Food and Agriculture Organization of the United Nations
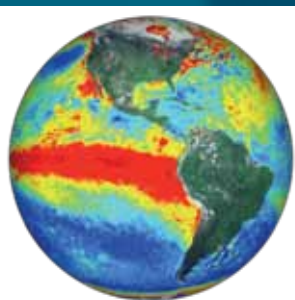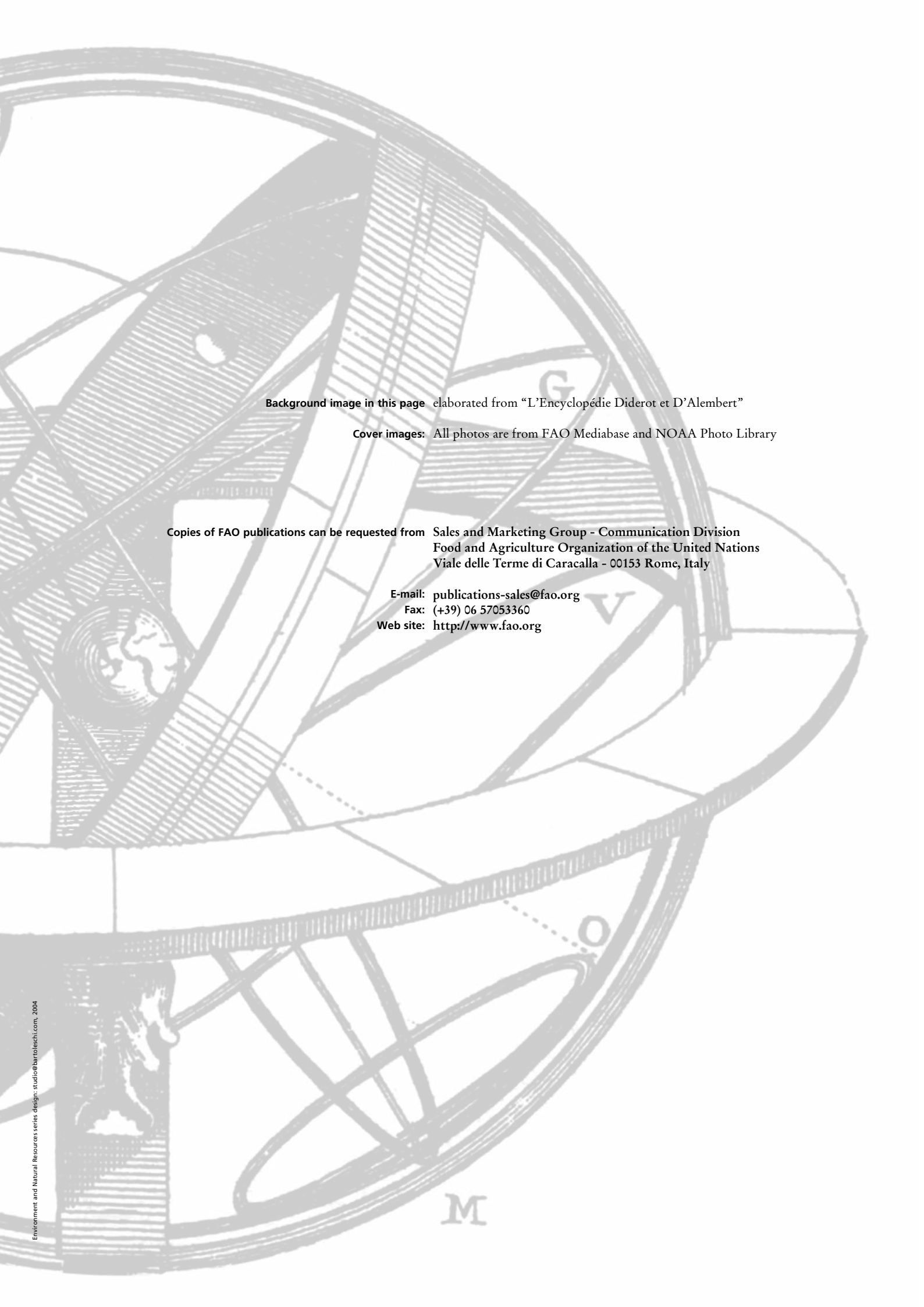
Understanding the drought impact of El Niño on the global agricultural areas:

An assessment using FAO's Agricultural Stress Index (ASI)

Understanding the drought impact of El Niño on the global agricultural areas:

An assessment using FAO's Agricultural Stress Index (ASI)

Oscar Rojas, NRC (FAO)
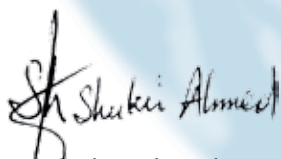**Yanyun Li, EST (FAO)**
Renato Cumani, NRL (FAO)

FOREWORD

Disasters and food insecurity are directly interconnected. Droughts, floods, hurricanes, tsunamis and other hazards can spoil food; destroy agriculture, livestock, fishing, food processing infrastructure, assets, inputs and production capacity. They interrupt market access, trade and food supply, reduce income, deplete savings and erode livelihoods. Drought, plant pests and diseases such as locusts and armyworms, animal diseases like African swine fever, and food contamination or adulteration have a direct economic impact by reducing or eliminating farm production, by adversely affecting prices, trade, and market access and by decreasing farm income and employment. Economic crises such soaring food prices reduce real income, force the poor to sell their assets, decrease food consumption, reduce their dietary diversity and access to safe and quality food. Disasters create poverty traps that increase the prevalence of food insecurity and malnutrition.

FAO, through its several specialized units, monitors the evolution of hazards and provides early indications and warnings on possible impacts on agriculture and food security. One such phenomenon is the periodic occurrence of El Niño. During El Niño episodes the normal patterns of tropical precipitation and atmospheric circulation are disrupted, hence triggering extreme climate events around the globe: droughts, floods and affecting the intensity and frequency of hurricanes. Agriculture is one of the main sectors of the economy that could be severely affected by El Niño phenomenon. FAO monitors the El Niño-Southern Oscillation (ENSO) phenomenon, among other weather related hazards, with a special focus on the potential impacts on the agricultural sector. FAO-GIEWS communicates developments during the gestation period and issues alerts and warnings if and when necessary. The objective of this study is to enhance our understanding of the El Niño phenomenon using FAO's Agricultural Stress Index System (ASIS). FAO-ASIS, developed with the support of EU/FAO Improved Global Governance for Hunger Reduction Programme, is based on remote sensing data that highlights anomalous vegetation growth and potential drought in arable land during a given cropping season.

This study is carried out under the auspices of the new FAO Strategic Framework, for the Strategic Objective 5 "Increase the resilience of livelihoods to threats and crises", Major Area of Work on Natural Hazards. The study outcomes are expected to enhance further discussions on our understanding of the El Nino Phenomenon and add to the growing literature. This would in turn improve effective early warning capabilities of FAO and partners to issue and trigger timely disaster risk reduction measures.

Shukri Ahmed
Senior Economist
(EST)

Stephan Baas
Natural Resources Officer
(NRC)

Luca Russo
Programme Coordinator
(ESA)

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

1 INTRODUCTION

El Niño is a local warming of surface waters that takes place in the entire equatorial zone of the central and eastern Pacific Ocean of the Peruvian coast and which affects the atmospheric circulation worldwide (Kiladis and Diaz, 1989). It usually peaks around Christmas, hence the name of the phenomenon: El Niño is Spanish for Christ Child. La Niña refers to the cold equivalent of El Niño. It is a recurrent weather phenomenon that takes place approximately every two to seven years and usually lasts between 12 and 18 months (CPC, 2005). An El Niño event is defined by a high Oceanic Niño Index (ONI), which is based on Sea Surface Temperature (SST) departures from average in the region in the central equatorial Pacific. An El Niño episode is associated with persistent warmer than average sea surface temperatures and consistent changes in wind and rainfall patterns (Figure 1) (Ropelewski and Halpert, 1992; IRI, 2013). Despite their periodic and recurrent manifestations, El Niño episodes do not have a **deterministic trend**[1] with fixed occurrence periods and a constant intensity. As a result, **stochastic models**[2] have been developed to predict the onset and the intensity of El Niño episodes. However, while the accuracy of these models in predicting the onset of an El Niño episode is fairly high, the intensity is much more difficult to predict due to random atmospheric disturbances that may dampen or amplify the intensity of an El Niño occurrence and thus its impact on weather patterns (CPC, 2005).

The Southern Oscillation is an East-West balancing movement of air masses between the Pacific and the Indo-Australian areas. It is associated (roughly synchronized) with typical wind patterns and El Niño, and measured by the Southern Oscillation Index (SOI) (Parker, 1983). El Niño is the oceanic component, while the Southern Oscillation is the atmospheric one. This combination gives rise to the term ENSO (El Niño - Southern Oscillation). Although there is no perfect correlation between El Niño and the Southern Oscillation as regards minor variations, large negative values of the SOI are associated with warm events.

Altough FAO does not have a mandate in the geo-physical aspects of the El Niño phenomenon, yet the Organization's interests focus in the impacts on agriculture and, consequently, food security of the extreme negative/positive climatic events that can be triggered by El Niño (FAO, 2013).

_____

1 Processes or projects having only one outcome are said to be deterministic: their outcome is 'pre-determined'. A deterministic algorithm, for example, if given the same input information, will always produce the same output information.

2 In probability theory, a purely stochastic system is one whose state is non-deterministic (i.e. random) so that the subsequent state of the system is determined probabilistically. Any system or process that must be analysed using probability theory is stochastic at least in part.

El Niño conditions are closely monitored by major meteorological institutes and forecasts are updated accordingly. The early warning provided by climate scientists each year enables governments throughout the region to discuss and implement El Niño-related contingency plans. This short paper describes the impact that El Niño has had on major crop production areas, focusing on cereals. To assess the impact of drought, the FAO Agriculture Stress Index (ASI) is used as an indicator. ASI is based on remote sensing data that highlights anomalous vegetation growth and potential drought conditions in arable land during a given cropping season (Rojas *et al.*, 2011).

The main threat to crops is drought. However, El Niño could produce other climatic impacts, including flash floods or intense hurricanes that could influence the crop season, disrupting agricultural activities and damaging crops. ASI cannot assess the negative impact of flash floods or hurricanes, but only the positive ones, if any, due to the increase of water availability after intense rains.

FIGURE 1

Normal conditions (upper part) compared with El Niño conditions (lower part).
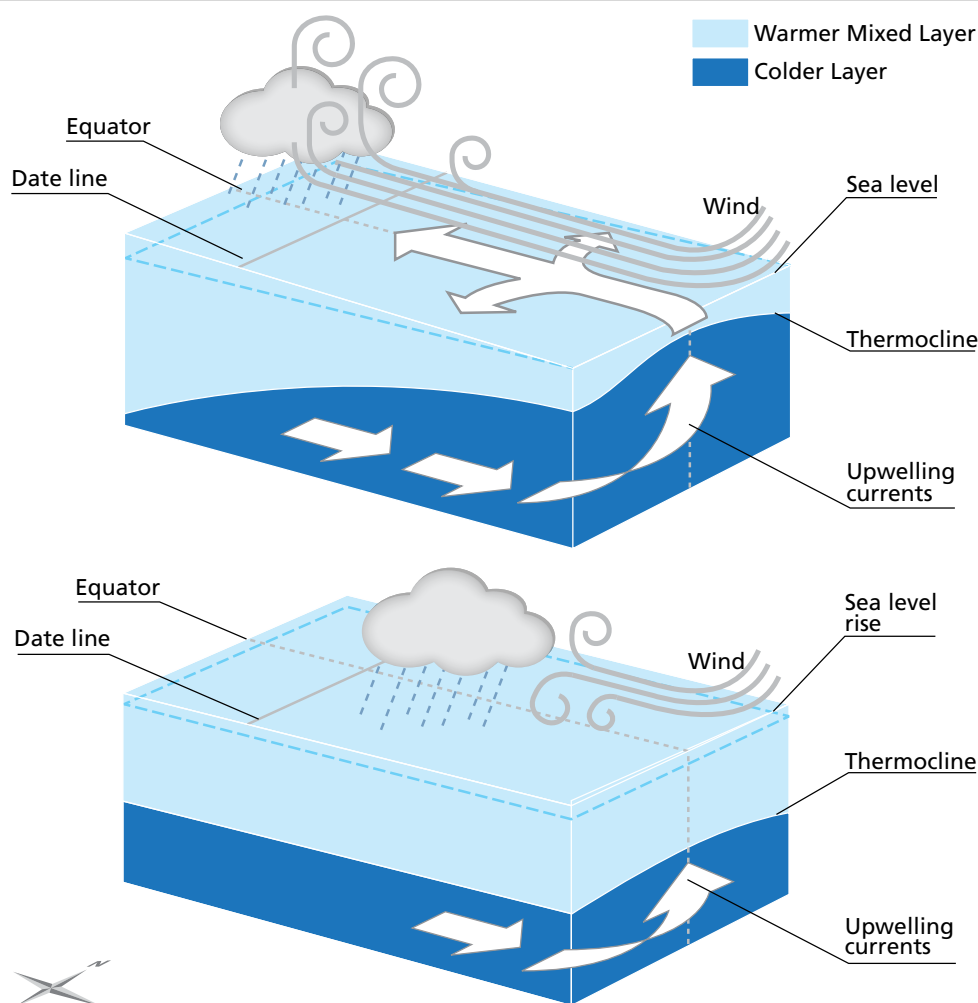
Source: National Oceanic and Atmospheric Administration (NOAA).

2 WHAT WE KNOW AND WOULD LIKE TO KNOW ABOUT EL NIÑO

According to the World Meteorological Organization (WMO, 2014), research conducted over recent decades has shed considerable light on the important role played by interactions between the atmosphere and ocean in the tropical belt of the Pacific Ocean in altering global weather and climate patterns. During El Niño events, for example, sea temperatures at the surface in the central and eastern tropical Pacific Ocean become substantially higher than normal. In contrast, during La Niña events, the sea surface temperatures in these regions become lower than normal. These temperature changes are strongly linked to major climate fluctuations around the globe and, once initiated, such events can last for 12 months or more.

The strong El Niño event of 1997-1998 was followed by a prolonged La Niña phase that extended from mid-1998 to early 2001. El Niño/La Niña events change the likelihood of particular climate patterns around the globe, but the outcomes of each event are never exactly the same. Furthermore, while there is generally a relationship between the global impacts of an El Niño/La Niña event and its intensity, there is always potential for an event to generate serious impacts in some regions irrespective of its intensity. There is a consensus among climatologic agencies about the general impacts of El Niño around the globe summarized in Figure 2.

From an agricultural and food security point of view, referring only to cereal crops, it is important to know the potential impacts of El Niño: is the potential damage of drought linked to the intensity, duration or onset of the phenomenon? Are some countries or regions more vulnerable to the impact than others? What has been the frequency and impact of droughts in crop lands over the last 30 years?

In order to answer these questions the recent outputs of ASI from 1984 to the present have been examined. During this 30 year timeframe of remote sensing data, only nine El Niño events occurred (each event normally covers two years).

FIGURE 2

The upper half corresponds to the northern hemisphere winter (October to March) and the lower half covers impacts during April to September. Dry indicates drought, Wet unusual high rainfall (not necessarily intense rainfall) and Warm indicates abnormal warm periods.
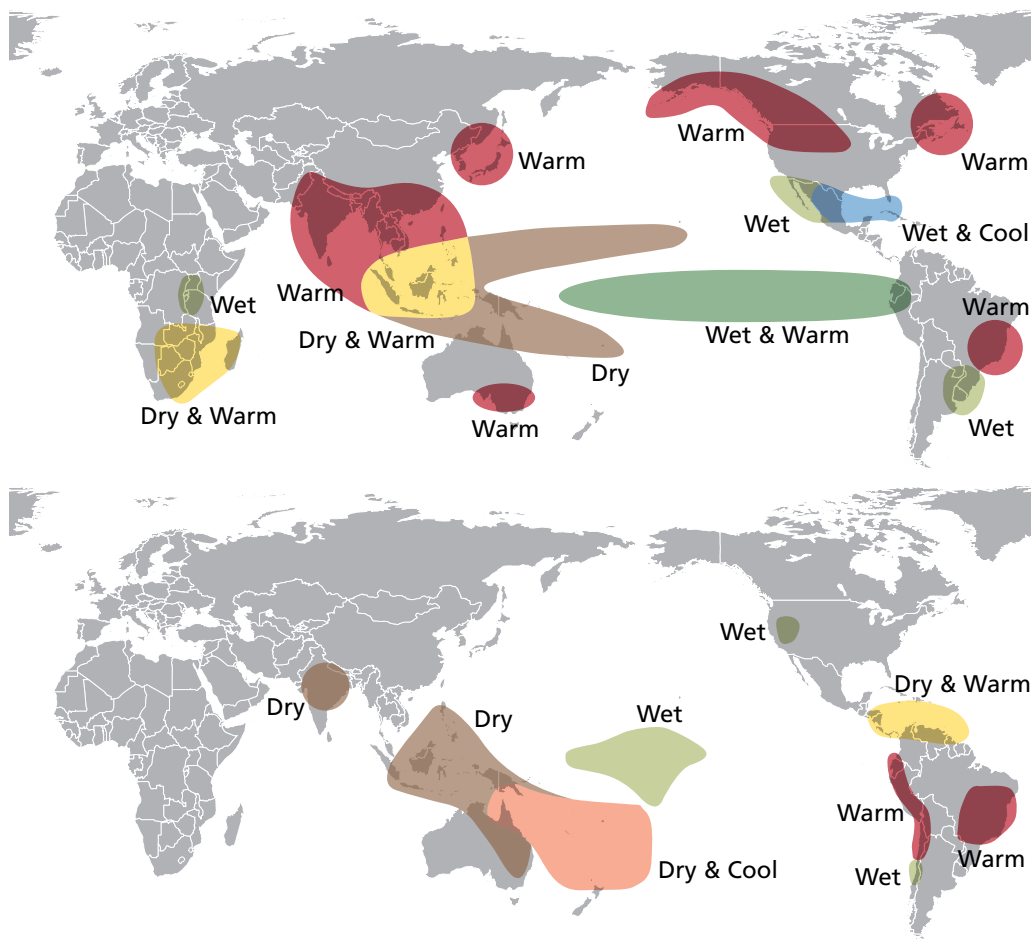
Source: http://www.srh.noaa.gov/jetstream/tropics/enso_impacts.htm
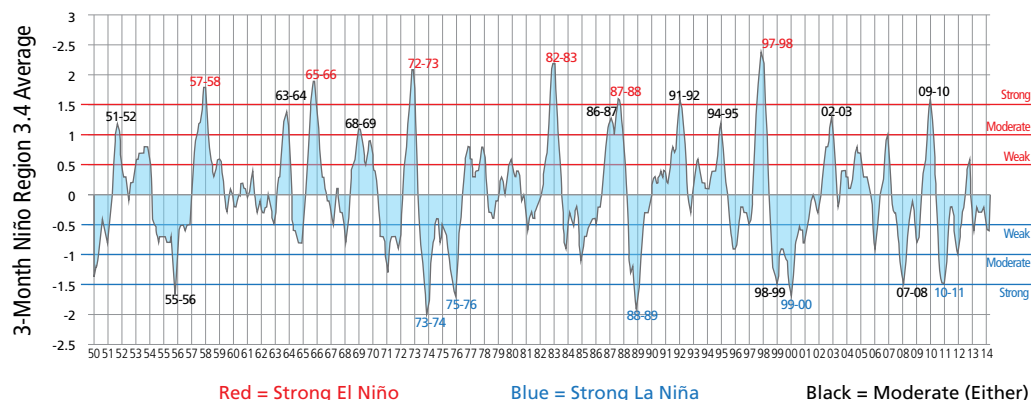
3 DATA USED IN THIS STUDY

A. THE OCEANIC NIÑO INDEX (ONI)

The Oceanic Niño Index (ONI) has become the *de facto* standard that the National Oceanic and Atmospheric Administration (NOAA) uses to identify El Niño (warm) and La Niña (cool) events in the tropical Pacific (Figure 3). It is the three month mean SST anomaly for the El Niño 3.4 region (i.e., 5°N-5°S, 120°-170°W). Events are defined as five consecutive overlapping three month periods at or above the +0.5°C anomaly for warm (El Niño), events and at or below the -0.5 anomaly for cold (La Niña) events. The threshold is further broken down into Weak (with a 0.5 to 0.9 SST anomaly), Moderate (1.0 to 1.4) and Strong (≥ 1.5) events. For an event to be categorized as weak, moderate or strong. it must have equalled or exceeded the threshold for at least three consecutive overlapping three month periods.

FIGURE 3

The Oceanic Niño Index (ONI)

Red = Strong El Niño   Blue = Strong La Niña   Black = Moderate (Either)

Source: http://ggweather.com/enso/oni.htm

B. SOUTHERN OSCILLATION INDEX (SOI)

The Southern Oscillation Index, or SOI, gives an indication of the development and intensity of El Niño or La Niña events in the Pacific Ocean. The SOI is calculated using the pressure differences between Tahiti and Darwin. There are different methods of calculating the SOI. This study uses the data calculated by the Australian Bureau of Meteorology.

http://www.bom.gov.au/climate/glossary/soi.shtml

Sustained negative values of the SOI below −8 often indicate El Niño episodes. These negative values are usually accompanied by sustained warming of the central and eastern tropical Pacific Ocean and a decrease in the strength of the Pacific trade winds.

Sustained positive values of the SOI above +8 are typical of a La Niña episode. They are associated with stronger Pacific trade winds and warmer sea temperatures to the north of Australia. Waters in the central and eastern tropical Pacific Ocean become cooler during this time.

FIGURE 4

The Southern Oscillation Index (SOI) (1876-2013) calculated by the Australian Bureau of Meteorology

Source: http://www.bom.gov.au/climate/current/soihtm1.shtml
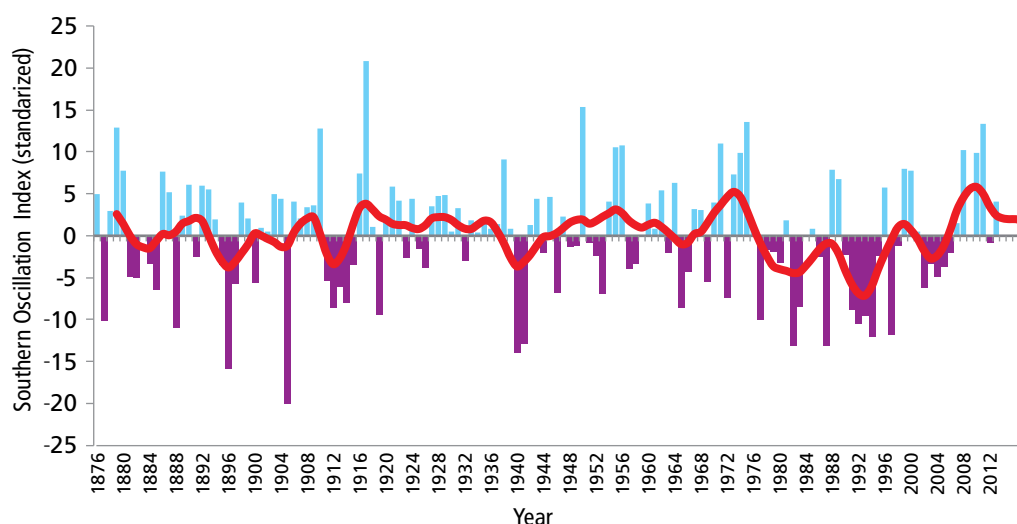
C. AGRICULTURE STRESS INDEX (ASI)

The Agriculture Stress Index (ASI) is an FAO indicator that highlights anomalous vegetation growth and potential drought in arable land during a given cropping season

http://www.fao.org/giews/earthobservation/.

ASI, was developed with the support of EU/FAO Improved Global Governance for Hunger Reduction Programme.

http://www.fao.org/europeanunion/eu-projects/global-governance/en/

ASI integrates the Vegetation Health Index (VHI) in two dimensions that are critical to assess a drought event in agriculture: temporal and spatial. ASI assesses the temporal intensity and duration of dry periods and calculates the percentage of arable land affected by drought. Pixels with a VHI value below 35 percent – were identified as a critical level in previous studies to assess the extent of the drought (Kogan, 1994; Unganai and Kogan, 1998). The whole administrative area is classified according to the percentage of arable area affected by drought conditions (Rojas, *et al.* 2011). ASI cannot assess the impacts of flash floods. The current version of ASI has the following limitations:

- The index detects extreme events of drought, which means that agricultural areas affected by moderate drought (referring to temporal intensity at pixel level) would be neglected.
- It defines two cropping seasons around the globe. This works properly for most areas; however, there are regions such as Central America where there are four crop seasons in a calendar year. In ASI the first crop season does not necessarily represent the main crop season, but rather the first crop season in a calendar year.
- The current version gives equal weight to all phenological phases when calculating the temporal integration without regard to the crop water requirements and their implications on crop yield reduction.

D.   AUXILIARY DATA

This study uses a generalized global crop mask at 250 m resolution produced by the Joint Research Centre (JRC) (Vancutsen *et al*. 2013), combining existing land cover/land use maps[3]. To determine the growing period, the start of season (SOS) and end of season (EOS) were derived from the SPOT-VGT time series (1998-2011). The method of White *et al*. (1997) was modified applying a 25 percent threshold for SOS and a 75 percent threshold for EOS, thresholds that the study considered more appropriate for defining the growing period of annual crops. This resulted in the following maps:

FIGURE 5.

Generalized global crop mask produced by JRC and adapted by VITO at 250 m resolution[4].

Cropland extent (%)
0   20   40   60   80   100

_____
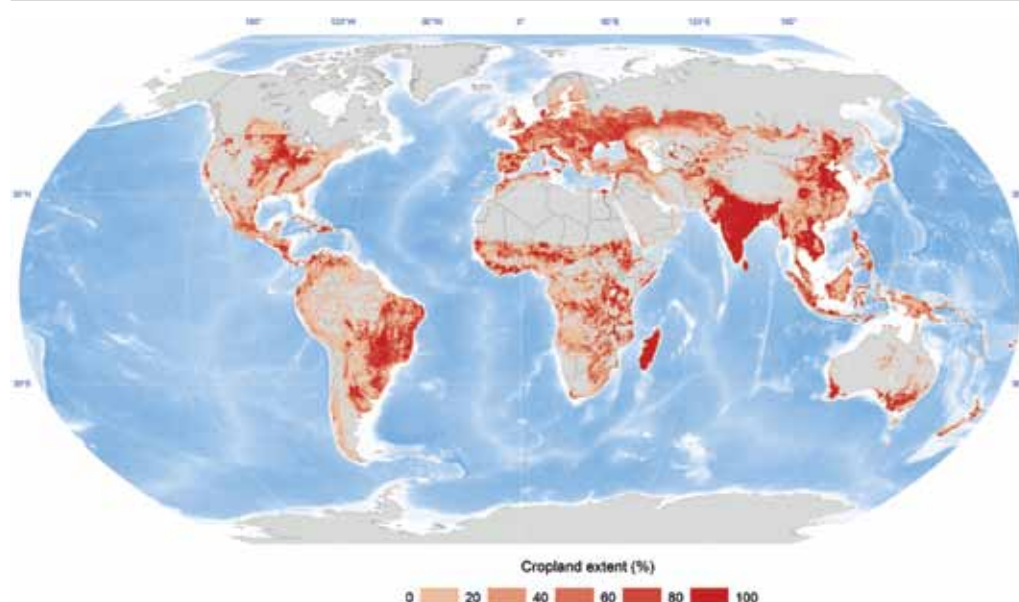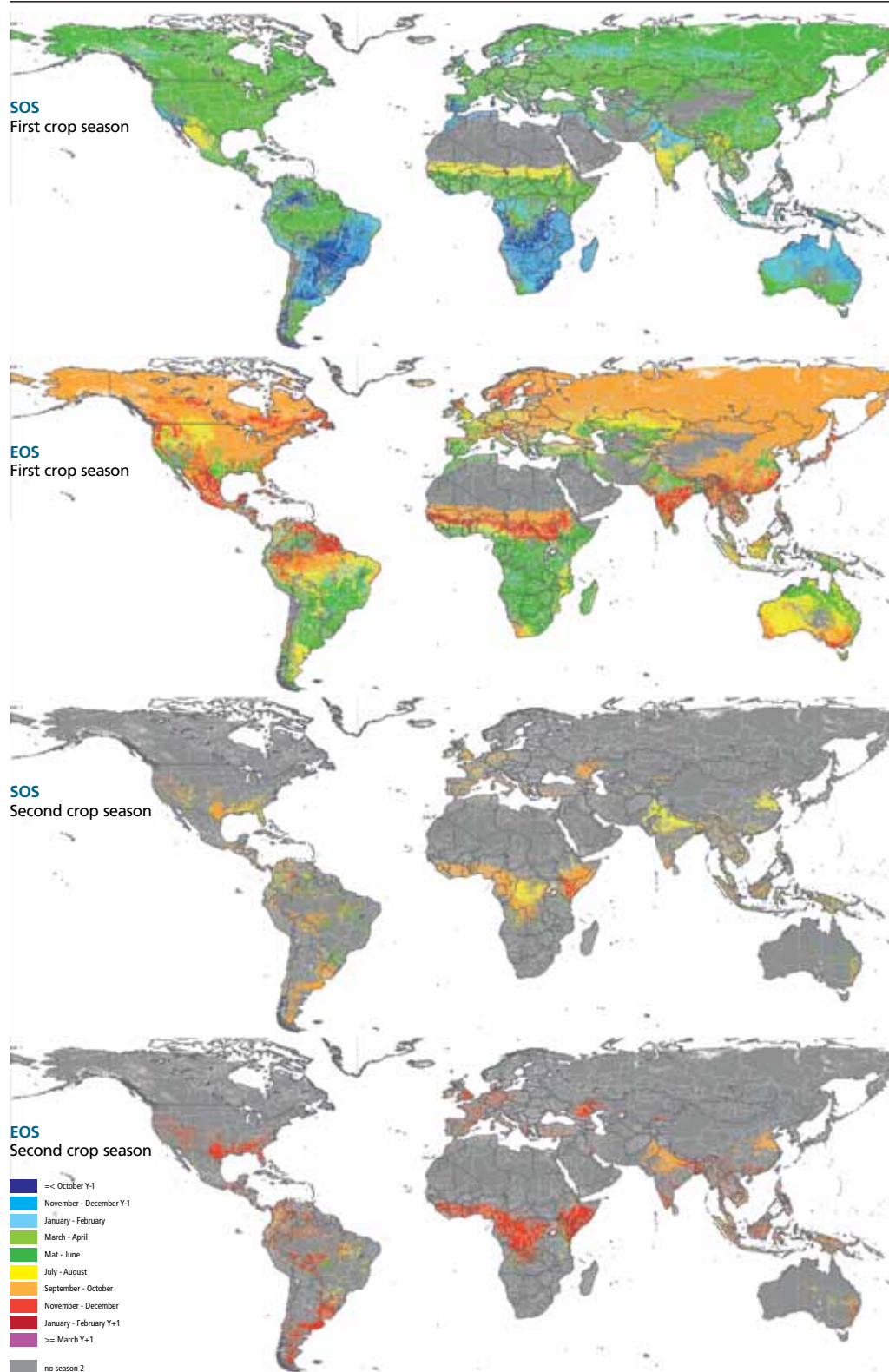
3 The methodology is described by Vancutsen *et al* (2013) for the case of the African continent. The global crop mask was slightly modified based on the field experience of FAO-GIEWS. The Department of Agriculture, Fisheries and Forestry of Australian Government, ABARES contributed with the crop mask of Australia.

4 Data sources for the maps: El Niño data, http://ggweather.com/enso/oni.htm; ASIS data, http://www.fao.org/giews/earthobservation; GAUL, www.fao.org/geonetwork; Bathymetry, http://www.gebco.net.

Background image on the maps: Elaborated from "General Bathymetric Chart of the Oceans"

FIGURE 6

Start of season (SOS) and End of Season (EOS) for two crop seasons at global level based on SPOT-VGT data (1998-2011).

SOS
First crop season

EOS
First crop season

SOS
Second crop season

EOS
Second crop season

=< October Y-1
November - December Y-1
January - February
March - April
Mat - June
July - August
September - October
November - December
January - February Y+1
>= March Y+1

no season 2

4

THE INFLUENCE OF EL NIÑO ON THE GLOBAL AGRICULTURAL AREAS

EL NIÑO 1986-1988

El Niño 1986/87 and 1987/88 were two consecutive warm events without interruption that together influenced the climate for 19 months, the most prolonged period during 1984-2013 time frame. El Niño 1986/87 is classified as moderate while 1987/88 is classified as a strong one. This combination of moderate/strong El Niño has happened only once in 64 years of recording these events (1950-2013), representing a particular case. The ONI value of El Niño 1986/87, surpassed the value of 0.5 in July-August-September of 1986 and peaked at 1.3 in January-February-March 1986 (relatively late) and El Niño 1987/88 peaked at 1.6 exceptionally early in July-August-September 1987. The conditions previous to El Niño 86/87 were neutral with ONI values close to -0.5.

Figure 7 (p.14) shows that the countries affected by drought in 1986 during the first crop season were: in the **Americas**, the United States, Mexico (some drought spots), southern Brazil and a few spots in Argentina; in **Africa**, Morocco (some spots), Tunisia (severely affected[5]), Mauritania, Senegal, Mali, Niger, Nigeria, Chad, Sudan, Botswana (severely affected), South Africa and Madagascar.

During the second crop season of 1986, the countries affected were: Somalia, Pakistan, India and China (Figure 8, p.15).

During the first crop season of 1987, the countries affected were: in the **Americas**, United States (some drought spots), Mexico, Brazil and Argentina; in **Africa**, Morocco, Mali, Burkina Faso, Niger, Nigeria, Chad, Sudan, Eritrea, Ethiopia, Somalia, Namibia, Botswana (severely affected), Zimbabwe, South Africa and southern Mozambique; and in **Asia**, Pakistan, India (severely affected), Bangladesh (severely affected), Thailand, Cambodia and China (Figure 7, p.14).

During the second crop season of 1987, Pakistan and India were severely affected by drought (Figure 8, p.15).

During the first crop season of 1988, there was a low drought impact except in India with a few spots in which ASI shows moderate drought conditions. This could be due to the exceptionally early peak of El Niño 1987/88, approximately three months before normal (El Niño normally peaks in December). However, during 1988, there was a severe drought in the United States and Canada, areas normally linked to El Niño that were less evident during 1986 and 1987.

---

5 This refers to strong/moderate drought considering the spatial dimension of the event and not the temporal one. Moderate drought is interpreted as a drought event with a medium spread in the administrative unit, considering the number of pixels classified as severely affected by drought (VHI<35).

EL NIÑO 1991/1992

El Niño 1991/92 lasted 14 months, the second longest of the last 30 years and classified as moderate in intensity. The conditions previous to El Niño 1991/92 are considered as neutral with ONI values close to 0.4.

Figure 9 (p.16) shows areas affected by drought during the first crop season of 1991. In the **Americas** drought affected the United States, Central America (Nicaragua and Honduras) and the Caribbean (Haiti and the Dominican Republic), Colombia, Venezuela, and Rio Grande do Sul and Natal in Brazil. In **Asia** the areas affected by drought were India, Iran, Pakistan, Thailand, Cambodia, Philippines and some spots in China. In **Africa**, Sudan, Ethiopia, Senegal, Mauritania, Niger, Nigeria, the southern part of Madagascar and Zimbabwe were affected.

During the second crop season of 1991, the areas affected by drought were in the **Americas**, the central part of the United States and the state of California, Central America, Colombia, Venezuela, and Rio Grande do Sul and Santa Catarina in Brazil. In **Africa** drought affected Sierra Leona, Ivory Coast, Ghana, Nigeria, Ethiopia, Uganda and Somalia. In **Asia**, Pakistan, India and Indonesia were affected.

During the first crop season of 1992, the areas affected by drought in the **Americas** were the northwestern part of the United States and the northern parts of Brazil and Peru. In **Africa** drought affected Morocco, Senegal, Somalia and Southern Africa (South Africa, Zimbabwe, Botswana, Malawi, Mozambique, and the southern part of Madagascar), which was severely affected. In **Asia**, India, Turkey, Philippines, Cambodia, Thailand and some areas in Indonesia were affected.

Taking into account the magnitude of the negative impacts provoked in agricultural areas around the globe, El Niño 1991/92 is classified, as the most severe event of the last 30 years. However, based only on the ONI indicator, is difficult to explain why El Niño 1991/92 had such a devastating impact on agriculture at global level.

EL NIÑO 1994/1995

El Niño 1994/95 began relatively late in August-September-October 1994 and lasted only seven months. It was classified as moderate in intensity, peaking at 1.2 in November-December-January. During the first crop season of 1994, some areas were affected by moderate drought in the Asia-Pacific Islands, mainly in Indonesia and Malaysia (Figure 10, p. 17).

During the second crop season of 1994, ASI shows only moderate drought in Sumatra, Indonesia. During the first crop season of 1995, Figure 10 (p. 17) shows some spots in the **Americas** in northern Texas in the United States, in the northern part of Mexico and some spots in Bahia, Brazil. In **Africa** there was a strong impact in Morocco, Tunisia, Botswana and Zimbabwe. In **Europe** the southern part of Spain was affected and in **Asia** there were some spots of moderate drought in China and the northern part of Bangladesh. Due to its short duration and its late peak, El Niño 1994/95 caused few negative impacts on global agriculture.

EL NIÑO 1997/1998

El Niño 1997/98 was classified as strong in intensity, reaching the maximum ONI value of the last 64 years at 2.4. It started in April-May-June 1997 and lasted 12 months. The conditions previous to El Niño 1997/98 were considered neutral with ONI values close to -0.5. Due to its extreme intensity, it was called the 'climate event of the century'. However, the impacts on the agriculture sector do not seem to be directly correlated with the intensity of the phenomenon.

Figure 11 (p. 18) shows the impacts on agricultural areas during the first crop season of 1997. In the **Americas** a few spots in the United States and central Mexico were severely affected. Drought also affected some parts of Argentina. In **Asia,** Iran, Pakistan, northern Afghanistan, spots in India, and China were affected. In **Africa**, Senegal, Algeria and Tunisia were severely affected, and some spots of moderate drought were recorded in Niger, Sudan, Ethiopia and northern Tanzania. In Oceania, southern Australia was affected by moderate drought.

During the second crop season of 1997, there were some spots of drought in Colombia in the **Americas,** and some spots of drought in **Asia** in China and Indonesia.

During the first crop season of 1998, the areas affected by drought in the **Americas** were spots in the United States and Mexico, and the northeastern part of Brazil (severely affected). In **Africa** there was moderate drought in northern Namibia and Botswana. In **Asia** there were some spots of moderate drought in Myanmar and Indonesia; and in **Oceania,** Papua New Guinea was affected by moderate drought in parts.

EL NIÑO 2002/2003

El Niño 2002/03 was classified as moderate in intensity with an ONI value of 1.3 that peaked in October-November-December 2002. It began in April-May-June 2002 and lasted ten months. The conditions prior to El Niño 2002/03 are considered neutral with ONI values close to -0.3 (Figure 12, p. 19).

During the first crop season in 2002, impacts on agriculture were observed in the **Americas** in Canada and the United States, some spots in Mexico, Colombia and Venezuela (severely affected). In **Africa** drought affected Senegal, Mali, Burkina Faso, Nigeria, Sudan, Ethiopia, Coast Province in Kenya, Morocco and Algeria. In **Europe** Sicily was affected in Italy. In **Asia** the countries affected were Pakistan, India, China and Mongolia (severely affected). In **Oceania** Australia was severely affected.

During the second crop season of 2002, the areas affected in the **Americas** were some spots in the central part of the United States, Colombia, Venezuela, Ecuador and Brazil. In **Africa** drought affected some spots in Ethiopia. In **Asia** the countries affected were Pakistan, India (severely affected), China and some spots in Indonesia.

During the first crop season of 2003, the following countries in the **Americas** were affected by drought: Canada, the United States (severely affected); some spots in Mexico, Colombia, Honduras, Nicaragua, northern Brazil and Argentina. In **Africa** drought affected Ethiopia, Nigeria, Tanzania, Botswana (severely affected) and South Africa. In **Asia** drought affected India and Myanmar, China and Mongolia with moderate spots, and the Asia-Pacific Islands. In **Oceania,** there was drought in Australia and New Zealand (severely affected).

EL NIÑO 2004/2005

El Niño 2004/05 was classified as weak in intensity, with an ONI value of 0.8 that peaked relatively early in August-September-October 2004. It started relatively late in June-July-August 2004 and lasted only seven months. The conditions prior to El Niño 2004/05 are considered neutral with ONI values close to -0.3.

Agriculture was impacted by El Niño 2004/05 mainly during the first crop season of 2004 (Figure 13, p. 20). In the **Americas**, drought affected the northwestern United States (spots), Mexico, Honduras, Cuba, Colombia, Ecuador, Brazil, Uruguay and Argentina. In **Africa** the affected countries were Mali, Burkina Faso, Sudan, Ethiopia, Somalia (severely affected), Tanzania, Coast Province in Kenya and Uganda (the two last countries were severely affected). In **Asia**, Pakistan, Myanmar, Thailand, Vietnam, Indonesia, Malaysia, China and Mongolia were affected. In **Oceania**, drought affected Australia and New Zealand (severely affected).

During the second crop season of 2004 drought affected some spots in the **Americas** in southern Brazil and Argentina; in **Africa,** parts of Kenya and Tanzania, in **Asia** some spots in Pakistan, India, Myanmar, Thailand and few spots in Indonesia.

During the first crop season of 2005 impacts of drought in the agricultural areas of the globe were much lower. There were some spots of moderate drought in the United States, Mexico, southern Brazil, Somalia, China, Myanmar, Thailand, Vietnam and Australia.

EL NIÑO 2006/2007

El Niño 2006/07 was classified as weak in intensity, with an ONI value of 1.0 that peaked in October-November-December 2006. It began late in August-September-October 2006 and lasted only five months, the shortest duration in 64 years. The conditions prior to El Niño 2006/07 are considered as negative with ONI values peaking at -0.9 (transition from La Niña to El Niño) (Figure 14, p. 21). However, El Niño 2006/07 produced severe droughts in Tanzania and Australia (the worst droughts in the last 30 years in both countries).

In 2006, most of the impacts were concentrated during the first crop season. In the **Americas** the United States was severely affected; there was also drought in Paraguay and southern Brazil, and moderate drought in southern Argentina. In **Africa** drought affected southern Mali, the central part of Ethiopia, Somalia (moderate to strong drought), Madagascar and Tanzania (severely affected). In **Asia**, Afghanistan, Pakistan, India, and a few spots in China were affected. In **Oceania** Australia suffered the worst drought of the century.

During the second crop season of 2006, impacts were recorded in a few localized spots of the United States, Brazil, India and China.

During the first crop season of 2007, El Niño provoked some spots of drought in the **Americas** in the United States and Mexico, and localized drought in the south of the Buenos Aires Province in Argentina. In **Africa** drought affected Morocco (severely), Mali, Burkina Faso, with moderate drought spots in Niger, Nigeria, and Somalia. Uganda was severely affected, and there were severe drought spots in Botswana, South Africa and Madagascar. In **Asia** Turkey, Afghanistan, Mongolia and China were affected. In **Oceania** there was moderate to strong drought in Australia.

EL NIÑO 2009/2010

El Niño 2009/10 was classified as moderate in intensity, with an ONI value of 1.6 that peaked in November-December-January 2009. It began relatively late in June-July-August 2009 and lasted ten months. The conditions prior to 2009/10 were considered as negative with ONI values peaking at -0.8, with a transition from La Niña to El Niño (Figure 15, p. 22).

During the first crop season of 2009, the Impacts of El Niño on agriculture were noted in several countries. In the **Americas** drought affected a few spots in the United States, Venezuela with moderate to severe drought, Argentina (severely affected), Paraguay and Brazil (some spots of moderate drought). In **Africa** countries affected were Sierra Leone, Sudan with moderate drought, Ethiopia, Somalia and Kenya where the worst drought in 30 years ocurred. In **Asia** there were a few spots of drought in India and China. In **Oceania,** southeastern Australia was affected by drought.

During the second crop season of 2009, the countries affected in the **Americas** were: Argentina, which was severely affected, and some spots in Colombia and Venezuela. In **Africa** there were some moderate drought spots in Somalia, Kenya and Tanzania; and in **Asia**, a few localized spots in Pakistan, India and China.

During the first crop season of 2010, there were only four relevant spots of drought affecting agriculture: Madagascar, Pakistan, northwest India and southwest Australia.

FIGURE 7

El Niño episodes associated with crop growing conditions

FIRST CROP SEASON
1986

FIRST CROP SEASON
1987

FIRST CROP SEASON
1988

ASI (%)

🟩	< 10
🟩	10 - 25
🟨	25 - 40
🟧	40 - 55
🟧	55 - 70
🟥	70 - 85
🟥	> = 85

⬛	no data
⬛	no seasons
⬜	no cropland

Running 3-Month Mean ONI values — 1987/88

1986   1987   1988

1.3   1.6

19 months

ONI values

Running 3-Month (J=January up to D=December)

FIGURE 8

El Niño episodes associated with crop growing conditions

SECOND CROP SEASON
1986

SECOND CROP SEASON
1987

ASI (%)

- < 10
- 10 - 25
- 25 - 40
- 40 - 55
- 55 - 70
- 70 - 85
- > = 85

- no data
- no seasons
- no cropland

Running 3-Month Mean ONI values — 1987/88
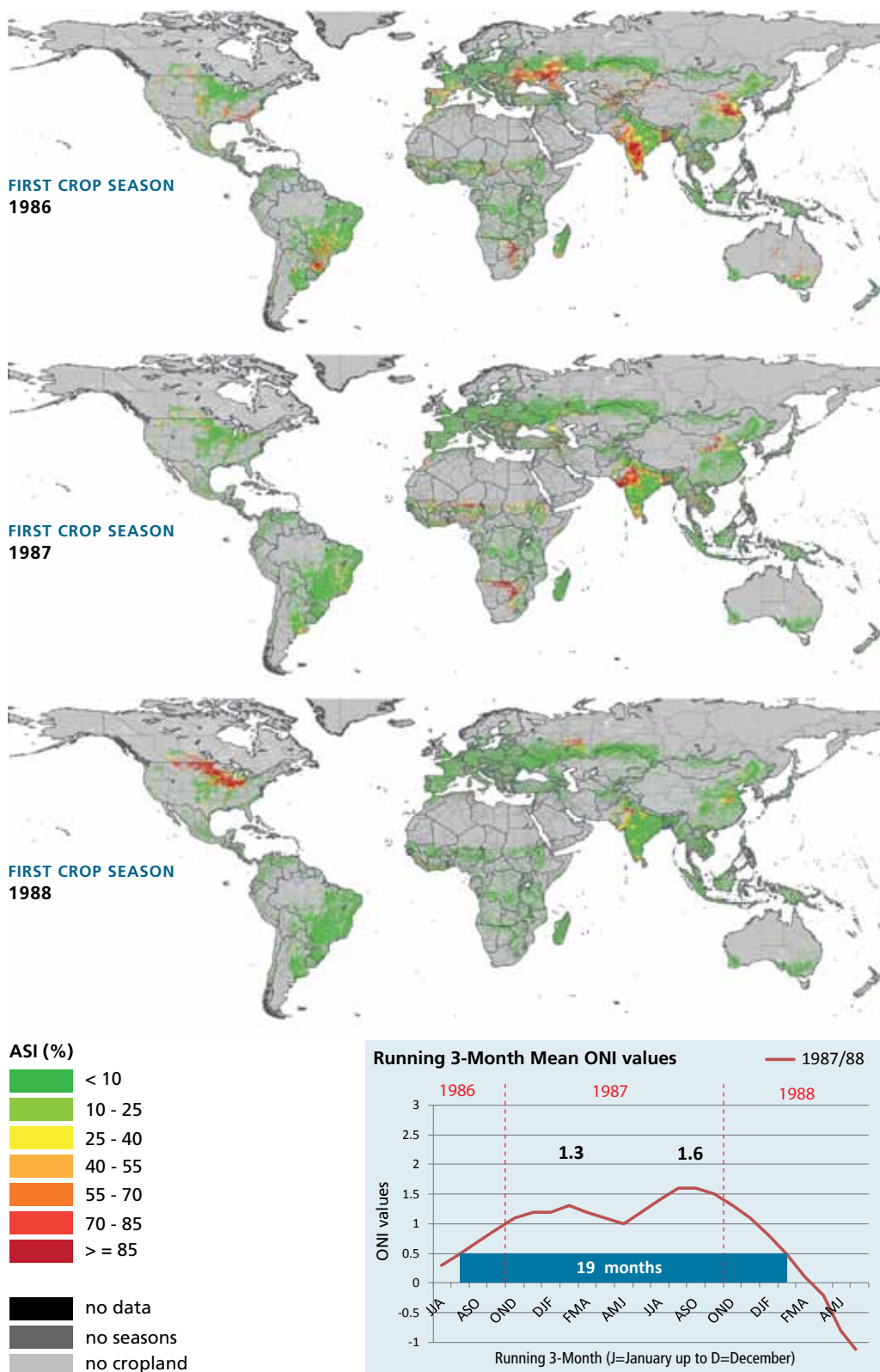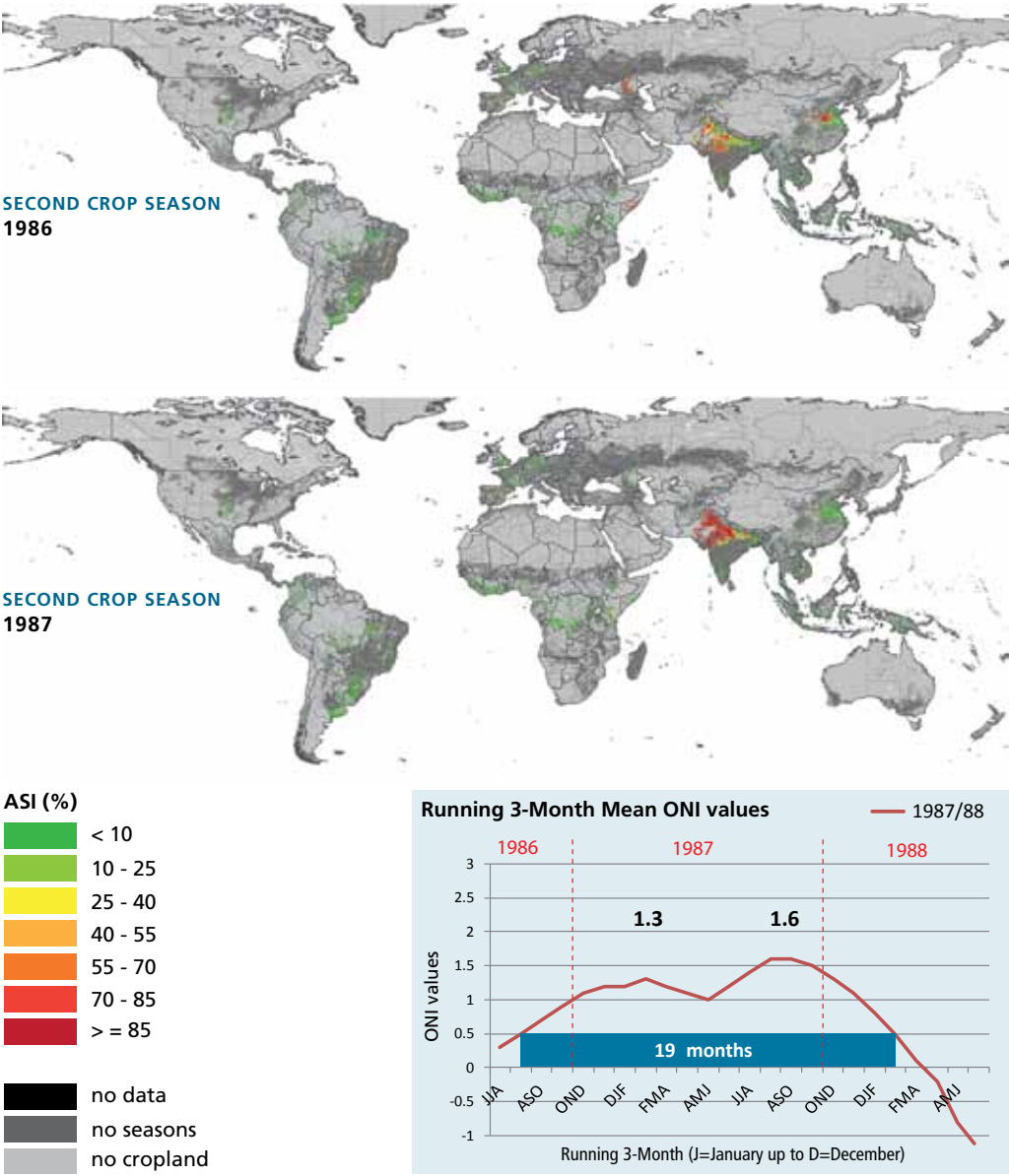
FIGURE 9

El Niño episodes associated with crop growing conditions

FIRST CROP SEASON
1991

SECOND CROP SEASON
1991

FIRST CROP SEASON
1992

ASI (%)

	< 10
	10 - 25
	25 - 40
	40 - 55
	55 - 70
	70 - 85
	> = 85

	no data
	no seasons
	no cropland

Running 3-Month Mean ONI values 1991/92

Running 3-Month (J=January up to D=December)
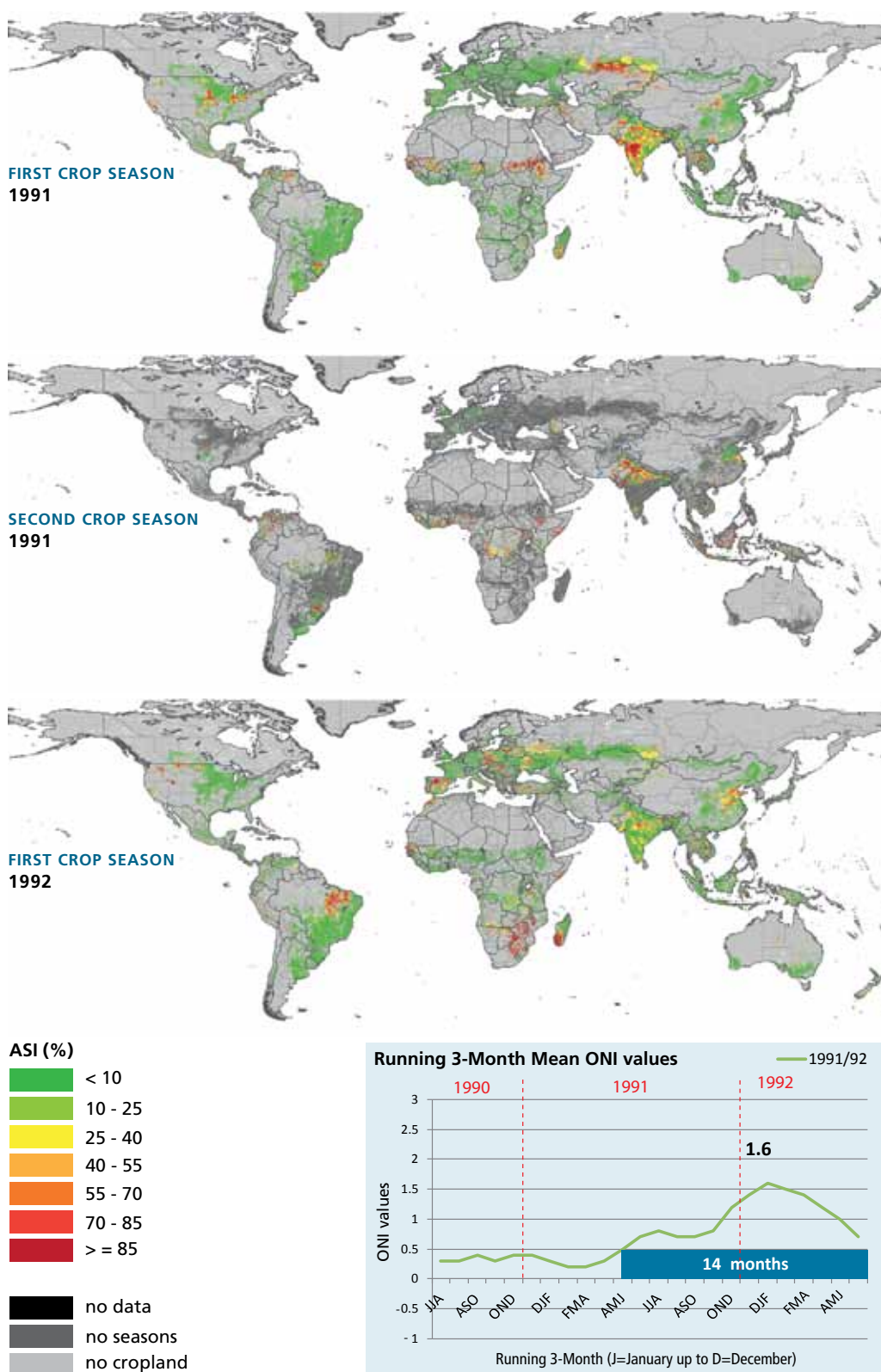
FIGURE 10

El Niño episodes associated with crop growing conditions

FIRST CROP SEASON
1994

SECOND CROP SEASON
1994

FIRST CROP SEASON
1995

ASI (%)

■	< 10
■	10 - 25
■	25 - 40
■	40 - 55
■	55 - 70
■	70 - 85
■	> = 85

■	no data
■	no seasons
■	no cropland

Running 3-Month Mean ONI values ── 1994/95
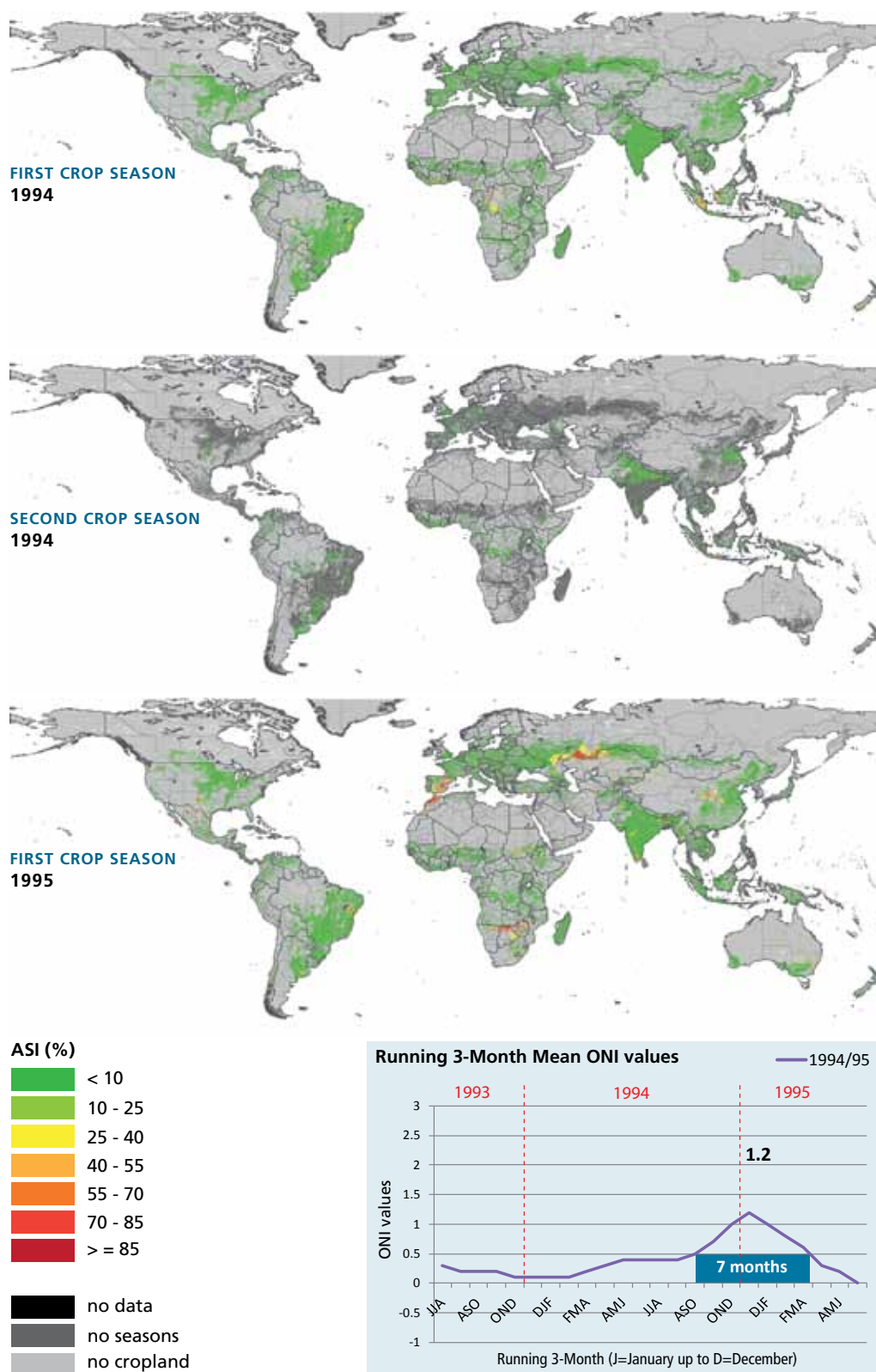
FIGURE 11

El Niño episodes associated with crop growing conditions

FIRST CROP SEASON
1997

SECOND CROP SEASON
1997

FIRST CROP SEASON
1998

ASI (%)

▇	< 10
▇	10 - 25
▇	25 - 40
▇	40 - 55
▇	55 - 70
▇	70 - 85
▇	> = 85

▇	no data
▇	no seasons
▇	no cropland

Running 3-Month Mean ONI values　　——1997/98

1996　　　1997　　　1998

2.4

12 months

ONI values

Running 3-Month (J=January up to D=December)
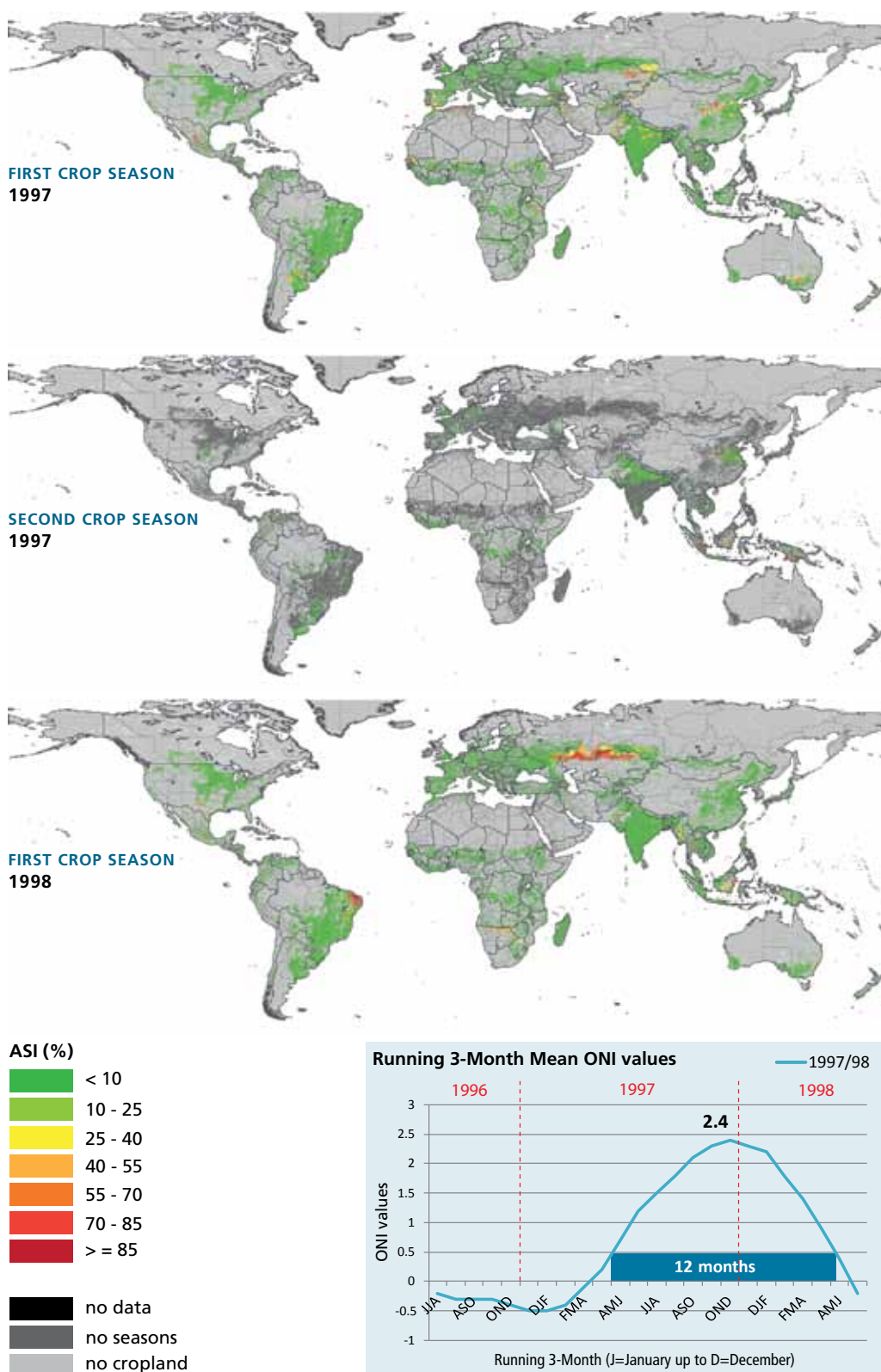
FIGURE 12

El Niño episodes associated with crop growing conditions

FIRST CROP SEASON
2002

SECOND CROP SEASON
2002

FIRST CROP SEASON
2003

ASI (%)

- < 10
- 10 - 25
- 25 - 40
- 40 - 55
- 55 - 70
- 70 - 85
- >= 85

- no data
- no seasons
- no cropland

Running 3-Month Mean ONI values — 2002/03

2001   2002   2003

1.3

10 months

ONI values

Running 3-Month (J=January up to D=December)

FIGURE 13

El Niño episodes associated with crop growing conditions

FIRST CROP SEASON
2004

SECOND CROP SEASON
2004

FIRST CROP SEASON
2005

ASI (%)

🟩	< 10
🟢	10 - 25
🟨	25 - 40
🟧	40 - 55
🟧	55 - 70
🟥	70 - 85
🟥	> = 85

⬛	no data
⬛	no seasons
⬜	no cropland

Running 3-Month Mean ONI values — 2004/05

2003   2004   2005

0.8

7 months

ONI values

Running 3-Month (J=January up to D=December)

FIGURE 14

El Niño episodes associated with crop growing conditions

**FIRST CROP SEASON
2006**

**SECOND CROP SEASON
2006**

**FIRST CROP SEASON
2007**

ASI (%)

- ◼ < 10
- ◼ 10 - 25
- ◼ 25 - 40
- ◼ 40 - 55
- ◼ 55 - 70
- ◼ 70 - 85
- ◼ >= 85

- ◼ no data
- ◼ no seasons
- ◼ no cropland

Running 3-Month Mean ONI values —— 2006/07

2005   2006   2007

1.0

5 months

ONI values

Running 3-Month (J=January up to D=December)

FIGURE 15

El Niño episodes associated with crop growing conditions

FIRST CROP SEASON
2009

SECOND CROP SEASON
2009

FIRST CROP SEASON
2010

ASI (%)

■	< 10
■	10 - 25
■	25 - 40
■	40 - 55
■	55 - 70
■	70 - 85
■	> = 85

■	no data
■	no seasons
■	no cropland

Running 3-Month Mean ONI values —— 2009/10

Running 3-Month (J=January up to D=December)

CHARACTERISTICS OF EACH EL NIÑO EVENT

Table 1 summarizes some characteristics of each of the El Niño events that occurred during the last 30 years, sorted by duration. El Niño 1986/87 and 1987/88 were considered as one event because they were consecutive events without interruption, keeping ONI values above 0.5 for 19 months.

TABLE 1.

Characteristics of each El Niño event

EL NIÑO	DURATION IN MONTHS	START OF THE EVENT*	MAXIMUM ONI VALUE	MONTHS OF PEAK	INTENSITY
1986-88	19	JAS	1.3 - 1.6	JFM and JAS	Moderate/Strong
1991/92	14	AMJ	1.6	DJF	Moderate
1997/98	12	AMJ	2.4	OND	Strong
2002/03	10	AMJ	1.3	OND	Moderate
2009/10	10	JJA	1.6	NDJ	Moderate
1994/95	7	ASO	1.2	NDJ	Moderate
2004/05	7	JJA	0.8	ASO	Weak
2006/07	5	ASO	1	OND	Weak

* Running 3-Month (J=January up to D=December)

5 RELATIONSHIP BETWEEN ASI AND EL NIÑO

Figure 16 shows that any phase (neutral, warm and cold) could be associated with droughts in global cropping areas. From a climatic and oceanic point of view, the neutral years have specific characteristics, but the impact of neutral ENSO conditions on agriculture is not clear. For instance, during the period of analysis (1984-2013), two pure neutral years were present: 1990, in which drought had a high impact on agricultural areas (12%) and 1993, in which drought had a low impact (3%).

Few years are under the influence of only one specific El Niño phase; most years are characterized by a transition phase. In the last 30 years, nine years were influenced by one phase and among these only one by the warm phase (El Niño): 1987 (warm), 1990 (neutral), 1993 (neutral) 1996 (cold), 1999 (cold), 2000 (cold), 2008 (cold), 2011 (cold) and 2012 (cold). There are cycles where consecutive years were under the influence of a warm or cold phase: from 1984 to 1992, the El Niño phase appeared dominant for nine years; from 1993 to 2000, eight years were under the influence of La Niña; 2001 to 2007 were years under the influence of El Niño; and the years 2008 to 2013 were influenced by the La Niña effect. The cycles dominated by El Niño were associated with more area affected by drought at the global agricultural level (Figure 16).

Neutral and La Niña years during the dominance of El Niño behave as El Niño years, causing extended droughts in agriculture. The largest drought that occurred in the last 30 years, during the first crop season, corresponds to La Niña (1989) under the influence of El Niño's dominant cycle, affecting 20 percent of agricultural surface. The year 1990, a neutral year also under the influence of an El Niño dominant cycle, produced extended droughts in global agriculture (12 %).

On the other hand, an El Niño year that takes place during La Niña's dominance seems to have less impact on crop areas. This could explain why El Niño 1997/98 did not produce the impacts anticipated, affecting only four percent of the total agricultural area. The historical cycles of the dominant phases are clear in the indices that measure the El Niño, such as ONI and SOI (Figures 3 and 4, pp. 5 and 6). Unfortunately, remote sensing information before the 1980s is not available to confirm the hypothesis from an agricultural point of view.

FIGURE 16.

Relationship between ASI and El Niño events in the tropical Pacific of the last 30 years for the first and second crop seasons. Bars represent the agricultural area affected by drought in percentage. January is on the top of the bar and December at the bottom of each year. Two colours present in a bar signify a transition event in the same year. The red line represents the five-year moving average of cropping area affected at global level. The total crop area used as a reference is 2,344 Mha and 580 Mha during the first and second crop seasons respectively. The Southern Oscillation Index (SOI) gives an indication of the development and intensity of El Niño or La Niña events in the Pacific Ocean. The SOI is calculated using the pressure differences between Tahiti and Darwin. The five year moving average of the SOI year-average values have been used.
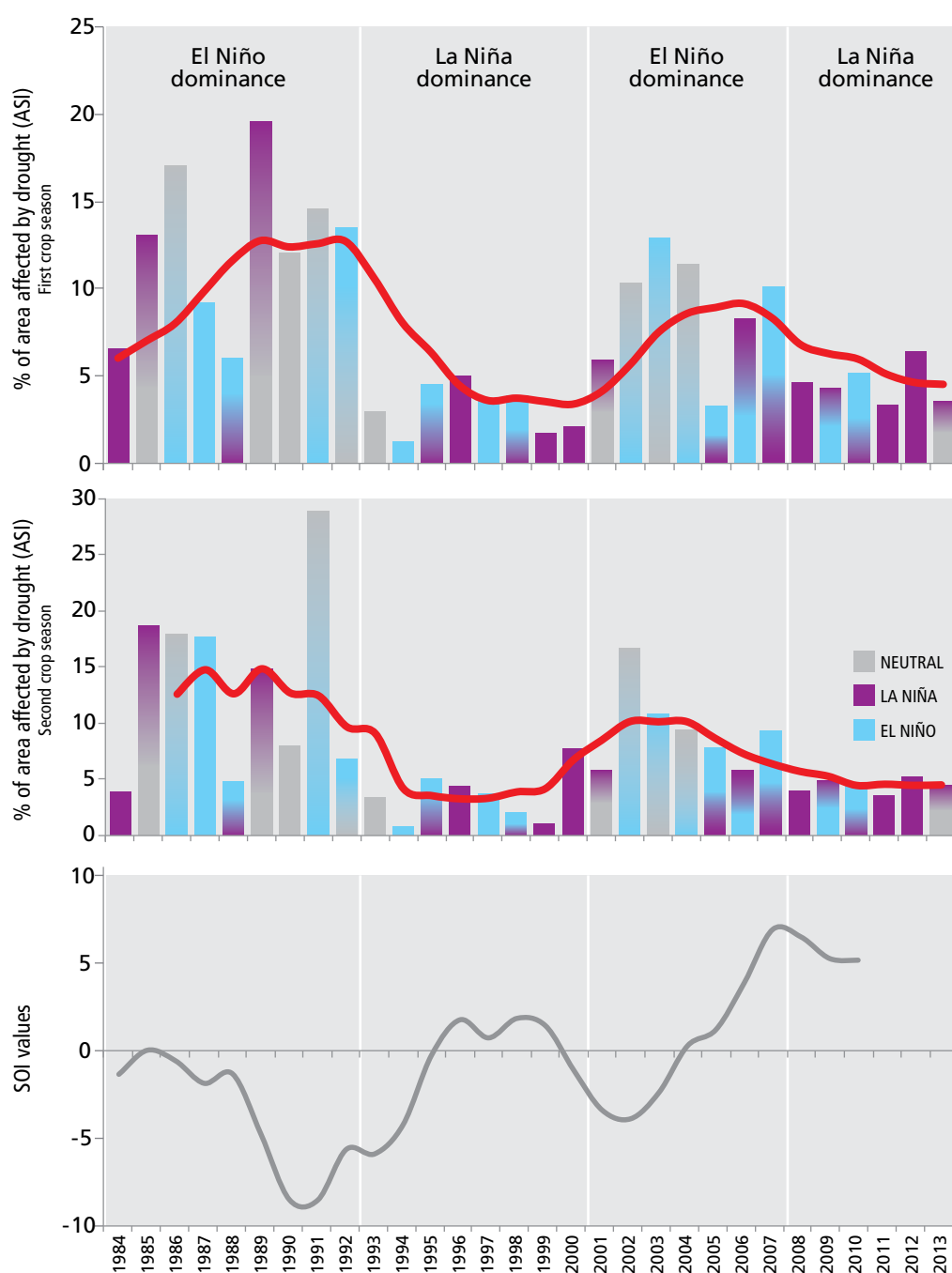
STATISTICAL ANALYSIS

Comparisons of two means

A Student's t-test was performed on two data sets to compare the means of agricultural area affected by drought during El Niño and La Niña years. Generally, the test quantifies the signal to noise ratio, where the signal is the difference of means and the noise is a function of the error around the means. If the signal is large and the noise is small, one can be more confident that the difference between the means is real or significant. To prove a significant difference, the null hypothesis needs to be disproved. The null hypothesis (Ho) is that there is no difference between the two means. If the null hypothesis can be disproved, then it can be said that the two groups are statistically different within a known level of confidence. The results of the two data sets: El Niño and La Niña years show that there is no significant evidence to disprove the null hypothesis, meaning that the area affected by drought is similar in the El Niño and La Niña years (Table 2). The same test was done grouping the agricultural area affected by drought during the El Niño and La Niña dominance cycles. In this case, using the TTEST function, with tails = 2 and test type = 3, the function gives a T-test value of 6.511E-06. Since the T-test value is less than 0.05 (95 percent confidence level) we can conclude that the null hypothesis can be rejected, concluding that the two means of agricultural area affected by drought are statistically different at 95 percent confidence level during El Niño and La Niña dominance cycles.

TABLE 2.

T-test value using the TTEST function, with tails=2 and test type=3 for El Niño and La Niña years and El Niño and La Niña dominance cycles.

	EL NIÑO/ LA NIÑA YEARS	EL NIÑO/ LA NIÑA YEARS DOMINANCE CYCLE
T-test value	0.56	6.51E-06

The Student's t-test confirmed that, from the point of view of agricultural area affected by drought, there is no significant difference during El Niño and La Niña years, both events producing similar droughts. However, the t-test shows that there is a statistical difference in the impact of drought during the dominance's cycles of El Niño or La Niña.

Correlation between areas affected by drought and El Niño indices

A correlation analysis was done between the agricultural area affected by drought (ASI) and El Niño indices (ONI and SOI). The time series of data was split into two data sets: one containing the positive values of each El Niño indicator and the other with the negative ones. The positive values of ONI represent El Niño years (in the case of SOI the negative values) and negative values of ONI represent La Niña years (positive values of SOI). Non neutral years were considered based on our previous findings.

Spearman's correlation is a nonparametric measure of statistical dependence between

two variables, even if their relationship is not linear. The sign of the Spearman correlation indicates the direction of association between the independent variable (El Niño index) and the dependent variable (ASI). If the agricultural area affected by drought tends to increase when the El Niño index (ONI or SOI) increases, the Spearman correlation coefficient is positive. If the agricultural area affected by drought tends to decrease when the El Niño index increases, the Spearman correlation is negative.

The colour red is assigned to the positive correlation because the area affected by drought increases at GAUL level 2 (district level) when the El Niño index increases. The red areas on the maps show the more sensitive agricultural areas during El Niño years. Green areas show an inverse correlation during El Niño years. In these areas favourable climatic conditions seem to prevail during El Niño and an increased crop production is expected. Even if both El Niño indices (ONI and SOI) overall determine the same areas of positive correlation during the first crop season, it is clear that ONI values during El Niño years are highly correlated with droughts in agriculture in Africa, Central America and the Caribbean. Meanwhile SOI is highly correlated with droughts in Asia and Indonesia. This is the case particularly close to the border between Kazakhstan and Russia where ONI is positively to neutrally correlated with agricultural droughts and SOI is negatively correlated. Overall the correlations are weak.

During La Niña years, both El Niño indices are positively correlated in the Horn of Africa and southern part of South America. However, there is some disparity in the northern hemisphere.

FIGURE 17

Correlation between Agriculture Stress Index and Oceanic Niño Index, positive values (El Niño). First crop season, period of analysis 1984-2013.

Spearman's correlation coefficent

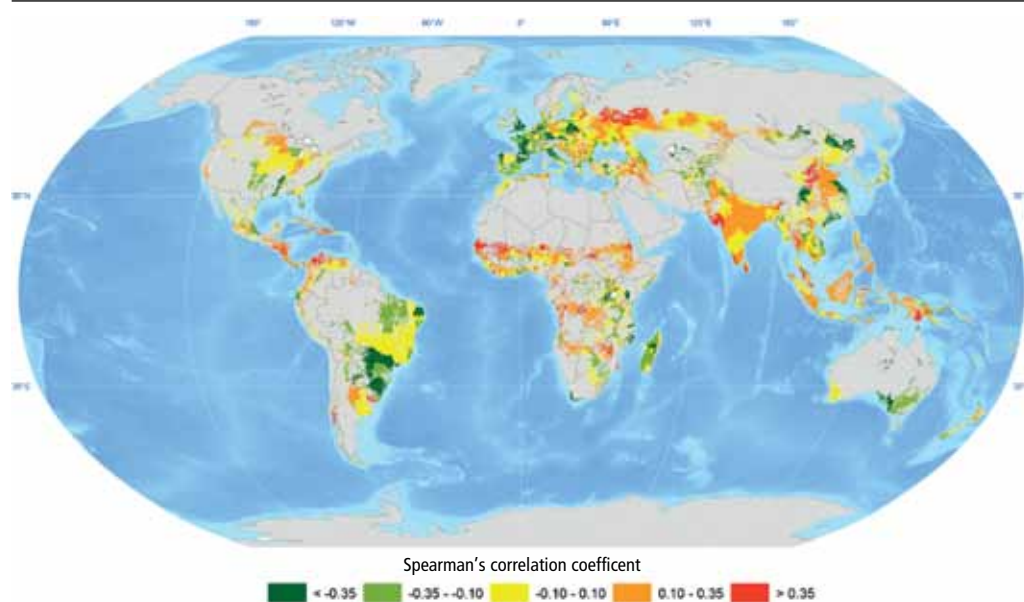< -0.35   -0.35 - -0.10   -0.10 - 0.10   0.10 - 0.35   > 0.35

FIGURE 18

Correlation between Agriculture Stress Index and Southern Oscillation Index, negative values (El Niño). First crop season, period of analysis 1984-2013.
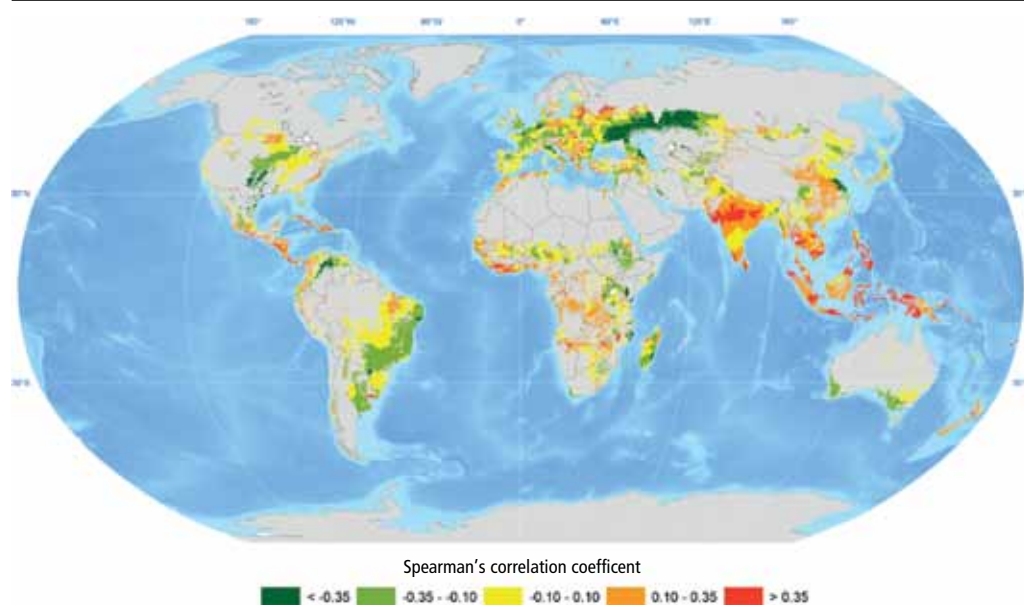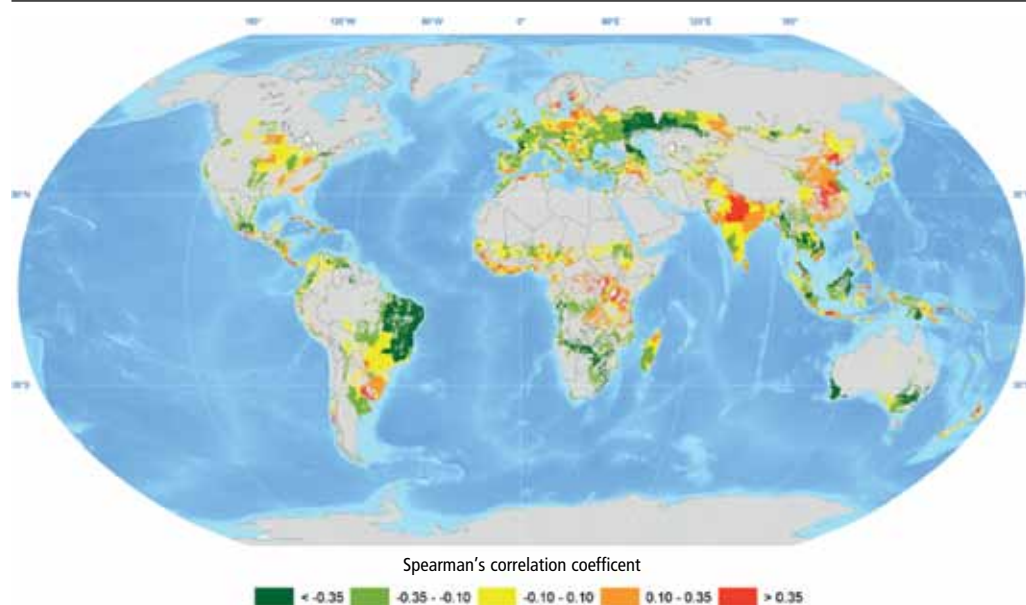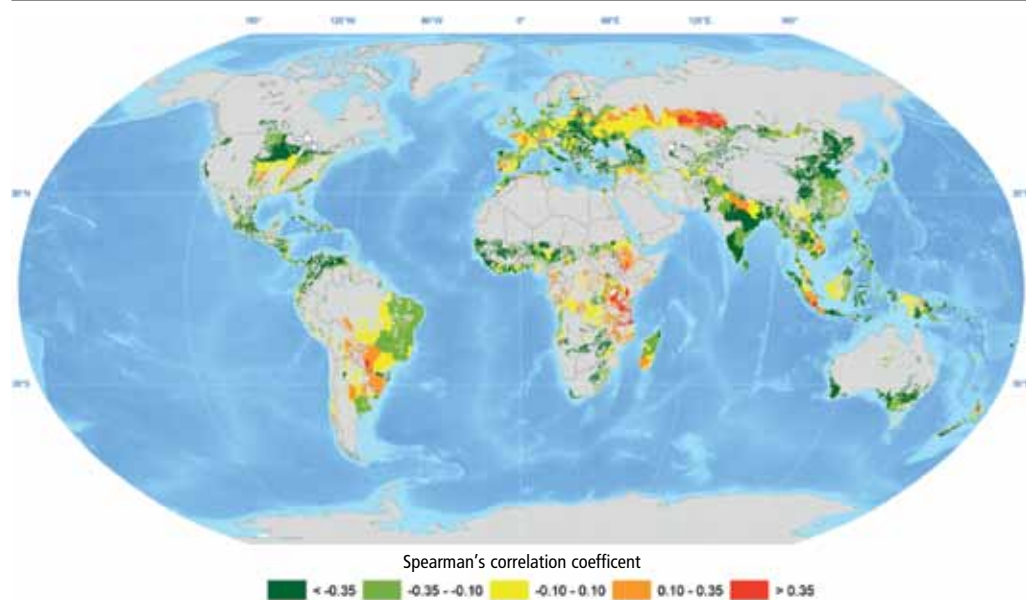

Spearman's correlation coefficent

< -0.35   -0.35 - -0.10   -0.10 - 0.10   0.10 - 0.35   > 0.35

FIGURE 19

Correlation between Agriculture Stress Index and Oceanic Niño Index, negative values (La Niña). First crop season, period of analysis 1984-2013.

Spearman's correlation coefficent

< -0.35   -0.35 - -0.10   -0.10 - 0.10   0.10 - 0.35   > 0.35

FIGURE 20

Correlation between Agriculture Stress Index and Southern Oscillation Index, positive values (La Niña). First crop season, period of analysis 1984-2013.

Spearman's correlation coefficent

< -0.35   -0.35 - -0.10   -0.10 - 0.10   0.10 - 0.35   > 0.35

FIGURE 21

Correlation between Agriculture Stress Index and Oceanic Niño Index, positive values (El Niño). Second crop season, period of analysis 1984-2013.

Spearman's correlation coefficent

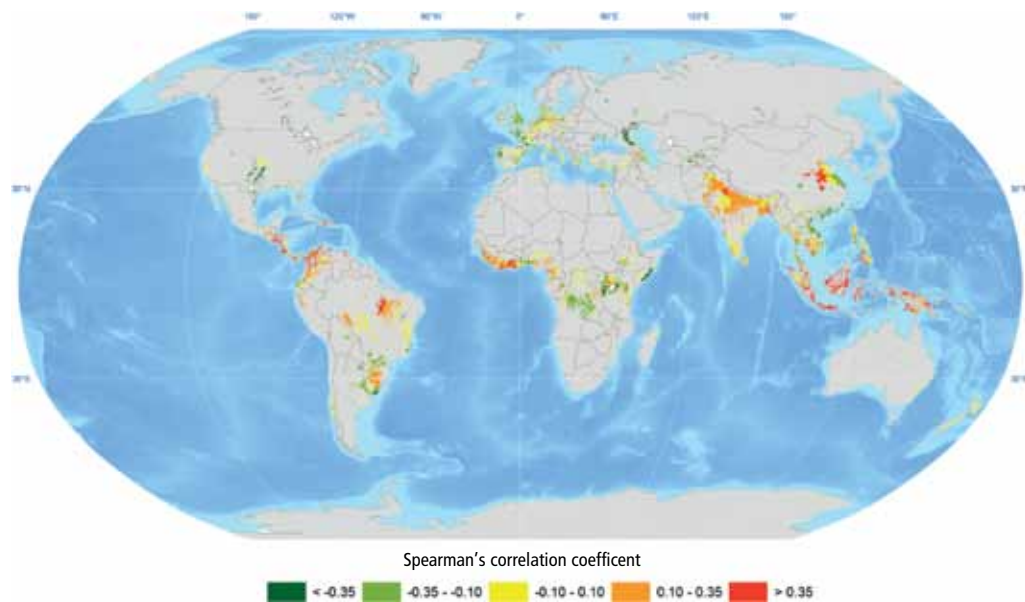< -0.35   -0.35 - -0.10   -0.10 - 0.10   0.10 - 0.35   > 0.35

FIGURE 22

Correlation between Agriculture Stress Index and Southern Oscillation Index, negative values (El Niño). Second crop season, period of analysis 1984-2013.
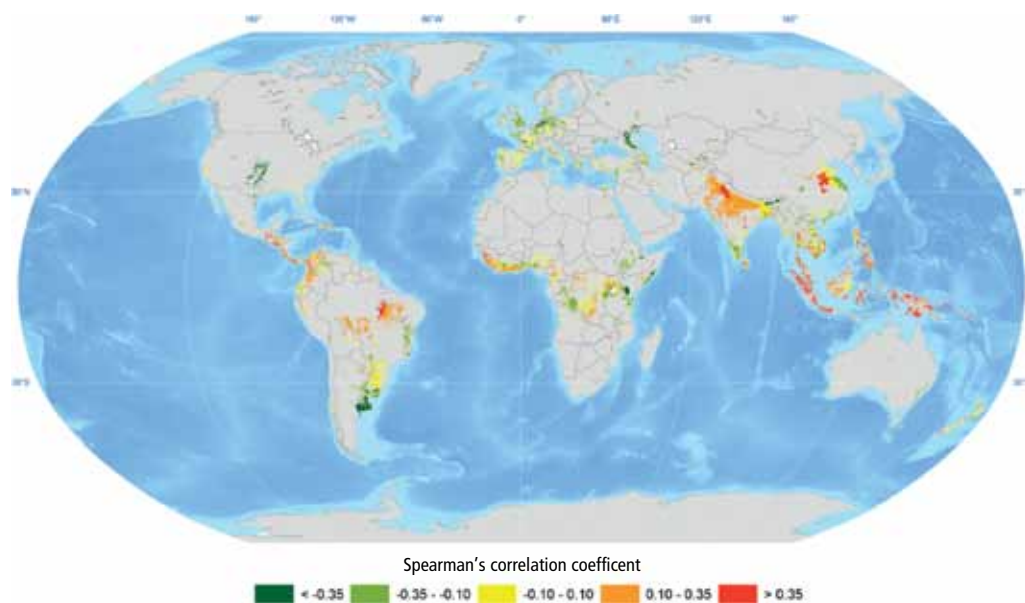

Spearman's correlation coefficent

< -0.35   -0.35 - -0.10   -0.10 - 0.10   0.10 - 0.35   > 0.35

FIGURE 23

Correlation between Agriculture Stress Index and Oceanic Niño Index, negative values (La Niña). Second crop season, period of analysis 1984-2013.
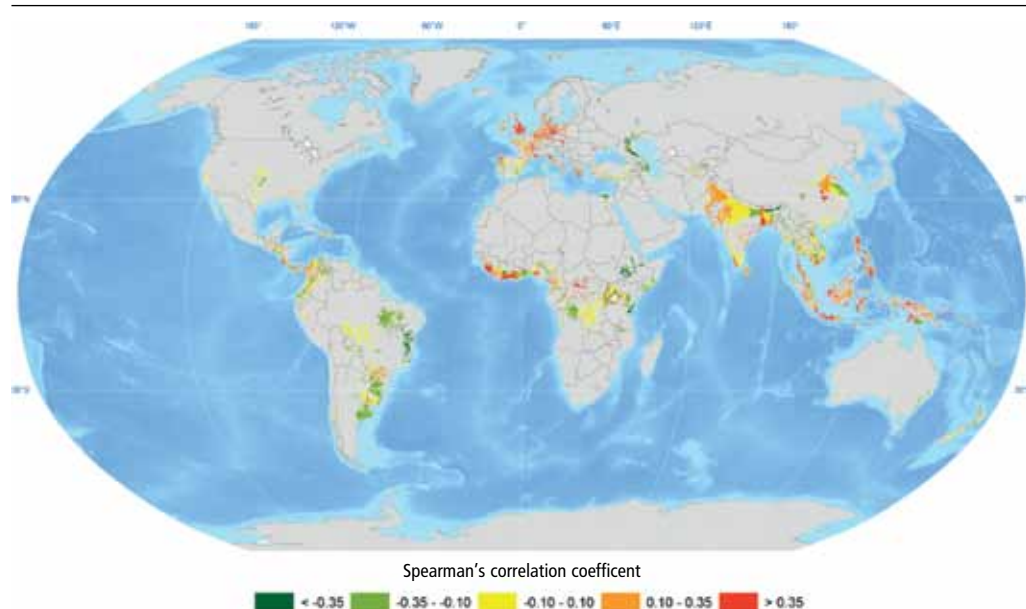

Spearman's correlation coefficent

< -0.35 | -0.35 - -0.10 | -0.10 - 0.10 | 0.10 - 0.35 | > 0.35
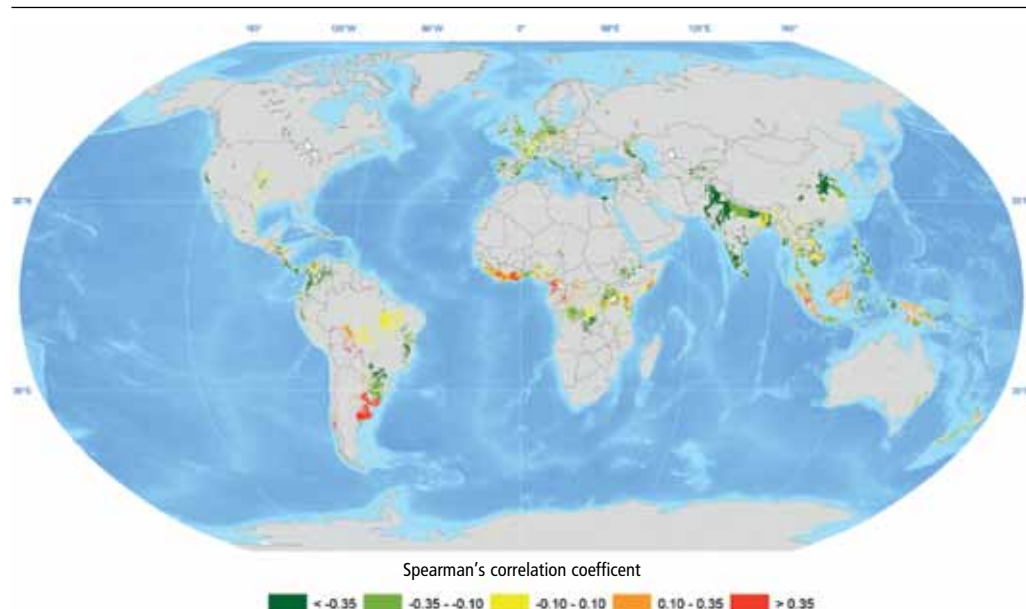
FIGURE 24

Correlation between Agriculture Stress Index and Southern Oscillation Index, positive values (La Niña). Second crop season, period of analysis 1984-2013.

Spearman's correlation coefficent

< -0.35 | -0.35 - -0.10 | -0.10 - 0.10 | 0.10 - 0.35 | > 0.35

AGRICULTURAL DROUGHT FREQUENCY

The frequency of drought affecting more than five percent of the cropping area at GAUL level 2 (district level) was calculated as a complementary analysis of the correlation presented on the previous session. This analysis shows the hot spot areas at global level that could be seriously affected during El Niño years and the frequency of their occurrence. The frequency was calculated for the first and second crop seasons independently (Figures 25 and 26). Then the joint frequency of five percent of an area affected by drought during the first and/or second season was calculated. The results were expressed by an agriculture drought frequency index (Figure 27). During the first crop season the higher frequencies of droughts are localized in the western part of the United States, northern Mexico, northern Colombia, northern Venezuela, the Horn of Africa, Pakistan, India, northeast China, southern Myanmar and New South Wales in Australia. During the second crop season the overall frequencies decrease; the higher frequencies are localized in California in the United States, northern Brazil, the Horn of Africa and Indonesia. The joint risk shows the increase of frequencies in the Horn of Africa mainly in Somalia and the Amhara region in Ethiopia. In Asia there is an area of relative high frequency of droughts during El Niño years in the northern border of Kazakhstan and Russia.

FIGURE 25

Agriculture Drought Frequency of El Niño declared years (Period of analysis 1984-2013). First crop season.
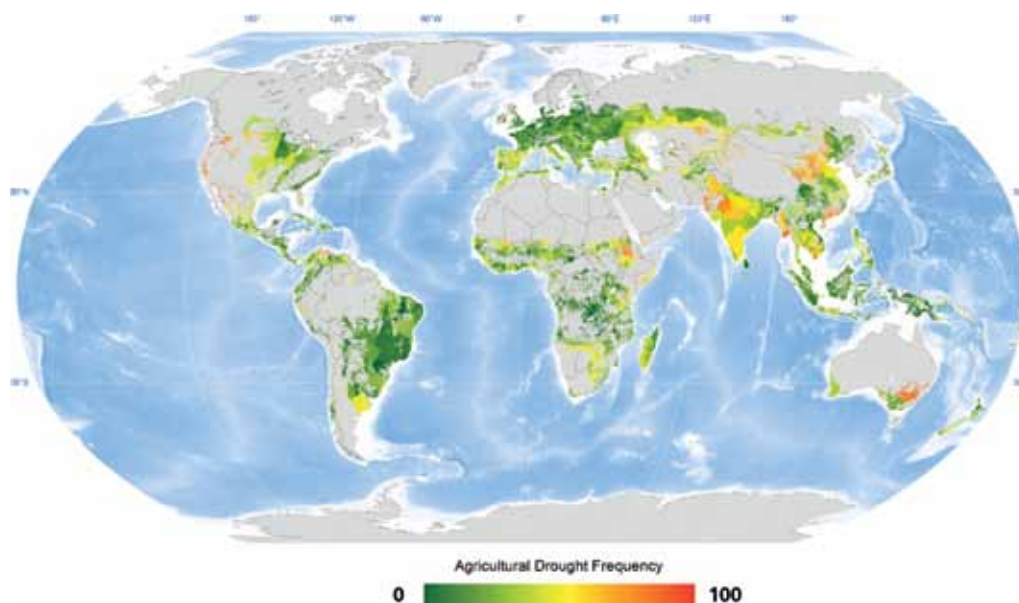
FIGURE 26

Agriculture Drought Frequency of El Niño declared years (Period of analysis 1984-2013). Second crop season.
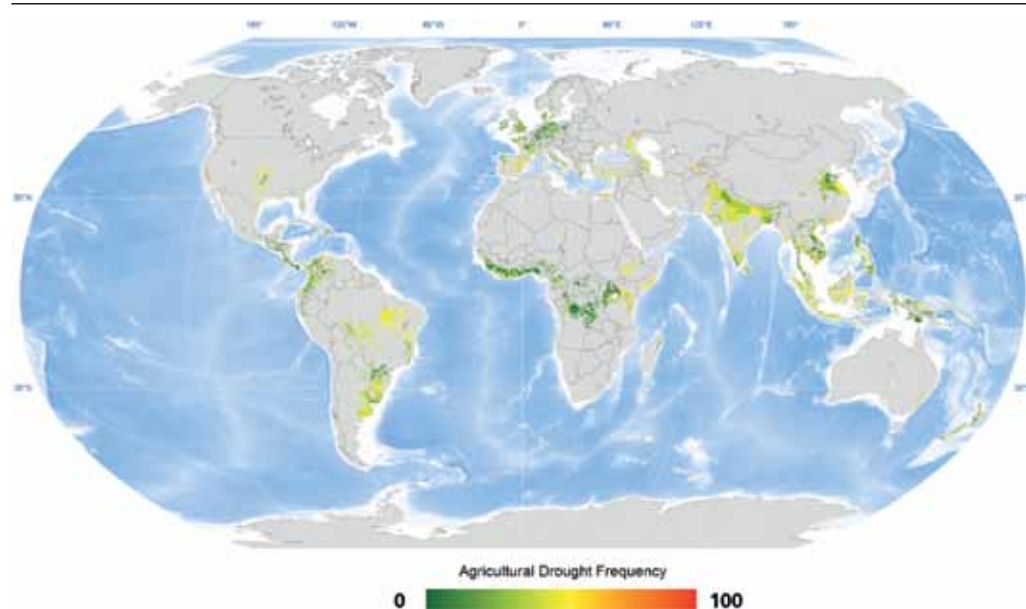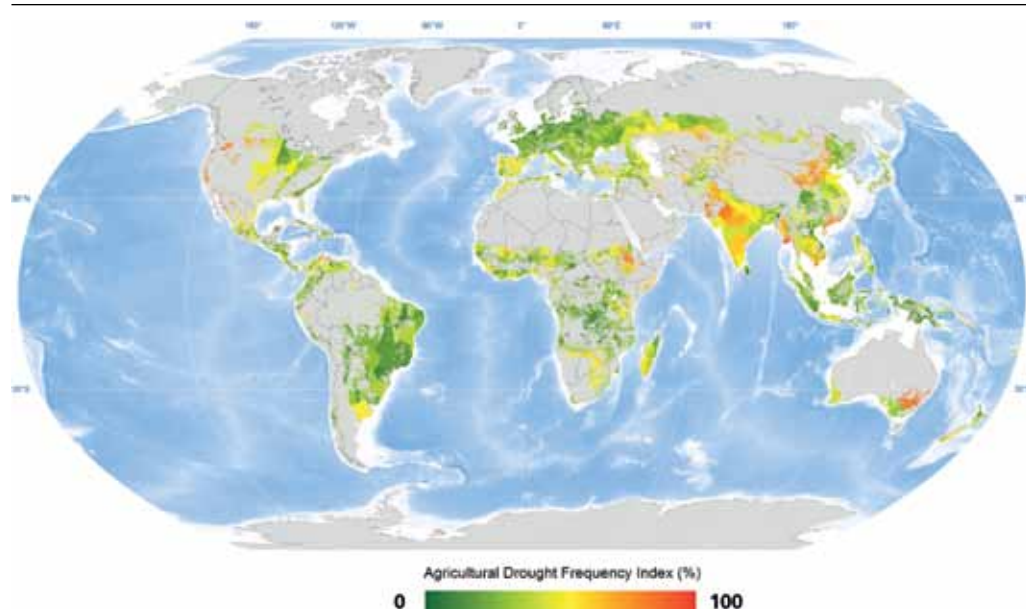

FIGURE 27

Agriculture Drought Frequency of El Niño declared years (Period of analysis 1984-2013). First and second crop season.

6 DEVELOPMENTS 2014

BOX 1
Is understanding the impacts on agriculture during the gestation period as important as forecasting the occurrence of El Niño?
By Oscar Rojas, and Shukri Ahmed

As of December 2014, no official declaration of El Niño has been made, as the sea surface temperature of the Pacific Ocean (Niño 3.4 region) has not reached the threshold of +0.5 degrees for three consecutive months. Climatological centres, however, are forecasting at least a 70% chance that El Niño may be declared in the months ahead. Nonetheless, the gestation of a probable El Niño 2014/15 (Figure 28) may have already resulted in drought conditions in the dry corridor of Central America and in Colombia and Venezuela in South America between May and July of 2014. In addition, in Nicaragua and Venezuela, the drought conditions observed by satellite in 2014 are very comparable to those of the El Niño year of 1991/92, the most severe event in the last 30 years from agriculturual point of view (Figure 29).

The announced probabilities of the development of an El Niño phenomenon in 2014 were based on the results of several different models that did not provide specific recommendations for prompt action during the gestation period to mitigate any possible negative outcomes. Furthermore, in the first week of December 2014, signs of abnormal dryness were apparent in areas that are normally associated with El Niño phenomenon including Brazil, Argentina and in Santa Cruz province of Bolivia, in South America and in South Africa, Mozambique, Zambia and Madagascar in southern Africa.

The above instances may indicate that there are important gaps in our understanding of the complexities of the El Niño phenomenon. Although considerable progress was made in the last few decades, the El Niño phenomenon and its possible impacts on agriculture requires more research work to provide adequate and timely warning to national authorities and farmers.

FIGURE 28

Running 3-month mean of Oceanic Niño Index (ONI). ONI values of 2014/15 (red) compared with previous warm events of the last 30 years.
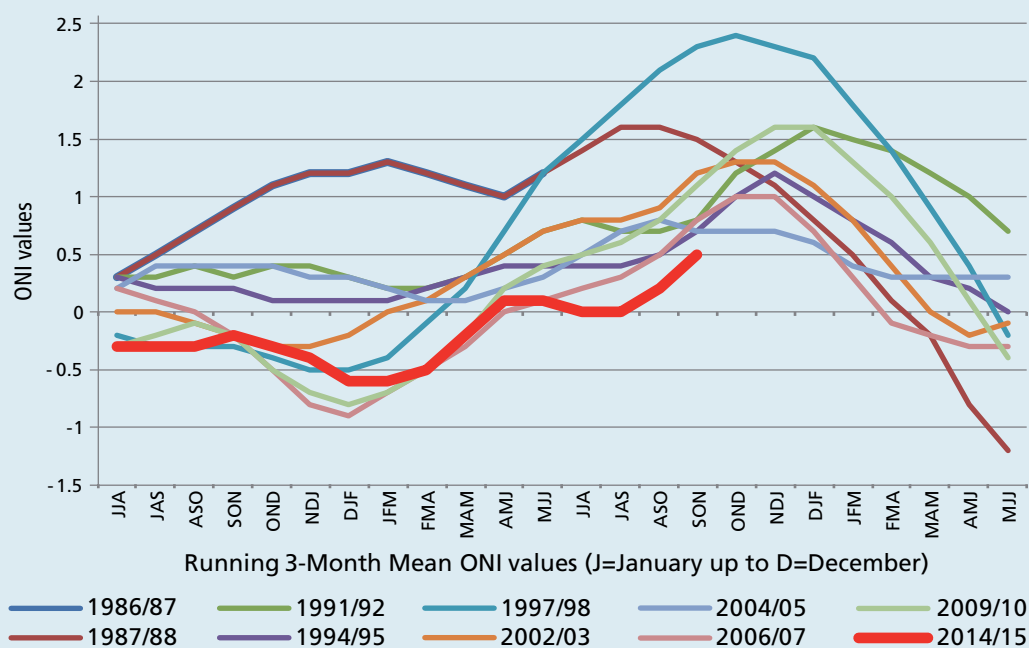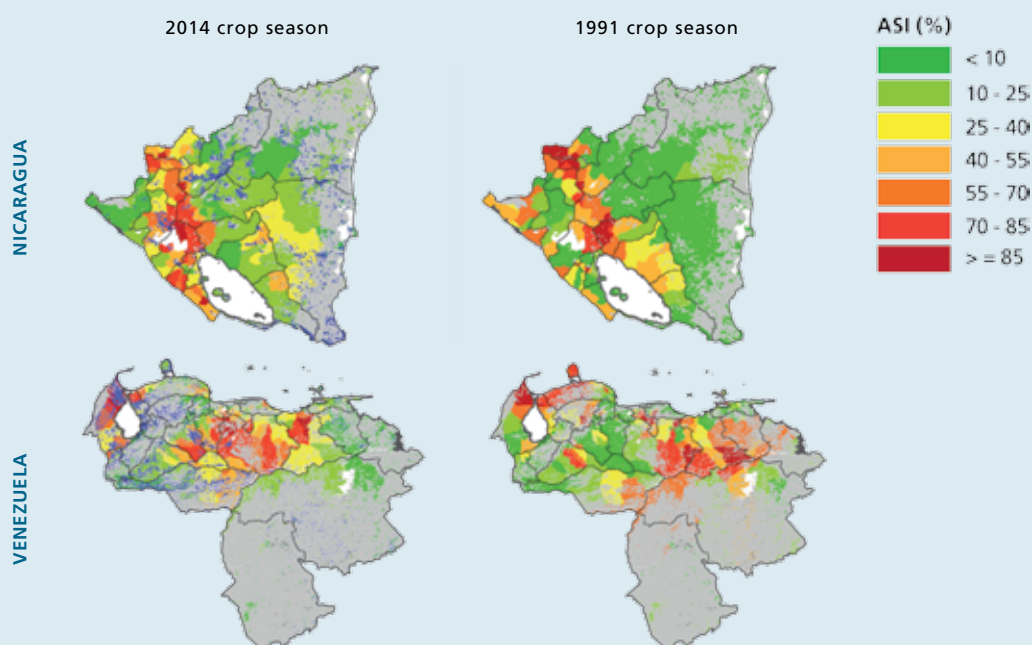

FIGURE 29

Percentage of agricultural areas affected by drought (ASI) during (a) 2014 crop season in Nicaragua and Venezuela and (b) 1991 crop season in Nicaragua and Venezuela.

7 CONCLUSIONS

- According to the findings of this study, the impacts on agriculture of an El Niño occurrence could be mitigated by a La Niña's dominance cycle, and, *vice versa*, La Niña impacts on agriculture could be exacerbated by an El Niño dominance period. This fact could explain the weak correlation found between the intensity of an El Niño event and drought conditions at global level (chapter 5). For instance, El Niño 1997/98, defined "the climate event of the century" did not have major impacts on the agricultural areas of the world. The reasons are not completely clear. El Niño 1997/98 started at the same time as El Niño 1991/92 in April/May/June with a similar duration (only two months shorter) at almost twice the intensity, but had very little influence on agriculture: El Niño 1991/92 caused drought in approximately 350 million hectares while El Niño 1997/98 affected 80 million hectares (77 percent less). Additional information is necessary (beyond the ENSO indices ONI and SOI) to capture the complexity of the interaction between agricultural production, climate and oceanic temperatures and currents.

- Any characterization of El Niño and connection with its impacts on agriculture is difficult to ascertain because many variables also have a sway in each event, including the gestation period, which may start from a neutral, positive (La Niña) or negative (El Niño) phase and in the onset time, intensity and duration of an El Niño occurrence. All these variables, in turn, interact with other dynamic variables of vegetation development (Figure 30). For instance, El Niño's impact on crop conditions and development depends on the sensitivity of the phenological phase of crops during the peak period of influence of the event, because the flowering and grain filling phases of cereal crops are more sensitive to water stress (moisture deficits). In addition, crop conditions and times of each phenological phase are more heterogeneous during the first crop season than during the second one. It is also important to consider the variation in technology used in different agricultural areas (Iizumi *et al.*, 2014). The real numbers of variables are unknown, making the situation more complex, while atmosphere, ocean and crop dynamics interact at different moments of time. The whole situation is similar to trying to solve Rubik's Cube (Figure 31).

- Annual crops planted in October-November in the southern hemisphere have a low probability of being affected during an El Niño event (ONI value above 0.5), because planting occurs in the previous year and harvesting takes place in March-April, normally before the declaration of El Niño. During the last 30 years, early onsets

of El Niño events have occurred in April-May-June, with the exception of El Niño 1953/54 that reached an ONI value of 0.5 in December 1952 and January/February 1953, representing a unique case in 64 years of recording these events. On the other hand, these areas have a high probability of being affected during the second year of El Niño. The intensity of the negative impact has demonstrated to be linked to the duration of the event. Annual crops planted in April-May in the southern hemisphere and harvested in August-September have a higher probability of being affected by El Niño in the same year of gestation and onset of the event. For instance, in Australia, crops were affected by drought from the beginning to the end of the 2006 crop season. However, in 2007 (the second year of El Niño 2006/07), crops were affected mainly during the first half of the crop season as conditions improved at the end of the cycle when the effects of El Niño diminished.

- In the northern hemisphere, annual crops planted in May in the Americas during some El Niño years show the first signals of drought during the development of El Niño. For instance, the dry corridor of Central America, the Caribbean, Colombia and Venezuela are very likely to suffer from drought if El Niño gestation develops early in the year (before May). In Central America, El Niño could intensify the effect of the phenomenon known as Canícula or Veranillo de San Juan, a reduction of the rainfall during July-August affecting the first crop season (primera) and the planting period of the second one (postrera). The United States and Canada, where crops are planted in March/April, can be affected during the first year of El Niño because flowering and grain filling occur around August. In the second year of El Niño, these areas are less likely to be affected (exceptions occurred in 2008 and 2003). In Asia, countries where crops are planted earlier in the year, such as China, could be affected by El Niño during the second half of the crop season during the first year of the warm event. Countries such as Indonesia or Sri Lanka, where planting takes place at the end of the year (November), could be affected during the whole cycle.

- The statistical analysis showed the areas where El Niño is most likely to negatively affect agriculture causing drought conditions, with ensuing reductions in agricultural production and potential food security implications. In these areas, governments should implement mitigation programmes to increase the resilience of farmers during El Niño events.

- Finally, the outcomes of this study pose new challenges to the scientific community. If our hypothesis of El Niño/La Niña dominance cycles is correct, it would not be sufficient to forecast El Niño or La Niña years to anticipate drought impacts on agriculture but it would be necessary to know if the event would be under El Niño/La Niña dominance. This in turn, would require the identification of the breaking point years in dominance cycles, an extremely difficult task.

FIGURE 30

Phenological phases of maize in which flowering and yield formation are more sensible to moisture deficit.
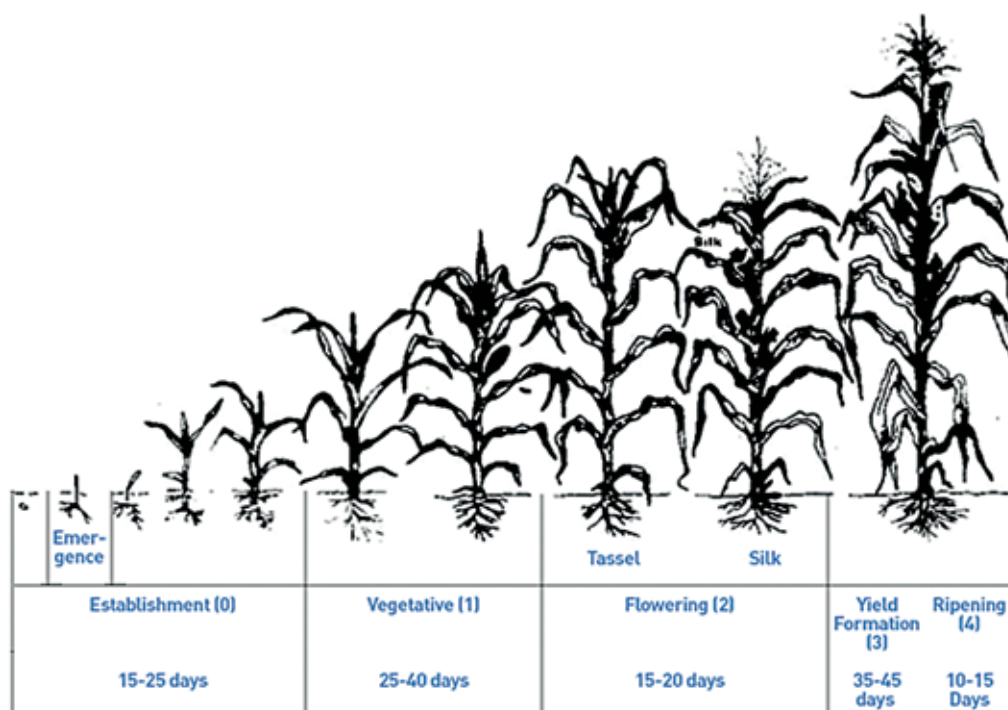
Source: http://www.fao.org/nr/water/cropinfo_maize.html
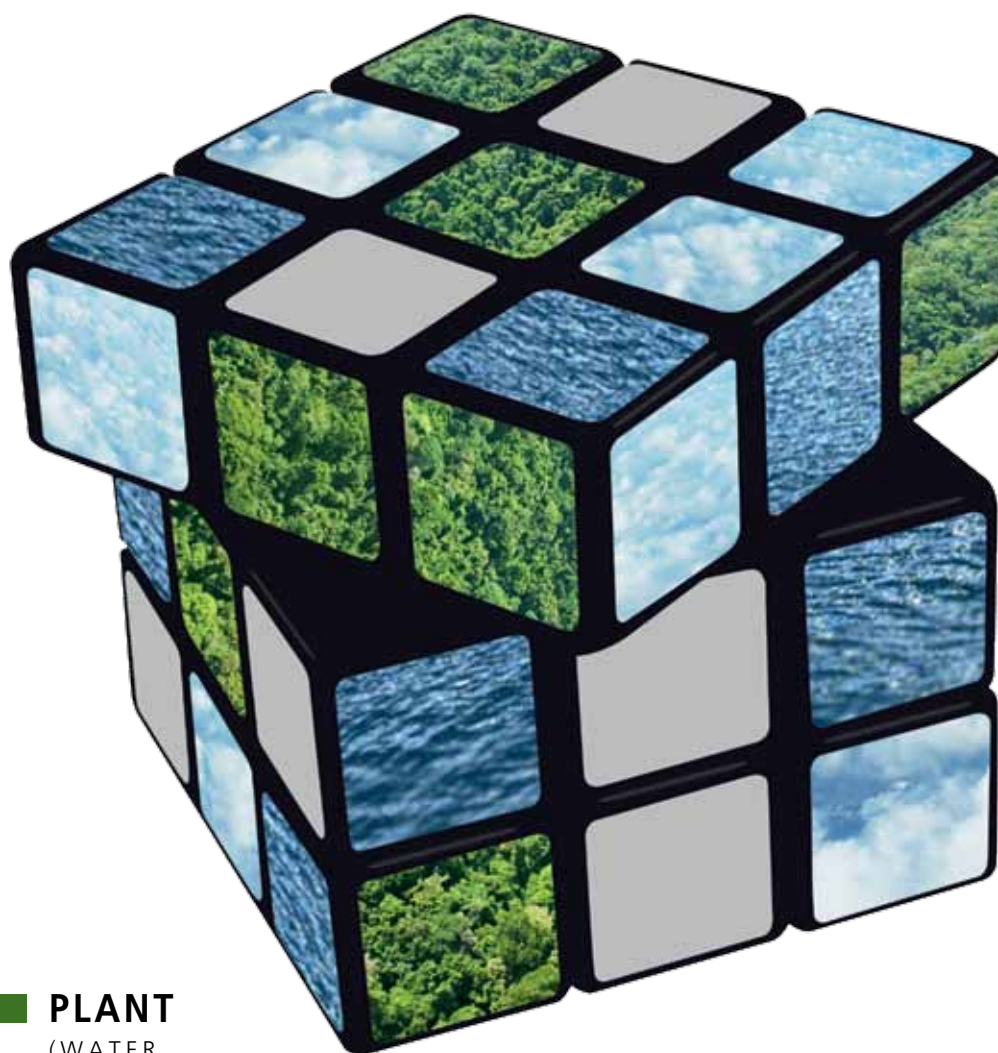
FIGURE 31

Rubik Cube description of the determinant variables of the occurrence of an El Niño phenomenon.

■ **ATMOSPHERE**
(INITIAL STATE, INTERACTION WITH OTHERS PHENOMENON, ENERGY BALANCE, ETC.)

■ **UNKNOWN**

■ **PLANT**
(WATER REQUIREMENTS OF THE DIFFERENT PHENOLOGICAL PHASES AND DIFFERENT CROPS)

■ **OCEAN**
(INITIAL STATE, SEA TEMPERATURES ON SURFACES AND DEEPLY WATER, ETC.)

LITERATURE CITED

Climate Prediction Center. 2005. ENSO *FAQ: How often do El Niño and La Niña typically occur?* National Centers for Environmental Prediction. http://www.cpc.ncep.noaa.gov/

FAO. 2013. *Climate impact on agriculture. An El Niño primer*. Rome. http://www.fao.org/nr/climpag.

FAO (GIEWS). 2014. Ethiopia: El Niño-Southern Oscillation (ENSO) and the main Kiremt rainy season. An assessment using FAO's Agricultural Stress Index System (ASIS). *GIEWS Up date*, 30 June 2014. http://www.fao.org/giews/english/shortnews/enso27062014.pdf

FAO (GIEWS). 2014 El Niño-Southern Oscillation (ENSO): Review of possible impact on agricultural production in 2014/15 following the increased probability of occurrence. *GIEWS Up date*, 17 June 2014. http://www.fao.org/giews/english/shortnews/enso17062014.pdf

Kiladis G., & Diaz H. 1989. Global climatic anomalies associated with extremes in the southern oscillation. *Journal of Climate*, 2: 1069–1090.

Kogan, F. 1994. Droughts of the late 1980's in the United States as derived from NOAA polar-orbiting satellite data. *Bulletin of the American Meteorological Society*, 76(5): 655–668.

Parker D. 1983. Documentation of a southern oscillation index. *Meteorological Magazine*, 12: 184–188.

Rojas O., Vrieling A., & Rembold F. 2011. Assessing drought probability for agricultural areas in Africa with coarse resolution remote sensing imagery. *Remote Sensing of Environment*, 115: 343-352. doi:10.1016/j.rse.2010.09.006.

Ropelewski, C. F. & Halpert, M. S. 1992. Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation. *Mon. Wea. Rev*., 115: 1606–1626 (1992).

International Research Institute on Climate and Society (IRI). 2013. Schematic effects of ENSO. http://iri.columbia.edu/climate/ENSO/globalimpact/temp_precip/region_elnino.html

Lizumi,T., Luo, J., Challinor A., Sakurai, G., Yokozawa, M., Sakuma, H., Brown, M. & Yamagata, T. 2014 Impacts of El Niño southern oscillation on the global yields of major crops. *Nature Communi*., 5: 3712; doi: 10.1038/ncomms4712.

Unganai, L. & Kogan, F. 1998. Drought monitoring and corn yield estimation in Southern Africa from AVHRR data. *Remote Sensing of Environment*, 63; 219-232.

Vancutsem, C., Marinho, E., Kayitakire, F. See, L., & Fritz S., 2013. Harmonizing and combining existing land cover/land use datasets for cropland area monitoring at the African continental scale. *Remote Sensing 2013*, 5: 19-41; doi:10.3390/rs5010019.

White, M. A., Thornton, P. E., & Running, S. W. 1997. A continental phenology model for monitoring vegetation responses to inter-annual climatic variability. *Global Biogeochemical Cycles*, 11(2): 217–234.

World Meteorological Organization (WMO). 2014. El Niño/La Niña background. http://www.wmo.int/pages/prog/wcp/wcasp/enso_background.html

DATA SOURCES FOR THE MAPS

El Niño data:

> http://ggweather.com/enso/oni.htm

ASIS data:

> http://www.fao.org/giews/earthobservation

GAUL:

> www.fao.org/geonetwork

Bathymetry:

> http://www.gebco.net

Background image on the maps:

> Elaborated from "General Bathymetric Chart of the Oceans"

During El Niño episodes the normal patterns of tropical precipitation and atmospheric circulation become disrupted triggering extreme climate events around the globe: droughts, floods and affecting the intensity and frequency of hurricanes. Disasters create poverty traps that increase the prevalence of food insecurity and malnutrition. Agriculture is one of the main sectors of the economy that could be severely affected by El Niño event. FAO monitors the El Niño-Southern Oscillation (ENSO) phenomenon, among other weather related hazards, with a special focus on the potential impacts on the agricultural sector.

The objective of this study is to enhance our understanding the El Niño phenomenon using FAO's Agricultural Stress Index System (ASIS). This study is carried out under the auspices of the new FAO Strategic Framework, for the Strategic Objective 5 "Increase the resilience of livelihoods to threats and crises". The study outcomes are expected to enhance further discussions on our understanding of the El Niño Phenomenon and add to the growing literature. This would in turn improve effective early warning capabilities of FAO and partners to issue and trigger timely disaster risk reduction measures.