Under global surface warming, increased weather extremes reduce crops yields.

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American Geophysical Union Fall 2021 Conference

2021 Abstract Title: Under global surface warming, increased weather extremes can reduce crops yields.
Using the IPCC AR6 WG 1 interactive atlas, we find yield declines may compromise world food security at 1.5°C which may be severe for major food producing regions at 2°C, especially if compound extremes, and increased surface ozone.
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Session Number and Title: NH15G: 2021 Extreme Weather Events and Natural Hazards III
13 December 2021
World cereal production is still increasing (though slower since 2019)
- but so are extreme weather events

It is indisputable that human activities are causing climate change, making extreme climate events, including heat waves, heavy rainfall, and droughts, more frequent and severe.
Severe Weather Events

- Super-storms
- Extraordinary cold snaps
- Hurricanes-cyclones
- Tornadoes
- Torrential rains
- Flooding
- Heatwaves
- Forest fires
- Drought
- Compound events

All being affected by climate change with adverse effects, most with examples of extreme damage -including to crops, as well as soil erosion and land degradation.
In the IPCC treats extreme weather events as one impact category, in which forest wild fires are included.

The extreme weather impact is most damaging to human population and crops, doubly damaging for labor intensive agriculture.

Increasing extreme weather on agriculture is the most vitally important effect of climate change (disruption) effect today.

IPCC Reasons for Concern “burning embers”

**Current policies & promises**
- 1.5°C: Widespread major impacts
- 2.0°C: Unavoidable 2030
- 2.5°C: Today

**IPCC 2018 1.5°C Report**
- Extreme weather events
- Food supply instability

**2°C**
- Red: Significant and
The world has now entered the world food insecurity stage of global climate disruption.

Red: Significant and widespread impacts/risks.

- Extreme weather events
- Food supply instability

1.5°C
Red: Significant and widespread impacts/risks.

2°
- Extreme weather events
- Food supply instability
- Warm water corals
- Fin fish

1.5°
- Hi
- Hi
- HI

1°
- MOD
- HI

IPCC 2018 15°C Report

Level of additional risk/impact

- Very high
- High
- Moderate
- Undetectable
Global production potential as equivalent to crop yield or Net Primary Productivity (NPP), is threatened at +1°C local temperature change

(IPCC 2007 AR4 5.4.2.2 p.285
Review of crop impacts versus incremental temperature change)
Persistent Extreme Drought Affecting Western USA and Central Canada
31 October 2021

North American Drought Monitor
October 31, 2021

Intensity:
- Abnormally Dry
- Drought - Moderate
- Drought - Severe
- Drought - Extreme
- Drought - Exceptional

California

Peter Carter, Climate Emergency Institute
Influence of extreme weather disasters on global crop production
UBC and McGill

We show that droughts and extreme heat significantly reduced national cereal production by 9–10%.

A 7% greater production damage from more recent droughts (getting worse)

There was 10% more damage in developed countries than in developing ones.

Key Background Research Paper

Anthropogenic climate change has slowed global agricultural productivity growth
(Total factor productivity)
Temperature as limiting factor of crop growth
FUNDAMENTAL: Surface temperature is the crop yield limiting factor for agriculture (without irrigation)

IPCC AR6 WG1
Global Surface Heating Agricultural Tipping Point

At crop intolerance temperature increase tipping point - decline is irreversible and committed temperature increase is higher.
Irrigation

Large benefit against heat and drought

but likely has a limit to effectiveness
Agriculture Irrigation

Africa hardly any

Depend on rivers

Global Map of Irrigation Areas Version 4

278.8 Mio ha are equipped for irrigation at the global scale. (About 68% of the total irrigated area is located in Asia, 17% in America, 9% in Europe, 5% in Africa and 1% in Oceania.) The largest contiguous areas of high irrigation density are found in North India and Pakistan along the rivers Ganges and Indus (A), in the Hai He, Huang He and Yangtze basins in China (B), along the Nile river in Egypt and Sudan (C), in the Mississippi-Missouri river basin (D), in parts of California (E), in the Po river plain in northern Italy (F) and along the lower Danube (G). Smaller irrigation areas are spread across almost all populated parts of the world.
Increasing extreme weather events come on top of this
World Agriculture at Breaking Point
Effects of climate change on crops

**POSITIVE IMPACTS**
- Increased productivity with warmer temperatures
- Possibility of growing new crops
- Longer growing seasons
- Increased production from higher CO2
- Accelerated maturation rates
- Decreased moisture stress

**NEGATIVE IMPACTS**
- Increased insect infestations
- Crop damage from extreme heat
- Planning problems and less reliable forecasts
- Stronger storms
- Torrential rain
- More floods
- Increased weeds
- Increased crop diseases
- Decreased herbicide and pesticide efficacy
- Increased moisture stress
- Increased drought

As temperatures increase, the negative effects increasingly overwhelm the potential positive effects, after which all crops in all regions decline and more so as temperatures continue to increase.

**ADDITIVE IMPACTS**
- Warming stress
- Increase in ground level ozone
- Climate variability
- Waterlogging of land
- Highly specialized, high chemical food production, less adaptable, more soil erosion
- Sickness, loss of human labor

Most negative impacts are not captured by models.

Feedback:
Global warming acceleration
So many adverse impacts of global surface heating and climate disruption on agriculture:

- Surface warming
- Climate disruption
  - Human health
    - Air pollution
    - Malnutrition
    - Disease
    - Poverty/Debt
  - Reduced labor for production
  - Increased soil erosion
    (storms, torrential rains, floods, drought, forest fires)

Agricultural productivity:

- Stratospheric ozone depletion
- UV radiation
- Impaired photosynthesis
- Plant toxic
- Tropospheric ozone
- Pests
- Weeds
- Heat waves
- Drought
- Floods
- Extreme heavy rains
- Freshwater decline for irrigation
- Melt down mountain top glaciers
- Conflict resource scarcity
- Biodiversity loss and ecosystem function
- Loss of labour
- Desertification and land degradation
Heat Extremes Affect All Food Sources

Crops, Livestock, Fisheries
Fisheries: Extreme Sea Surface Heat Events (2019)

On top of ocean heating

Marine Heatwave Map

Category: I Moderate, II Strong, III Severe, IV Extreme

World Meteorological Organization 2019
Model Projections of climate change impact on crops are linear. They don’t capture extreme events.
The several non-linear extreme events are not captured by models

Huge range in model projections for temperate wheat and large range for tropical wheat.

Without adaptation all crops all regions are in decline by 2°C with 1 exception at 3°C.

With adaptation:

IPCC last 5th assessment

IPCC 2014 AR5 Figure 7-4 | Percentage simulated yield change as a function of local temperature change for the three major crops and for temperate and tropical regions.
Many Climate-Crop Model Gaps

Assessment of crop yields under climate change assume linear changes as temperature changes, so does not account for abrupt changes under extreme weather events, nor for compound events.

Weeds, pests and plant pathogens are no captured by models.

Tropospheric ozone is not accurately captured.

Combined adverse impacts are not captured.

Effects on soil erosion and land degradation are not captured.

The does not provide what needed for future crop production.

There will abrupt, hard to predict losses with climate variability and extreme events.

In IPCC projections adaptation is assumed to be successful even at rising degrees of climate change, and to be able to reverse risks to crops.

In addition, if a crop decline is observed at a particular temperature +T°C, that decline will continue because the temperature increase will continue, so we don’t need simple %age crop decline at corresponding +T°C, we need to project full crop decline and loss at the committed temperature ++T°C.
As population grows, water resources per capita per year are decreasing rapidly.

From 6994.9 m³ in 2000 to 6029.4 m³ in 2012 to 5630.2 m³ in 2018.
About 58.6 million people are facing severe acute food insecurity in East Africa.

Africa is projected to suffer increasing drought with little to no irrigation

Past 1 months

Drought (SPEI)
(Standardised Precipitation-Evapotranspiration Index)

INCREASING DROUGHT
Compared to past 12 months (left) the past 1 month (right) shows large expansion and increasing drought severity

Past 12 months

December 2021

Peter Carter, Climate Emergency Institute

Government of Spain, SPEI Global drought monitor, Santiago Beguería et al
IPCC August 2021 6th Assessment (AR6)  
Working Group 1  
Science
Chapter 11: Weather and climate extreme events in a changing climate

(in assessment for the first time)

FAQ 11.3: Climate change and extreme events
Extreme events have become more probable and more intense.

![Diagram showing the relationship between climate change and extreme events](image-url)
FAQ 11.2: Will climate change cause unprecedented extremes?

Yes, in a changing climate, extreme events may be unprecedented when they occur with...

- Larger magnitude
- Increased frequency
- New locations
- Different timing
- New combinations
Extreme weather is increasing attributed to emissions driven climate change and will continue to increase.

IPCC August 2021, 6th assessment, WG1

**EXTREME EVENTS**

They will increase further with warming.

It is indisputable that human activities are causing climate change, making extreme climate events, including heat waves, heavy rainfall, and droughts, more frequent and severe.

**EVERY REGION**

Climate change is already affecting every region on Earth, in multiple ways.

The changes we experience will increase with further warming.
FAQ12.2, Figure 1: Crop response to maximum temperature thresholds. Crop growth rate responds to daily maximum temperature increases, leading to reduced growth and crop failure as temperatures exceed critical and limiting temperature thresholds, respectively.
Hot Extremes

IPCC AR6 WG1, Figure SPM.3 | Synthesis of assessed observed change in hot extremes attributed to human contribution

‘Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes’

World-wide Increase in Climate Change Driven Extreme Heat since 1950s

Adapted from IPCC AR6 WG1, synthesis of assessment of observed change in extremes and confidence in human contribution to the observed changes in the world’s regions

Peter Carter, Climate Emergency Institute
(b) Synthesis of assessment of observed change in heavy precipitation attributed to human contribution
IPCC AR6 WG1, Figure SPM.3 Synthesis of assessment of observed change in agricultural and ecological drought attributable to human contribution
Climate Extremes

FAO state of World Food Security 2021
Food insecurity now affects over 30% of the world population.

FIGURE 4 MODERATE OR SEVERE FOOD INSECURITY HAS BEEN CLIMBING SLOWLY FOR SIX YEARS AND NOW AFFECTS MORE THAN 30 PERCENT OF THE WORLD POPULATION

Peter Carter,
Climate Emergency Institute
How climate change drives extreme events impact on crops

Increasing extreme weather is being driven by climate change and so will increase with global temperature increase. They have yield impact shocks, depending on severity, duration and combination of extreme events.

IPCC has Extreme Weather Events (that includes fires) as a single category of climate change impacts. It is the most damaging impact to people and crops - even more so on crop yields with labour intensive Africa and lower latitude food production.

Climate change crop impacts

- Extreme heat
- Wild fires
- Drought
- Powerful storms
- Heavy precipitation
- Floods
  - Water logged land
  - Soil erosion
  - Increased surface ozone

Global surface warming
- Increased water vapor
  - Lower atmosphere energized
- Surface ozone is increased by heat toxic to crops

MODELS Climate change crop yield models in climate change assessments do not capture the impact of extreme weather.

CLIMATE SHOCKS Extreme weather acts as production shocks, but if severe, widespread and long lasting (blocking phenomenon) can impact a regional harvest.
Killer heatwave grips Northern Hemisphere as temperature records broken from Canada to Oman
At least 54 people have died amid an extreme heatwave in the Canadian province of Quebec

Quasiresonant amplification of planetary waves and recent Northern Hemisphere weather extremes
Climate change driven disasters are increasing and will continue to increase with global surface temperature.

Source: The December 2021 Global Humanitarian Overview 2022, United Nations Office for the Coordination of Humanitarian Affairs (OCHA)
Increasing northern hemisphere land area affected by extreme heat and increasing extreme heat temperatures over time

IPCC 2021, AR6, WG1, Box 11.4, Figure 1: Analysis of the percentage of land area affected by temperature extremes larger than two (orange) or three (blue) standard deviations in June-July-August (JJA). These panels show for both estimates a substantial increase in the overall land area affected by very high hot extremes since 1990 onward.
Extreme Heat Will Affect Most Food Producing Regions
from AR6 WG1 interactive atlas

Crop extent and density

USGS Crop area and density 2017 (satellite data)
Extreme heat
1.5°C
Extreme heat

2°C
Extreme heat
3°C
Extreme Heat Will Affect Most Food Producing Regions

Extreme heat at 1.5°C, 2°C and 3°C from IPCC AR6 WG1 Interactive Atlas

+1.5°C (2030 /soon after) +2.0°C (2045) +3.0°C (by national emissions targets)

Studies have documented a large negative sensitivity of crop yields to extreme daytime temperatures around 30°C. These sensitivities have been identified for several crops and regions and exist throughout the growing season (high confidence)

IPCC, 2014, AR5 WG2, Ch.7
Food Security and Food Production Systems

Peter Carter, Climate Emergency Institute
Extreme heat affects major food producing regions at 1.5°C-2°C

Maximum of maximum temperature (TXx) global change °C, June-August relative, to 1850-1900

USGS Crop area and density 2017 (satellite data)
Extreme heat affects US food producing regions at 1.5°C-2°C

Maximum of maximum temperature (TXx) change °C June-August relative to 1850-1900

1.6°C of increasing severity

2.4°C

USGS Crop area and density 2017 (satellite data)
Days of temperatures above 35°C

‘Studies have documented a large negative sensitivity of crop yields to extreme daytime temperatures around 30°C.

These sensitivities have been identified for several crops and regions and exist throughout the growing season (high confidence)’

IPCC, 2014, AR5 WG2, Ch.7
Food Security and Food Production Systems
Heat stress temperatures to crops is projected in major food producing regions for an increasing number of days, from 1.5°

**Days of temperatures above 35°C**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Year</th>
<th>Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5°C</td>
<td>2030</td>
<td>now unavoidable</td>
</tr>
<tr>
<td>2°C</td>
<td>2045</td>
<td></td>
</tr>
<tr>
<td>3°C</td>
<td>2065</td>
<td>with COP26 failure &amp; current policies</td>
</tr>
</tbody>
</table>

Studies have documented a large negative sensitivity of crop yields to extreme daytime temperatures around 30°C. These sensitivities have been identified for several crops and regions and exist throughout the growing season (high confidence)

IPCC, 2014, AR5 WG2, Ch.7
Food Security and Food Production Systems

USGS Crop area and density 2017 (satellite data)

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Maximum Summer Temperatures above 35°C at global warming of 1.5°C

Number of days above crop intolerant temperature >35°C
Crop intolerance and decline at 30°C (IPCC)

- Crop yields have a large negative sensitivity to extreme daytime temperatures around 30°C (86°F), throughout the growing season (high confidence).

IPCC 2014 TS

CROPS
Affects
USA
South America
Spain
Saudi Arabia
Iraq
Iran
Pakistan
Turkey
The ...stans
All African regions
Thailand
Cambodia
Australia
Affected but less so
(Italy)
(Greece)
(China)
China ranks first in the world in terms of the production of cereals, cotton, fruit, vegetables, meat, poultry, eggs and fishery products. (FAO)
Heat Stress affects crops in US and Mexico food producing regions for an increasing number of days at and from 1.5°C. Canada’s grain belt is also stressed.

Canada's grain belt is also stressed.

1.5°C (2030)  

2.0°C (2045)

August 2021, IPCC AR6, WG1, Interactive Atlas

Peter Carter, Climate Emergency Institute
At 3°C of global warming almost all food producing regions have maximum high temperatures above 35°C for many days-long periods in USA and Mexico.
At 3°C of global warming almost all food producing regions have maximum high temperatures above 35°C for many days. Longest: USA and Mexico.
Toxic Surface Ozone

Formed from fossil fuel air pollutants

Also called tropospheric or ground level ozone

Toxic to humans and green plants, so crops

It is increased by heat

-so increased by heat waves
Chemical reaction
Fossil fuel air pollutants
Heat from the sun

Toxic Surface Ozone
Toxic to humans and green plants
Increased by heat

NOx + VOC + Heat & Sunlight = Ozone
Ground-level or "bad" ozone is not emitted directly into the air, but is created by chemical reactions between NOx and VOCs in the presence of heat & sunlight.

Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of oxides of nitrogen (NOx) and volatile organic compounds (VOC).
Toxic Surface Ozone
Toxic to humans and green plants
Increased by heat

Tropospheric/ground level ozone is toxic to green plants. This reduces CO2 uptake and so will feedback effect amplifying the global warming that causes it.

It is damaging to crops

Crop damage

Forest damage

Global warming increases ground level ozone

Fossil fuel air pollutants + solar heat
Tropospheric (surface or ground level) ozone is a toxic air pollutant, toxic to green plants including crops - as well the human respiratory tract.

Its level increases with surface temperature.

**Increasing Surface Ozone (mainly northern hemisphere)**

Aircraft observations since the 1990s reveal increases of tropospheric ozone at multiple locations across the Northern Hemisphere.

A. Gaudel et al, 21 August 2021
Surface ozone has increased mainly in the northern hemisphere with increasing air pollution and global surface warming.

Tropospheric (surface/ground level) Ozone Rapid Increase

Mainly the temperate northern hemisphere

Heat increase surface ozone, which is toxic to crops as well as human health.
1.5°C
2°C
Drought
Increasing world-wide drought from 1.5°C affecting major food producing regions

Simulated change at 1.5°C global warming

Simulated change at 2°C global warming

Soil moisture change

Drier

Change (standard deviation of interannual variability)

Wetter

USGS Crop area and density 2017 (satellite data)

CROPS

IPCC, 2021, AR6 WG1, SPM, Figure SPM.5

Changes in ...soil moisture
Soil Moisture Change at 1.5°C and 2°C

DROUGHT

1.5°C

2°C

(d) Annual mean total column soil moisture change (standard deviation)

USGS Crop area and density 2017 (satellite data)

IPCC, 2021, AR6 WG1, SPM, Figure SPM.5 | Changes in ...soil moisture
By 2040, the average proportion of global cropland affected by severe drought will likely rise to 32 per cent each year, more than three times higher than the historic average.

Climate change risk assessment 2021, Chatham House Royal Institute of International Affairs, Environment and Society Programme September 2021, Daniel Quiggin et al.
% Increases in drought at 2.4°C

**Figure 10a.** Proportion of global winter wheat crop area experiencing damaging hot spells

**Figure 10b.** Proportion of global rice crop area experiencing damaging hot spells

Source: Adapted from Arnell et al. (2019).

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Climate change risk assessment 2021, Chatham House Royal Institute of International Affairs, Environment and Society Programme September 2021, Daniel Quiggin et al
% Increases in drought at 2.4°C

Figure 12. Proportion of continental cropland experiencing severe drought of three months or more at 2.4°C.

Source: Adapted from Arnell et al. (2019).
Proportion of regional cropland exposed to severe drought, in 2050

Figure 9b. Proportion of regional cropland exposed to severe drought, in 2050

CROPS

USGS Crop area and density 2017 (satellite data)

Source: Adapted from Arnell et al. (2019).
Extreme Rainfall
Floods
Almost all countries affected at 2°C

Damaging to crops and agricultural land

IPCC AR6 WG1
River Flooding

IPCC, 2018 1.5°C Report
Compound extreme events

*Interacting and Cascading Risks*

1.5°C

2°C

IPCC, 2018, 1.5°C Report

USGS Crop area and density 2017 (satellite data)
Compound extreme events

*Interacting and Cascading Risks*

1.5°C

USA

China

2°C

USA

China

IPCC, 2018, 1.5°C Report, Figure 3.19 | Multi-sector risk maps for 1.5°C and 2°C

USGS Crop area and density 2017 (satellite data)
CONCLUSION

The world today is in a state of world food insecurity emergency due to impacts at already committed degrees of climate change at 1.5°C to 2°C

The world’s food producing regions are impacted substantially by multiple extreme weather events at 1.5°C increasing to 2°C

This includes compound extreme events

Increased surface ozone is an added adverse effect of high temperatures and heat waves, particularly the temperate northern hemisphere

These impacts affect the industrialized northern hemisphere as well as the south
This includes top world food producing countries, USA and China

Africa is impacted by far the worst

These impact on top of world agriculture systems at breaking, and also on top increasing linear impacts of global climate change on food production
The world today is in a world food
The climate change background of increasing extreme events
CMIP6 - Total precipitation (PR) Change % - Warming 2°C SSP5-8.5 (rel. to 1850-1900) - June to August (33 models)
Crop yields are very sensitive to temperature and rainfall. They are especially sensitive to high temperatures during the pollination and grain filling period. For example, corn (left) and soybean (right) harvests in Illinois and Indiana, two major producers, were lower in years with average maximum summer (June, July, and August) temperatures higher than the average from 1980 to 2007. Most years with below-average yields are both warmer and drier than normal. There is high correlation between warm and dry conditions during Midwest summers due to similar meteorological conditions and drought-caused changes.
Increasing US crop yield decline with increase of global warming above 1.5°C

Unpacking the climatic drivers of US agricultural yields, 2019

1.6°C: unavoidable,
2.4°C: requires immediate rapid emissions decline
2.8°C: national emissions policies projection

Unpacking the climatic drivers of US agricultural yields, A. Ortiz-Bobea, H, Wang, Carrillo and T. Ault, 29 April 2019

Figure 4. Climate change impact projections on United States crop yields. Each dot represents a particular GCM in CMIP5 for the end of the century (2050–2100). Vertical lines around each dot represents the 95% confidence. The horizontal solid black line and the colored bands correspond to the mean and ± two standard deviation of each ensemble, respectively. Climate change scenarios are increasingly severe from RCP 2.6–8.5. Traditional model with constant intra-seasonal effects of precipitation and temperature.
“Anthropogenic climate change has reduced global agricultural TFP by about 21% since 1961, a slowdown that is equivalent to losing the last 9 years of productivity growth.

The effect is substantially more severe (a reduction of ~30-33%) in warmer regions such as Africa and Latin America and the Caribbean.

We also find that global agriculture has grown more vulnerable to ongoing climate change.”
IPCC 2019 Land Report, food Prices under climate change

IPCC 2019 Land Report Figure 5.14 | Regional impacts of climate change on food price in 2050 under different socio-economic scenarios (SSP1, SSP2 and SSP3) based on AgMIP Global Economic Model analysis.