ATM S 111: Global Warming Ecosystems & Agriculture

Jennifer Fletcher
Day 20: July 20 2010

Potential Benefits of Global Warming to Crops

- Adding CO_2 will increase growth
  - However, this seems to help trees more than crops.
  - And plants need extra nitrogen to be able to take advantage of the extra CO_2.
- Global warming is expected to increase nighttime temperatures more than daytime (why?). This will lengthen the growing season in middle and high latitudes.
- Fewer frosts, especially in western North America and Europe.
- Gains in output and resulting GDP are likely to be greatest for North America and former Soviet Union. Much of this will be from increases in cereals.

Potential Drawbacks of Global Warming to Crops

- Large losses expected in the tropics and subtropics, where most of the world's food is grown.
- Partly due to drought/flooding, but temperature is even more important. Intense heat reduces yield for important staples such as groundnut, wheat, and rice.
- Adaptation is key to reducing the harm caused by global warming, but many of the potentially hardest-hit countries are poor.

Climate Change and Global Food Security

Courtesy of David Battisti, UW Atmospheric Sciences

1. Where do the Food Insecure live? What do they eat?
2. Projections of climate at the end of the 21st Century
3. Climate Change and crop yields
4. Impact on Tropical Ecosystems
5. Summary

David Battisti in Indonesia talking to farmers

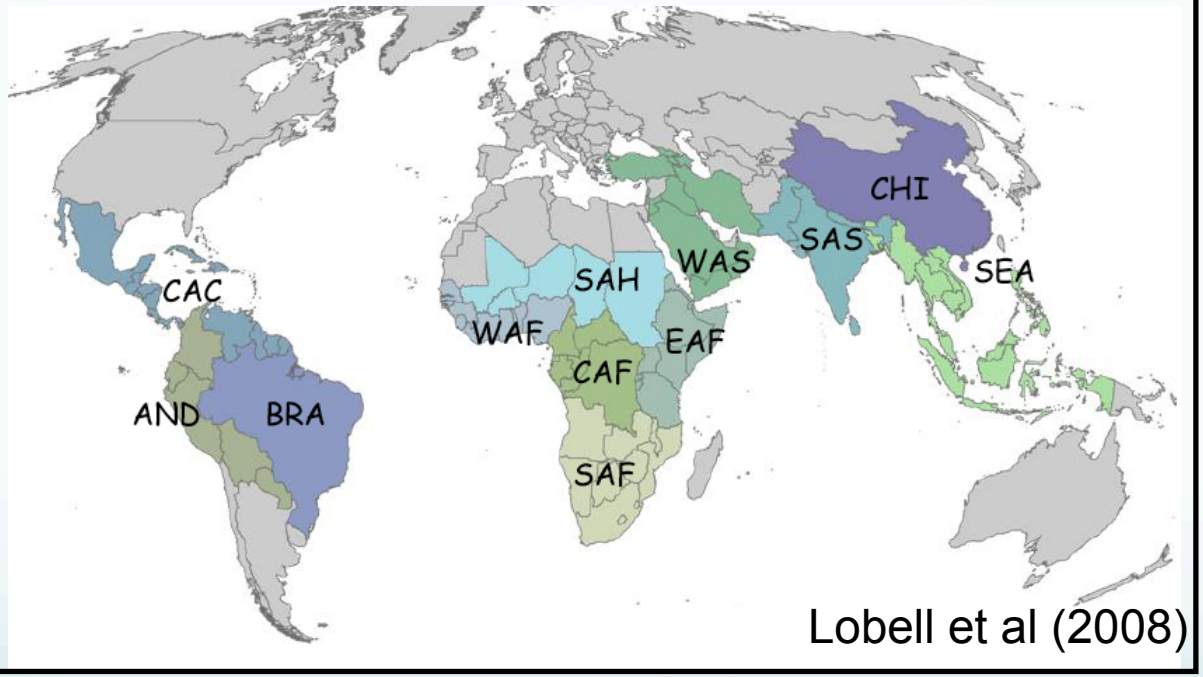
Work is with R. Naylor[1], D. Vimont[2], W. Falcon[1] and M. Burke[1]

(1) Stanford, (2) University of Wisconsin

Where do Food Insecure People live?

800 M people are malnourished today

- 95% are in the tropics/subtropics

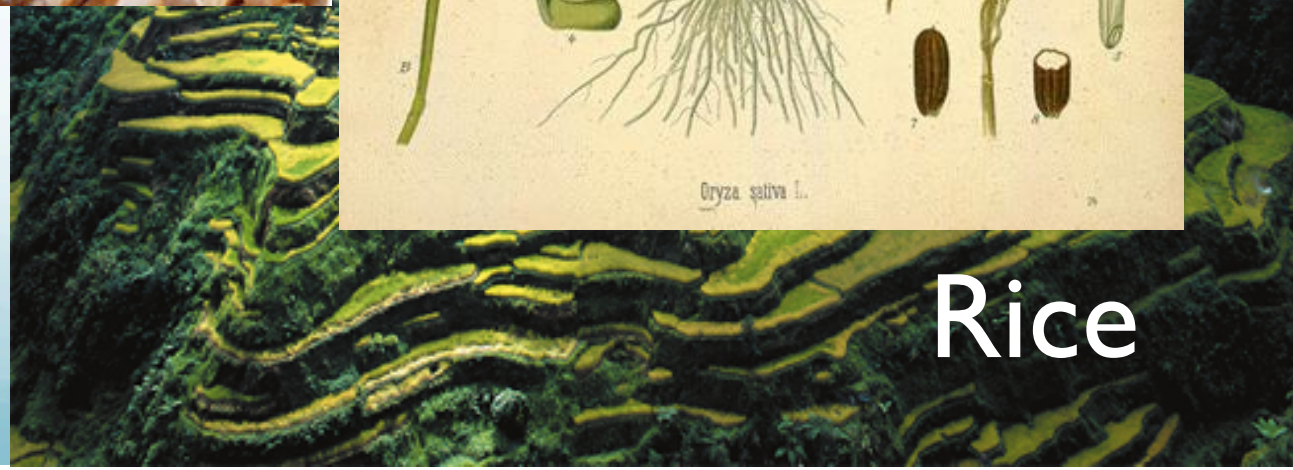


Lobell et al (2008)

The food insecure are also the poor. They depend heavily on agriculture for both food and income.

What do Food Insecure People eat?

- Rice (26%)
- Wheat (17%)
- Sugar Cane (8%)
- Maize (6%)
- Nuts (5%)
- Cassava (Yuca) (4%)
- *Other* (34%)



Rice

Wheat

Maize (corn)

Cassava (Yuca)


Climate Change and Global Food Security
Climate Change and crop yields

The 1998-2001 drought in the Middle East

~ 30% annual mean precip deficit

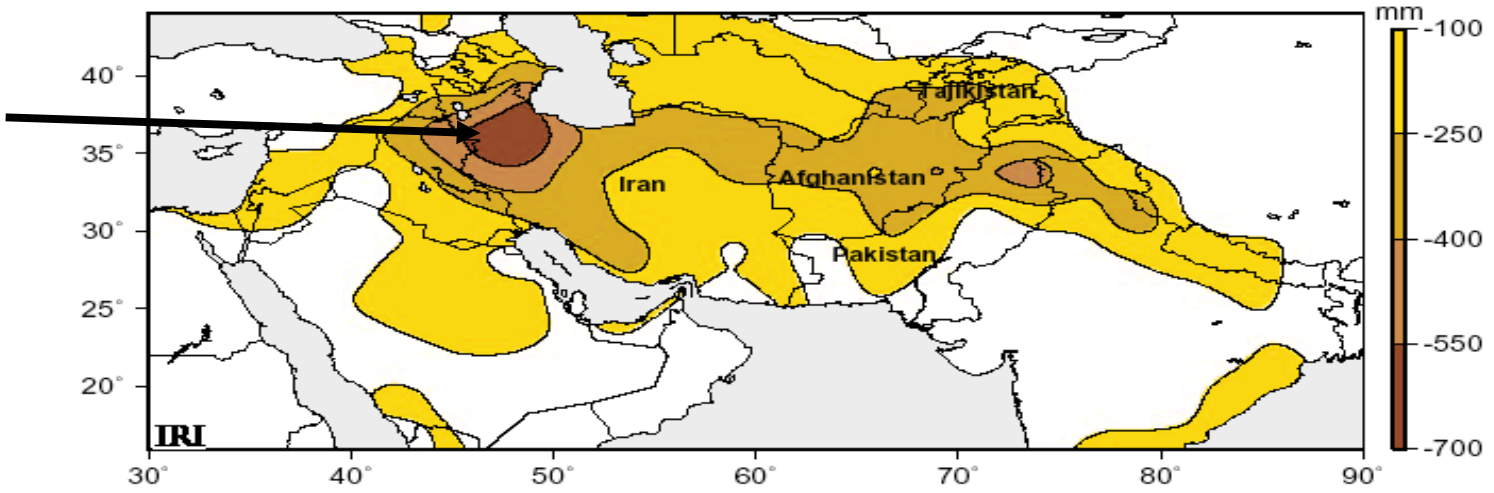


Figure 2. *Regional Drought Situation: Deficit in precipitation totaled over 1998-2001.*

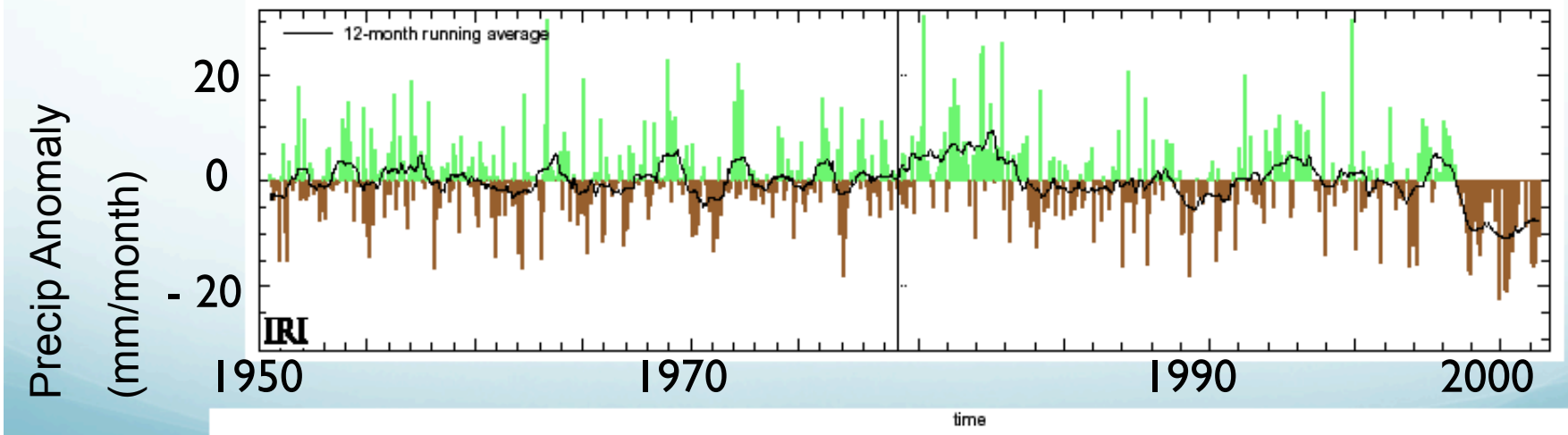


Figure 6. *Precipitation Anomalies: Monthly precipitation departures from the historical average over Central and Southwest Asia (over 25N-42N; 42E-70E), from Jan.1950 - Sep. 2001.*

The 1998-2001 drought in the Middle East

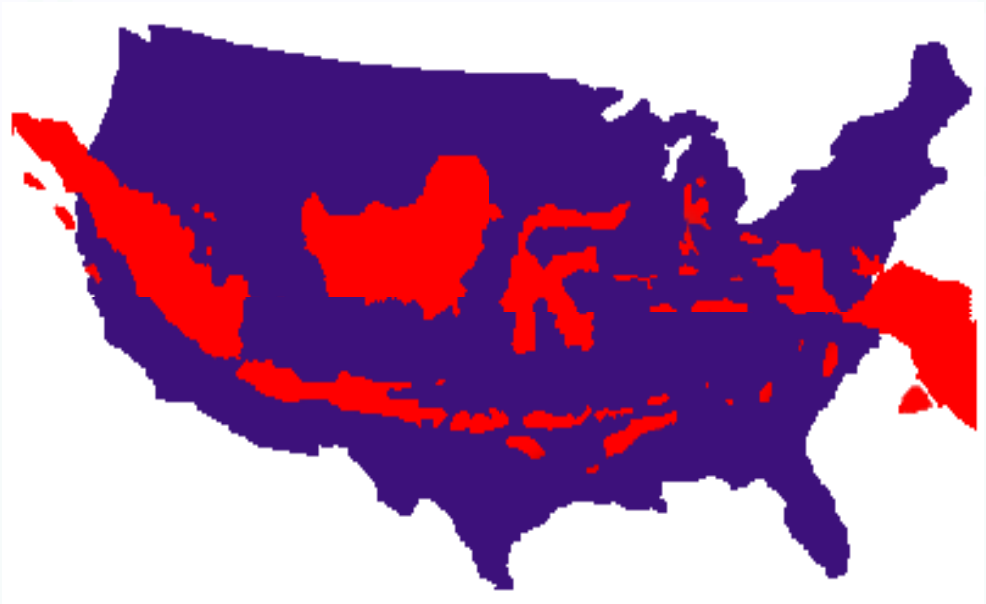
- Iran: 80% of livestock lost
  35 - 75% reduction in wheat & barley
- Afghanistan: 40% of livestock lost
- Pakistan: 50% of livestock lost
- Tajikistan: 50% of grain crop lost

By the end of the century, similar *water* stress on agriculture will be the norm throughout the tropics and subtropics due to the *climate changes* associated with increasing CO_2.

Last Time: Global Warming Impacts on Agriculture

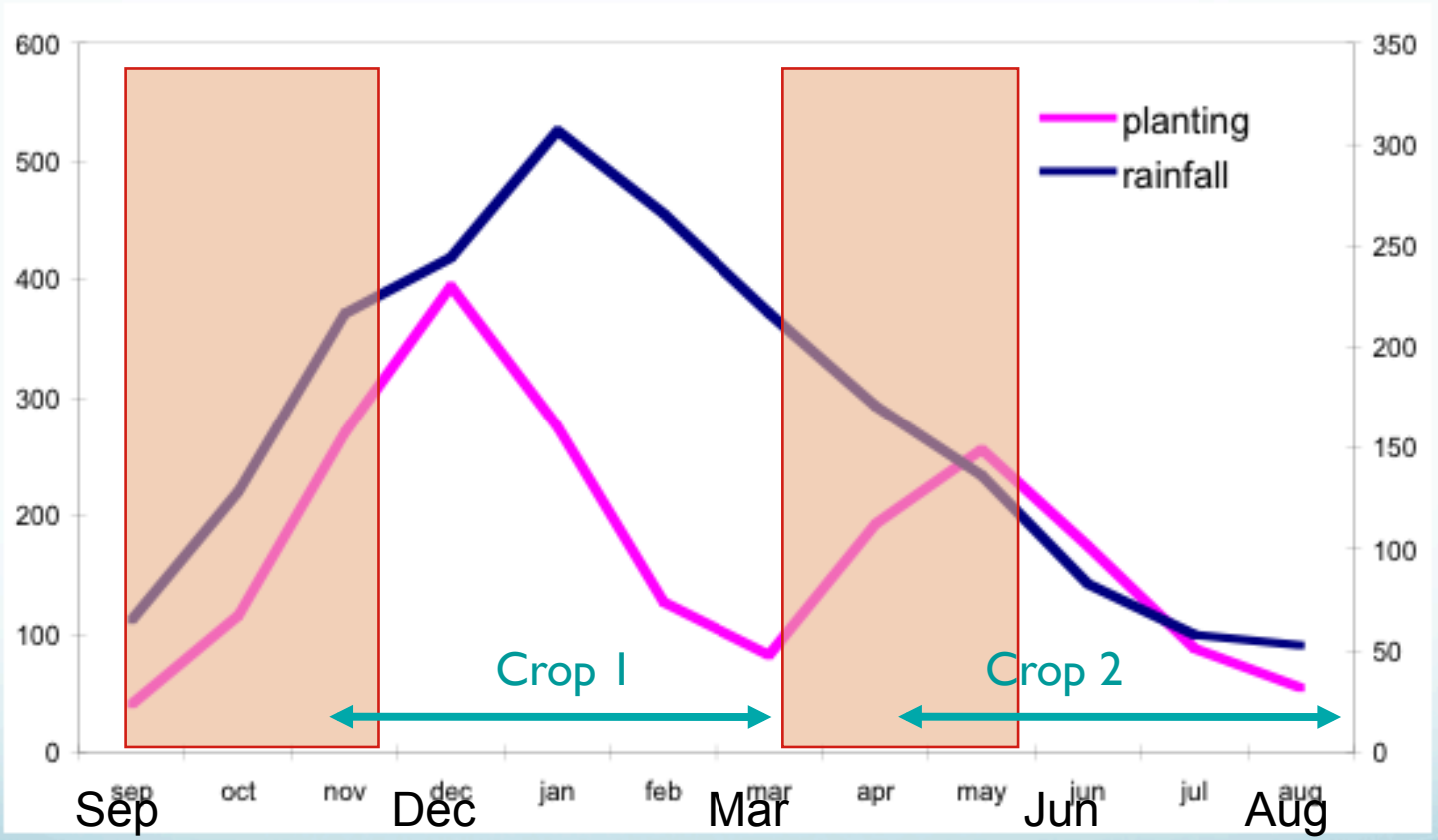
- Benefits:
  - Increased CO_2 could give some crops a boost, if there's enough nitrogen in the soil.
  - Longer growing season will likely help northern countries the most and is expected to increase production of cereals in North America and the former Soviet Union.
- Drawbacks
  - Droughts/floods in subtropics and tropics, where most food is grown, will likely reduce output.
  - Increased temperatures at least as harmful as changes in precipitation.
- Drought in Middle East, 1998-2001:
  - Major impact on grain and livestock production in Iran, Tajikistan, Afghanistan, and Pakistan.

Facts about Indonesia



- About 240M people (fourth in world)
- 50% of the population in agriculture; 17% in poverty
- *Rice* is the staple crop in Indonesia:
  - Two crops per year, depending on rainfall
  - Mostly irrigated by run-of-the-river

Indonesian Rice and rainfall



Indonesia and Rice Today

- A late onset of the monsoon season
  - Delays the first planting (lengthens the hungry season)
- El Niño greatly affects annual rice production by delaying monsoon onset
- The typical El Niño event delays onset by ~30 days
  - reduces total *annual* rice production by 1,000,000 metric tons (enough to feed 15M people for a year)
  - Impact is non-linear (threshold)
  - Increases domestic and traded rice prices
- Forecasts of rice production supplied by Battisti's team since 2001

Projecting rainfall in Java/Bali in 2050

- How will the annual cycle of rainfall over Java/Bali change with global warming?
  - Will a 30-day monsoon delay occur more frequently in the future?

- How will the impact of El Niño-based variability on rice production change in the future with global warming?

Climate Change and Global Food Security

Projections of climate at the end of the 21st Century (from IPCC)

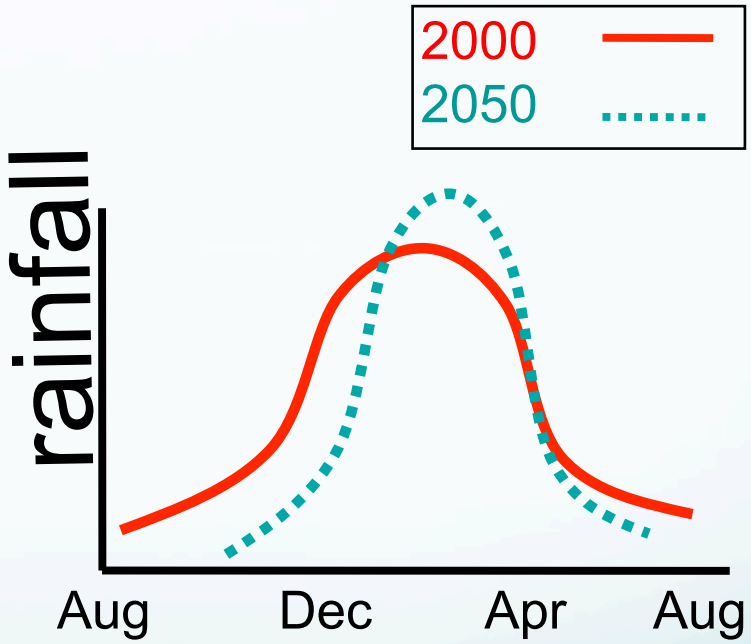
- Focus on those changes that are “very likely” (i.e., those that are either deemed to have a greater than 90% chance to occur “based on quantitative analysis or an elicitation of the expert views”)

Projecting rainfall in Java/Bali in 2050

- Use the output from climate models with two emissions scenarios
  - A2: relatively **high** greenhouse gas emissions
  - B1: **low** emissions, sustainable development
- Estimate the precipitation associated with the new climate patterns from these models.
- *Provides full range of projections to determine the uncertainty*

Findings: Java/Bali rainfall in 2050

- The monsoon rains will start 1-2 weeks later
- Rainfall will increase during the monsoon season
- The monsoon will end abruptly and the dry season will be drier

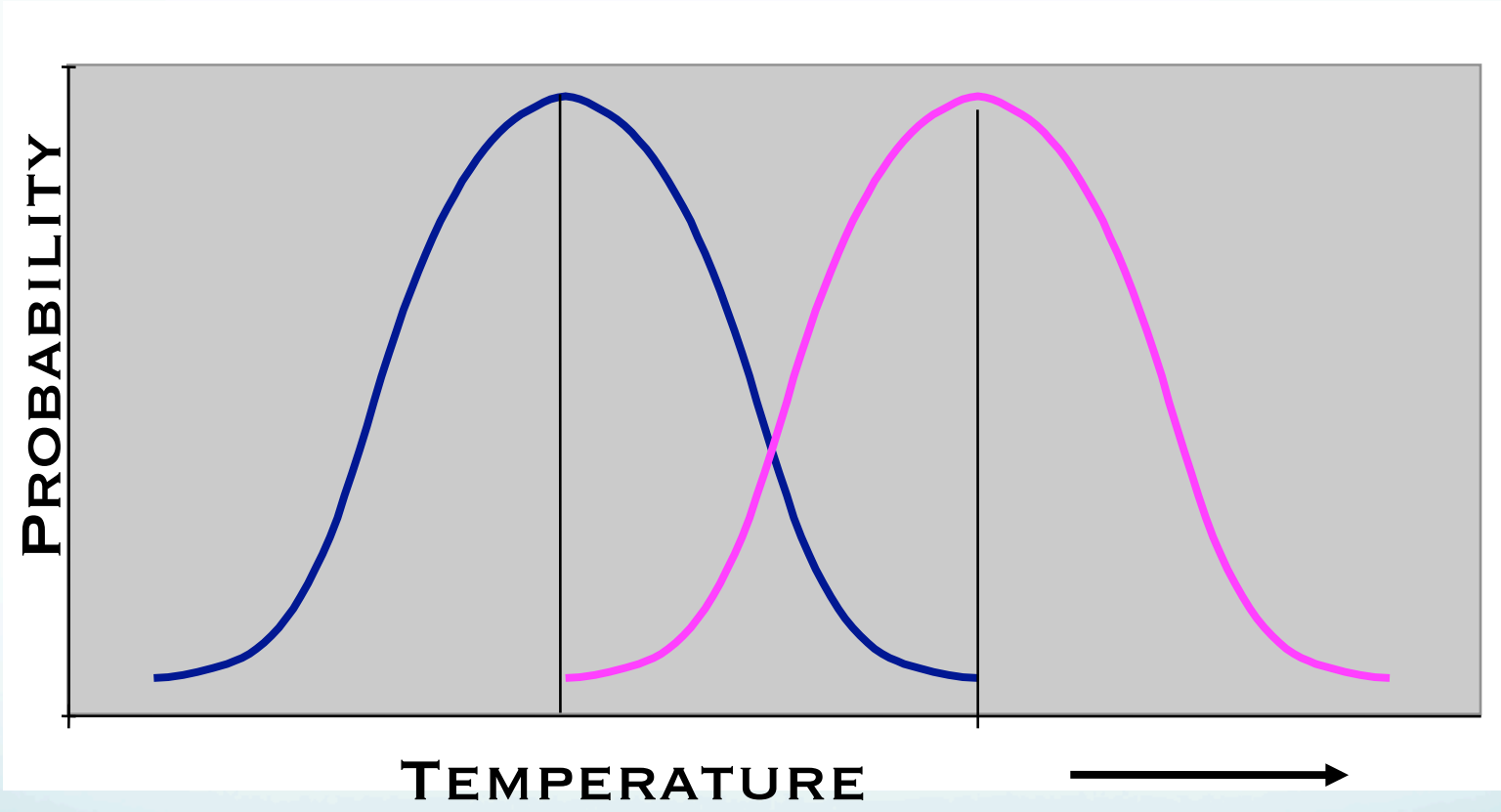


*Net impact: By 2050, the second season rice crop is marginal (**too short for two crops**) & highly vulnerable*

Next: Effect of Temperature Increase

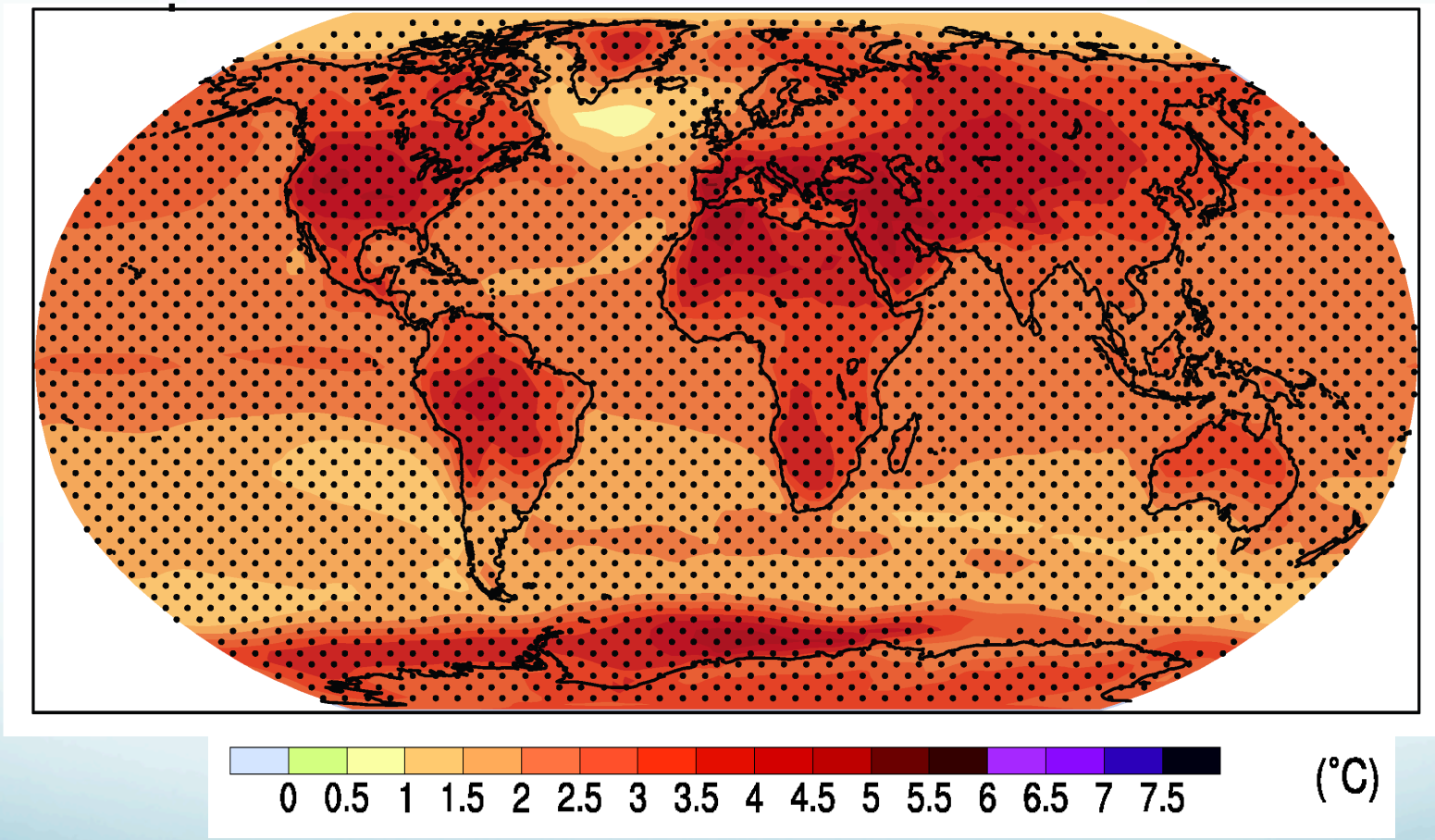
- Indonesia case is classic example of how **precipitation** affects food production
- Next we'll show a case where **temperature** affects food production

Projections of future temperature



"Shifting the distribution": remember this?

Projected Jun-Aug Average Surface Temperature Change: “2080-2099” minus “1980-1999”



Average of 21 climate models forced by Scenario A1B. Multiply by ~1.2 for A2 and ~0.66 for B1

Extreme Heat in Western Europe in 2003: JJA temperature 3.6°C above normal

- Italy: 36% maize reduction
- France: 30% maize and fodder (animal feed) reduction

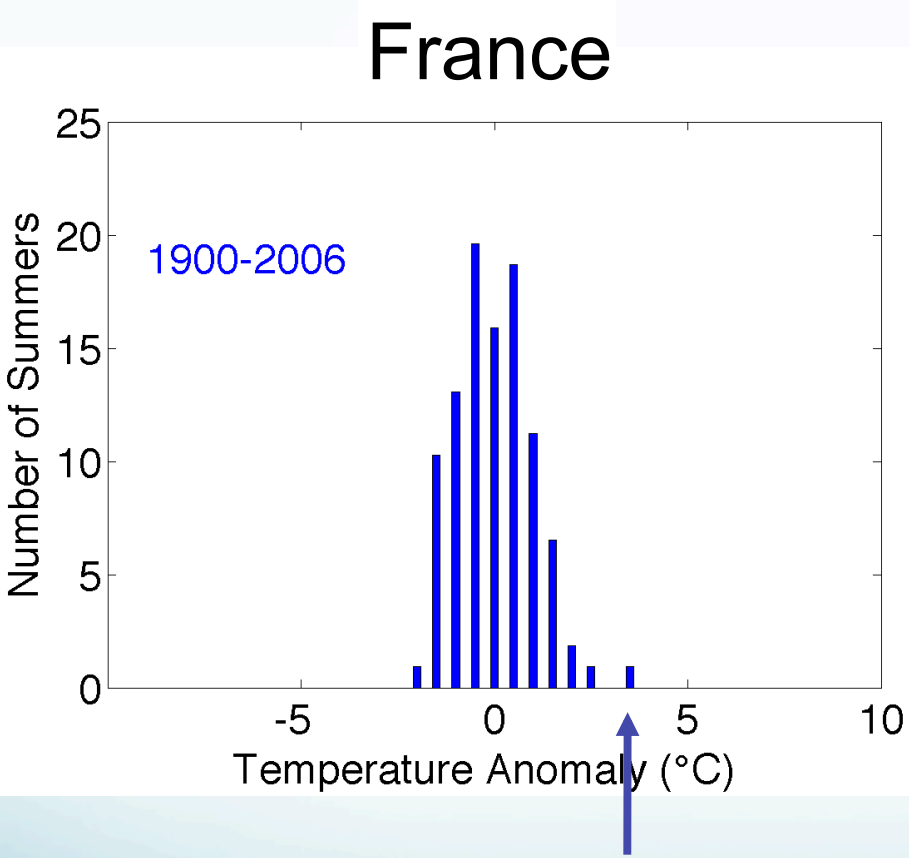
  25% fruit reduction

  21% wheat reduction

By 2100, years of similar *temperature* stress on agriculture will be the norm throughout the tropics and subtropics due to the summer *average* temperature changes.

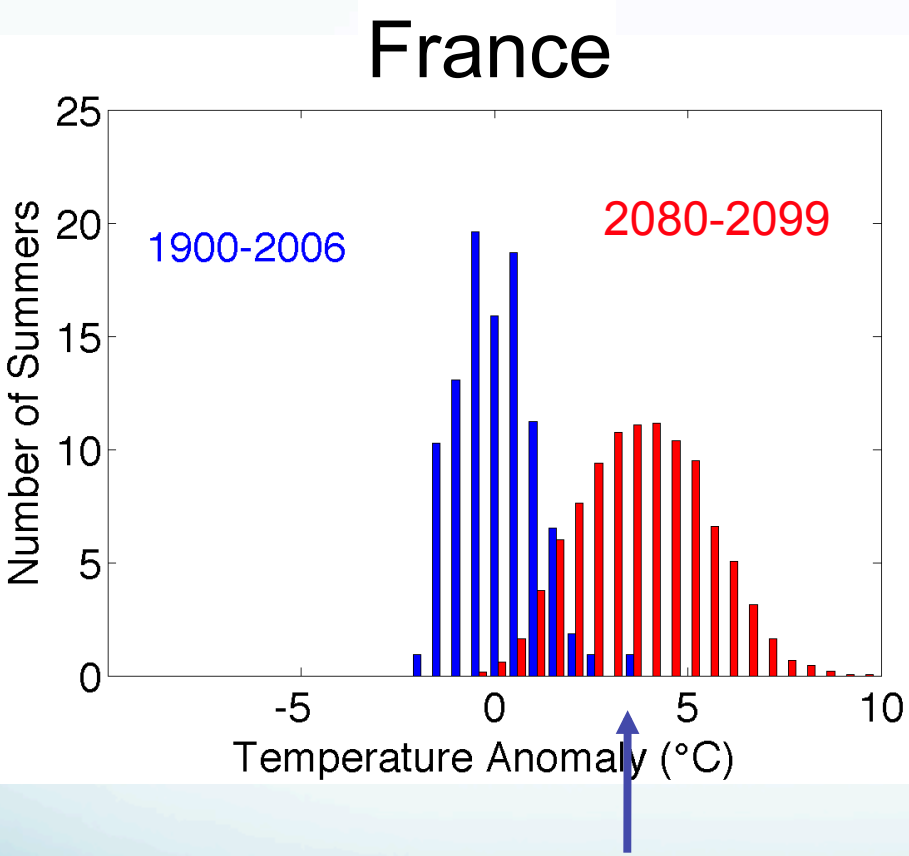
Refs: UNEP 2007; Easterling 2007; Earth Policy Institute 2006; Eurosurveillence 2005

Growing Season Temperature



Observed JJA Temp
(1900-2007)

Growing Season Temperature

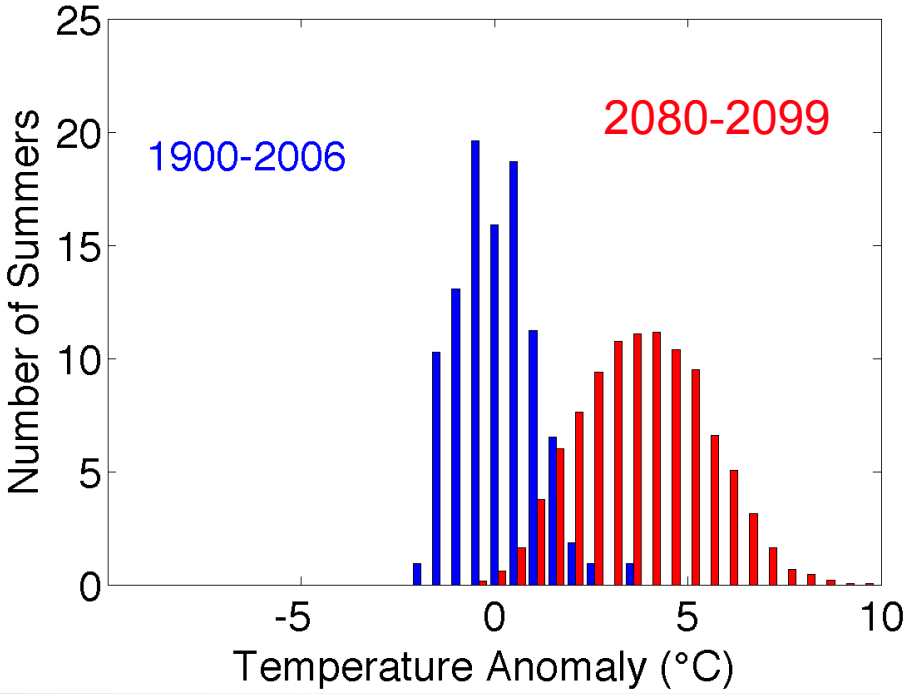


Observed JJA Temp
(1900-2007)

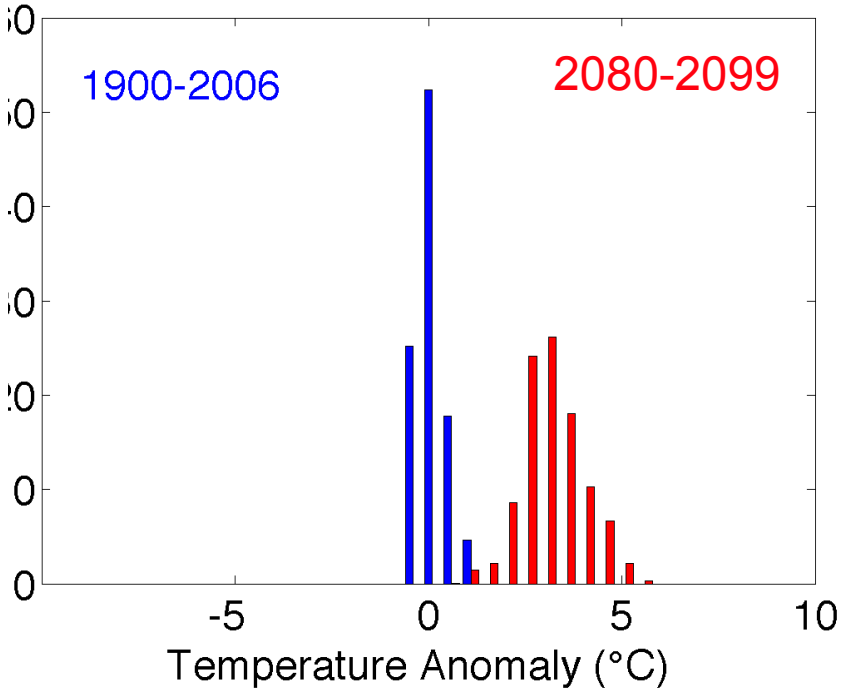
Projections use 22 climate models (IPCC AR4) forced by A1B Emission scenario. Variability taken from observations

Projections of Growing Season Temperature

France



The Sahel

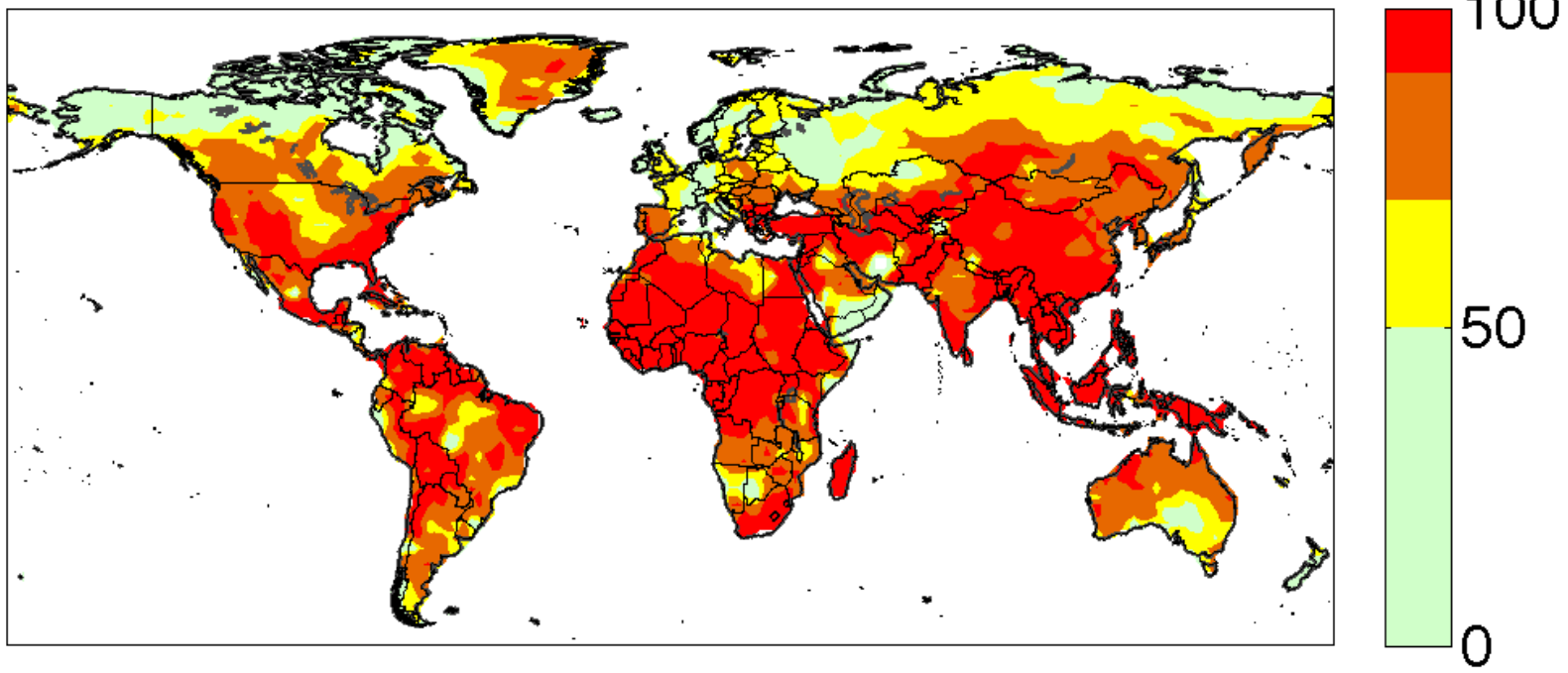


Extremes like 2003 are the norm

Every year exceeds extremes of past (mainly due to smaller variability)

Projections of Growing Season Temperature

Summers from 2080-2099 warmer than warmest on record %



By the end of the 21st Century it will be much hotter everywhere

In most of the tropics/subtropics, the seasonal average temperature will very likely exceed the warmest year on record

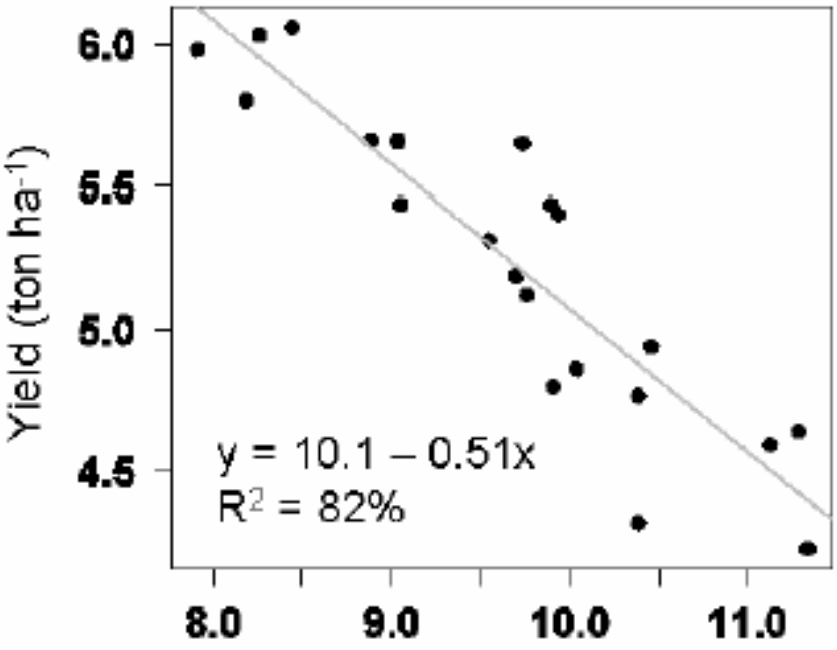
Impacts of Climate Change on Food Security

Increasing temperature over the next 50 years will cause decreases in yield:

- Decrease in grain filling
- Decrease in spikelet fertility (not as many seeds formed)
- Increased water stress
- Increased respiration

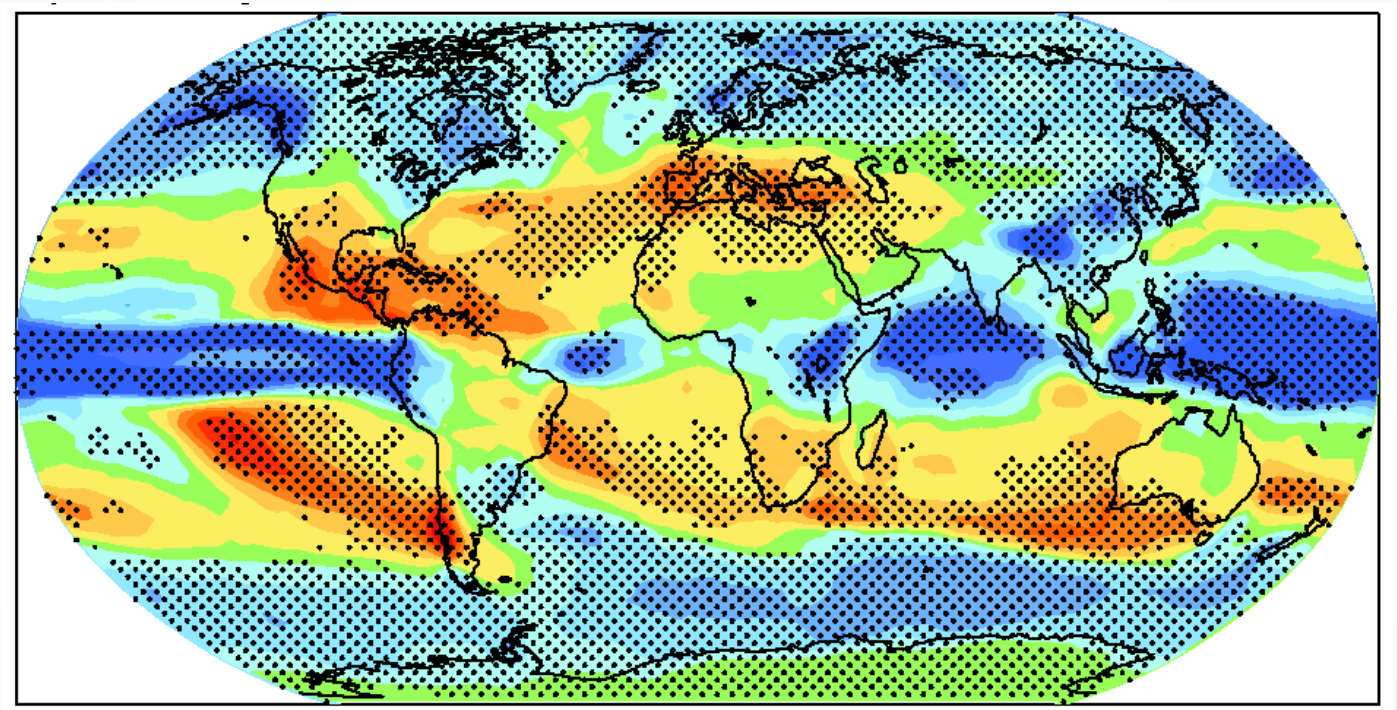
Important for all crops, but especially for wheat, rice, soybeans and maize

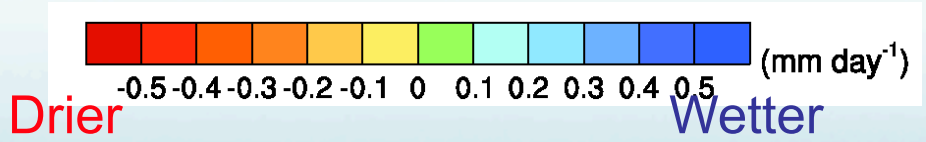
Wheat Yield in Yaqui Valley, MX



Lobell 2007

Projected Annual Average Precipitation: "2080-2099" minus "1980-1999"





Scenario A1B

There is a *robust* drying of the subtropics, 20-35N&S.

Stippling is where the multimodel average change exceeds the standard deviation of the models

Impacts of Climate Change

- Reduced yields of wheat, rice, maize, and soybeans in the tropics/subtropics
  - Approximately -10% for each degree warming
  - Estimated reduction of 30-40% by 2100 in India, Africa, Middle East, Central America, etc
- Reduced nutritional content (especially in wheat and rice)
- Increased disease transmission rates

Indirect Effects

- Changes in pests and pathogens (yet unknown)
- Increased CO2 and plants
  - **Enhanced** growth rates for some plants (benefits are limited to extratropics and they will reach a threshold though)

Summary

- By 2100, growing season temperatures will *very likely* exceed the warmest on record throughout the tropics and subtropics
  - ➡ 20-40% reduction in yields of major crops

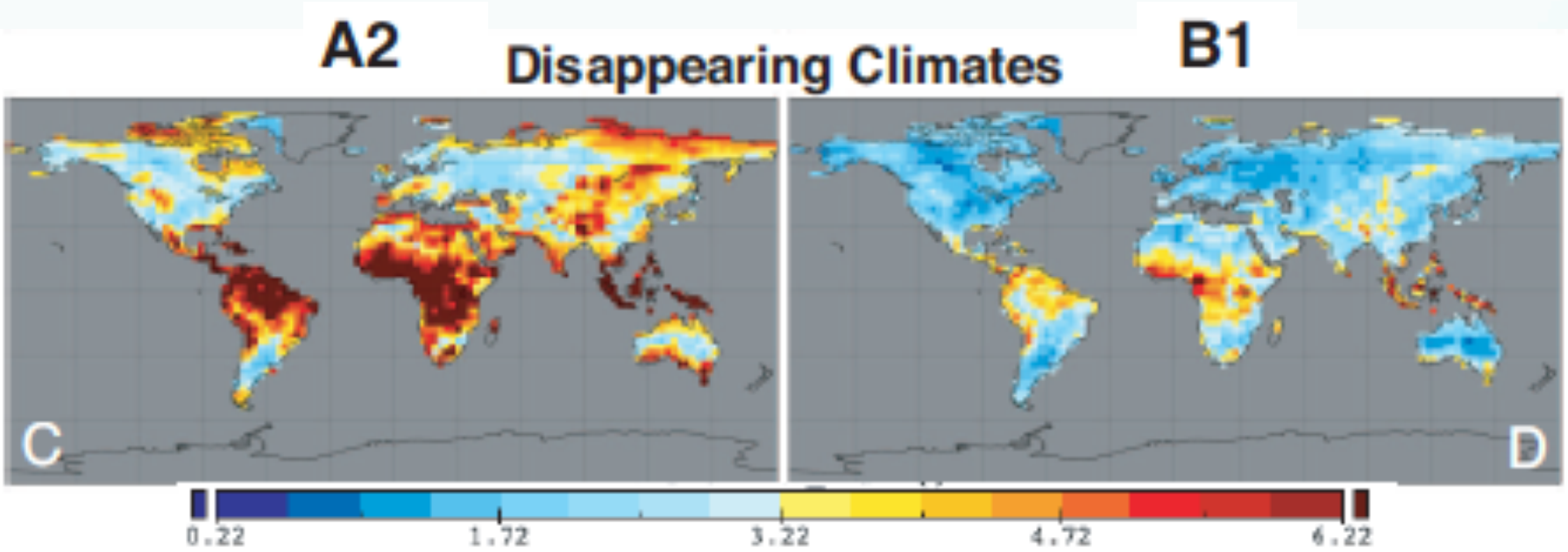
- In subtropics, crops will be further stressed by reduced rainfall
- Increased CO_2 (fertilization) effect is small when nitrogen limitation and ozone increase are taken into account

Now: impacts on ecosystems

- What species and ecosystems are most vulnerable?
- What species will benefit?
- How will life adapt to climate change?

Shifting Climate Zones

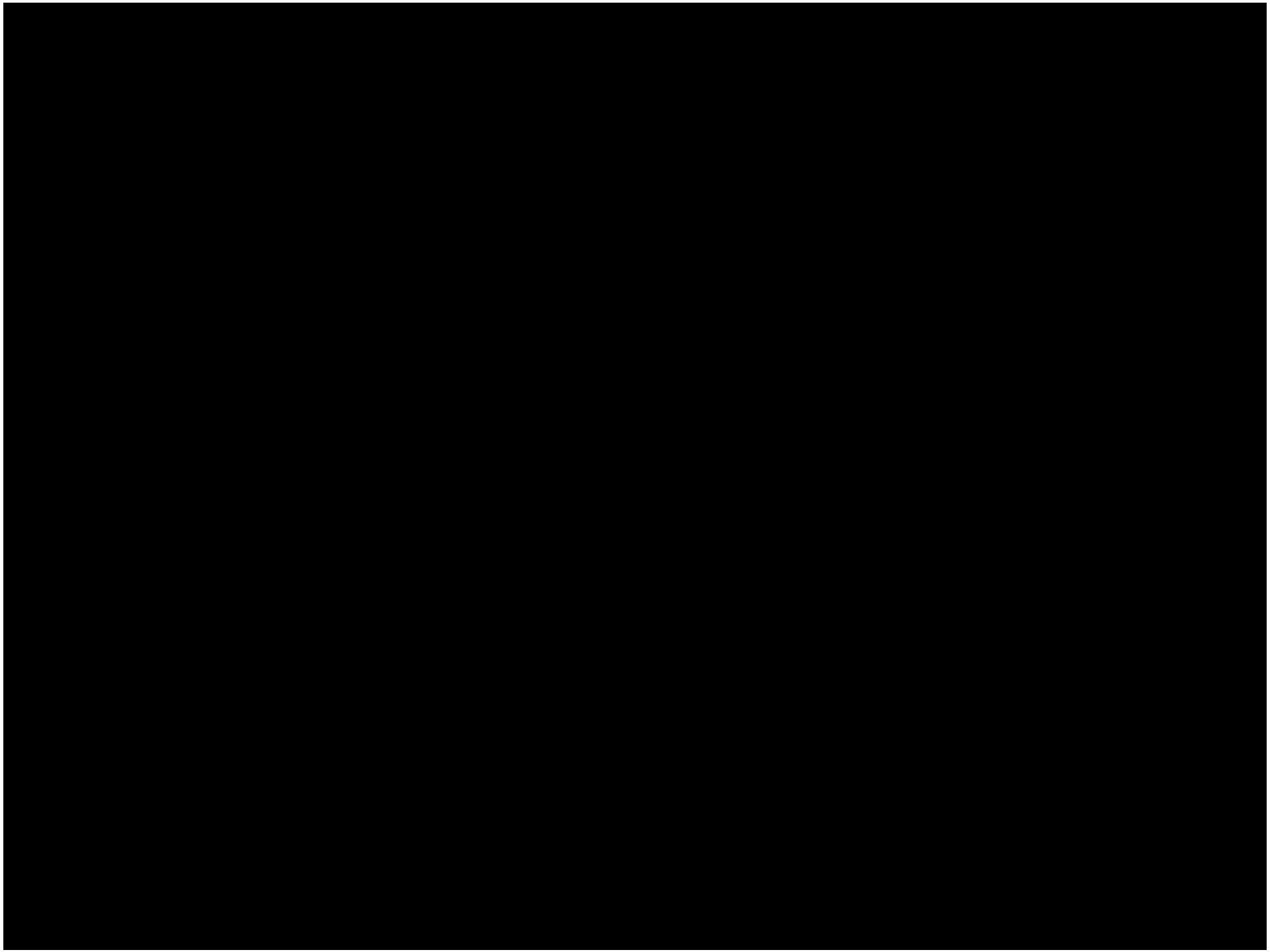
- Williams et al, 2007: study using a range of climate models. Map shows how different the climate (in temperature and precipitation) will be by 2100 under two different emissions scenarios.
- What is measured is how different the 2100 climate in a location is from the climate anywhere within 500 km of it in 2000.
- Warmer colors = more difference.



Predicting Extinction

- Hard to do, even without uncertainty in climate change projections!
- Expectations based on climate model projections (Thomas et al, 2004):
  - Looks at how climate zones will have shifted by 2100.
  - If climate zones disappear entirely, species that can only live in those zones are expected to go extinct.
  - If climate zones move, likelihood of extinction is estimated based on individual species' ability to migrate.
  - Estimate that 15%-37% of the 1130 species considered will go extinct by 2100.
- Geologic record indicates that previous climate change – even gradual change – has led to mass extinctions, followed (millions of years later) by *increases* in biodiversity.

American Pika: A Vulnerable Species

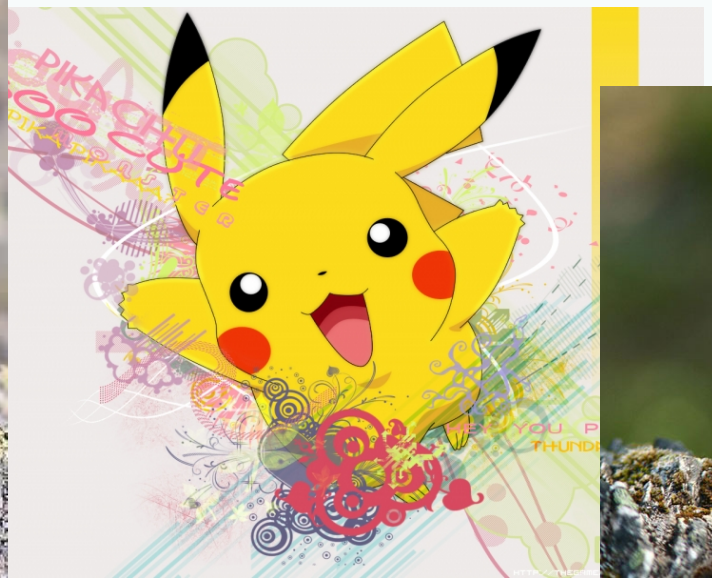


American Pika

- Lives in mountains in western US/Canada
  - Makes a distinctive whistling noise
  - Dense fur, well-suited to cold temperatures

Pikas and Global Warming

- Pikas can get heat stroke & die after brief exposure in temperatures above 78 F
  - Heat can lead to less time for foraging in addition to direct harm
  - Also lack of insulating snow in the winter can be harmful



Pikas and Global Warming

- Local extinctions have occurred in several populations in the US already
  - They live essentially on high-altitude islands of colder temperatures
  - Migration to higher altitudes or more northern locations is not always possible

Other Vulnerable Species Worldwide

- Amphibians & reptiles
  - Cold-blooded and close to ground lead to vulnerabilities
  - Many frog species are disappearing – climate change may help deadly fungi, and drought dries out the shallow ponds they need to spawn.
  - Diseases spreading more easily due to climate has been implicated in some extinctions.
  - Often fragmentation of ecosystems, pollutants are to blame for unhealthy populations
- Butterflies
  - Some species are climbing to higher elevations to escape heat.
  - Drought and flooding can kill them too.

“Disrupted Synchrony”

- Disrupted synchrony is when things used to happen at the same time, but are shifting. This is because some species do things when the temperatures get warm or cool enough, while other species use changes in sunlight as their cue to breed or migrate.
  - Ex 1: Caterpillars hatching earlier. Bird no longer hatches at same time that caterpillars are out, so birds go hungry.
  - Ex 2: Plantains in California are dying off earlier due to heat. Caterpillars/butterflies can’t use these as foods.

What species will benefit?

- Species that like warm temperatures (like fire ants!) will be less likely to see their habitat disappear from Earth entirely.
- Species that are adaptable to a range of environments may thrive in the place of more sensitive species.
- Some of these might be familiar invasive species, such as the Russian thistle (tumbleweed).

Insects & Forests

- Bark beetle:
  - Spreading across North America due to warmer winters & increased drought
  - Killed 7 million acres of forest in US, 34 million in Canada.
  - Montana, Wyoming, Colorado, and British Columbia pine forests particularly hard-hit
  - Often attack already weakened trees
  - Bad for ecosystems and timber industry

Red trees are damaged by fungus carried by bugs

Parasitic Diseases

- Many will likely increase with warmer and moister climates.
- Malaria: carried by mosquitoes
  - Cold weather kills mosquitoes. They thrive in warm conditions.
  - Malaria is spreading into regions of African highlands not previously seen.
  - However, there is not conclusive evidence that this is due to global warming.
  - Short-term variations in rainfall are also very important (mosquitoes lay their eggs in water).
  - More people are moving to the Central African Highlands as well.

Summary

- Global warming will lead to shifts in climate zones, with some zones possibly disappearing and new ones emerging.
- Species will need to adapt or migrate in order to survive.
- Although many species are currently going extinct, global warming isn't always to blame.
- As warming accelerates, more species are likely to go extinct or migrate to new regions, following their climate zone.