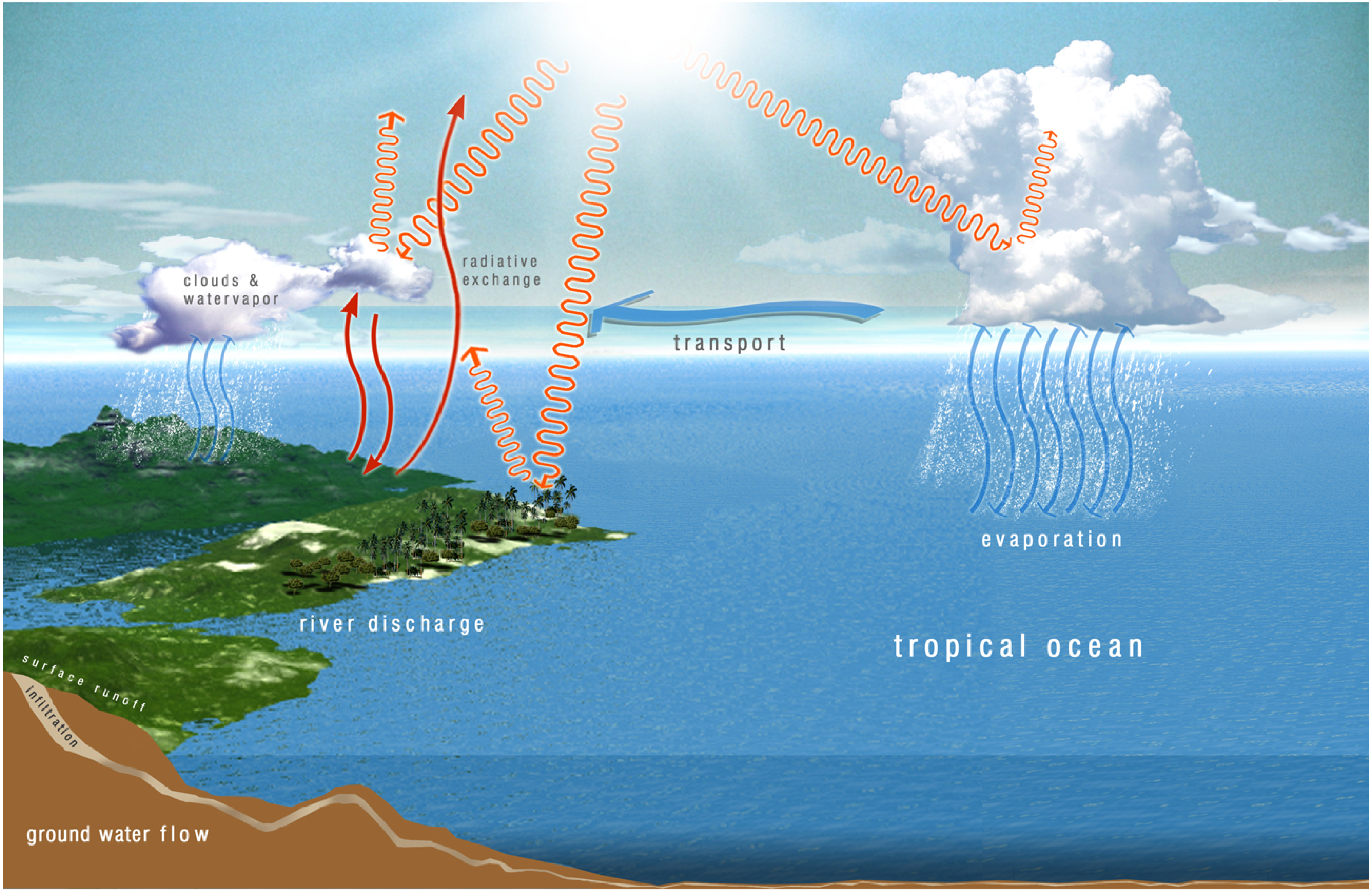
WHERE DOES RAIN COME FROM?

1) Sunlight reaches the earth, goes through the atmosphere, and warms the surface of the earth. Very little sunlight is absorbed in the atmosphere.
2) Because earth is mostly covered by water, and because water absorbs about 98% of the sunlight that reaches the ocean's surface, most sunlight that reaches earth is absorbed by the ocean. Most sunlight is absorbed in the tropics.
3) The ocean's surface temperature is constant when averaged over many years, so all the heat absorbed by the ocean must ultimately be lost by the ocean.
4) The ocean loses heat mostly by sweating (evaporation). Some heat is lost by emission of infrared radiation. The loss of heat by evaporation is called latent heat loss.
5) The water evaporated from the ocean is gained by the atmosphere. Ultimately, the atmosphere must lose the vapor by precipitation, mostly by rain in the warmest tropical areas.
6) Condensation of water vapor in the atmosphere releases the latent heat gained from the ocean. This heat, plus absorption of infrared radiation from the sea, heats the atmosphere. The heating causes winds, which carry water vapor to the land.
7) Thus:
    - The ocean, not the sun, heats the atmosphere.
    - Rain on land comes from water evaporated from the tropical ocean.

Stewart (1)

The Water Cycle

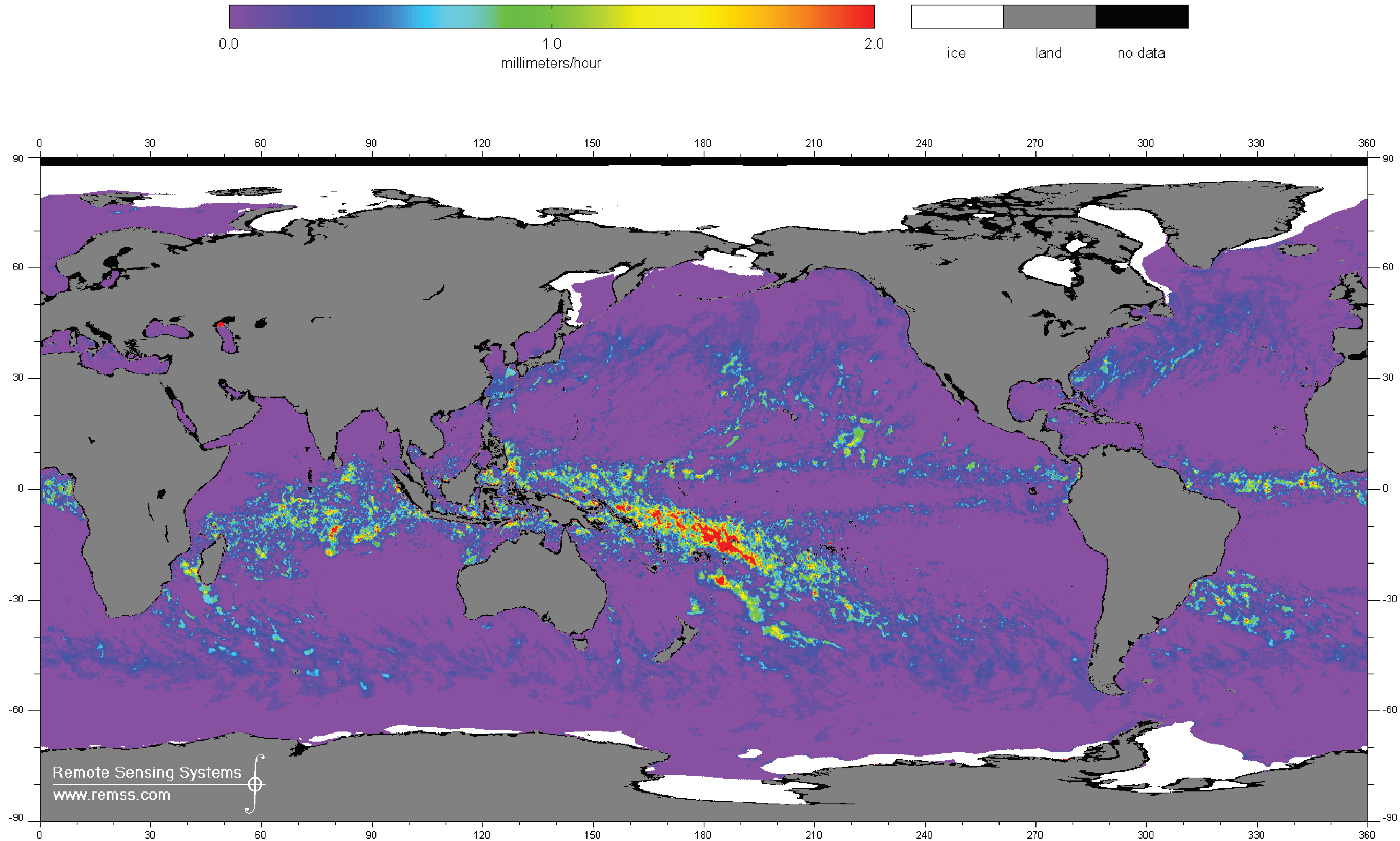


Stewart (2)

WHERE IS IT RAINING?

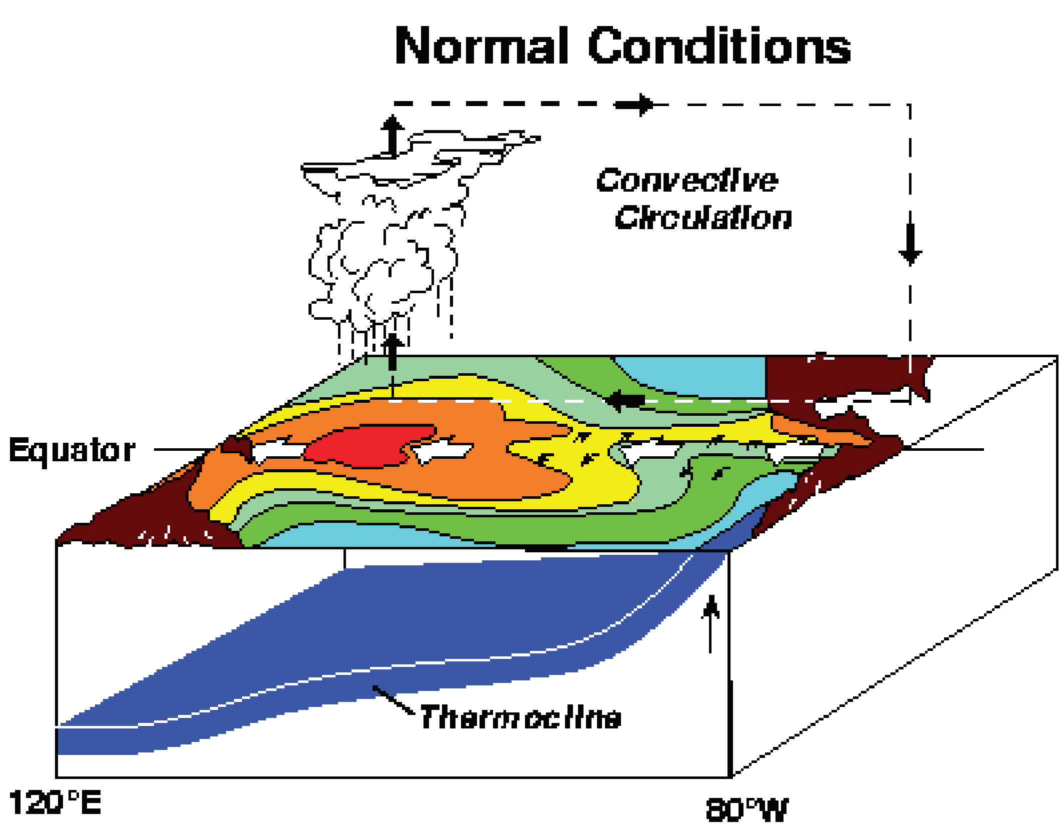
F13 Precipitation Rate

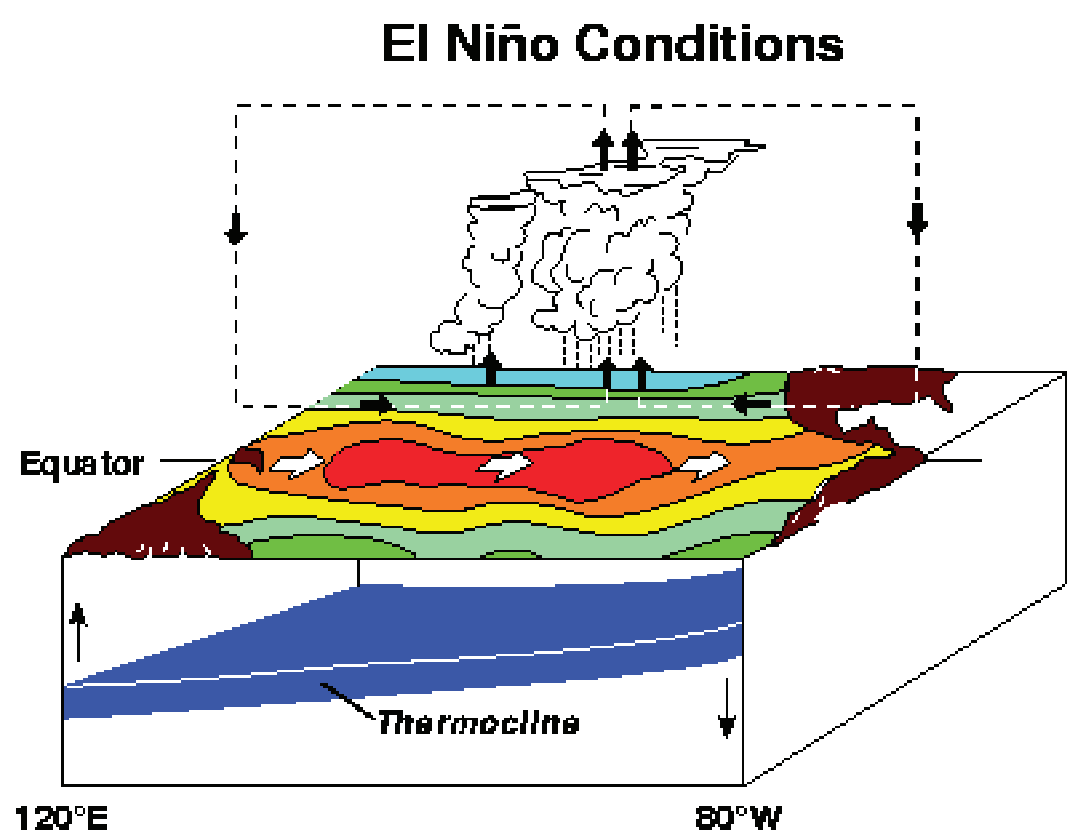
Average of month: February, 2006



WHAT CAUSES YEAR-TO-YEAR VARIABILITY IN RAIN?

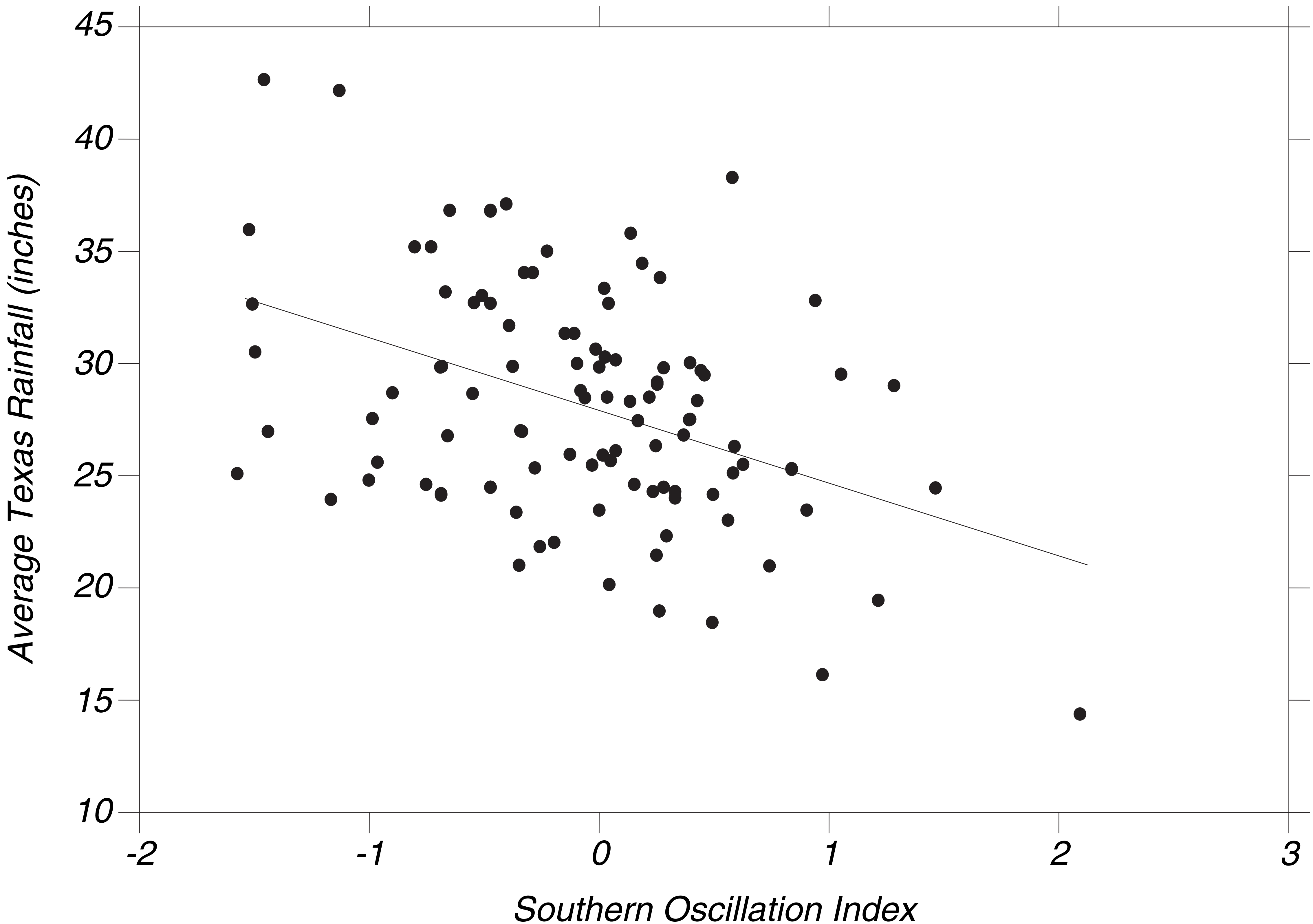
1) Variations in the temperature of tropical waters influence where rain falls in the tropics.
2) Because this rain warms the atmosphere, the changes in the position of rainy areas changes where the atmosphere is heated. This changes the atmospheric circulation.
3) The biggest change is called El Nino.
4) During El Nino, the eastern equatorial Pacific warms up, rain moves eastward with the warm water, and the atmosphere adjusts.
5) The Pacific is so large, and it has the most rain, El Nino changes weather patterns around the earth. The changes last 1–2 years.
6) El Nino changes the rainfall in Texas. Teas rain tends to be greater during El Nino.





TEXAS RAINFALL AS A FUNCTION OF THE SOUTHERN OSCILLATION INDEX

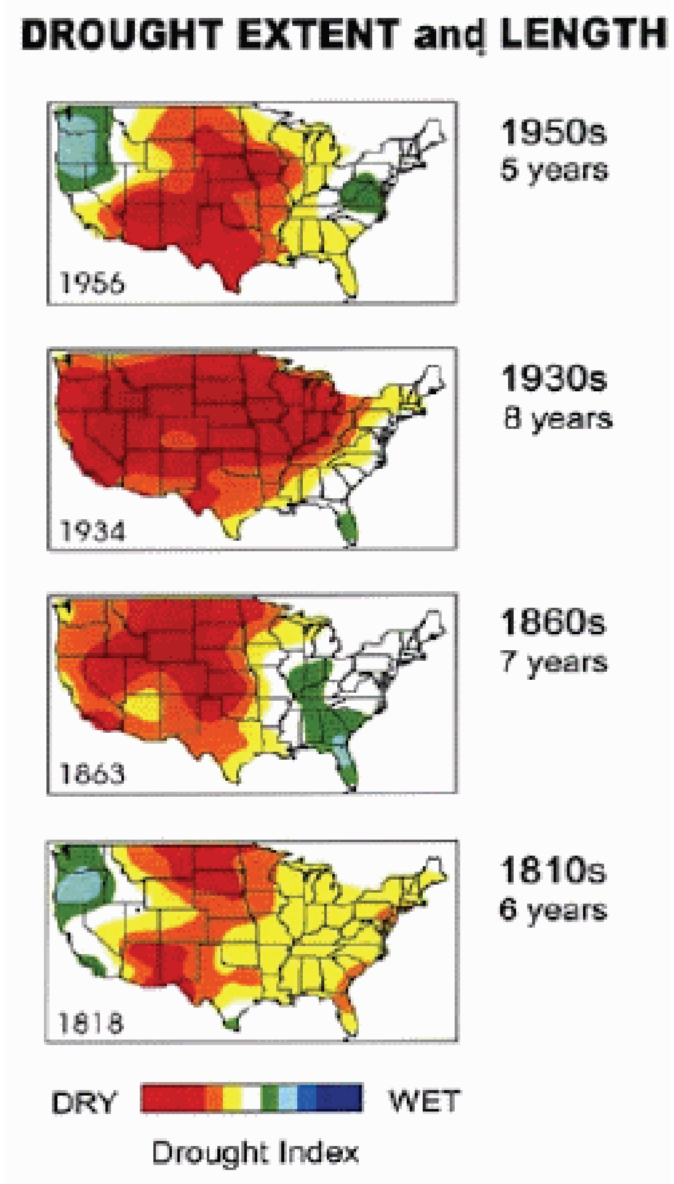
El Nino influences Texas Rainfall, but not strongly.



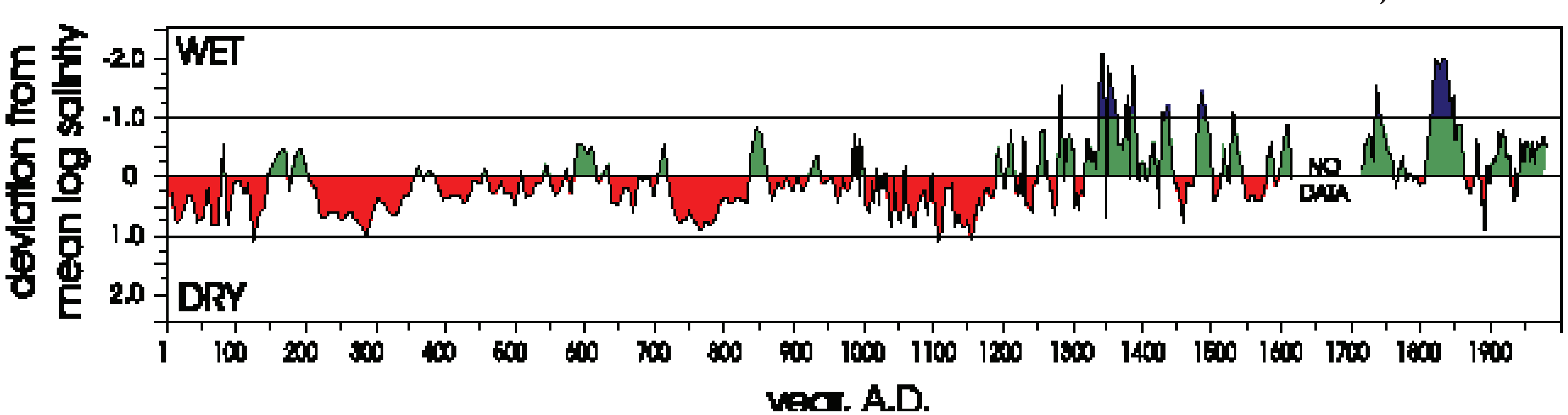
Stewart (5)

WHAT CAUSES LONG-TERM VARIABILITY IN RAIN?

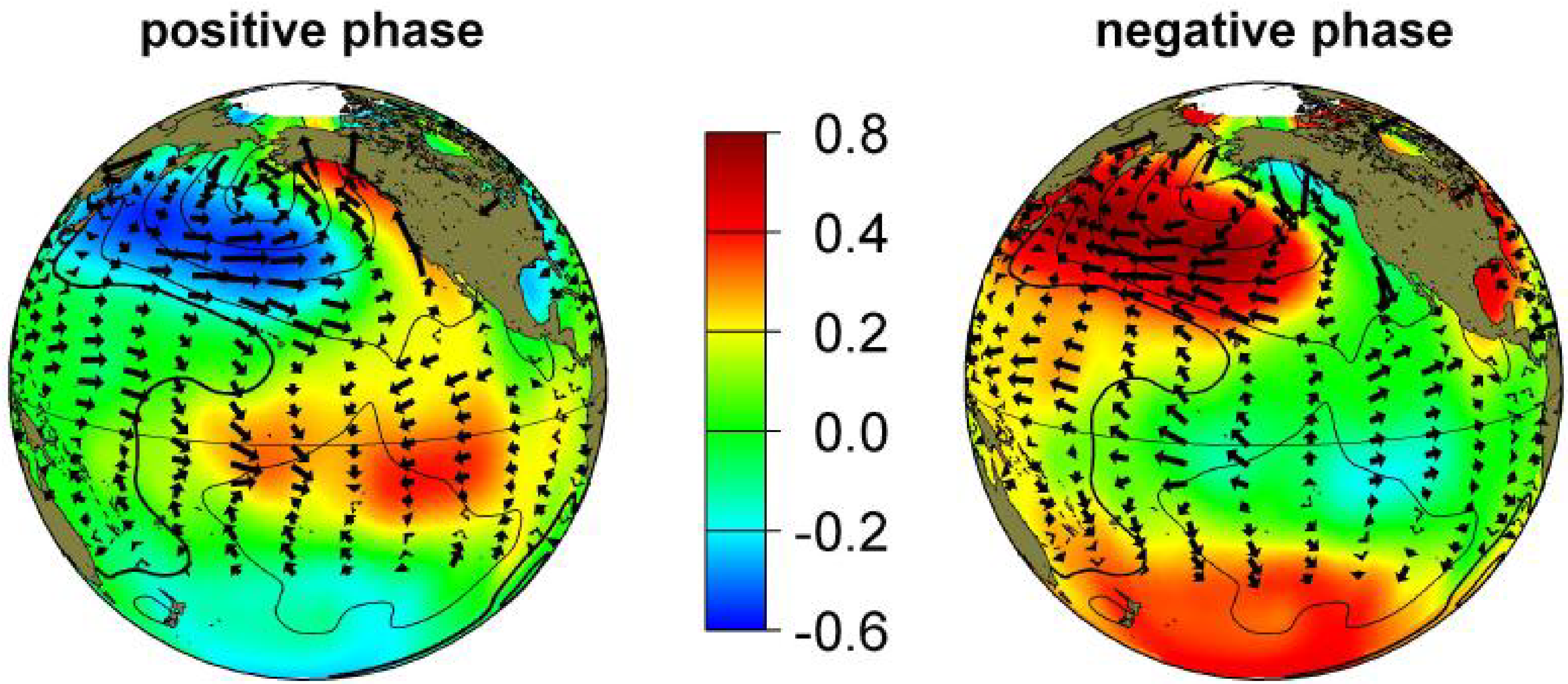
1) Variations in the temperature of tropical waters from decade to decade also influence where rain falls in the tropics.
2) Two big variations have been studied:
   - The Pacific Decadal Oscillation, which influences the entire Pacific.
   - The Atlantic Multidecadal Oscillation, which influences the entire Atlantic.
3) Both influence Texas weather and rainfall.
   Both have been tied to mega droughts in North America.
4) Even longer term changes in rainfall seem to be related to temperature of the ocean.
   - The medieval warm period, around 800 – 1200 AD, is associated with mega droughts over North America, and the decline of the Anasazi and Mayans.
   - The little ice age, around 1300 – 1850 AD, is related to increased rainfall over North America and the Great Plains.
5) The long-period relationships are not well understood.
6) What will be the influence of global warming? Another mega drought in the Great Plains?



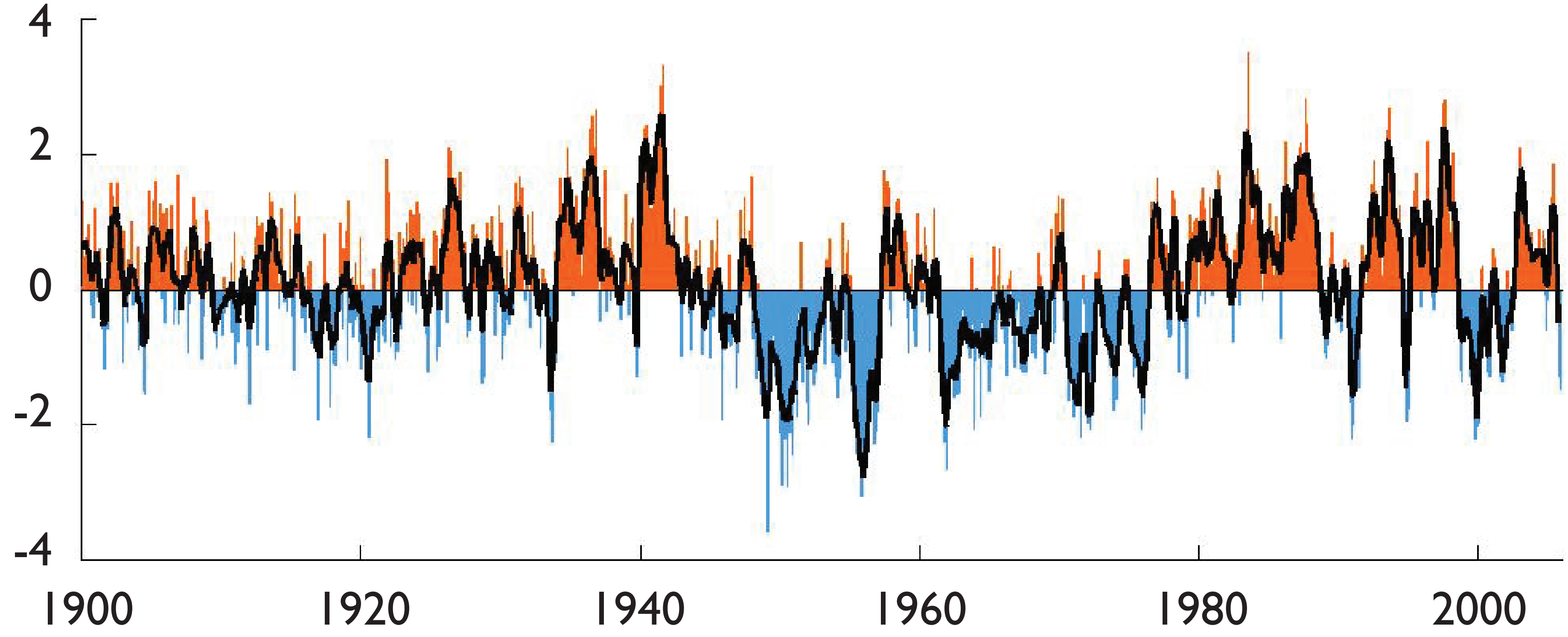
SALINITY AS A MEASURE OF DROUGHT–MOON LAKE, ND



Pacific Decadal Oscillation



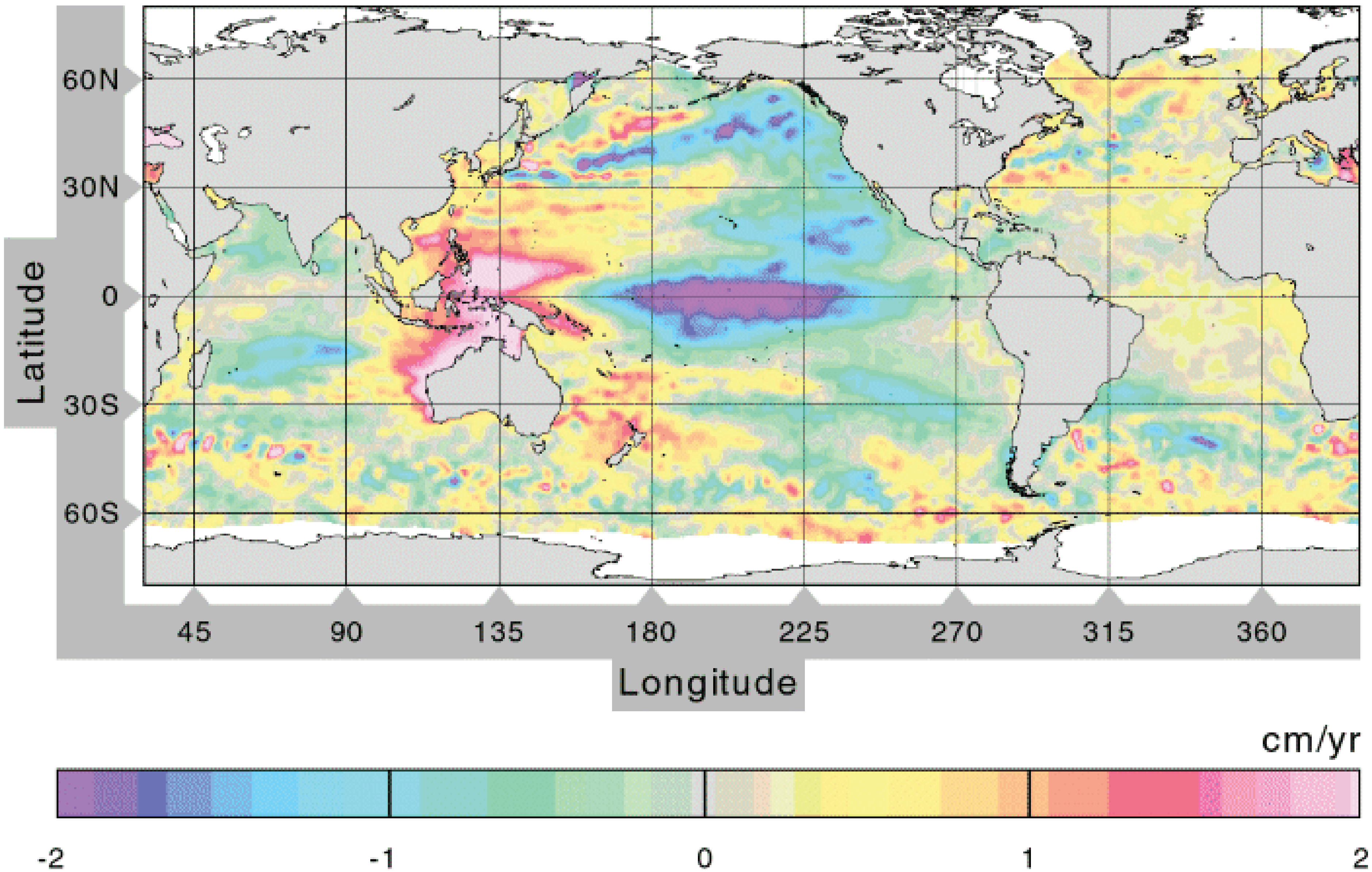
MONTHLY VALUES FOR PACIFIC DECADAL OSCILLATION



Stewart (8)

THE ATLANTIC IS WARMING

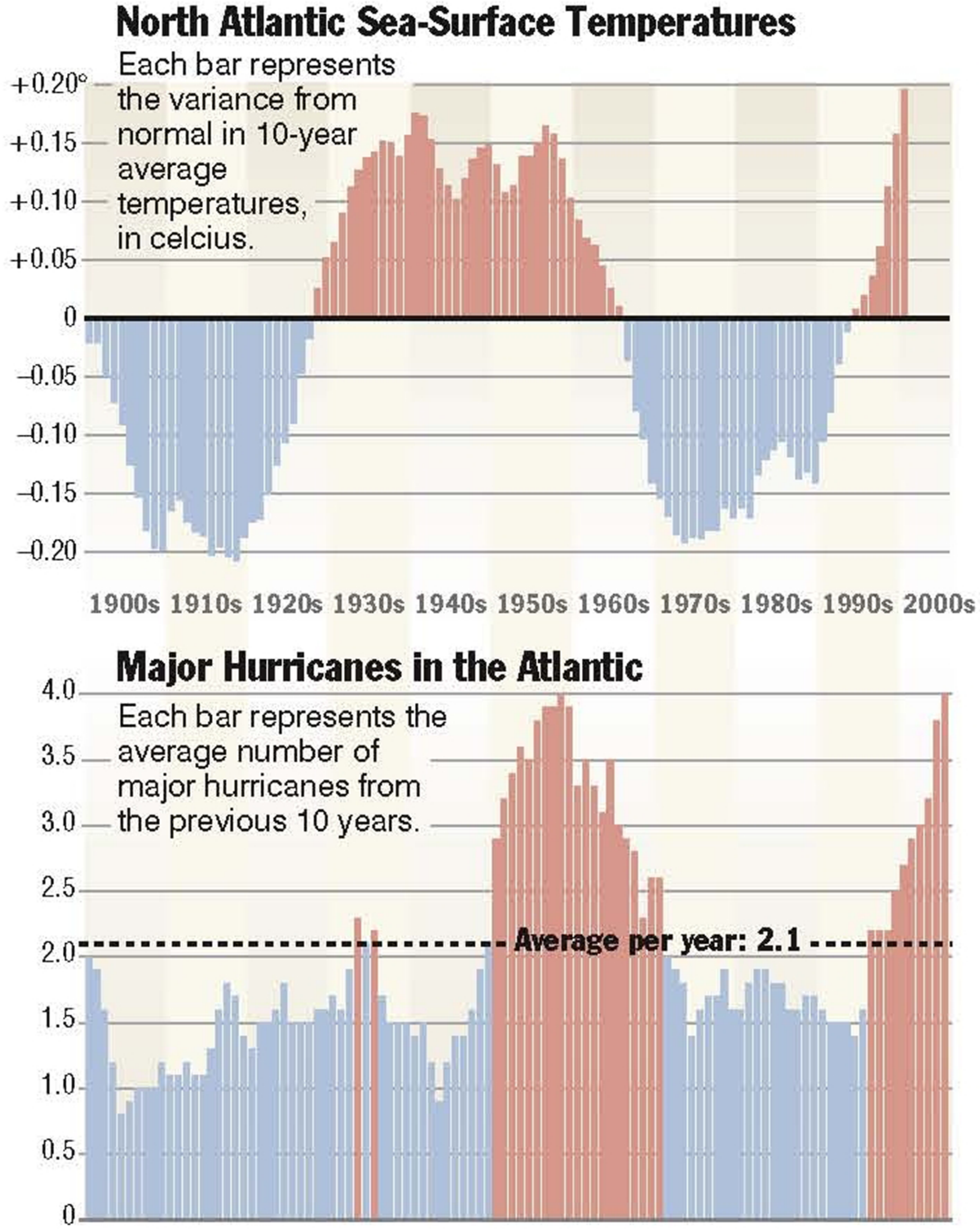
1) This map shows the long term change in sea level measured by satellite altimeters.
   As water warms, it expands, and sea level rises.
2) Thus the map indicates that the north-east Pacific is cooling, and the North Atlantic is warming.



From: http://www-aviso.cnes.fr:8090/HTML/information/publication/news/news8/knudsen_fr.html

Hurricanes and Warm Water

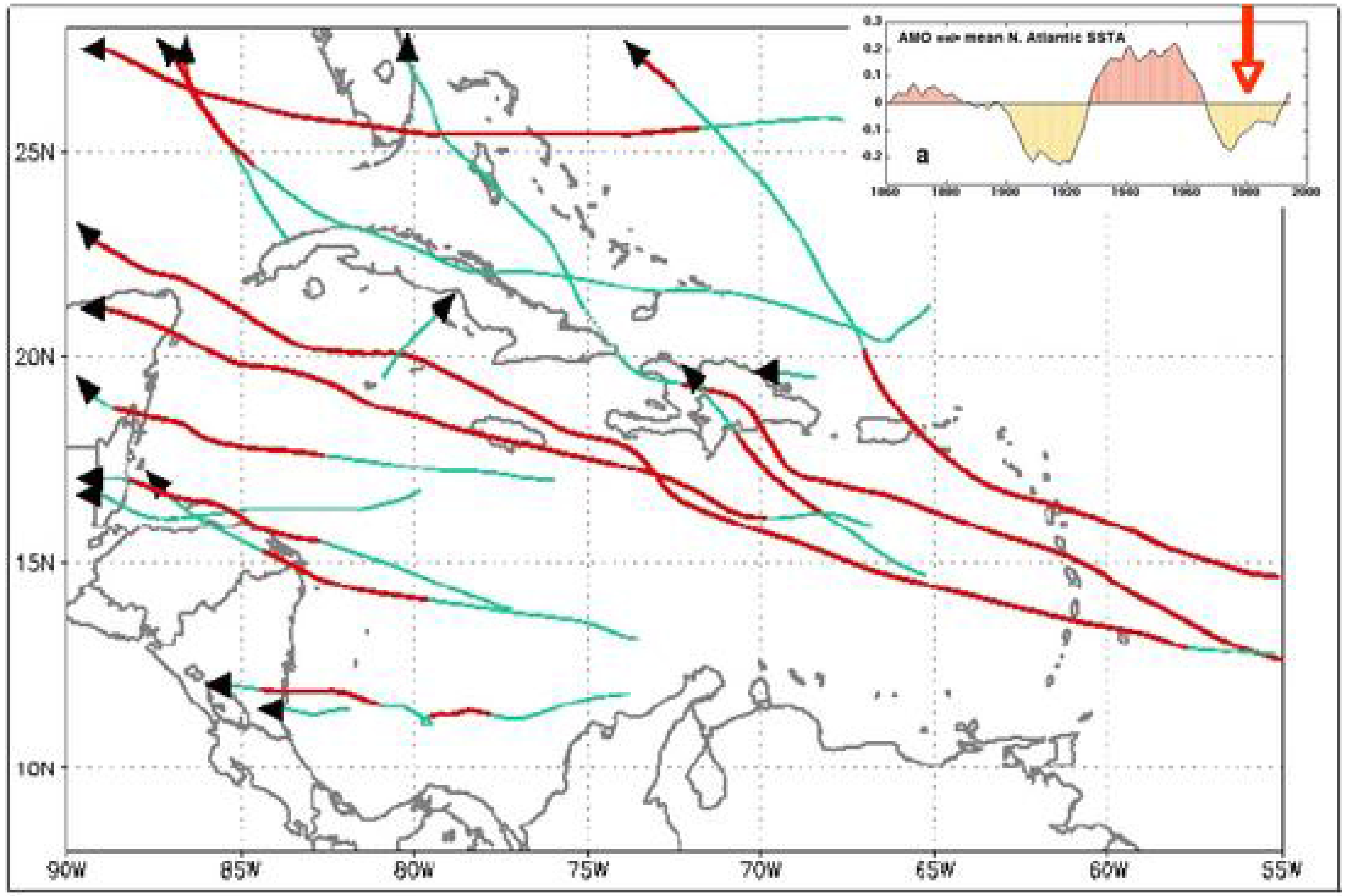
Small changes in North Atlantic sea-surface temperatures can produce big changes in storm activity. During warm-water phases, the number of tropical storms that intensify into major hurricanes increases.



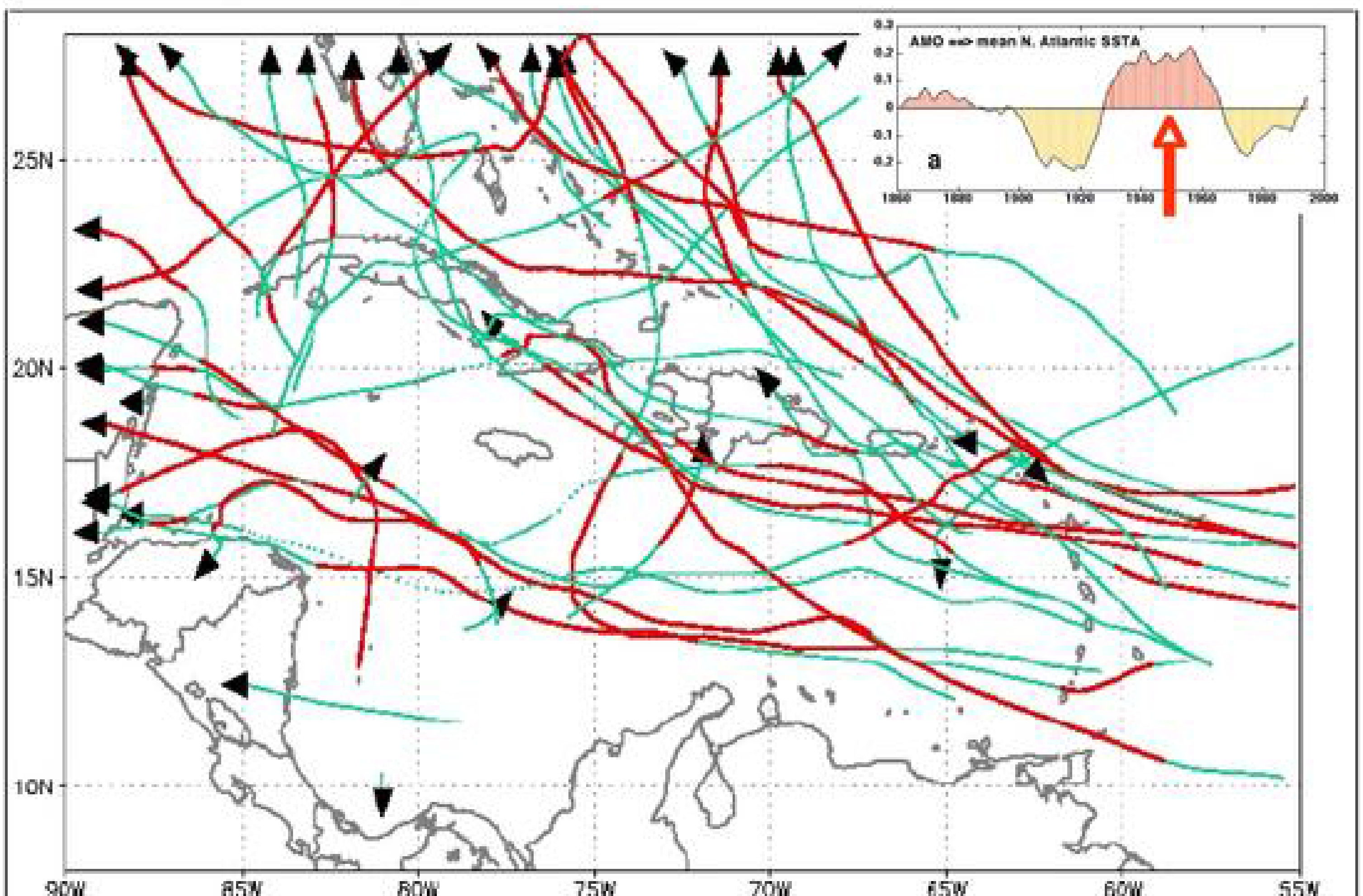
SOURCES: National Oceanic & Atmospheric Administration; Unisys

JOHN DUCHNESKIE / Inquirer Staff Artist

HURRICANE TRACKS IN THE ATLANTIC



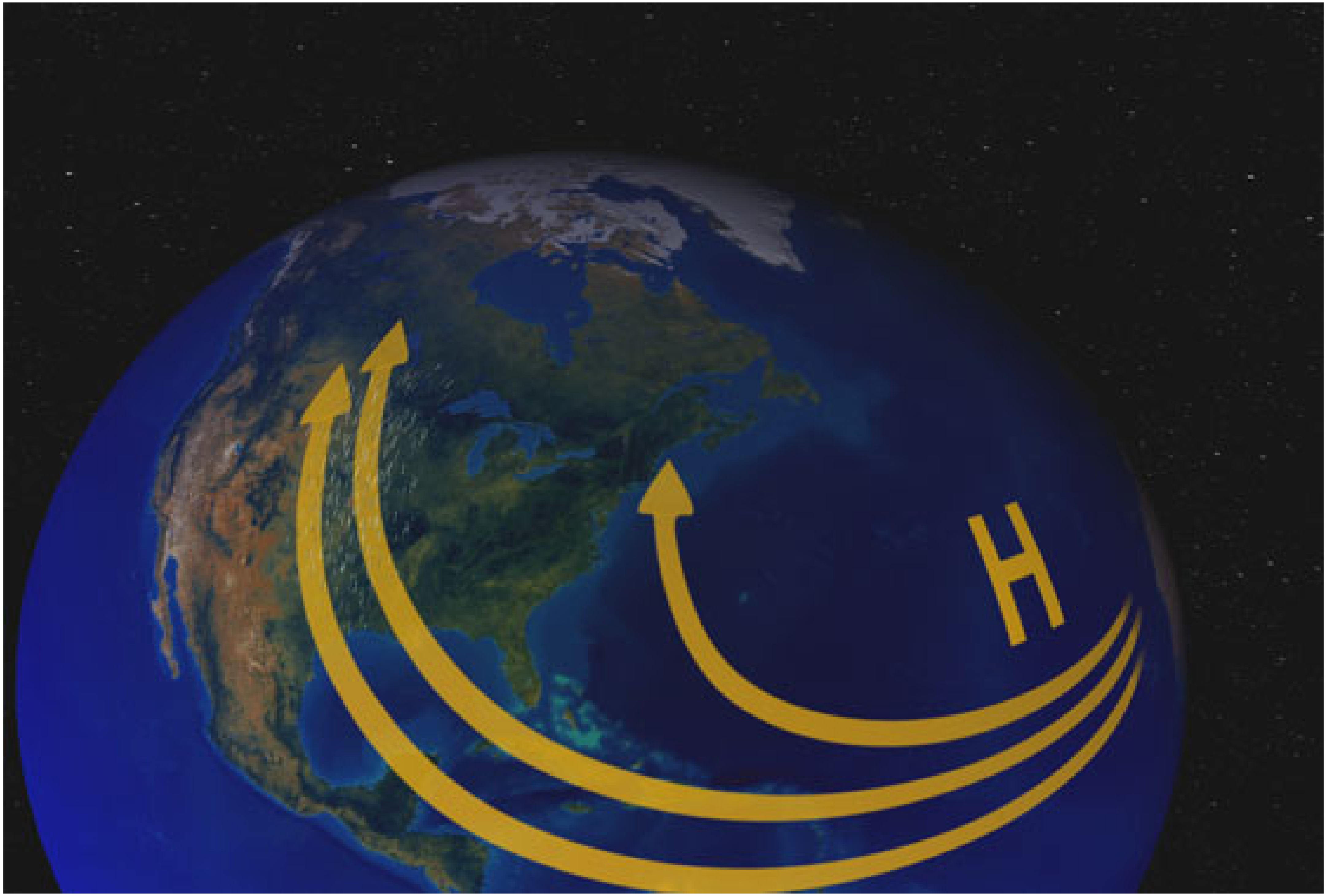
Cold Atlantic



Warm Atlantic

Stewart (10)

JET STREAM LOCATION IN THE ATLANTIC

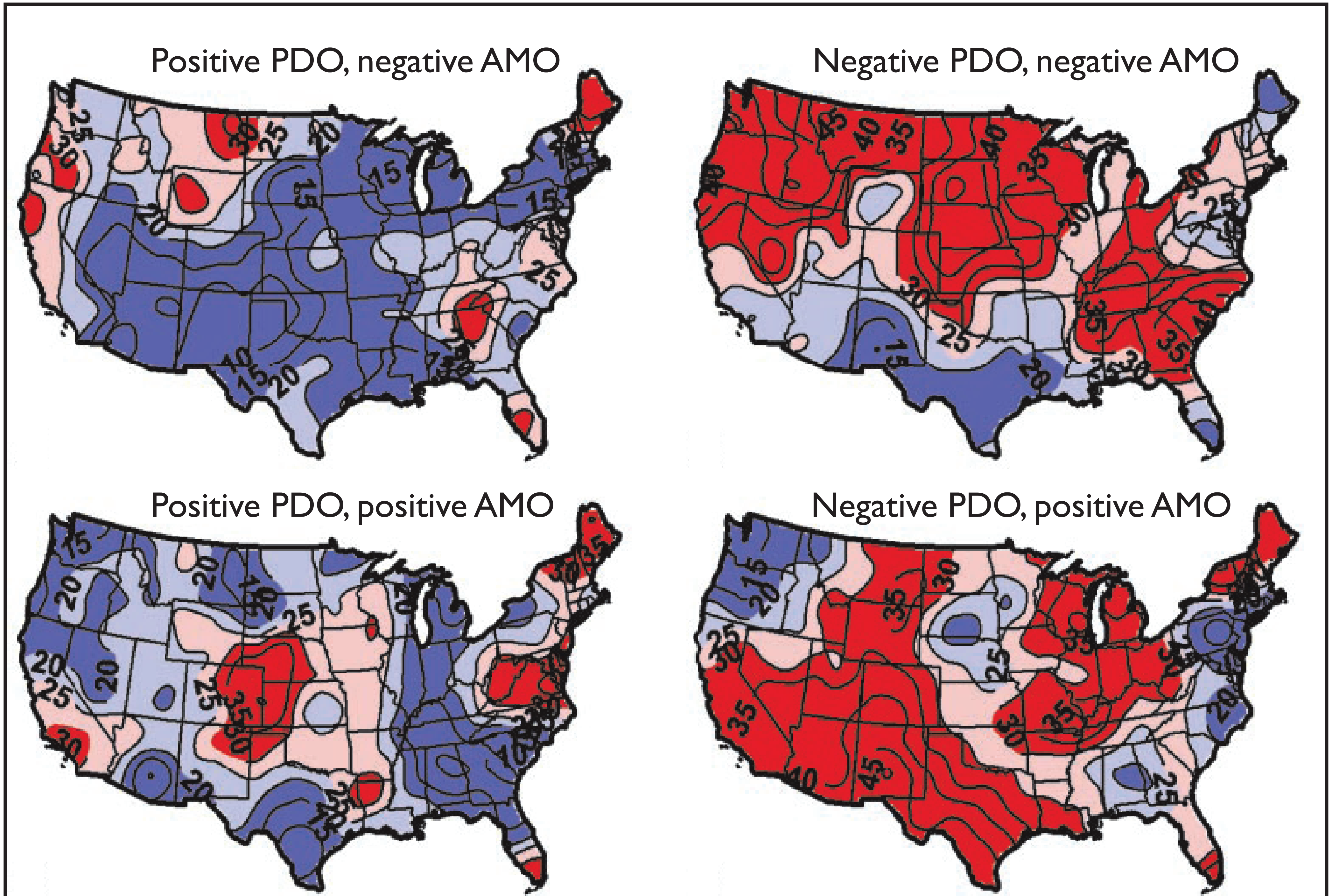


PATTERNS OF NORTH AMERICAN DROUGHT RELATED TO THE ATLANTIC MULTIDECADAL OSCILLATION (AMO), and the PACIFIC DECADAL OSCILLATION (PDO)

1) More than half (52%) of the spatial and temporal variance in multidecadal drought frequency over the conterminous United States is attributable to the
   - Pacific Decadal Oscillation (PDO) and the
   - Atlantic Multidecadal Oscillation (AMO).
2) An additional 22% of the variance in drought frequency is possibly related to increasing Northern Hemisphere temperatures or some other unidirectional climate trend [such as global warming].
3) Recent droughts with broad impacts over the conterminous U.S. (1996, 1999–2002) were associated with North Atlantic warming (positive AMO) and northeastern and tropical Pacific cooling (negative PDO).

From: McCabe et al (2004) Pacific and Atlantic Ocean influences on multidecadal drought frequency in the United States.

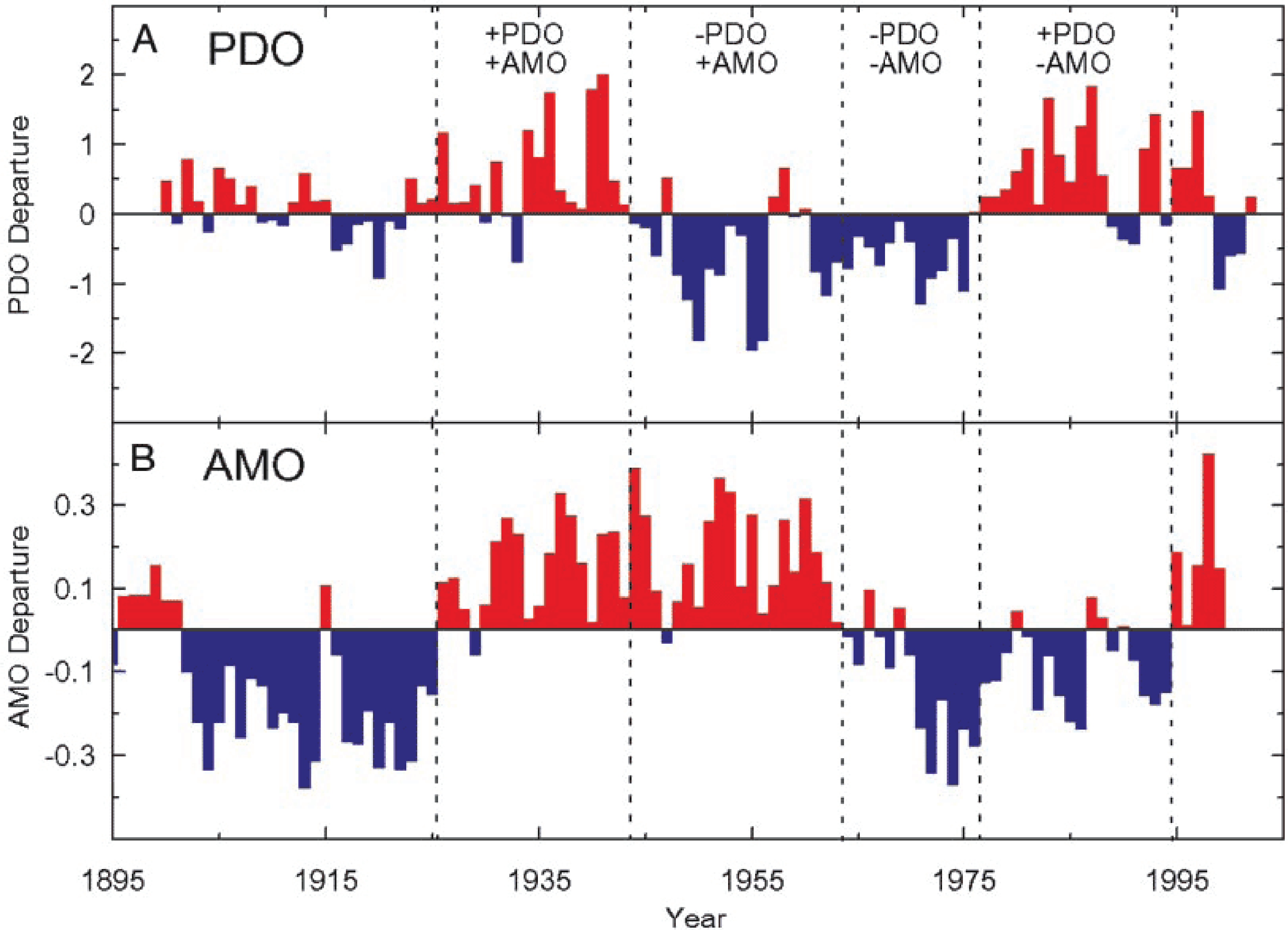
PATTERNS OF NORTH AMERICAN DROUGHT RELATED TO THE ATLANTIC MULTIDECADAL OSCILLATION (AMO), and the PACIFIC DECADAL OSCILLATION (PDO)



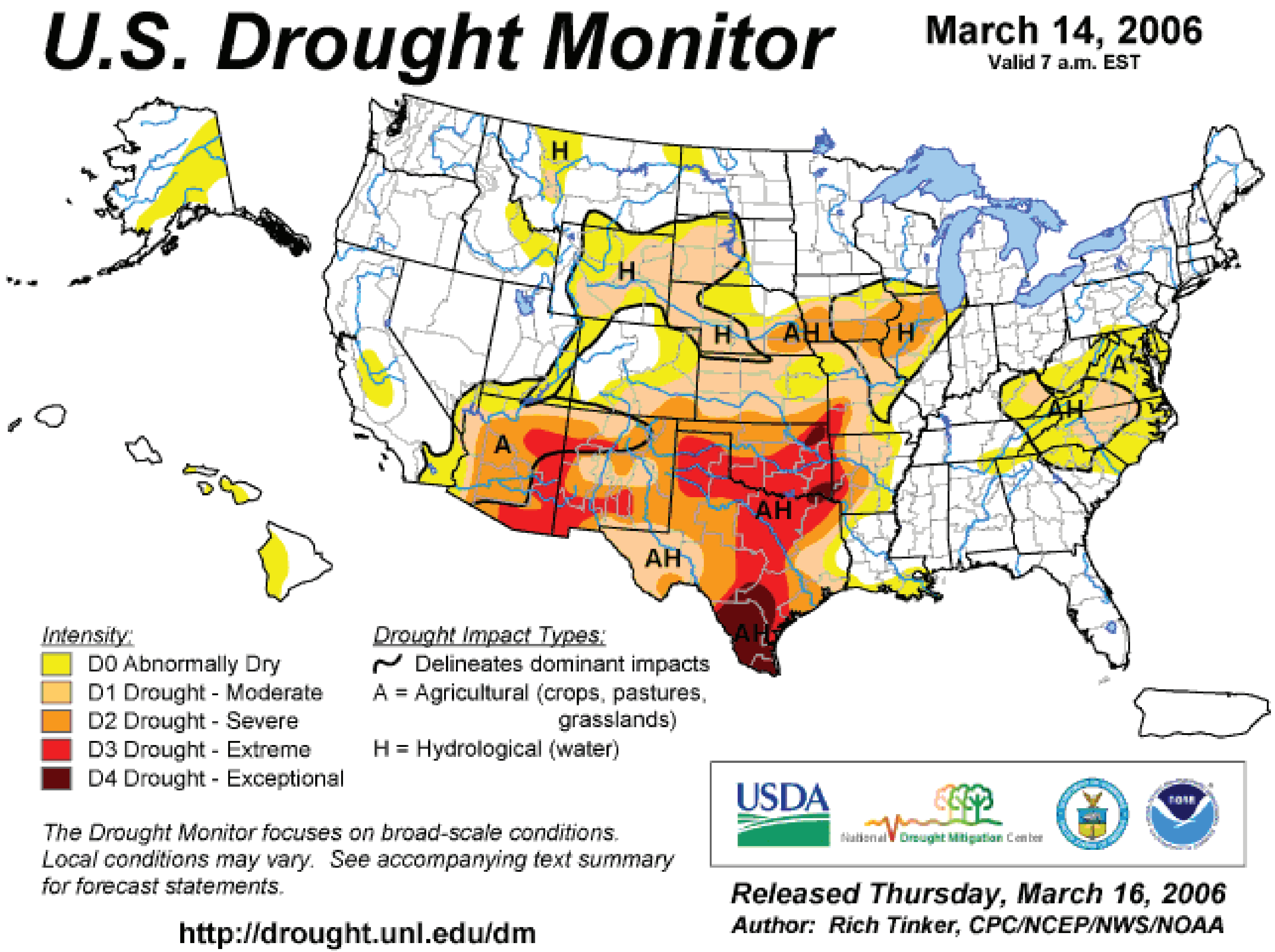
From: McCabe et al (2004) Pacific and Atlantic Ocean influences on multidecadal drought frequency in the United States.
Stewart (13)

LOW FREQUENCY OCEANIC VARIABILITY

PDO = Pacific Decadal Oscillation AMO = Atlantic Multidecadal Oscillation



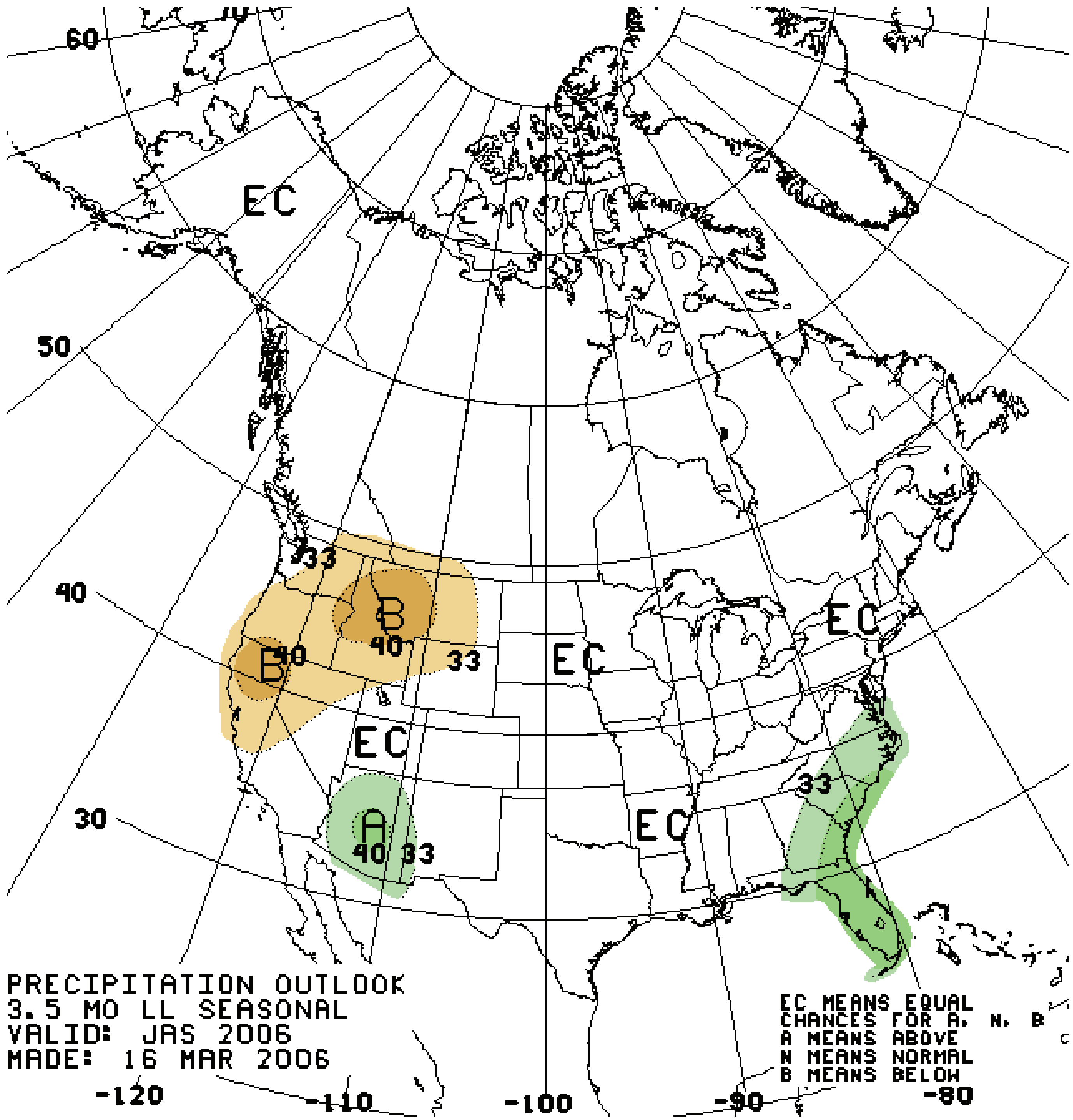
Stewart (12)



U.S. Drought Monitor
March 14, 2006
Valid 7 a.m. EST
H
H
H
AH
H
A
AH
A
AH
AH
AH
Intensity:
D0 Abnormally Dry
D1 Drought - Moderate
D2 Drought - Severe
D3 Drought - Extreme
D4 Drought - Exceptional
Drought Impact Types:
Delineates dominant impacts
A = Agricultural (crops, pastures, grasslands)
H = Hydrological (water)
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.
http://drought.unl.edu/dm
USDA
National Drought Mitigation Center
Released Thursday, March 16, 2006
Author: Rich Tinker, CPC/NCEP/NWS/NOAA

MONTHLY FORECASTS

1) The National Centers for Environmental Prediction produces seasonal forecasts of temperature and rain for North America.
2) The forecasts are based mostly on oceanic conditions.



FORECASTING CLIMATE CHANGE

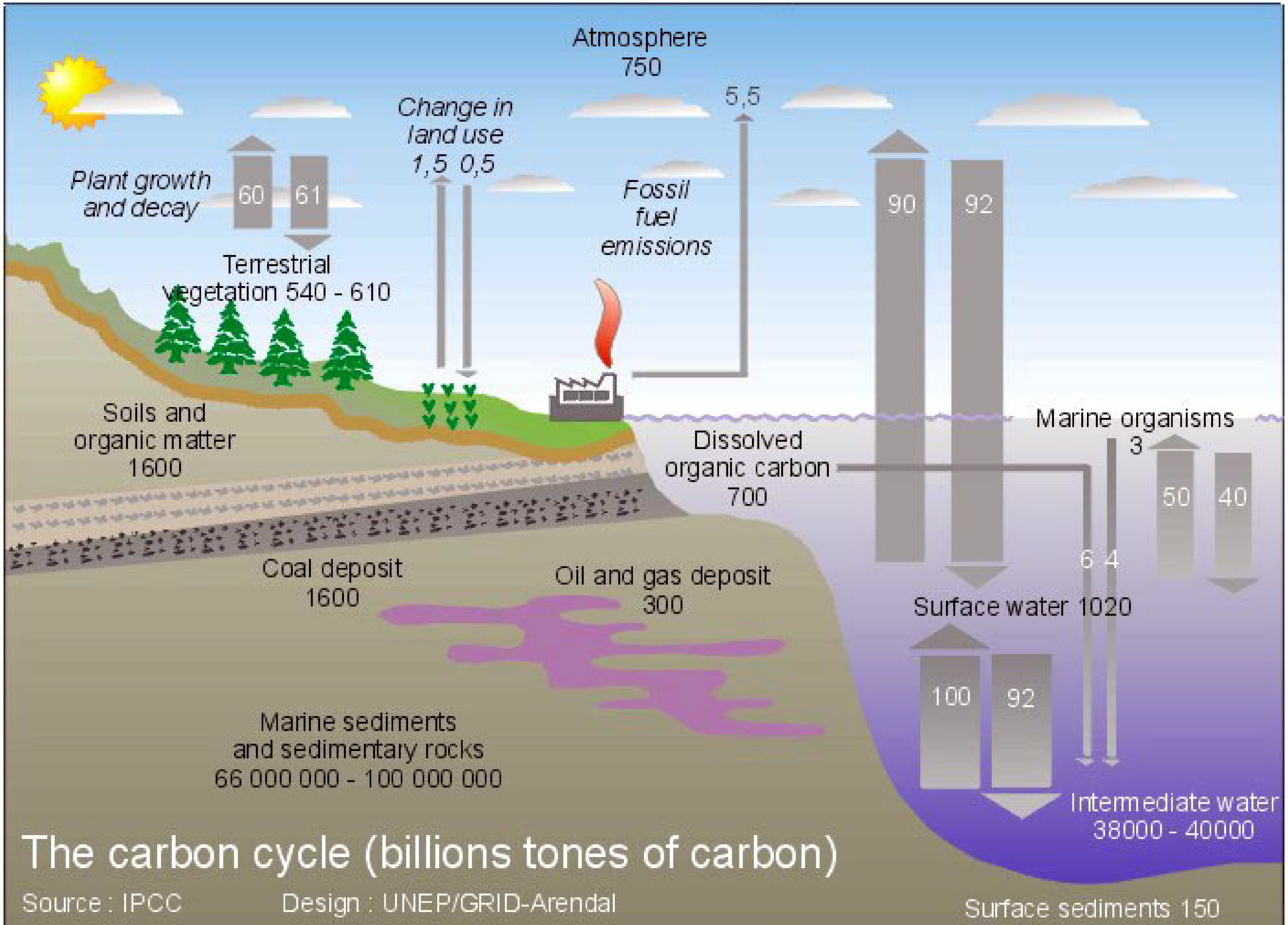
The increase of carbon dioxide in the atmosphere has led to forecasts that global average surface temperature will increase by 3-8°C in the next 100 years. What are the implications for Texas?

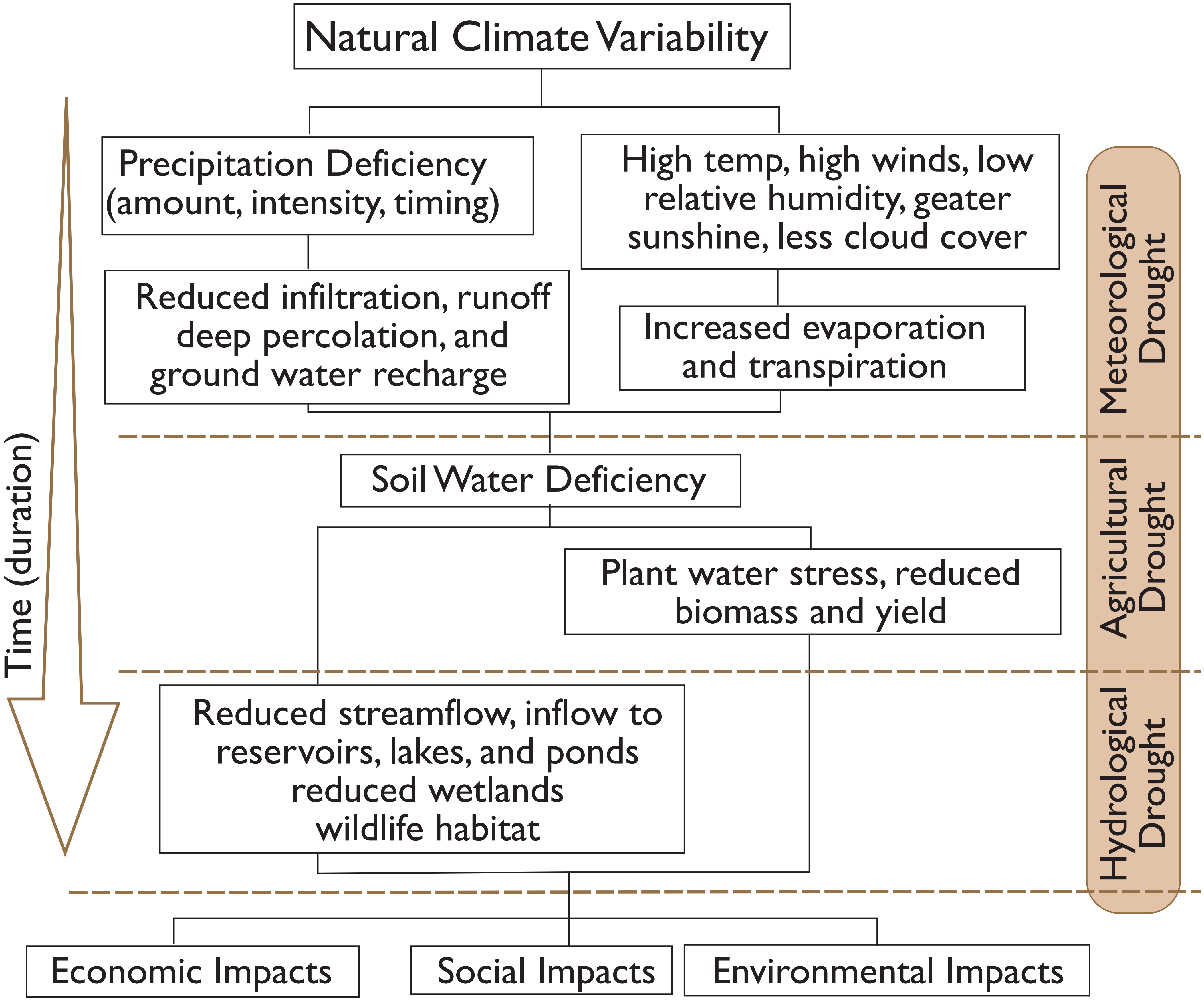
100 year global forecasts are unreliable. Regional forecasts are even less reliable.

Causes of uncertainty:

- Everything is related to everything else. There are many positive and negative feedback loops in the climate system. We don't understand most.
- Atmospheric carbon dioxide is only a small part of the available carbon dioxide. The ocean has 50 times more carbon dioxide. Yet, we don't know how the ocean operates, especially the deep ocean where most carbon dioxide is stored.
- We don't know how much carbon dioxide will be put into the atmosphere by human activities. The climate change forecasts are based on economic models that assume that third-world countries will have per-capita income in 100 years that exceeds that of the US or Europe.
- Carbon-dioxide production depends on geological, economic, and political factors. None are well known.
  How much oil, gas, and coal is left?
  What will these fuels sell for?
  Will governments change laws, leading to more use of alternate energy supplies?
  How will changing price of fuels effect their use and conservation efforts?
- Computer models used for forecasts cannot yet reproduce past changes in climate.
  How can they be expected to make good future forecasts?
  Some forecasts even predict global cooling: The *Day After Tomorrow*.

THE GLOBAL CARBON CYCLE





From: Thomas B. McKee, et al (2000) A History of Drought in Colorado: Lessons Learned and What Lies Ahead.

TEXAS WATER RIGHTS (1)

Texas water rights are a complex mix of Spanish law that applies to old Spanish land grants and English common law that applies to other land.

The law distinguishes between surface and ground water.

What follows is a very much simplified description of Texas water law.

Water in the rivers, streams, underflow, creeks, tides, lakes and every bay and arm of the Gulf is state water. Surface water is treated as state property by Texas, and as state property, it is subject to regulation, sale and protection by the state and its agencies.

The major agency having oversight responsibility for water (quantity and quality) is the Texas Natural Resources Conservation Commission (TNRCC).

Priority use is determined mainly by the *doctrine of prior appropriation*.

- *First in time is first in right.*
- Permits can be bought and sold as private property.

Other important aspects related to priorities include:

- Domestic and livestock use are always highest priority;
- The older water right has first priority in times of shortage;
- With the exception of the Lower Rio Grande Valley which is served by the Falcon and Amistad reservoirs, municipal use DOES NOT take priority over other uses such as irrigation;
- Upstream water storage may be forced to allow water flow during shortages if a downstream right has priority;
- In most areas of the state, the *honor system* still governs compliance with water rights;
- In the future the monitoring of water policy compliance will be governed by the TNRCC Watermaster program.

From: Water Rights (and Responsibilities). (http://aggie-horticulture.tamu.edu/syllabi/315/water.html)

TEXAS WATER RIGHTS (2)

The drought of 1996 that affected many areas of the state prompted legislation to clarify water rights and water allocation on a priority basis.

The legislation that was implemented and will be implemented is known collectively as Senate Bill One.

Important elements of Senate Bill One include:

- Designates the Texas Water Development Board (TWDB) as the lead state drought response planning agency and creates the drought planning and monitoring committee.
- Allows the executive director of TNRCC to issue emergency permits or temporarily suspend or amend permit conditions without notice or hearing to address emergency drought conditions for not more than 120 days.
- Allows the executive director of TNRCC or a watermaster to mandate without notice or hearing, for not more than 120 days, and only in emergency drought conditions, the transfer of surface water from a permittee holding a permit for other than domestic or municipal use to a city or utility for domestic or municipal use.
- Removes the limit (50 percent of a water right) on deposits in the State Water Bank.
- Establishes that groundwater conservation districts are the state's preferred governmental entity for the management of groundwater resources in Texas.

From: Water Rights (and Responsibilities). (http://aggie-horticulture.tamu.edu/syllabi/315/water.html)

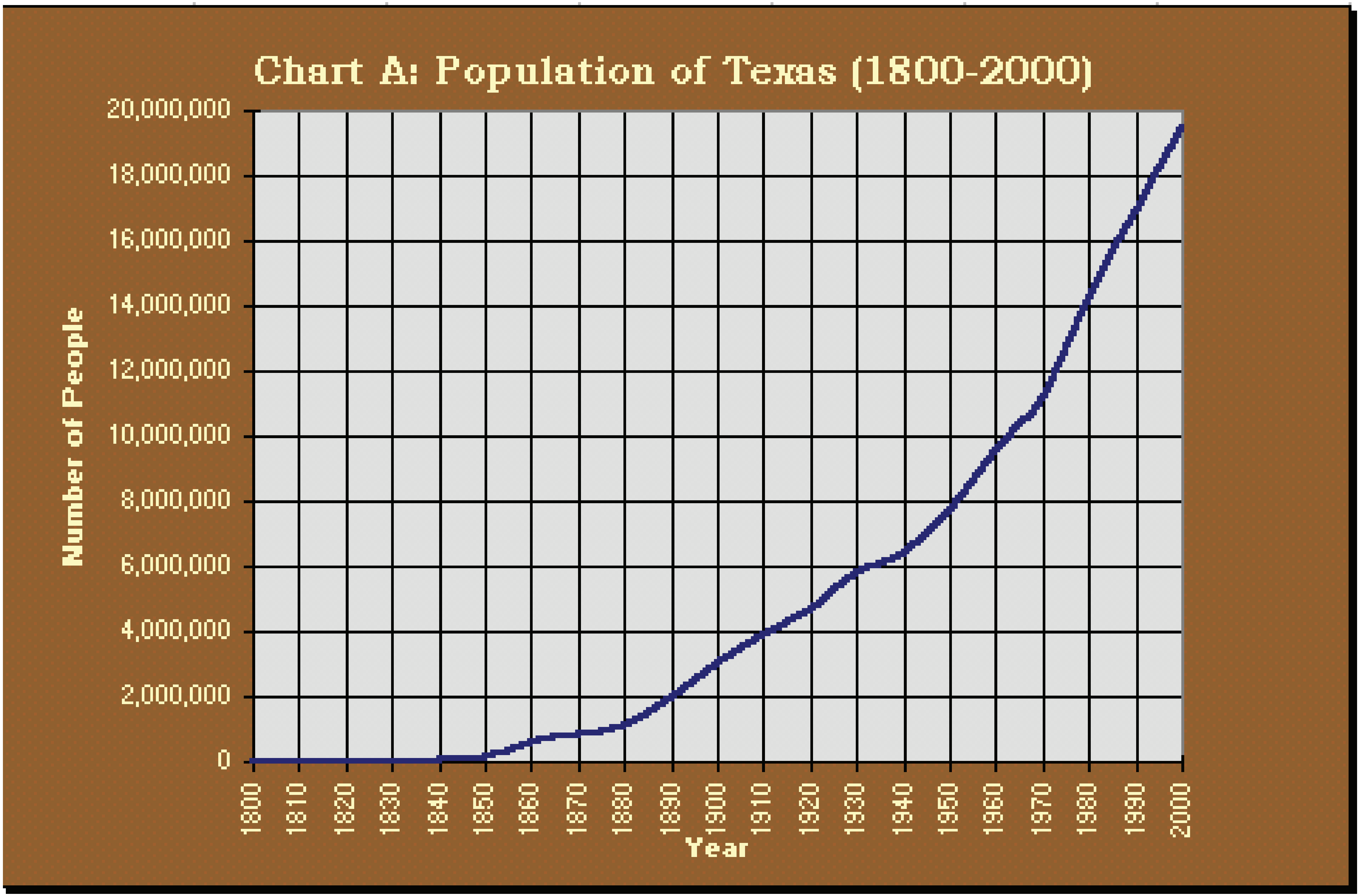
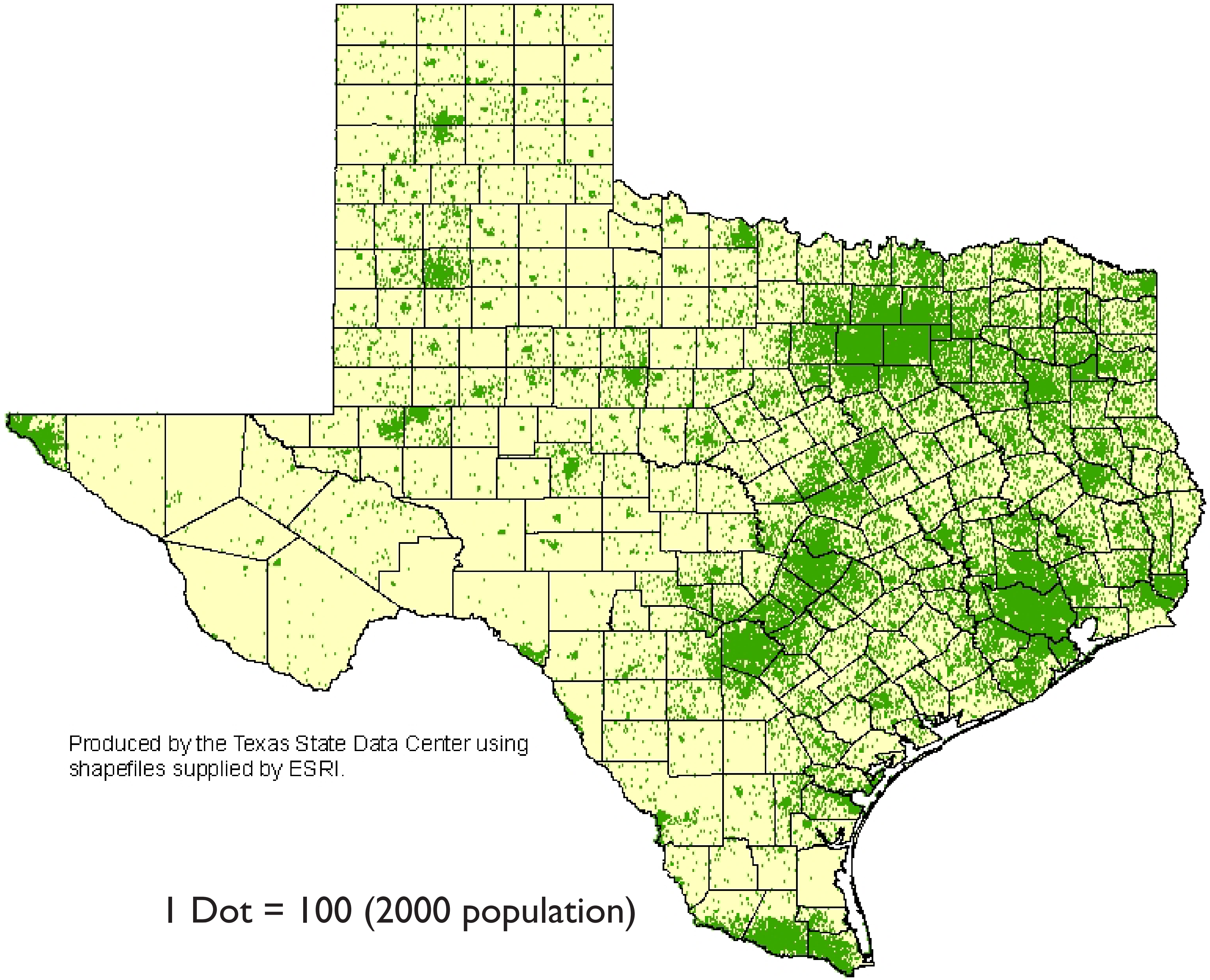


Chart A: Population of Texas (1800-2000)
Number of People
20,000,000
18,000,000
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Year

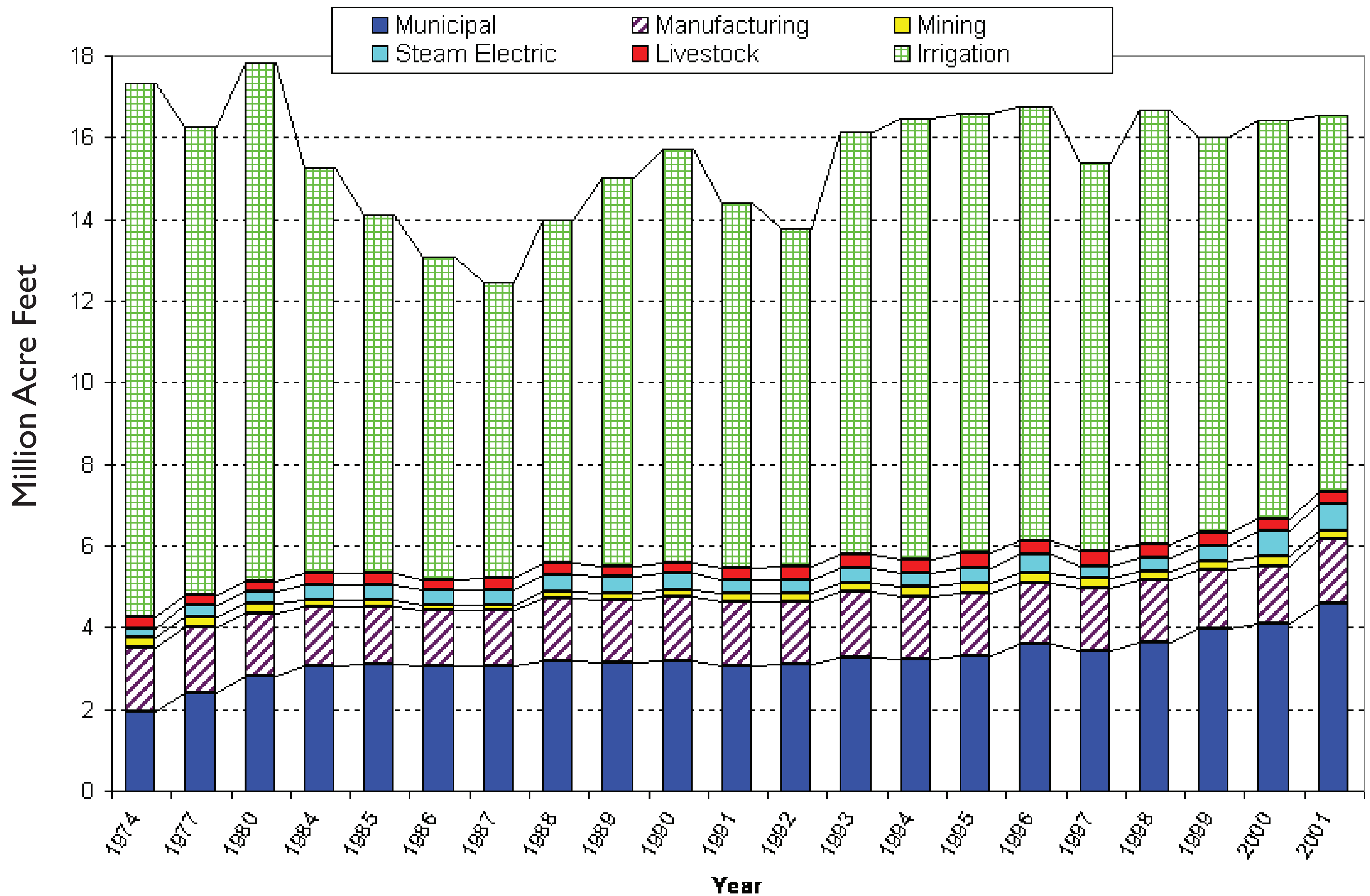
Stewart (22)

TEXAS POPULATION DENSITY



From: http://txsdc.utsa.edu/maps/thematic/Pop_Density_BlkGrp2000.jpg

HISTORICAL WATER USE SUMMARY IN TEXAS 1974 – 2001



Stewart (24)

SOLUTIONS TO WATER PROBLEMS

Marq de Villiers gives four solutions to water problems:

1) If you need more water, get more water. This means either importing water from someplace where there is a surplus, or you make more freshwater yourself.
2) If you can't get more water, use less of it. Reduce demand. This can be done in three ways:
    a) By conservation.
    b) By pricing mechanisms, make water more expensive.
    c) By using water more efficiently.
3) Reduce populations using water. Population decreases are not likely, barring war and epidemics. The population of Europe dropped during the Black Plague, and people flee drought-stricken areas.
4) Steal water from others. Wars have been fought over access to water in dry areas, and this is an increasing threat in the future.

Marc de Villiers, 2000. *Water: The Fate of Our Most Precious Resource.*

SUMMARY

1) Rainfall in Texas depends on conditions in the Atlantic and Pacific.
2) Long term changes in temperature in the Atlantic and Pacific indicate Texas may by in for a long-term drought.
3) The last major drought in Texas was in 1955 when population was much smaller.
4) The Texas legislature, recognizing the possibility of drought, has asked all water districts to produce a water plan that will accommodate future use and population growth.
5) Nevertheless, if the present drought continues, or intensifies, many water districts will face major problems.
6) What can be done?