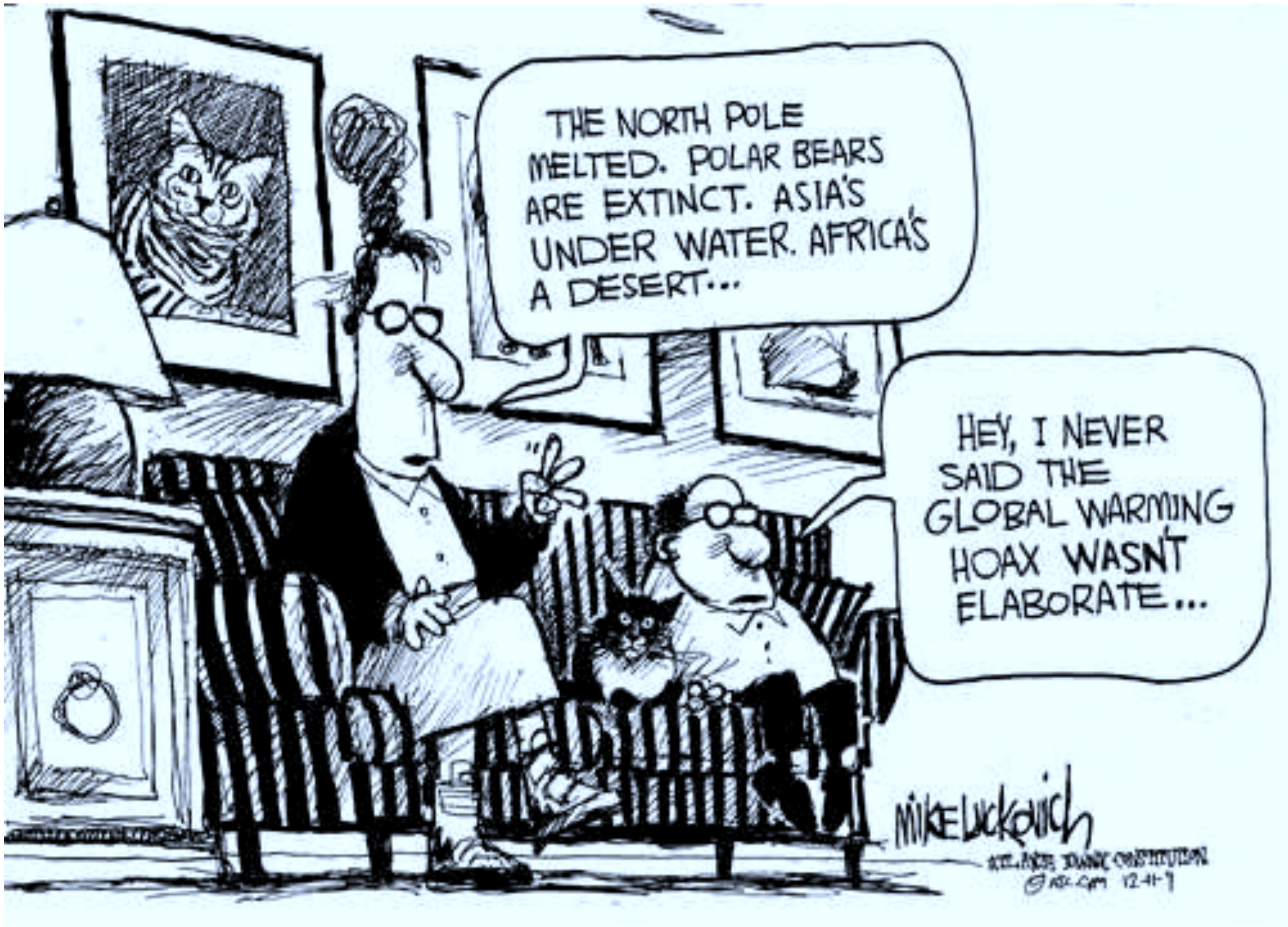
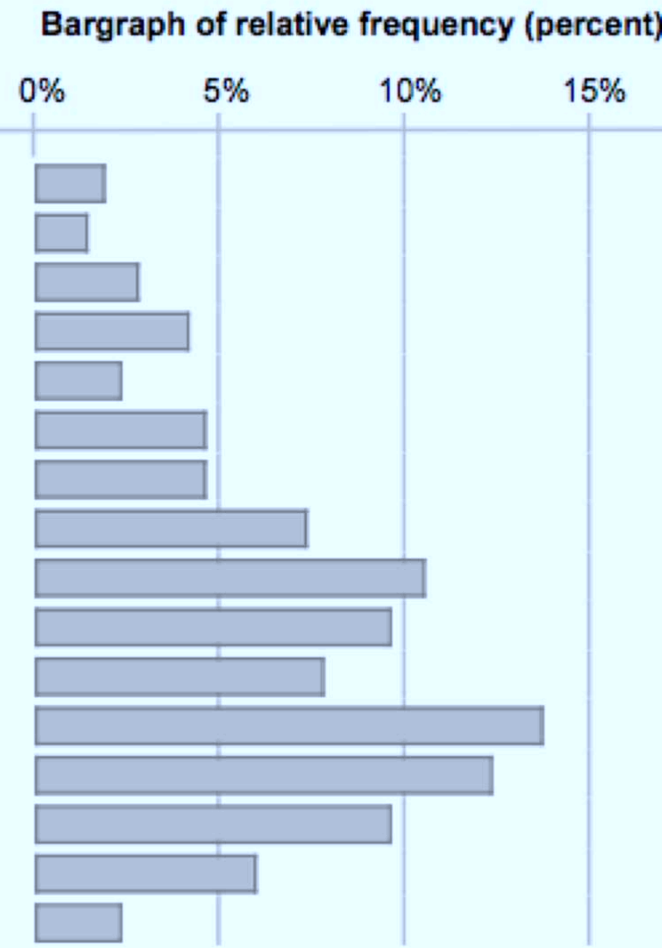
Welcome to ATMS 111 Global Warming

http://www.atmos.washington.edu/2010Q1/111



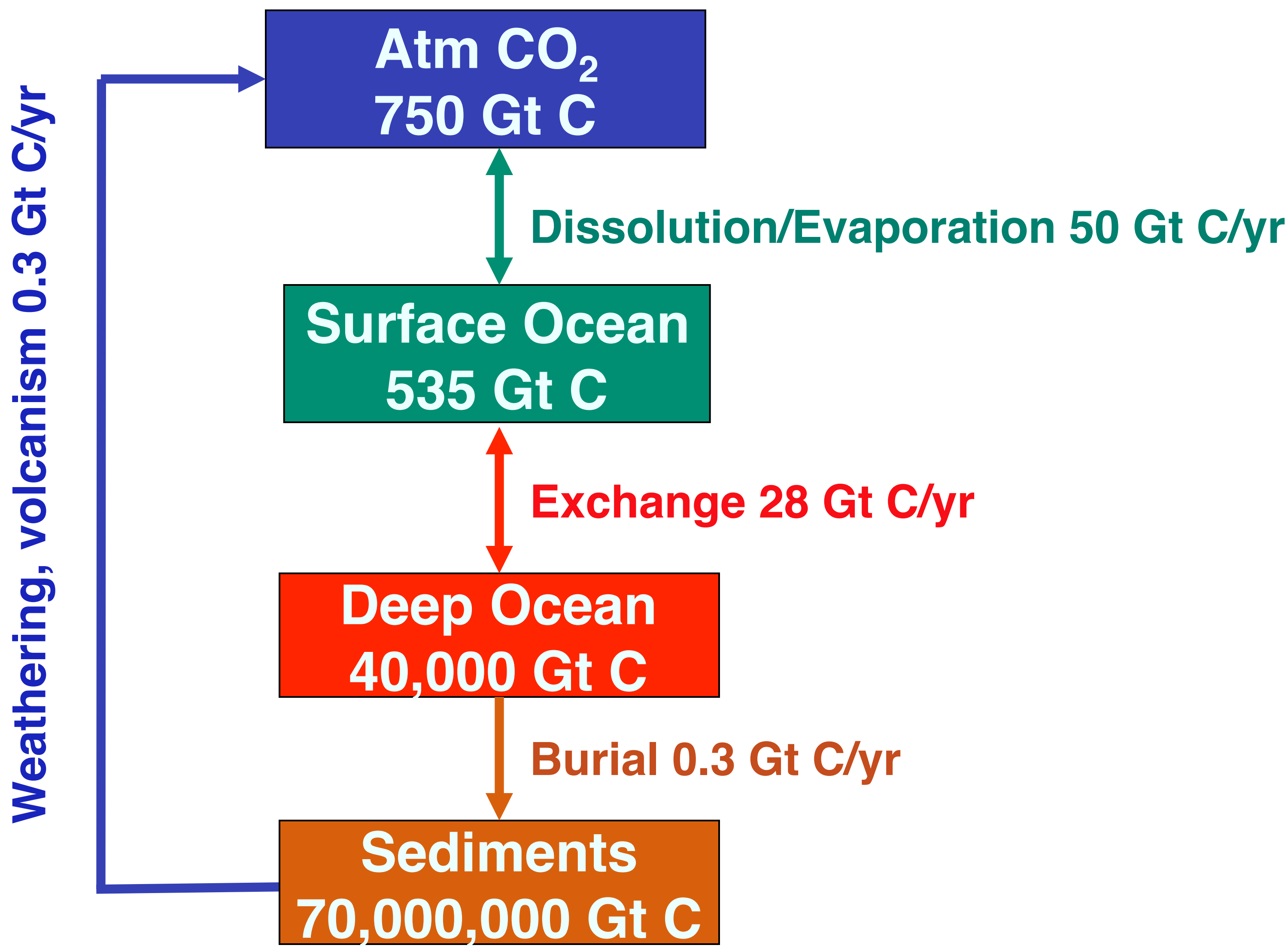
Score	Freq	Percent	Cum. Percent
5	4	1.82	1.82
6	3	1.36	3.18
7	6	2.73	5.91
8	9	4.09	10.00
9	5	2.27	12.27
10	10	4.55	16.82
11	10	4.55	21.36
12	16	7.27	28.64
13	23	10.45	39.09
14	21	9.55	48.64
15	17	7.73	56.36
16	30	13.64	70.00
17	27	12.27	82.27
18	21	9.55	91.82
19	13	5.91	97.73
20	5	2.27	100.00



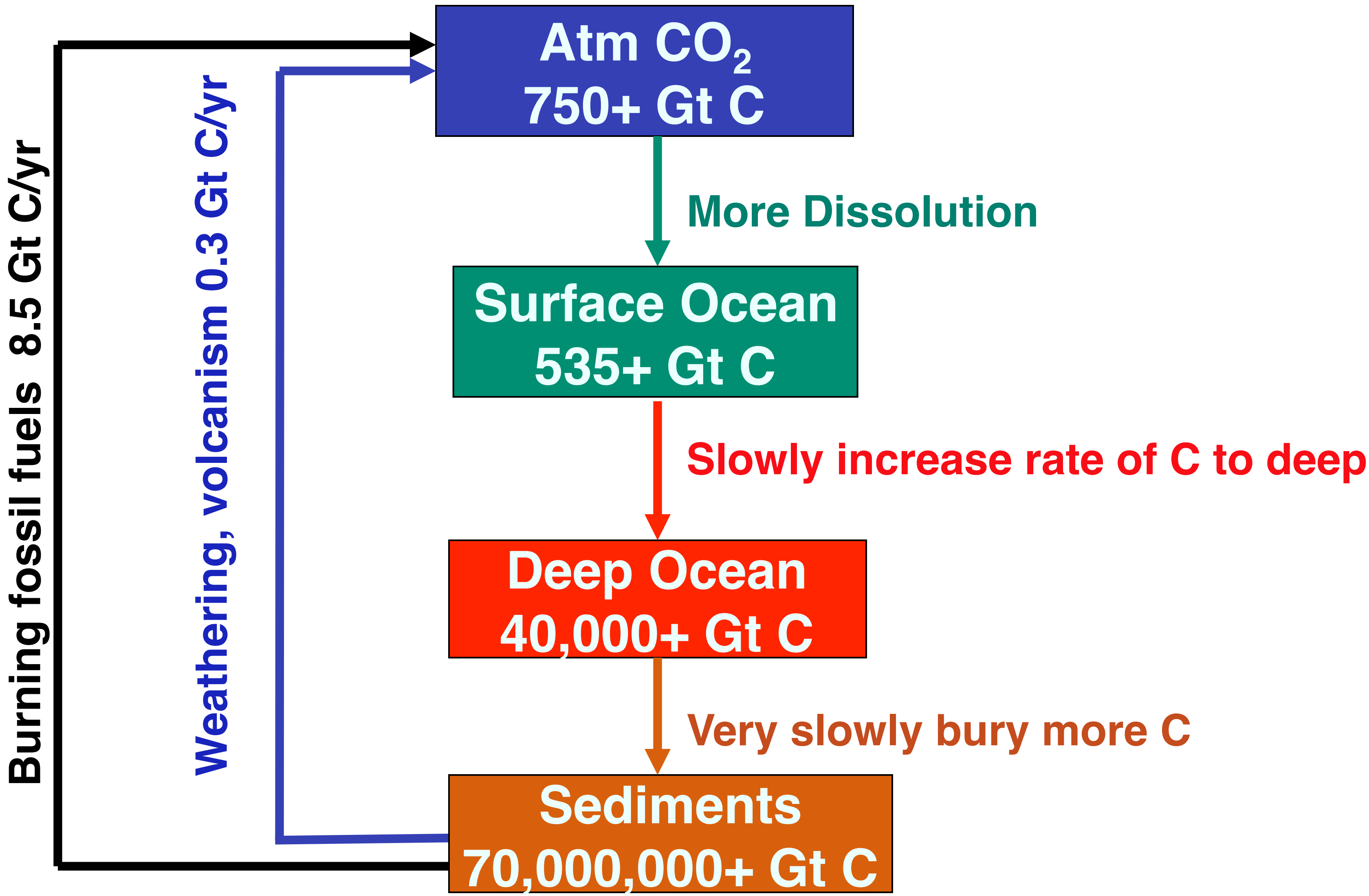
1 student = 0.45% of the group.

Score Name	Number of Students	Average Score	Standard Deviation
Quiz2	220	14.14	3.58

The marine carbon cycle



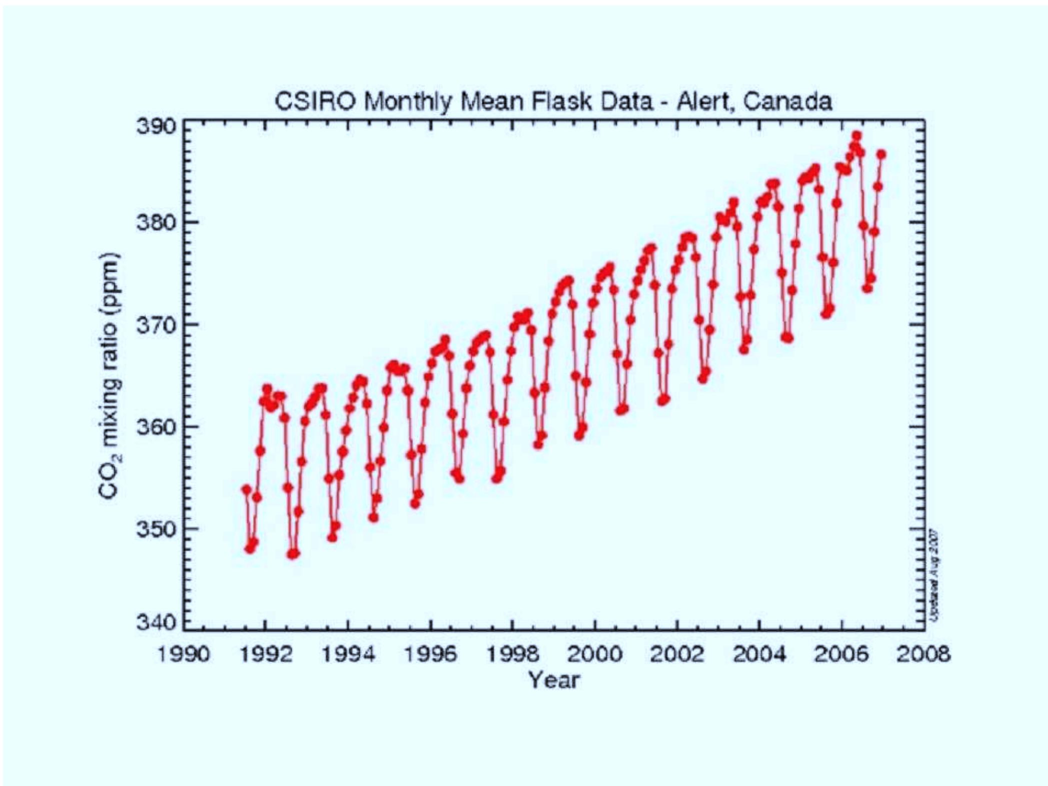
The marine carbon cycle
with human's burning oil under the ocean



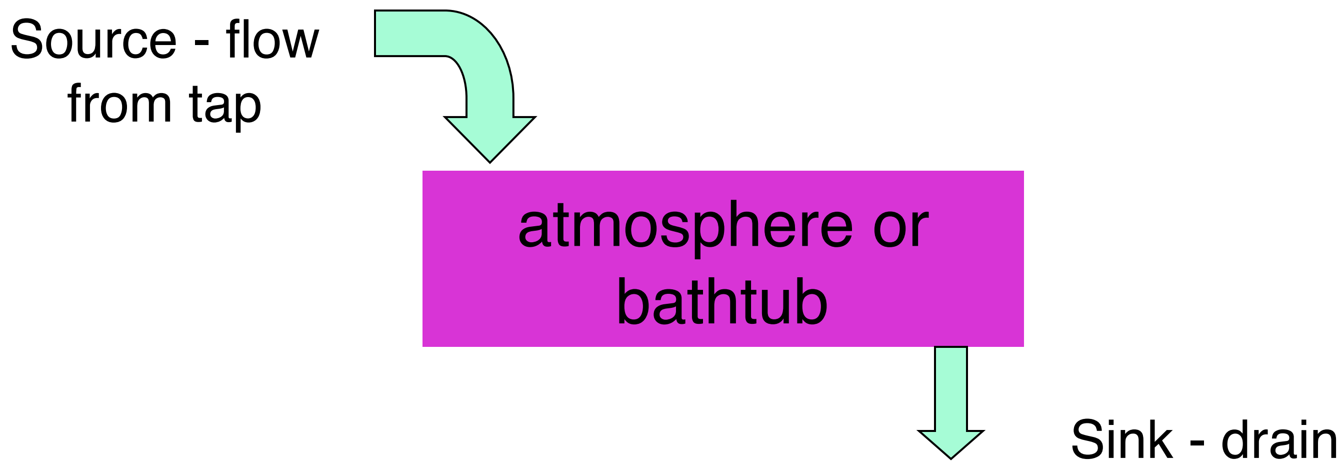
Even though the Reservoir Time in the atmosphere for the sink of carbon to the upper ocean through dissociation, is ~15 yrs

The additional CO2 we are adding lasts longer because it is removed by INCREASING the land (or ocean) uptake, which is happening, but the timescale is not equal to the residence time

This timescale is instead set by the sensitivity of these systems to an **increase** in the atmospheric CO2 concentration. These timescales are not well known, but we think it takes ~100 yr or more.



Imagine the fill rate increases by 2 ppt/yr and the empty rate increases by 1 ppt/yr



After 100 years, the atmosphere will contain 100 ppm extra CO_2. Now make the fill rate normal, but keep the empty rate 1ppt/yr higher. How long will it take to remove the extra?

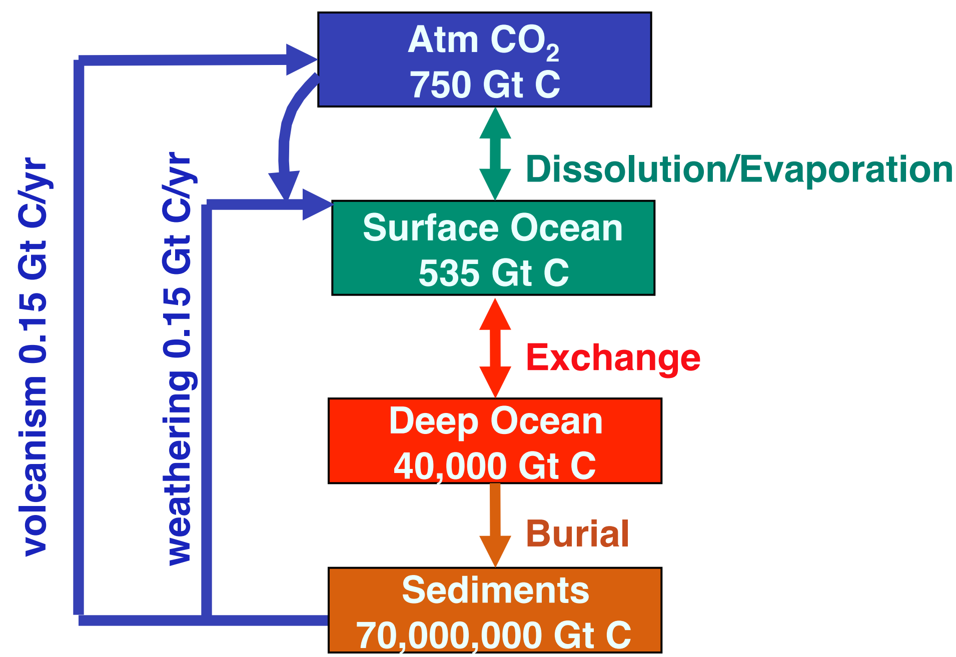
100 more years
(repaired after lecture)

Coming Clean on Chemical Weathering

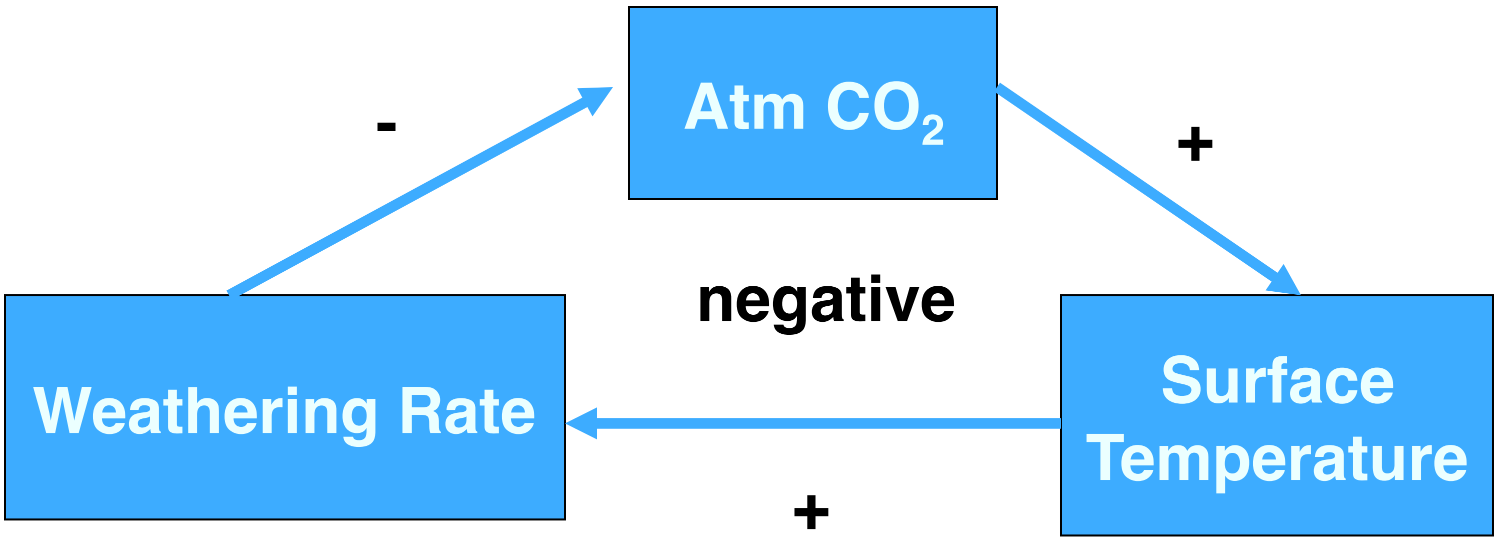
CO_2 dissolved in rain water makes carbonic acid, which then reacts with rocks.

Removes carbon from atmosphere reservoir and sediment/rock reservoir, and places the carbon back in the ocean in the form of carbonate ion.

This is better than before:



Weathering Negative Feedback Loop



Higher atmospheric CO_2 , warms planet, weathering rate increases, draws down CO2 and moves carbon to the ocean.

Hurricanes and other storms RG p128-146

A taste of things to come?

Keeping count: will there be more cyclones in the future?

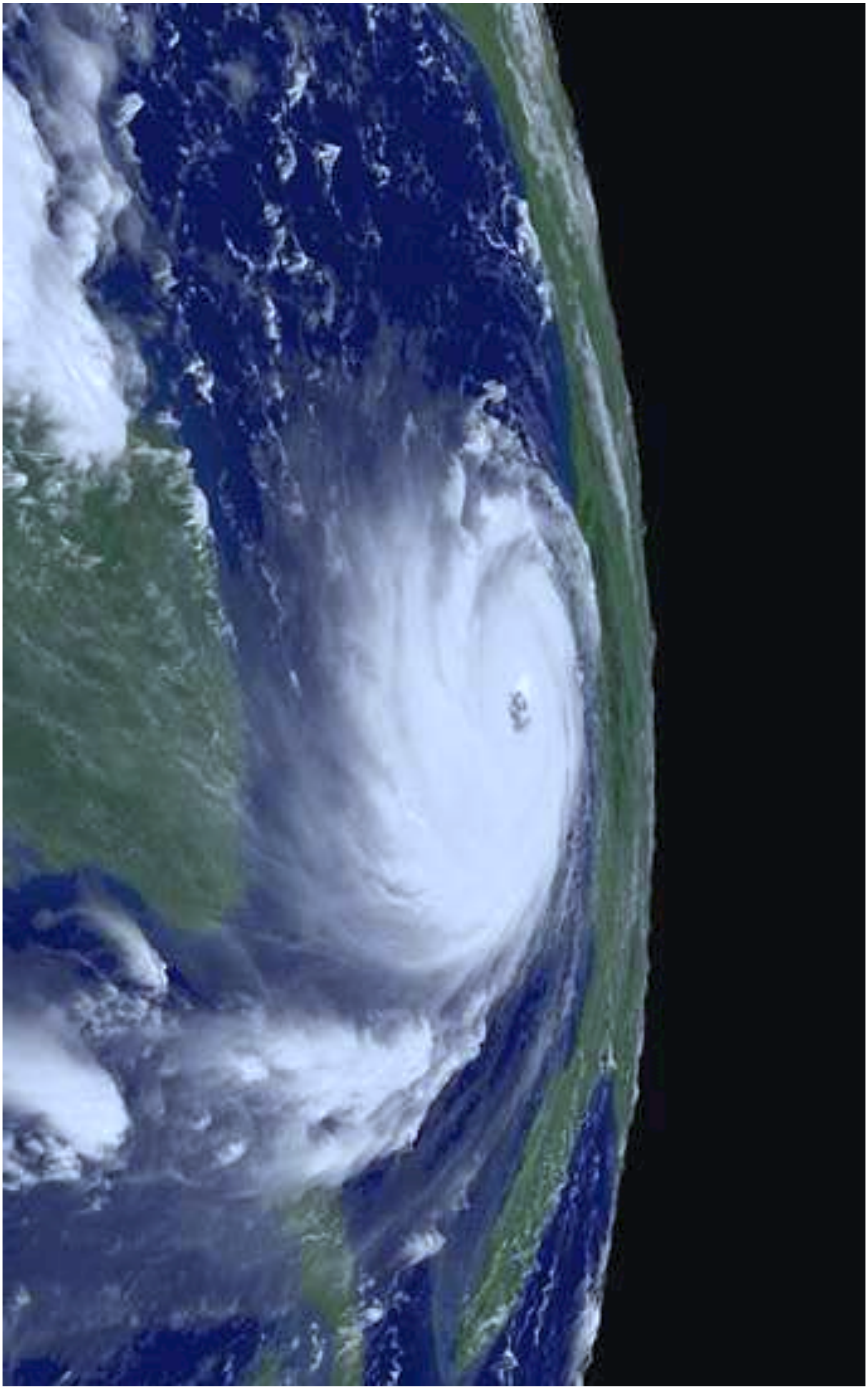
Surges and downpours

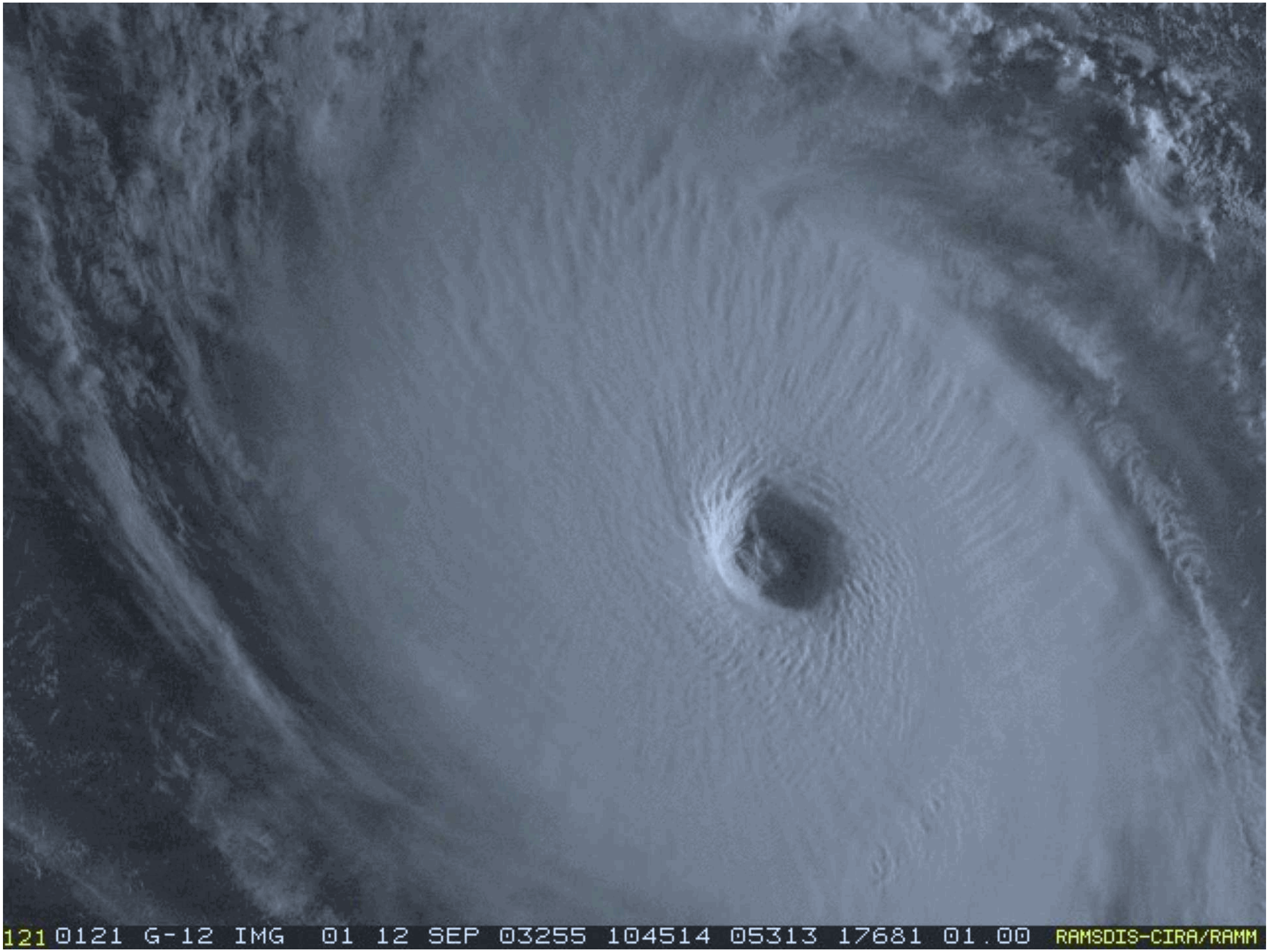
Coastal concerns beyond the tropics

Coastal storm flooding: a deepening problem

Tornadoes: an overblown connection?


Hurricane Katrina
August 28, 2005

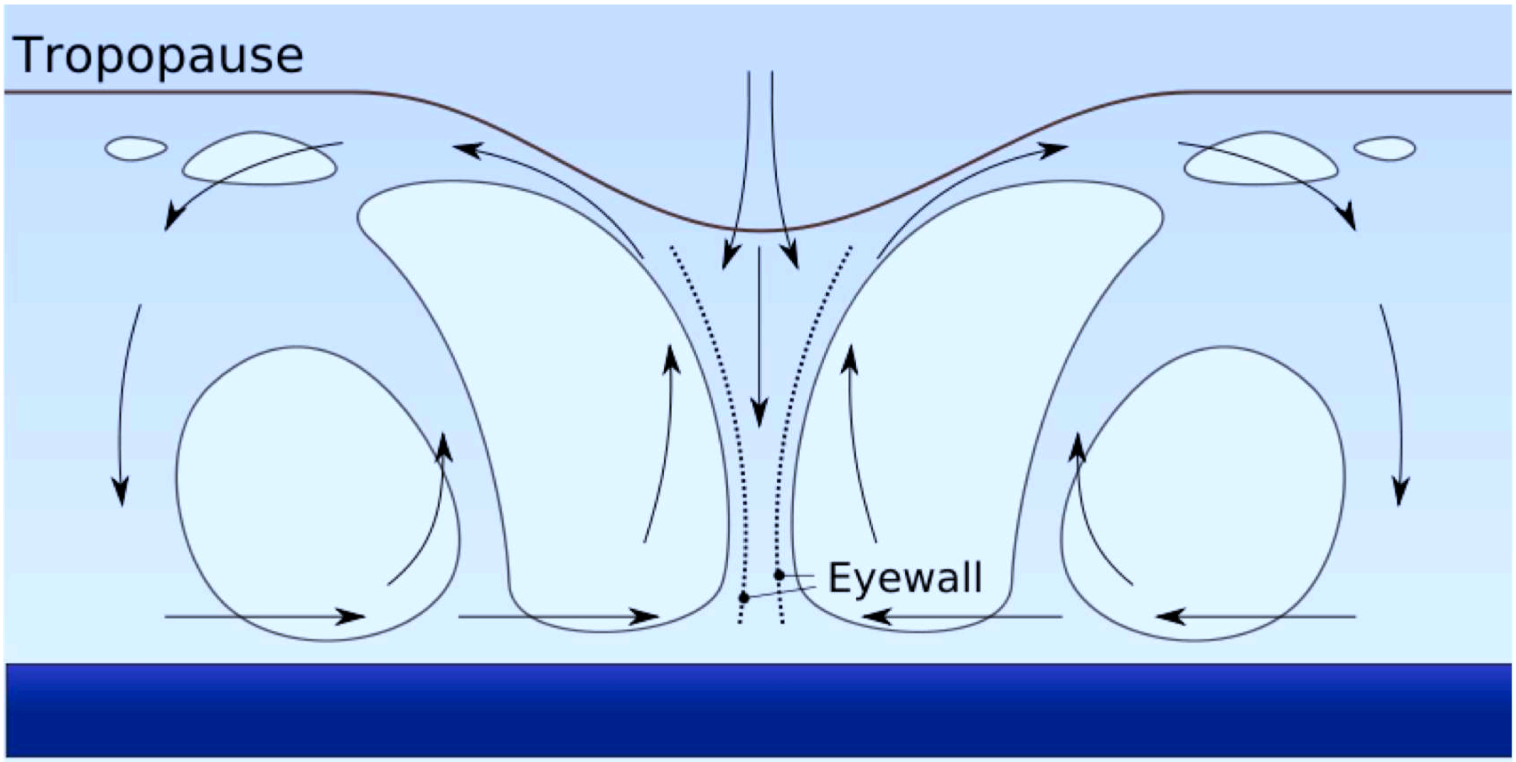




http://orca.rsmas.miami.edu/~schen/Isabel/goes_floater030912.avi

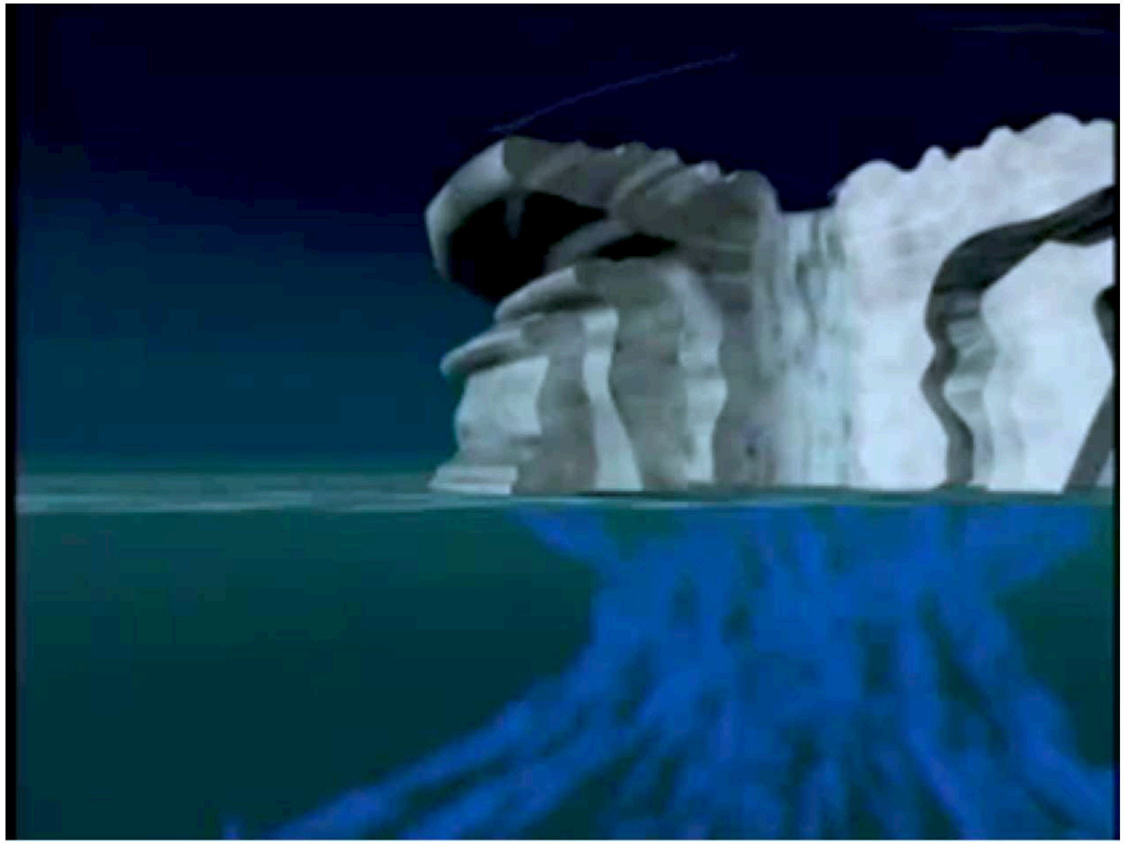

Eye of Katrina
Photo by UW Prof R. Houze

Profile of a tropical cyclone



The ocean surface is heated by the sun, this heat is efficiently moved upward into the storm by evaporation (cooling the ocean) and condensation (warming the cloud)

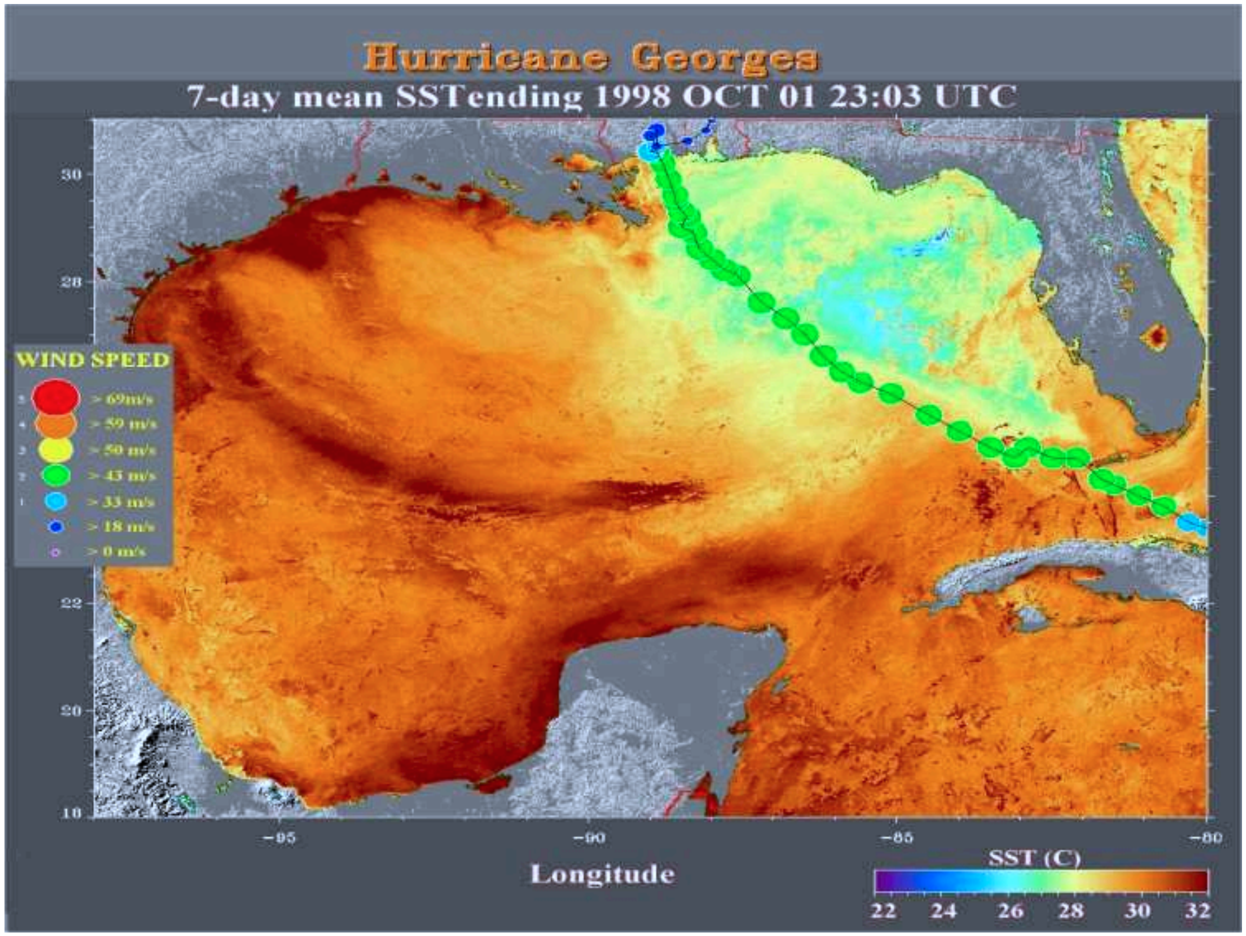
The eye has sinking air, which is therefore dry (just like the worlds desert regions occur on the sinking branches of the Hadley Circulation)



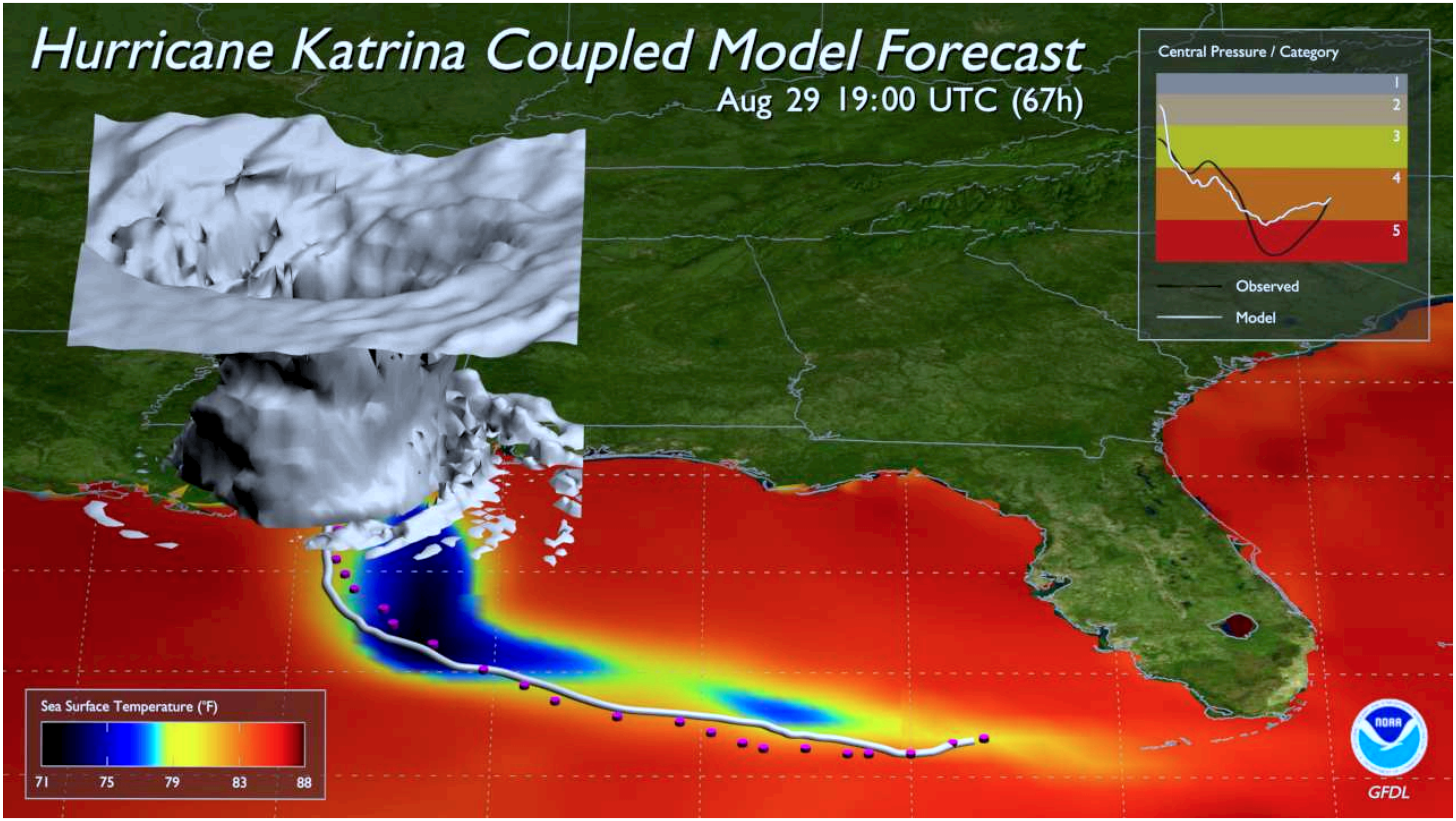
The first storm churns up colder, deeper waters and leaves a trail of cool in its wake. The second storm loses strength when intersects this cold water trail. NASA NASA's Aqua and TRMM of SST. Sea height using the Jason-1 satellite.

http://www.nasa.gov/centers/goddard/earthandsun/eye_to_eye.html

Another example of cooler SST after storm passes

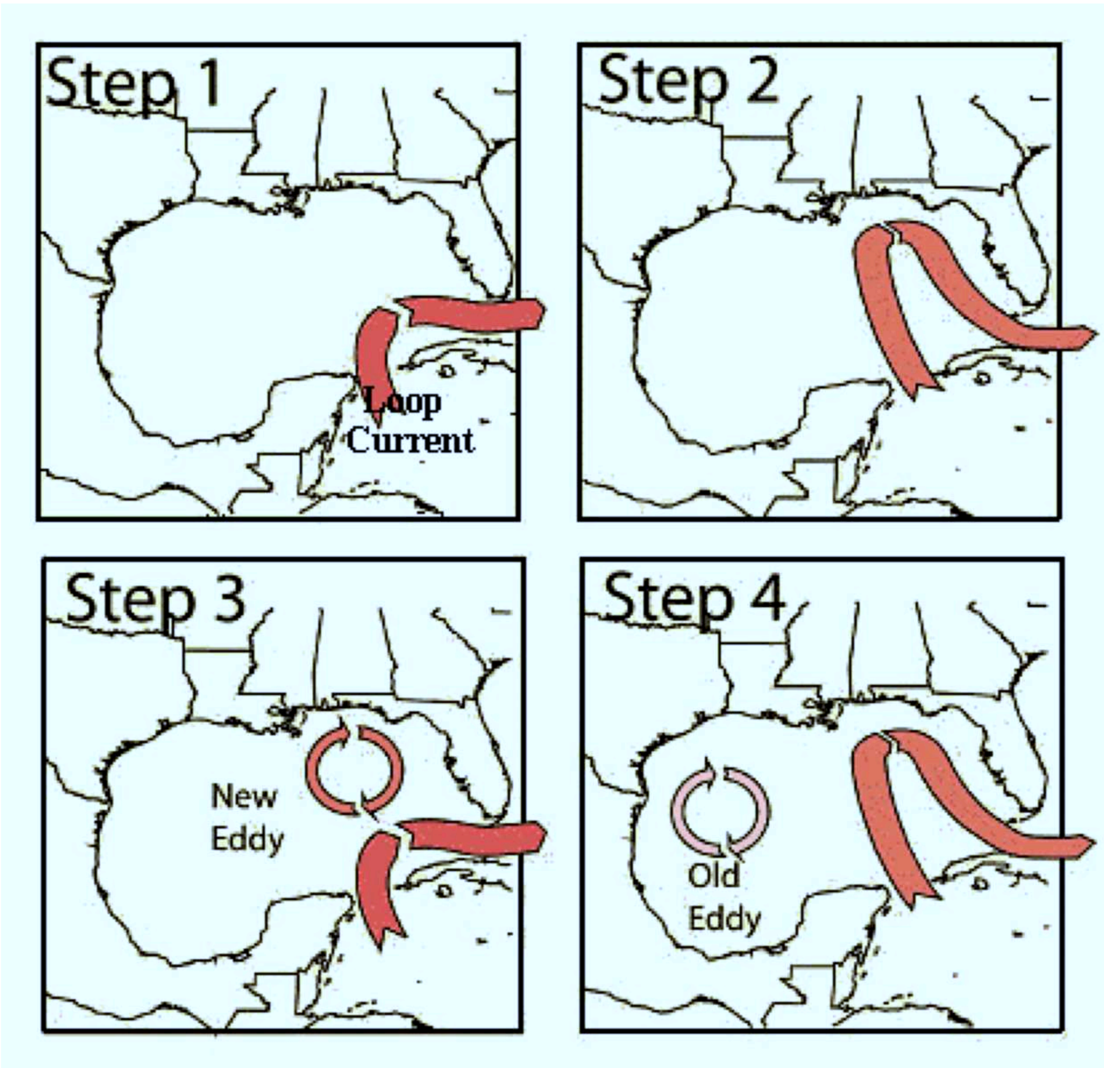


Cold ocean temperature in Katrina's Wake



http://www.gfdl.noaa.gov/visualizations-hurricanes

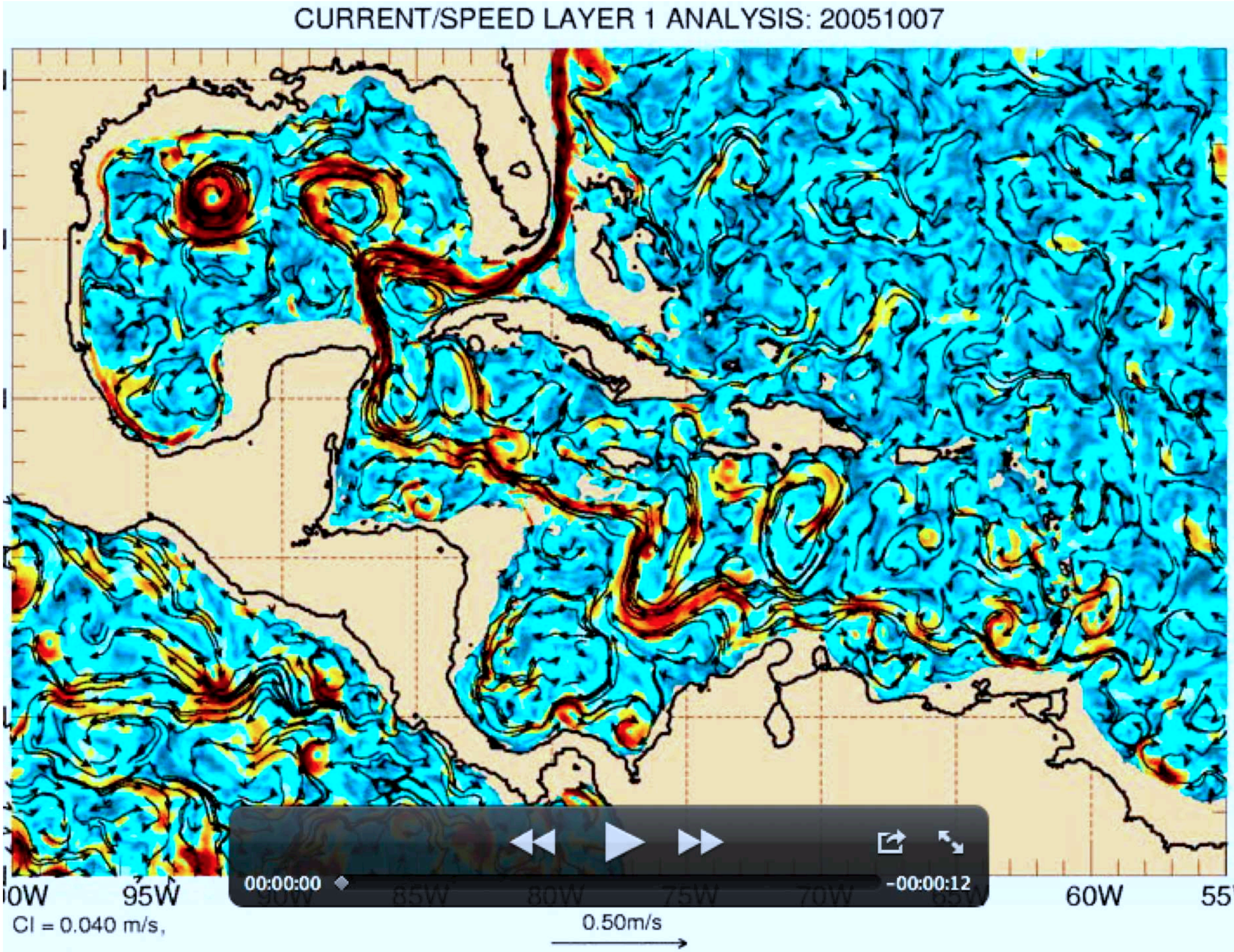
Loop Current



200-300km wide
80-150 m deep
warm current ribbon

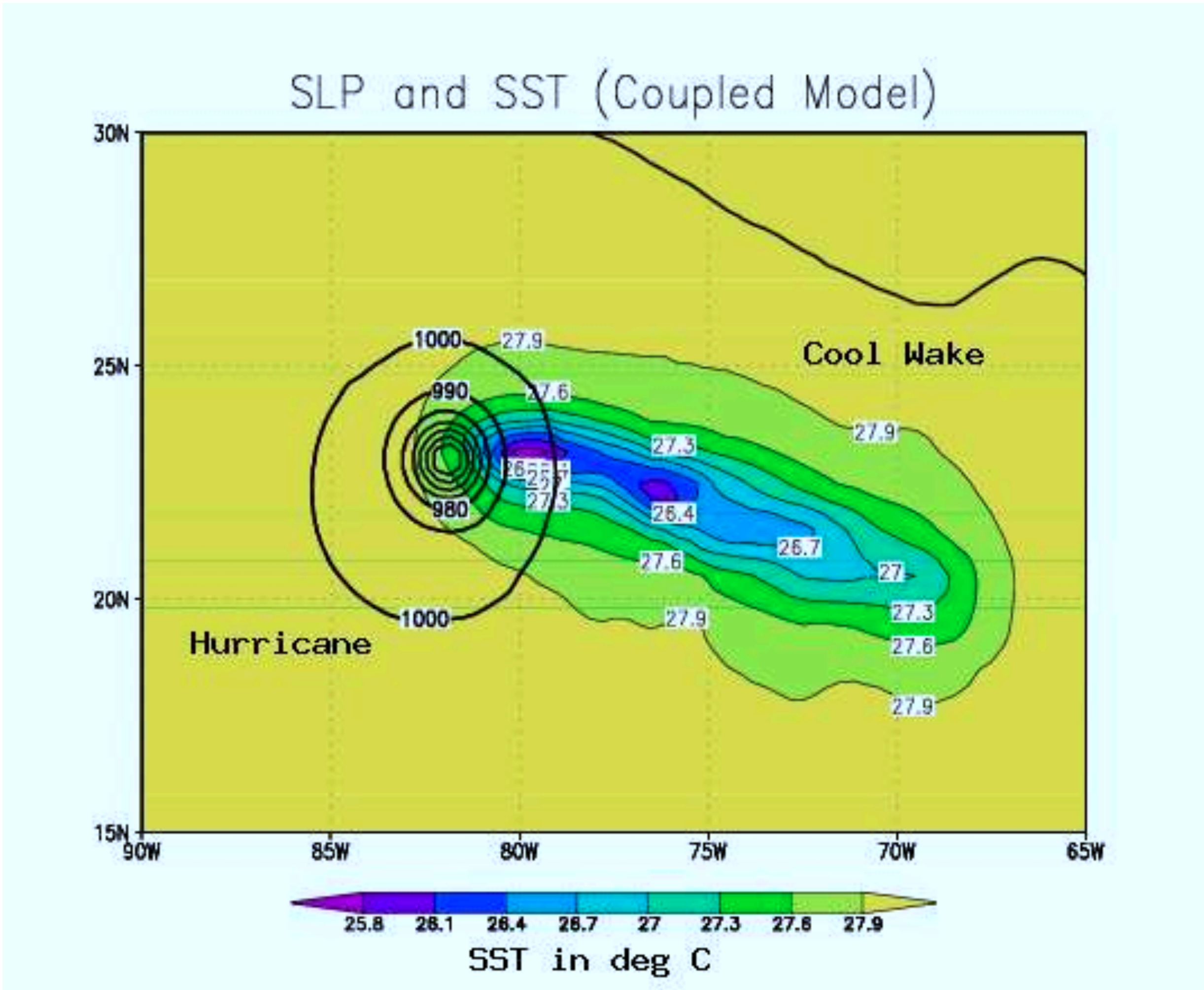
In step 2 it has stretched so that it breaks off an eddy in step 3

Happens about ~6-11 months



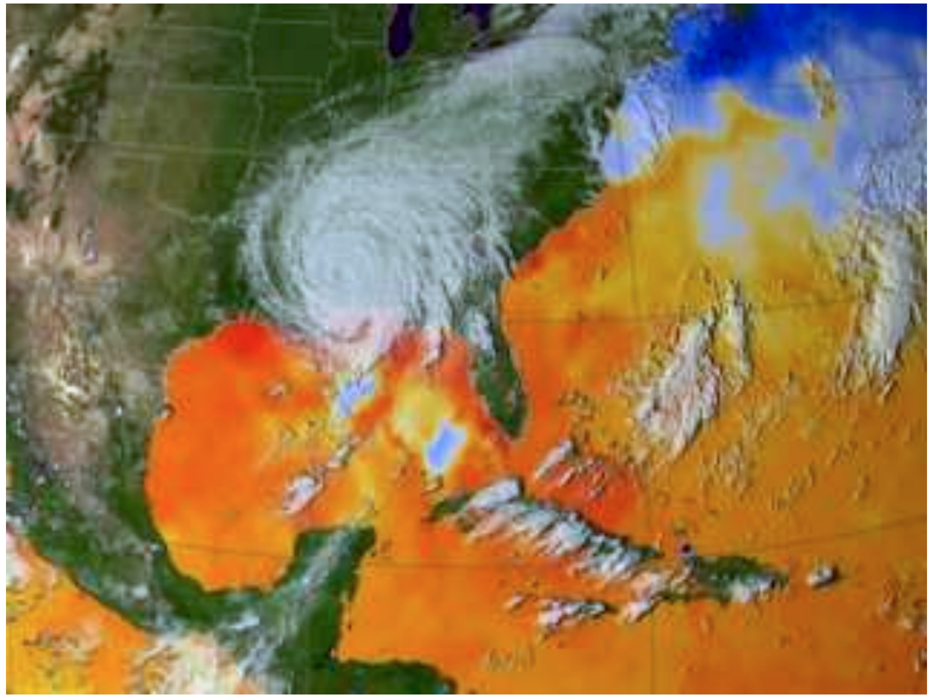
http://www7320.nrlssc.navy.mil/global_nlom32/ias.html

Hurricane produce oceanic upwelling beneath the eye



Upwelling of cold water cools the SST and can provide a strong negative feedback that limits the strength of the hurricane.

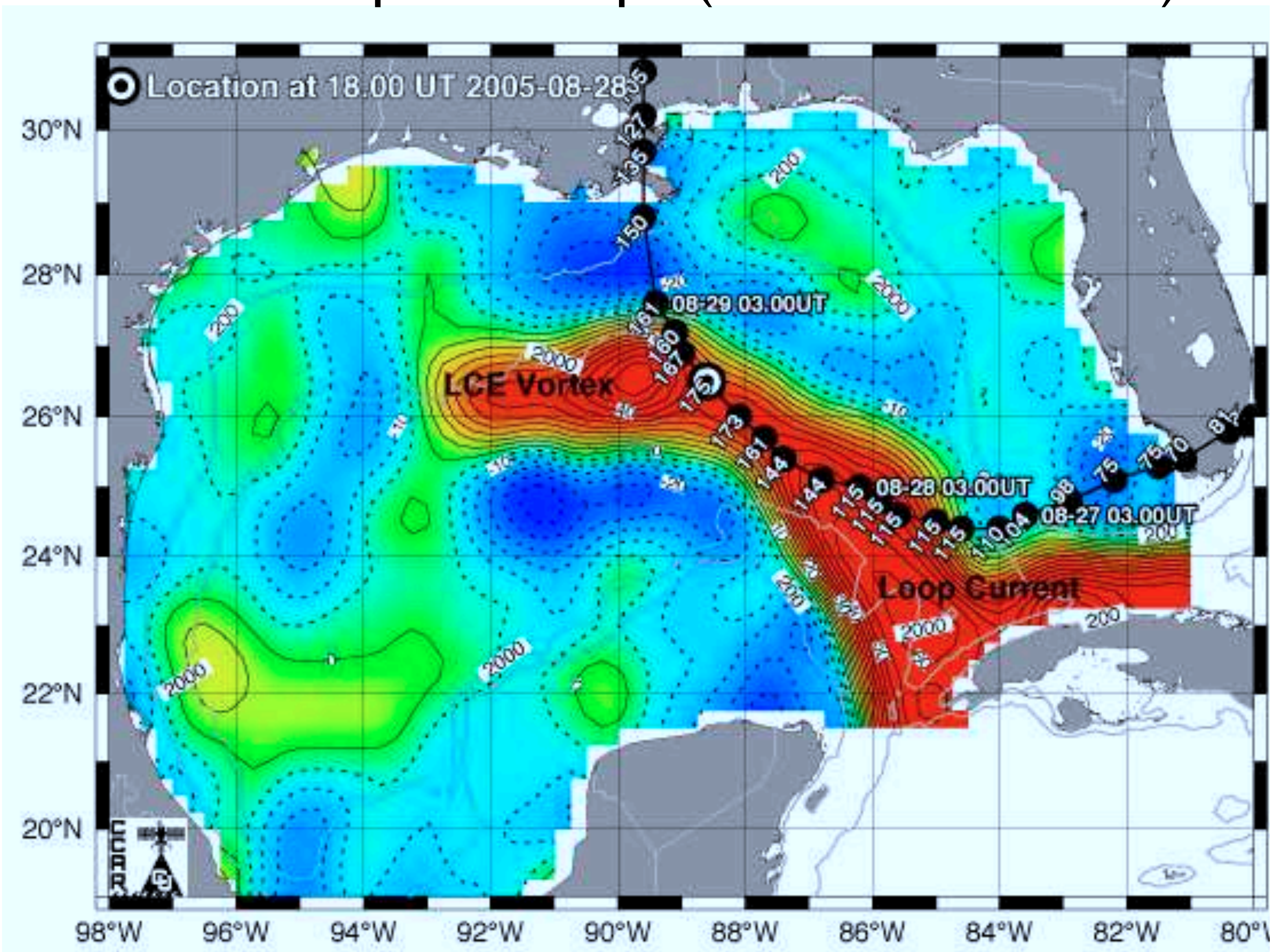
Sea Surface Temperature after Hurricane Katrina passed

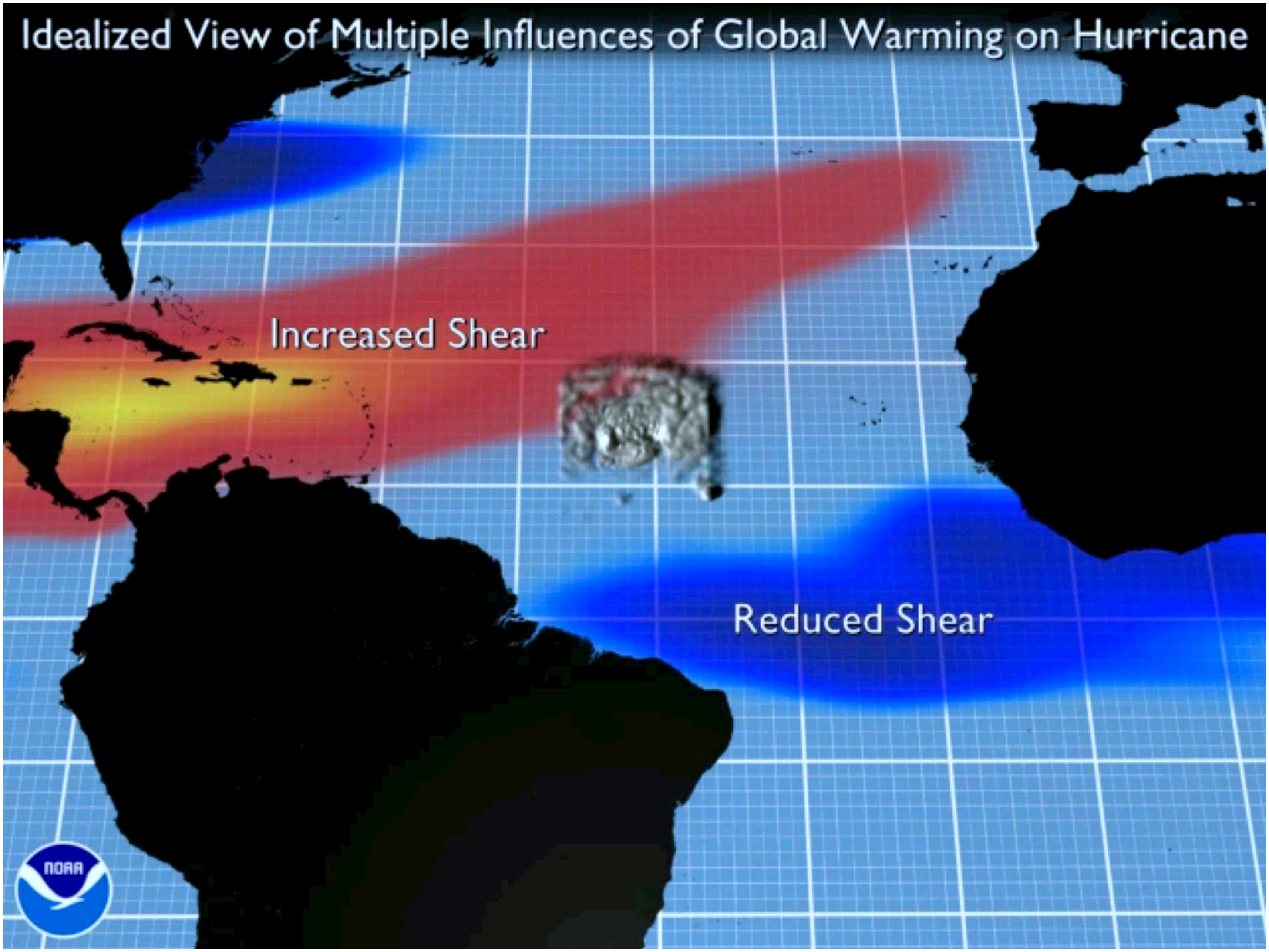


In the "loop current" the warm water extends through a deep layer. Hence, the even the upwelled water is warm, and the negative feedback is minimal.

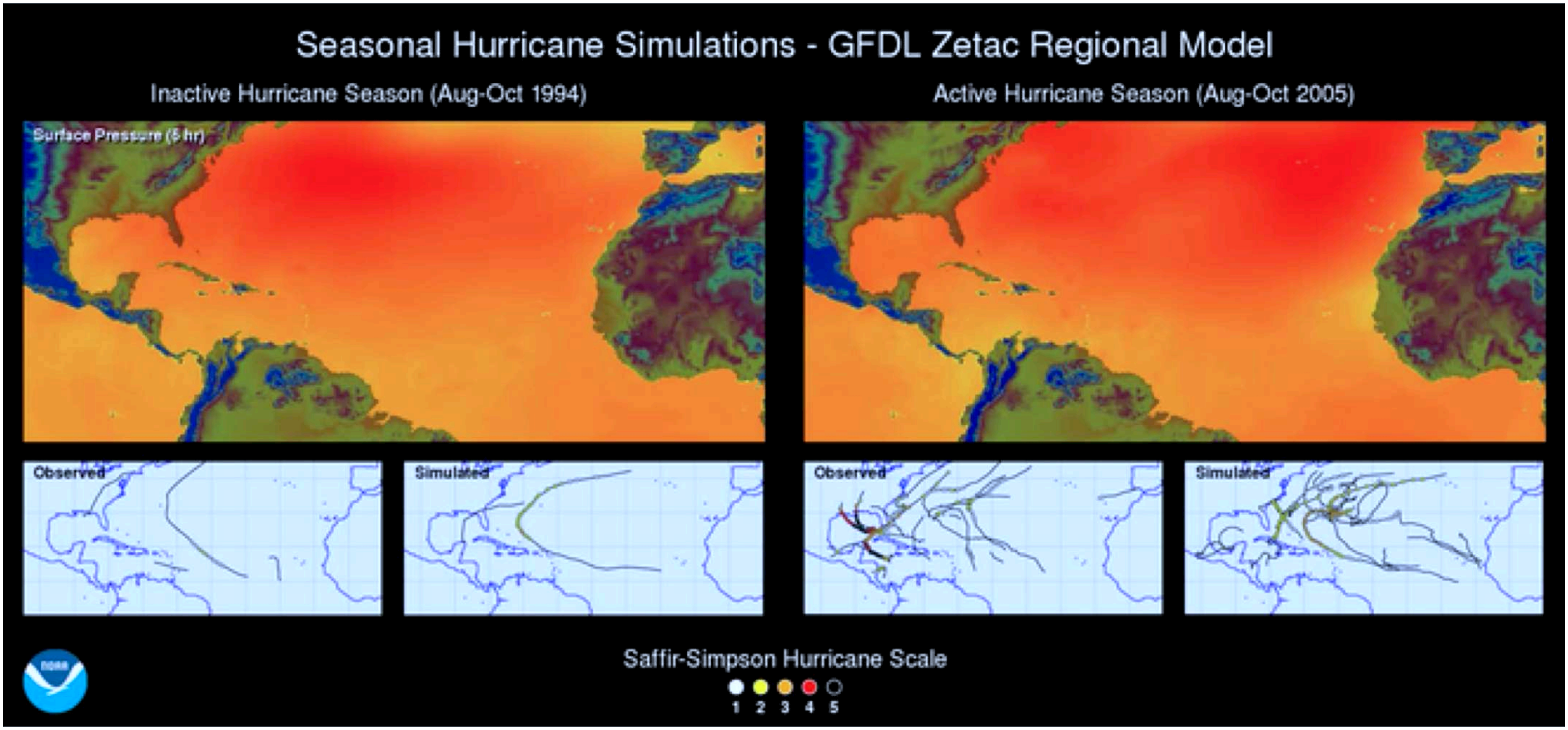
Hence, tropical storms tend to intensify when they pass over features like the loop current.

Hurricane Katrina: Ocean Heat Content (not SST) and wind speed in mph (next to black dots)





http://www.gfdl.noaa.gov/visualizations-hurricanes



http://www.gfdl.noaa.gov/visualizations-hurricanes

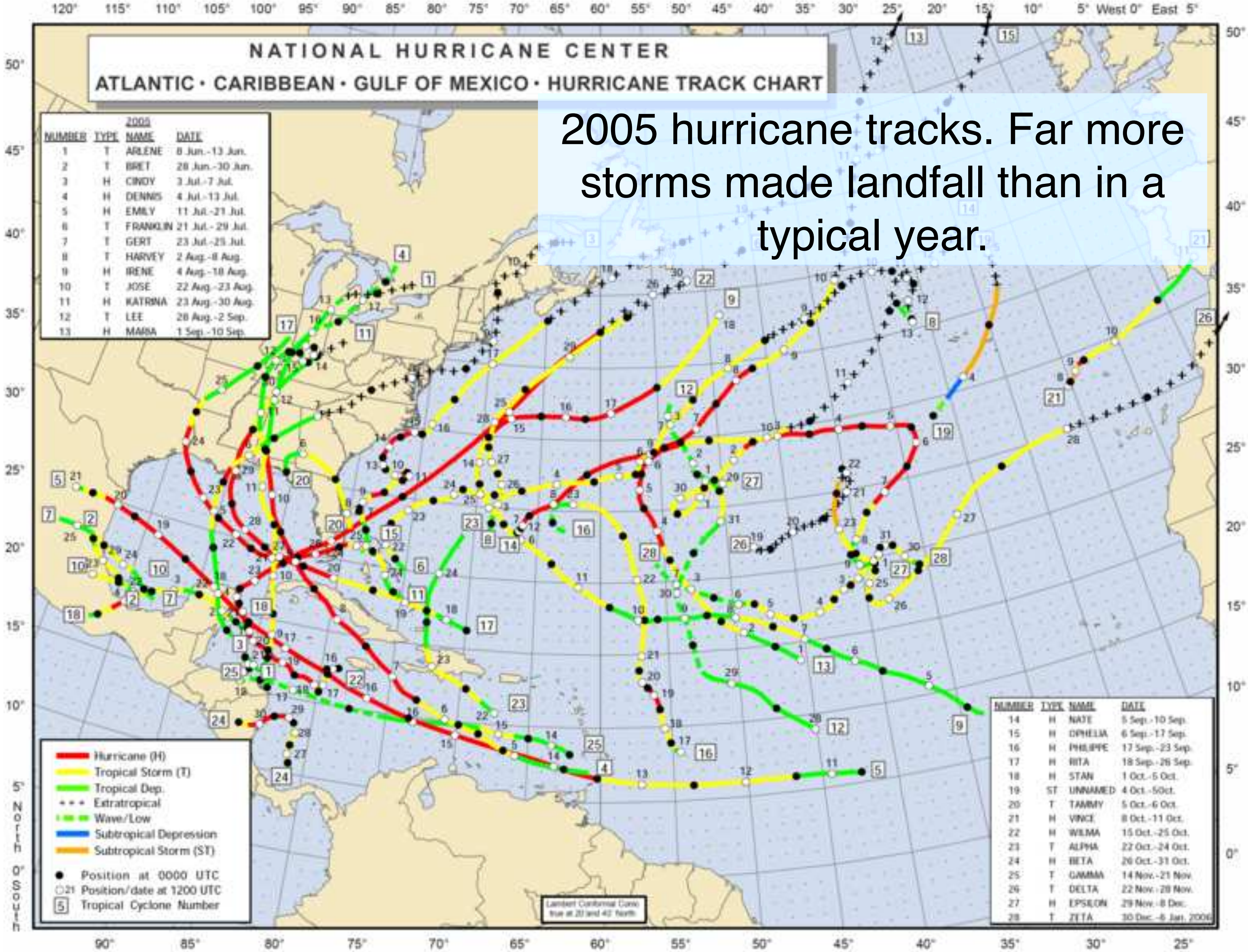
More Hurricane General Facts

SST must be at least 26^{o} C throughout a depth of 100 m

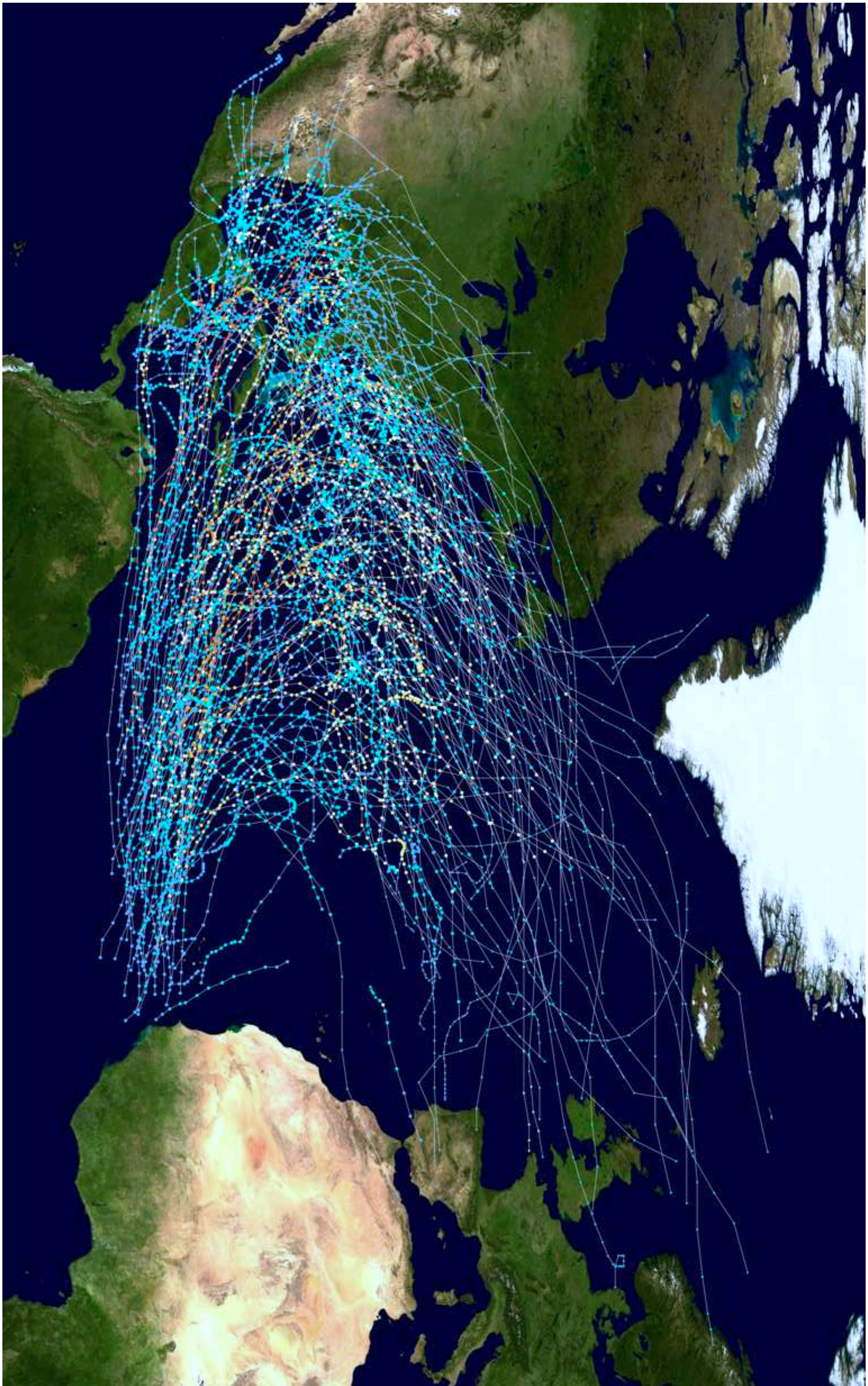
Must be at least 5^{o} off the equator

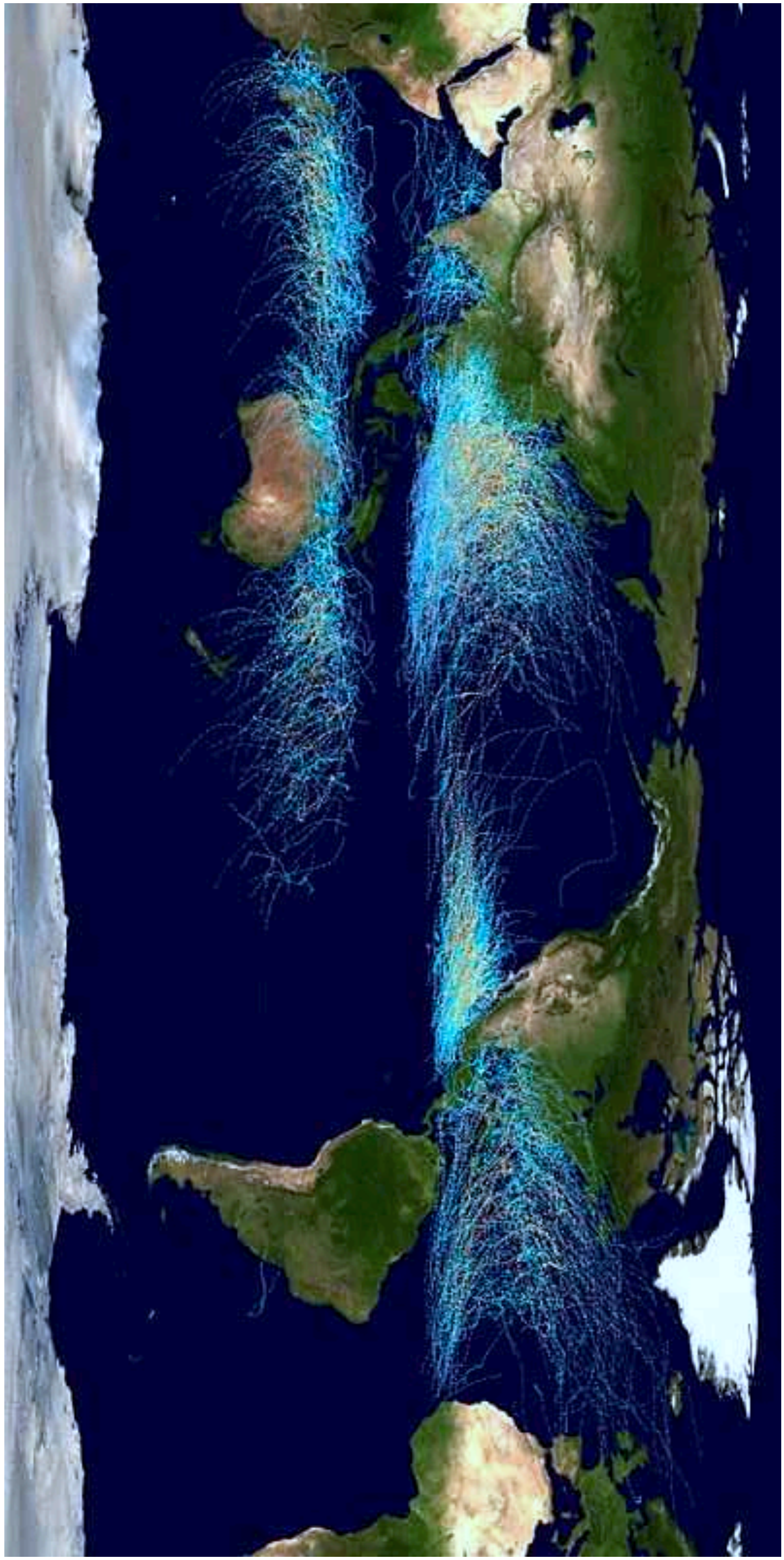
Weakened by high vertical wind shear

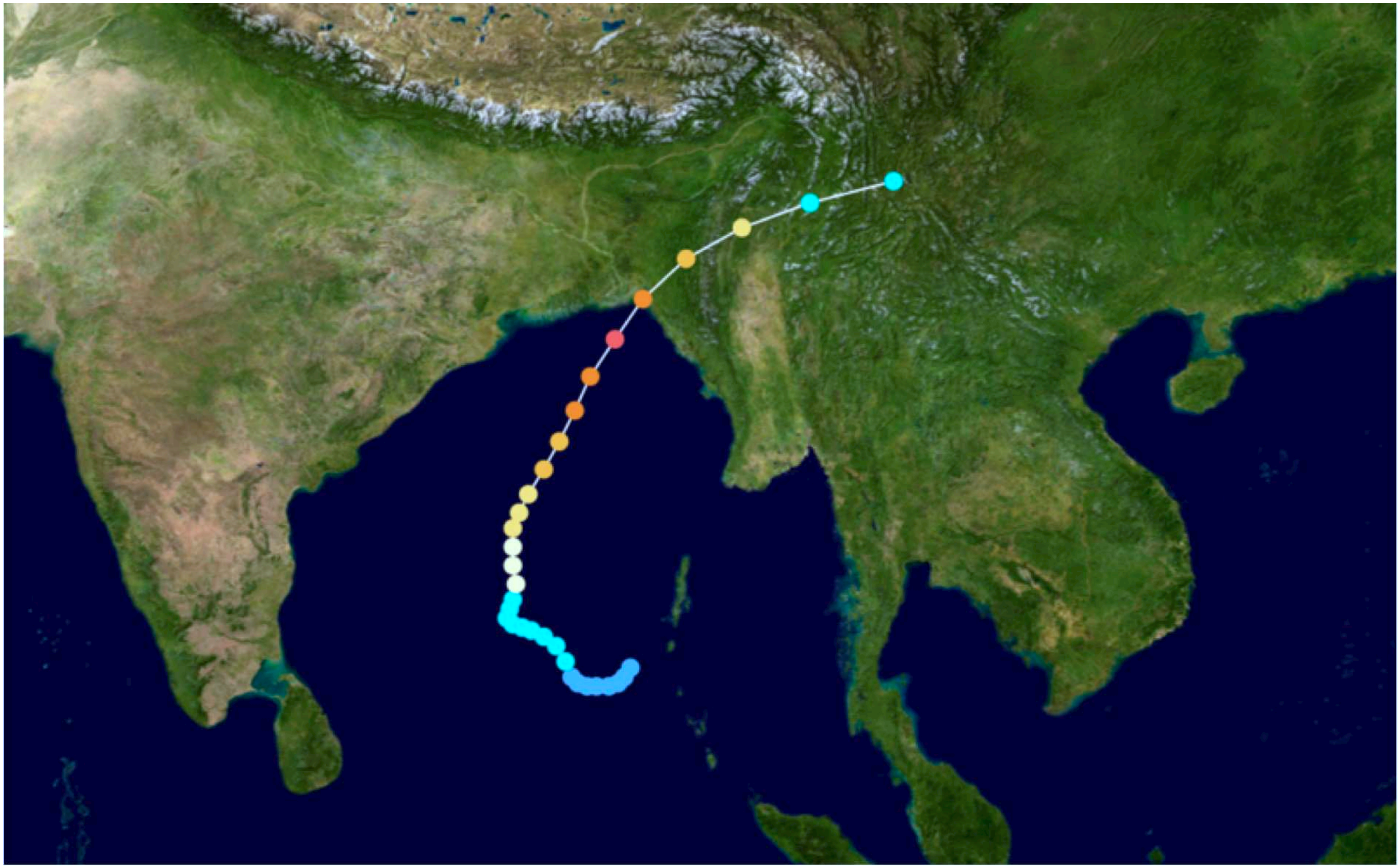
Not all storms make landfall



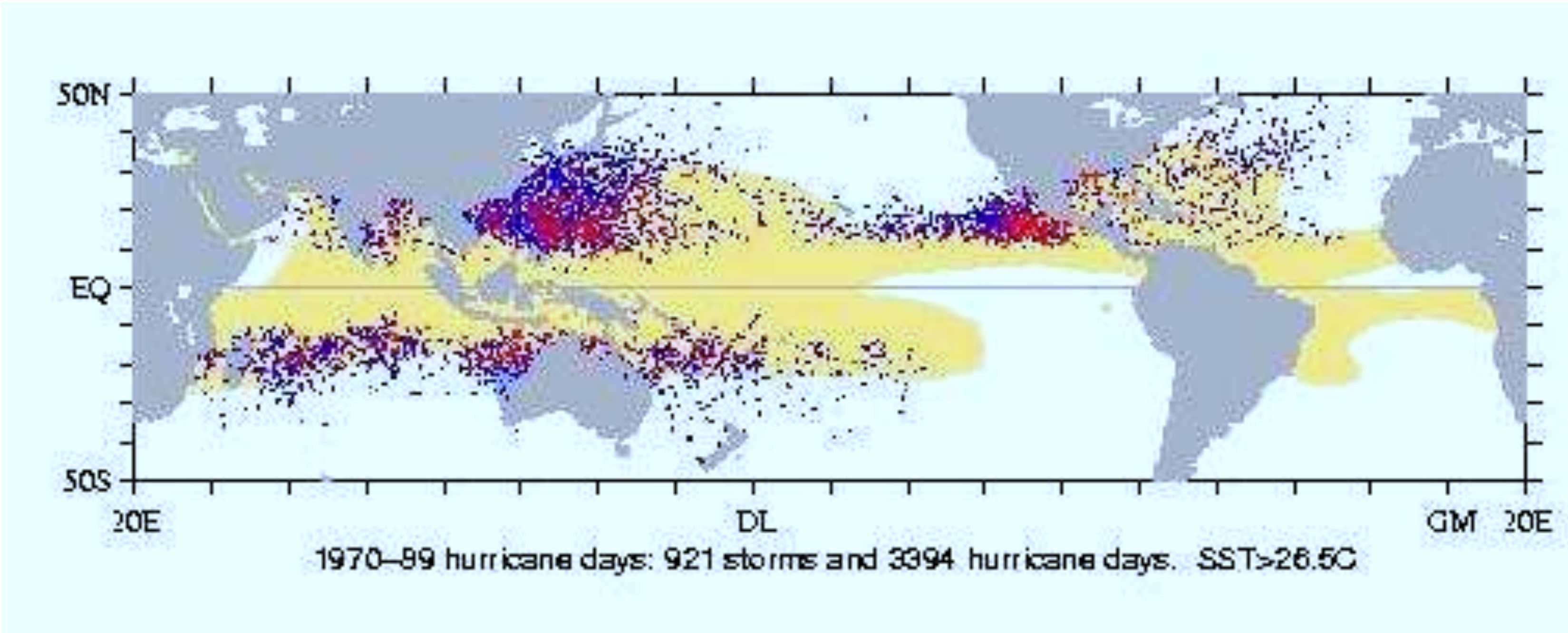
2005 hurricane tracks. Far more storms made landfall than in a typical year.

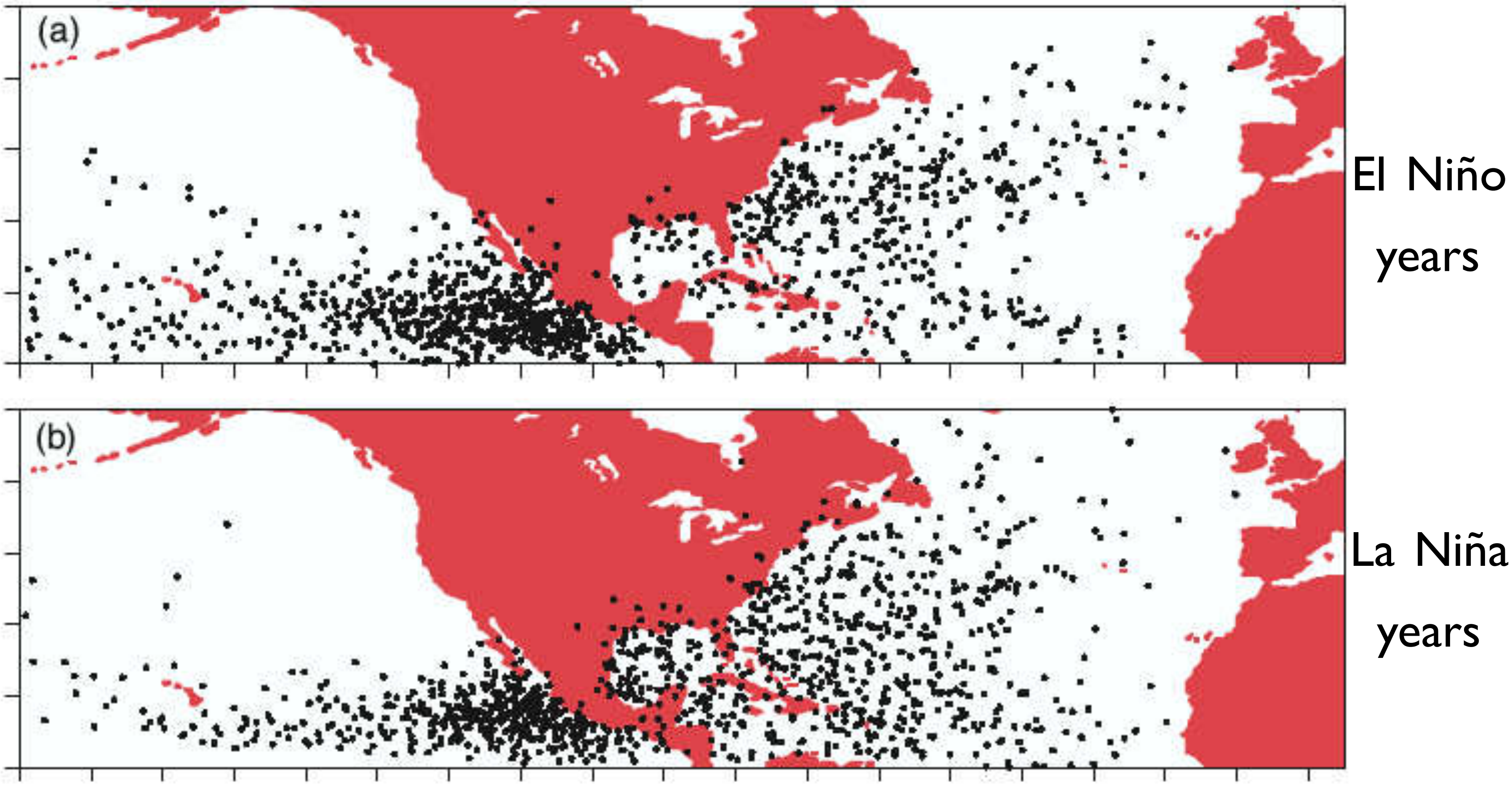






1991 Bangladesh cyclone: 144,000 fatalities


50N
EQ
50S
20E
DL
GM
20E
1970–89 hurricane days: 921 storms and 3394 hurricane days. SST>26.5C

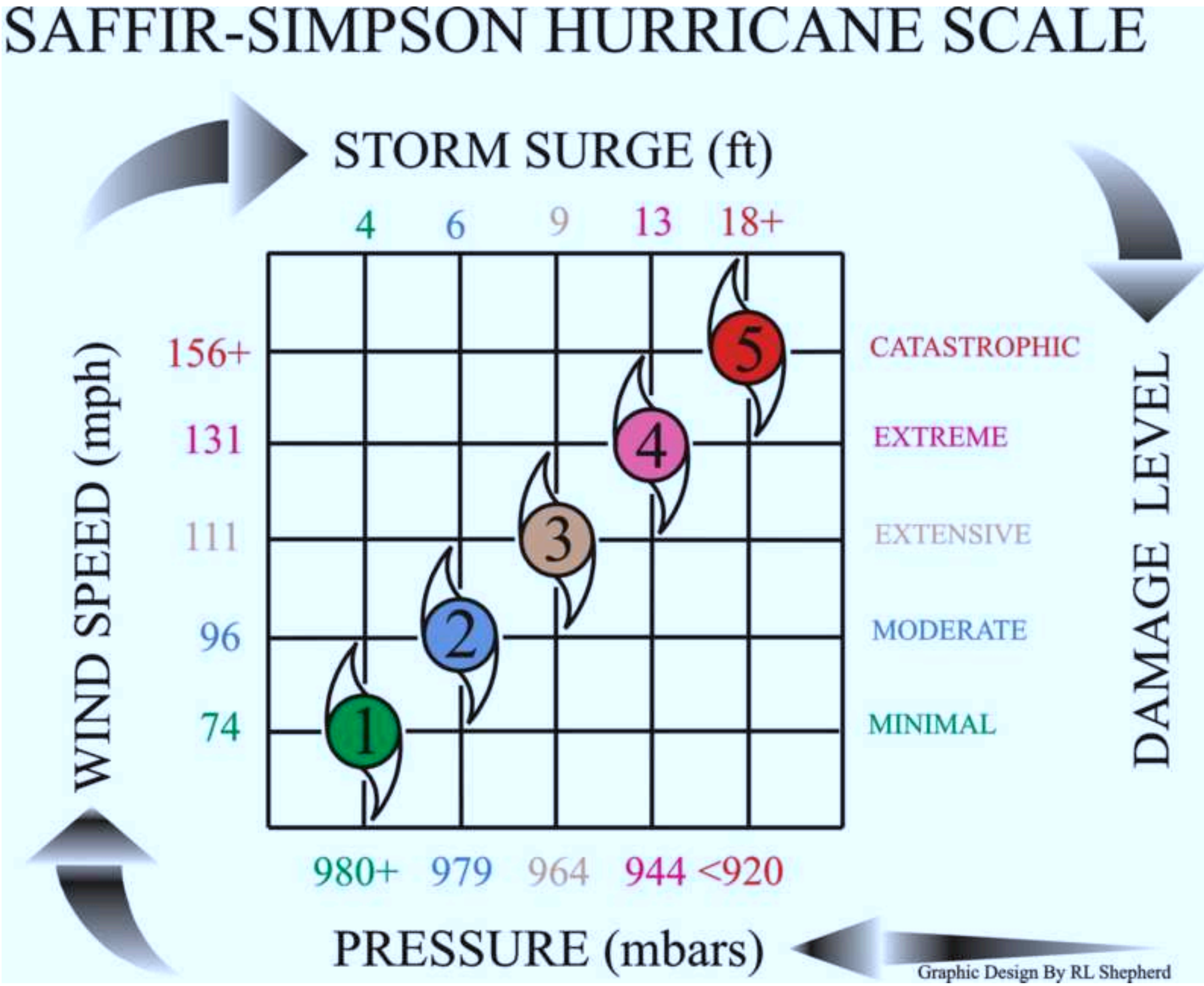


Hurricane positions on the last day that they exhibit hurricane-force winds

Hurricane damage

- winds
- storm surges
- flooding

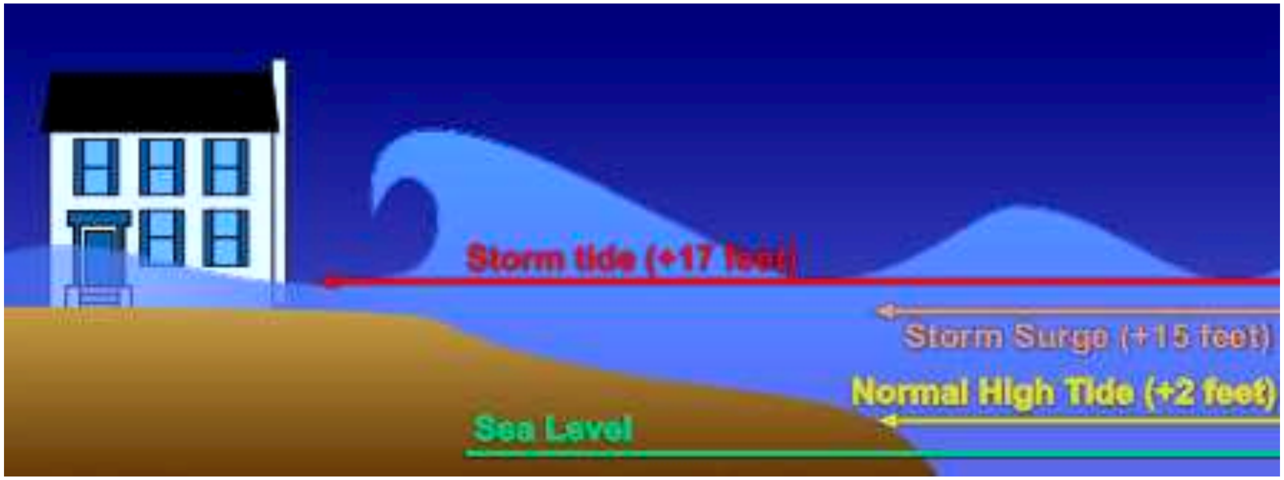
Winds



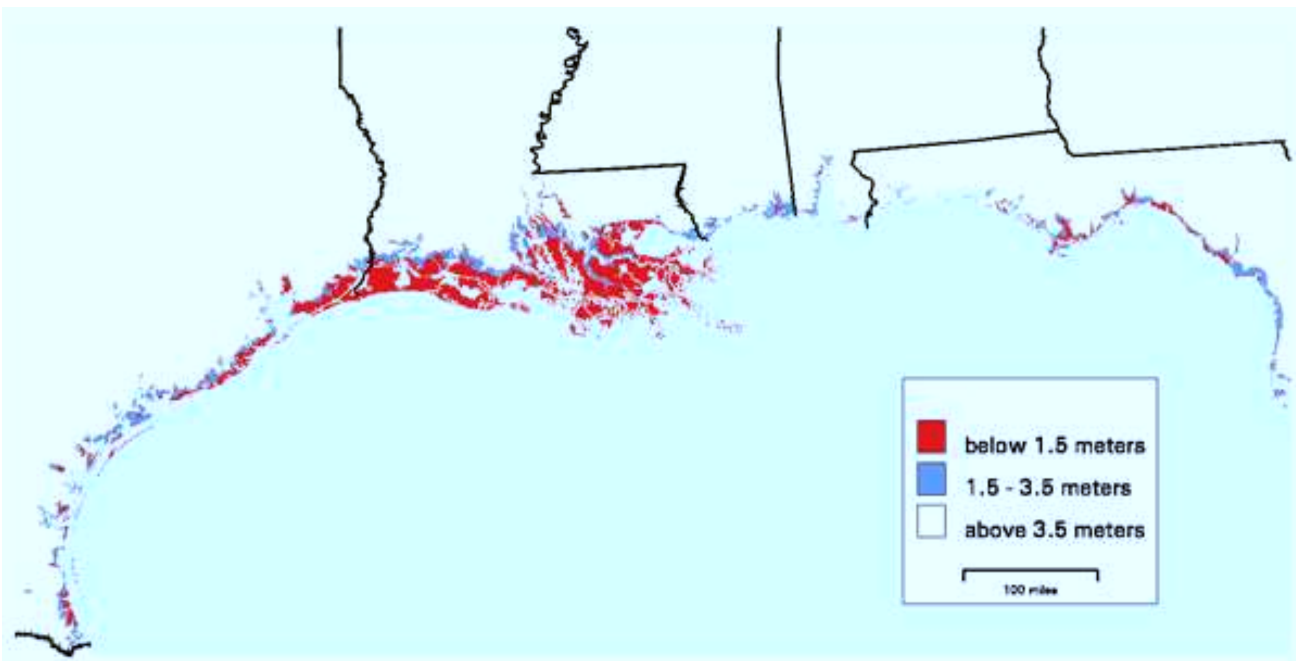
Rita had 882 mbar

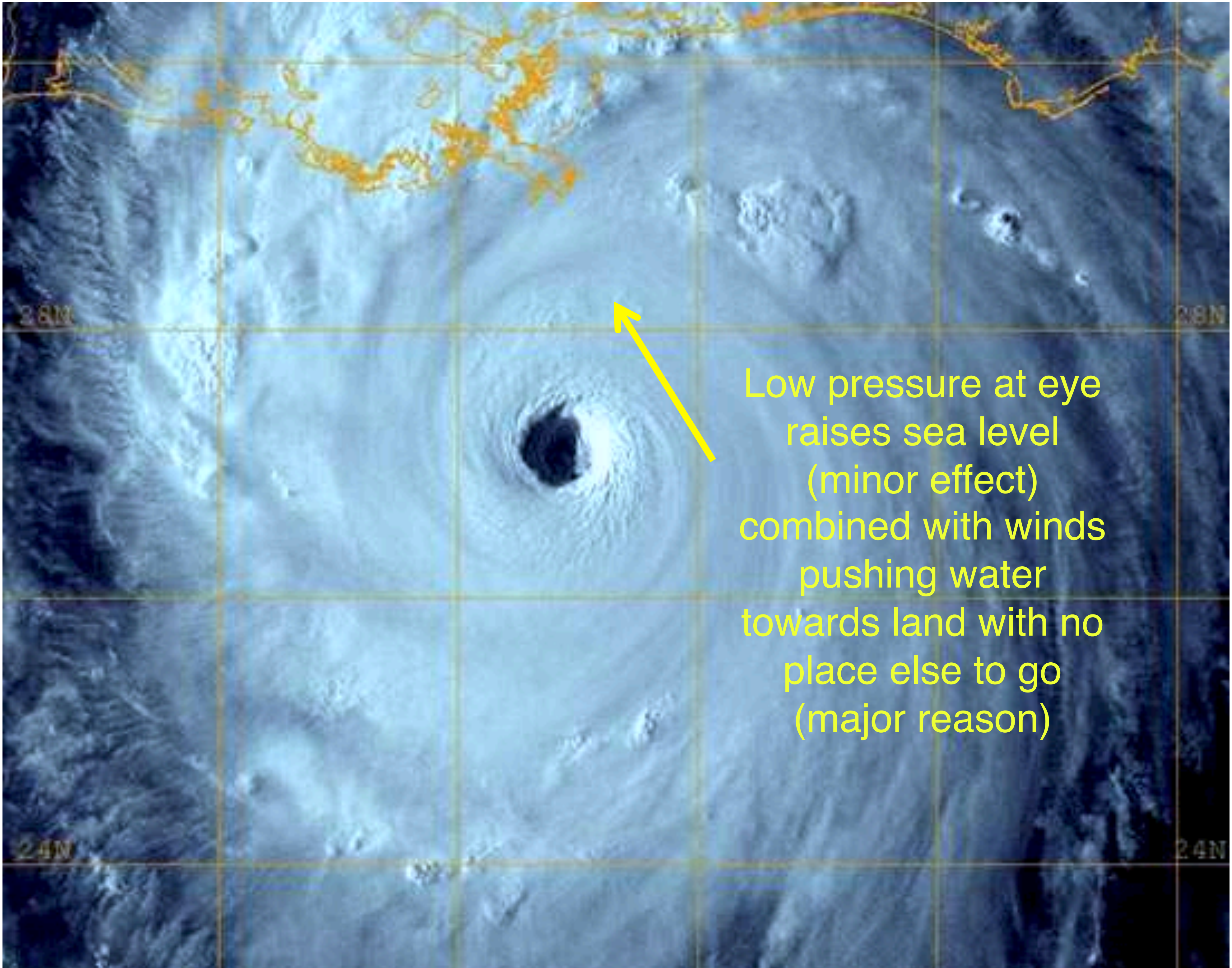
Winds

Storm surge

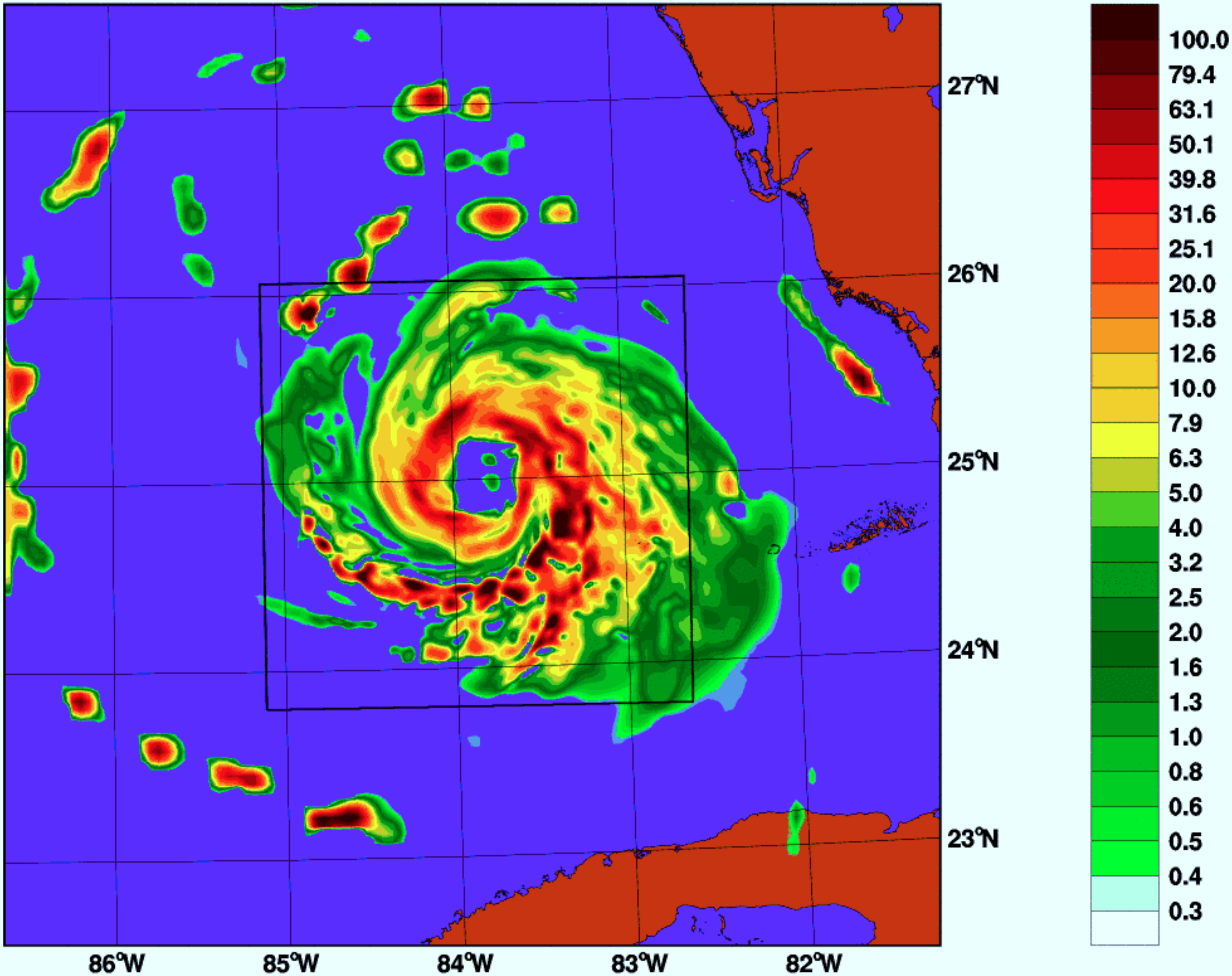

Storm tide (+17 feet)
Storm Surge (+15 feet)
Normal High Tide (+2 feet)
Sea Level


Storm Surge Before and After


below 1.5 meters
1.5 - 3.5 meters
above 3.5 meters
100 miles


Low pressure at eye raises sea level (minor effect) combined with winds pushing water towards land with no place else to go (major reason)

Katrina MM5-GFDL 1.67 km Rain Rate (mm/h) 0600 UTC 27 Aug 2005



Total energy released through cloud/ rain formation

Chris Landsea

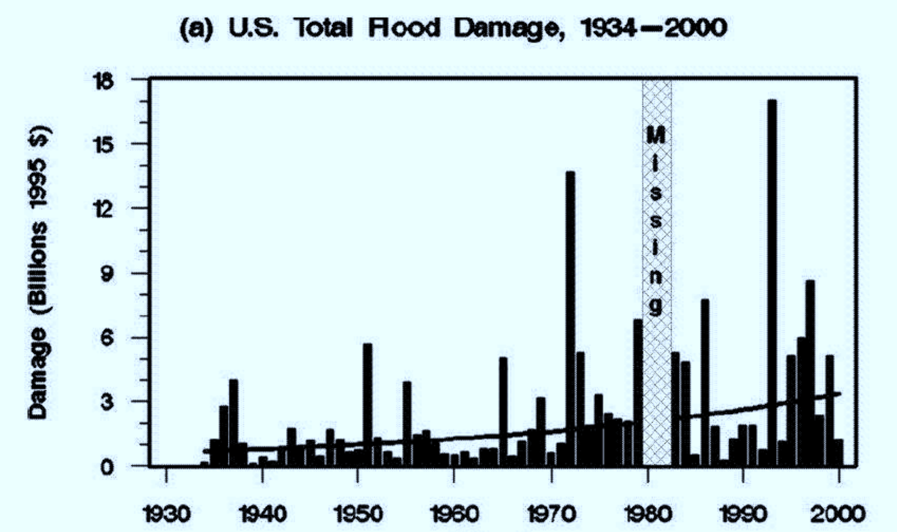
An average hurricane produces 1.5 cm/day of rain inside a circle of radius 665 km Converting this to a volume of rain gives 2.1×10^{16} cm^3/day.

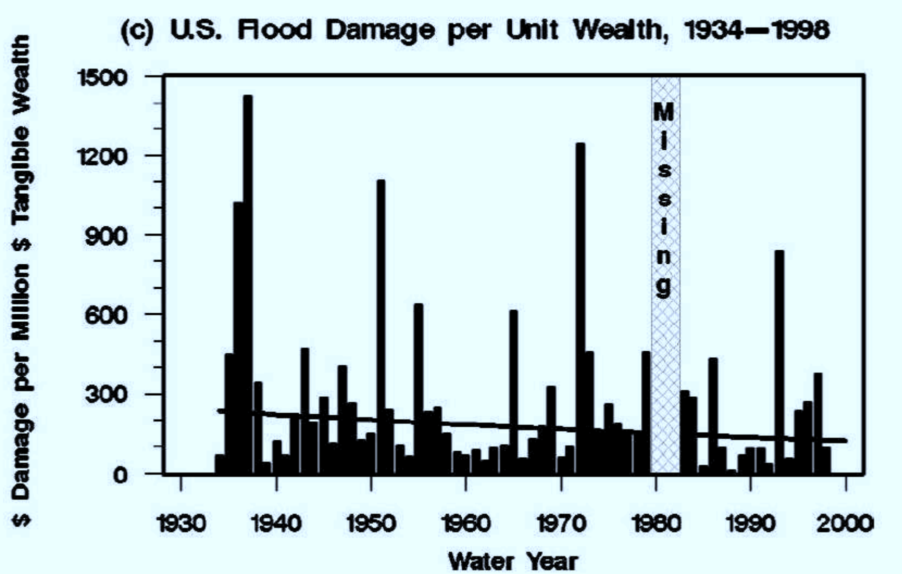
Using the latent heat of condensation, this amount of rain produced gives 5.2×10^{19} Joules/day.

This is equivalent to 200 times the world-wide electrical generating capacity!

Flooding

Is hurricane damage increasing?





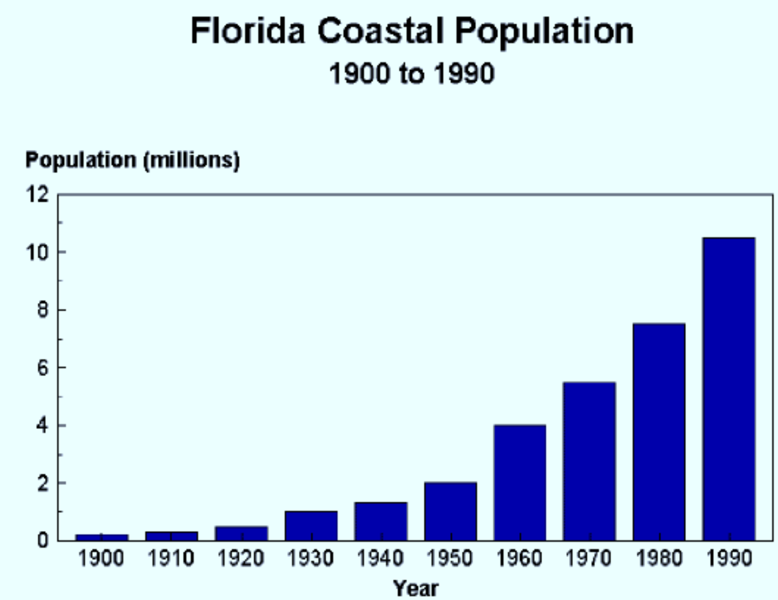
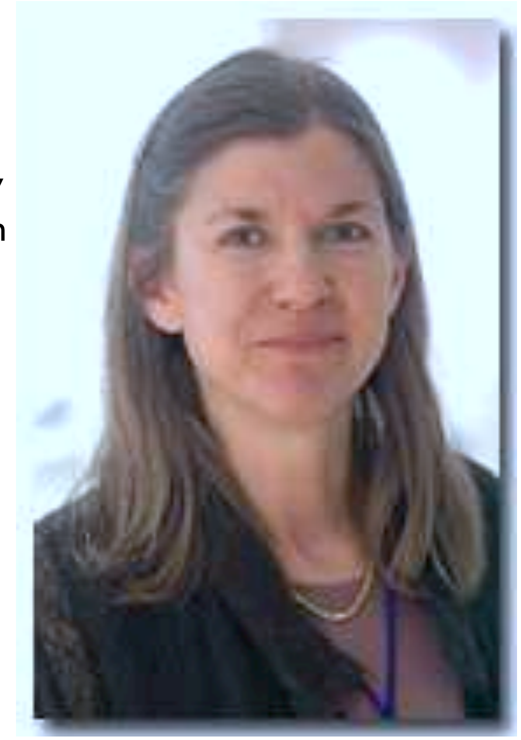


Figure 3. Growth in Florida's coastal population 1900-1990.
Source: U.S. Census.

The hurricane controversy

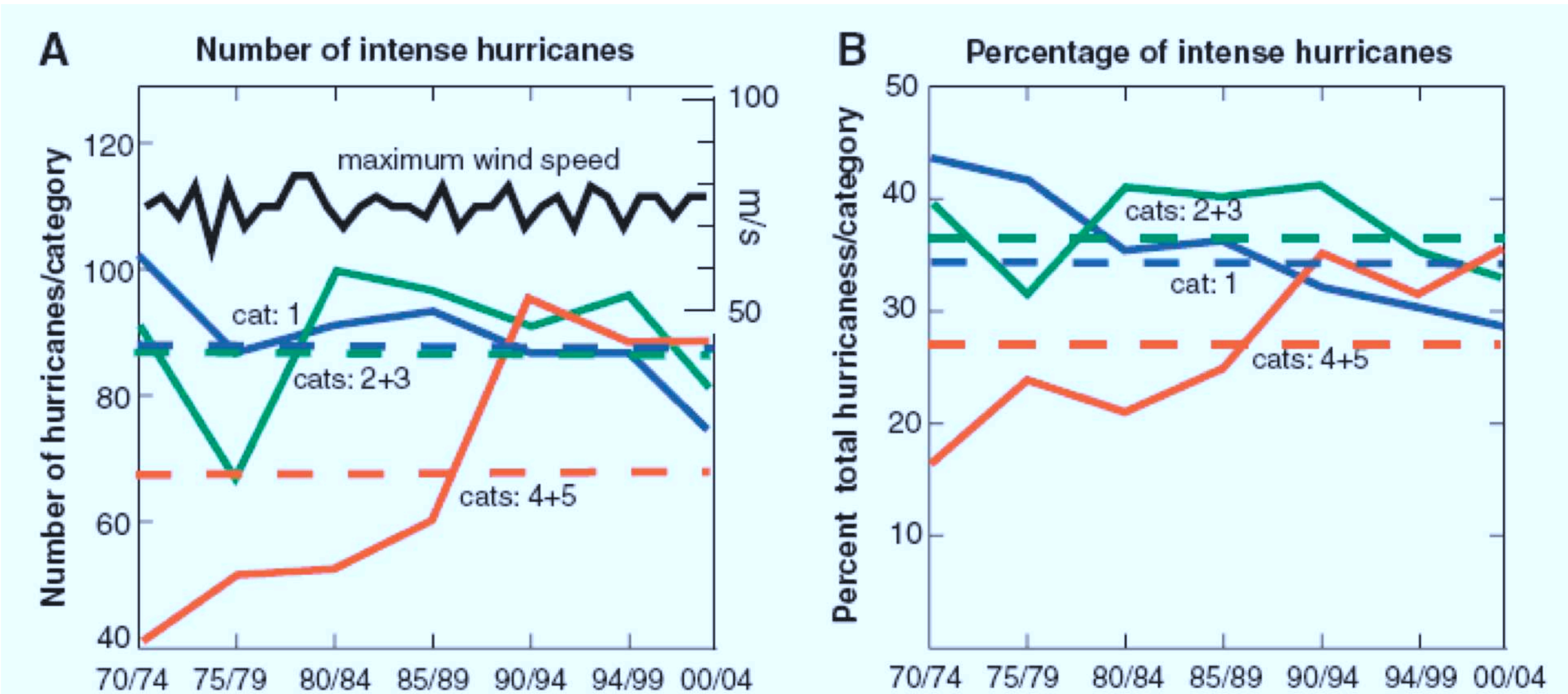
William Gray
Colorado State University



Judith Curry
Georgia Tech

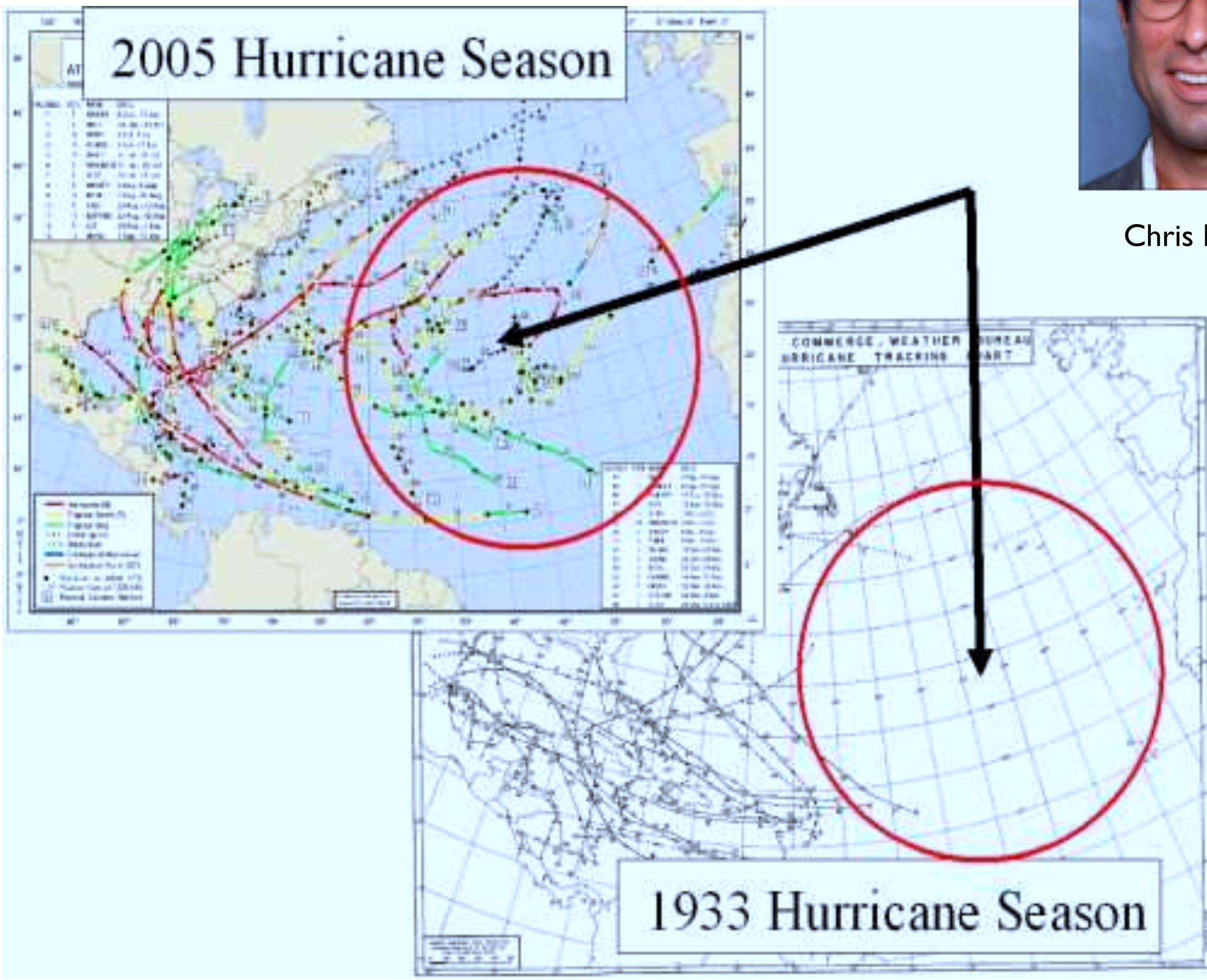
Christopher Landsea
NOAA/AOML
Miami

Kerry Emanuel
MIT



From recent paper of Webster, Holland, Curry and Chang

Claim a ~50% increase in category 4&5 hurricanes



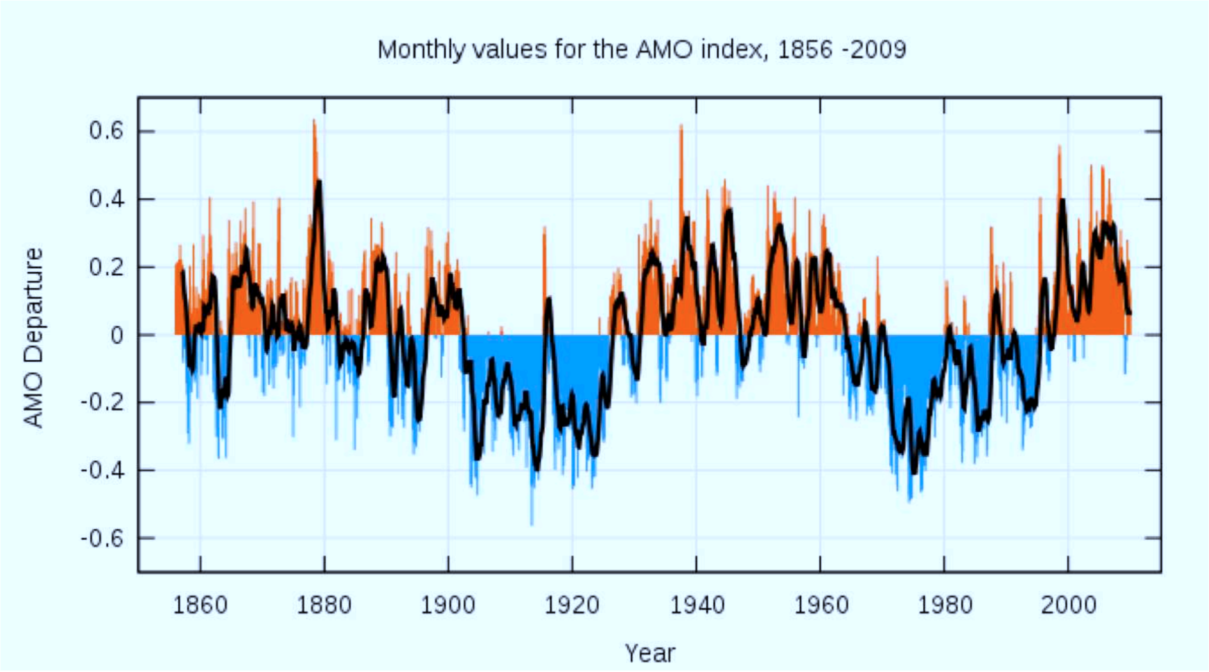
Chris Landsea

Argues that recording instruments changed
not the hurricanes

William Gray

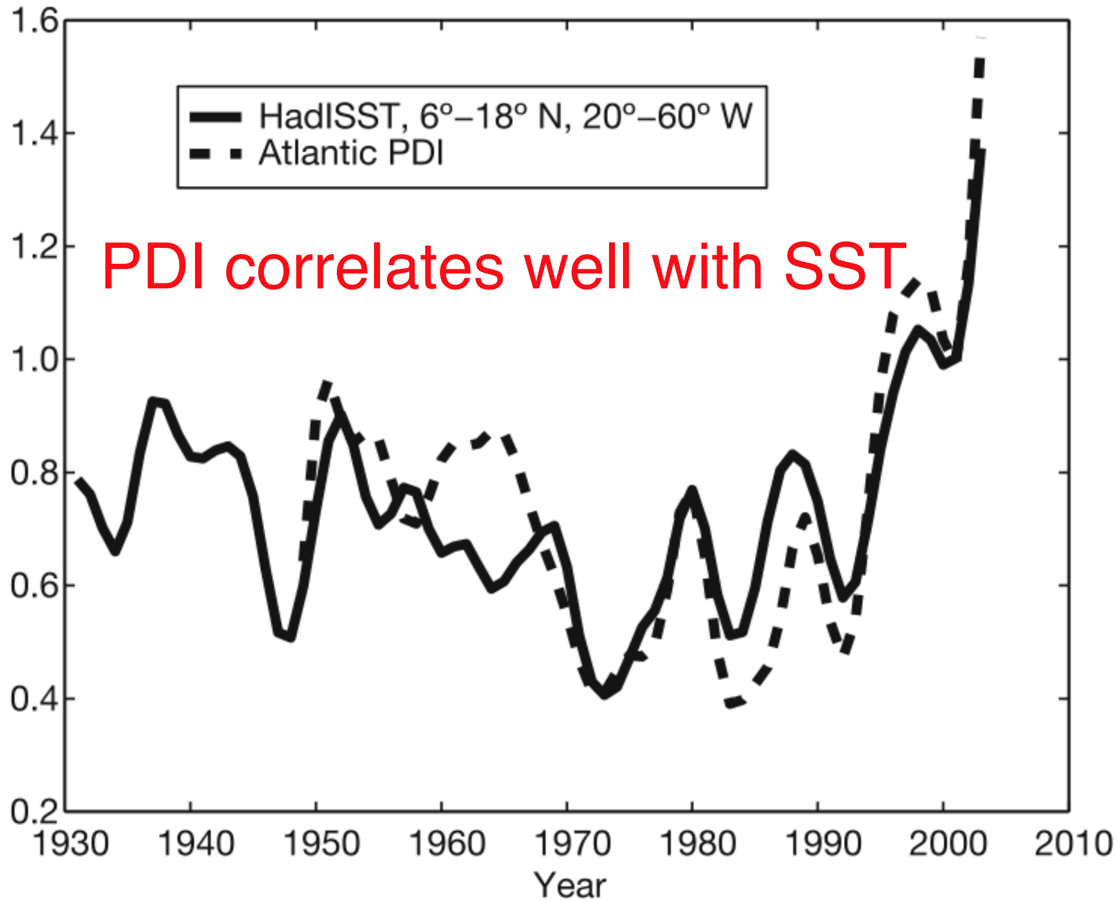
Made a career predicting hurricanes each season, mainly from ocean temperature and El Nino index

Claims hurricanes are tied to Atlantic Multidecadal Oscillation (probably varies with Atlantic deep water formation)



Correlation with hurricanes is weak and only applicable to Atlantic

Are hurricanes becoming more intense?



Kerry Emanuel

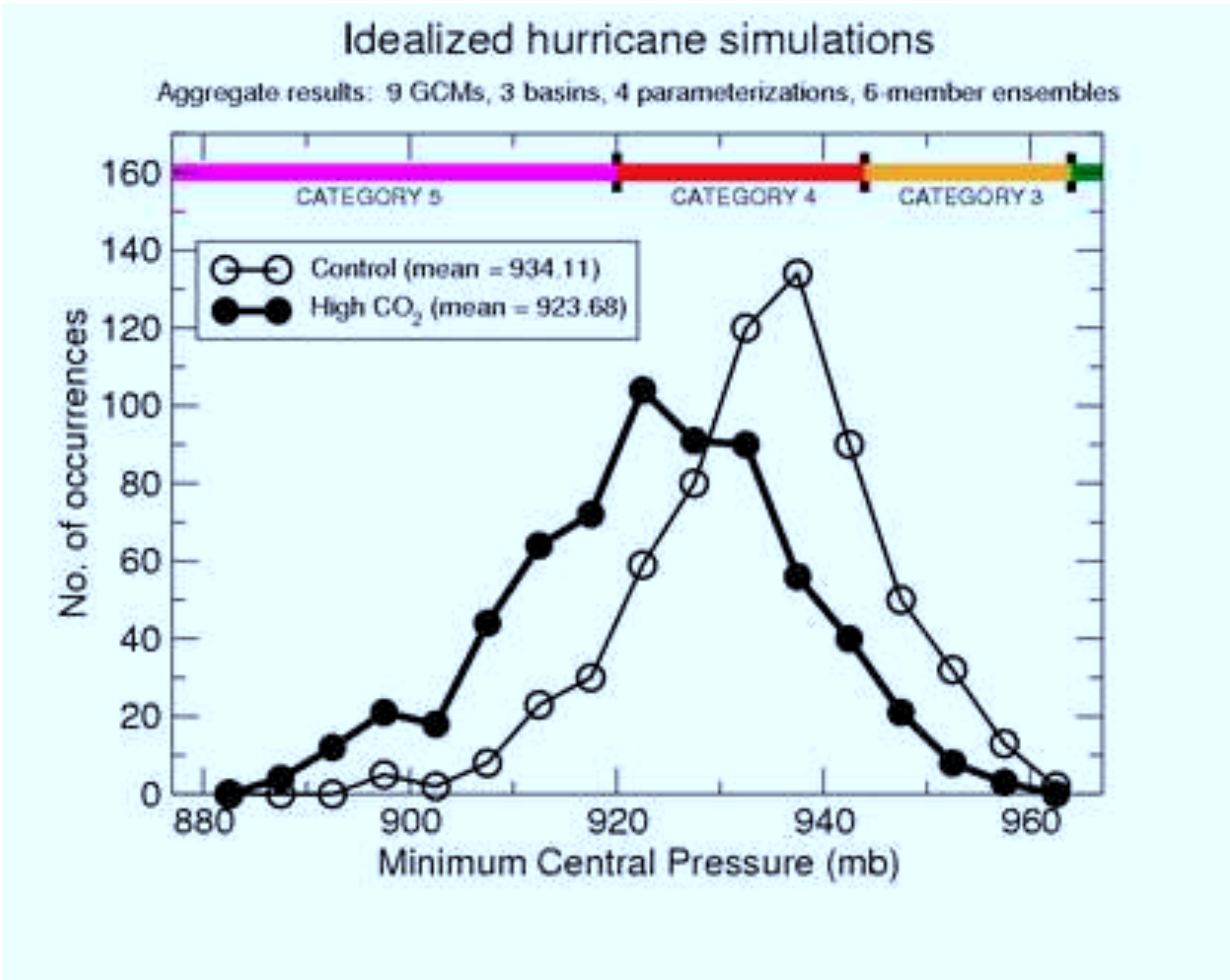
PDI stands for “power dissipation index” a measure of the cube of the maximum wind speed

Should we expect that hurricanes will become more intense?

Competing factors: Higher SST, but more frequent high wind shear (as in El Ninos)

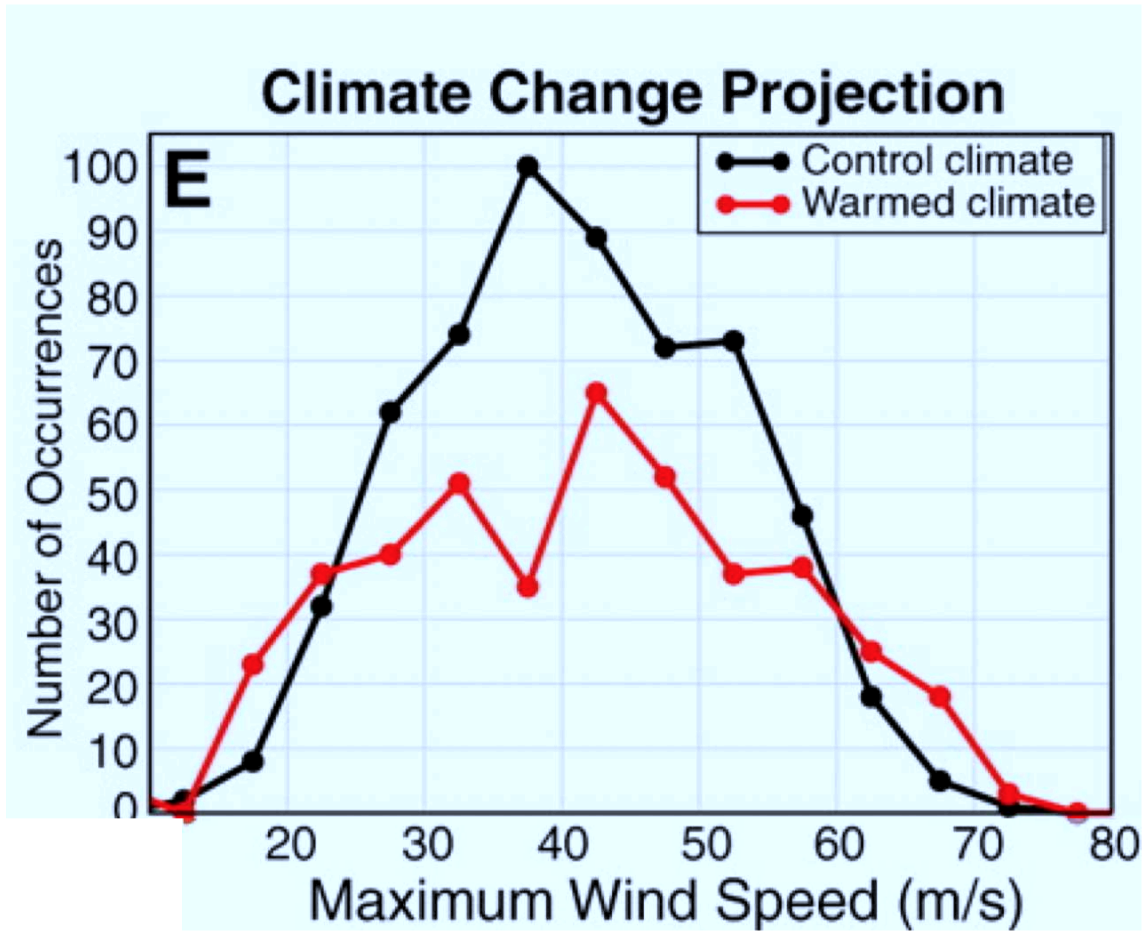
Which wins?

Knutson and Tuleya (2004) said fewer total but more frequent intense storms



Tom Knutson

Updated by Bender, Knutson et al (2010) used twice as many models and found same basic result, with many more high speed (or intense) storms. But won't be detectable until nearly 2100!



Can individual hurricanes like Hurricane Katrina be attributed to global warming?

No

Can it be said that global warming made an individual hurricane like Hurricane Katrina stronger than it would have otherwise been?

Not a good way to frame the question. Confuses climate and weather.

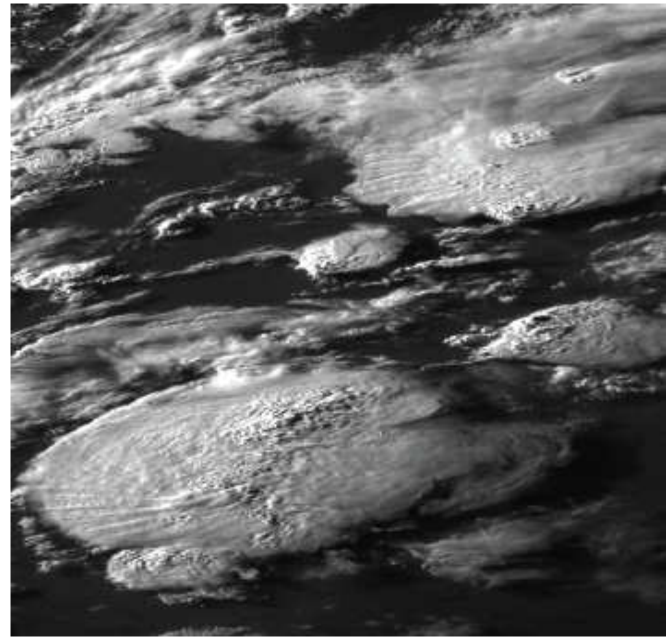
Are hurricanes becoming more intense?

The evidence is suggestive, but not conclusive at this point.

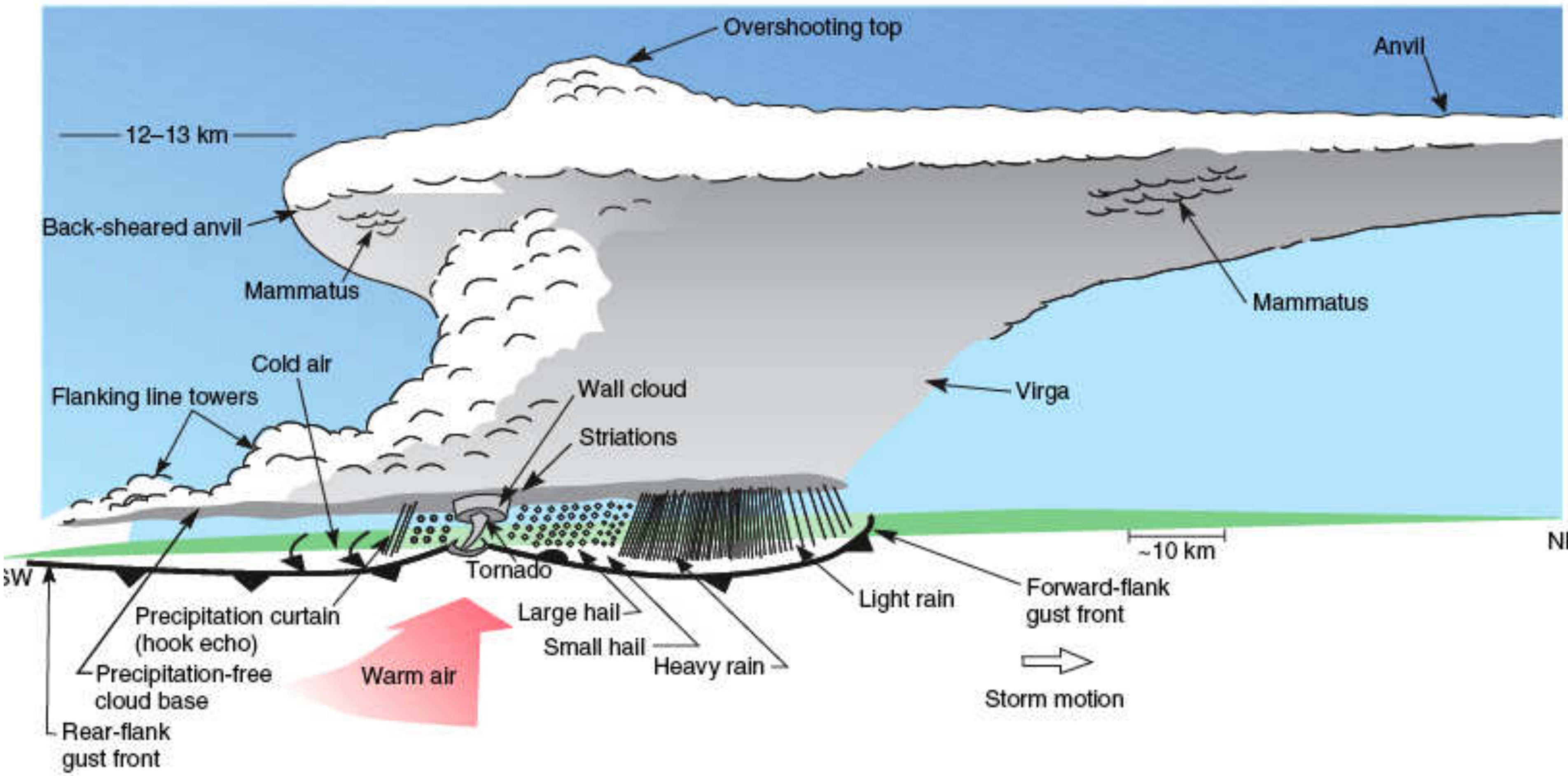
Should we expect that hurricanes will become more intense?

Yes. Heavier rains, stronger winds, stronger storm surges.




More tornadoes?



Overshooting top
Anvil
12–13 km
Back-sheared anvil
Mammatus
Mammatus
Cold air
Flanking line towers
Wall cloud
Striations
Virga
SW
Tornado
NE
~10 km
Precipitation curtain
(hook echo)
Precipitation-free
cloud base
Rear-flank
gust front
Warm air
Large hail
Small hail
Heavy rain
Light rain
Forward-flank
gust front
Storm motion

Will global warming bring more tornadoes?

Same issues as with hurricanes

Hard to prove the existence of a trend, but

there's reason to believe that storms that derive their energy from the release of latent heat with the condensation of water vapor will be more intense in a warmer world with more atmospheric water vapor.

Summary of Storm Impacts

SST must be at least 26^o C throughout a depth of 100 m for Hurricanes to strengthen. They must be at least 5^o off the equator. These are general, not absolute, rules.

Hurricanes are weakened by high vertical wind shear. La Nina’s are associated with a shift in location of high probability of tropical cyclones.

Not all hurricanes make landfall.

Tropical cyclones have caused devastation throughout history. They have Bangladesh once in 1991 killing 144,000 and before in 1970 killing a half million.

Hurricanes range in strength on the Saffir-Simpson scale from 1 to 5, depending on wind speed.

Summary of Storm Impacts

Winds cause direct damage, but they also can blow water against the shore. The storm surge is the sum of this plus the rise in sea level cause by the very low pressures of the tropical cyclone. Hurricanes can also rain ~10cm/h for a few hours.

The global warming impact on hurricanes is hotly debated. As warm SST fuels storms, it seems plausible that they might become more intense. Climate models agree but also show a decrease in total number.

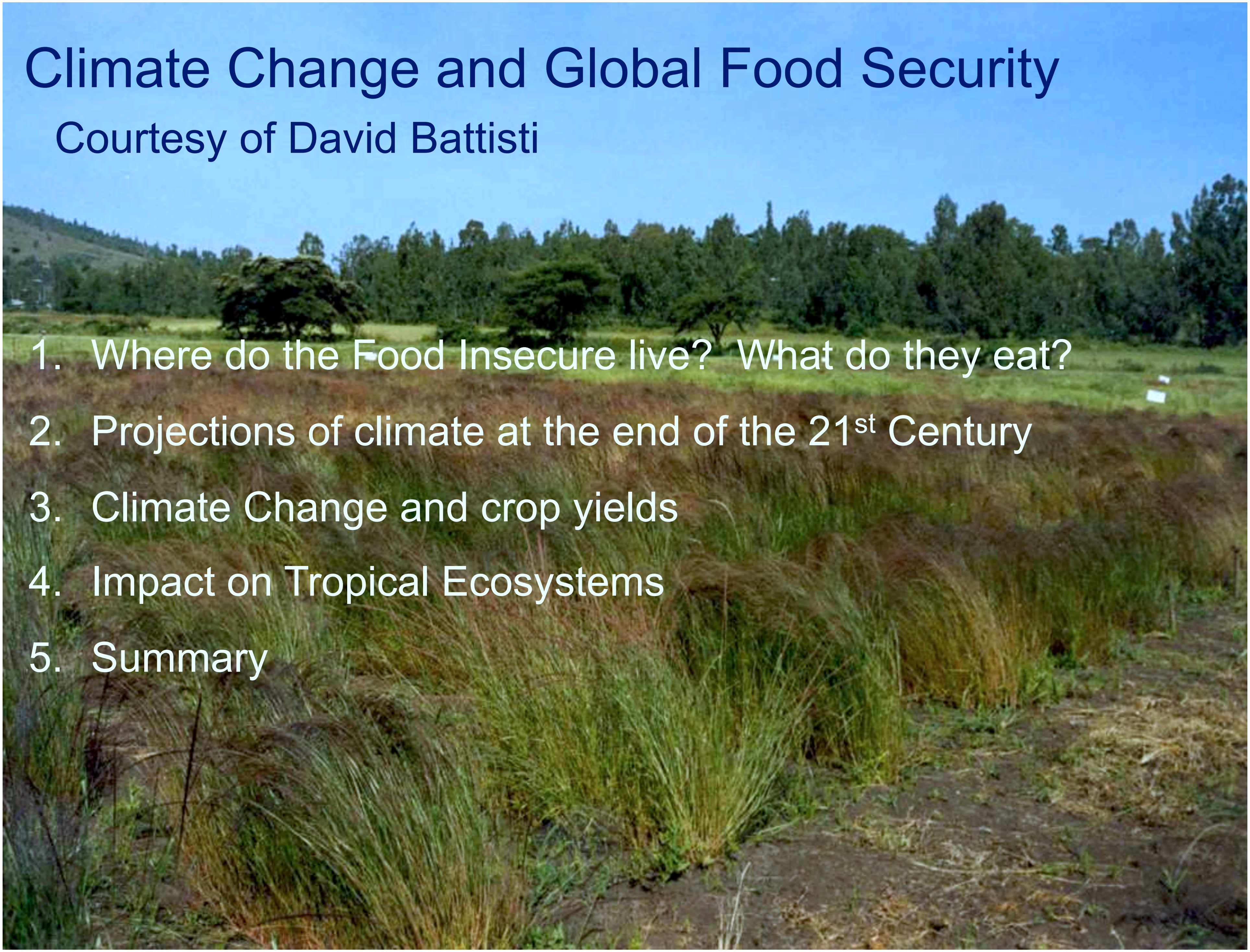
The data appear to show a rise in intense hurricanes, but some argue this is a result of instrumental changes. Climate models suggest that the trend should not be significant until near the end of this century.

There might be compensating changes in wind shear (more frequent El Nino’s) associated with global warming that reduces hurricane number/strength.

Summary of Storm Impacts

The damages from hurricanes appears to have risen moderately, but it could be just because people are moving towards the coasts.

Tornadoes also are likely to become more intense, but it is equally hard to prove whether it has happened yet.



Climate Change and Global Food Security

Courtesy of David Battisti

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

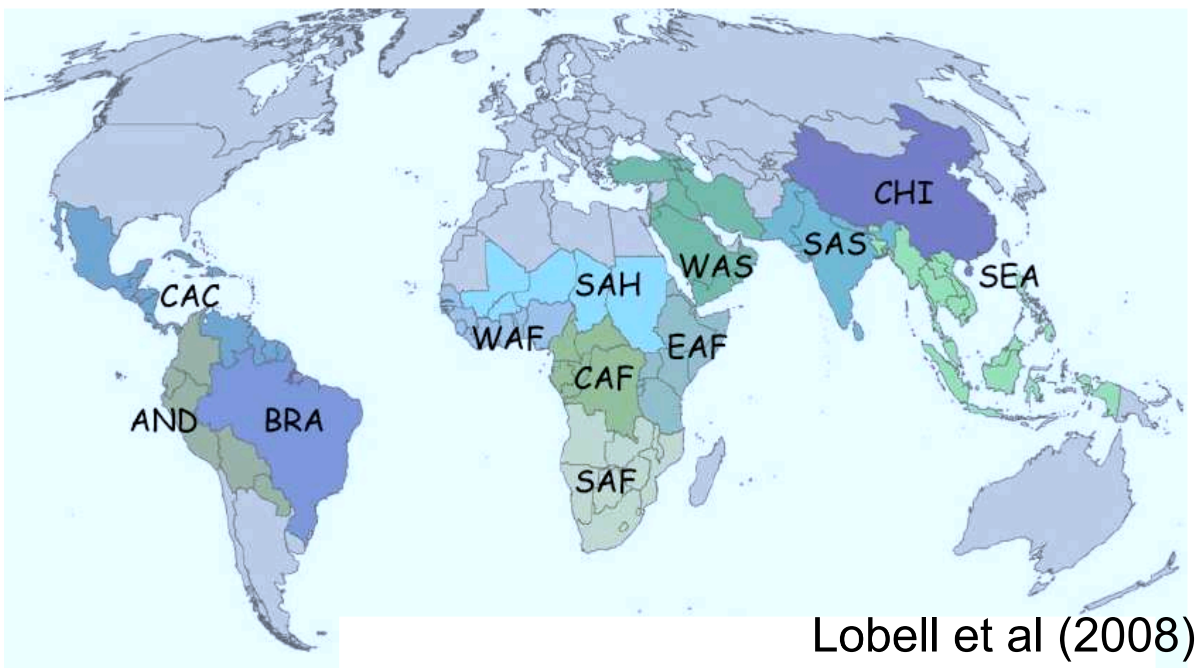
David Battisti in Indonesia talking to farmers

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

(1) Stanford, (2) University of Wisconsin

Where do the Food Insecure live?

800 M people are malnourished today
- 95% are in the tropics/subtropics

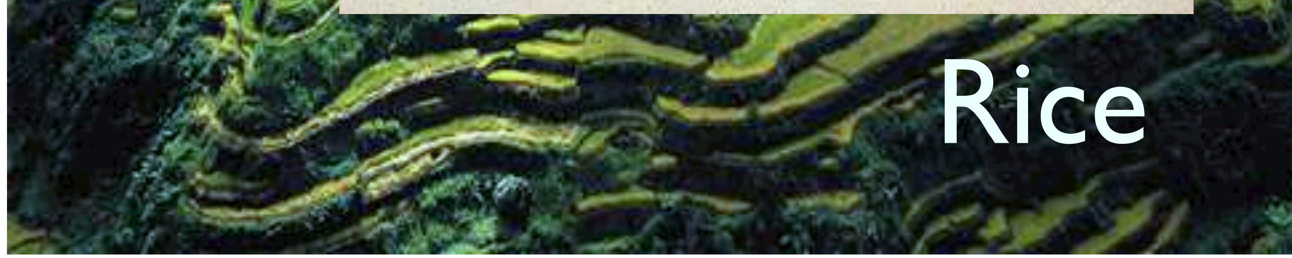


Lobell et al (2008)

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

What do the Food Insecure eat?

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



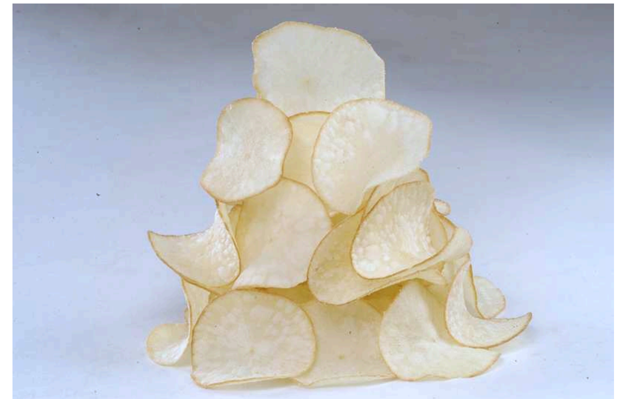
Rice


Wheat



Maize (corn)

Cassava (Yuca)




Climate Change and Global Food Security
Climate Change and crop yields

The recent 1998-2001 drought in the Central Asia

~ 30% annual mean precip deficit

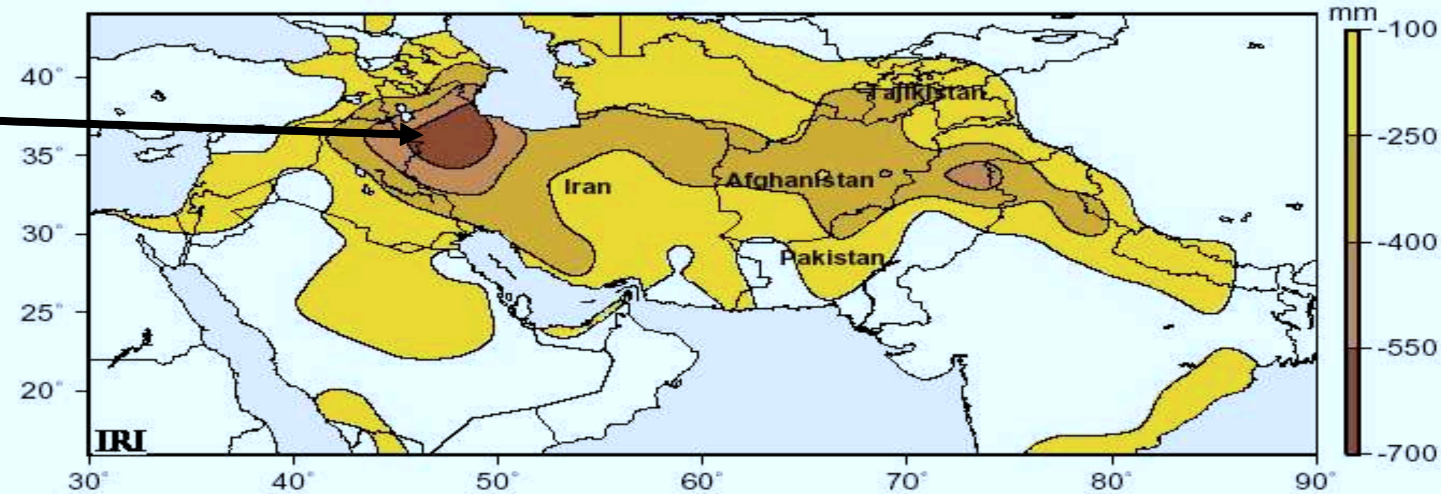


Figure 2. *Regional Drought Situation: Deficit in precipitation totaled over 1998-2001.*

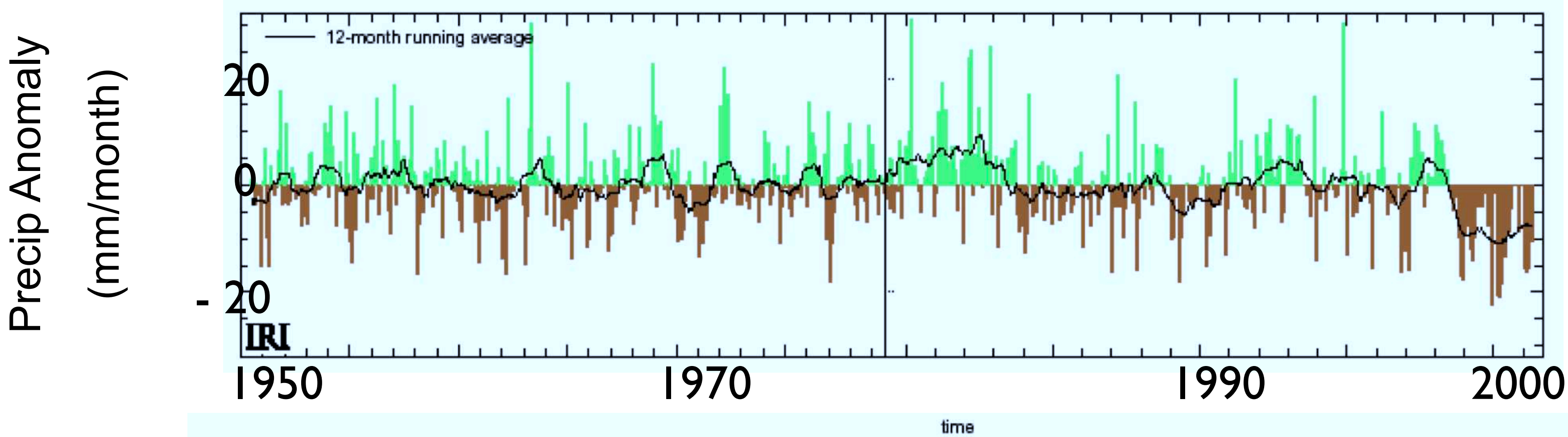


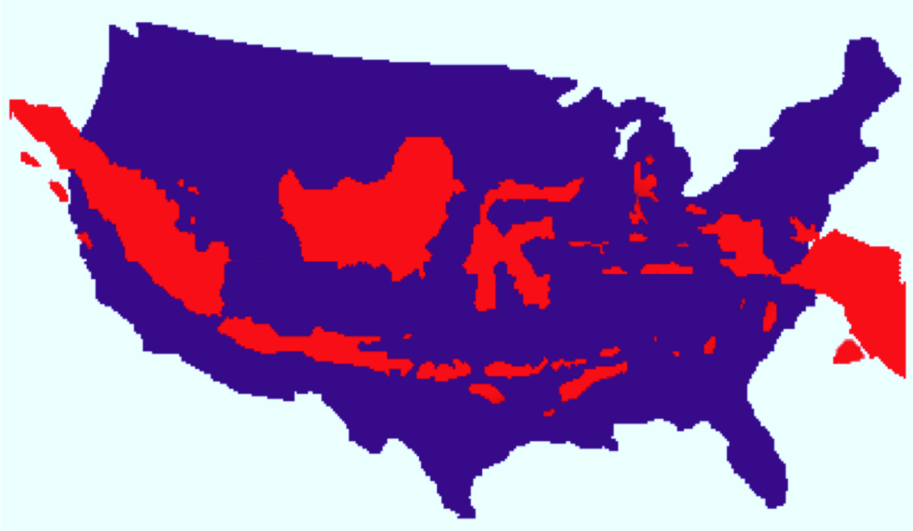
Figure 6. *Precipitation Anomalies: Monthly precipitation departures from the historical average over Central and Southwest Asia (over 25N-42N; 42E-70E), from Jan.1950 - Sep. 2001.*

The recent 1998-2001 drought in the Central Asia

•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

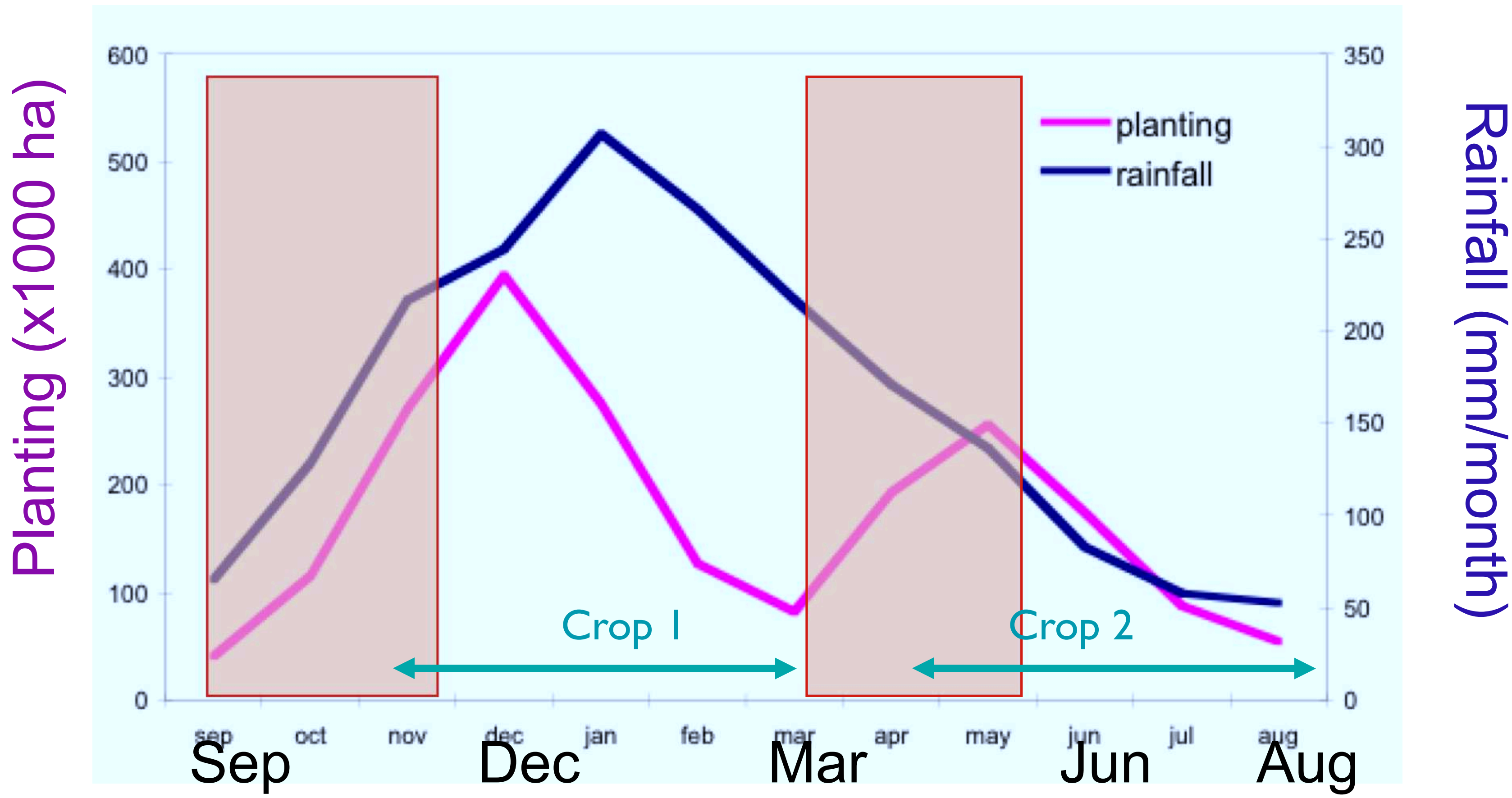
By the end of the century, similar *water* stress on agriculture will be the norm throughout the tropics and subtropics due to the *climate changes* associated with increasing CO_2.

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 Nino/Southern Oscillation (ENSO) greatly affects annual rice production by delaying monsoon onset
- The typical El Nino event delays onset by ~30 days
  - reduces total *annual* rice production by 1,000,000 metric tonnes (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
  - Building on long-term relationships key

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 ENSO-based variability on rice production change in the future with global warming?

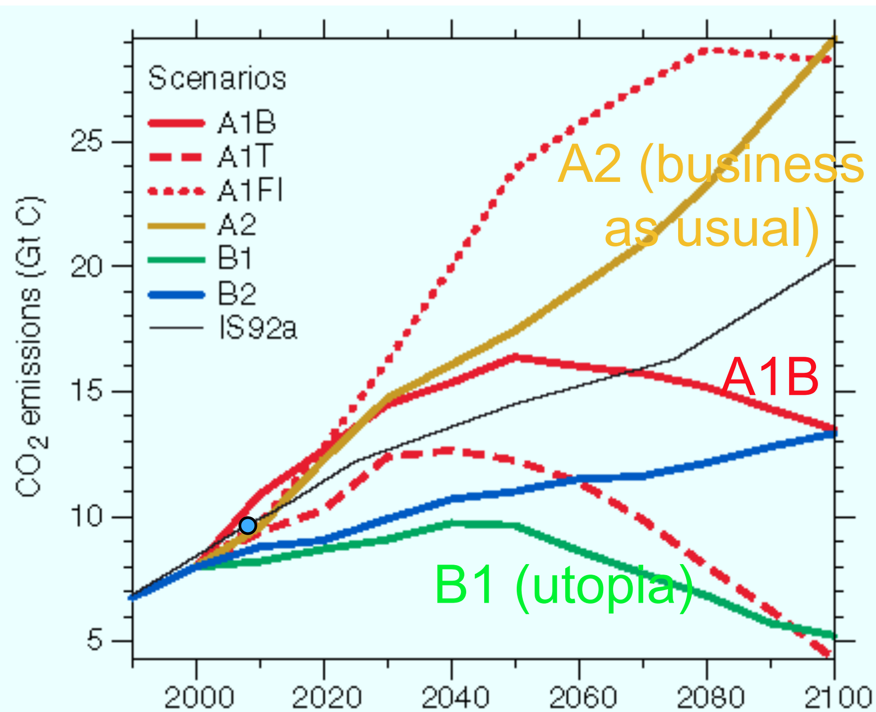
Climate Change and Global Food Security

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

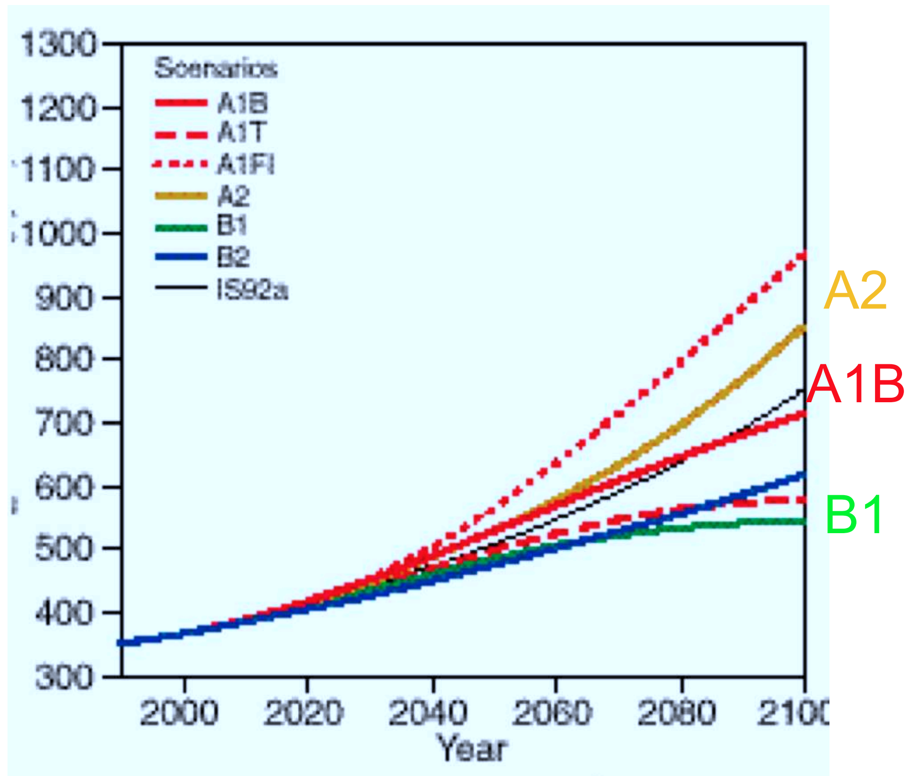
– Focus on those changes that are “very likely” (i.e., those that are either deemed to have a greater than 90% chance to occur “based on quantitative analysis or an elicitation of the expert views”)

How much Carbon Dioxide will be released into the atmosphere?

Emissions

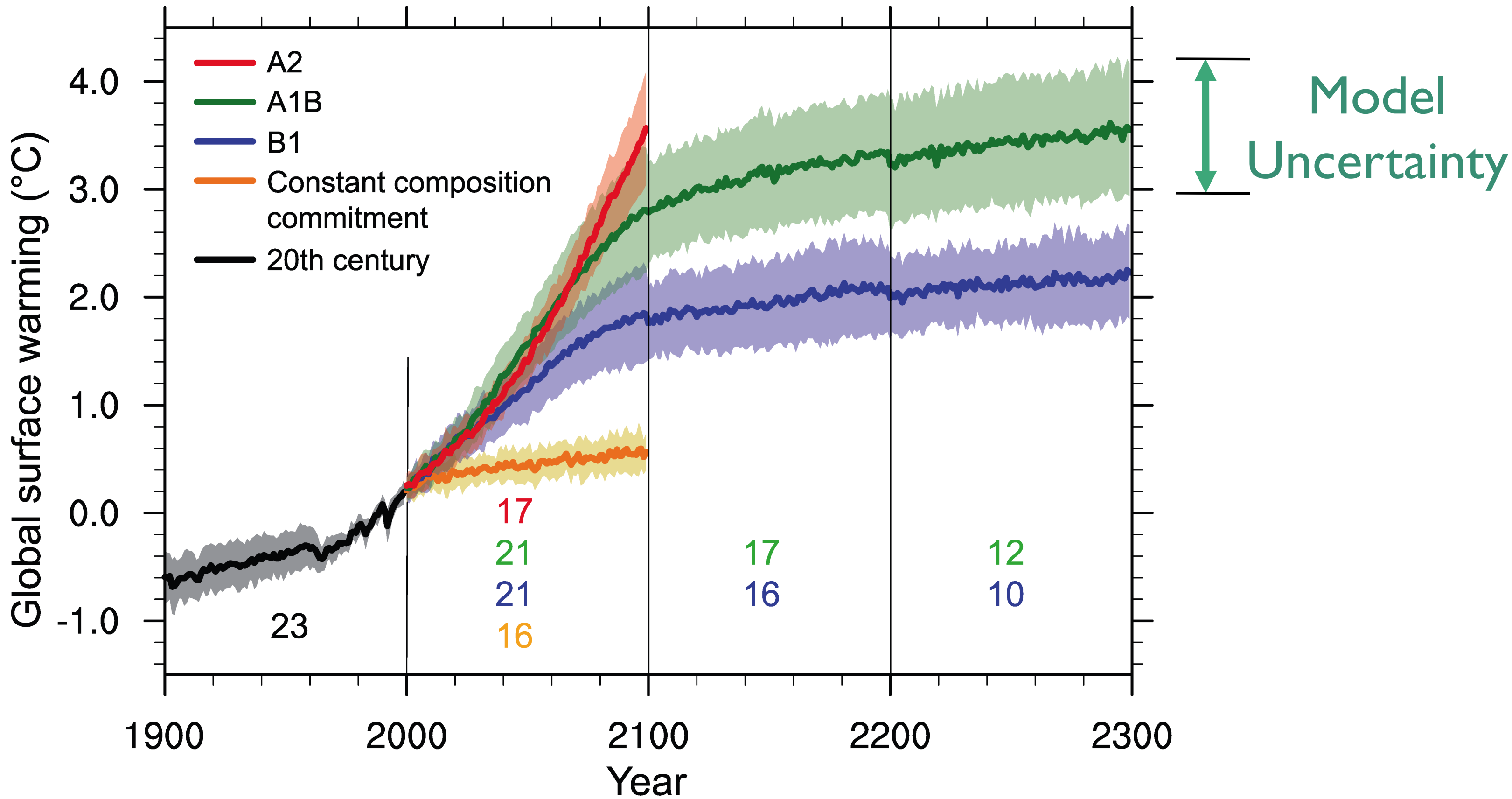


Concentrations



Estimates depends on population and economic projections, future choices for energy, governance/policy options in development (e.g., regional vs. global governance)

Global Annual Average Surface Temperature



Referenced to the 1980-1999 Average Temperature

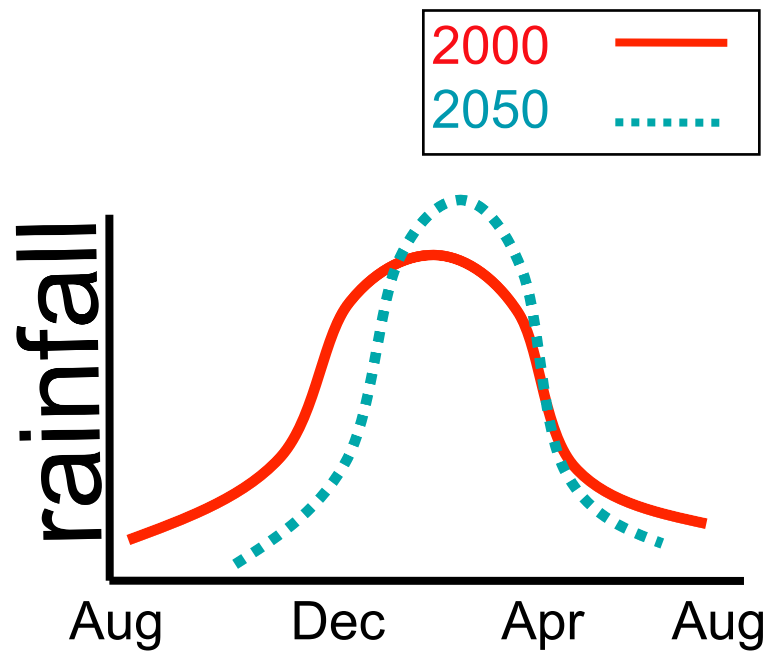
Solid lines: average of all models used. Number of models used varies; shaded area is the standard deviation of the models

Projecting rainfall in Java/Bali in 2050

- Use the output from IPCC models with two emissions scenarios
  - A2: relatively high greenhouse gas emissions (15)
  - B1: low emissions, sustainable development (19)
- Build empirical models to downscale and de-bias precipitation from climate models
- *Provides full range of projections to span the space of uncertainty*

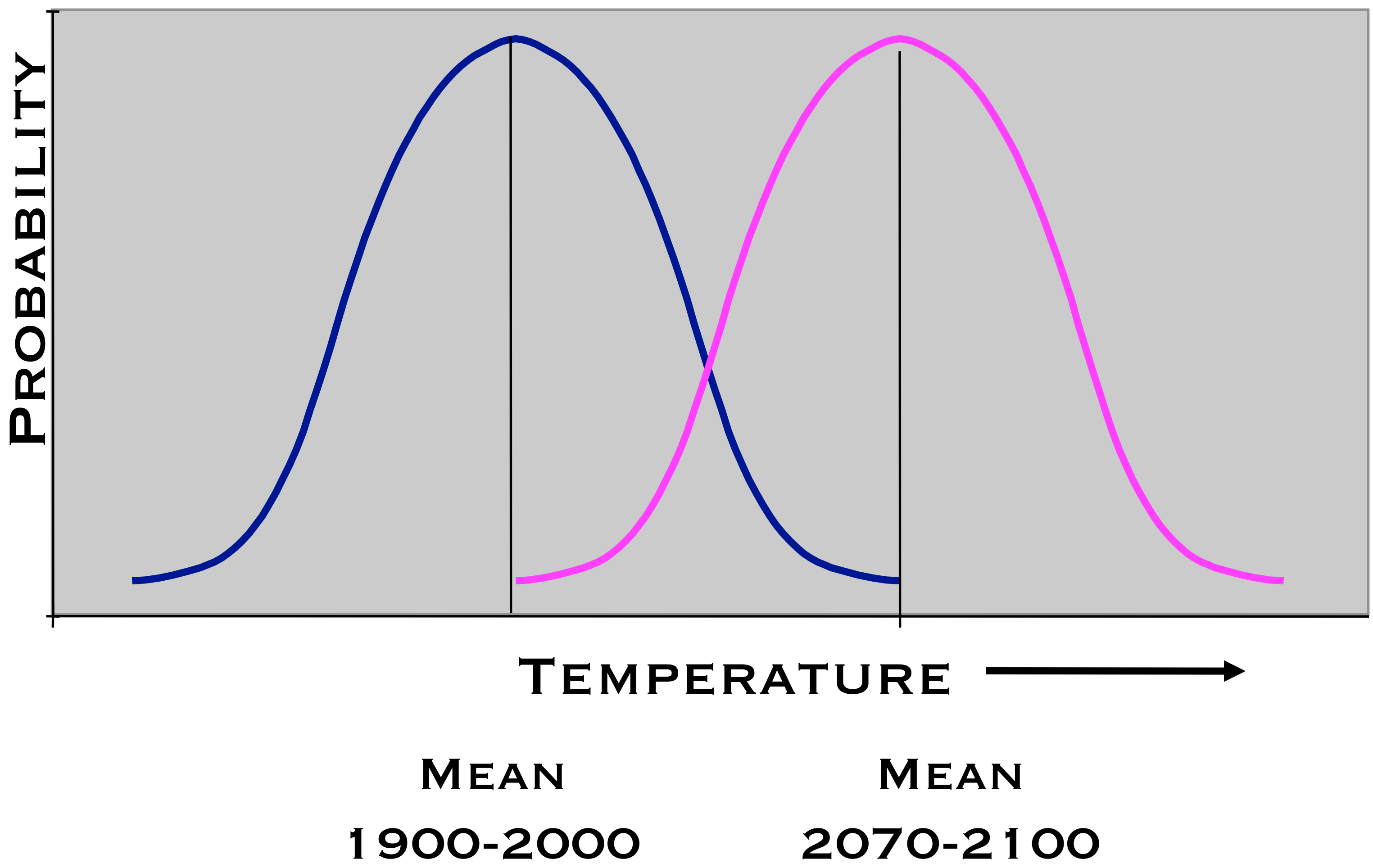
Findings: Java/Bali rainfall in 2050

- 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

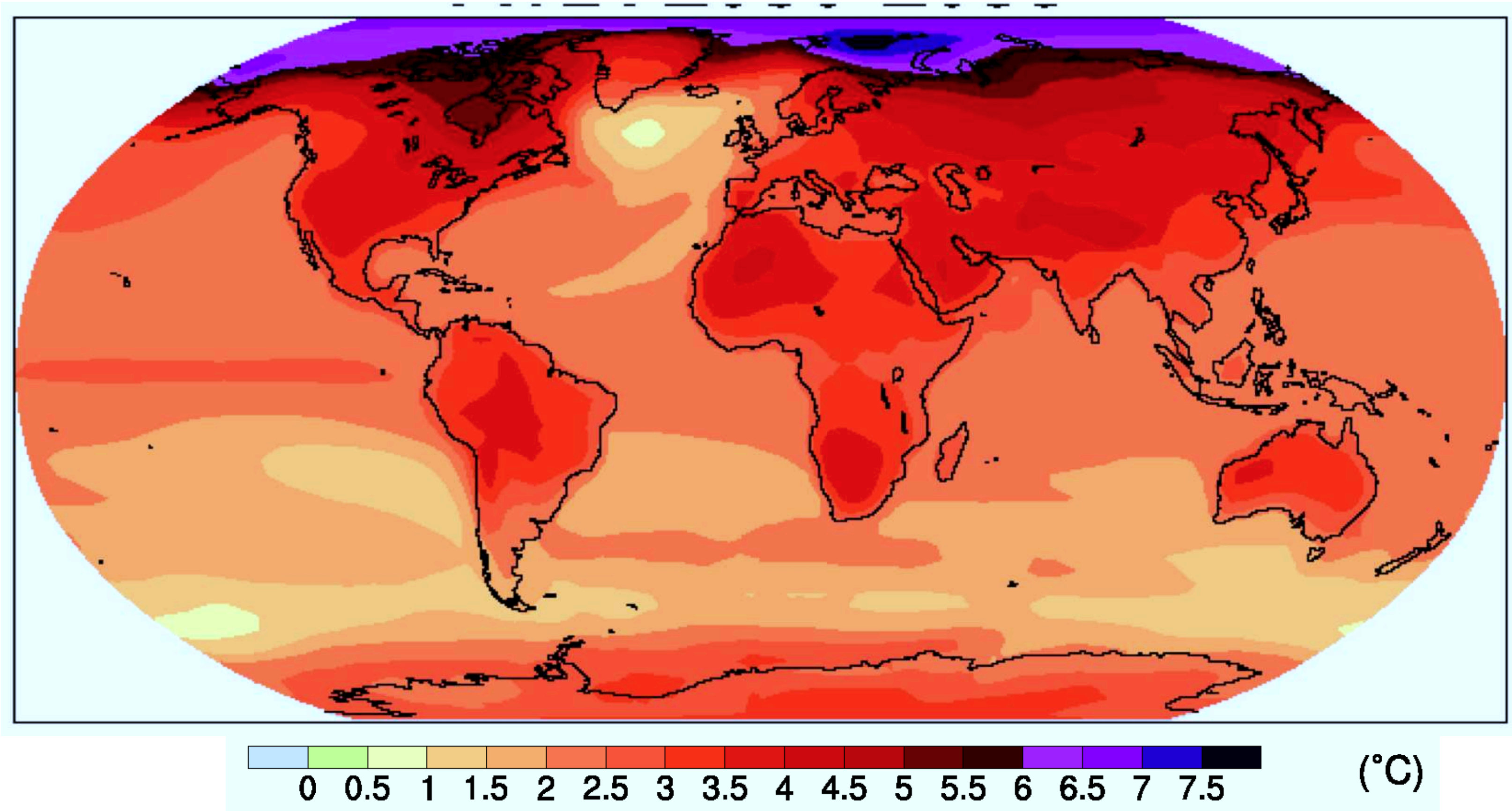


Net impact: By 2050, the second season rice crop is marginal (too short for two crops) & highly vulnerable

Projections of future temperature

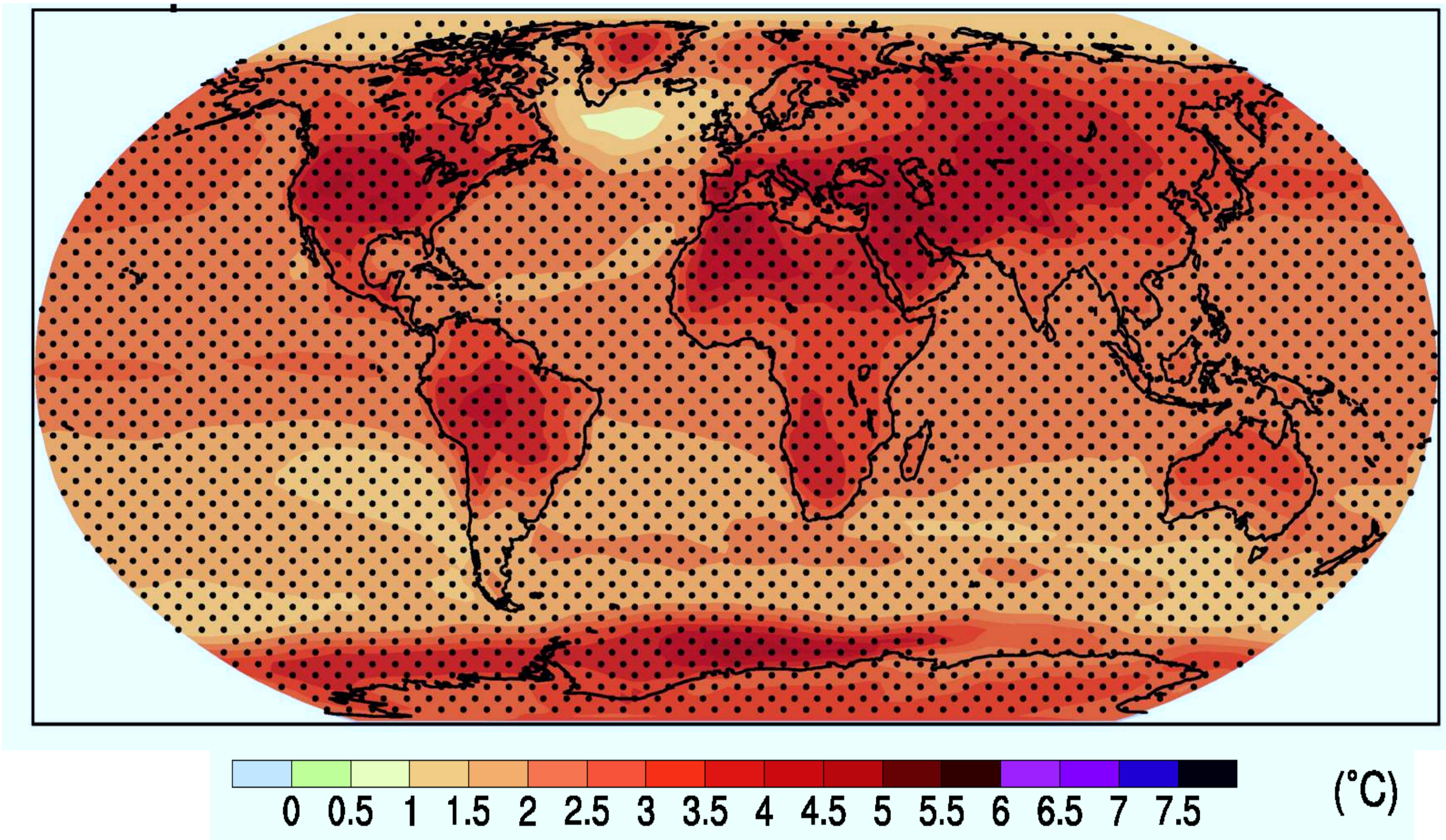


Projected Annual Average Surface Temperature Change: "2080-2099" minus "1980-1999"



Average of 21 climate models forced by Scenario A1B.
Multiply by ~1.2 for A2 and ~0.7 for B1

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

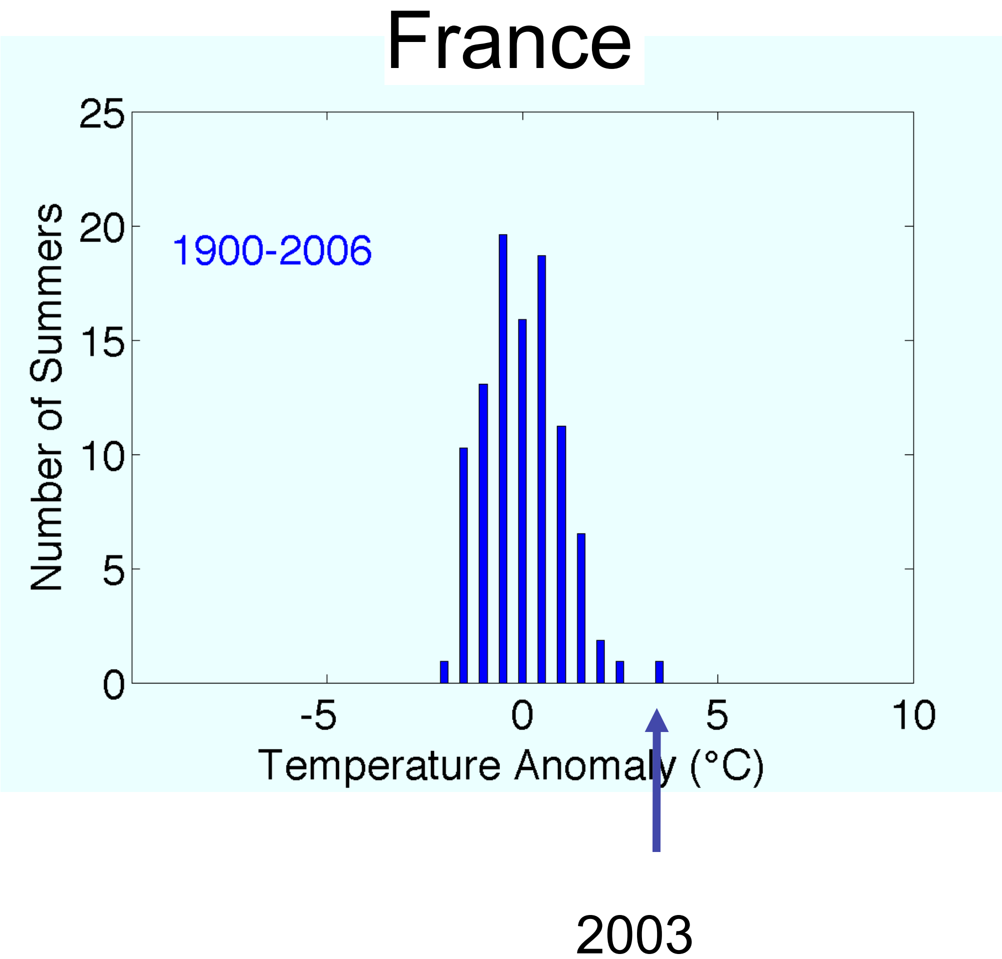
Extreme Heat in Western Europe in 2003:
JJA temperature 3.6°C above normal

• Italy:	36% maize
• France:	30% maize and fodder
	25% fruit
	21% wheat

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.

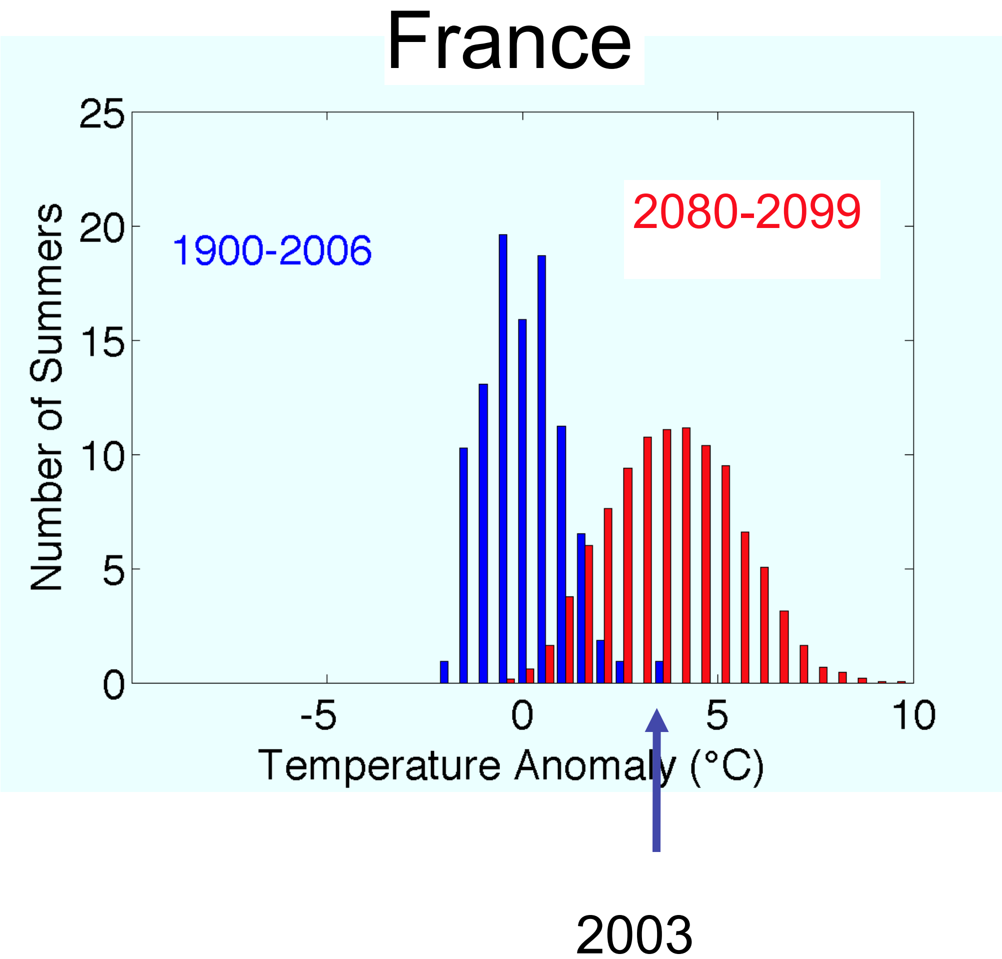
Refs: UNEP 2007; Easterling 2007; Earth Policy Institute 2006; Eurosurveillence 2005

Growing Season Temperature



Observed JJA Temp
(1900-2007)

Growing Season Temperature

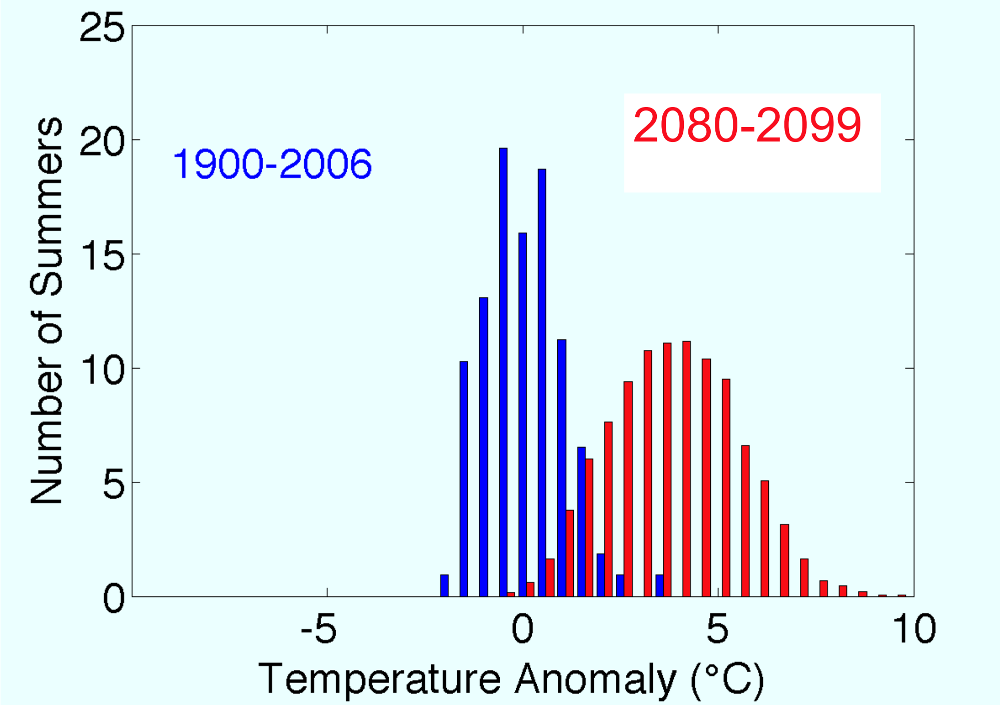


Observed JJA Temp
(1900-2007)

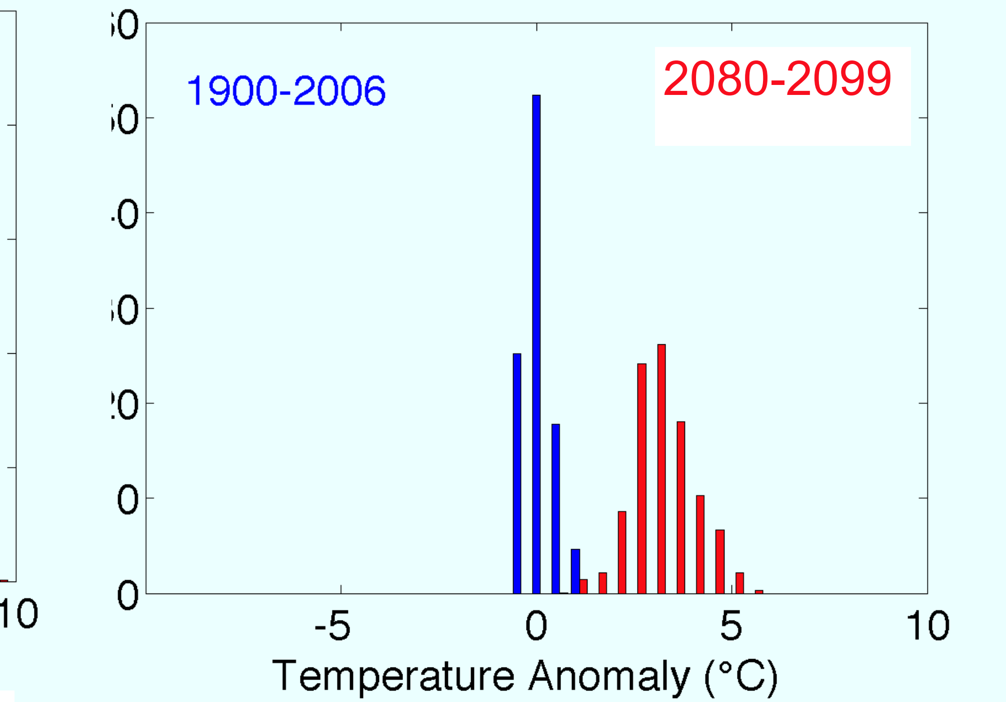
Projections use 22 climate models (IPCC AR4) forced by A1B Emission scenario. Variability taken from observations

Projections of Growing Season Temperature

France



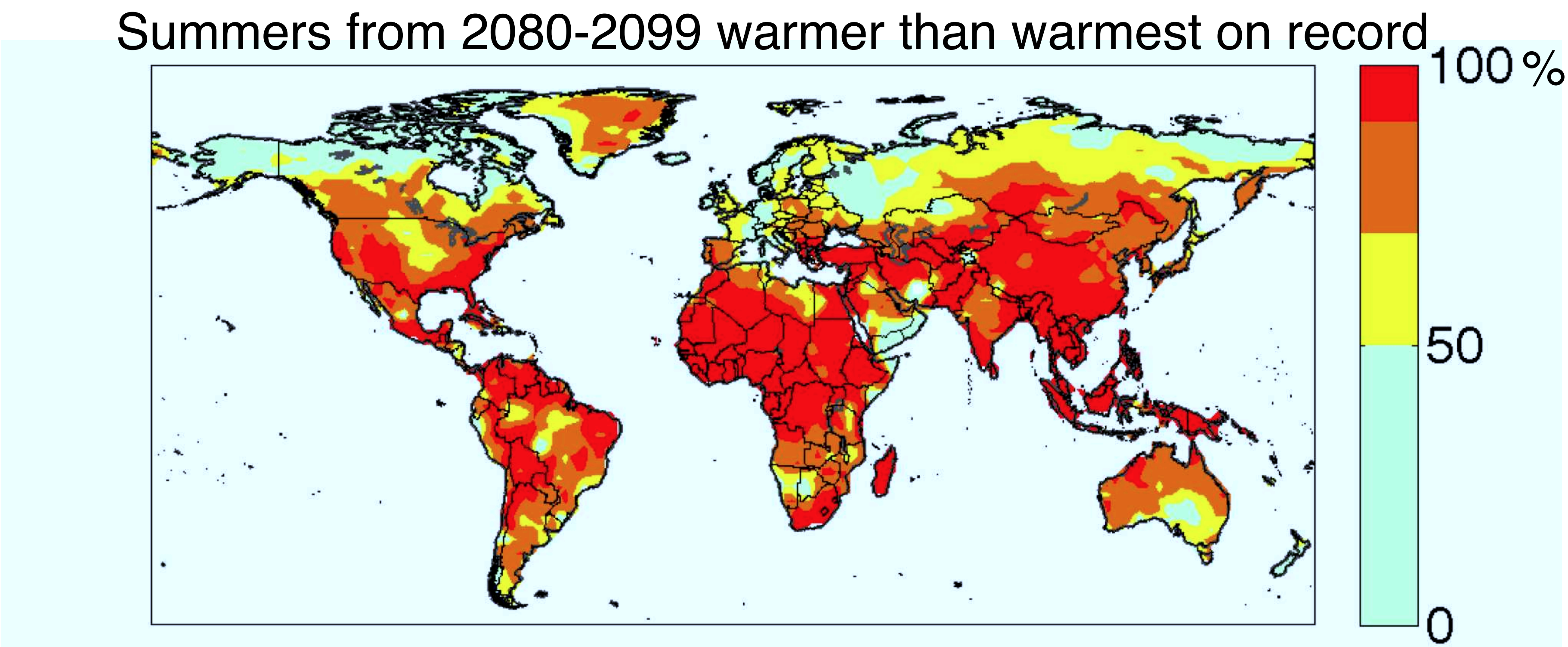
The Sahel



Extremes like 2003 are the norm

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

Projections of Growing Season Temperature



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

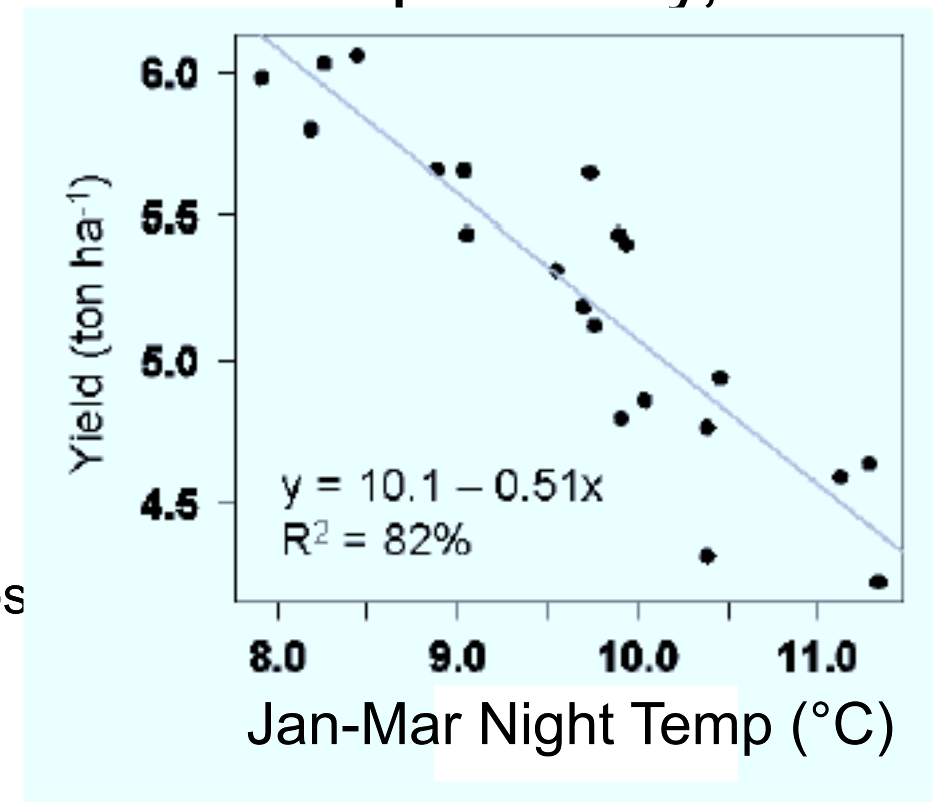
• Decrease in spikelet fertility

• Increased water stress

• Increased respiration

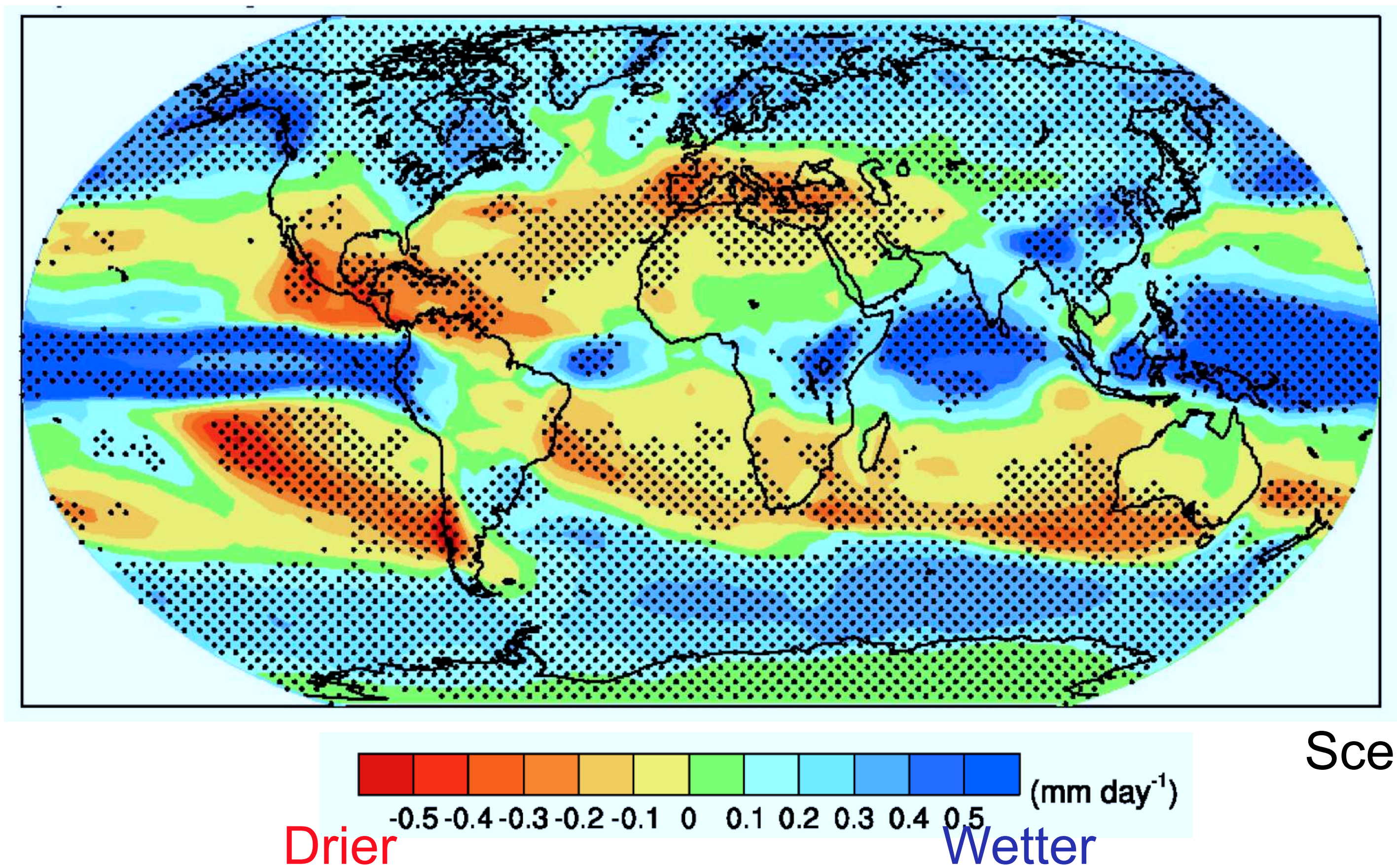
Important for all crops, but especially for wheat, rice and soybeans (nb, these are the C3 crops that would otherwise benefit from increased CO_2) **and maize**

Wheat Yield in Yaqui Valley, MX



Lobell 2007

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

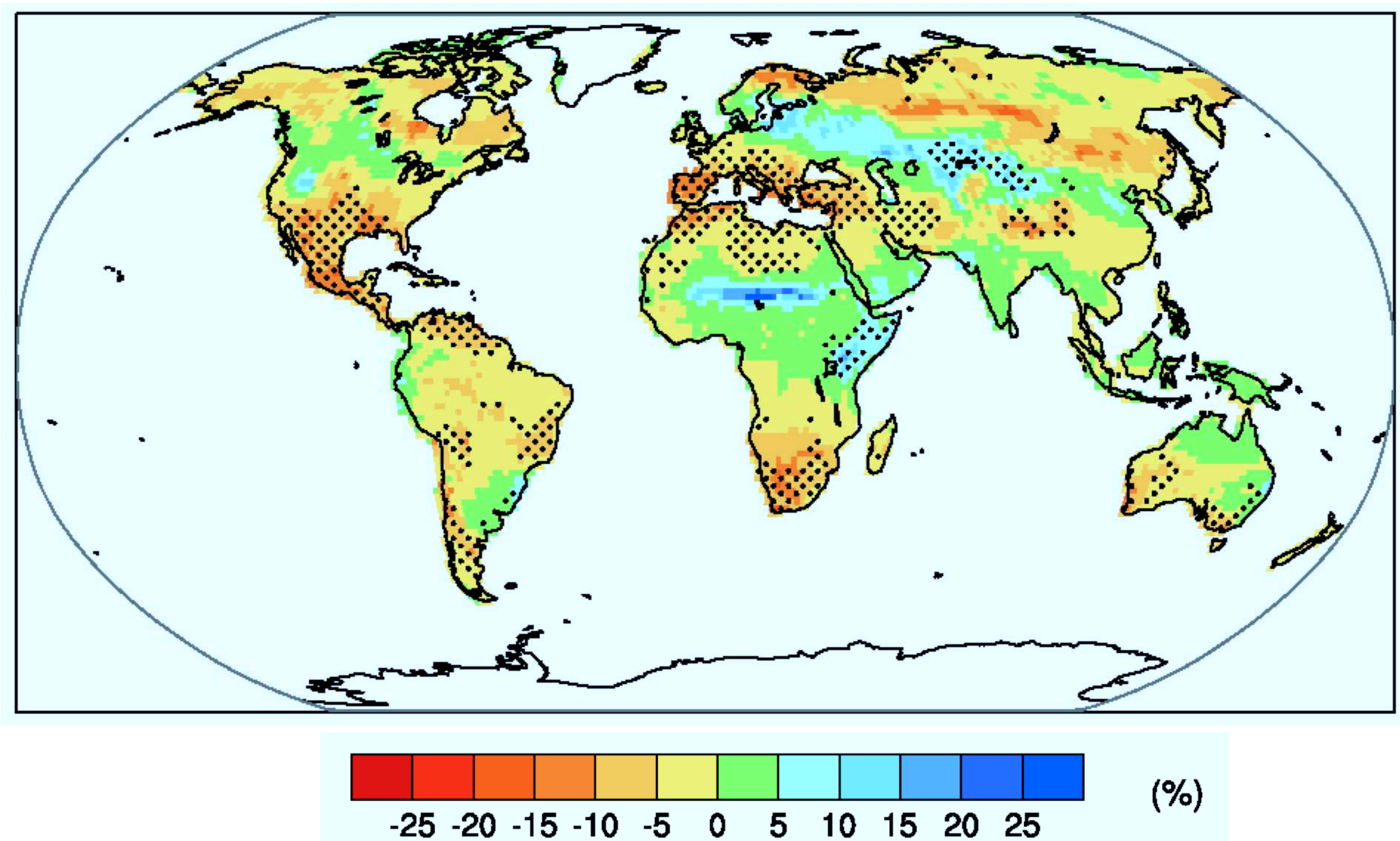


Scenario A1B

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

Projected Soil Moisture Change:
“2080-2099” minus “1980-1999”



Scenario A1B Drier Wetter

Climate changes due to human activity

Phenomenon[a] and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Virtually certain*[d]
Warmer and more frequent hot days and nights over most land areas	*Virtually certain*[d]
Warm spells/heat waves. Frequency increases over most land areas	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Very likely*

Virtually certain > 99%

Very likely >90%

IPCC 2007

Impacts of Climate Change

- Reduced yields of wheat, rice, maize and soybeans in the tropics/subtropics
  - Approximately -10% per 1ºC warming
  - Estimated reduction of 30-40% by 2100 in India, Africa, Middle East, Central America etc.
- Reduced nutritional content (especially protein in wheat and rice)
- Increased disease transmission rates
- Loss of water stored in snow pack and glaciers (e.g., Sierra, Himalaya)
  - Reduced duration of river supplied water, especially important for India and Bangladesh

Indirect effects

- Changes in pest and pathogens (yet unknown)
- Increased carbon dioxide and plants
  - Enhanced growth rate for **some plants** (benefits limited to the extratropics and they will reach threshold) “CO2 fertilization”
  - Effects on plant pathology (reduced protein content and resilience to disease)

Summary

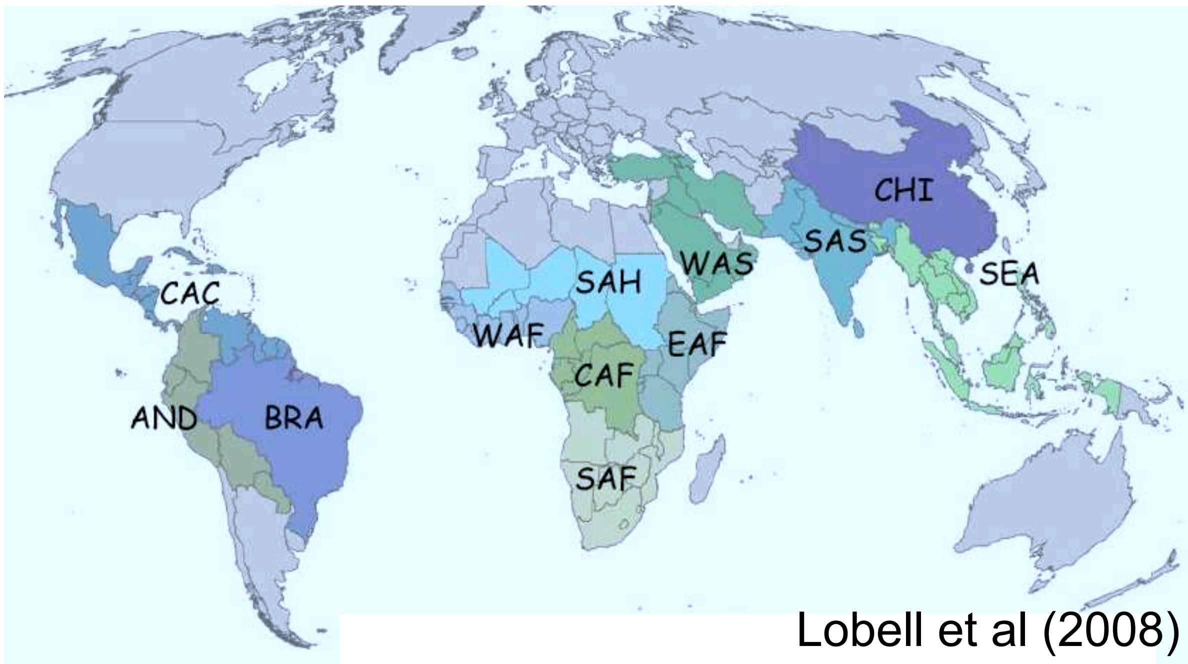
- By 2100, growing season temperatures will *very likely* exceed the warmest on record throughout the tropics and subtropics

  ⟹ 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

Where do the Food Insecure live?

800 M people are malnourished today
• 95% are in the tropics/subtropics



Lobell et al (2008)

The food insecure
- depend heavily on agriculture for food and income

- live in regions where agriculture will be most stressed by global warming

- live in countries with greatest population growth

Estimates: 200-400 M *more* people at risk of hunger by 2080 due to climate change