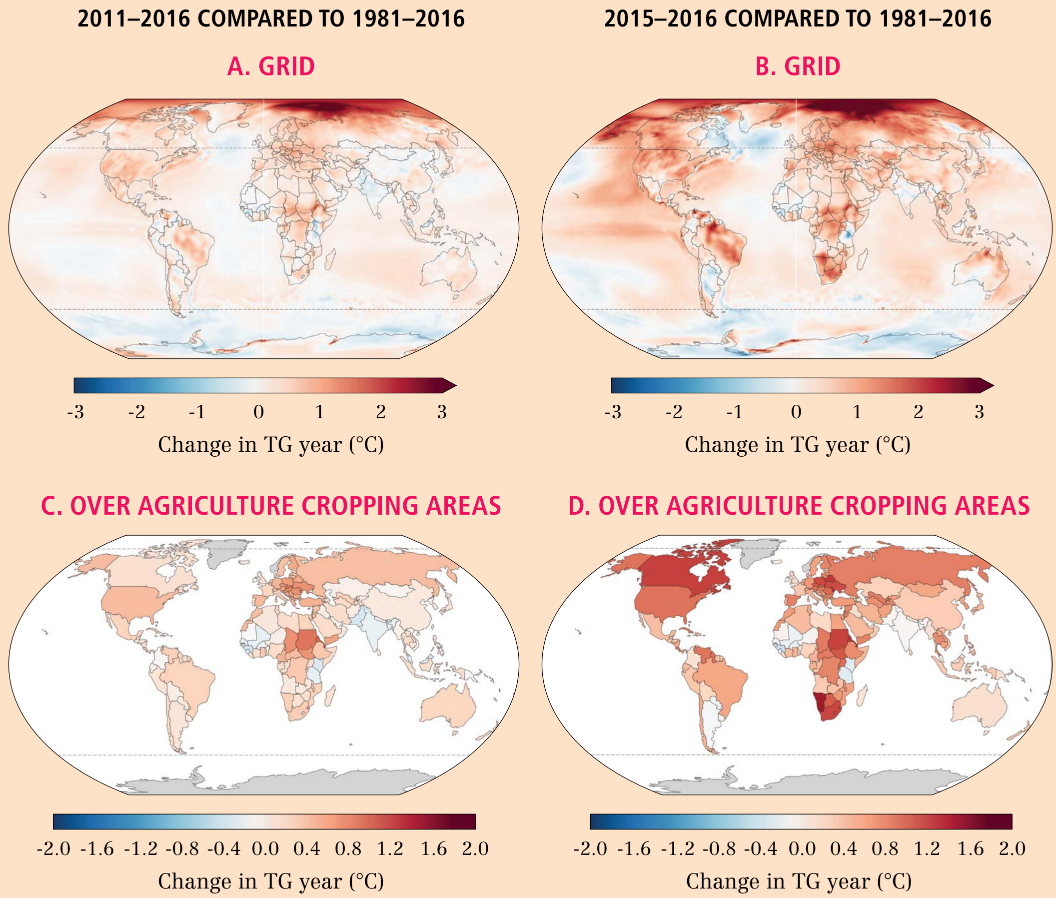


Source: Weather Impacts of ENSO (available at www.weather.gov/jetstream/enso_impacts).

The El Niño–Southern Oscillation (ENSO) is one of the Earth's most important climatic phenomena. The ENSO cycle describes the fluctuations in the sea surface temperature of the east-central Equatorial region of the Pacific Ocean. La Niña is known as the cold phase and El Niño as the warm phase. These temperature variations can have large-scale impacts not only on oceanic processes, but also on global weather and climate. The typical climatological impacts of El Niño and La Niña events on different regions of the globe, and during different seasons (i.e. boreal winter and summer), are shown in the below figure.

The 2015–2016 El Niño was extreme and one of the strongest events in the past 100 years. The event resulted in record-breaking warm conditions for many tropical and subtropical countries, and the global average surface air temperature for 2015 and 2016 marked two of the warmest years on record. Large parts of Asia and the Pacific experienced hot spring and summer seasons, and many extreme weather events were observed, including cyclones, flooding, severe droughts and extreme temperatures.

FIGURE 8 Recent temperature anomalies compared to the 1981–2016 average

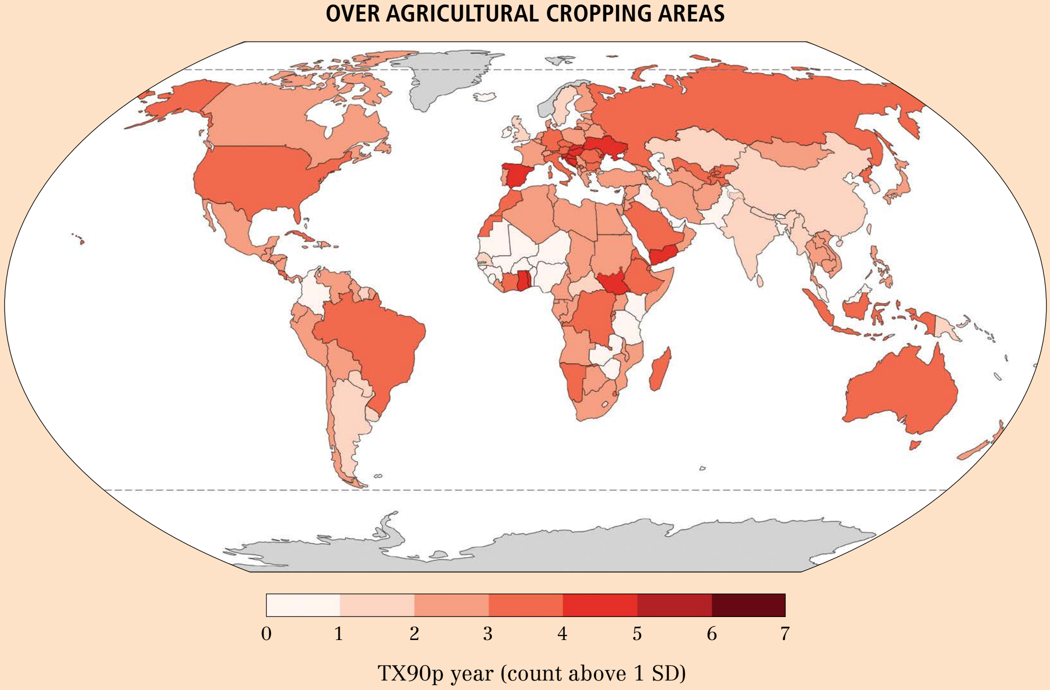


Notes: The maps show changes in mean surface air temperature (TG) in degrees Celsius (°C). Panels a and b) are grid-level figures. Panels c) and d) are aggregated per country over agriculture cropping areas. In these cases, climate data are given larger weight where there is cropping compared to where there is not. Areas with insufficient data coverage are denoted in grey. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. Final status of the Abyei area is not yet determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

Source: Authors' elaboration based on Crespo *et al.* (2018) data and analysis on temperature. Conforms to Map No. 4170 Rev. 19 UNITED NATIONS October 2020.

The analysis further shows that there was an increase in mean temperatures over agricultural areas, and for both periods (2011–2015 and 2015–2016) there were more frequently occurring extremely hot conditions (Figure 9). Not only was the percentage of very hot days (TX90p) more frequent, but the hottest days were also hotter.[6] A TX90p above one standard deviation (SD) from the mean (i.e. more hot days) occurring for an increasing number of years supports the evidence of a globally warming climate. The figure shows that particularly extreme conditions are to be found for instance in Brazil, Ethiopia and the Democratic Republic of the Congo, where more frequent hot days have been observed for at least three or more years, or in South Sudan and Yemen that have experienced such extremes for at least four years (66 percent of the time or more) out of the six analysed, 2011–2016 (Figure 9).[7]

FIGURE 9 Number of years with frequent hot days over agriculture cropping areas (2011–2016 compared to 1981–2016)



Notes: The map shows the number of years where the percentage of days when daily temperature is higher than the 90th percentile (TX90p) exceeds the mean percentage plus one annual standard deviation (SD). It uses country aggregate maximum temperature data over agriculture cropping areas. In these cases, climate data are given larger weight where there is cropping compared to where there is not. Areas with insufficient data coverage are denoted in grey. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. Final status of the Abyei area is not yet determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

Source: Authors' elaboration based on Crespo *et al.* (2018) data and analysis on temperature. Conforms to Map No. 4170 Rev. 19 UNITED NATIONS October 2020.

6 TX90p indicates the percentage of days when daily maximum temperature is higher than the 90th percentile.

7 Typically, in a normal distribution, deviations above 1 SD are expected to occur for less than one-third of the time. Thus, considering the six-year time period of 2011–2016, deviations are expected to occur for two out of the six years. Occurrences of extreme hot temperatures for more than two years are worrisome.

3.3 Rainfall: high spatial variability

As seen earlier, historical trends in annual precipitation are far more diverse, with both positive and negative trends depending on the region. There have been more statistically significant regional increases than decreases in heavy rainfall, especially in the more recent 1951–2010 period, but there are strong regional and subregional variations. The six-year period of 2011–2016 was dominated or strongly influenced by rainfall extremes driven by ENSO. This period was for instance marked by the second wettest year over global land on record since 2010 (NOAA, 2012)[8] and the world's driest year over land since 1993 (WMO, 2016).

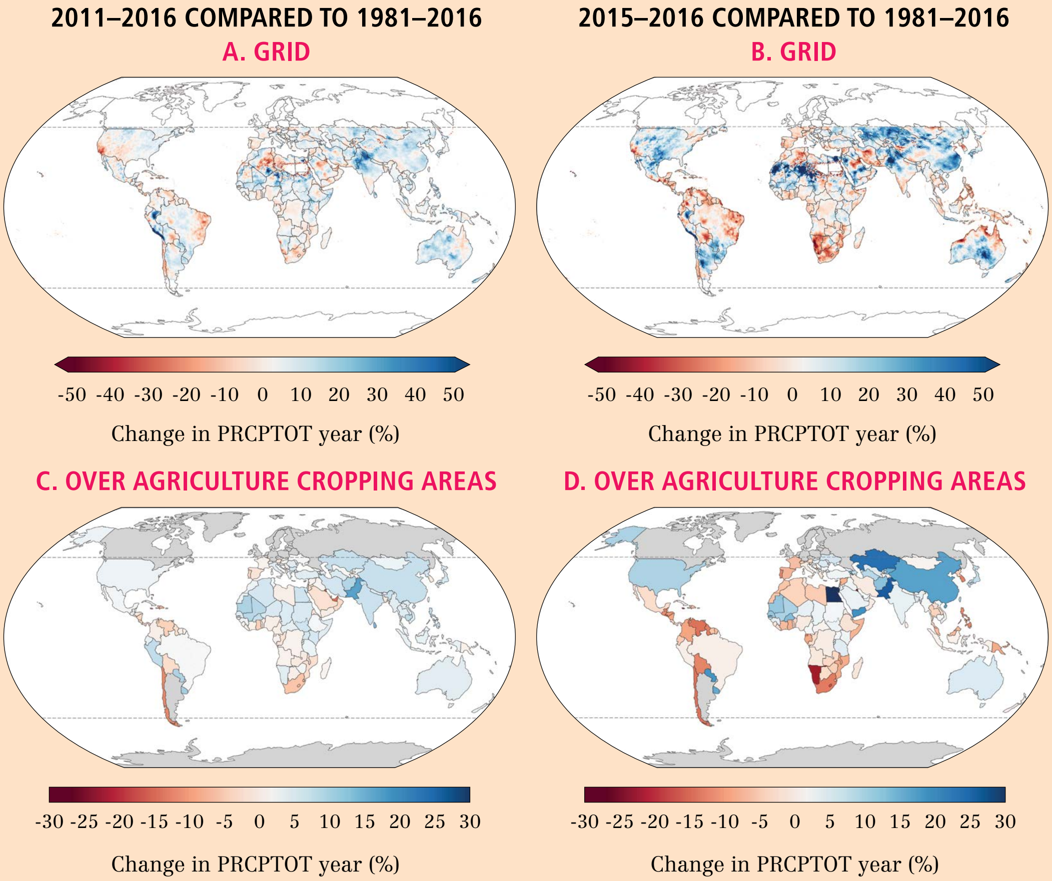
Figure 10 shows the precipitation anomalies over agricultural areas for the 2011–2016 and 2015–2016 periods. Rainfall changes during more recent years (2011–2016) show greater variety and are more balanced between both positive and negative anomalies. They are also less consistent with IPCC-derived rainfall trends than the temperature anomalies.[9] Most notable are the below-normal rainfall levels over much of the globe during the 2015–2016 period, some of which are also evident during the 2011–2016 period, again highlighting the influence climate variability (especially strong global events such as ENSO) has on the sub-decadal time scale. These anomalies are equally striking when applying country crop masks (Figure 10 c, d), with below-normal precipitation levels apparent during 2015–2016 in Africa, Central and South America, South-eastern Asia, the Philippines and Papua New Guinea. These are regions where millions of smallholder farmers, pastoralists and agropastoralists depend on rainfall for their livelihoods.

During the 2015–2016 El Niño, large parts of Asia experienced greater than normal rainfall, with Brazil and Southern Africa experiencing less. These changes are reflected in the anomalies for the longer 2011–2016 period.

8 Global precipitation over land in 2011 was well above the 1961–1990 average for the second year in a row, ranking as the second wettest year on record, behind 2010 (NOAA, 2012) (see www.ncdc.noaa.gov/sotc/global/201113#gprcp).

9 It is important to note that these are not trends (change/year) as in the IPCC figure (Figure 6) above, but rather they are anomalies for each recent period relative to the 1981–2016 reference period. It is not possible to robustly determine rainfall trends over such short analysis periods. Given the large natural variability of annual rainfall from year to year, we wouldn't expect these recent anomalies to strongly align with the century time-scale historical trends analysed in the IPCC figures.

FIGURE 10 Recent precipitation anomalies compared to the 1981–2016 average



Notes: Comparison of average annual precipitation (PRCPTOT) anomalies. The relative changes in precipitation in Panels c) and d) are aggregated per country over agriculture cropping areas. In these cases, climate data are given larger weight where there is cropping compared to where there is not. Areas with insufficient data coverage are denoted in grey. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. Final status of the Abyei area is not yet determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

Source: Authors' elaboration based on Crespo *et al.* (2018) data and analysis on temperature. Conforms to Map No. 4170 Rev. 19 UNITED NATIONS October 2020.

3.4 Changes in seasonality

There is a growing body of evidence that precipitation regimes are also changing, for instance in terms of late and/or early start of rainy seasons and unequal distribution of rainfall within the season. These do not register as extreme weather events, but have a significant impact on food security and nutrition.

A number of studies have highlighted changes in intra-seasonal rainfall and temperatures. For example in the Afram Plains region of Ghana, farmers are noticing delays in the onset of the rainy season, mid-season heat waves, and high-intensity rains that cause flooding, resulting in crop loss and low yields and reducing the availability of household food (Codjoe and Owusu, 2011). Similarly in Wenchi, Ghana, farmers consider both poor rainfall distribution and frequent droughts as the most important climate-related changes

(Adjei-Nsiah *et al.*, 2010). Farmers in the Kagera region of northern United Republic of Tanzania and in the Nigerian savanna are also noticing changing rainfall patterns and shorter growing seasons (Tambo and Abdoulaye, 2013; Trærup and Mertz, 2011). Very few studies, however, have related farmer reports of changing seasonal patterns to actual climatic data from meteorological sources.[10]

It is difficult to make global comparisons between seasonal precipitation distributions and onset and length of seasons, given that these vary depending on the specific crop and livestock systems, the multitude of differing agriculture calendars and the varying seasonal patterns in a given year across regions and countries. It is possible though to examine climate data to determine the frequency of rainfall in a given year (based on the number of rainy days) as well as the distribution of rainfall (based on the average intensity per rainy day). These data demonstrate that many countries and regions have experienced changes in the distribution (frequency and intensity) of rainfall over cropped areas in the last few years.

For example, in the 2011–2016 period analysed, there is evidence of large rainfall deficits, not only through lower total precipitation, but also through lower-intensity and fewer days of rainfall (Figure 11). Smaller amounts of precipitation that occur with considerably lower frequency are particularly problematic for crop production and rangelands, as this can negatively affect the phenology or vegetation growth of plant life cycles (Kimball, 2014). This is particularly true for tropical regions where most precipitation is concentrated during the rainy season, and changes in rainy season onset and length have substantial implications for agricultural production and food security. For instance, areas such as sub-Saharan Africa and north-east Brazil are expected to experience both delays in seasonal onset and shortening of rainy seasons under 1.5 °C and 2.0 °C warming scenarios (Saeed *et al.*, 2018).

Changes in the nature of seasonality, however, are more apparent from an in-depth analysis of inter-annual changes of vegetation phenology retrieved using remote sensing vegetation coverage to detect changes in the length of seasons, as well as their onset. Africa is particularly vulnerable to changes in seasonality due to the predominance of dryland farming and pastoral rangeland activities – therefore we focus on this continent for the remote sensing in-depth analysis. Figure 12 shows the major emerging crop- and rangeland vegetation growing season length (GSL) trends in the African continent (Figure 12a) and the year with the lowest seasonal biomass production proxy (i.e. the seasonal cumulative value of NDVI, or cNDVI) for cropland and rangeland areas (Figure 12b).

The remote sensing analysis shows that the GSL of cropland and rangeland areas have significantly decreased in Western and Southern Africa (red colours), as confirmed by the negative slope values in Figure 12a.[11] Overall, the figure shows that significant reductions in GSL are predominantly seen in Southern African countries. Spatial patterns are evident when observing the most extreme years in terms of lower vegetation production for the period 2004–2016 (Figure 12b).[12]

[10] Exceptions are Debela *et al.* (2015) where in the two decades of the study in Borno, Ethiopia (1992–2012), rainfall was less, rainy days were fewer and temperatures were higher, in comparison to the preceding decade 1980–1992.

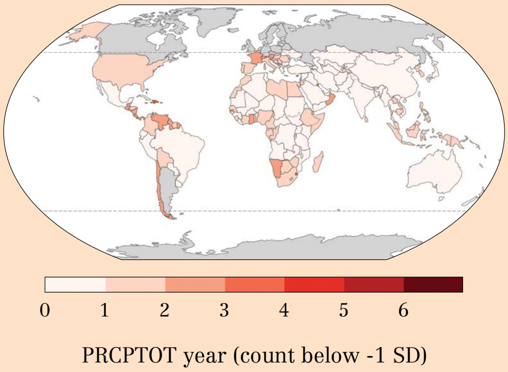
[11] The phenological parameters used to capture the length and onset date of a season include, among others, the start of season (SOS), the time of maximum NDVI (TOM), the end of season (EOS) and the resulting growing season length (GSL). Regarding SOS and EOS, a positive trend indicates a delay of the timing whereas a negative trend indicates an anticipation. Regarding GSL, a positive trend indicates an increase in season length, and a negative trend indicates a decrease. Maps in Figure 12refer to the only growing season in monomodal areas (e.g. unique growing season), and to the first growing season in bimodal areas (e.g. two growing seasons).

[12] The proxy for the lowest seasonal biomass production is the seasonal cumulative value of NDVI (cNDVI). The NDVI is used to detect anomalies during the growing season over the 2003–2016 period. The index is a satellite-derived 10-day period index at 1 km spatial resolution. To exclude non-extreme years, areas with a reduction of cNDVI smaller than 10 percent of the multiannual average cNDVI are masked out.

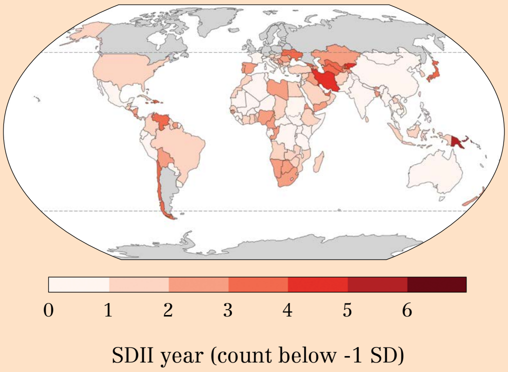
Some spatial variations are evident. In Southern African countries including South Africa, Botswana, Namibia, southern Angola, Lesotho, and parts of Mozambique, Zambia and Malawi, blue areas indicate that the 2015–2016 El Niño years were the ones with the lowest biomass production. Also, during the 2004–2005 El Niño, minimal biomass production was observed in many Southern African countries as well as parts of Central Africa (Figure 12b).

FIGURE 11 Recent negative anomalies in total annual precipitation and in precipitation intensity and frequency (2011–2016 compared to 1981–2016)

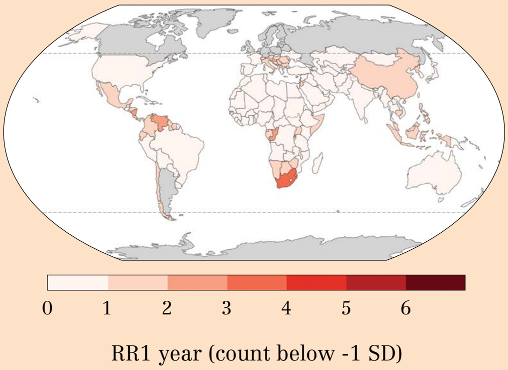
A. ANOMALIES IN TOTAL ANNUAL PRECIPITATION



B. ANOMALIES IN PRECIPITATION INTENSITY



C. ANOMALIES IN PRECIPITATION FREQUENCY



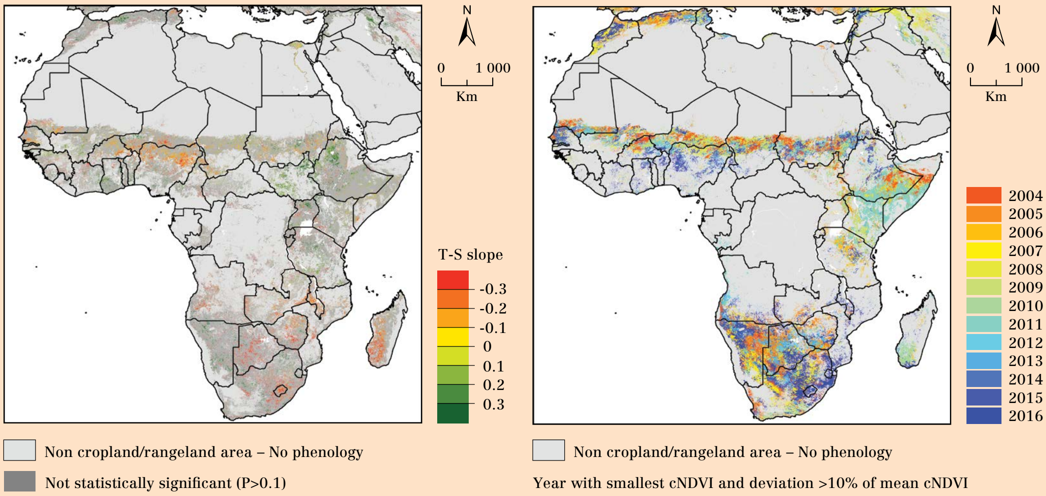
Notes: The maps show the number of years a country experienced negative precipitation anomalies in the period 2011–2016 in terms of: a) total accumulated annual rainfall as measured by total annual precipitation (PRCPTOT); b) rainfall intensity as measured by the ratio of annual total rainfall to the number of days during the year when rainfall occurred (SDII); and c) precipitation frequency as measured by the number of days when rainfall was above 1 mm (RR1). Anomalies occurring in more than three years out of seven for the period 2011–2016 is considered outside normal variation (below - 1 standard deviation [SD]). Country climate data are aggregated over cropping areas smoothed for small-scale (geographically) events, especially in large countries. Areas with insufficient data coverage are denoted in grey. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. Final status of the Abyei area is not yet determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

Source: Authors' elaboration based on Crespo *et al.* (2018) data and analysis on temperature. Conforms to Map No. 4170 Rev. 19 UNITED NATIONS October 2020.

FIGURE 12 Decreased growing season length and poorest cumulative normalized difference vegetation index over cropland and rangeland areas, 2004–2017

A. GSL FIRST SEASON – CROPLANDS AND RANGELANDS

B. ANNUAL cNDVI – CROPLANDS AND RANGELANDS



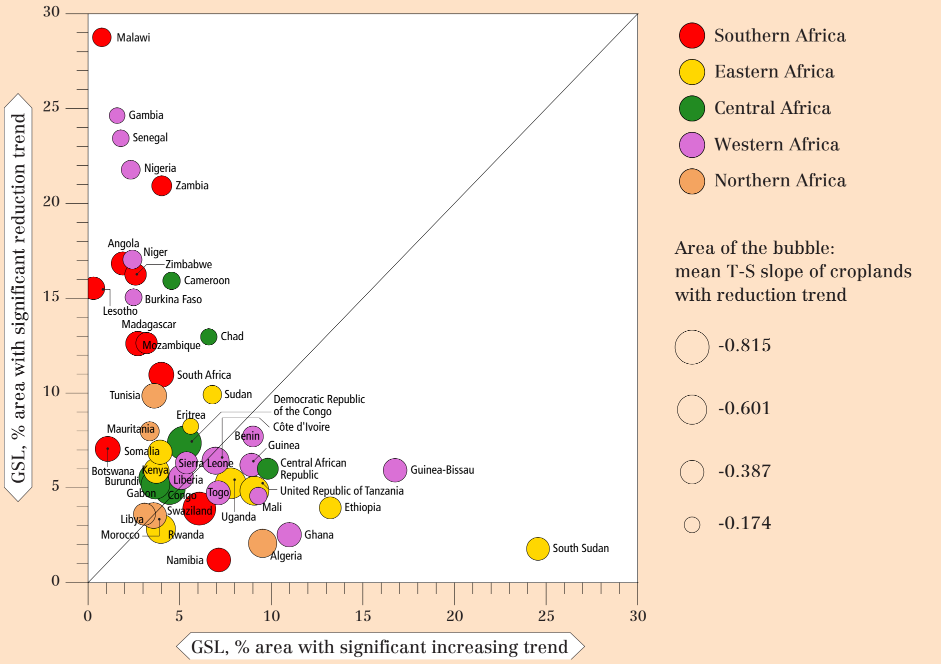
Notes: a) shows cropland and rangeland vegetation growing season length (GSL) trends. The orange to red colours denote areas with significantly reduced GSLs; b) shows the year with the lowest annual vegetation biomass production based on remote sensing vegetation coverage data, represented through the annual cumulative value of the normalized difference vegetation index (cNDVI). The colour scale indicates which year was most extreme in terms of minimum vegetation production. The T-S slope is the average change in dekad (10-day period) per year. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. Final status of the Abyei area is not yet determined.

Source: Authors' elaboration based on data from the European Commission. 2020. NDVI – Normalized Difference Vegetation Index and GSL – Growing Season Length. In: *European Commission* [online]. [Cited 2 October 2020]. https://mars.jrc.ec.europa.eu/asap. Conforms to Map No. 4045 Rev. 8.1 UNITED NATIONS July 2018.

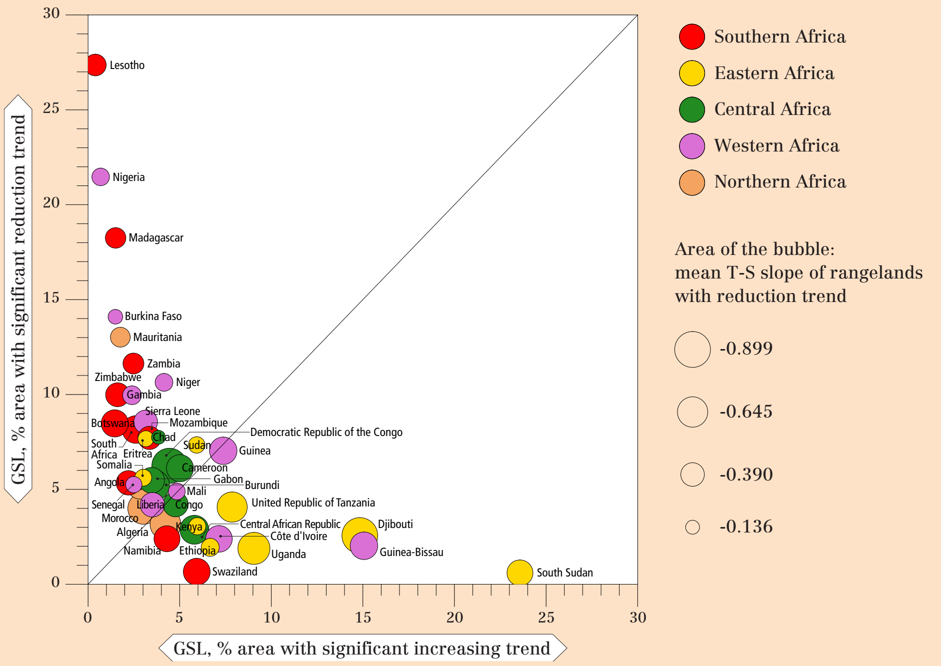
The scatter plots of Figure 13 give an overview of the areas affected by the GSL trend for all African countries, grouped by macroregions. According to the scatter plot for croplands, the country with the largest area affected by significant GSL reduction is Malawi, followed by a group of Western African countries and Zambia. For pastoral areas, Lesotho is the country with the largest area affected by shortening growing seasons, followed by Nigeria and Madagascar. It must be noted, however, that part of the changes might not be climate-related and could be explained by land use change due to land degradation in the areas with shortening seasons, or conversion to agriculture and especially irrigation in the areas with lengthening seasons.

FIGURE 13 Cropland and rangeland reduction in length of the first growing season

A. CROPLANDS, SEASON 1



B. RANGELANDS, SEASON 1



Notes: Scatter plot of the percentage of the crop area showing a significant increasing trend in growing season length (GSL) vs that showing a significant reduction trend. Data points refer to cropland a) and rangeland b) area and trend of monomodal areas and first seasons of bimodal areas. The T-S slope is the average change in dekad (10-day period) per year.

Source: Authors' elaboration based on data from the European Commission. 2020. GSL – Growing Season Length. In: *European Commission* [online]. [Cited 2 October 2020]. https://mars.jrc.ec.europa.eu/asap

3.5 Severe drought

Evidence from several studies show that recent years have been characterized by a number of severe droughts in many regions – some of the most extreme droughts historically (e.g. California in the United States of America, Australia) and droughts that were unusually prolonged and extended over larger areas (e.g. Somalia, Southern Africa, India and the Central American Dry Corridor) (Blunden and Arndt, 2016; Griffin and Anchukaitis, 2014; WMO, 2016).

Drought is a complex phenomenon which originates from anomalous rainfall deficiency and results in lower runoff, soil moisture and groundwater, and finally in the shortage of available fresh water for plants, animals and humans. However, drought does not depend only on precipitation but also on other factors such as air temperature, humidity and winds, which can substantially contribute to exacerbate drought impact.

For this reason, while drought occurrence is associated with climate variables, especially low rainfall and high temperature, it is analysed more directly by using the NDVI that measures the impact of extreme weather events (water stress and high temperature) on croplands and rangelands. In this study, agricultural drought conditions are derived from an indicator that summarizes the severity of NDVI anomalies – the Anomaly Hotspots of Agriculture Production (ASAP) early warning system. This indicator measures the percentage of time when ASAP warnings (i.e. severe drought) are observed in specific areas.[13]

The analysis shows that there was a high frequency of drought conditions in 2015–2017 compared to 2004–2017, confirming the strong impact of the 2015–2016 El Niño on agricultural cropping areas (Figure 14). Compared to 2004–2017, parts of Central America, Brazil and the Caribbean as well as Australia and parts of the Near East experienced higher frequency in drought conditions during 2015–2017. Also the Sahel, the Horn of Africa and Southern Africa were strongly affected by drought. These areas (coloured in dark red) have been affected by drought for more than 16 percent of the dekads, which means an average of at least 6 dekads per year.

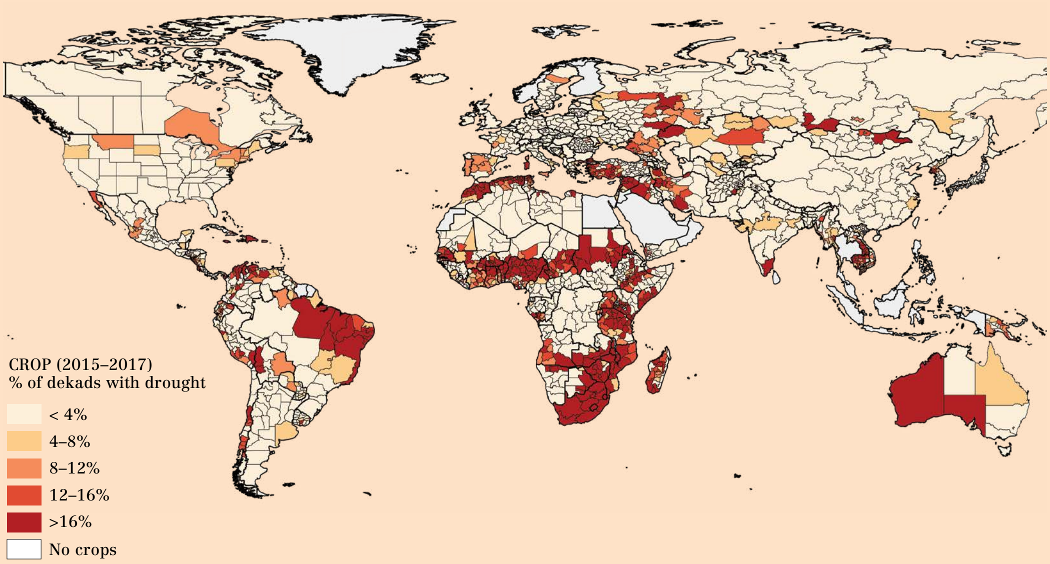
A report of the International Organization for Migration shows that El Niño-driven drought was the major factor contributing to the greatest number of people newly displaced in Ethiopia in the first quarter of 2016, compared to the same time frame in the three previous years: 2013, 2014 and 2015 (WMO, 2017). Years 2012–2015 saw the return of widespread rainfall deficiencies across large parts of Australia since the end of the 2010 and 2011 La Niña events. The failure of the northern wet season in much of Queensland (Australia) in 2012–2015 contributed to these deficiencies (BOM, 2015). Over the longer time period (2004–2017) frequent drought conditions have been observed also in Spain, Central and Southern Asia, Eastern Europe and California. California experienced the most severe drought events during 2012–2014, with a peak in 2014 which was the worst drought of the last 1 200 years (Griffin and Anchukaitis, 2014).

Although global-level drought conditions are useful for observing some of the major dynamics at a global scale (like the El Niño years), interannual differences become more clearly visible when looking at geographic regions or single countries. For example, Figure 15 shows the drought conditions frequency for the African continent only. Percentages are higher compared to the global figures, and the frequency of drought conditions are increasing towards the end of the time series – the latter result being associated with the effects of El Niño in 2015–2016.

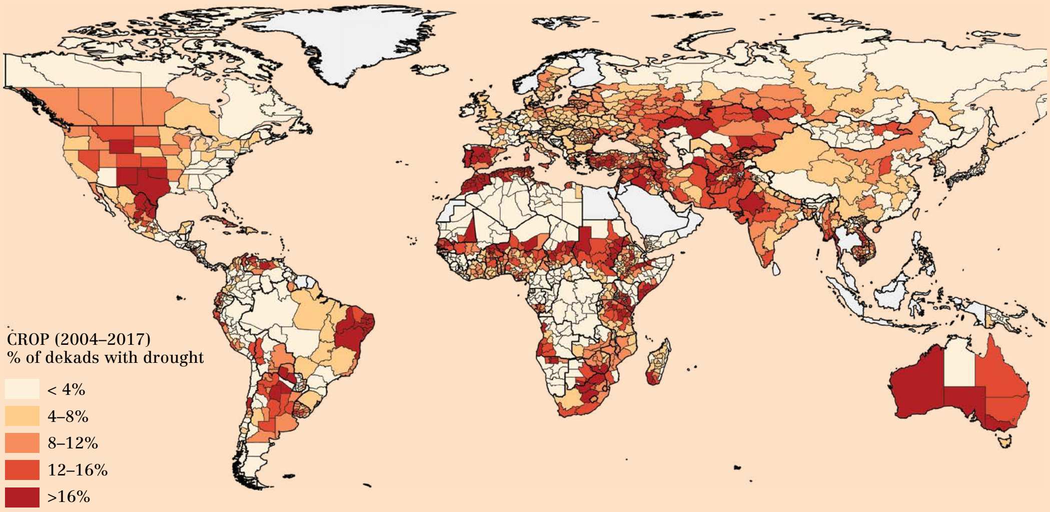
13 In particular, the percentage of time is expressed as the percentage of dekads (10-day periods) when a severe standardized NDVI anomaly (i.e. anomaly < -1 SD) of the cumulative value of NDVI is observed over large areas (i.e. more than 25 percent of crop and rangeland areas within an administrative unit).

FIGURE 14 Frequency of drought conditions during the 2015–2017 El Niño compared to the 2004–2017 average

A. OVER AGRICULTURE CROPPING AREAS (2015–2017)



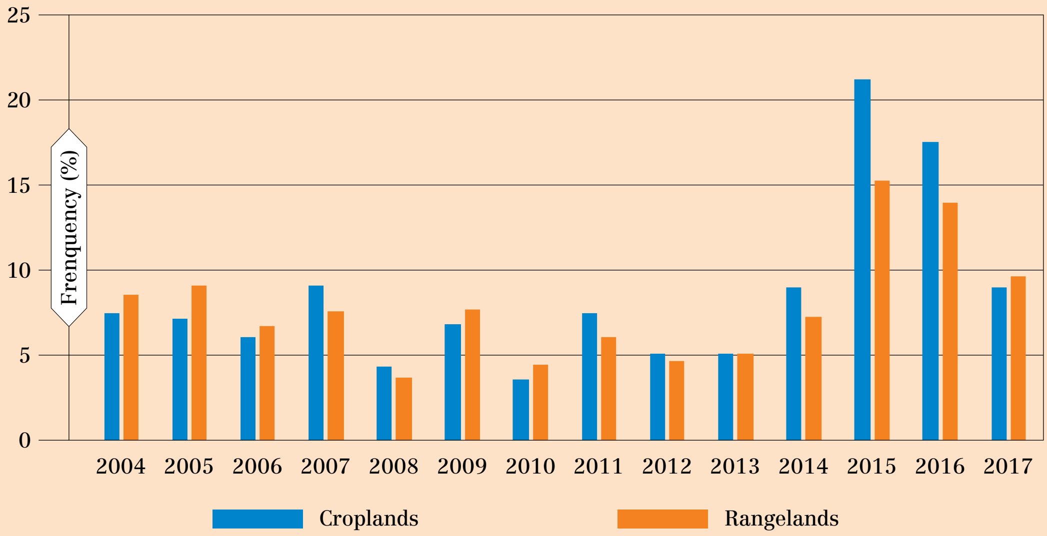
B. OVER AGRICULTURE CROPPING AREAS (2004–2017)



Notes: Figure shows the percentage of time (a dekad is a 10-day period) with active vegetation when the Anomaly Hotspots of Agriculture Production (ASAP) warning system signalled possible agricultural production anomalies according to normalized difference vegetation index (NDVI) drought warnings for more than 25 percent of the crop areas in 2015–2017 (panel a) compared to 2004–2017 (panel b). Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. Final status of the Abyei area is not yet determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

Source: Authors' elaborations based on data from the European Commission. 2020. ASAP – Anomaly Hotspots of Agricultural Production. In: *European Commission* [online]. [Cited 2 October 2020]. https://mars.jrc.ec.europa.eu/asap. Conforms to Map No. 4170 Rev. 19 UNITED NATIONS October 2020.

FIGURE 15 Drought conditions in Africa: frequency for croplands and rangelands (2004–2017)



Note: Drought conditions frequency (percentage of active dekads) for cropland (blue) and rangeland (orange) areas for Africa.

Source: Authors' elaborations based on data from the European Commission. 2020. ASAP – Anomaly Hotspots of Agricultural Production. In: *European Commission* [online]. [Cited 2 October 2020]. https://mars.jrc.ec.europa.eu/asap

3.6 Severe floods and storms

Floods are the leading cause of weather-related disasters globally. As shown earlier, there are more natural disasters due to floods than any other extreme weather-related disasters (Figure 2) and they have the highest increase in occurrence over the last 25 years (a 65 percent increase). Quite alarmingly, 73 percent of the world population will experience increasing flood risk in the future, with an average increase of 100 percent at a global warming of 1.5 °C, and a 170 percent increase at 2 °C warming, compared to the impact measured using the reference period 1976–2005 (Alfieri *et al.*, 2017; Hoegh-Guldberg *et al.*, 2018).

Asia is the region with the highest occurrence of flood disasters, followed by Africa and Latin America and the Caribbean (Figure 16a). Flood-related disasters in Africa, however, have declined dramatically since 2006, and were surpassed by those in Latin America and the Caribbean in 2013. Asia, India, Indonesia, Pakistan, the Philippines and Viet Nam record the highest number of multiple flood-related disasters every year, though the number and magnitude varies over time. Other Asian countries experiencing flood disasters include Thailand, the Lao People's Democratic Republic, and Malaysia.

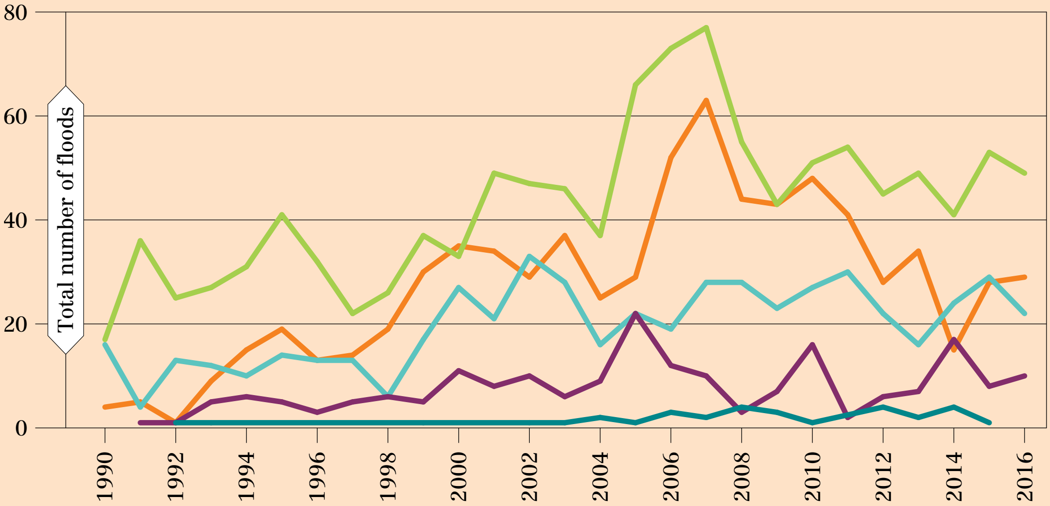
Storms are the second-largest driver of climate-related disasters (Figure 2), occurring most often in Asia (Figure 16b).[14] Storm-related disasters in this continent average between twenty and thirty every year. Latin America and the Caribbean have the second highest occurrence of storm-related disasters, though countries in the Caribbean account for most of the flood disasters for this region. Africa also registers some of the highest numbers of

[14] Severe storms and cyclones, also referred to as hurricanes and typhoons in some regions, cause powerful winds, torrential rains, high waves, and storm surges – all of which can have major impacts on society and ecosystems. It is estimated that about 90 tropical cyclones occur globally each year, although interannual variability is large.

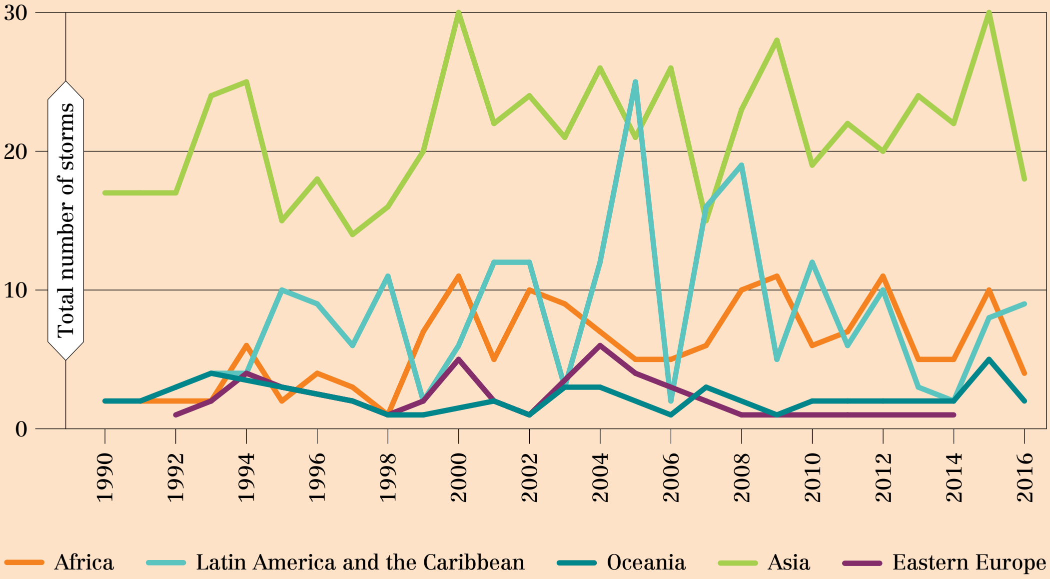
storm-related disasters, however these tend to be more localized (Figure 16b). River floods, oceanic storm surges and tropical cyclones negatively impact on low-lying areas, flood plains and deltas. A detailed study of 33 deltas around the world found that 85 percent had experienced severe flooding in the past decade, causing the temporary submergence of 260 000 km of land (Syvitski *et al.*, 2009).

FIGURE 16 Frequency of flood- and storm-related disasters by region (1990–2016)

A. FLOOD DISASTERS BY REGION, 1990–2016



B. STORM DISASTERS BY REGION, 1990–2016



Notes: Total number of storm- and flood-related disasters by region in low- and middle-income countries during the period 1990–2016.

Source: Authors' elaboration based on data from CRED. 2017. EM-DAT - the international disasters database. In: *Centre for Research on the Epidemiology of Disasters (CRED)* [online]. [Cited 2 October 2020]. https://www.emdat.be

Storms in African countries are not common, and their occurrence is localized (around

1 000–2 000 people affected in Mozambique, Zimbabwe and Nigeria in 2016), with the exception of Madagascar that experienced two storms in 2015 involving a much higher number of people (182 437). For many areas, exposure of populations and assets to delta and coastal flooding is growing faster than national averages owing to coastward migration, coastal industrialization, and urbanization (IPCC, 2014; McGranahan, Balk and Anderson, 2007; Seto, 2011; Smith, 2011). Increased landslide impacts (measured by casualties or losses) in Southern and South-eastern Asia, where landslides are triggered predominantly by monsoon and tropical cyclone activity, are largely attributed to population growth leading to increased exposure (Petley, 2012).

Although the number of flood- and storm-related disasters has increased, the number of people affected has declined over time. An analysis of annual fatalities from tropical cyclones showed these to be heavily concentrated in low-income nations, even though there was high exposure in many upper-middle- and high-income nations (with larger economic losses in these nations as well) (UNISDR, 2009). A regional analysis of changes in exposure, vulnerability and risk indicates that although exposure to flood and cyclone hazards has increased since 1980, the risk of mortality has generally fallen.

Although the risk of mortality has declined, evidence presented in Section 4 suggests that the risk of food insecurity and malnutrition has increased due to the high vulnerability of agriculture, food systems, and livelihoods to floods and storms.

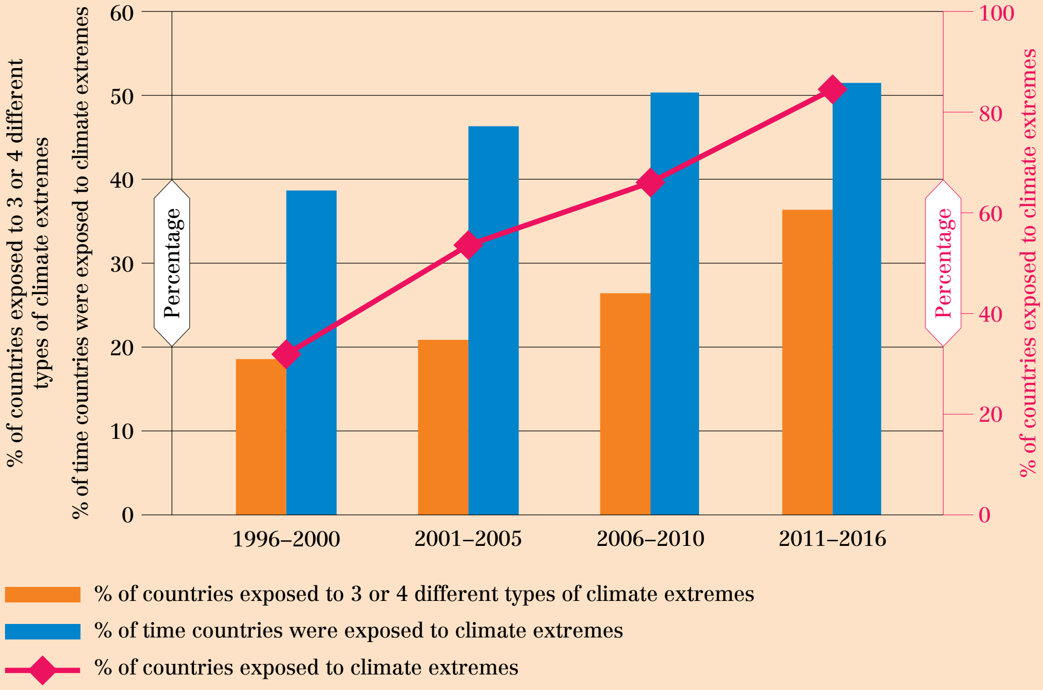
3.7 Increased exposure to climate extremes

In the last 20 years, not only has countries' exposure to climate extremes risen in terms of both frequency and intensity, but these increases have occurred in countries already vulnerable to the risk of food insecurity and malnutrition. Specifically, there has been an increase in exposure to climate shocks such as drought, floods, storms and heat spells in low- and middle-income countries where undernourishment, production and yields are already vulnerable to the effects of such events.

An analysis of country exposure among low- and middle-income countries to climate shocks shows that not only are more of these countries exposed to climate shocks, but the frequency, in terms of number of years exposed in a five-year period, and the intensity of exposure, in terms of the number of types of climate extremes in a five-year period, have both increased (Figure 17). For definitions of climate extremes and exposure, see Annex 2.

The number of low- and middle-income countries exposed to these shocks has increased from 83 percent in the period 1996–2000 to 96 percent in the period 2011–2016 (Figure 17). The frequency or total number of years when these countries were exposed to climate extremes was more than 30 percent between 1996–2000 and 2011–2016. On average, countries experienced climate extremes for at least 2 out of 5 years in 1996–2000, 2.4 years in 2006–2010, and 3 years in 2011–2016. There is also a notable increase in the occurrence of multiple types of climate shocks over the past 20 years. Whereas only 18 percent of the countries were exposed to three or four types of climate extremes (extreme heat, drought, floods or storms) in 1996–2000, this increased to 36 percent by 2011–2016. In other words, the number doubled in the last 20 years.

FIGURE 17 Increased exposure to more frequent and multiple types of climate extremes in low- and middle-income countries



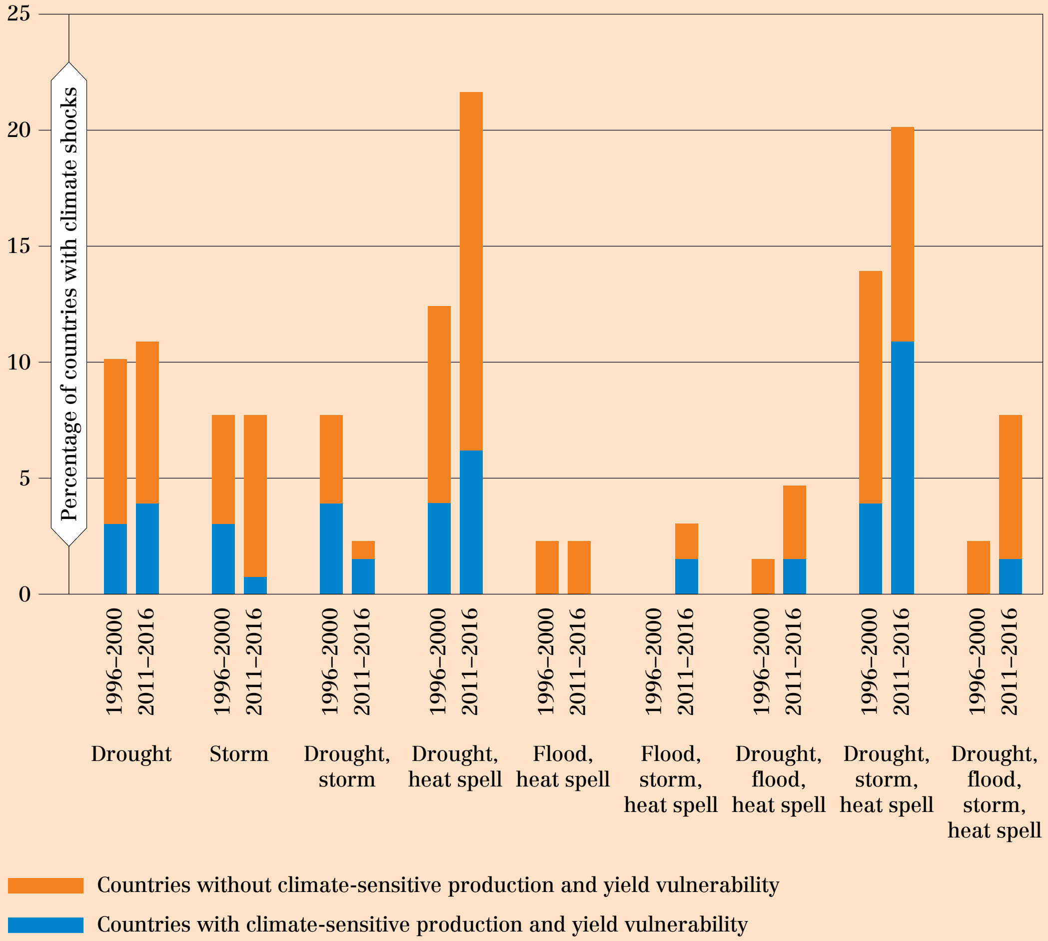
Note: Percentage of low- and middle-income countries exposed to three or four types of climate extremes (extreme heat, drought, floods and storms) during any of the periods shown; percentage of time (based on the average number of years within a period) that a country was exposed to climate extremes; and percentage of countries exposed to at least one climate extreme in each period. Results are presented using five-year periods, except for 2011–2016 which is a six-year period. See Annex 2 for definitions of exposure to climate extremes and Annex 4 for country group definition. Analysis is only for low- and middle-income countries.

Source: Authors' elaborations based on data from the European Commission for the Anomaly Hotspots of Agriculture Production (ASAP); EM-DAT - the international disasters database for data on storms; Crespo *et al.* (2018) for analysis on extreme heat spells and precipitation.

A closer look shows how striking the increase is in the occurrence of multiple types of climate shocks over the past twenty years (Figure 18). While droughts and heat spells occurred during 1996–2000 in 12.4 percent of the countries analysed, by 2011–2016, the percentage of countries hit by the two shocks increased to 21.7 percent (an increase of 9.3 percentage points), with a consistent increase in countries with production and yields vulnerable to climate extremes. Similarly, only 14 percent of countries were hit by droughts, storms and heat spells in the first period, whereas this increased to 20.2 percent of the countries in the last period (i.e. more than doubled). Finally, the percentage of countries experiencing all four shocks during the two periods increased from 2.3 percent in 1996–2000 to 7.8 percent in 2011–2016 (more than triple).

At the regional level, the analysis reveals even greater increases in the intensity of climate extremes compared to the global averages (see Annex 4 for list of countries). For instance, the occurrence of three or more different types of climate extremes has increased by 160 percent for countries in Africa, from 10 percent in 1996–2000 to 25 percent in 2011–2016. Similarly, the percentage of Asian countries experiencing multiple shocks more than doubled to 51 percent in 2011–2016, up from 23 percent in 1996–2000. The intensity of climate extremes in Latin America and the Caribbean also more than doubled, from 26 percent in 1996–2000 to 56.5 percent in 2011–2016.

FIGURE 18 **Change in occurrence of climate extreme typologies, and production and yield vulnerability to climate variability and extremes (1996–2000 vs 2011–2016)**



Note: Percent of low- and middle-income countries affected by climate extremes by event typology and time – years 1996–2000 vs 2011–2016. Stacked columns denote the countries where national production and yields are vulnerable to climate variability and extremes (blue) and those which are not (orange).

Source: Authors' elaborations based on data from the European Commission for the Anomaly Hotspots of Agriculture Production (ASAP); EM-DAT - the international disasters database for data on storms; Crespo *et al.* (2018) for analysis on extreme heat spells and precipitation.

Many countries – especially in Africa and Asia – are also now more exposed to changing seasonal or intra-seasonal climate variability, either in terms of early or delayed onset of growing seasons, decreased growing season length, or both. Fifty-one low- and middle-income countries experienced early or delayed onset of seasons, 29 experienced seasons of shorter length, and 28 experienced both. This is an added risk factor affecting food security and nutrition. Furthermore, we observe that all countries exposed to intra-seasonal variability are also exposed to climate extremes (Annex 4).

4 Climate impacts on agriculture and food security

KEY MESSAGES

- Increased climate variability and extremes inflicts high levels of economic loss on agriculture and often trigger changes in agricultural trade flows, leading to increased import expenditures and reduced export revenues for several countries.
- Climate impacts on agricultural incomes are significant given the high level of dependency of the poor and of food-insecure people on agriculture for their incomes, including rural agricultural labourers, family farmers and smallholder producers.
- Climate is negatively impacting food access, not only through lower incomes that reduce people's ability to purchase food, but also through spikes and volatility in food prices which tend to follow climate extremes.
- Climate variability and extremes are a key driver behind the recent rise in global hunger and one of the leading causes of severe food crises.
- Severe droughts linked to the strong El Niño of 2015–2016 affected many countries, contributing to the recent uptick in undernourishment at the global level.
- Hunger is significantly worse in countries with agricultural systems that are highly sensitive to rainfall and temperature variability and to severe drought, and where the livelihoods of a high proportion of the population depend on agriculture.

It is clear from the above analysis that climate variability and extremes have increased in the current decade compared to the last four decades. The increase in global hunger, occurring consecutively for the last two years after more than two decades of decline, brings increased urgency to understanding the role of climate variability and extremes. Increasing climate variability and extremes directly affect food security, primarily through its impact on agriculture, given the latter's sensitivity to climate and its primary role in determining food supply and providing livelihoods for the rural poor.

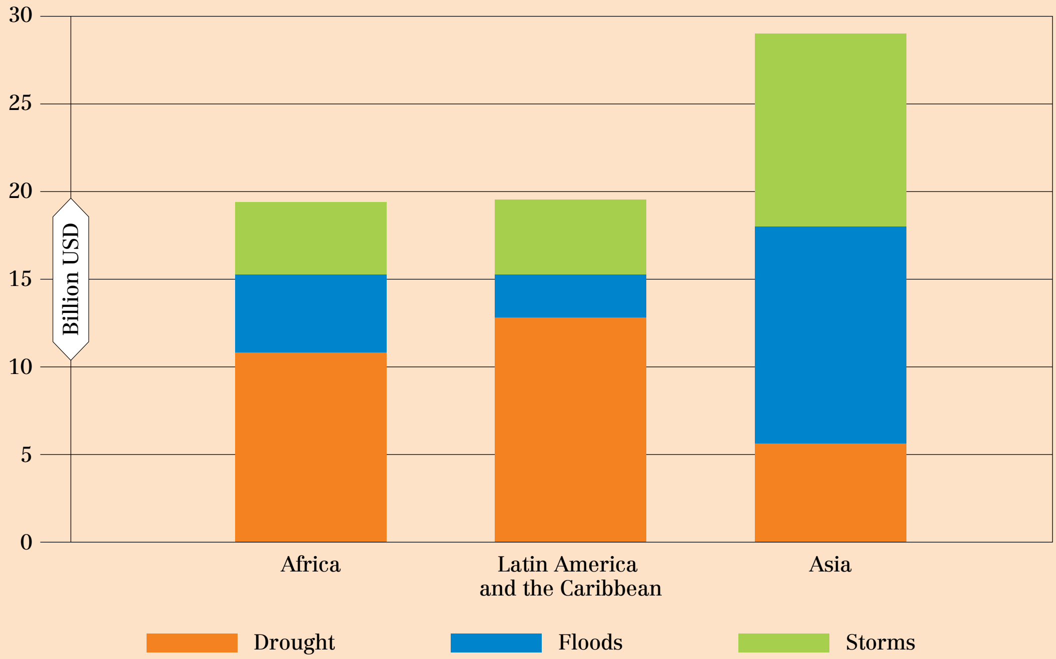
Increased climate variability and extremes are directly and indirectly impacting all four dimensions of food security (availability, access, utilization and stability), with cascading impacts that combine to undermine food security and nutrition. Food security and nutrition is particularly undermined through combined effects on the livelihoods of low-income populations, who have less capacity to cope and adapt and who depend on highly climate-sensitive activities, such as agriculture and natural resources, for livelihoods. When climate shocks caused by extreme weather events lead to wider impacts on food systems, including the disruption of markets, food price increases, and loss of incomes and assets, these can have more far-reaching impacts, affecting the ability of the poor (both rural and urban) to purchase food, as well as affecting the nutrient content of food.

4.1 Impacts on agriculture

Medium- and large-scale climate shocks related to increasing climate variability and extremes inflict high levels of economic loss on agriculture. Estimates of the financial costs to developing countries alone in terms of losses to crops and livestock is estimated at USD 80 billion for the ten-year period of 2003–2013 (Figure 19) (FAO, 2015). It is estimated that more than 25 percent of all economic losses and damages inflicted by medium- and large-scale climate shocks in developing countries fall on the agriculture sector. Where extreme climatic events lead to recurring natural disasters, the accumulated costs for the agricultural sector are even more significant. For example, between 2006 and 2013 the Philippines was struck by 75 disasters (mostly typhoons, tropical storms and floods) which caused accumulated damage and losses of some USD 3.8 billion to the country's agriculture sector, an average of USD 477 million per year – about one-quarter of the national budget allocated to the sector in 2014 (FAO, 2015).

In an analysis of 140 medium- and large-scale climate- and weather-related disasters that occurred in 67 developing countries between 2003 and 2013, a significant negative trend was seen in agriculture value-added growth[15] in 55 percent of the disasters. The study found that after each disaster there was an average loss of 2.6 percent of national agriculture value-added growth, with a much more significant impact likely at subnational levels (FAO, 2015).

FIGURE 19 Crop and livestock losses caused by climate-related disasters by region, in USD billions (2004–2015)



Note: Climate-related disasters in the analysis include drought, floods and storms.

Source: FAO. 2015. *The impact of natural hazards and disasters on agriculture, food security and nutrition.* Rome.

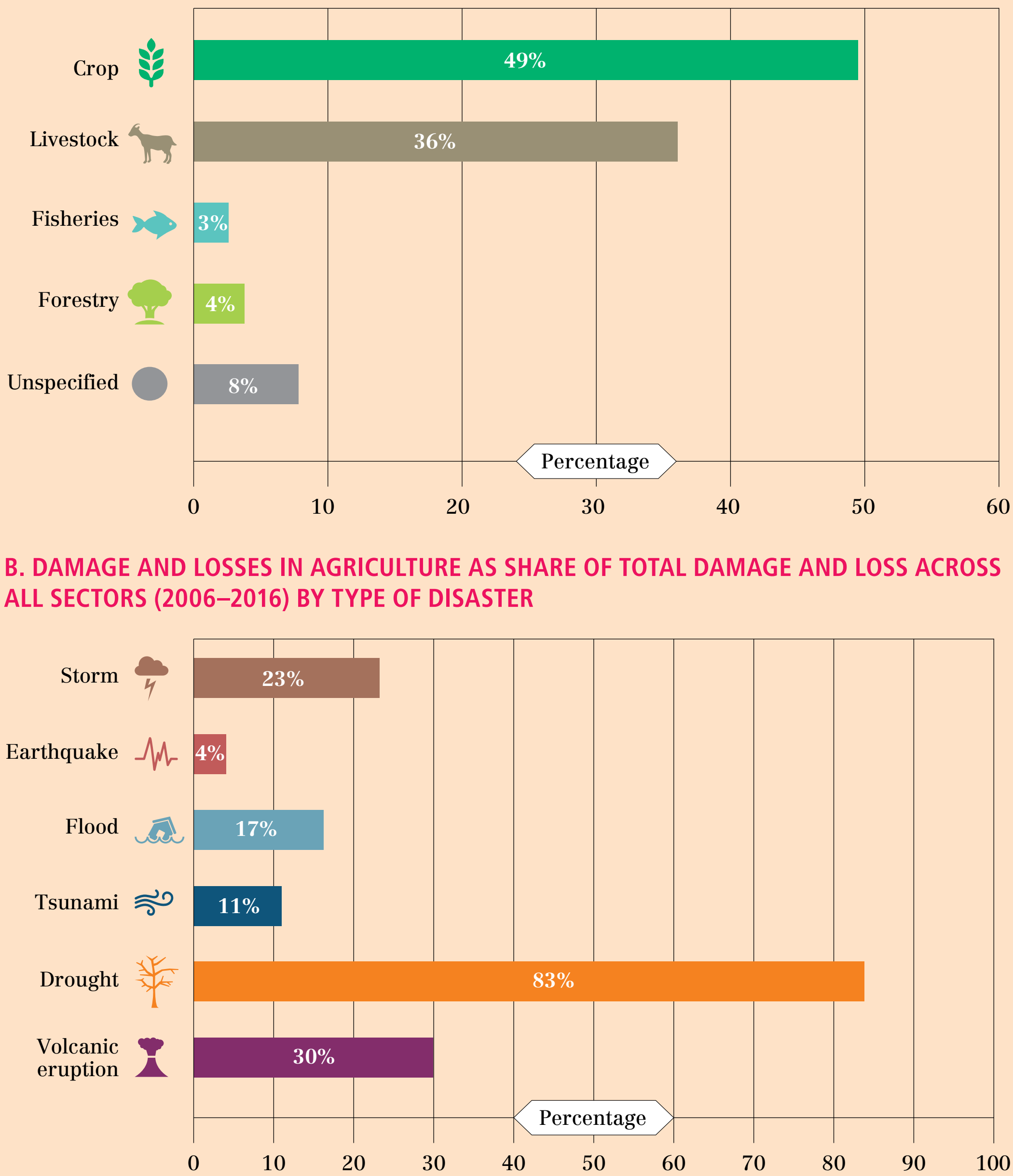
15 Agriculture value added is the net output of the agriculture sector and subsectors after adding all outputs and subtracting intermediate inputs. Agriculture value-added growth is the annual percentage change in agriculture value added.

These damages and losses to the agriculture sector are largest for the crop production and livestock production subsectors. For example, more than 80 percent of the damage and losses caused by droughts affect the agricultural sector, especially crop production and livestock (Figure 20). Fisheries are most affected by tsunamis and storms, whereas the strongest economic impacts on forestry are caused by floods and storms (FAO, 2015).

FIGURE 20 Damages and losses in agriculture due to climate-related disasters, by subsector and type of disaster (2006–2016)

A. DAMAGE AND LOSSES IN AGRICULTURE BY AGRICULTURE SUBSECTOR, PERCENTAGE SHARE OF TOTAL (2006–2016)

B. DAMAGE AND LOSSES IN AGRICULTURE AS SHARE OF TOTAL DAMAGE AND LOSS ACROSS ALL SECTORS (2006–2016) BY TYPE OF DISASTER



Notes: FAO, based on Post Disaster Needs Assessments (PDNA), 2006–2016. The sectors of fisheries, aquaculture and forestry often are under-reported. Impact of disasters on forestry is generally acknowledged in assessments, although rarely quantified in monetary terms.

Source: FAO. 2018. *The impact of disasters and crises on agriculture and food security 2017*. Rome.

The above-mentioned statistical analysis (FAO, 2015) of natural disasters occurring between 2003 and 2013 estimated that approximately USD 80 billion was lost as a result of declines in crop and livestock production after natural disasters caused by extreme weather.[16] This corresponds to 333 million tonnes of cereal, pulses, meat, milk and other commodities, or an average of 7 percent of national per capita dietary energy supply (DES) after each disaster. This is already significant at the national level, but is likely higher at the subnational level, where losses in calories may increase household food insecurity unless relevant measures are taken to compensate and fill the gap in DES (FAO, 2015).

Country case studies presented in the next section illustrate the severity of the impact of climate extremes on agriculture, and the repercussions in terms of livelihood loss, food insecurity and malnutrition. For example, the Central American Dry Corridor (see Section 5.3), in particular in Guatemala, Honduras and El Salvador, was heavily impacted by the El Niño phenomenon in 2015–2016, leading to severe and prolonged drought impacts that resulted in significant reductions in agriculture production, with losses estimated between 50 and 90 percent of crop harvest (FAO, 2016a). Similarly, in Southern Africa the strong El Niño in 2015–2016 induced a drought, the worst in 35 years, which led to an extensive regional-scale crop failure and a regional cereal deficit of 7.9 million tonnes in early 2016 (see Section 5.1) (FNSWG, 2016). This had a devastating impact on the millions of smallholder subsistence farmers reliant on crop production for their food and livelihoods, forcing them to become almost entirely dependent on the markets for food.

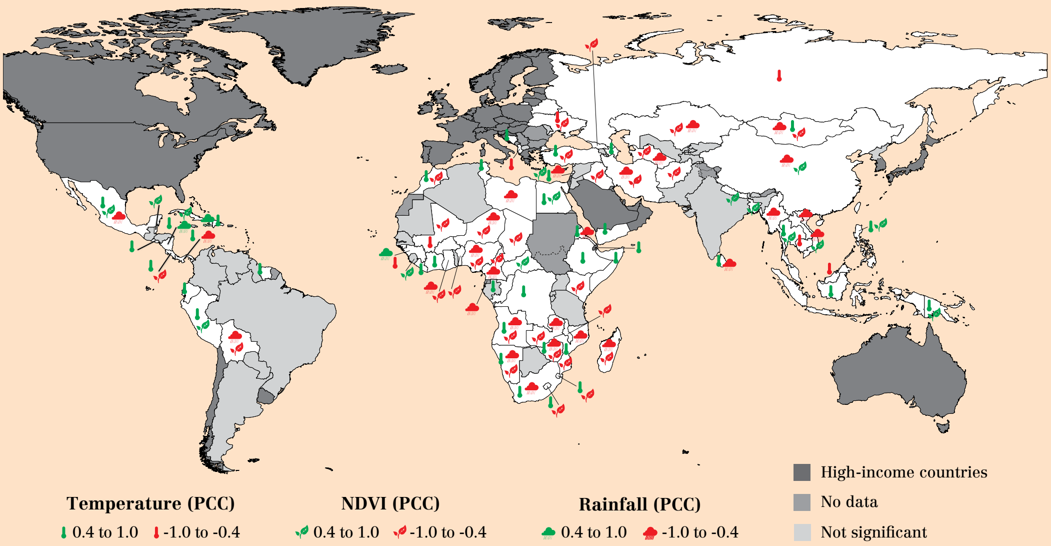
Climate-related disaster damages and losses in the livestock subsector, mainly due to severe drought, accounted for 36 percent of all agricultural damages in losses in 2006–2016 (Figure 20). Livestock mortality depends on both positive and negative rainfall extremes and can rapidly increase either due to drought-induced fodder and water deficits or diseases spread by excessive rainfall. In the Eastern African drylands for example, the increased drought frequency since 2009, alternated with more intense rainfall, has resulted in high livestock losses and forced the most vulnerable small-scale herders into alternative livelihoods (Gitonga *et al.*, 2013). The negative impact of drought on the livestock sector in the Horn of Africa in recent years is significant (see Section 5.2), affecting livestock grazing, production, income, trade, and terms of trade – which in turn severely impact on food security and nutrition.

Climate variability and extremes also affect food imports as countries try to compensate for domestic production losses (Figure 21). For low- and middle-income countries, high temperatures and low rainfall / low NDVI generally show a significant correlation with high cereal imports, indicating vulnerability to climate variability and extremes. This applies to the MENA countries and those in Western and Southern Africa, while in Eastern Africa and Central America temperature seems to be the single indicator most directly linked to imports.

An in-depth analysis of the impact of droughts in sub-Saharan Africa provides a stark illustration of this. The study estimates that after the occurrence of droughts between 1991 and 2011 in the region, food imports increased by USD 6 billion and exports of the same commodities fell by nearly USD 2 billion. Further, countries lost an average of 3.5 percent of agriculture value-added growth after each drought – arguably, a figure that is likely to be more acute at the subnational level.

16 The statistical analysis used FAO agricultural databases to help quantify crop and livestock production losses, as well as changes in trade flows and agriculture value-added performance.

FIGURE 21 Correlation between climate variability and extremes and cereal imports

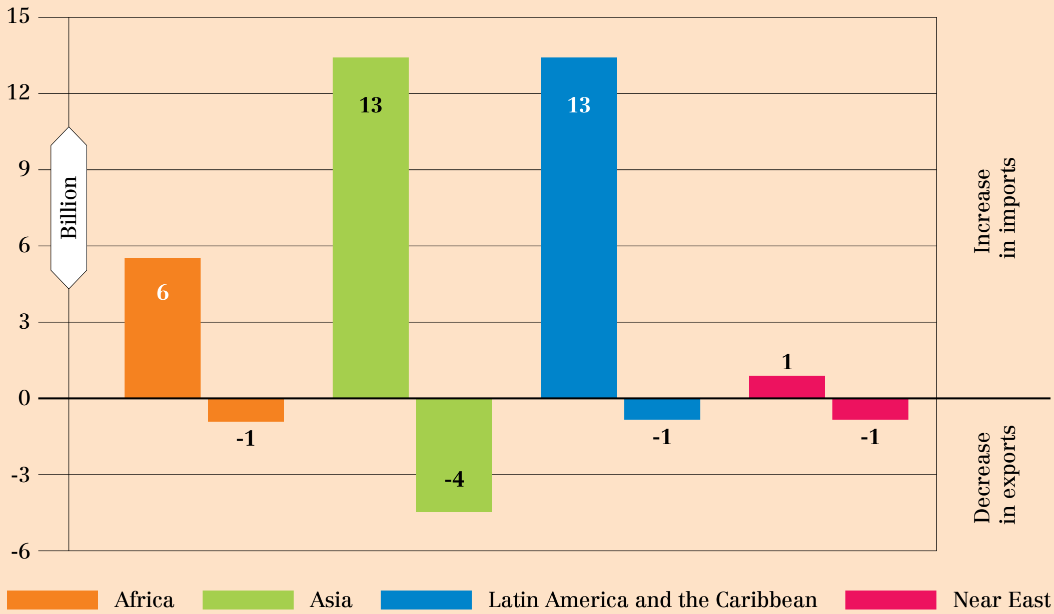


Notes: For low- and middle-income countries, the map shows areas where cereal import variability is explained by climate indicators. The size of the symbols is proportional to the coefficient of determination of the correlation regression. Colours reflect the sign of the correlation (green = positive, red = negative). The map shows correlation results between total annual cereal imports (data source: GIEWS) and cumulative precipitation (CHIRPS), annual temperature and cumulative normalized difference vegetation index (NDVI) during active crop season. All climatic indicators are extracted using an agriculture mask. NDVI is cumulated for the average crop season, while the other indicators are aggregated over the whole year. Countries have been mapped according to the highest significant correlation (determination coefficients > 0.4) and only for correlations with a significance of at least 90 percent. R2 is percent of variance in annual cereal production explained by climatic indicators. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. Final status of the Abyei area is not yet determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

Source: Authors' elaborations based on data from FAO GIEWS Cereal Balance Sheets for cereal imports; Crespo *et al.* (2018) for temperature and precipitation data; European Commission for the Normalized Difference Vegetation Index (NDVI). Conforms to Map No. 4170 Rev. 19 UNITED NATIONS October 2020.

Declines in agriculture production after climate-related disasters can trigger changes in agricultural trade flows, leading to increased import expenditures and reduced export revenues (FAO, 2015). Food imports following domestic production losses related to extreme climate events can be significant as countries try to cover the food availability shortfalls created by production losses. Figure 22 shows estimated agricultural commodity decreases in exports and increases in imports as a result of domestic production losses due to climate shocks for four regions.

FIGURE 22 Increases in imports and decreases in exports of agricultural commodities after climate-related disasters, by region (2003–2011)



Note: Increases in imports and decreases in exports of agriculture commodities in USD, by region.
Source: FAO. 2015. *Impact of disaster on agriculture and food security.* Rome.

4.2 Impact on food access

Climate variability and extremes negatively impact food access through three channels: a) loss of food production for own consumption; b) loss of income for people whose livelihoods depend on agriculture and natural resources, reducing their ability to purchase food; and c) spikes and volatility in food prices following climate shocks, which reduce purchasing power of people dependent on markets to purchase food.

The negative impact of climate variability and extremes on agricultural production directly translates into additional impacts on food access for people who directly depend on agriculture for their food and livelihoods. Those most affected are smallholder rural agriculture households, especially the poorer households, who have limited options to cope with climate shocks. For example, 63 and 69 percent of the food in Kenya and the United Republic of Tanzania, respectively, is produced by small-scale farmers; in Nepal the figure is 70 percent, and in the Plurinational State of Bolivia, 85 percent (Rapsomanikis, 2015). Dependence on uncertain rainfall and exposure to climate risk characterize the livelihoods of roughly 70 percent of the population of sub-Saharan Africa (Hansen *et al.*, 2011). It is estimated that 2.5 billion small-scale farmers, herders, fishers and forest-dependent communities derive their livelihood and incomes from renewable natural resources (FAO, 2016c).

Climate shocks not only negatively impact households' own food production, but also negatively affect rural incomes as agricultural production falls. In food-insecure regions, many smallholder farmers both consume their product and sell it in local markets for income. When climate variations cause production to decrease, these farmers have less of their own food production available for consumption and also less product to sell. Their income goes down while their costs go up to maintain basic consumption (Brown and Funk, 2008;

Krishnamurthy, Lewis and Choularton, 2012). For example, in Malawi, an increase in temperature that exceeds the upper confidence interval by 1 °C reduces overall consumption per capita by about 19.9 percent and food calorie intake by about 38.7 percent. In Ethiopia and the Niger, both rainfall and maximum temperature variability exert a negative impact on household income and consumption expenditure. This indicates that there is insufficient coping capacity and a lack of options for income-smoothing behaviour (FAO, 2016b).

The negative effects of climate variability and extremes are felt not only by smallholder producers but also by rural agricultural labourers. Climate shocks have negative impacts on the demand for agriculture labour, thus indirectly reducing the income and access to food of rural agriculture labourers. There is also evidence that climate shocks not only affect the level of income, but also its variability. For example, in household studies both in Malawi and in Zambia, it has been found that increased variation in seasonal rainfall (defined over 30 years) not only decreases expected incomes but also increases their variance (Arslan *et al.*, 2018; Asfaw *et al.*, 2019; Asfaw and Maggio, 2018).

The impacts of climate variability on agricultural incomes can be significant given the high level of dependency of the poor and food-insecure people on agriculture for their incomes – including rural agricultural labourers, as well as family farmers and smallholder producers. For example, the 2010 floods in Pakistan affected 4.5 million workers, two-thirds of whom were employed in agriculture, with over 70 percent of farmers losing more than half of their expected income (FAO, 2015).

Climate variabilities and extremes alter agricultural yields, production and stocks, which also leads to related effects on food prices. The impacts on access to food, therefore, can affect distant populations – outside of the areas where agriculture production is negatively affected by climate shocks – through food price spikes, volatility and disrupted trade. The impact of price and volatility in agricultural prices on consumers is negative and falls heaviest on the urban poor, who may spend as much as 75 percent of their income on food (FAO, 2016c). However, sharp food price increases and price volatility can also impact negatively on small-scale food producers, agriculture labourers and the rural poor who are net-food buyers, forcing these populations to reduce the quantity and quality of their food consumption.

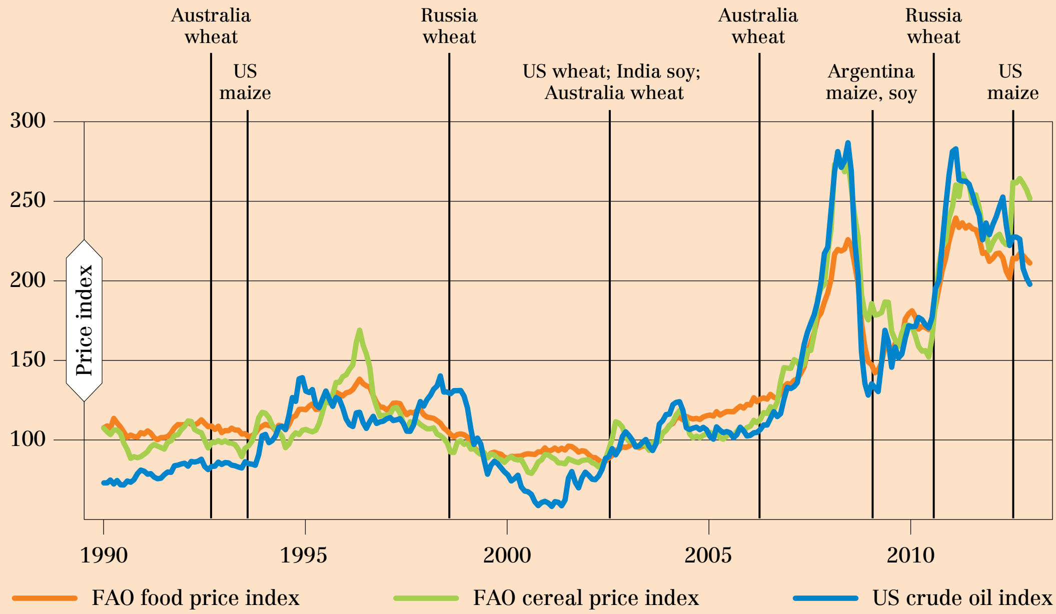
A number of studies empirically demonstrate that extreme climate events affect agricultural price levels and volatility (Chatzopoulos *et al.*, 2020). Periods of rapid food and cereal price increases are found to succeed periods of climate extremes in key producing regions and indicate a sensitivity of current markets to climate extremes, among other factors (IPCC, 2014).

Studies have also linked the effects of climate trends on crop yields to prices, and to trade (Wheeler and von Braun, 2013). There is strong statistical evidence that the price of a food basket in communities affected by floods, droughts or cyclones was not only higher than in the control communities, but the effect lasted for up to nine months (Béné *et al.*, 2015). In particular, from correlation analysis between major commodity prices and climate variables, it appears that in countries such as Benin, Eritrea, Ethiopia and Malawi, years with higher average temperatures coincide with higher maize prices.

There is also some evidence of global food price spikes and volatility following climate extremes. A study that examined the effects of variability in climate shocks related to El Niño and La Niña (see Box 1) on international maize and soybean price volatility from 1960 to 2014 (Peri, 2017). The study found evidence that both events increase expected price volatility of maize, showing the strongest impact during the El Niño phase in spring/summer. Soybean price volatility tends to slightly decrease during autumn/winter and to increase during the spring/summer period.

Further, a mapping of international food and cereal prices from 1990 to 2016 shows that global food price spikes often follow climate extremes for top global cereal producers. Figure 23 shows trends in international food and cereal prices, with vertical lines indicating events when a top five global producer of a crop had yields 25 percent below the trend line, indicating a seasonal climate extreme. In many of these cases, global food prices rose. Climate effects on food price volatility, however, are shown to be greatly influenced by domestic policies, with export bans contributing to price fluctuations (FAO, 2016b).

FIGURE 23 Food price spikes following climate extremes for top global cereal producers, 1990–2016



Notes: The plot shows the history of FAO food and cereal price indices (composite measures of food prices), with vertical lines indicating events when a top five producer of a crop had yields 25 percent below the trend line (indicative of a seasonal climate extreme). All indices are expressed as a percentage of 2002–2004 averages. Food price and crop yield data from FAO (www.fao.org/worldfoodsituation/foodpricesindex and www.fao.org/faostat/en/#home) and oil price data from U.S. Energy Information Administration (www.eia.gov).

Source: IPCC. 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK and New York, USA, Cambridge University Press.

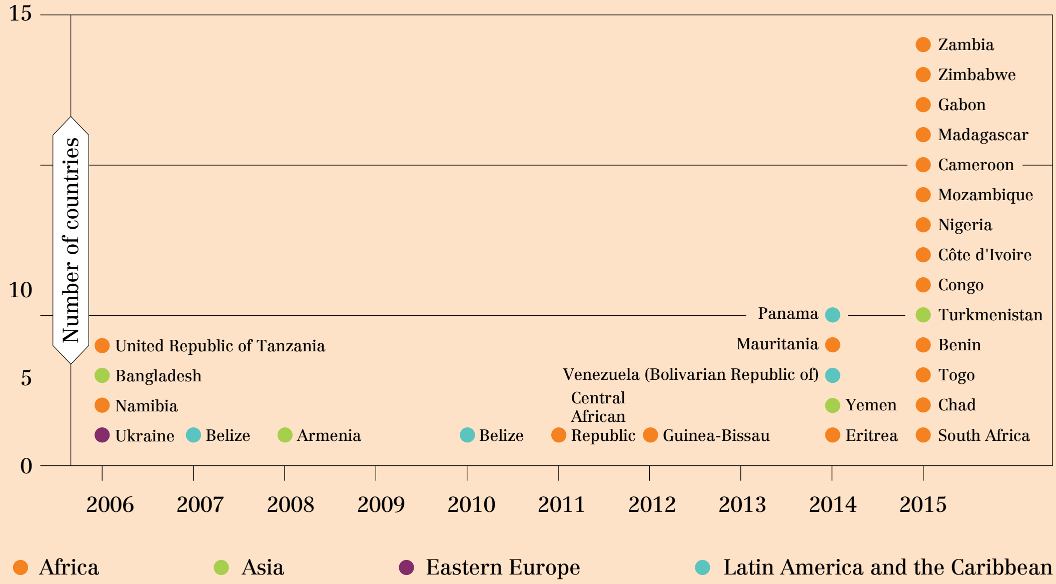
4.3 Impact on hunger and food crises

At the country level, an extreme climate event such as a drought, if severe enough and widespread, can potentially affect national food availability and access and thus lead to an increase in hunger, as measured by the PoU at a national scale.[17] This is particularly the case where a country's agriculture production is highly vulnerable to climate variability and extremes (see Figure 3) and there are insufficient support measures to counter the potential negative effects of extreme climatic events.

17 Undernourishment is estimated at the national level and therefore by its gross aggregate scale. Thus, significant changes in food availability or access are required to affect national-level estimates, and changes usually occur over time.

Although it is difficult to establish a direct causal relationship between climate extremes and PoU due to the way in which the PoU is computed and smoothed over time,[18] it is possible to examine whether change points in the PoU time series correspond temporally to occurrences of extreme climate events (see Annex 3 for methodology for the PoU change point analysis). The change point analysis of PoU time series between 2005 and 2016 indicates that out of the 91 PoU change points in 76 countries, 28 of them in 27 countries occurred in correspondence with severe agricultural drought stress (Figure 24).

FIGURE 24 PoU change points associated with the occurrence of severe drought



Notes: The figure shows the number of countries with change points of prevalence of undernourishment (PoU) which occurred in correspondence with severe drought conditions by year, between 2006 and 2015. See Annex 3 for PoU methodology and list of countries with PoU change points related to severe drought conditions.

Source: Authors' elaborations based on data from FAO for the prevalence of undernourishment and from the European Commission for the Anomaly Hotspots of Agriculture Production (ASAP).

In other words, for almost 36 percent of the countries that have experienced a rise in hunger, as measured by the PoU in the last ten years, this uptick is associated with the occurrence of extreme drought. There are also important regional and temporal elements in the observed association between PoU change points and high drought stress. Out of 27 countries with change points associated with severe drought, most (19) are in Africa, with the remaining 4 in Asia, 3 in Latin America and the Caribbean and 1 in Eastern Europe. Most striking is the significant increase in the number of change points related to high drought stress from 2014–2015. More than two-thirds of change points occurred during this period and are linked to severe droughts driven by the 2015–2016 El Niño.

18 The PoU estimates the proportion of the population habitually meeting the (average) minimum daily dietary intake requirements. It uses the mean dietary energy consumption which is computed as a three-year average. This means that the PoU is a highly smoothed data time series, which can be expected to reflect to some extent major variations in production, in those cases where a country is not able to compensate large production drops with stocks and imports. Due to the way the PoU is computed and smoothed over a three-year period, direct regression with climatic indicators is not appropriate, but it is possible to examine whether major climate shocks, such as extreme droughts, can be put in relation with change points in PoU.

A closer review reveals that many countries have experienced periods of increased undernourishment in the past years. However, it is only from the period 2014–2015, when there was a dramatic increase in the number of countries experiencing increased undernourishment, that this combined change across so many countries became strong enough to reverse the global-level trend.

In some countries the PoU change points occurring in correspondence with drought also mark years with low production and high imports, and stalling or decreasing cereal availability. For example, simple trend lines of cereal production, imports and severe drought warnings in Namibia, South Africa and Nigeria confirm also that PoU change points often occur in correspondence with consecutive years of drought.

Although drought is only one of many factors that can have an impact on the PoU, and only in cases where the country is not able to put in place sufficient mitigation strategies, this change analysis does support the hypothesis that, particularly for the period 2014–2016, extreme drought linked to the strong El Niño of 2015–2016 is one of the important driving factors behind the increases in PoU.

Exposure and vulnerability: implications for hunger

As seen earlier (see Figure 17), not only has countries' exposure to climate variability and extremes increased in the last 20 years, but many more countries are vulnerable to the risk of food insecurity and malnutrition as a result of the increase in exposure to multiple types of climate shocks such as drought, floods, storms and heat spells. This increased exposure is associated with increased vulnerability of national agriculture production and yields to climate extremes.

Simple correlation analysis shows that there are higher levels of undernourishment in countries with high levels of exposure to climate shocks. High exposure is defined for countries experiencing climate extremes for more than three years in the six-year period of 2011–2016, irrespective of whether they are low- or middle-income countries. This indicates an increased frequency of exposure to climate shocks, repeated within a short period of time.

In 2017, the unweighted average of the PoU in countries with high exposure to climate shocks (severe droughts and floods) was almost 3.2 percentage points higher than countries with low or no exposure to climate shocks (Figure 25). Even more striking is that countries affected by high exposure to climate shocks have more than double the number of undernourished people (351 million more people) as countries without high exposure to climate shocks.

Of the 51 countries identified as experiencing high exposure to climate extremes in 2011–2016, 23.5 percent are low-income countries and 76.5 percent are middle-income. In terms of geographical location, most (76 percent) are in Africa and Asia (39 and 37 percent, respectively), 15.5 percent in Latin America and the Caribbean, and the rest in Oceania and Europe (see Annex 4 for list of countries).

It is not only a country's high exposure to climate variability and extremes that is critical for food security, but also the degree of vulnerability to these climate characteristics. Vulnerability here is defined as the conditions that increase the probability that climate variability and extremes will negatively affect food security.

Vulnerability to climate extremes is an important risk factor for food security and nutrition, especially in low- and middle-income countries. Although there are many vulnerability factors, there are three that show the greatest relative importance for food availability and access. Specifically, we define three types of vulnerability to climate variability and extremes:

1. *Vulnerability related to climate-sensitive production and/or yields:* countries with at least part of their national cereal production or yield variance explained by climate

factors – i.e. there is a high and statistically significant association between production and climate or biophysical indicators such as temperature, rainfall and vegetation growth (see Figure 3).

2. *Vulnerability related to severe drought food security sensitivity:* countries with severe drought warnings corresponding with the occurrence of PoU change points (see Figure 24).
3. *Vulnerability related to high dependence on agriculture:* countries with a high dependence on agriculture, measured by the percentage of people employed in the sector according to the World Bank (2017), indicating that many derive their livelihood and income from the sector.

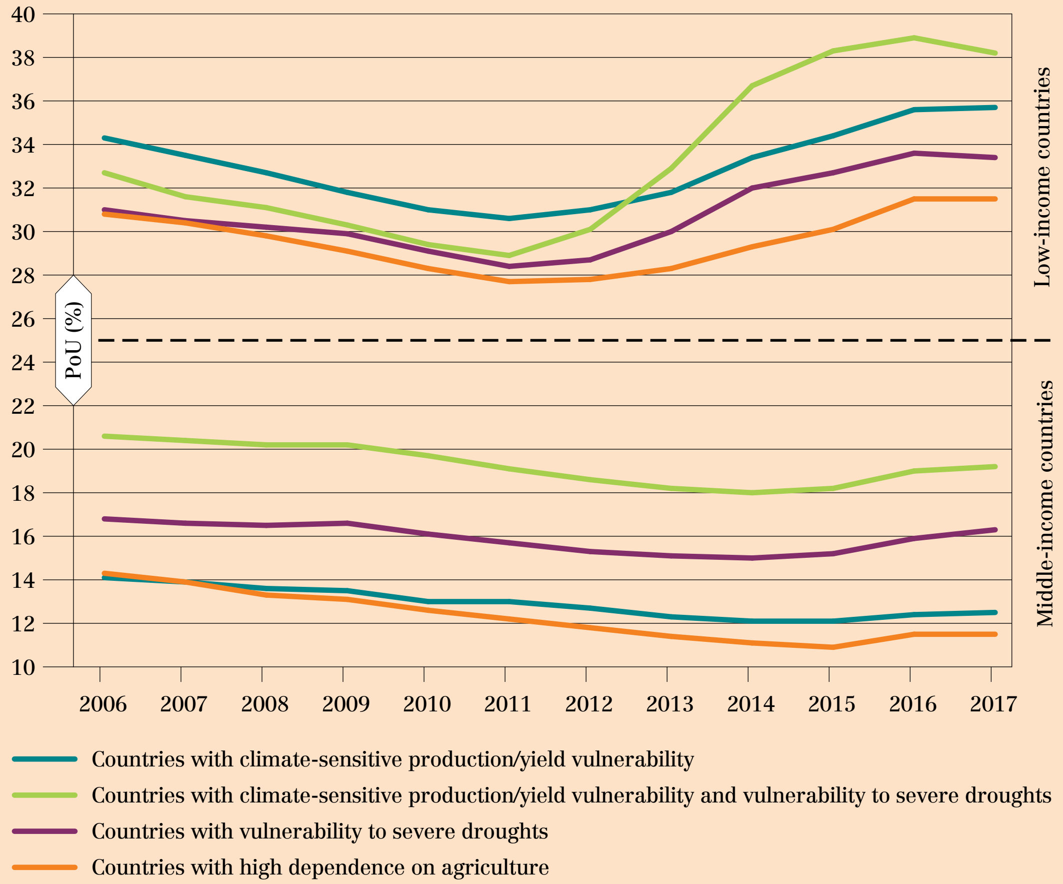
FIGURE 25 Prevalence and number of undernourished people by degree of exposure to climate extremes (as of 2017)

Notes: Prevalence (unweighted) and number of undernourished people in low- and middle-income countries with high and low exposure to climate extremes during the period 2011–2016. Countries with high exposure are defined as being exposed to climate extremes (heat, drought, floods and storms) for more than 66 percent of the time, i.e. for more than three years in the period 2011–2016; low exposure is for three years or less. See Annex 4 for the list of countries with high exposure to climate extremes and methodology.

Source: Authors' elaborations based on data from FAO for the prevalence and number of undernourishment; the European Commission for the Anomaly Hotspots of Agriculture Production (ASAP); EM-DAT - the international disasters database for data on storms; Crespo *et al.* (2018) for data and analysis on extreme heat spells and precipitation.

There are statistically significant differences in the PoU of the 128 countries identified in the present analysis when considering the three types of vulnerability defined above (Figure 26). For example, in 2017 the PoU average was 15.4 percent for all countries exposed to climate extremes. At the same time, the average was 20 percent for countries that additionally showed high vulnerability of agriculture production/yields to climate variability, or 22.4 percent for those with high vulnerability to drought. When there is both high vulnerability of agriculture production/yields and high PoU sensitivity to severe drought, the PoU average is 9.8 points higher (25.2 percent). Moreover, a high dependence on agriculture, as measured by the number of people employed in the sector, yields a PoU that is 9.6 percentage points higher (25 percent); for low-income countries, the increase is equal to 13.6 percentage points (29 percent).

FIGURE 26 **Prevalence of undernourishment for countries with exposure to climate extremes and high levels of vulnerability in agriculture**



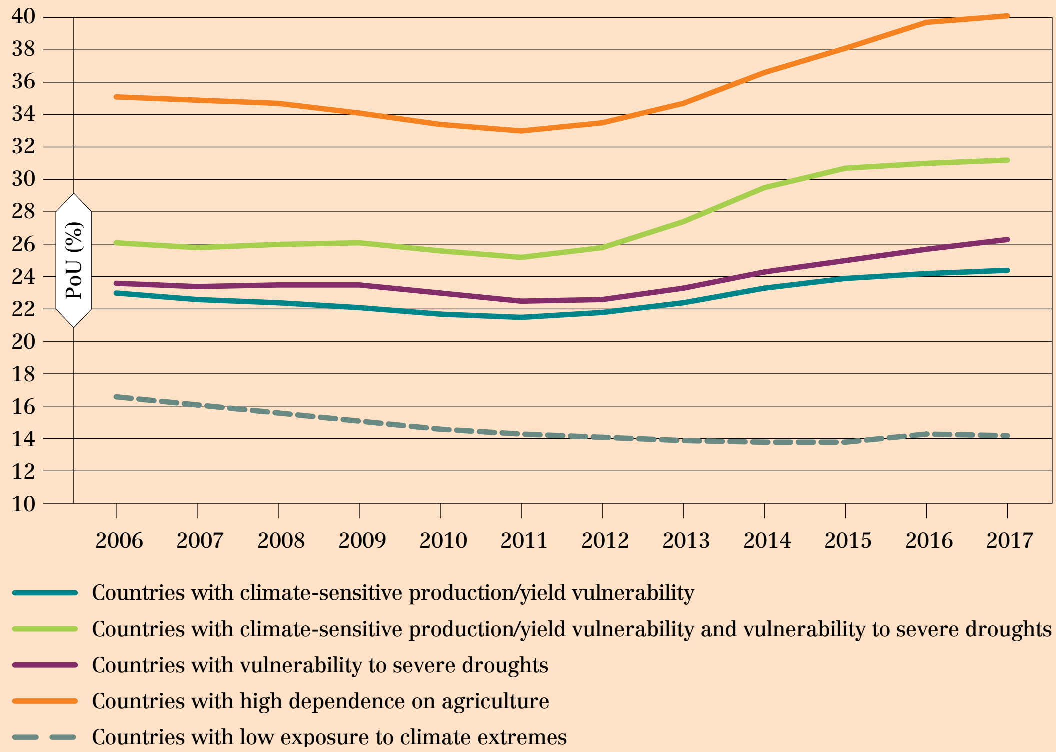
Notes: The estimates in the graph refer to the unweighted population average of the prevalence of undernourishment (PoU) in a sample of 128 low- and middle-income countries with exposure to climate extremes, for countries with high levels of different vulnerabilities as identified in Annex 4. Exposure to climate extremes is not differentiated in this figure, i.e. it includes all levels of exposure to climate extremes, both high and low. See Annex 2 for more detailed definitions and methodology of the different types of vulnerability to climate variability and extremes.

Source: Authors' elaborations based on data from FAO for the prevalence and number of undernourishment; FAO GIEWS Cereal Balance Sheets for cereal production; the European Commission for the Anomaly Hotspots of Agriculture Production (ASAP); EM-DAT - the international disasters database for data on storms; Crespo *et al.* (2018) for data and analysis on extreme heat spells and precipitation; World Bank for national data on employment in agriculture. In: *World Bank – Databank* [online]. Washington, DC. [Cited 2 October 2020]. https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS

What is also striking from Figure 26 is that the uptick in PoU occurs earlier and the increase is higher and sharper for low-income countries as compared to middle-income countries. This difference is even more pronounced in countries with high vulnerability of agriculture production/yields and high sensitivity of PoU to severe drought. For middle-income countries the rise in PoU is less pronounced and occurs later (from the period 2015–2016). This indicates that middle-income countries were able to absorb the impacts of increased exposure to climate extremes before 2015–2016, but may not have been able to cope as well during the 2015–2016 period, possibly due to the severity of exposure to El Niño.

The increase in PoU is even more pronounced beginning in 2011 for those countries with both high exposure to climate extremes (more than 66 percent of the time) and high levels of vulnerability (Figure 27). Countries with high exposure to climate extremes combined with a high dependence on agriculture show the highest PoU levels, whereas countries experiencing both climate-sensitive vulnerability of production/yields and vulnerability to severe drought show the sharpest increase in undernourishment starting from 2011, followed by countries with either climate-sensitive production/yield vulnerability or vulnerability to severe drought.

FIGURE 27 Prevalence of undernourishment for countries with both high exposure to climate extremes and high vulnerability



Notes: Low- and middle-income countries with high exposure are defined as exposed to climate extremes (heat, drought, floods and storms) for more than 66 percent of the time, i.e. more than three years in the period 2011–2016. The estimates in the figure refer to unweighted population averages of the prevalence of undernourishment in a sample of 51 low- and middle-income countries with high exposure to climate extremes in 2011–2016, differentiated by type and combination of vulnerability (identified in Annex 4), and a sample of 77 low- and middle-income countries with low exposure to climate extremes (undifferentiated by type or combination of vulnerability). See Annex 2 for more detailed definitions and methodology of the different types of vulnerability to climate variability and extremes.

Source: Authors' elaborations based on data from FAO for the prevalence and number of undernourishment; FAO GIEWS Cereal Balance Sheets for cereal production; the European Commission for the Anomaly Hotspots of Agriculture Production (ASAP); EM-DAT - the international disasters database for data on storms; Crespo *et al.* (2018) for data and analysis on extreme heat spells and precipitation; World Bank for national data on employment in agriculture. In: *World Bank – Databank* [online]. Washington, DC. [Cited 2 October 2020]. https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS

Climate variability and extremes as a major driver of global food crises

Climate shocks, including extreme climate events such as droughts, floods, cyclones and storms, but also seasonal variability in rainfall, are one of the principal drivers behind observed high levels of global acute food insecurity that require emergency humanitarian actions. In 2017, almost 124 million people across 51 countries and territories faced "crisis" levels of acute food security or worse (IPC Phase 3 and above or equivalent) and required urgent humanitarian assistance to save lives and livelihoods. More than 76 percent of the total population affected, or almost 95 million people, were affected by climate shocks in 34 countries (Table 1).

TABLE 1 Climate shocks as drivers of food crisis situations in 2017

Regions	Climate shocks	Countries affected by climate shocks (also affected by conflict)	Number of people (millions)	
			IPC/CH Phase 3 (Crisis)	IPC/CH Phase 4 (Emergency)
Africa	Droughts	Burundi, Djibouti, Eswatini, Kenya, Lesotho, Namibia, Somalia	8.4	2.3
	Dry spells/ low rainfall	Angola, Chad, South Sudan, Uganda	6.9	1.7
	Seasonal variability (late onset of the rainy season)	Sudan, Zambia	3.7	0.1
	Late onset and dry spells/ erratic rainfalls	Cameroon, Gambia, Mauritania (early cessation rainy season), Niger, United Republic of Tanzania	5.7	0.1
	Late onset and floods	Guinea-Bissau	0.3	0
	Droughts and other climate shocks	Malawi	5.1	N/A
		Ethiopia	8.5	N/A
		Zimbabwe	3.5	0.6
		Democratic Republic of the Congo	6.2	1.5
		Madagascar, Mozambique	3.4	1.3
Asia	Floods and other climate shocks	Afghanistan, Nepal, Pakistan	7.8	3.3
		Bangladesh	2.9	0.5
		Sri Lanka, Yemen	11.1	6.8

TABLE 1 (cont.) **Climate shocks as drivers of food crisis situations in 2017**

Regions	Climate shocks		Countries affected by climate shocks (also affected by conflict)	Number of people (millions)	
				IPC/CH Phase 3 (Crisis)	IPC/CH Phase 4 (Emergency)
Latin America and the Caribbean	Drought and other climate shocks	+	Guatemala, Haiti	2.1	0.7
		+	Honduras	0.4	0
				76.8	**18.9**
				94.9	

Countries affected by conflicts

Countries affected by dry spells

Countries affected by seasonal variability

Countries affected by floods

Countries affected by droughts

Countries affected by flash flood

Countries affected by storms

Notes: This table is elaborated on the basis of the 2018 Global Food Crisis Report (GFCR). The table reports the number of people who are classified food-insecure according to the Integrated Food Security Phase Classification (IPC) or the *Cadre Harmonisé* (CH) and reports on the occurrence of specific climate shocks (droughts, floods and cyclones) which are drivers contributing to food insecurity. This information is complemented with information on other types of climate shocks linked with food insecurity (dry spells, flash floods and seasonal variability). Information for these were identified from the 2018 GFCR and the FAO Global Information and Early Warning System on Food and Agriculture (GIEWS) Country briefs. Population in IPC Phase 4 for South Sudan also includes population in IPC Phase 5. Some countries are not included in the report due to lack of recently validated data or because variations in the geographical coverage of IPC or CH analysis represent a technical limitation in showing trends for certain countries.

Source: Authors' elaboration based on FSIN. 2018. *Global Report on Food Crisis 2017*. Rome.

Where conflict and climate shocks occur together, the impact on acute food insecurity is more severe. In 2017, 14 out of the 34 food crisis countries experienced the compounding impact of both conflict and climate shocks, which led to significantly more severe levels of acute food insecurity. A total of 67.5 million people (IPC Phase 3 and above) required immediate humanitarian assistance in 2017, of which 13.3 million suffered very extreme levels of acute food insecurity requiring urgent life-saving assistance (IPC 4 and above).

Most climate-related food crisis countries are not affected by conflict, yet climate shocks and stressors are a major factor driving emergency levels of acute food insecurity (20 out of 34 countries). For these climate-affected food crisis countries, 27.2 million people required humanitarian assistance (IPC Phase 3 and above), including 3.3 million people in need of urgent life-saving emergency assistance (IPC 4 and above).

Drought was a driving climatic factor in 21 out of the 34 countries in 2017 (Table 1). However, in only 7 of these did drought occur without other climate shocks. In most cases, countries are also exposed to drought combined with floods, cyclones, and other less extreme but equally detrimental climate events, including dry spells and erratic rainfall, and late onset of rainy seasons. Africa was the region where climate shocks and stresses had the biggest impact on acute food insecurity, affecting 59 million people in 24 countries and requiring urgent humanitarian actions.

Where climate shocks combine with conflict to drive food crises, there are extremely high rates of acute child malnutrition, including in Darfur in the Sudan (28 percent), South Sudan (23 percent), the Lake Region of Chad (18 percent), Yemen (10–15 percent), the Diffa Region of the Niger (11 percent), Democratic Republic of the Congo (8–10 percent), and Afghanistan (9.5 percent). There is also a high burden of acute malnutrition in areas or countries affected by drought and/or floods, including northern Kenya, the Sindh province in Pakistan, Ethiopia, and Madagascar (FSIN, 2017). Climate shocks compound the factors that underlie acute malnutrition, including high levels of food insecurity; inadequate access to diverse and nutrient-rich foods; high prevalence of diseases, such as diarrhoea, malaria and fever; inadequate quantities of nutritious food; poor access to primary health care and safe water; inadequate sanitation; and suboptimal breastfeeding practices.

5 Case studies

KEY MESSAGES

- Case studies offer an integrated picture illustrating how increasing climate variability and extremes are negatively affecting agriculture, resulting in destructive secondary impacts on livelihoods, income, food prices and coping capacity, resulting in increasing food insecurity.
- It is not only extreme climate events, such as severe droughts and floods, that are negatively affecting agriculture and leading to food insecurity, but also changing seasonal patterns, including shorter rainy seasons and poorly distributed rainfall within seasons.
- The 2015–2016 El Niño had a devastating impact on agriculture and food security in several countries, with a clear association between severe drought events and a steep increase in both chronic hunger (PoU) and emergency levels of acute food insecurity.
- More frequent occurrences of extreme climate conditions and changes in seasonality are having a cumulative effect on agriculture and food security in many countries, undermining people's coping capacity and leading to more severe forms of food insecurity.

To provide a more nuanced understanding of how recent climate events are negatively affecting agriculture and food security, three case studies are presented below. These case studies offer an integrated picture of how increasing climate variability and extremes are negatively affecting agriculture, resulting in destructive secondary impacts on livelihoods, income, food prices and coping capacity, resulting in increased food insecurity.

5.1 Southern Africa

Growth rates of Southern Africa[19] in the last 20 years were characterized by moderate growth that was followed by a recession after the 2008–2009 crisis, due to the sharp decline in global demand for the region's exports. The economic recession further exacerbated the fragile situation of the region in terms of weather-related shocks, such as increasing rainfall variability, widespread droughts and water shortages driven by El Niño events that have drastically reduced agricultural production in recent years. During the last El Niño in 2015–2016, large parts of Southern Africa suffered from reductions in the numbers of both rainy days and average rainfall intensity, which severely impacted crop growth and pastures.

The El Niño-induced drought has decreased cereal yields and led to crop failure and loss of livestock and wildlife. Overall, the region has recorded cereal and maize deficits of 9 million and 5 million tonnes, respectively (SADC, 2016). If agricultural growth was at 2.9 percent

[19] Southern Africa includes the following countries: Angola, Botswana, Eswatini, Lesotho, Malawi, Mozambique, Namibia, South Africa, Zambia, Zimbabwe.

in 2007–2009, it turned negative (-1 percent) in 2014–2016 due to unfavourable climate conditions that led to slowdowns in the whole area, including the two largest economies of Angola and South Africa (AfDB, 2018).

As a result, food prices doubled between 2015 and 2016, compromising people's access to food. Inflation spiked in Zambia, due to the removal of fuel and electricity subsidies, as well as in Angola, Malawi and Mozambique (AfDB, 2018). By 2016, the severe impact of El Niño left 12 million food-insecure people in need of urgent action in Lesotho, southern Madagascar, Malawi, Mozambique, Eswatini and Zimbabwe, weakening households' capacity to effectively cope with shocks (FSIN, 2017). The Southern African Development Community (SADC) has declared a "regional drought disaster" and has issued a Regional Humanitarian Appeal for local and international assistance to cover a gap of USD 2.5 billion to finance a plan in response to the crisis. An estimated 41 million affected people should benefit from the plan (about 14 percent of the total SADC population), with 26 million requiring immediate humanitarian assistance (SADC, 2016).

The exposure to recurrent climate anomalies and variability has driven the food crisis and the observed uptick in chronic food insecurity as measured by the PoU. Significant increases in PoU are observed in 2015–2016 in correspondence with severe drought warnings related to El Niño events. Southern African countries that show an increased PoU associated with severe droughts are Zambia, Zimbabwe, Madagascar, Mozambique and South Africa (see Figure 24).[20] In particular, Madagascar is extremely vulnerable to drought, cyclones, flooding and locust infestations. At the end of 2016, following three years of consecutive drought exacerbated by El Niño, almost one million people in Madagascar's southern regions required humanitarian assistance (FSIN, 2018).

Mozambique is also prone to a wide range of extreme climate shocks that regularly destroy infrastructure and disrupt economic growth. Although the country has reached its Millennium Development Goal of halving the number of hungry people, 80 percent of the population still cannot afford a minimum adequate diet (FSIN, 2018). Data are also alarming for Zimbabwe: almost two in three Zimbabweans (62.6 percent) live below the poverty line, and over 2.4 million are estimated to face crisis (or worse) levels of food insecurity (Phase 3 IPC classification) (FSIN, 2018). This country is also facing an economic crisis due to the collapse of the national currency, which is likely to further threaten people's livelihoods (FAO, 2018a). The effect of depreciating currencies in several countries has added further upward pressure to domestic food prices and increased the cost of food imports (FSIN, 2017). At the end of 2017, the areas experiencing a food security crisis (IPC / *Cadre Harmonisé* [CH] Phase 3) in the region were central Mozambique, southern Madagascar and Zimbabwe.

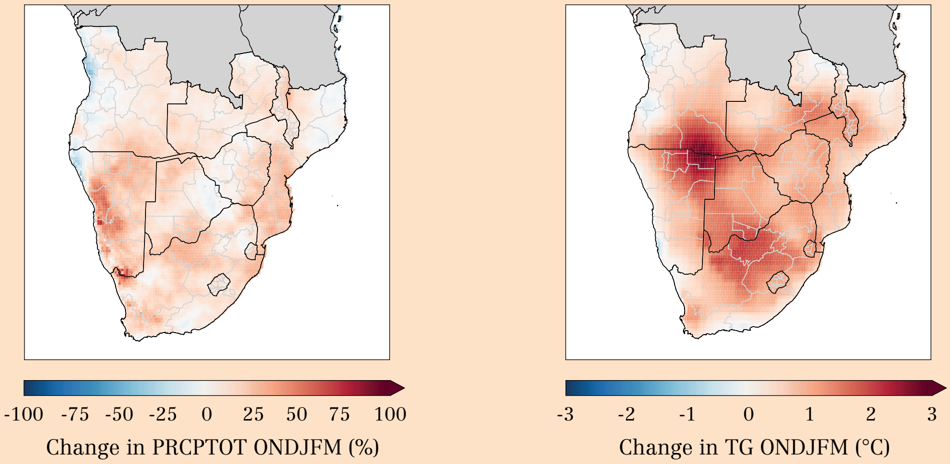
Furthermore, the northern parts of Namibia and southern areas of Angola were particularly impacted by the drought in 2016, where a reduction in precipitation and a sharp increase in temperatures during 2015–2016 are clearly visible compared to the long-term trend (Figure 28). Both years were characterized by poor agricultural seasons that severely undermined resilience capacities of the population and led the Government of Namibia to provide food assistance to 0.6 million people through the Drought Relief Food Programme until March 2017 (FSIN, 2017).

Besides recurring dry spells and droughts, Southern African countries have experienced a reduction in GSL during the period 2004–2016, affecting an average of 13 percent of agriculture cropping areas and 10 percent of rangeland areas. Recurrent delays in the start of the growing season drive this reduction, one that is quite strong in magnitude. For instance, an average decrease in GSL of 2.8 days per year is found in Zambia; in Malawi,

20 Significant increases in PoU are detected through the PoU change point analysis. For further information see Annex 3.

the average decrease is 2.4 days. The largest proportions of crop areas showing a significant trend of growing season reduction are detected in Zimbabwe, Zambia and Malawi, whereas for rangelands the largest decrease is occurring in Botswana and South Africa (Figure 29).

FIGURE 28 Total precipitation and mean temperature in Southern Africa during the October–March period of 2015–2016 compared to the October–March period of 1981–2016

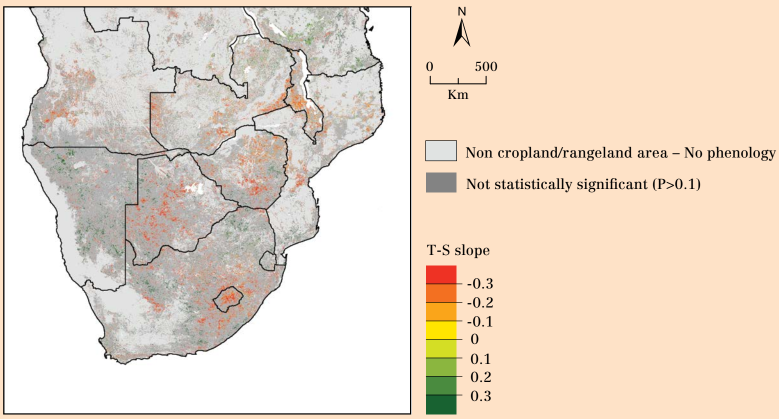


Notes: Red areas denote scarcity of rainfall (panel a) and hot temperature (panel b); blue areas denote excess of rainfall (panel a) and cold temperature (panel b).

Source: Authors' elaboration based on Crespo *et al.* (2018) data and analysis on precipitation. Conforms to Map No. 4045 Rev. 8.1 UNITED NATIONS July 2018.

FIGURE 29 Reduction trend in growing season length in Southern Africa for croplands and rangelands, 2004–2016

GSL FIRST SEASON – CROPLANDS AND RANGELANDS



Notes: The maps show dekads per year with a change in growing season length (GSL) for cropland and rangeland areas in Southern Africa. Only pixels with significant trends are shown. Non-significant trends are masked out in dark grey; non-cropland and non-rangeland areas are masked out in light grey. Red pixels denote a negative trend (i.e. a decrease in average growing season length in dekads per year) and green pixels denote a positive trend.

Source: Authors' elaboration based on data from the European Commission. 2020. NDVI – Normalized Difference Vegetation Index. In: *European Commission* [online]. [Cited 2 October 2020]. https://mars.jrc.ec.europa.eu/asap. Conforms to Map No. 4045 Rev. 8.1 UNITED NATIONS July 2018.

Spotlight on South Africa

The effects of the 2015–2016 widespread droughts in Southern African countries induced crop failure and loss of livestock, with cereal and maize deficits amounting to 9 million and 5 million tonnes, respectively (SADC, 2016). This has particularly threatened food security, as maize accounts for 76 percent of the total cereal production in the region. The bulk of the subregional maize production contraction occurred in South Africa, which declared a partial draught disaster in response to El Niño, and reported a 26.7 percent decrease in maize production in 2016 with respect to the previous year (FAO, 2018b; SADC, 2016).

Data from the Food Balance Sheets for years 2000-2017 (Figure 30a) clearly show a sharp drop in cereal production in South Africa for 2015–2016 (orange line), in correspondence with a dramatic drought warning (sharp rise in the grey line). Concomitantly, the consecutive droughts in 2015, 2016 and 2017 led to an acceleration of the rate of increase of the PoU in 2015–2016. In fact, the PoU change point analysis suggests that a steep increase in chronic hunger in 2015 (Figure 24) occurred in coincidence with consecutive agricultural droughts in South Africa. The drought and the rise in chronic hunger occurred alongside a sharp decrease in cereal production as well as a surge in cereal imports that reached their highest level in 2015–2016 (Figure 30 a, b). Although food insecurity has intensified in the country, its superior national capacities (compared to other countries in the region) helped it respond to shocks and avert a crisis (FSIN, 2017).

The decrease in cereal production and its availability posed a challenge for all other countries in the subregion that rely on South Africa for their maize consumption, since they had to resort to importing maize from elsewhere at a significantly higher cost in order to meet their import requirements. This was particularly challenging for countries with an ongoing weakening of local currencies and decreased government revenues (SADC, 2016), resulting in higher maize prices in Lesotho, Malawi, Mozambique and Eswatini.

FIGURE 30 Trends in cereal production, cereal imports and undernourishment following severe drought warnings in South Africa during 2015–2016

A. CLIMATE IMPACT ON PRODUCTION AND IMPORTS

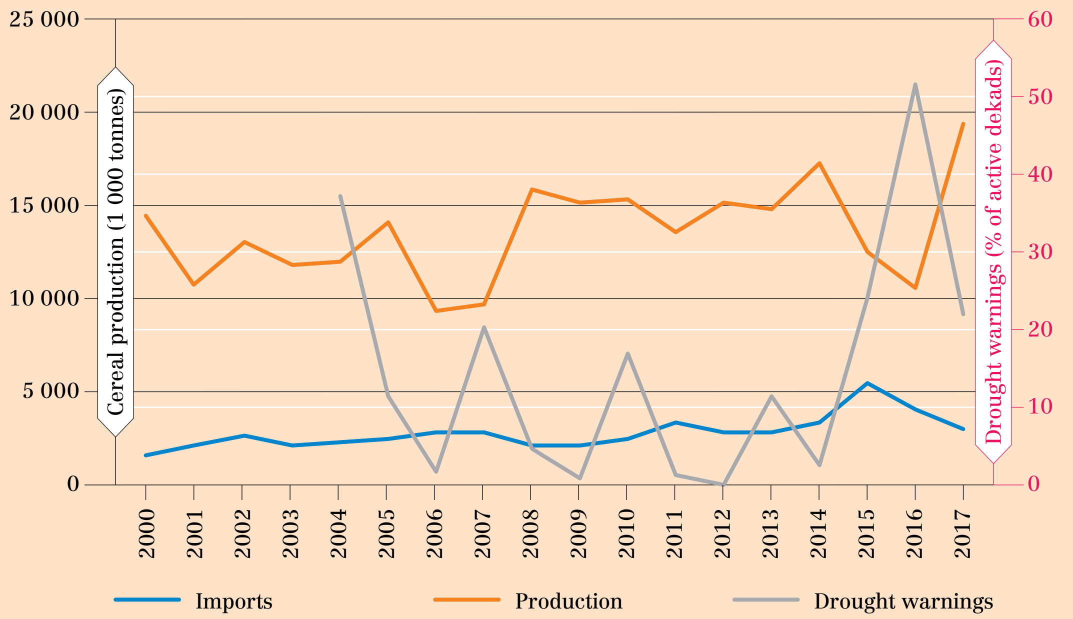
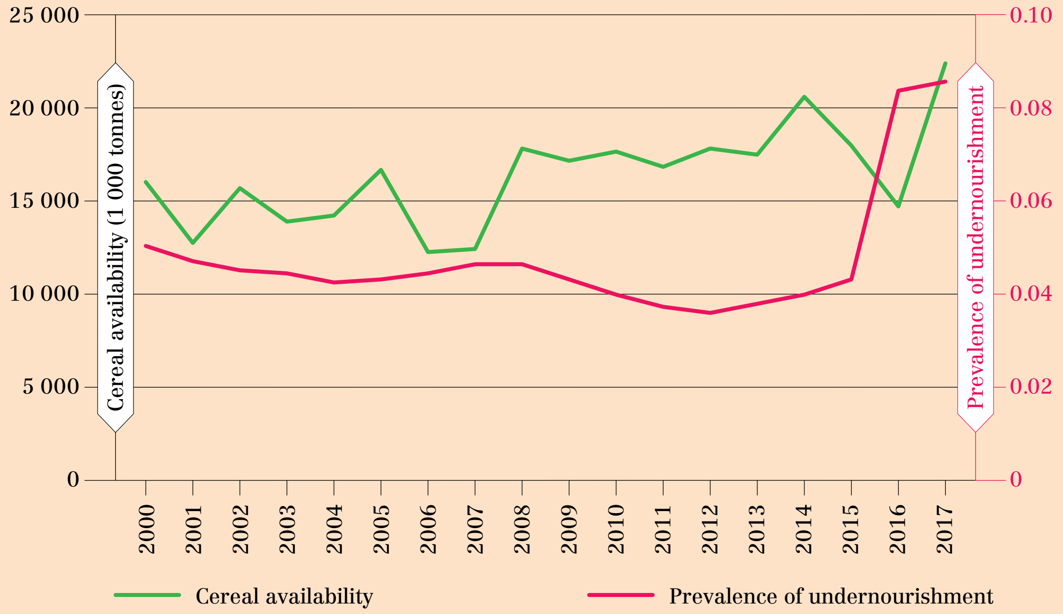


FIGURE 30 Trends in cereal production, cereal imports and undernourishment following severe drought warnings in South Africa during 2015–2016 (cont.)

B. CEREAL AVAILABILITY AND PREVALENCE OF UNDERNOURISHMENT



Source: Authors' elaborations based on data from FAO for the prevalence of undernourishment; FAO GIEWS Cereal Balance Sheets for cereal production and imports; the European Commission for the Anomaly Hotspots of Agriculture Production (ASAP).

Spotlight on Malawi and Zambia

Besides the occurrence of recurrent dry spells and droughts in recent years, Zambia and Malawi are facing an increasing trend of changing seasonality that has important implications for crop production and food security. Both countries have some of the largest proportions of crops subjected to shorter growing seasons over the last 14 years in the African continent (Malawi being ranked first, and Zambia sixth).

The GSL is significantly decreasing in Zambia for 21 percent of agricultural crop areas, with a reported average reduction rate of 2.8 days per year. The negative slope of 0.28 dekads per year in Zambia (see Figure 13 in Section 3.4) indicates an average length of reduction of 2.8 days each year. Specifically, 19 percent of the crops show a significant delay in the start of the growing season (average rate of 1.8 days per year), and almost 18 percent of crops show a significant anticipation in the end of the season. Therefore, the general observed trend in the country is a delayed start and an anticipated end of the season, indicating an overall reduction in GSL, with clear implications in terms of agricultural production and food security. Changes in the GSL also affect rangelands (16 percent), with a prevalent trend of length reduction in 82 percent of these areas.

Seasonality is monomodal also in Malawi (i.e. only one growing season) and cropped area represents 93 percent of the total agricultural area versus 7 percent of rangeland. Overall, a significant decrease in the length of the season is detected for 30 percent of the crop area. Almost the whole area (98 percent) shows an average GSL reduction rate of 2.4 days per year (see Figure 13 in Section 3.4). Akin to Zambia, a delayed start and anticipated end of growing season is observed for a significant portion of the crop area. The former is observed for almost 24 percent of the crops, while the latter is observed for approximately 17 percent of the crops.

Climate variability and shocks in these countries threaten agricultural production. In 2016, significantly reduced maize harvest and higher food prices in Malawi led to an estimated 6.5 million people in need of humanitarian assistance (FAO, 2016a). The general food security situation has improved with good production from the 2016/2017 growing season, especially with most of the districts in the northern and central regions at IPC/CH Phase 1 (none or minimal), whereas the remaining districts especially in the south were at Phase 2 (MVAC, 2017). According to the Famine Early Warning System Network (FEWS NET), during October to January 2019, when food supply levels will be at their lowest and food prices at their highest, poor households in parts of the central and southern regions are expected to face Stressed (IPC/CH Phase 2) and Crisis (IPC/CH Phase 3) levels of acute food insecurity as they deplete their food stocks and rely on market purchases for consumption (USAID, 2018).

In Zambia, the promotion of maize production in 2014 at the expense of other crops has made maize a monocrop in many districts, resulting in an undiversified agricultural system that exposes farmers to food insecurity in case of a drop in maize production (SADC and OCHA, 2014). In fact, the heavy production decline in 2015 driven by the severe and extensive El Niño-induced drought decreased cereal yields and increased crop losses, while the delayed start of seasonal rains curbed plantings, further contributing to the reduced output (FAO, 2016a). Decreased agricultural production limited exports of cereal from Zambia to neighbourhood countries, producing 60 percent higher maize prices than the previous year in the area (FSIN, 2017). In 2017, the number of food-insecure people in need of urgent assistance was almost 500 000 (FSIN, 2018).

The most negative impacts of climate variability in Zambia occur in the southern and central regions, where food insecurity is most vulnerable to climate shocks. Evidence shows that due to the shorter GSL and increasing dry conditions, the anticipation of climate shocks and variability through regional and global forecasts can increase the resilience of the population. Farmers who received weather information (only 21 percent) before the 2015–2016 agricultural season successfully integrated drought-tolerant crops (e.g. millet, sorghum, cassava) and drought-resistant cash crops such as cotton in their cropping systems, thus minimizing agricultural losses (Maggio, Sitko and Ignaciuk, 2018). Increasing the share of farmers that receive this information can help increase rural farmers' adaptive capacity to changing climatic conditions.

Crop diversification has also been found to be an adaptive measure in Malawi and Zambia, with land size playing a key role in increasing the probability of diversification (FAO, 2018c). In Zambia, crop, livestock and income diversification significantly increase the level of per capita income in the presence of climate shocks and vulnerability, while they decrease the probability of falling below the poverty line (Arslan *et al.*, 2018). Higher resilience measured by reduced income variability is observed in more diversified systems, especially crops incorporating legumes. FAO (2018c) show that maize-legume systems are associated with a 17–38 percent increase in maize yields in Malawi, compared to the maize monocrop system. Furthermore, high prices of maize and other seeds are a disincentive toward adoption of diversified cropping systems: a 1 percent increase in maize seed prices decreases the probability of adoption of maize-legume staple systems by 5 percent (FAO, 2018c). In Zambia, proximity to markets is a push factor towards diversification: households residing in villages with more private grain buyers are more likely to move away from maize monocropping and to adopt diverse, commercially oriented systems, e.g. legumes/cash crops (FAO, 2018c).

In Malawi, climate shocks in the 2009/2010 and 2012/2013 agricultural seasons point to a decrease in farmer households' consumption. A scarcity of rainfall during the rainy season decreases consumption by 18 percent, whereas excess of rainfall is associated with a 13 percent average decrease. In terms of ex-post coping strategies, seasonal variability in rainfall patterns increases the probability of experiencing food shortages, and of relying on external help (informal/formal) and family savings, as these additional resources possibly act as a financial support to adjust households' farming strategies in the face of climate uncertainty. Scarce rainfall events not only increase the probability of food shortages and the use of household savings but also push households to partially liquidate assets by selling crops and/or livestock. Along with food shortages, the latter is also alarming as it represents a strong disinvestment which may be helpful in the short term to smooth consumption, but could create long-term vulnerabilities.

Furthermore, complementarities are found across a set of coping strategies undertaken by Malawian households. Relying on only one coping strategy after climate shocks is often not sufficient, pushing households to simultaneously engage in more, often negative, coping strategies to mitigate the effects of climate extremes/variability. For instance, eating less food is usually accompanied by one of the following: selling crops and/or livestock, spending savings, receiving monetary help or engaging in extra working activities. Furthermore, coping mechanisms change according to a household's poverty status. Engaging in more work or receiving external help are adopted in combination only among the poor, highlighting that neither of these mechanisms by itself is sufficient to enable the poor to cope with climate shocks. For the non-poor, selling crops/livestock is done in combination with spending savings or receiving help. This may suggest that selling crops/livestock is more frequent among wealthier households because they possibly have more stable assets to liquidate, and thus they then use internal (own savings) or external resources (receiving help) for mitigation purposes.

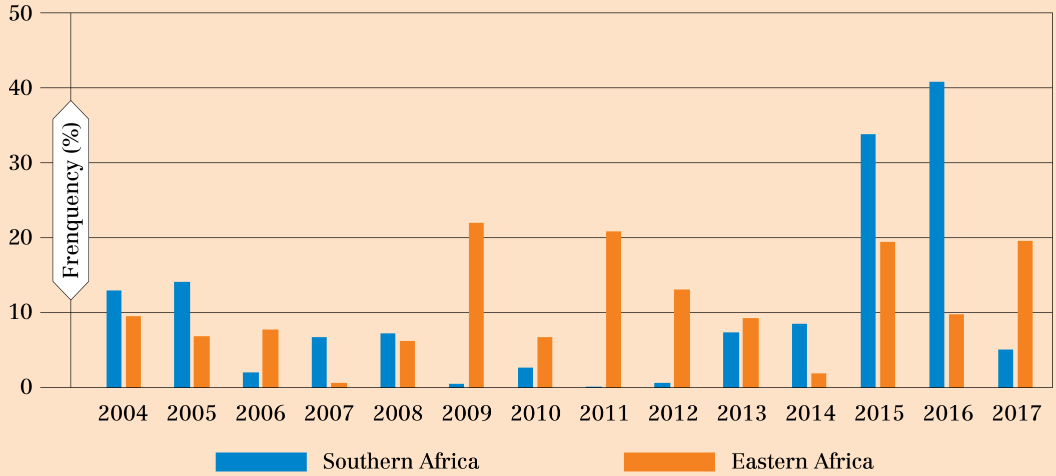
5.2 Horn of Africa

In Africa, the last decades have been characterized by an increasing occurrence of drought conditions that culminated with El Niño in 2015–2016. A closer look within the African continent shows different patterns in the frequency of droughts in the last 14 years (Figure 31). In Southern Africa, there was a relatively low frequency of drought conditions in the period 2006–2014, with an outstanding increase reported in the years influenced by El Niño: 2004–2005 and, to a higher extent, 2015–2016, when the subregion was hit by droughts for 35–40 percent of the time. On the contrary, Eastern Africa (orange bar in Figure 31) experienced more years with a drought frequency equal to or higher than 20 percent (years 2009, 2011, 2015, and 2017). This is possibly linked to the combined effect of other regional climate drivers such as La Niña and the Indian Ocean Dipole, where irregular oscillations of the sea surface temperature make the western part of the Indian ocean alternatively warmer and colder than the eastern part.

The Horn of Africa[21] has experienced frequent and intense droughts in recent decades with severe impacts including famine and socio-economic consequences. The region's drought crisis in 2011 affected 13 million people, with that year being recorded as the driest in the eastern Horn of Africa in 60 years (FSNAU and FEWS NET, 2013; Slim, 2012). This regional drought has worsened an already fragile situation characterized by multiple shocks such as successive bad rains and rising inflation, and threatened livestock survival and water and food availability.

21 This region includes Djibouti, Eritrea, Ethiopia and Somalia.

FIGURE 31 Drought conditions frequency over croplands, 2004–2017



Note: Drought conditions frequency (ASAP – Anomaly Hotspots of Agriculture Production) indicating the percentage of dekads in a year with a drought event for croplands in Southern (blue) and Eastern Africa (orange).

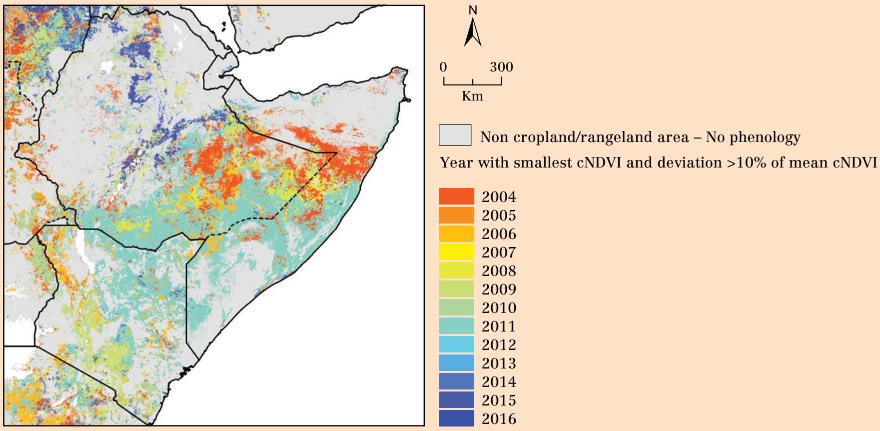
Source: Authors' elaborations based on data from the European Commission. 2020. ASAP – Anomaly Hotspots of Agricultural Production. In: *European Commission* [online]. [Cited 2 October 2020]. https://mars.jrc.ec.europa.eu/asap

The most affected areas of the 2011 regional crisis were southern Ethiopia and south-central Somalia, with severe consequences for pastoralist and agriculturalist communities. However, people in Somalia were more vulnerable to disaster than those in Ethiopia, due to pre-existing political instability that made people's risk of death higher. Furthermore, the country experienced extensive livestock deaths and the smallest cereal harvest since the 1991–1994 civil war, as well as a sharp drop in labour demand with consequences on household incomes and the capacity to cope with these multiple shocks (Slim, 2012). Between 2010 and 2012, 258 000 people died including 133 000 children under the age of five (FSNAU and FEWS NET, 2013).

The drop in cereal production and reduced food supplies increased staple food prices to extreme levels that strongly compromised access to food, especially for smallholder households who became increasingly dependent on the market. In southern Somalia, 11 out of the 16 surveys on nutrition and mortality conducted in 2011 showed that the prevalence of global acute malnutrition exceeded the IPC/CH threshold for Phase 5 (Famine) of 30 percent (Salama *et al.*, 2012). In five areas, Crude Death Rates exceeded the IPC/CH Phase 5 threshold of 2/10 000 per day, while in the remote agropastoral zones of the south more than 20 percent of households faced extreme food shortages (Salama *et al.*, 2012). Although the impact of drought on food security is known to be mediated by several factors, the 2010–2011 drought is an example of a direct link between the two.

For Kenya and Somalia, where detailed food security reports are available thanks to countrywide acute IPC analysis, a significant and direct association was found between the IPC phase at the district level and drought intensity proxied by remote sensing and districts where the remote sensing identifies the most severe droughts corresponded to the three most severe IPC phases (from crisis to famine) (Meroni *et al.*, 2014). For the period 2004-2016, remote sensing data from ASAP confirm that 2011 was the year with the with the lowest vegetation productivity in Central and Southern Somalia, Eastern Kenya and parts of Southern Ethiopia (Figure 32) and make it possible to map at a 1 km resolution crop and rangelands concerned.

FIGURE 32 Year with the lowest croplands and rangelands productivity in the 2004–2016 period



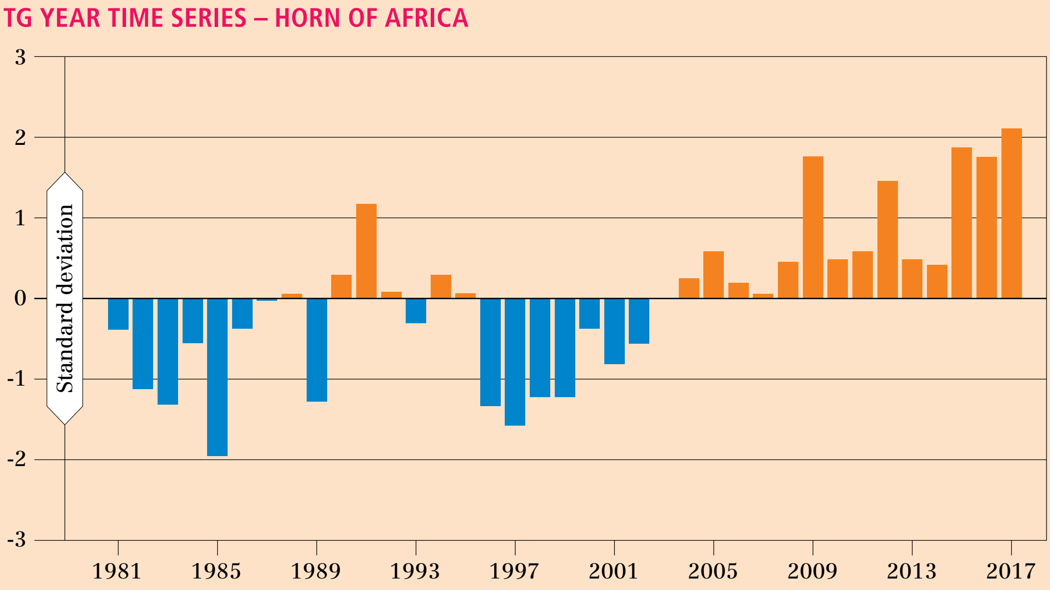
Notes: The figure shows the year with the lowest annual vegetation biomass production based on remote sensing vegetation coverage data, represented through the annual cumulative value of the normalized difference vegetation index (cNDVI). The colour scale indicates which year was most extreme in terms of minimum vegetation production. The final boundary between the Republic of the Sudan and the Republic of South Sudan has not yet been determined. Final status of the Abyei area has not yet been determined.

Source: Authors' elaborations based on data from the European Commission. 2020. NDVI – Normalized Difference Vegetation Index and GSL – Growing Season Length. In: *European Commission* [online]. [Cited 2 October 2020]. https://mars.jrc.ec.europa.eu/asap. Conforms to Map No. 4045 Rev. 8.1 UNITED NATIONS July 2018.

During the El Niño-induced drought in 2015–2016, the most affected areas of the region were central and southern Somalia and south-eastern Ethiopia, which received less than one-quarter of their normal seasonal rainfall (FAO, 2016d). Below-average March–May rains in 2016 eroded the resilience capacity of many households, requiring timely and effective support to the agricultural sector. In Ethiopia, vegetation levels were significantly below average in the affected areas and rangeland conditions were extremely poor. As a result of severe water and pasture shortages, livestock health rapidly deteriorated and livestock migration and deaths were reported. The most devastating effects in terms of animal loss were reported in the southern and south-eastern regions of Ethiopia (FAO, 2016e). In this country, the impact of El Niño-related drought on the agriculture sector left an estimated 9.7 million people in need of urgent food assistance in 2016 (FSIN, 2017). In Djibouti, the impact of the 2015–2016 El Niño was strong, as nearly 80 percent of the population is dependent on pastoralism or agropastoralism. Overall, 200 000 people in the country faced acute food insecurity (ICP/CH Phase 3 Crisis), thus compromising access to nutritious food. A regional migrant and refugee crisis represented an additional burden, leading to flows of people from Somalia, Yemen and Ethiopia (FSIN, 2017).

In the Horn of Africa, the mean temperature has been increasing over time, with a clear majority of below-average anomalies in the first half of the time series presented in Figure 33 (blue bars), and mostly above-average anomalies in the second half (red bars). In fact, considering the 1981–2016 reference period, the Horn of Africa experienced above-normal (hotter) temperature anomalies in the recent past, including three very recent events close to +2 SD, indicating that these events occur once every 40 years. Furthermore, the increase in overall mean temperature in the period from April to September was determined by a combination of reduced numbers of cold days and increased numbers of hot days. This had severe consequence in the region if we consider that in a large part of the Horn of Africa, the growing season occurs between April and July.

FIGURE 33 Standardized anomalies of the mean temperature over a 37-year period (1981–2016)



Note: Blue bars denote below-average anomalies (colder temperatures) while orange bars denote above-average anomalies (hotter temperatures) in the Horn of Africa.

Source: Authors' elaboration based on Crespo *et al.* (2018) data and analysis on precipitation.

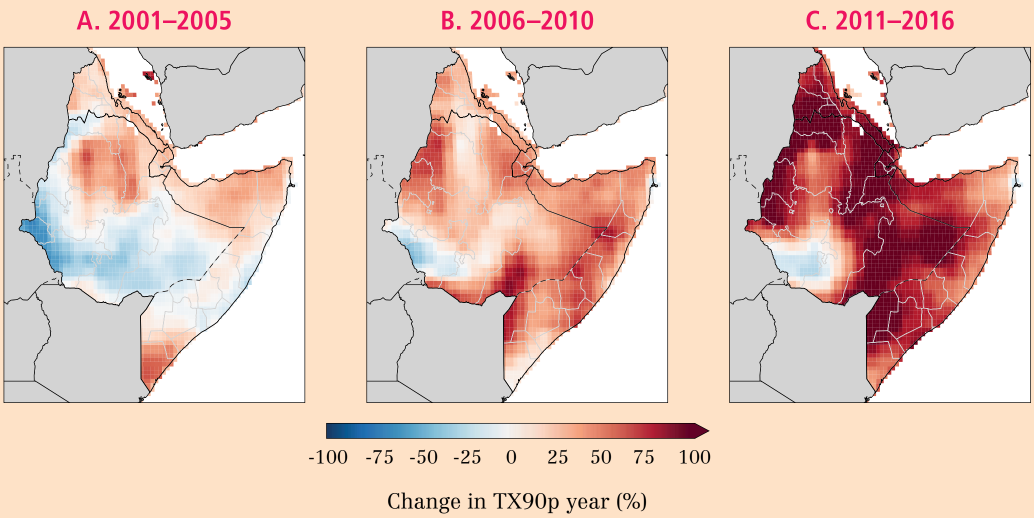
The five-year analysis of temperature anomalies compared to the long-term trend (1981–2016) shows that the number of hot day anomalies over land has dramatically increased in the Horn of Africa (Figure 34). Starting from localized anomalies in northern Ethiopia and southern Somalia, over time it has spread to encompass most of the area but the tri-border Ethiopia-Kenya-South Sudan region and the Somalian tip of the Horn (Figure 34, years 2011–2016). Years 2015–2016 were particularly extreme and saw intense increases in the number of hot days that drove the high temperature rise between 2011 and 2016.

While globally the highest level of agricultural drought conditions over croplands were recorded in 2006 and 2015, for rangeland areas similar patterns emerge in addition to a marked effect of drought conditions in 2009 related to the strong El Niño. This was the year when rangelands in large parts of Eastern Africa, particularly in northern Kenya, experienced a major drought and high livestock losses in 2009.

An analysis of coping strategies undertaken after the occurrence of climate shocks in Ethiopia shows that households engage in negative coping strategies that include less food consumption, as well as spending household savings and selling crops and/or livestock (Holleman and Conti, forthcoming). However, when households are targeted by government or non-governmental support programmes, such as the Productive Safety Net Programme (PSNP), the effects of climate shocks are mitigated, with recipients having 10 percentage points higher consumption compared to households experiencing the shock but not enrolled in these programmes. However, these protective measures do not eliminate the higher food insecurity deriving from climate shocks, being not effective enough to decrease households' vulnerability and food insecurity. Safety nets should be better targeted at specific groups that are vulnerable to climate disasters, and better integrated in disaster adaptation and mitigation interventions. For instance, insurance schemes can play a significant role in mitigating risks in this area.

Out of the 50 million pastoralists in sub-Saharan Africa, over 20 million live in the Horn of Africa, where the exports of livestock and livestock products exceed USD 1 billion annually (Mude and Lead, 2017). Being the main source of livelihood and wealth for pastoralists, livestock losses can be especially catastrophic in this area as shocks can thrust prosperous households into chronic destitution (Jensen, Barrett and Mude, 2015). The Kenya Livestock Insurance Programme (KLIP) is a public-private partnership offering index-based livestock insurance that in 2017 covered 22 000 households across eight counties of northern Kenya. The insurance, started as a pilot project in 2010, relies on satellite indicators of drought to trigger compensation to insured pastoralists during periods of severe forage scarcity, which can be used to purchase feed, water, and veterinary and other inputs to protect the core breeding stock. During the 2016–2017 severe drought in the Horn of Africa, KLIP triggered three consecutive large seasonal payouts, disbursing over USD 7 million to more than 15 000 pastoral households, representing a record for the Kenyan insurance scheme.

FIGURE 34 Number of hot days above the 90th percentile of the temperature distribution in the Horn of Africa – five-year periods between 2001 and 2016



Notes: Standardized anomalies in the number of hot days (TX90p) in the Horn of Africa from April to September. Spatial 5-year anomalies are compared to climatology (1981–2016) for consecutive periods from 2001 through to 2016. Red areas denote the percentage of hot days in the period, defined as those days above the 90th percentile of the temperature distribution. Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined. Final status of the Abyei area is not yet determined.

Source: Authors' elaboration based on Crespo *et al.* (2018) data and analysis on precipitation. Conforms to Map No. 4045 Rev. 8.1 UNITED NATIONS July 2018.

5.3 Central American Dry Corridor

Central America is one of the regions most vulnerable to disaster risks due to its geographical location, high climate variability, exposure to extreme hazards, and institutional and socio-economic weaknesses of its population. Extreme weather conditions can cause damage in agriculture and disrupt the food and nutrition security of the rural population. The term "Dry Corridor" refers to a climatic phenomenon, as this is one of the areas in Central America most affected by extreme natural hazards. The term has an ecological basis and defines a group of ecosystems in the ecoregion of dry tropical forests in Central America that cover the lowlands of the Pacific coastal area, and most of the central pre-mountain region of El Salvador, Guatemala, Honduras, Nicaragua, Guanacaste in Costa Rica, and the *Arco Seco* in Panama (Figure 35).

FIGURE 35 Location of the Central American Dry Corridor and *Arco Seco* (Panama)

Note: Purple areas in the Dry Corridor of Central America and the *Arco Seco* of Panama have been identified based on the occurrence of drought periods lasting more than four months.

Source: Central American Atlas for Sustainable Territory Management.

It is estimated that more than one million families rely on subsistence farming in the Central American Dry Corridor. The levels of poverty and malnutrition are alarming and mainly affect rural populations and indigenous communities. Most livelihoods are very climate-sensitive: the percentage of producers of basic grains varies from 54 percent in El Salvador and Honduras to 67 percent in Guatemala. The effects of climate hazards are even worse due to the low percentage of cropland surface irrigated in the region, representing 25 percent of the total area in Costa Rica, 18 percent in Honduras, 4.9 percent in Panama, 3.2 percent in Nicaragua, and only 1.6 percent in El Salvador.

In 2015, Guatemala, Honduras and El Salvador experienced one of the worst droughts of the last ten years with over 3.5 million in need of humanitarian assistance (FAO, 2016a). The most harmful socio-economic consequences were borne by smallholder households in rural areas, who suffered crop failure and depletion of their assets and have since been forced to migrate to overpopulated urban areas. In Guatemala, 1.5 million people are in need of humanitarian assistance (FAO, 2016a). Eighty-two million tonnes of maize were lost in 2015, causing a deterioration of the food security situation due to a rapid erosion of basic grain stocks in households. Approximately 915 000 people became moderately to severely food-insecure, as drought led to a third consecutive year of decreased harvests (FAO, 2016a).

In El Salvador, 190 000 people became moderately to severely food-insecure as a result of the 2015 drought, leading to a 60 percent loss of maize crop. The estimated loss for the economy amounts to approximately USD 100 million, with investment losses in seeds, fertilizers, pesticides and land preparation estimated at USD 29 million (FAO, 2016a). Similar losses are found in Honduras, where maize and bean losses are estimated at 60 and 80 percent, respectively.

In addition to climate extremes, the food security situation in the area was further threatened by the coffee leaf rust epidemic that hit Central America and Mexico starting from the 2011/2012 harvest season. The epidemic was caused by a leaf disease that dramatically reduced coffee production by 16 percent in 2013 compared to 2011–2012 (Avelino *et al.*, 2015). The epidemic had indirect effects on food insecurity, given that in these areas coffee represents the main source of income and is often used to buy food and supplies for the cultivation of basic grains (Avelino *et al.*, 2015). For many farmers in the area, the coffee leaf rust epidemic resulted in the loss of multiple crop cycles, translating into a loss of income for multiple years that pushed many farmers to give up on farming coffee. In 2016, the epidemic affected 70 percent of farms in the area, with over 1.7 million coffee workers losing their jobs, leading to USD 3.2 billion in damage and lost income (World Coffee Research, 2020).

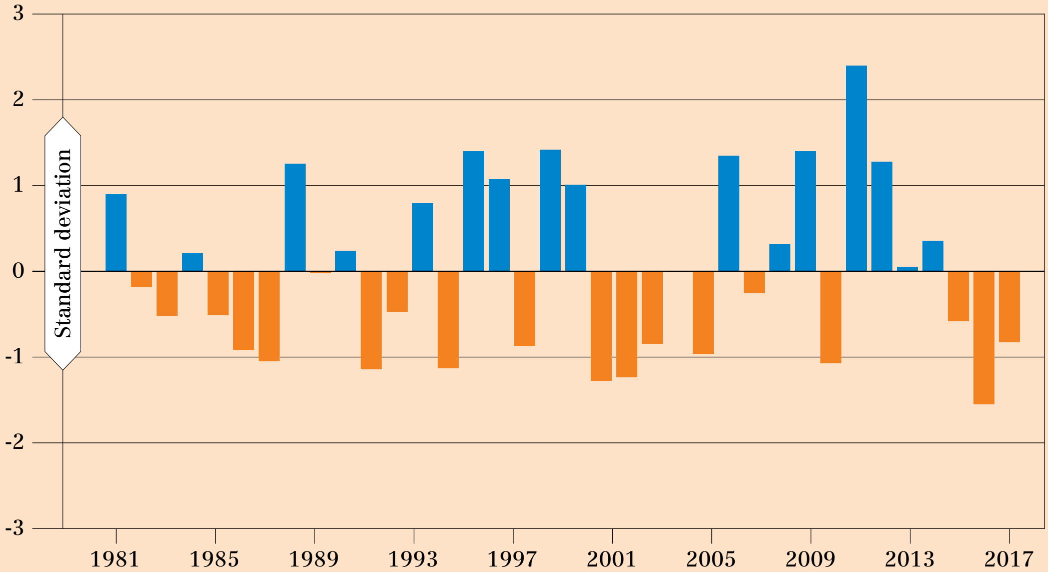
Climate risks in the Dry Corridor are mainly represented by recurrent droughts, excessive rains and severe flooding affecting agricultural production, with greater intensity in degraded areas. In the region, extreme drought events are highly correlated with the presence of the El Niño phenomenon that disrupts the normal wind circulation, thus reducing rainfall. This reduction generally occurs during the months of July, August and September. This coincides with the flowering and grain-filling phases of cereals, but also with a phenomenon known locally as *canícula*, involving a remarkable reduction in precipitation levels during the rainy season. The *canícula* is accentuated by the presence of El Niño, affecting the maturity of the first crop season and delaying planting of the second crop season. Furthermore, the number of cold nights has shown a slight overall decrease from April to September, and (although irregularly) there have been largely above-normal anomalies of hot days in very recent years.

Looking at regional trends over time, this area is also characterized by high variability of rainfall, with multiple dry years followed by excessively wet periods. Figure 36 shows four consecutive years of anomalies in rainfall scarcity in the early 2000s, followed by periods of excessive rainfall with three events above 1 SD in 2005, 2008 and 2011, and one event above 2 SD in 2010 (Figure 36). The two most serious El Niño-induced rainfall reductions are visible in 1991–1992 and, more recently, in 2014–2015.

When looking at remote sensing variables over the period 2003–2016, there is no major GSL trend in the region. But at the national level, El Salvador and Nicaragua show significant positive GSL trends, meaning longer growing seasons, for more than 10 percent of cropland. However, within the Dry Corridor there are remarkable spots with a shortening growing season that are particularly concentrated in Honduras and El Salvador (Figure 37).

FIGURE 36 Anomalies of total precipitation, 1981–2015

PRCPTOT YEAR TIME SERIES – DRY CORRIDOR

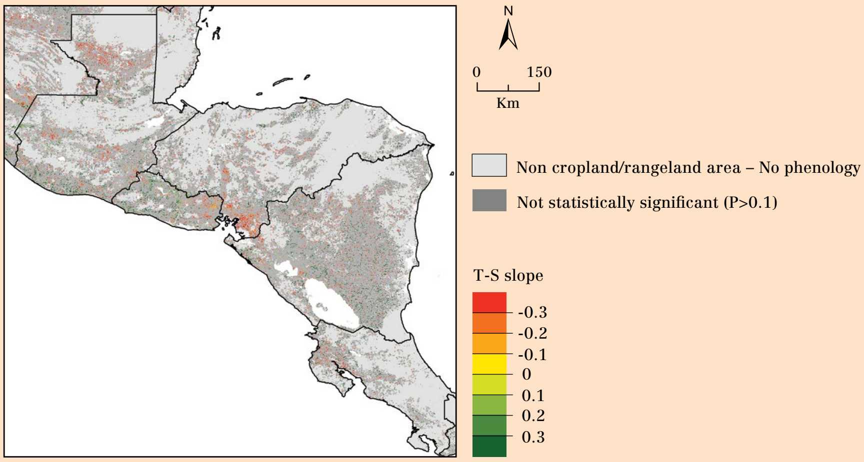


Note: Blue bars denote above-average anomalies (excess of rainfall) while orange bars denote below-average anomalies (scarcity of rainfall) in the Dry Corridor.

Source: Authors' elaboration based on Crespo *et al.* (2018) data and analysis on precipitation.

FIGURE 37 Trend in growing season length in the Central American Dry Corridor for croplands and rangelands, 2004–2016

GSL FIRST SEASON – CROPLANDS AND RANGELANDS



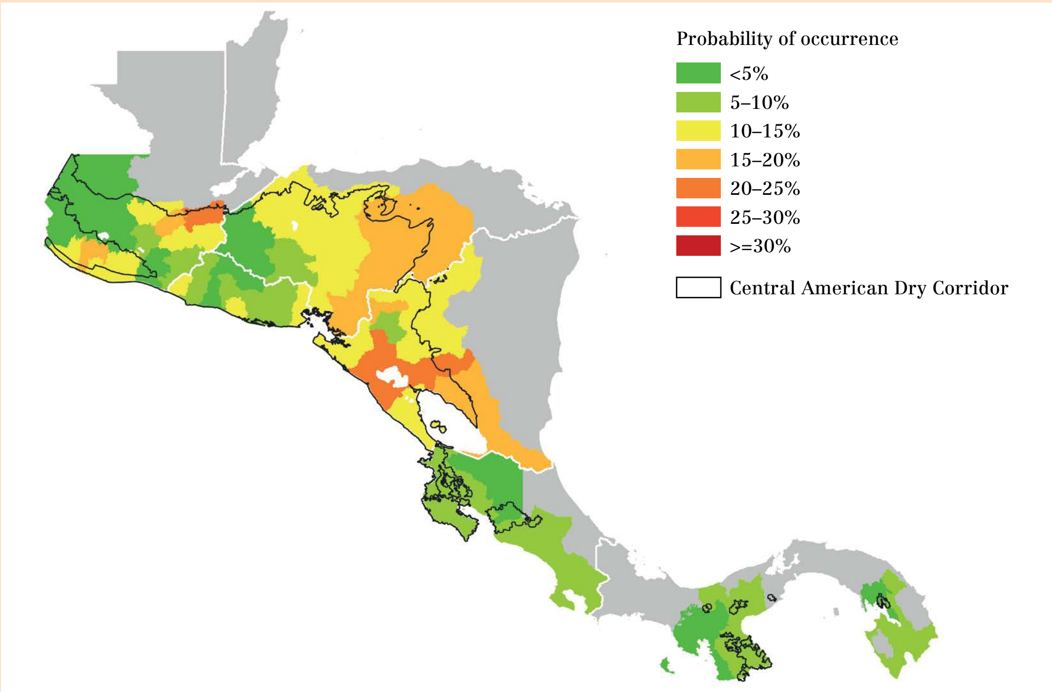
Notes: The map shows dekads per year with a change in growing season length (GSL) for cropland and rangeland areas in the Dry Corridor. The T-S slope is the average change in dekad (10-day period) per year. Only pixels with significant trends are shown (non-significant trends are masked out in dark grey). Non-cropland and non-rangeland areas are masked out in light grey. Red pixels denote a negative trend (i.e. a decrease in average growing season length in dekads per year) and green pixels denote a positive trend.

Source: Authors' elaboration based on data from the European Commission. 2020. NDVI – Normalized Difference Vegetation Index. In: *European Commission* [online]. [Cited 2 October 2020]. https://mars.jrc.ec.europa.eu/asap. Conforms to Map No. 4170 Rev. 19 UNITED NATIONS October 2020.

The FAO Agricultural Stress Index System (ASIS) has been useful for understanding the impact of the El Niño phenomenon on the agricultural areas of the Dry Corridor. The ASIS indicator highlights anomalous vegetation growth and potential drought in arable land during a given cropping season. ASIS is expressed as a percentage of arable land affected by drought at a local administrative unit. In line with Figure 8, ASIS detected 1991 and 2015 as the two years with extreme drought events that seriously affected the cropland in the Dry Corridor of most Central America countries: both years were being influenced by the El Niño phenomenon. Although the National Oceanic and Atmospheric Administration (NOAA) classified the 1991–1992 El Niño as "strong" and that of 2015–2016 as "very strong", the impact of drought on cropland areas was more intense in 1991 than in 2015 in the Dry Corridor. The most affected countries in 1991 were Nicaragua, Honduras and Guatemala, which lost 65, 47 and 32 percent of their cropland areas, respectively.

In 2015, the drought impact was more widespread in the region, varying the effect from 13 percent in Nicaragua to 23 percent of cropland affected by severe drought in Panama. There have been about ten El Niño events in the last 30 years, each different from the other in terms of impact on regional rainfall and geographical hotspots cropland damage. However, the areas in Nicaragua are more prone to drought than the rest of the countries in the Dry Corridor. When looking at the effect of severe drought at the provincial level, the central part of the Dry Corridor in Nicaragua and southern provinces of Honduras have a probability of severe drought occurrence of more than 25 percent, which means at least one event every 4 years (Figure 38). The Dry Corridor regions in Costa Rica and Panama are less prone to drought, as the main crop cultivated is rice and therefore has a significant irrigation surface area.

FIGURE 38 Probability of having more than 20 percent of cropland affected by severe drought at the provincial level in 2016



Source: Authors' elaborations based on data from FAO on the Agriculture Stress Index System (ASIS). Conforms to Map No. 4170 Rev. 19 UNITED NATIONS October 2020.

5.4 Bangladesh

Bangladesh is the most densely populated country in the world, with 1 223 inhabitants/km^2 (CIA, 2018). It has a low elevation and vast watercourses (7 percent of the country is occupied by water bodies) and it is highly susceptible to extreme weather events that are increasing in frequency and intensity (FSIN, 2018). Although half of its GDP is generated by the services sector, 70 percent of the territory is used for agricultural production and half of the inhabitants are employed in this sector. Rice is the main crop, accounting for almost half of total domestic crop production (Bangladesh Bureau of Statistics, 2017). The steady export growth in the garment sector (accounting for 89 percent of total exports), combined with USD 13 billion remittances from overseas Bangladeshis, contribute to rising foreign exchange reserves (Bangladesh Bureau of Statistics, 2017; CIA, 2018). The recent influx of 700 000 million refugees from Myanmar is putting pressure on the government's budget and the country's rice supplies, which declined in 2017 in part because of record flooding (FSIN, 2018).

Its tropical climate is characterized by four seasons – pre-monsoon, monsoon, post-monsoon and dry season. Around 80 percent of the annual rain comes during the monsoon season (from June to October), when floods occur regularly, while cyclones occur during the pre- and post-monsoon seasons. During the monsoon season a large portion of the floodwater from precipitation and river flow infiltrates into aquifers, to be used later during the dry season (Pacetti, Caporali and Rulli, 2017). Rice grows in three growing seasons: Boro, Aman and Aus, which are also the names of the three rice varieties cultivated. Boro is the most important and single largest crop in Bangladesh in terms of production volume; it grows during the dry season, once the floods have receded. Aman grows during the monsoon season when rainfall is plentiful, whereas Aus production takes advantage of rainfall during the spring transition toward the monsoon, allowing for a short growing season, with high variability from year to year (Ruane *et al.*, 2013). However, in the attempt to describe the growing season length in this country over all croplands and rangelands, a maximum of two growing seasons are detected per year using the NDVI, and are described in Figure 39. In fact, we only rely on 36 data points per year that make it difficult to separate the pattern over three seasons.

A higher frequency of natural disasters has been observed over time in Bangladesh. Recently, floods and cyclones (especially Cyclone Mora in May 2017) were observed in 2015–2017. Earlier, Bangladesh already witnessed a devastating tropical cyclone in 2007 (Cyclone Sidr) that caused enormous disruptions, damages and a devastating number of human deaths. When this occurred, the country was not yet fully recovered from a violent flood that had occurred only three months before, causing extensive damages to infrastructure. While in the past destructive cyclones occurred every 30 to 50 years, in recent years they are occurring nearly every eight years, signalling an increasing frequency of these events. However, the number of deaths are conspicuously lower in recent years, indicating that awareness, warning systems and responses to these shocks have improved (Hossain *et al.*, 2008).

Besides floods and cyclones, in the last two decades Bangladesh has experienced a high number of severe and extreme droughts such as those occurring in 1995, 1999 and 2006, with consequences in terms of price increases, higher unavailability of jobs, and reduced access to food for rural people. In correspondence with the most severe and recent drought warning reported in the country in 2006, a significant increase in PoU is detected through the PoU change point analysis. It suggests a strong association between chronic food insecurity as measured by the PoU, and extreme climate shocks (see Figure 24).

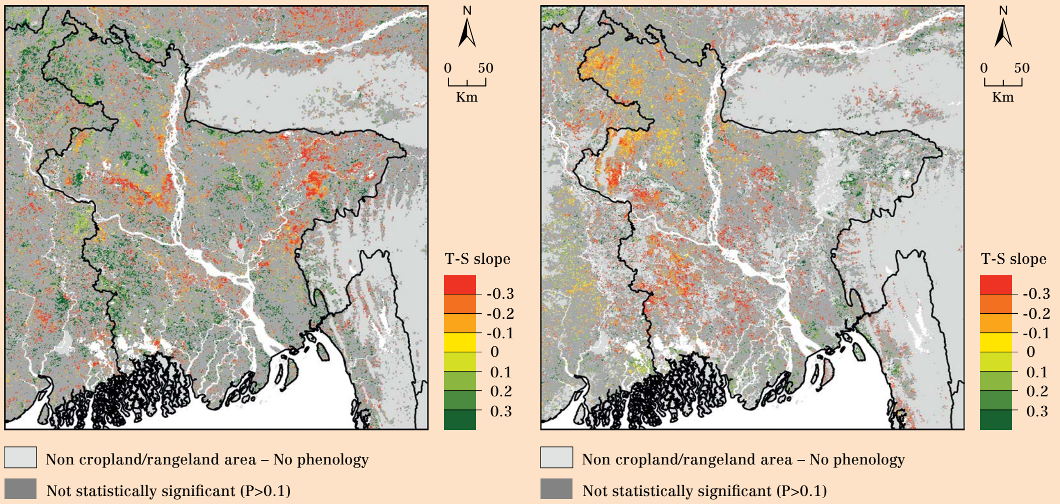
The country's agricultural area is mostly used for cropping activities, and accounts for 96 percent of the total area. 22 percent of the crop area exhibits a significant trend in length of the first growing season. Half of such area shows an increase in the length, whereas the other half shows a reduction. Regarding the second season, out of the 22 percent of crops where a change in season length is observed, 74 percent show an average reduction of 2.8 days per year. Similar findings hold for rangelands (Figure 39).

The country has achieved food self-sufficiency in terms of calorie availability, with per capita calorie intake in 2010 equal to 2 318 kcal per day – higher than the estimated minimum requirement of 2 122 kcal per day (Osmani *et al.*, 2016). Also food access has improved, with a decline in extreme poverty from 34 percent in 2000 to 13 percent in 2016 (FSIN, 2018). The major issue concerns the quality and diversity of diets, with cereals still occupying a predominant position. In terms of PoU, after registering high values between 1993 and 1996 (38–36 percent), the PoU has been progressively declining in 2010–2016, with a value of 15 percent observed in 2016 (FAO, 2017).

FIGURE 39 Decreased growing season length over cropland and rangeland in Bangladesh (2004–2016)

A. GSL FIRST SEASON – CROPLANDS AND RANGELANDS

B. GSL SECOND SEASON – CROPLANDS AND RANGELANDS



Notes: The map shows dekads per year with a change in the first and second growing season for cropland and rangeland areas in Bangladesh. The T-S slope is the average change in dekad (10-day period) per year. Only pixels with significant trends are shown (non-significant trends are masked out in dark grey). Non-cropland and non-rangeland areas are masked out in light grey. The orange to red pixels denote a negative trend (i.e. areas with a significantly reduced average growing season length in dekads per year), whereas green pixels denote a positive trend. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Source: Authors' elaboration based on data from the European Commission. 2020. NDVI – Normalized Difference Vegetation Index. In: *European Commission* [online]. [Cited 2 October 2020]. https://mars.jrc.ec.europa.eu/asap. Conforms to Map No. 4170 Rev. 19 UNITED NATIONS October 2020.

Despite overall progress, climate evolution in the country is increasingly threatening food security. Three episodes of severe and widespread floods occurred in Bangladesh in 2015–2017 and caused extensive damage to paddy crops in northern rice-growing areas, which led to sharp declines in rice output followed by prices rising to historical highs. This has affected food access nationally, particularly in Cox's Bazar, one of the poorest and most vulnerable districts in the south-eastern part of the country that is currently hosting almost a million Rohingya refugees fleeing from the northern Rakhine State in Myanmar, since August 2017 (FSIN, 2018). Cox's Bazar has been hit by cyclones for three consecutive years (2015–2017), making a complete recovery between cyclones impossible, and thus worsening the livelihoods of already vulnerable people in this area. Research suggests host communities have experienced greater losses from these climate disasters than from hosting the Rohingya refugees, with livelihood losses (including crops) and damage to housing as well as water, sanitation and hygiene facilities (FSIN, 2018). There are 3.4 million people in IPC Phase 3 in the country, with this increase being also driven by the influx of refugees (FSIN, 2018).

In terms of nutrition, the country has halved the number of stunted children since 1990, although the stunting rate stands at 36 percent and progress is highly unequal. Little improvements are observed for wasting, which still affects over two million children under the age of five (Development Initiatives, 2019). Studies from Bangladesh show that after floods, wasting and stunting rates increase in the following years among preschool children due to reduced access to food, increased difficulties in providing proper care, and greater exposure to contaminants (Tirado *et al.*, 2013).

In the country, wasting rates among children are high in cyclone- and flood-affected areas, and strong statistical evidence shows that stunting rates are higher even after drought events. In fact, the prevalence of chronic undernutrition has increased among children that were affected by the 1998 flood (Del Ninno, Dorosh and Smith, 2003). Similarly, using the Nutrition Surveillance Programme dataset, it was found that even 12 months after the 1991 cyclone Gorky, child wasting was still extremely high in April 1992 (32 percent), and remained above 15 percent until October 1992 (Bloem, Moench-Pfanner and Panagides, 2013).

6 Conclusions and recommendations

The results of this study present clear evidence that increasing climate variability and extremes are not only negatively impacting on agriculture but are key drivers behind the recent rise in global hunger and among the leading causes of severe food crises. While the uptick in hunger at the global level, as measured by the PoU, occurred in 2015, the analysis of this study shows that the rise in undernourishment occurred even earlier for many countries, in 2011. Moreover, the analysis reveals this rise in hunger was higher and more pronounced for countries with high exposure to climate extremes and where agriculture is highly vulnerable to changes in climate. Hunger is found to be significantly worse in countries with agricultural systems that are highly sensitive to rainfall and temperature variability and severe drought, and where the livelihoods of a high proportion of the population depend on agriculture.

Global changes in climate have led, and continue to lead to, increased climate variability and extremes. Analysis from this study shows that climate variability and extremes over agricultural areas have increased in the last decade as compared to the last four decades. Heat anomalies over cropland and rangeland areas continued to increase in the period of 2011–2015. Not only were temperatures hotter, but high temperatures occurred more frequently. Precipitation variability increased (both positive and negative) over much of the globe in 2011–2015, and often differently from the significantly positive long-term trends. In the last ten years, drought has been notably frequent in many regions around the globe, especially but not only tied to El Niño. Several countries also have experienced not only abnormally lower total accumulated rainfall, but also lower-intensity and fewer days of rainfall, especially in Africa, Central America and South-eastern Asia.

New analysis presented in this study shows that, indeed, climate variability and exposure to more complex, frequent and intense climate extremes constitute a key force behind the recent continued rise in global hunger. Severe droughts linked to the strong El Niño of 2015–2016 affected many countries, contributing to the recent uptick in undernourishment at the global level. Importantly, the results show that it is not only extreme climate events, such as severe droughts and floods, that are negatively affecting agriculture and leading to food insecurity, but also changing seasonal patterns, including shorter rainy seasons and poorly distributed rainfall within seasons.

The strongest direct impacts of increasing climate variability and extremes are felt on food availability, given the sensitivity of agriculture to climate and the primary role of the sector as a source of food and livelihoods for the rural poor. However, the overall fallout is far more complex, affecting more than productivity alone. Food access is significantly undermined too. Spikes in food prices and volatility follow climate extremes and extend well beyond the actual climatic event. Net buyers of food are hardest hit by price volatility; these include the urban poor, but also small-scale food producers, agriculture labourers and the rural poor. In addition, many of these people have already lost income as a result of the negative effects on agricultural productivity. This in turn makes it difficult for all the affected population groups to purchase food.

Case studies presented in this study provide a sobering integrated picture of how increasing climate variability and extremes are negatively affecting agriculture, resulting in destructive secondary impacts on livelihoods, income, food prices and coping capacities, resulting in increased food insecurity.

Without any doubt, changes in climate variability and extremes threaten food security and nutrition. They are among the leading causes of food crisis situations. In 2017, climate shocks were a factor in 34 out of the 51 countries facing food crises. What is new, however, is that climate variability and extremes are affecting chronic food deprivation or undernourishment. For example, the results of this study show that severe drought is associated with increases in undernourishment. For almost 36 percent of the countries that have experienced a rise in undernourishment since 2005, this has coincided with the occurrence of severe drought.

Climate change is not something that will occur in the future. It is happening now, and leading to increased climate variability and extremes that are negatively impacting on agriculture and linked to rises in hunger. The rise in hunger is a clear indication that the world is not doing enough to address the negative impacts of climate on agriculture and food security. Actions must be urgently taken, and building climate resilience is one of the solutions that must be prioritized. The good news is that we already have the knowledge and tools needed to address this problem. We also have experience and evidence pointing to the cross-cutting factors that lead to successful policies and practices to address climate risks.

The challenge is to scale up and accelerate actions that strengthen the resilience of food systems and livelihoods to climate variability and extremes. Integrated, rather than dissociated disaster risk reduction and management and climate adaption policies, programmes and practices are critical. All of these also need to be implemented with a short-, medium- and long-term vision, as the negative impacts of increasing climate variability and extremes are already falling heavily on the most food-insecure, and all climate projections foresee climate variability and extremes continuing to increase in severity and frequency in the coming years.

Climate risk monitoring and early warning systems are essential for governments and international agencies to monitor multiple hazards and predict the likelihood of climate risks affecting livelihoods and food security and nutrition. It is also critical to invest in vulnerability reduction measures, including climate-resilient good practices at the farm level and climate-proof infrastructure (including climate-proof food storage and preservation facilities), and to strengthen capacity for more efficient water management (including new water sources, irrigation, drainage, water harvesting and saving technologies, desalinization, and storm- and wastewater management).

In many areas, it is necessary to building resilience against changing seasonal patterns, including shorter rainy seasons and poorly distributed rainfall within seasons. For example, crop diversification can help spread production and income risk over a wider range of crops for farmers. Evidence also shows that by growing a mixture of crop varieties, whereby the best seeds from field trial plots are combined with traditional varieties for the next planting season, farmers are able to increase the climate resilience of their crops. The introduction of short-maturing seed varieties is another strategy that is helping farmers cope with shorter growing seasons, or allowing them to replant crops after flood damage even when the remaining seasonal rain amounts are lower.

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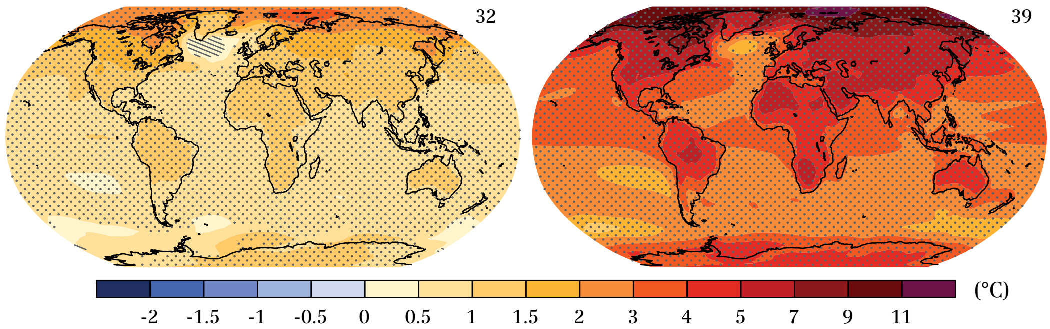
Annexes

Annex 1. Future climate projections

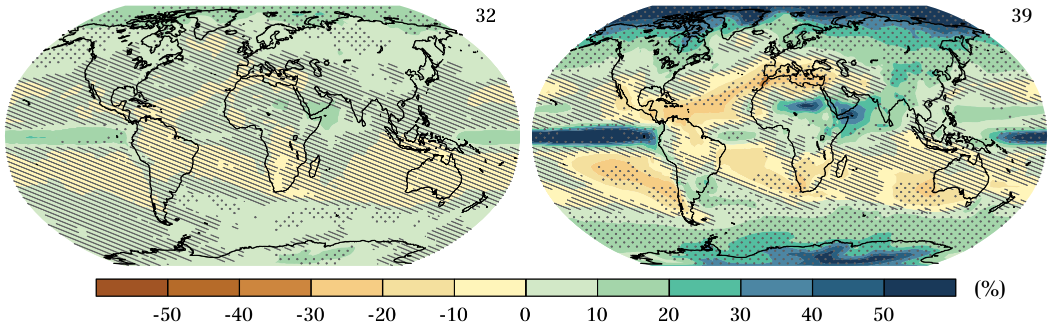
FIGURE A1.1 Two climate scenarios – change in temperature and precipitation

RCP2.6 RCP8.5

A. CHANGE IN AVERAGE SURFACE TEMPERATURE (1986–2005 TO 2081–2100)



B. CHANGE IN AVERAGE PRECIPITATION (1986–2005 TO 2081–2100)



Notes: Intergovernmental Panel on Climate Change (IPCC) maps showing mean results of the Coupled Model Intercomparison Project Phase 5 (CMIP5) multimodel for the two emission scenarios referred to as Representative Concentration Pathways (RCP2.6 and RCP8.5). Maps refer to years 2081–2100 for a) annual mean surface temperature change; b) average percent change in annual mean precipitation.

Source: IPCC. 2014. *Climate Change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea & L.L. White, eds. Cambridge, UK and New York, USA, Cambridge University Press.

Annex 2. Data sources and definitions of climate indices

Weather, climate and climate change

Weather describes conditions in the atmosphere over a short period of time (minutes or days), whereas climate describes the slowly varying aspects of the atmosphere–hydrosphere–land surface system and is typically characterized in terms of suitable averages of the climate system over periods of a month or more. This technical study does not analyse individual or specific weather events but instead focuses on climate variability and extremes (see below definitions) and their impact on food security and nutrition.

Definitions of climate variability

Climate variability refers to variations in the mean state of the climate (and other statistics, such as standard deviations and the occurrence of extremes) on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

This study also analyses inter-seasonal variability, in terms of late/early seasonal onset and growing season length. Although such variations generally do not register as extreme weather events, they are aspects of climate variability on shorter time scales that affect the growth of crops and availability of pasture for livestock, thereby impacting on food security and nutrition. Between-season variations are defined using phenological variables derived from the NDVI: i) a dominant reduction in season length is defined as when a significant trend of decreased length during the period 2003–2016 involves at least 10 percent of cropland and rangeland areas of a country; ii) delay in or early onset of the seasons denotes countries where at least 10 percent of cropland and/or rangeland areas are characterized by a delay in or early onset of the season during the period 2003–2016.

Definitions of climate extremes

Climate extremes refer to the occurrence of a value for a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values for that variable. For simplicity, both extreme weather events and extreme climate events are referred to collectively as “climate extremes” as well as being referred to as climate shocks.

Country exposure to climate extremes

Exposure is defined as the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social or cultural assets in places and settings that could be adversely affected by climate extremes. For the purposes of this analysis, country exposure to climate extremes is conceived as a combined measure of both the frequency and intensity of climate extremes over the areas that could be most adversely affected, as it relates most directly to impacts on food security and agricultural areas.

- **Exposure to heat spells** is defined as when the percentage of very hot days (temperature above the 90th percentile) over agriculture cropping areas is greater than 1 standard deviation (SD) in a given year/country compared to the long-term average temperature.
- **Exposure to drought** is defined in two different ways: based on precipitation for years 1996–2005 and based on ASAP frequency of drought conditions for years 2006–2016. Exposure to drought is defined as when i) rainfall in a given country/year over agriculture cropping areas is lower than 1 SD with respect to the long-term rainfall average, or when ii) the ASAP system indicates drought conditions occurring for more than 15 percent of the growing season of croplands or rangelands in a given country/year. Although ASAP

is considered to provide a more accurate measure of drought, it has only been available since 2006. Several robustness checks were performed and confirm the validity of using both ASAP and precipitation for the earlier period to identify exposure to drought.

- **Exposure to floods** is defined as when the rainfall in a given country/year over agriculture cropping areas is greater than 2 SD with respect to the long-term rainfall average in the country.
- **Exposure to storms** is defined based on the datasets of medium- and large-scale disasters from the Emergency Disasters Database. Exposure to storms is defined as when in a given country/year storms have produced at least one of the following effects: i) deaths of ten or more people; ii) 100 or more people affected/injured/homeless; iii) declaration of a state of emergency or an appeal for international assistance.

Climate extremes are measured as the occurrence of any of these four extreme climate events for each year of the time frame considered (1996–2016), and are reported yearly for each country. Four subperiods are used: 1996–2000, 2001–2005, 2006–2010 and 2011–2016. Note that, due to data limitations, it is not possible to count the total number of climate extreme events in any given year.

A. Climate observations used in the analysis

Identifying suitable climate observations, given the wide range of geographical locations involved, is challenging. The diversity and complexity of station observations from multiple countries, including the very high percentage of missing records in such datasets, dictates the use of synthetic gridded products. The table below provides the index name and description for the climate observations used in this study.

For precipitation data, the Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) dataset was used, as it provides a rainfall dataset extending from 50S to 50N at sufficiently high spatial resolution (0.25 or 0.05) and high temporal resolution (daily). To produce the temperature indices, the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim reanalysis 2-metre daily minimum and maximum temperatures were used. For a more detailed discussion on the selected climate observations see Crespo *et al.* (2018).

In order to detect how climate extremes and variability have changed over time, climate maps are based on the historical period covering years 1981–2016, often referred to as “climatology”. When maps are intended to show recent climate extremes and vulnerability (for instance, El Niño 2016–2016), climatology 1981–2016 represents the reference period against which climate indicators in recent years are compared to detect variations.

TABLE A2.1 Description of climate extremes

Index name	Index description – short	Index description – long
CDD	Consecutive dry days	Maximun length of dry spell
CWD	Consecutive wet days	Maximum length of wet spell
PRCPTOT	Precipitation total	Total accumulated rainfall
RR1	Daily precipitation above 1 mm	Count of days when rainfall ≥ 1 mm
RX5day	Maximum consecutive 5-day precipitation	Maximum rainfall recorded over a consecutive 5-day period
SDII	Simple precipitation intensity index	Sum of rainfall during wet days (RR1) / number of wet days
SPEI	Standardised precipitation-evapotranspiration index	
TG	Temperature average	Daily mean temperature
TN10p	Percentage of days when TN < 10th percentile	Percentage of days when daily minimum temperature is lower than 10th percentile
TX90p	Percentage of days when TX > 90th percentile	Percentage of days when daily maximum temperature is higher than 90th percentile

Source: Authors' elaborations based on ETCCDI Climate Change Indices (ETCCDI, 2020; Crespo *et al.*, 2018).

TABLE A2.2 Definitions and sources of climate extremes

Indicators	Variables	Years	Level of aggregation	Data source	Relevancy to analysis (national or case study)
Dryness/ aridity (informs drought)	**CDD**: maximum length of dry spell (and its standard deviation)	1981–2017 Yearly Seasonal	Country Subregion Region Global	Climate Hazards Group Infrared Precipitation with Stations (CHIRPS)	National Subnational/ case study where variable is household survey data
Rainfall intensity (informs flood)	**CWD**: maximum length of wet spell (and its standard deviation) **RX5day**: monthly maximum consecutive 5-day precipitation **SDII**: simple precipitation intensity index	1981–2017 Yearly Seasonal	Country Subregion Region Global	CHIRPS	National Subnational/ case study where variable is household survey data

TABLE A2.2 (cont.) Definitions and sources of climate extremes

Indicators	Variables	Years	Level of aggregation	Data source	Relevancy to analysis (national or case study)
Heat/cold (informs growth efficiency/ stress)	**TX90p**: percentage of days when TX > 90th percentile **TN10p**: percentage of days when TN < 10th percentile	1950–2017 Yearly Seasonal	Country Subregion Region Global	ERA_INT reanalysis	National Subnational/ case study where variable is household survey data

Source: Authors' elaborations based on data from Crespo *et al.* (2018).

TABLE A2.3 Definitions and sources of climate variability and seasonality

Indicators	Variables	Years	Level of aggregation	Data source	Relevancy to analysis (national or case study)
Rainfall, seasonal (informs distribution)	**RR1**: annual count of days when precipitation ≥ 1 mm **PRCPTOT**: total accumulated precipitation **SDII**: simple precipitation intensity index	1981–2017 Yearly Seasonal	Country Subregion Region Global	Climate Hazards Group Infrared Precipitation with Stations (CHIRPS)	National Subnational/ case study where variable is household survey data
Temperature/ heat seasonal (informs distribution)	**TG**: daily mean temperature	1950–2017 Yearly Seasonal	Country Subregion Region Global	ERA_INT reanalysis	National Subnational/ case study where variable is household survey data

Source: Authors' elaborations based on data from Crespo *et al.* (2018).

B. Remote sensing-based phenology

The mean growing season period is defined by using the satellite-derived phenology computed on the long-term average of 10-day Moderate-resolution Imaging Spectroradiometer (MODIS) NDVI data pre-processed by BOKU University (Klisch and Atzberger, 2016), starting from MOD13A2 and MYD13A2 V006 16-day global data at 1 km resolution. Phenology was extracted using the SPIRITS software (Eerens *et al.*, 2014; Rembold *et al.*, 2015) applied to the historical average of the smoothed NDVI over the period 2013–2016.

The following key parameters are retrieved for each pixel: number of growing seasons per year (i.e. one or two); start of season (SOS, occurring at the time at which NDVI grows above 25 percent of the ascending amplitude of the seasonal profile); time of maximum NDVI (TOM); start of senescence period (SEN, when NDVI drops below 75 percent of the descending amplitude); and end of season (EOS, when NDVI drops below 35 percent). ASAP warnings are based on this phenology tool.

Climate- and biomass-based warnings of crop condition anomalies retrieved from the ASAP system (drought warning)

ASAP drought warnings describe agroclimatic anomalies for crop- and rangelands during active vegetation cycles and are a direct indicator of failed or low-yield seasons. The data are available since 2004 for each GAUL1 unit globally. The time series of crop- and rangeland production anomaly warnings has been used to derive annual frequencies of climate/biomass warnings both at the GAUL1 and national level. The indicator made available for this analysis is the percentage of dekads with drought warnings for a critical portion of cropland/rangeland area out of the total number of active dekads, and can be interpreted as an agricultural drought frequency. At the national level we take the average of the GAUL1 units.[22]

Global agriculture mask

Cropland and rangeland masks are hybrid masks obtained by merging multiple land-cover products together to produce an integrated product that represents the best characterization of cropland or land cover at a particular location. In Africa, six global (GLC2000, MODIS land cover 2010, GlobCover 2009, GLCNMO 2008, LC-CCI 2010 and GlobeLand30) and 16 regional land-cover datasets were compared at the country level using multicriteria decision analysis to select the most appropriate one (Pérez-Hoyos *et al.*, 2017a, 2017b). Outside Africa, regional datasets were used where available, otherwise we compared the six global datasets plus LCCI 2015 and FAO GLC-SHARE and selected the optimal one based on its accuracy and the comparison with FAOSTAT data. The agriculture and rangeland masks described here have been used to compute the ASAP warnings.

22 For more details, please see European Commission (2020).

Annex 3. Methodology on PoU change point

The State of Food Security and Nutrition in the World 2017 indicated that extreme weather events and climate variability were among the factors behind the uptick in hunger, as measured by PoU. The PoU estimates the proportion of the population habitually meeting the (average) minimum daily dietary intake requirements. It uses the mean dietary energy consumption, which is computed as a three-year average, meaning that the PoU is a highly smoothed data time series. To some extent, it reflects major variations in production when a country is not able to compensate large production drops with stocks and imports. Looking at PoU variations over time, rather than performing regressions between the PoU and climate variables, the best way to detect associations between food insecurity increase and the occurrence of climate events is to compare major climate shocks with change points in the PoU.

Change points in the PoU time series have been identified by applying the multiple structural changes model proposed by Bai and Perron (1998). This involves finding the best combination of n possible breaks subject to the constraint that the distance between break intervals should be above a minimum length. “Best combination” refers to the minimum sum of squared residuals from an ordinary least squares (OLS) regression of the PoU on a set of dummies indicating the timing of the breaks. A minimum break interval of three years has been imposed in the identification of the optimal segmentation. An additional constraint has been used to identify the relevant change points, i.e. only those ones characterized by a subsequent increasing tendency (estimated by the OLS method) have been retained.

According to this analysis, most countries had at least one and a maximum of five (Lebanon) upwards PoU change points during 2008-2015. Increases in the PoU can be due to a multitude of factors including food availability and access limitations, especially in the absence of national mitigation interventions. As the occurrence of drought events is likely to have a negative effect on food availability, these events are examples of the extreme weather events that can lead to an increase in PoU at a national scale if the country is not able to put in place sufficient variability support measures.

In this study, we evaluate whether a change point in the PoU national time series can be associated with high agricultural drought stress conditions at the national level, by using annual ASAP drought conditions frequencies (percentage of dekads with ASAP warnings) for the period 2005–2016. The frequency of drought conditions for a country is defined according to the ASAP early warning system, developed by the EC-JRC. ASAP drought frequency is based on the percentage of total time of the year for which a relevant share of cropland or rangeland areas (> 25 percent) is affected by drought warnings, according to anomalies of rainfall and NDVI. To do so, we consider that drought conditions determining a structural change point in year Y can happen from Y - 1 to Y + 1, and we look at mean drought conditions frequencies during a three-year window. This is done with the purpose of having a time series that is as similar as possible to the PoU time series which is smoothed over three years.

Out of the 91 PoU change points in the period 2005–2016 that have been found for all low- and middle-income countries, we then select change points that correspond to the first four ranks of drought conditions frequencies for each country (29 change points). Table A3.1 shows, by country, the year of PoU change point, the mean ASAP warning frequency found in the three-year window described above, and the within-country magnitude rank of such drought frequency. Table A3.1 shows only the countries where the PoU change points are associated with one of the first four most severe droughts by country, in the attempt to define countries and times where PoU is sensitive to drought conditions. Many countries in Southern Africa (but not only) show a PoU change point in 2014 or 2015 which can be connected with the drought impact of El Niño in 2015.

TABLE A3.1 Countries with PoU change points corresponding to Anomaly Hotspots of Agriculture Production drought conditions

Year	Country	Group	Rank	ASAP mean
2008	Armenia	Lower-middle-income countries	1	24.69
2010	Belize	Upper-middle-income countries	1	5.376667
2011	Central African Republic	Low-income countries	1	5.21
2015	Chad	Low-income countries	1	22.04667
2014	Mauritania	Lower-middle-income countries	1	26.64667
2015	Mozambique	Low-income countries	1	28.31667
2014	Panama	Upper-middle-income countries	1	9.9
2006	Ukraine	Lower-middle-income countries	1	15.58
2015	Zambia	Lower-middle-income countries	1	24.15667
2015	Cameroon	Lower-middle-income countries	2	20.05
2014	Eritrea	Low-income countries	2	36.37667
2015	Nigeria	Lower-middle-income countries	2	28.61
2004	Eswatini	Lower-middle-income countries	2	32
2015	Togo	Low-income countries	2	14.05333
2015	Turkmenistan	Upper-middle-income countries	2	20.52333
2014	Venezuela (Bolivarian Republic of)	Upper-middle-income countries	2	36.84667
2015	Zimbabwe	Low-income countries	2	24.54667
2007	Belize	Upper-middle-income countries	3	4.3
2015	Benin	Low-income countries	3	19.62667
2015	Côte d’Ivoire	Lower-middle-income countries	3	9.973333
2015	Madagascar	Low-income countries	3	17.24
2006	United Republic of Tanzania	Low-income countries	3	25.92
2006	Bangladesh	Lower-middle-income countries	4	11.56667
2015	Congo	Lower-middle-income countries	4	6.326667
2015	Gabon	Upper-middle-income countries	4	5.553333
2012	Guinea-Bissau	Low-income countries	4	1.523333
2006	Namibia	Upper-middle-income countries	4	20.33
2015	South Africa	Upper-middle-income countries	4	25.93333
2014	Yemen	Lower-middle-income countries	4	10.15333

Source: Authors’ elaborations based on data from FAO for the prevalence of undernourishment and the European Commission for the Anomaly Hotspots of Agriculture Production (ASAP).

Annex 4. Country group definitions and lists

Exposure and vulnerability to climate extremes

Whether climate variability and extremes negatively affect people's food security and nutrition depends on the frequency and intensity of climate shocks, the degree of exposure to climate shocks and people's vulnerability to these shocks. This analysis is undertaken on low- and middle-income countries, where there are generally – though not exclusively – higher levels of undernourishment. Out of the 140 countries classified by the World Bank as low- and middle-income, the present analysis focuses on 129 countries. Eleven countries have been omitted from the analysis because climate information is not available for them: Grenada, Maldives, Marshall Islands, Mauritius, Micronesia (Federated States of), Nauru, Saint Lucia, Saint Vincent and the Grenadines, Sao Tome and Principe, Tonga, and Tuvalu.

Countries with high exposure to climate extremes

Defined as low- and middle-income countries and territories exposed to climate extremes for at least 66 percent of the time, or more than three out of six years during the most recent subperiod of six consecutive years (2011–2016). There are 51 low- and middle-income countries that meet these criteria. For a complete list, see Table A4.2.

Countries with low exposure to climate extremes

Defined as low- and middle-income countries and territories exposed to climate extremes for up to 50 percent of the time, or less than four out of six years during the most recent subperiod of six consecutive years (2011–2016). There are 78 low- and middle-income countries that meet these criteria.

Countries with high vulnerability to climate extremes

Vulnerability refers to the conditions that increase the probability that climate extremes will negatively affect food security. Although there are many other vulnerability factors, those below have been selected for analysis due to their relative importance for food availability and access.

Vulnerability related to climate-sensitive production and/or yields

Defined as low- and middle-income countries with at least part of their national cereal production or yield variance explained by climate factors – i.e. there is a high and statistically significant association between temperature, rainfall and vegetation growth (see Annex 3 for methodology and Table A4.1 column A for list of countries).

Vulnerability related to severe drought food security sensitivity

Countries with severe drought warnings corresponding with the occurrence of PoU change points (see Annex 3 for methodology and Table A4.1 column B for list of countries).

Vulnerability related to high dependence on agriculture

Countries with a high dependence on agriculture, with 60 percent or more of the population employed in the agriculture sector in 2017 – as measured by World Bank (2017) – so it can be assumed they are deriving their livelihood and income from the sector (see Table A4.1 column D for list of countries).

Countries with low vulnerability to climate extremes

Defined as low- and middle-income countries with statistically insignificant association between cereal production or yield variance and climate factors. Specifically, these countries meet one of the following criteria: a) show a statistically insignificant association between temperature, rainfall and vegetation growth; b) do not experience severe drought warnings in correspondence with the occurrence of PoU change points; c) do not show a high dependence on agriculture.

TABLE A4.1 List of countries by food security vulnerability factors

A. Climate-sensitive production and/or yields (N = 46)	B. Severe drought food security sensitivity (N = 27)	C. Climate-sensitive production/yields and severe drought food security sensitivity (N = 16)	D. High dependence on agriculture (N = 34)
Afghanistan	Armenia	Bangladesh	Afghanistan
Algeria	Bangladesh	Belize	American Samoa
Angola	Belize	Benin	Burundi
Argentina	Benin	Cameroon	Cabo Verde
Azerbaijan	Cameroon	Central African Republic	Cameroon
Bangladesh	Central African Republic	Côte d'Ivoire	Central African Republic
Belize	Chad	Eswatini	Chad
Benin	Congo	Madagascar	Democratic People's Republic of Korea
Botswana	Côte d'Ivoire	Mauritania	Democratic Republic of the Congo
Brazil	Eritrea	Mozambique	Dominica
Burkina Faso	Gabon	Namibia	Equatorial Guinea
Cameroon	Guinea-Bissau	Panama	Eritrea
Central African Republic	Madagascar	Venezuela (Bolivarian Republic of)	Eswatini
Costa Rica	Mauritania	Yemen	Ethiopia
Côte d'Ivoire	Mozambique	Zambia	Guinea
Democratic Republic of the Congo	Namibia	Zimbabwe	Guinea-Bissau
Egypt	Nigeria		Kiribati
Eswatini	Panama		Lao People's Democratic Republic
Georgia	South Africa		Madagascar
Ghana	Togo		Malawi
Guinea	Turkmenistan		Mali
Guyana	Ukraine		Mauritania
Haiti	United Republic of Tanzania		Mozambique
Honduras	Venezuela (Bolivarian Republic of)		Nepal
Jamaica	Yemen		Niger
Lesotho	Zambia		Rwanda
Liberia	Zimbabwe		Sierra Leone
Madagascar			Solomon Islands
Malawi			Somalia
Malaysia			South Sudan
Mauritania			

TABLE A4.1 (cont.) List of countries by food security vulnerability factors

A. Climate-sensitive production and/or yields (N = 46)	B. Severe drought food security sensitivity (N = 27)	C. Climate-sensitive production/yields and severe drought food security sensitivity (N = 16)	D. High dependence on agriculture (N = 34)
Mexico			Uganda
Mozambique			United Republic of Tanzania
Namibia			Vanuatu
Panama			Zimbabwe
Paraguay			
Russian Federation			
Rwanda			
Somalia			
Suriname			
Syrian Arab Republic			
Uganda			
Venezuela (Bolivarian Republic of)			
Yemen			
Zambia			
Zimbabwe			

Source: Authors' elaborations based on data from FAO GIEWS Cereal Balance Sheets for cereal production; the European Commission for the Anomaly Hotspots of Agriculture Production (ASAP); EM-DAT - the international disasters database for data on storms; Crespo *et al.* (2018) for data and analysis on extreme heat spells and precipitation; World Bank for national data on employment in agriculture. In: *World Bank – Databank* [online]. Washington, DC. [Cited 2 October 2020]. https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS

TABLE A4.2 Countries with high exposure to climate extremes during 2011–2016, by inter-seasonal variability, frequency and intensity of extremes, and vulnerability to climate and conflict

	High exposure to climate variability and extremes				Vulnerability					
	Climate extremes		Inter-seasonal variability							
Countries with high exposure to climate extremes list 2017	Number of years with exposure to climate extremes (2011–2016)	Multiple types of climate extremes (2011–2016)[1]	Countries with delay and/or early start of he season (2003–2016)	Countries with decreased length of the season (2003–2016)	Climate-sensitive production/yields (2001–2017)	Climate-sensitive imports (2001–2017)[2]	Severe drought food security sensitivity (2006–2015)	High dependence on agriculture (2017)	Low-income countries[3]	Countries affected by conflict[4]
Afghanistan	4	DSH			•	•		•	•	•
Algeria	4	DH			•					•
Bangladesh	6	S	•	•	•		•			
Belize	4	DFSH			•		•			
Bosnia and Herzegovina	4	FH								
Brazil	4	SH			•					
Bulgaria	4	DFSH								
Central African Republic	5	SH	•		•		•	•	•	•
Chad	6	DFH	•	•		•	•	•	•	•
China	6	DFSH				•				
Congo	4	DH	•				•			•
Croatia	4	FH								
Cuba	5	DSH								
Democratic People's Republic of Korea	6	DFSH						•	•	
Dominican Republic	4	DSH								
Eritrea	4	DH	•	•		•	•	•	•	•
Georgia	4	DSH			•	•				•
Ghana	4	DH	•		•	•				
Guatemala	4	SH	•							
Haiti	4	DSH			•				•	

TABLE A4.2 (cont.) **Countries with high exposure to climate extremes during 2011–2016, by inter-seasonal variability, frequency and intensity of extremes, and vulnerability to climate and conflict**

	High exposure to climate variability and extremes				Vulnerability					
	Climate extremes		Inter-seasonal variability							
Countries with high exposure to climate extremes list 2017	Number of years with exposure to climate extremes (2011–2016)	Multiple types of climate extremes (2011–2016)[1]	Countries with delay and/or early start of he season (2003–2016)	Countries with decreased length of the season (2003–2016)	Climate-sensitive production/yields (2001–2017)	Climate-sensitive imports (2001–2017)[2]	Severe drought food security sensitivity (2006–2015)	High dependence on agriculture (2017)	Low-income countries[3]	Countries affected by conflict[4]
India	6	DFS								•
Indonesia	4	SH								•
Iran (Islamic Republic of)	4	DSH	•	•		•				
Kyrgyzstan	4	SH								
Lebanon	4	DFSH	•			•				
Lesotho	4	DSH	•	•	•	•				
Libya	4	DH				•				•
Madagascar	6	DSH	•	•	•	•	•	•	•	
Malawi	4	DSH	•	•	•	•		•	•	
Mexico	4	DFH			•	•				
Morocco	4	DSH				•				
Mozambique	4	DSH	•	•	•	•	•	•	•	
Myanmar	4	DFSH				•				•
Namibia	4	DFH			•	•	•			
Nigeria	4	DSH	•	•		•	•			•
Papua New Guinea	4	DSH								
Paraguay	4	FSH			•					
Philippines	6	FSH	•	•						•
Somalia	5	DSH	•	•	•			•	•	•
South Africa	5	DSH	•	•		•	•			
Sri Lanka	4	DFSH				•				•
Sudan	4	DSH	•	•						•
Tajikistan	4	DH								•

TABLE A4.2 (cont.) Countries with high exposure to climate extremes during 2011–2016, by inter-seasonal variability, frequency and intensity of extremes, and vulnerability to climate and conflict

	High exposure to climate variability and extremes				Vulnerability					
	Climate extremes		Inter-seasonal variability							
Countries with high exposure to climate extremes list 2017	Number of years with exposure to climate extremes (2011–2016)	Multiple types of climate extremes (2011–2016)[1]	Countries with delay and/or early start of he season (2003–2016)	Countries with decreased length of the season (2003–2016)	Climate-sensitive production/yields (2001–2017)	Climate-sensitive imports (2001–2017)[2]	Severe drought food security sensitivity (2006–2015)	High dependence on agriculture (2017)	Low-income countries[3]	Countries affected by conflict[4]
Thailand	4	DFSH								•
Togo	4	DH	•				•		•	
Tunisia	4	DH		•						
Turkmenistan	5	DH				•	•			
Uganda	4	DFSH			•			•	•	•
Uzbekistan	6	DH								•
Viet Nam	6	DSH				•				
Yemen	5	DSH			•		•			•
Total = 51			**19**	**14**	**19**	**22**	**14**	**10**	**12**	**21**

Notes:

[1] D: drought; F: flood; H: heat spell; S: storm.

[2] Low- and middle-income countries with at least part of their cereal imports variance explained by climate factors – i.e. there is a statistically significant association between temperature, rainfall and vegetation growth.

[3] Low-income countries as defined by the World Bank (https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups).

[4] Countries affected by conflict and fragility as defined in FAO, IFAD, UNICEF, WFP and WHO. 2017. *The State of Food Security and Nutrition in the World 2017. Building resilience for peace and food security*. Rome, FAO, see Annex 2.

Source: Authors' elaborations based on data from FAO GIEWS Cereal Balance Sheets for cereal production; the European Commission for the Anomaly Hotspots of Agriculture Production (ASAP); EM-DAT - the international disasters database for data on storms; Crespo *et al.* (2018) for data and analysis on extreme heat spells and precipitation; World Bank for country and lending groups. In: *World Bank* [online]. Washington, DC. [Cited 2 October 2020]. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups; World Bank for national data on employment in agriculture. In: *World Bank – Databank* [online]. Washington, DC. [Cited 2 October 2020]. https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS; FAO, IFAD, UNICEF, WFP and WHO. 2017. *The State of Food Security and Nutrition in the World 2017. Building resilience for peace and food security*. Rome, FAO, for definition of countries affected by conflicts.

Global climate studies show that not only temperatures are increasing and precipitation levels are becoming more varied, all projections indicate these trends will continue. It is therefore imperative that we understand changes in climate over agriculture areas and their impacts on agriculture production and food security.

This study presents new analysis on the impact of changing climate on agriculture and food security, by examining evidence on recent climate variability and extremes over agriculture areas and the impact of these on agriculture and food security. It shows that more countries are exposed to increasing climate variability and extremes and the frequency (number of years exposed in a five-year period) and intensity (number of types of climate extremes in a five-year period) of exposure over agricultural areas have increased.

The findings of this study are compelling and bring urgency to the fact that climate variability and extremes are proliferating and intensifying and are contributing to a rise in global hunger. The world's 2.5 billion small-scale farmers, herders, fishers and forest-dependent people, who derive their food and income from renewable natural resources, are most at risk and affected. Actions to strengthen the resilience of livelihoods and food systems to climate variability and extremes urgently need to be scaled up and accelerated.

4

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Food and Agriculture Organization
of the United Nations (FAO)

Rome, Italy

ISBN 978-92-5-133718-9 ISSN 2521-7240

9 789251 337189

CB2415EN/1/12.20