Climate Change, Food, & Houston's Future

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Climate Change, Food, & Houston's Future

- *Why climate and weather are important.*
- Main Causes of "Normal" weather & climate
- What has been happening to the weather and climate.
- What may happen to the weather & climate
- Efforts to mitigate and their consequences
- Probable effects on our food supply
- Probable other effects on our area

Climate & Weather Are Important

- The term ***Weather*** refers to atmospheric conditions over a short period of time, while

- ***Climate*** refers to atmospheric dynamics averaged over longer periods of time.

- Roughly, this is the difference between daily temperature and moisture swings versus long term averages of the same.

- Climate affects rainfall and humidity as well as wind, cold, and heat, and therefore the ability of plants, animals, and people to live in an area.

- So it affects our food cost and quality.

Climate & Weather Are Important

- **It also affects our energy supply.**
- **Energy (and the cost of it) is a major factor in our ability to do *anything*.**
- **Heat, precipitation, and cold averages and extremes– are major reasons our need for energy varies.**
- **Drought risk mitigation and fire prevention are major investment costs.**
- **Under investment can be very costly.**
- **Climate affects what we need to survive—buildings, energy, nature, and food.**

Climate & Weather Are Important

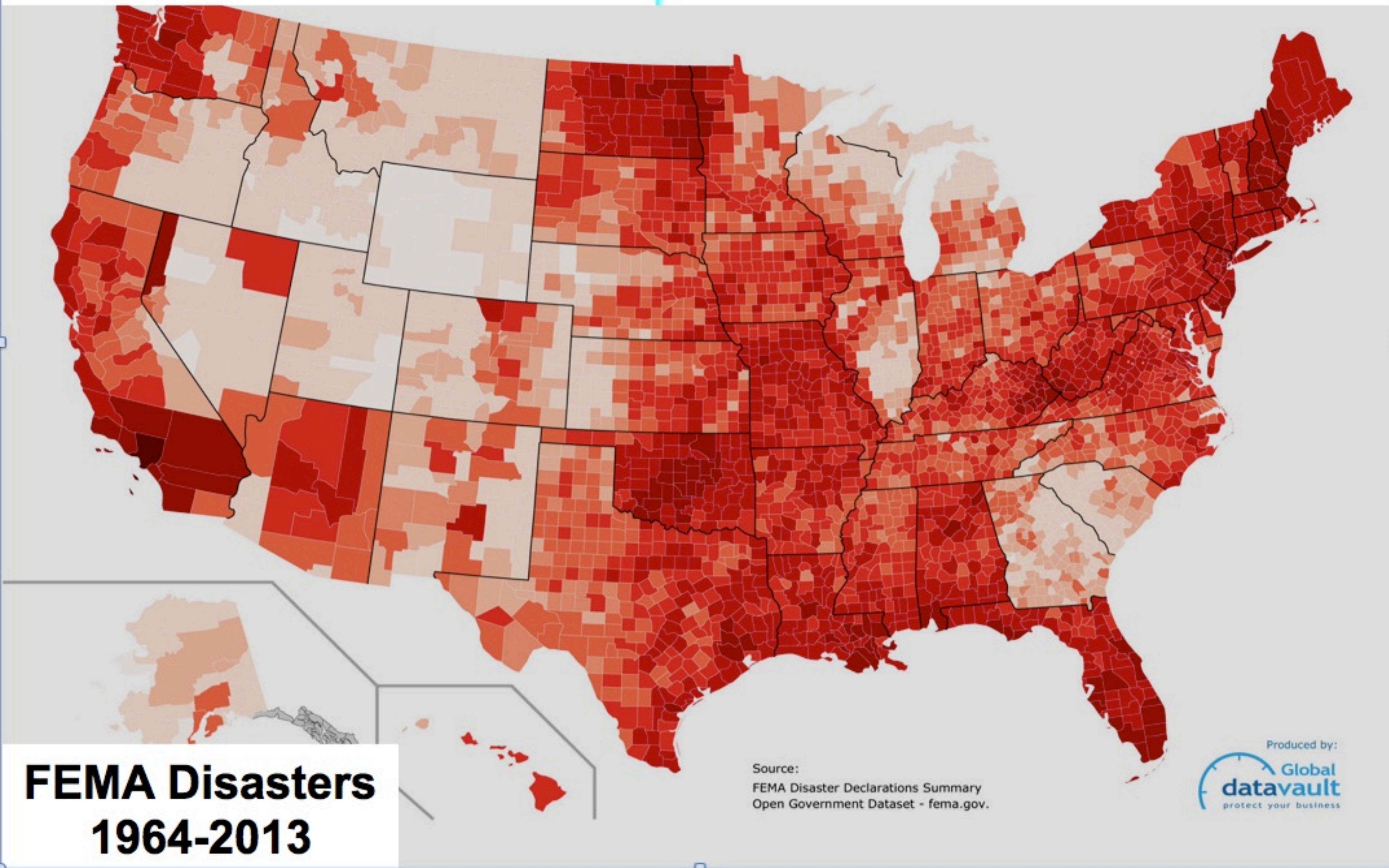
- Severe storms affect our ability to get to work or go to school safely, and this affects the economy.
- Storms also create energy and materials demands for specialized structures (roofs, storm drains, transportation infrastructure, dikes, retention ponds, etc.) and for cleanup after a disaster.
- So potential storms affect both the amount of private capital and tax money needed to mitigate storm damage, fund insurance, and recover from bad ones.

Disaster Return Period in Years

Average years between FEMA declared disasters for each U.S. county.
Includes all FEMA declared disasters from December 1964 to October 2013.

50y 5y 1y

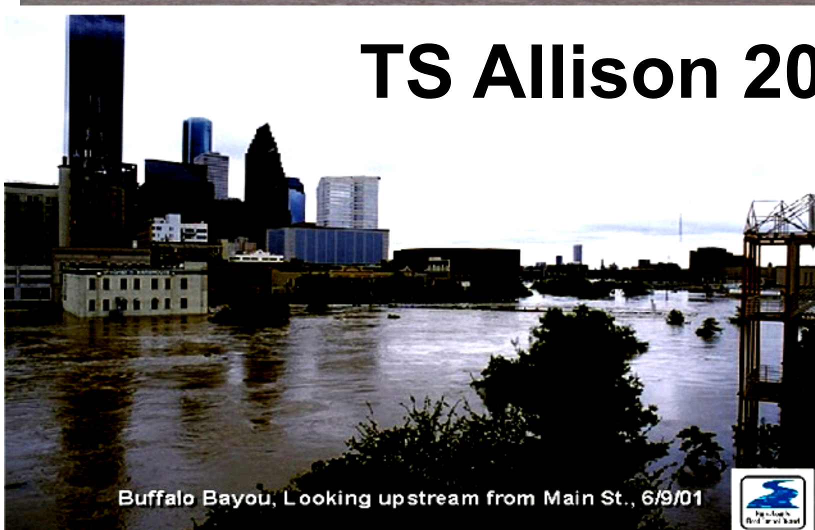
50 20 8 6 5 4 3 2 1



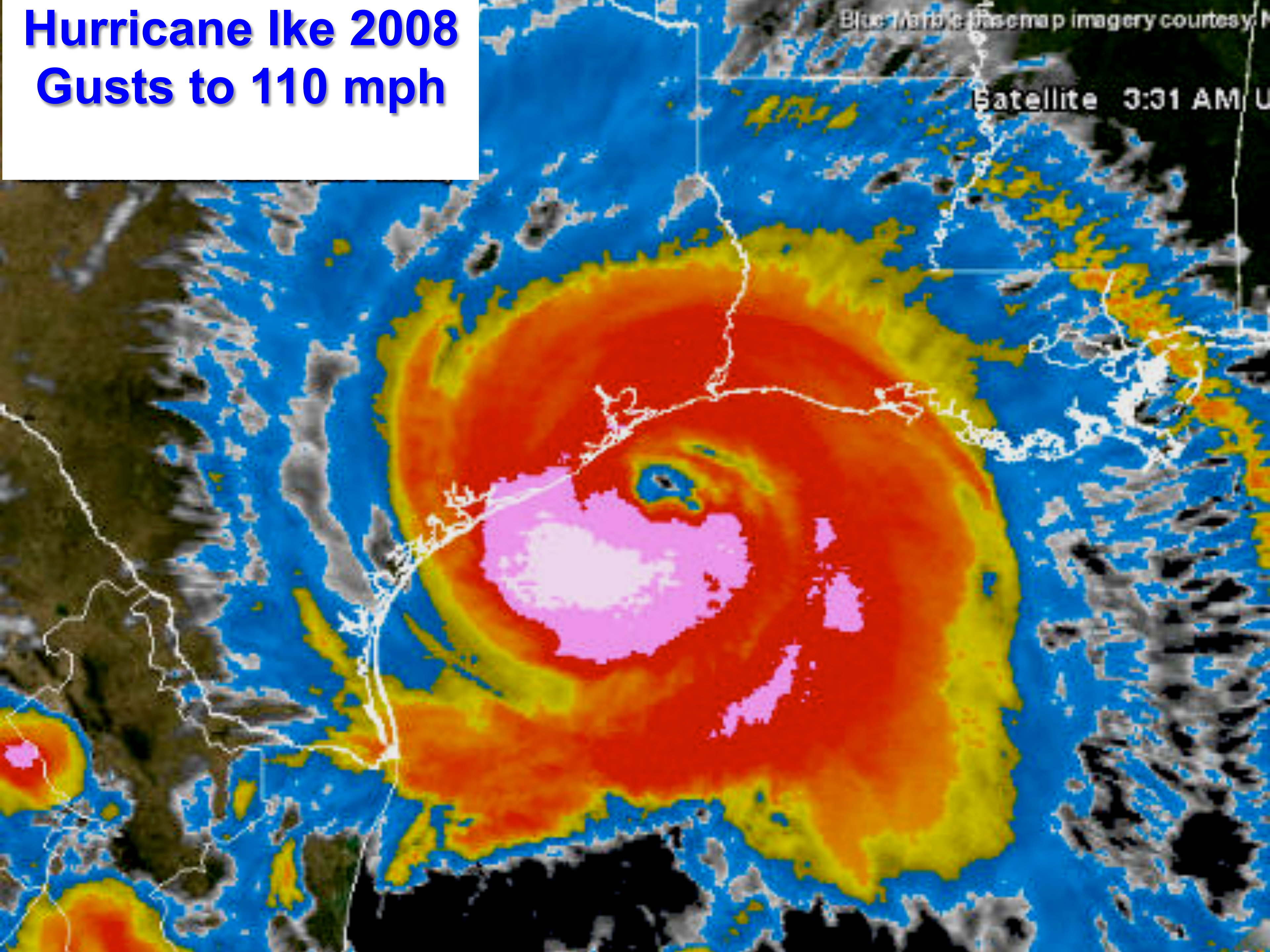
FEMA Disasters 1964-2013

Floods Create Hardships & Expense, and also the Energy Intensive Replacement Of Materials.

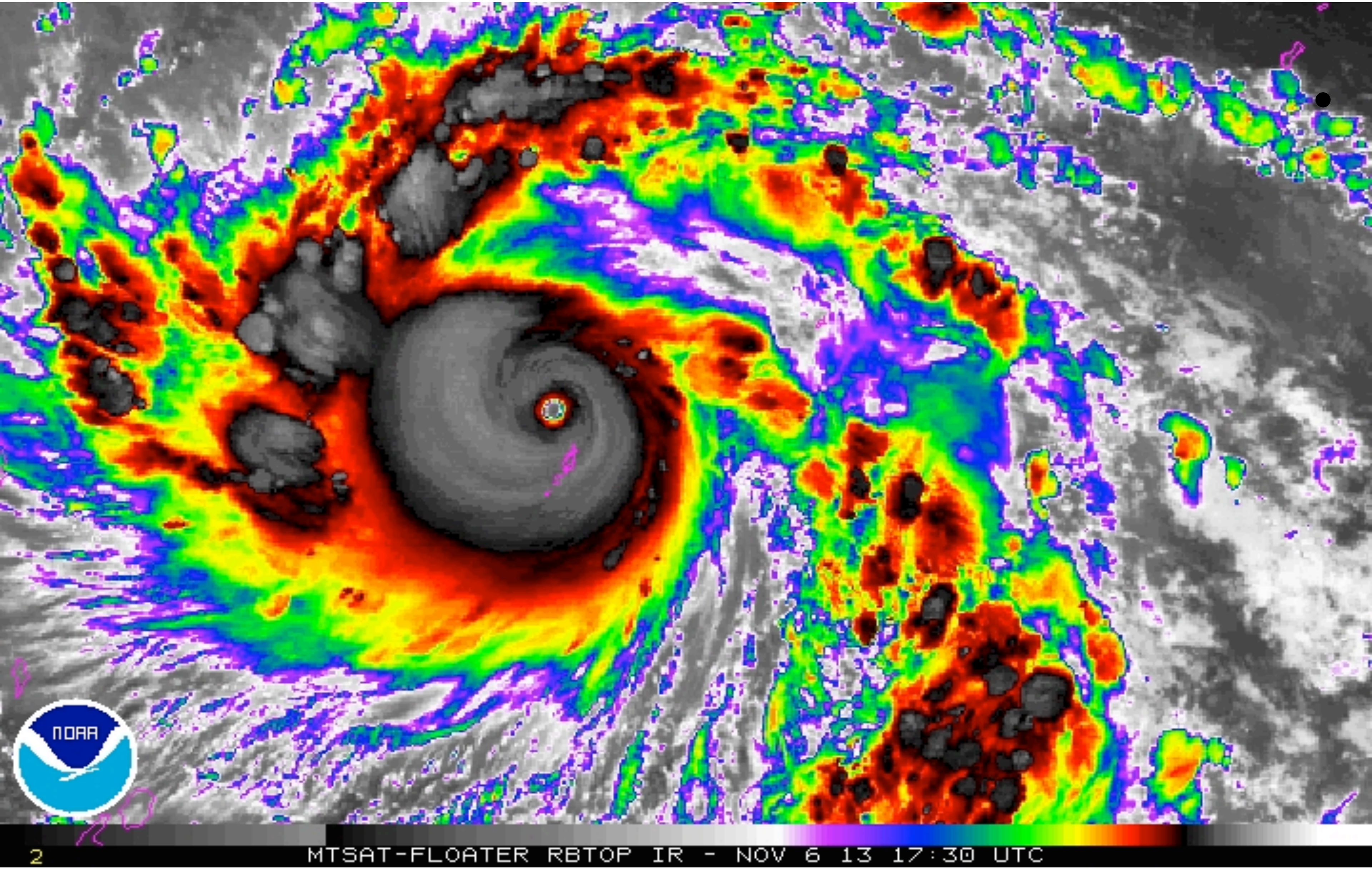
TS Allison 2001



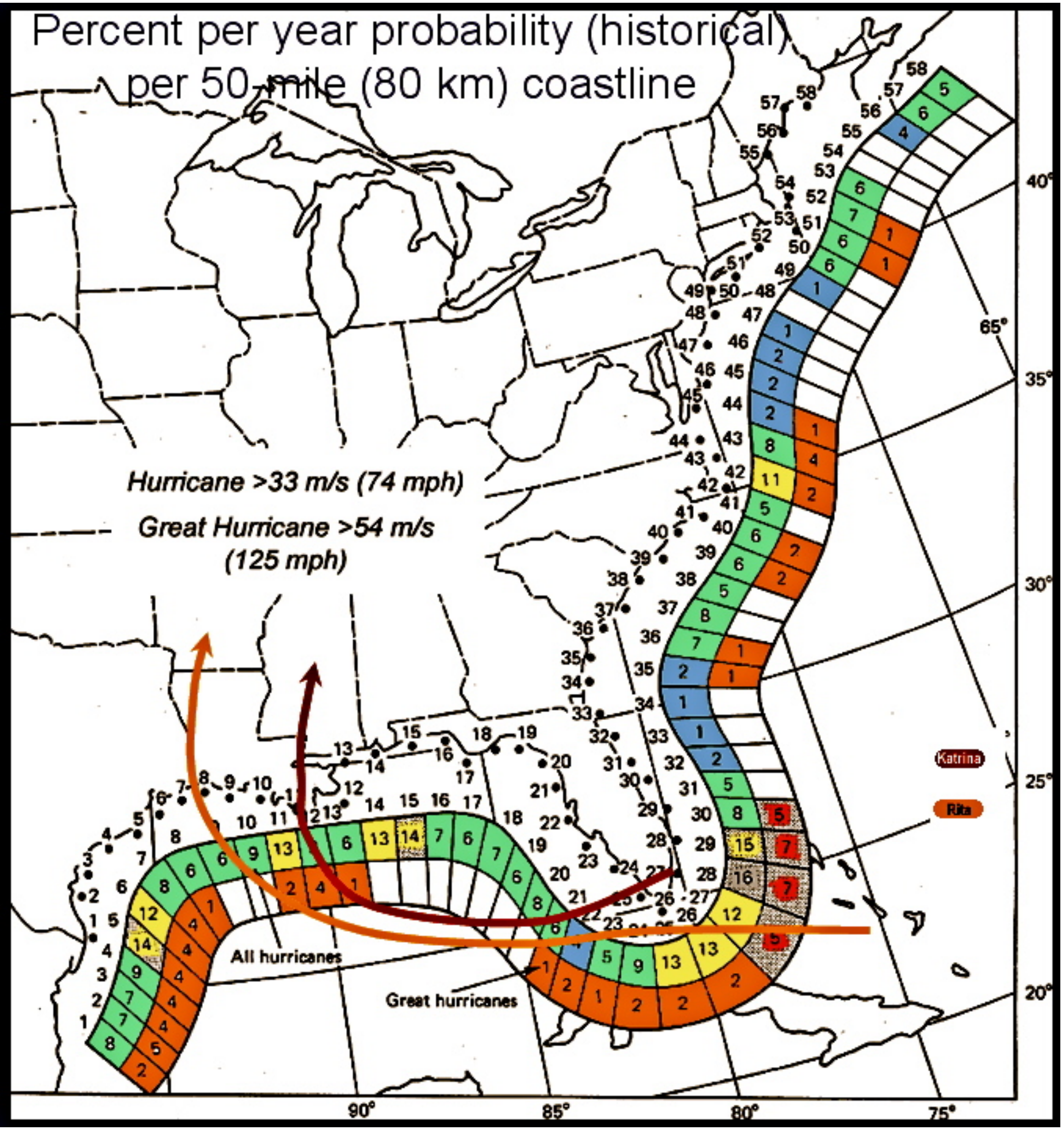
Hurricane Ike 2008
Gusts to 110 mph



2013 Typhoon Haiyan Goes Off Saffir Scale— Gusts Perhaps to 195 mph

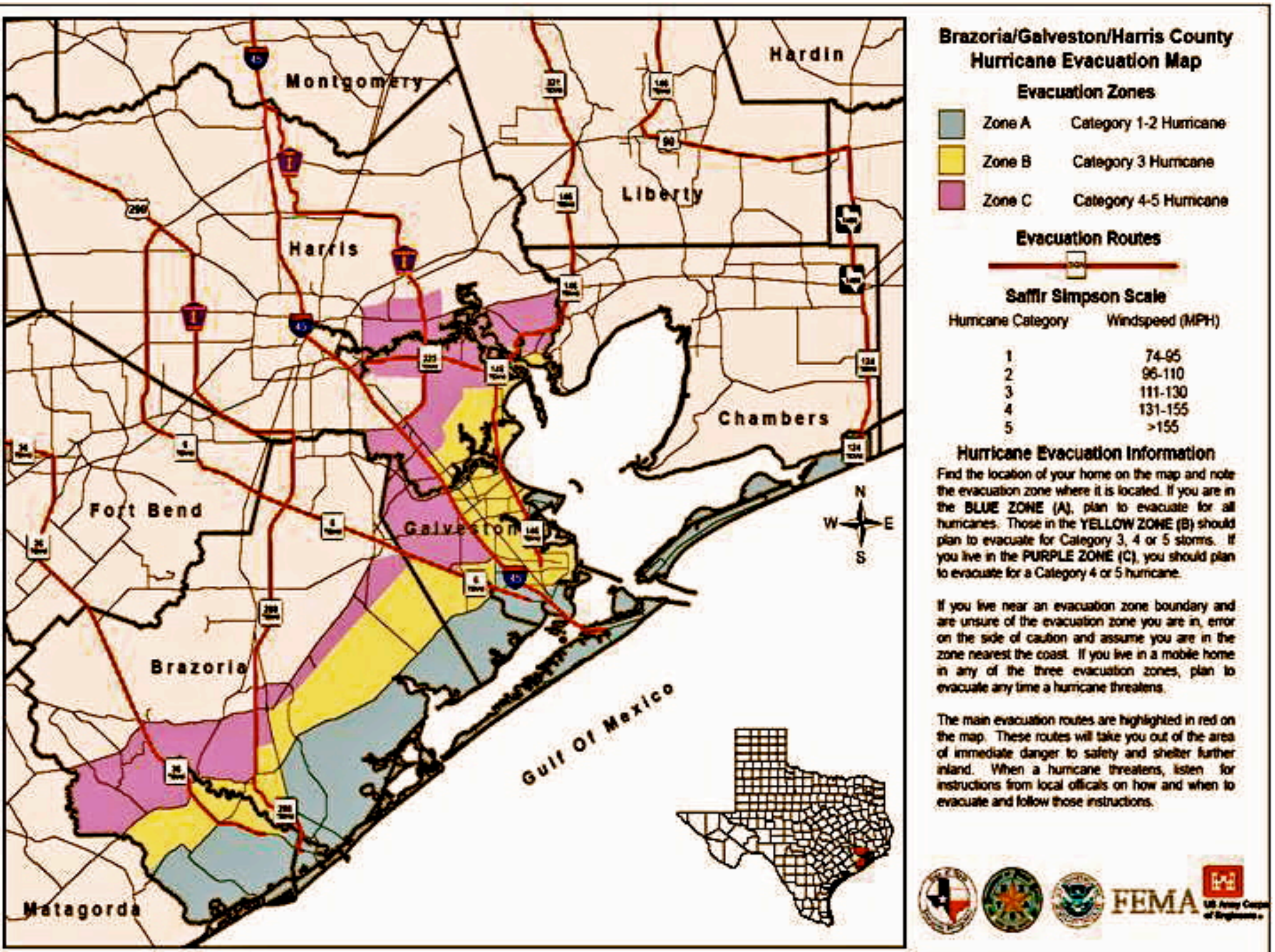


Hurricanes



Historically, we have a 6% chance per year of a coastal hurricane, and 1% for a Category 4 or 5.

Hurricanes



Brazoria/Galveston/Harris County
Hurricane Evacuation Map
Evacuation Zones
Zone A Category 1-2 Hurricane
Zone B Category 3 Hurricane
Zone C Category 4-5 Hurricane
Evacuation Routes
Saffir Simpson Scale
Hurricane Category Windspeed (MPH)
1 74-95
2 96-110
3 111-130
4 131-155
5 >155
Hurricane Evacuation Information
Find the location of your home on the map and note the evacuation zone where it is located. If you are in the BLUE ZONE (A), plan to evacuate for all hurricanes. Those in the YELLOW ZONE (B) should plan to evacuate for Category 3, 4 or 5 storms. If you live in the PURPLE ZONE (C), you should plan to evacuate for a Category 4 or 5 hurricane.
If you live near an evacuation zone boundary and are unsure of the evacuation zone you are in, error on the side of caution and assume you are in the zone nearest the coast. If you live in a mobile home in any of the three evacuation zones, plan to evacuate any time a hurricane threatens.
The main evacuation routes are highlighted in red on the map. These routes will take you out of the area of immediate danger to safety and shelter further inland. When a hurricane threatens, listen for instructions from local officals on how and when to evacuate and follow those instructions.
FEMA
Montgomery
Hardin
Liberty
Harris
Chambers
Fort Bend
Galveston
Brazoria
Matagorda
Gulf Of Mexico
N
W
E
S

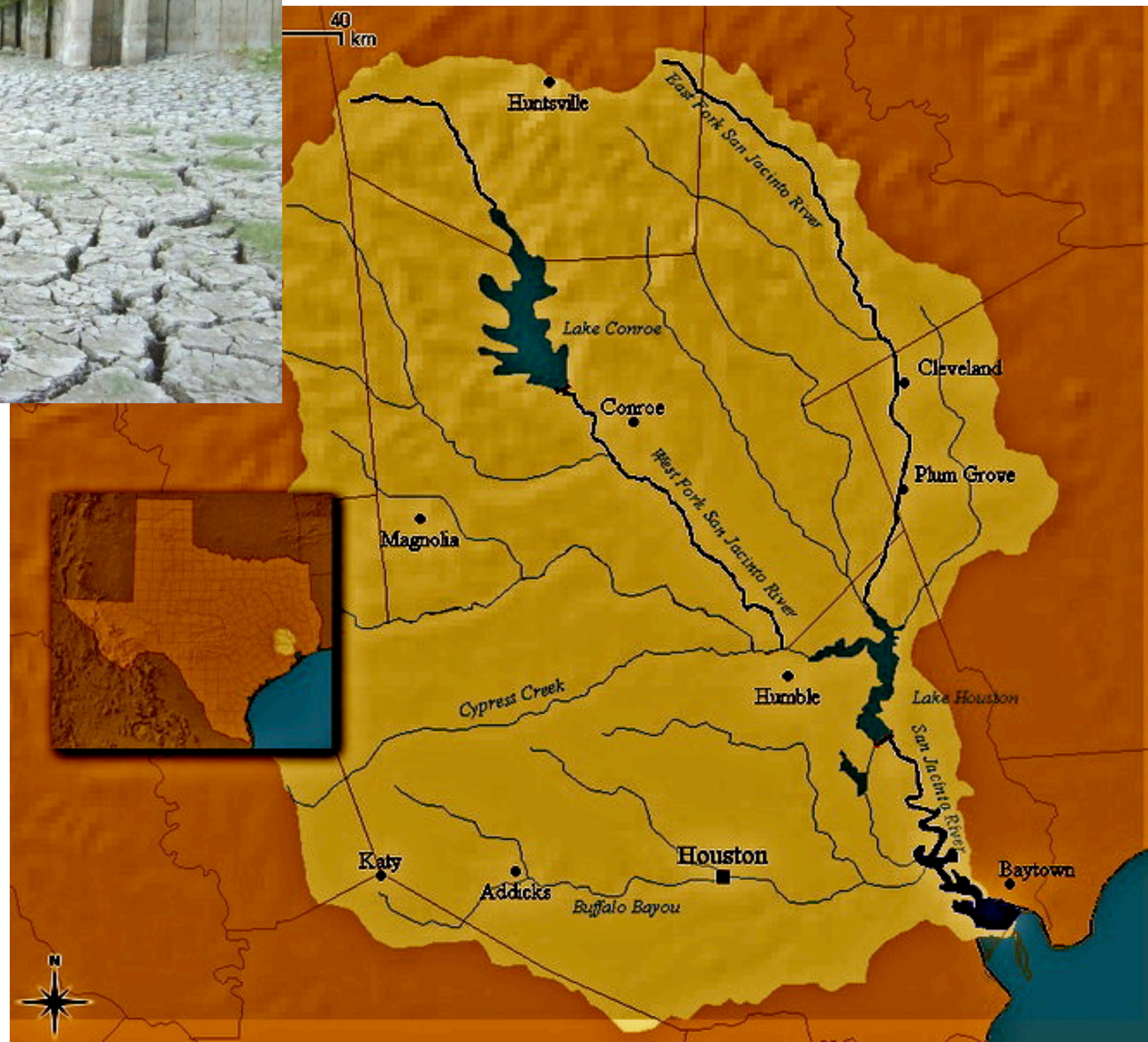
Sometimes it Gets Dry and Windy Increasing the Danger of Fire

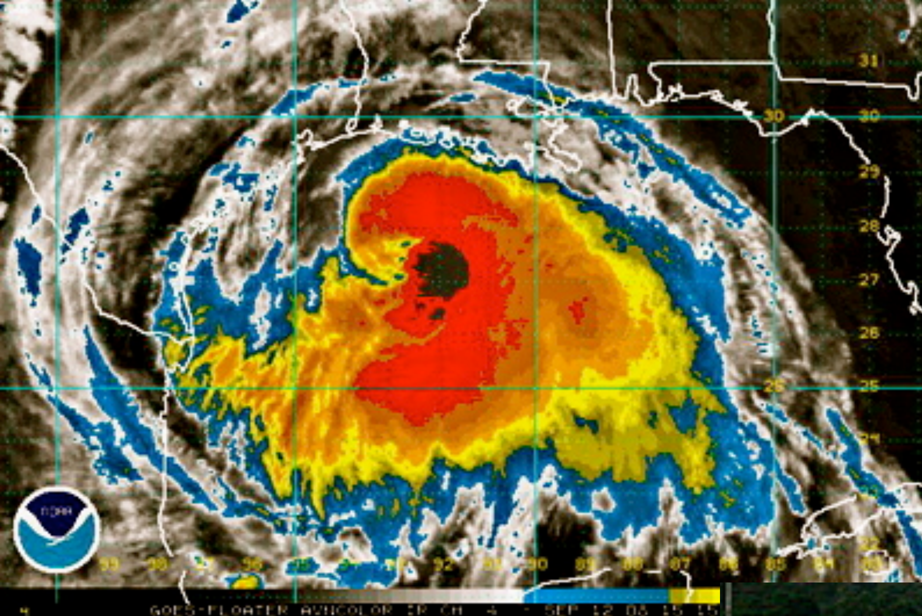
Houston Arboretum September 2011

Droughts Require Huge Investments In Water Storage And Fire Prevention

2011 Bastrop Wildfire

Lake Conroe —The City of Houston's Backup Water Supply 2011





Hurricanes and Tornadoes also create huge energy losses.

Hurricane Ike 2008

9/9/08 and 6 days Later

Wrecked Agriculture

Even 30 minutes of Hail Can Wreck A Lot of Tree Bark, Windows, Greenhouses, etc.

04/27/2014 E1.00 INCH BASTROP TX TRAINED SPOTTER

0730 PM HAIL 1 NNW PAIGE 30.23N 97.12W
04/27/2014 E1.00 INCH BASTROP TX TRAINED SPOTTER

0740 PM HAIL 4 E PAIGE 30.22N 97.05W
04/27/2014 E0.25 INCH LEE TX TRAINED SPOTTER

0809 PM HAIL 2 N GIDDINGS 30.21N 96.93W
04/27/2014 E2.75 INCH LEE TX LAW ENFORCEMENT

0810 PM HAIL 3 NW GIDDINGS 30.21N 96.96W
04/27/2014 E1.25 INCH LEE TX TRAINED SPOTTER

0813 PM HAIL 3 N GIDDINGS 30.23N 96.93W
04/27/2014 M3.00 INCH LEE TX PUBLIC

Quarter Size Hail from Paige, TX around 7:30 pm (Photo Credit: Bastrop County OEM)

Quarter Sized Hail in Bastrop

3 inch hail in Giddings

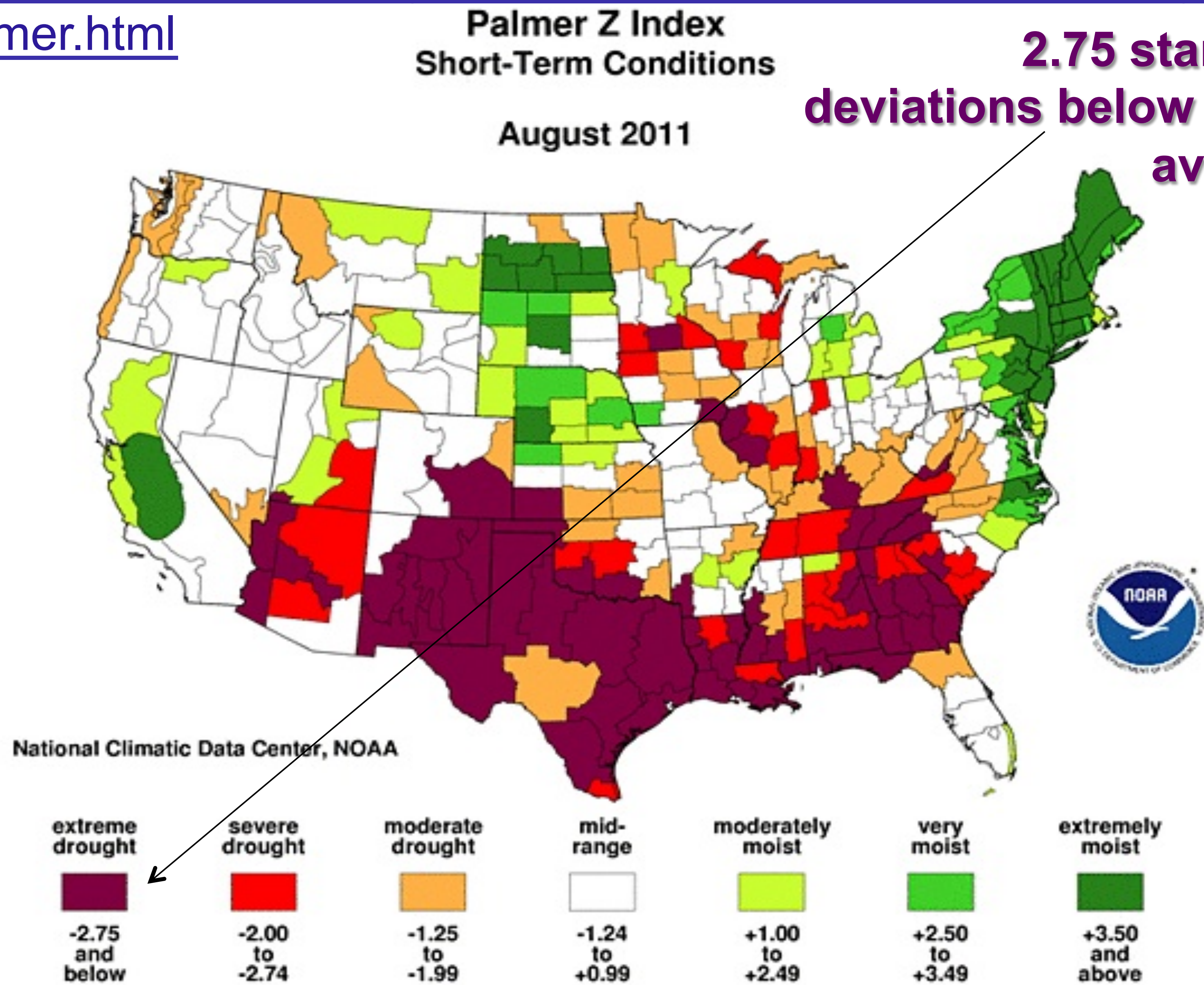
Several Large hail. One measured at 3 inches in diameter. Hail occurred around 8:15 pm north of Giddings, TX (Photo Credit: Tee D.

In Sum

Understanding weather and predicting it is *CRUCIAL* in designing for energy use, buildings, transport, gardening, farming, and eating.

http://www.ncdc.noaa.gov/oa/climate/research/prelim/drought/palmer.html

2.75 standard deviations below mean average



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- ***Main Causes of "Normal" weather & climate***
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Temperature Varies Across Our Area

- **Plants and structures need to be designed for the part of our area they are in.**

- **There is a huge range of winter temperatures from Galveston to Coldspring. See http://yearroundgardening.me/category/fruit-trees-winter-weather-in-southeast-texas/**

- **In general, *temperatures are warmer very near the Gulf (<12 mi.), and in built-up urban areas* especially south of downtown Houston.**

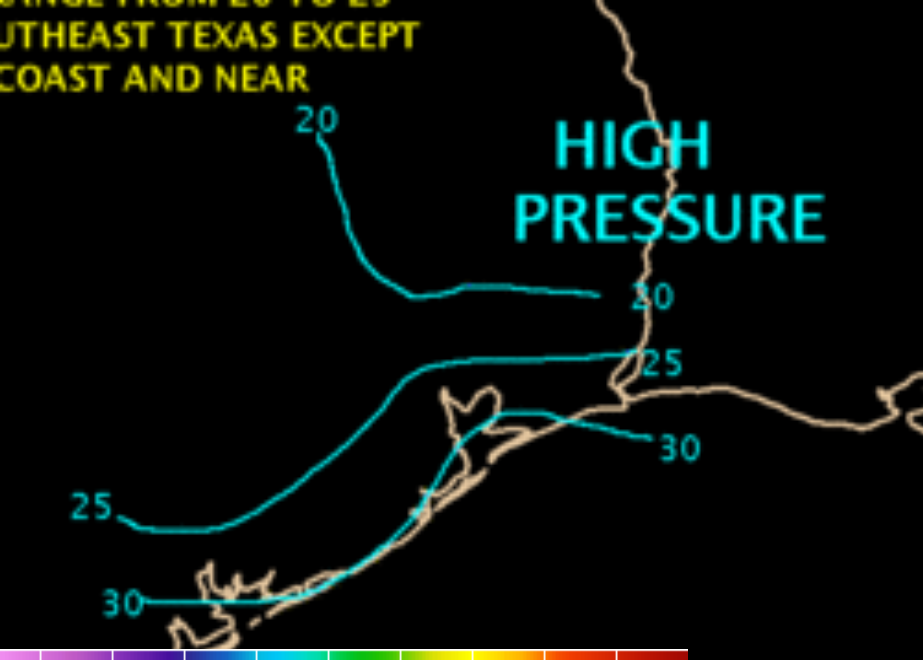
- **Other areas within 75 miles of the Gulf are less warm.**

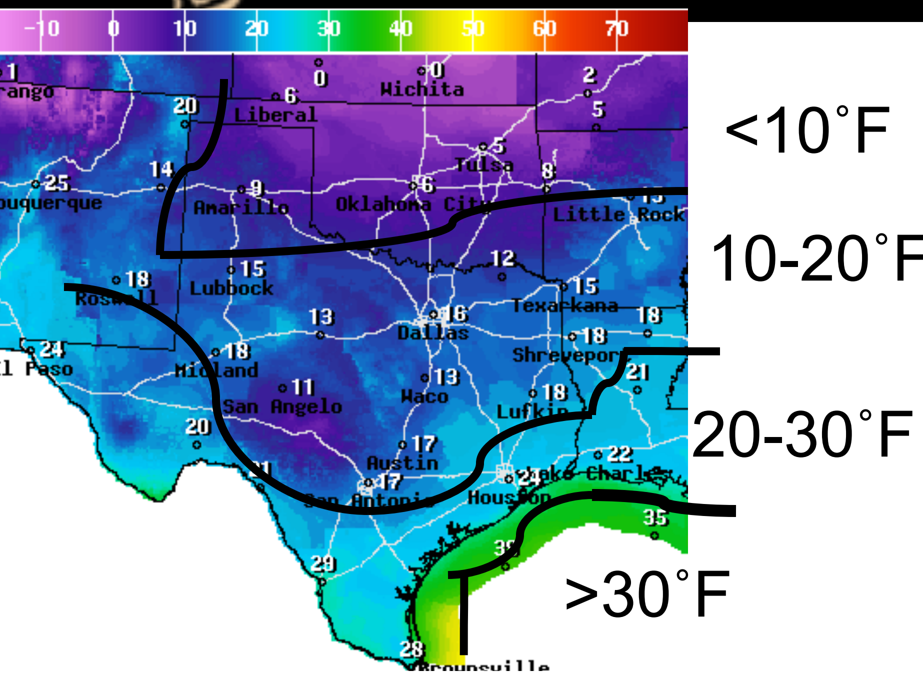
Temperature Varies Across Our Area

- Conroe averages more than 20 frosts while Galveston 0-1!

January 3, 2002, the lows were:

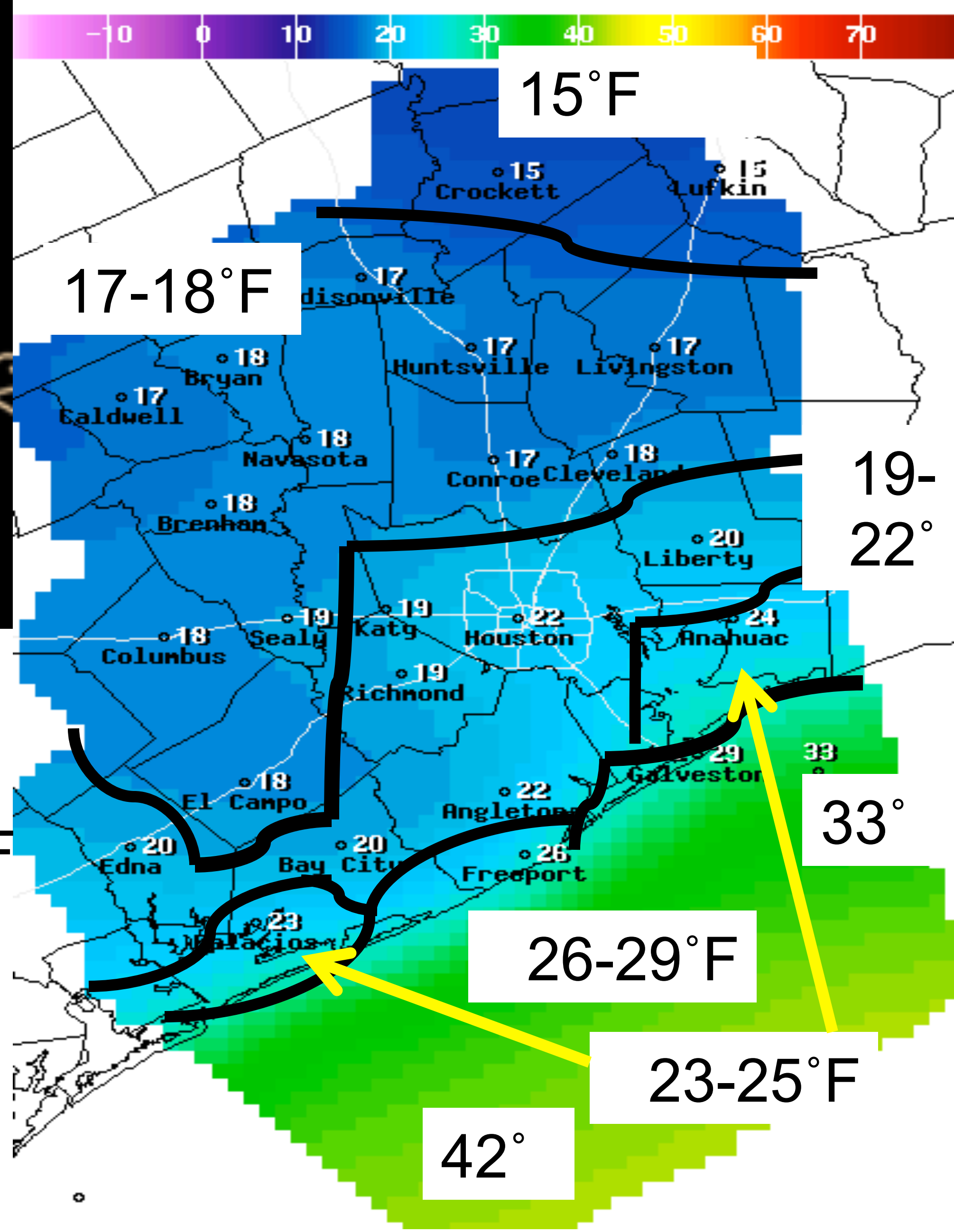
- Urban Austin 17˚F; Conroe 19˚;
- Intercontinental, Tomball, Sugar Land, Angleton 23˚; Hobby 27˚ ;
- Museum District 29˚, Galveston Island & Port of Houston 32˚.





A COLD NIGHT 1/9/10

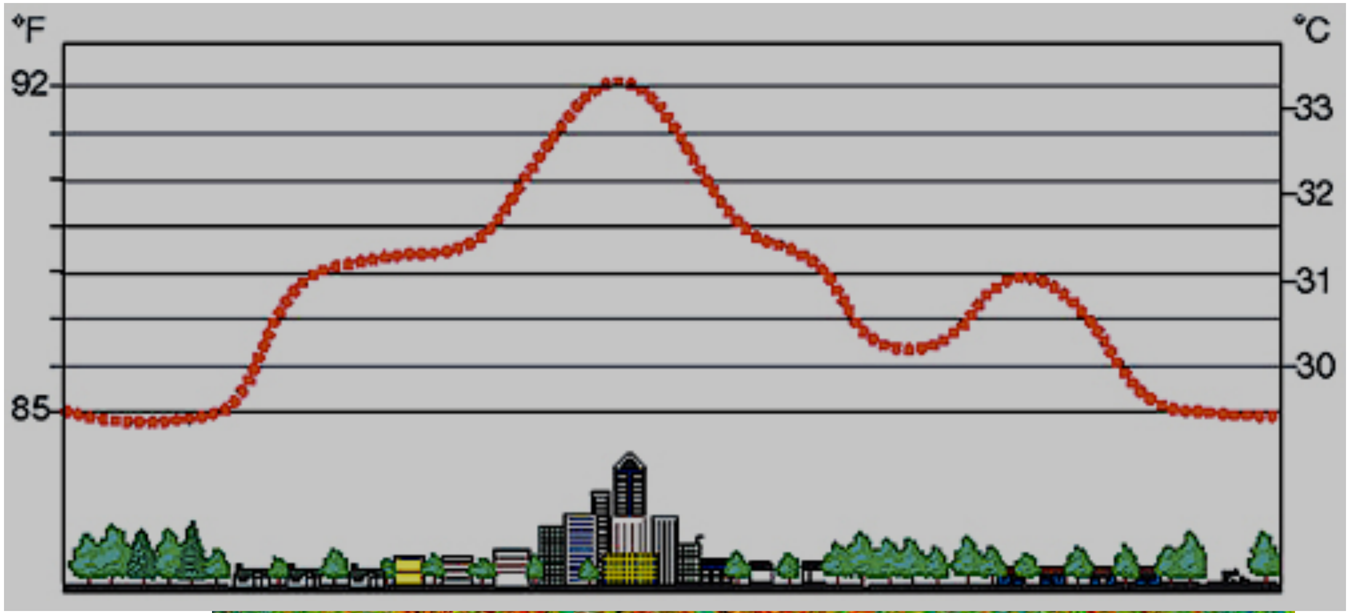
v6z issuance Graphic Created-Jan 09 3:16AM EST

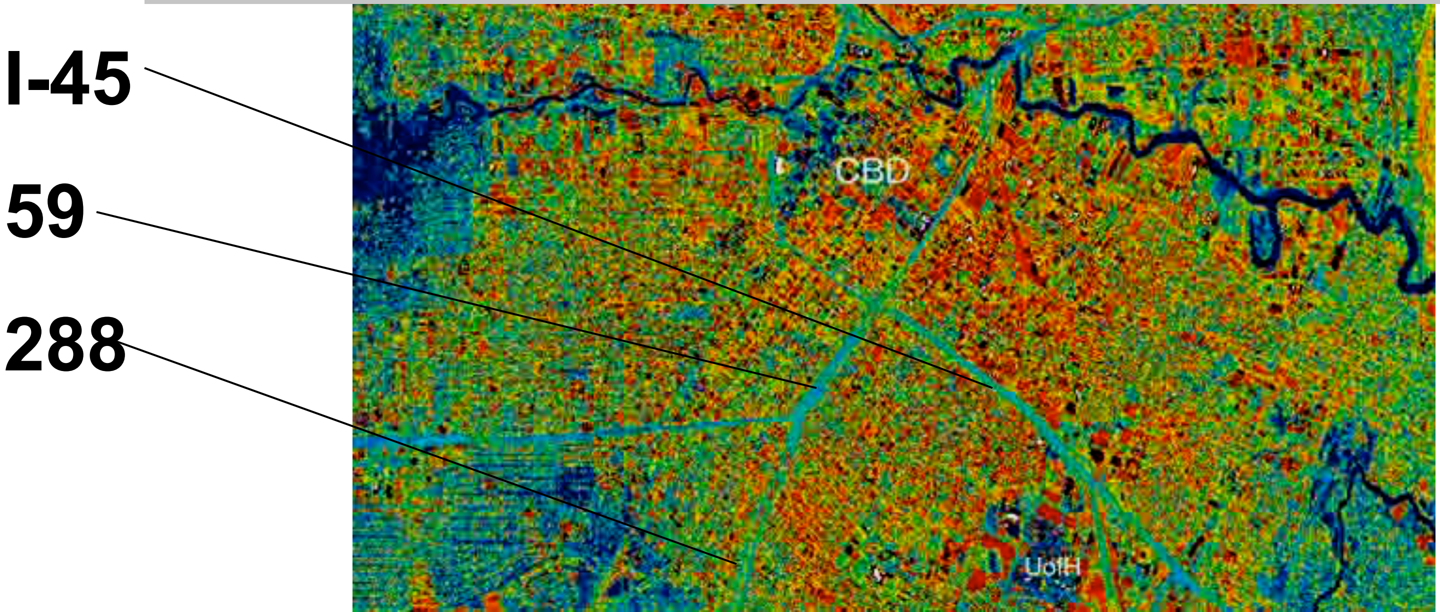


A COLD NIGHT 1/10/10

Graphic Created Jan 10 4:16AM CST

Urban Heat Island (from HARC)





Even Temperatures in one's Backyard Can Be Different in Different Places!

- **I have measured temperature differences *in my yard* of as much as 11˚.**
- **On very cold windy nights, there is usually a 7˚ difference between the warmest part of my yard (under the eaves near my house's southwest corner near trees) and**
- **the coldest (in open ground exposed to north winds), and on still cold nights it is about 4˚.**

Month to Month Temperature Variation

- *At Intercontinental*, all cool months Oct. to Apr. except Dec and January have had record high temperatures over 90˚.

- Dec. & Jan. --low 80˚s.

- April & Oct. average daily highs 76-86˚; Nov. & Mar. 68-76˚, Dec 63-68˚, and Jan. 61-63˚.

Month to Month Temperature Variation

- **All cool months have had freezing temperatures at least once.**
- **Records: Oct--32˚, Apr--31˚,Mar. 22˚, Nov. 19˚, Feb. 14˚, Dec. 7˚ in 1989, Jan. 5˚.**
- **April & Oct. average daily lows 53-63˚, Nov. & Mar. 45-54˚, Dec 41-45˚, and Jan. 40-41˚.**
- **Harris County has historically been below 20˚ 1 yr. in 10 but Hobby has been above 20 since 1991.**
- **IAH has been above since 1996.**

Summer Temperatures

- **Average (mean) daily temperatures are based on 24 hours.**
- **As the day shortens in July and August, longer nights bring down temperature averages**
- **But heat buildup and radiation from oceans and earth counters this until mid-August.**
- **The ocean begins to cool in September**

Year to Year Variation

- Over the area, Jan. mean temperatures for 1999 & 2000 were 8 degrees higher than in 2001
- So “the January Average” doesn’t help very much in selecting a plant or house insulation.
- Rather it is best ***to get 20 year summaries for an area***
- Much of the nation now has online weather archives for NWS Weather Stations, so you can find out what the January low has been for the last 10-20 years. Forget averages!

HOUSTON HOBBY'S ANNUAL TOP 10 LIST

The following is a list of Houston Hobby's Top 10 wettest, driest, warmest, an coolest years.

If random, one record per list every 8 years.

Houston Hobby's Annual Lists 1931-2011

Top 10 Wettest		Top 10 Driest		Top 10 Warmest		Top 10 Coolest	
83.02	1979	25.41	2011	72.4	2011	66.8	1940
82.14	1981	26.65	1988	72.3	1998	67.1	1970
81.68	2001	28.32	1956	71.4	2006	67.2	1979
80.59	1973	28.76	1954	71.4	2005	67.5	1983
76.79	1997	31.11	1931	71.3	2008	67.5	1936
73.33	1991	31.62	1932	71.1	2009	67.6	1976
72.86	1946	32.29	1963	71.1	2000	67.8	1978
71.19	1949	33.28	1951	71.0	2007	67.8	1937
69.66	1976	33.88	1950	70.9	2004	68.0	1942
68.23	1959	34.67	1999	70.9	1965	68.1	1947

The Minimum Temperature for the Whole Winter

Fall 1992-fall 2012	50% of winters = or >	100% of winters = or >
Galveston	33˚ F	25˚ F
Urban Coastal, Port of Houston, Ellington Field	30˚ F	20˚ F
Hobby AP, Baytown, Sugar Land, Pearland, urban Houston south of downtown	28˚ F	18-20˚ F
Richmond, League City, IAH Airport, Liberty, Anahuac, El Campo, Sealy, Alvin, Brenham, Angleton Lake Jackson, Spring, Tomball, Conroe	25˚ F	15-20 F
Rural Wharton, College Station, Huntsville, Bastrop, La Grange, Bellville, Cleveland, Coldspring	23˚ F	15-18˚ F
Livingston, Columbus, Madisonville, Washington County	20˚ F	8-18˚ F

Chill Summary

- Very Low Chill Zone-- Galveston Island, Freeport, Matagorda, Aransas, and other coastal areas. Purchase/Get 100-400 chill unit (CU) trees.
- Low Chill Zone-- dense urban Houston south of downtown out to Hobby, Pearland, and Port of Houston. Get trees with 400 CU or less.
- Medium Low Chill Zone--Angleton/Lake Jackson, Sugar Land, Richmond, Wharton County, and both rural southern and rural eastern Harris County. Get trees with 500 CU or less.
- Medium Chill Zone--Intercontinental Airport and urban north Harris, Liberty, Anahuac, Beaumont, and Port Arthur. Get trees with 500 CU or less.

- ***Medium High Chill Zone*-- Spring, Tomball, La Grange, San Antonio, and Fayette County. Get trees with 600 CU. Get 700 CU trees if there are a lot of late freezes.**

- ***High Chill Zone*--Conroe, Columbus, Bellville, Sealy, Brenham, College Station, Huntsville Airport, & urban parts of Austin. Get 700 CU.**

- ***Very High Chill Zone*--rural Huntsville, Cleveland, Coldspring, Madisonville, Washington County, and rural Austin. Get 800 CU trees.**

- ***Highest Chill Zone*-- Livingston, Crockett, Centerville, and Somerville Dam. Get 800 CU or higher trees. 5-10% of the time, this zone gets 1200 or more CU!**

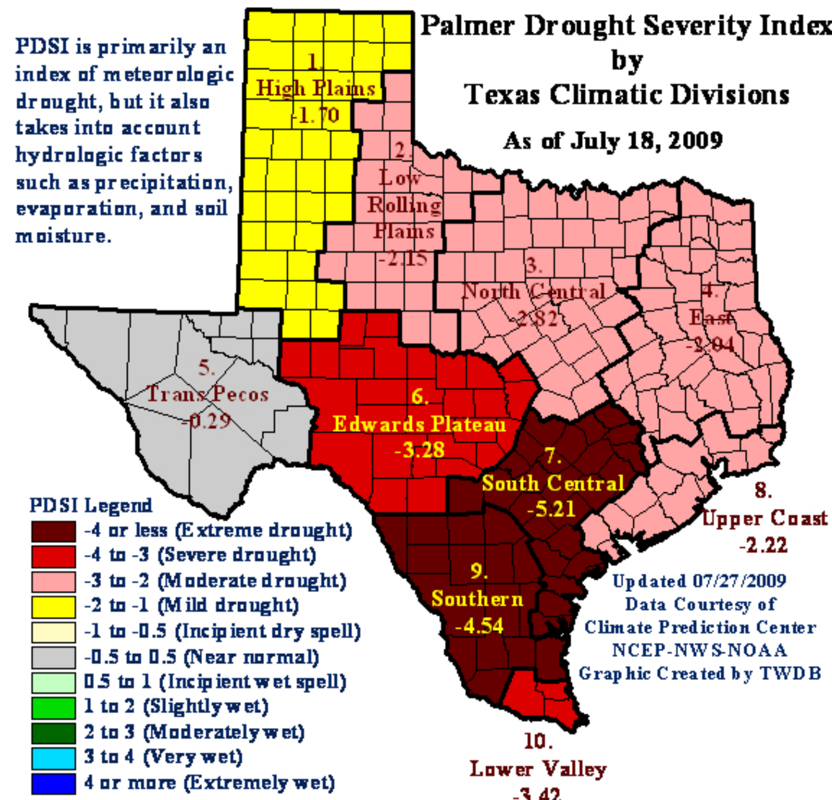
Weather & Climate

- **Why climate and weather are important.**
- **Getting Weather Data & Forecasts**
- **Plants & Temperatures**
- ***Rainfall & Drought***
- **Why does weather change year to year?**
- **How and why climate is changing.**

Area Precipitation and Evaporation

7/19/09

- In ***sunlight*** **on area lakes, evaporation exceeds precipitation by <u>8 inches</u> per year.**
- **Highest monthly evaporations ever are 7-8 inches in summer and fall, 4-6 inches in spring, and 3-4 inches in winter.**



report see http://www.texaswaterinfo.net/Monitoring/Meteorological/Drought/pdsi.htm

- ***In every month,*** **there are record high** ***monthly*** **rainfalls of between 8-14 inches.**
- **In some places there has been much more on isolated dates.**
- **May averages the wettest month (6 inches);**
- **Most months are 3-4 inches; Jan., Feb. March have the least rainfall.**
- **10 wettest Julys are 7-14 inches; 10 driest are 0-1.**
- **On July 25, 1979 Tropical Storm Claudette stalled over Alvin, TX and flooded the region with 43 inches of rain in 24 hours;**
- ***The maximum 24-hour rainfall in US history!***

Solar System & Climate

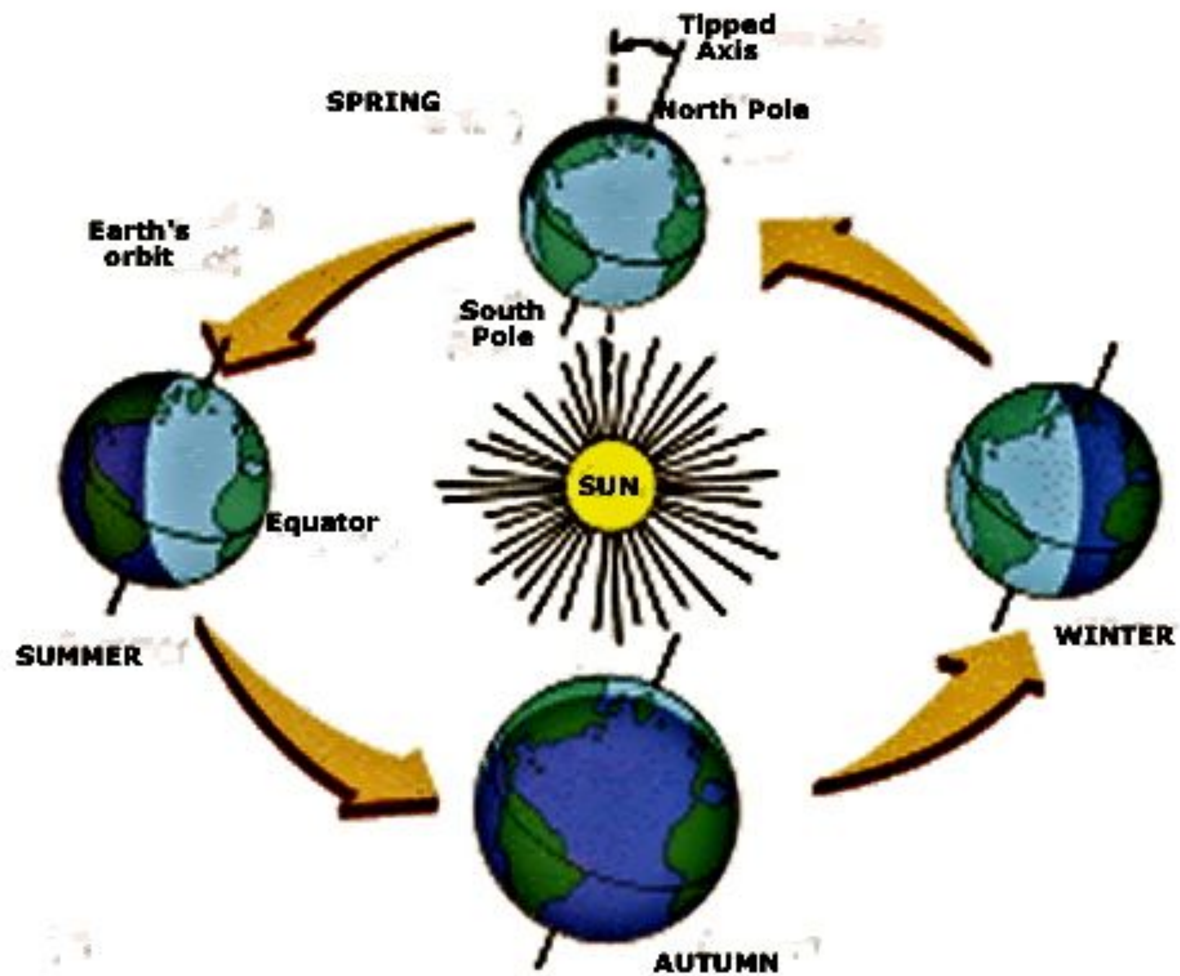
- The earth receives solar radiation from the sun.
- It absorbs some heat, and also reflects some heat and light back into space.
- How much heat the earth receives changes according to the output of the sun,
- And upon the position of the earth with respect to the sun.

Solar System & Climate

- The sun goes through intensity cycles called *sunspots* that happen on average about every 10.8 years.
- The sun is also VERY VERY gradually losing energy. And
- Over *tens and hundreds of thousands of years*, the earth's distance from the sun oscillates, as does its tilt towards the sun.
- This caused ice ages & warm periods in the past.

Earth's Position Vs. The Sun & Yearly Weather Changes

At any one place on earth, heat and light effects change over the year. Summer and winter are caused by the tilt of the earth on its axis and the position of the earth's hemispheres relative to the sun over the year.

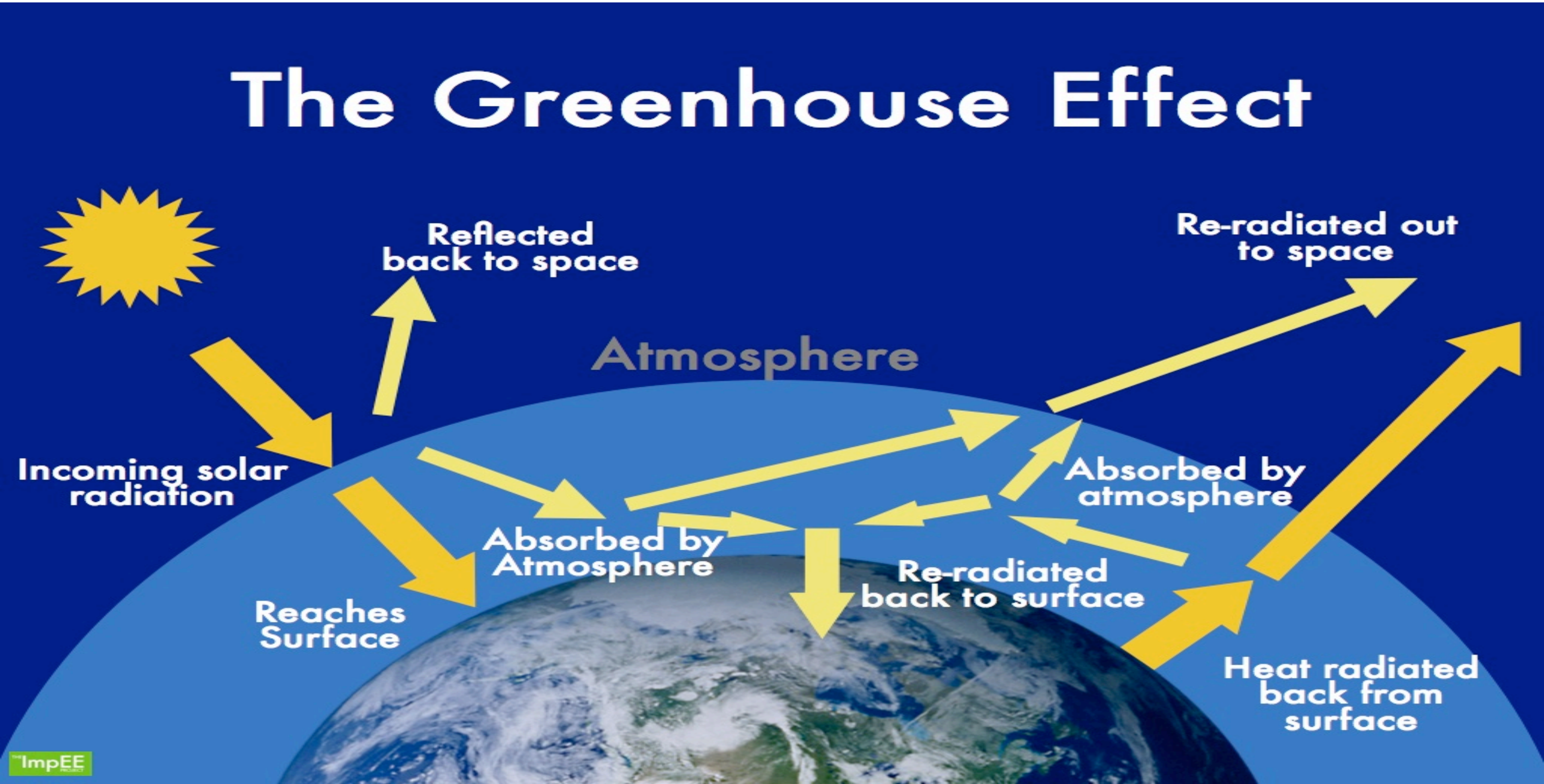


Heat Reflection & Trapping

- Particles in the earth's atmosphere also affect how much heat and light reaches earth.
- Volcanic eruptions can reduce the amount of sunshine reaching the earth, and therefore lower temperatures for a few years.
- Other types of particles such as water vapor clouds, jet engine exhaust and air pollution can reduce temperatures by reflecting heat into space.
- Light surfaces like snow reflect more heat

"Greenhouse" gases (water vapor, carbon dioxide, etc.) naturally blanket the Earth and by reflecting radiating heat back to earth, keep it about 93˚F warmer than without these gases in the atmosphere.

***Until a few centuries ago, it was in balance*.**

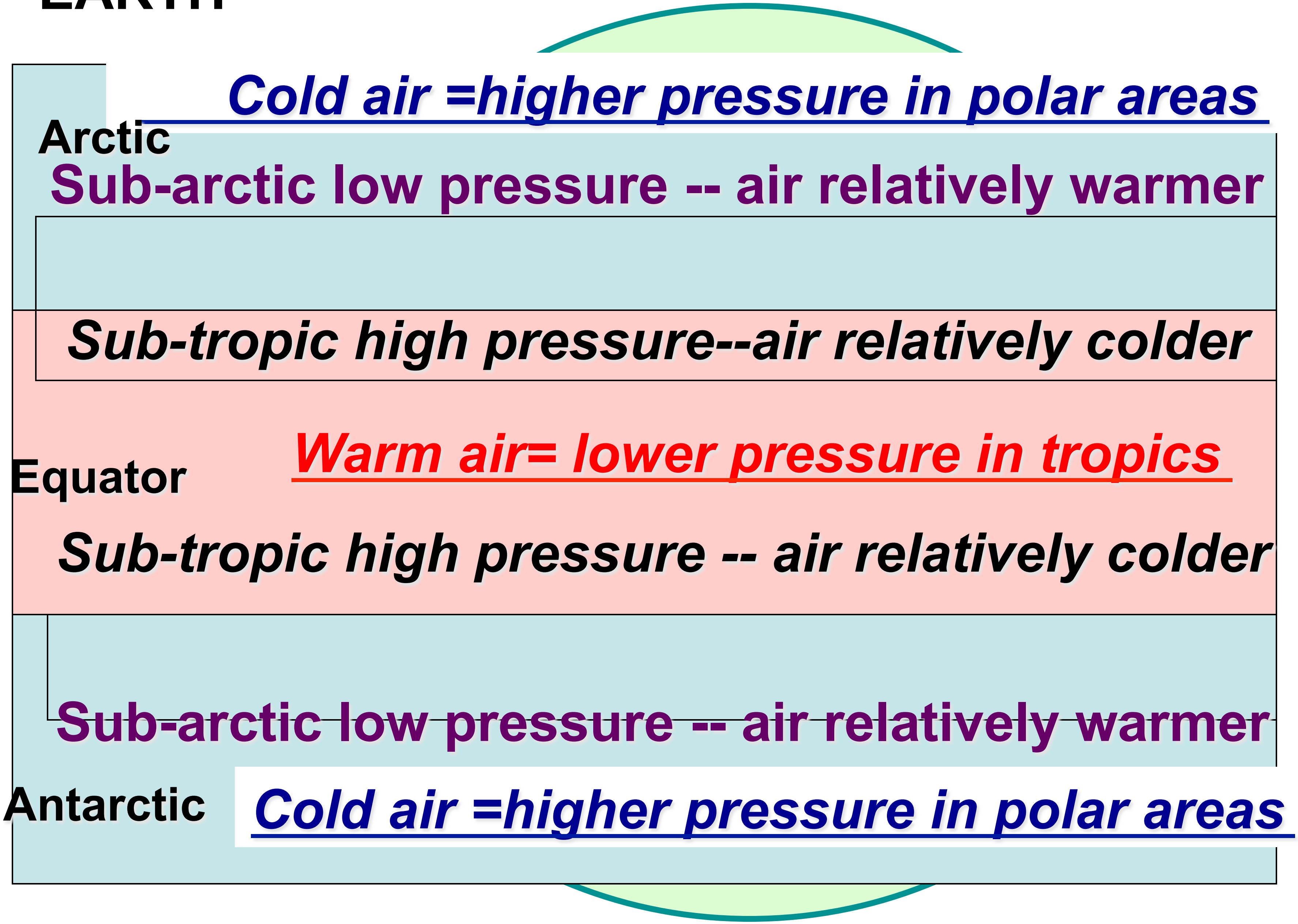


Main Causes of Weather

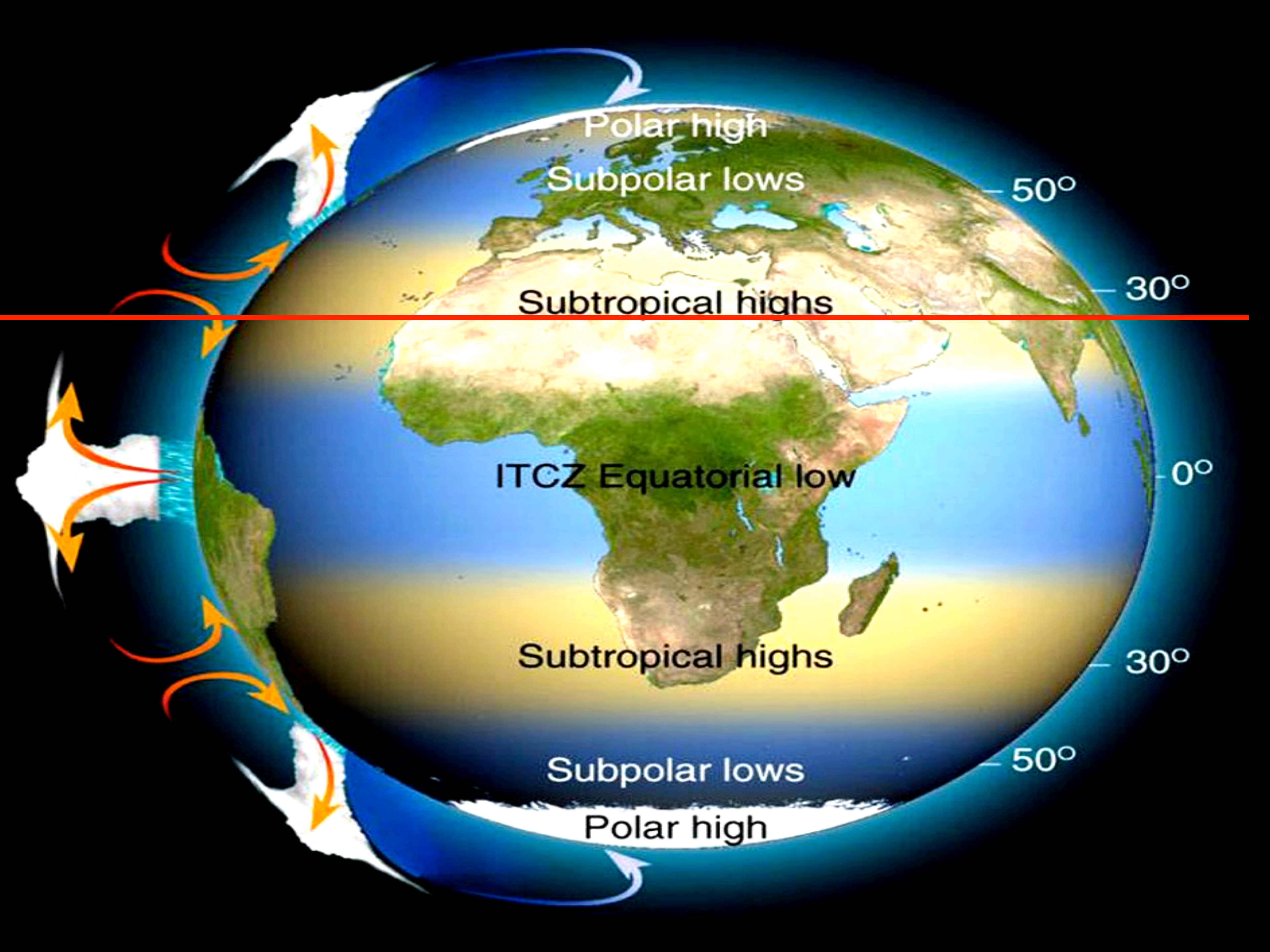
- **The main daily, monthly and yearly differences in weather result from *contrasts in temperatures between the poles and the equator*.**

- **Hot air rises more than cold air does.**
- **So parts of the planet with warm air tend to have lower air pressure than do cooler areas.**
- **These cooler areas have relatively higher pressure.**

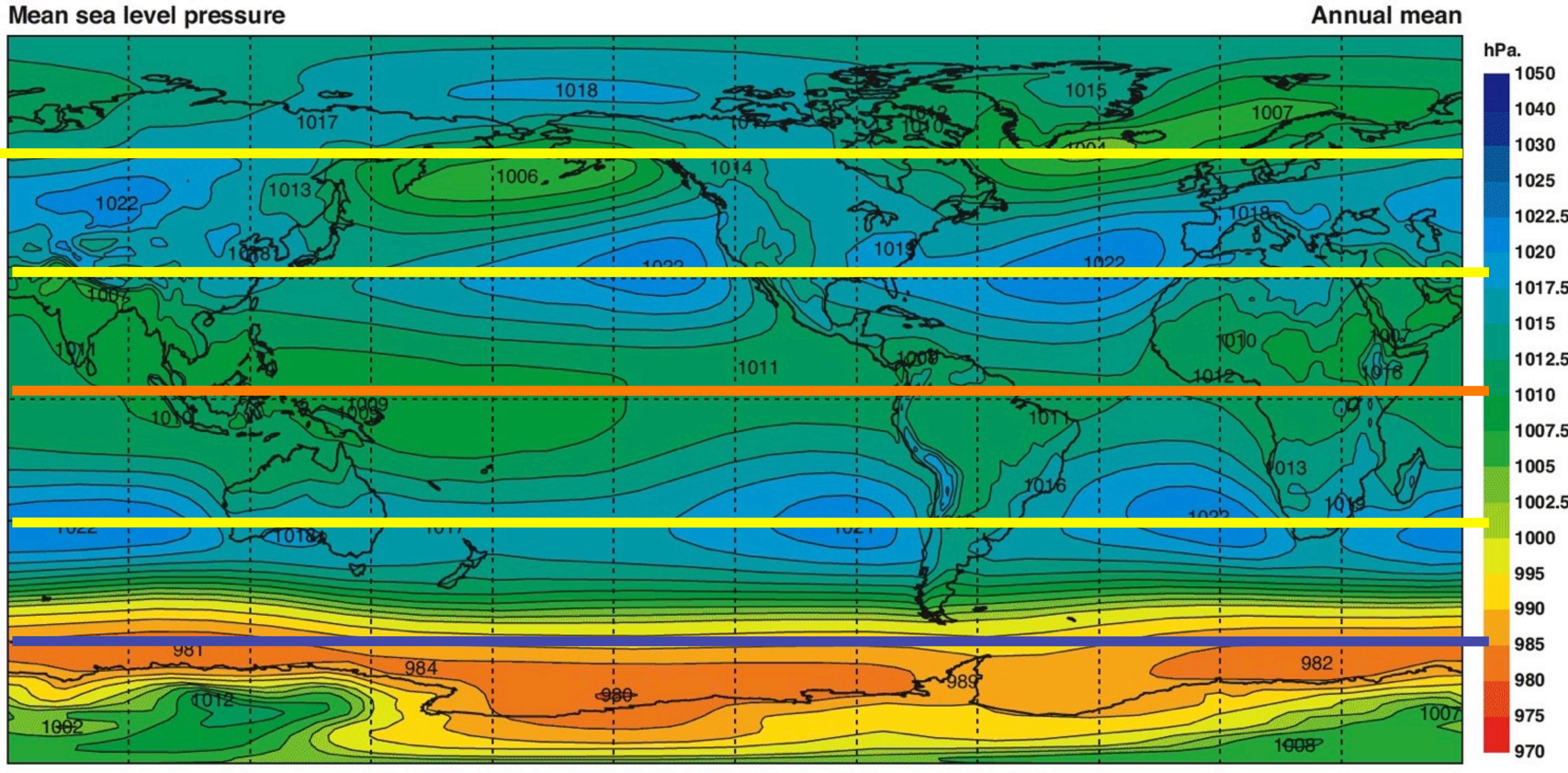
EARTH



Cold air =higher pressure in polar areas
Arctic
Sub-arctic low pressure -- air relatively warmer
Sub-tropic high pressure--air relatively colder
Warm air= lower pressure in tropics
Equator
Sub-tropic high pressure -- air relatively colder
Sub-arctic low pressure -- air relatively warmer
Antarctic
Cold air =higher pressure in polar areas


Polar high
Subpolar lows
50°
30°
Subtropical highs
ITCZ Equatorial low
0°
Subtropical highs
30°
Subpolar lows
50°
Polar high

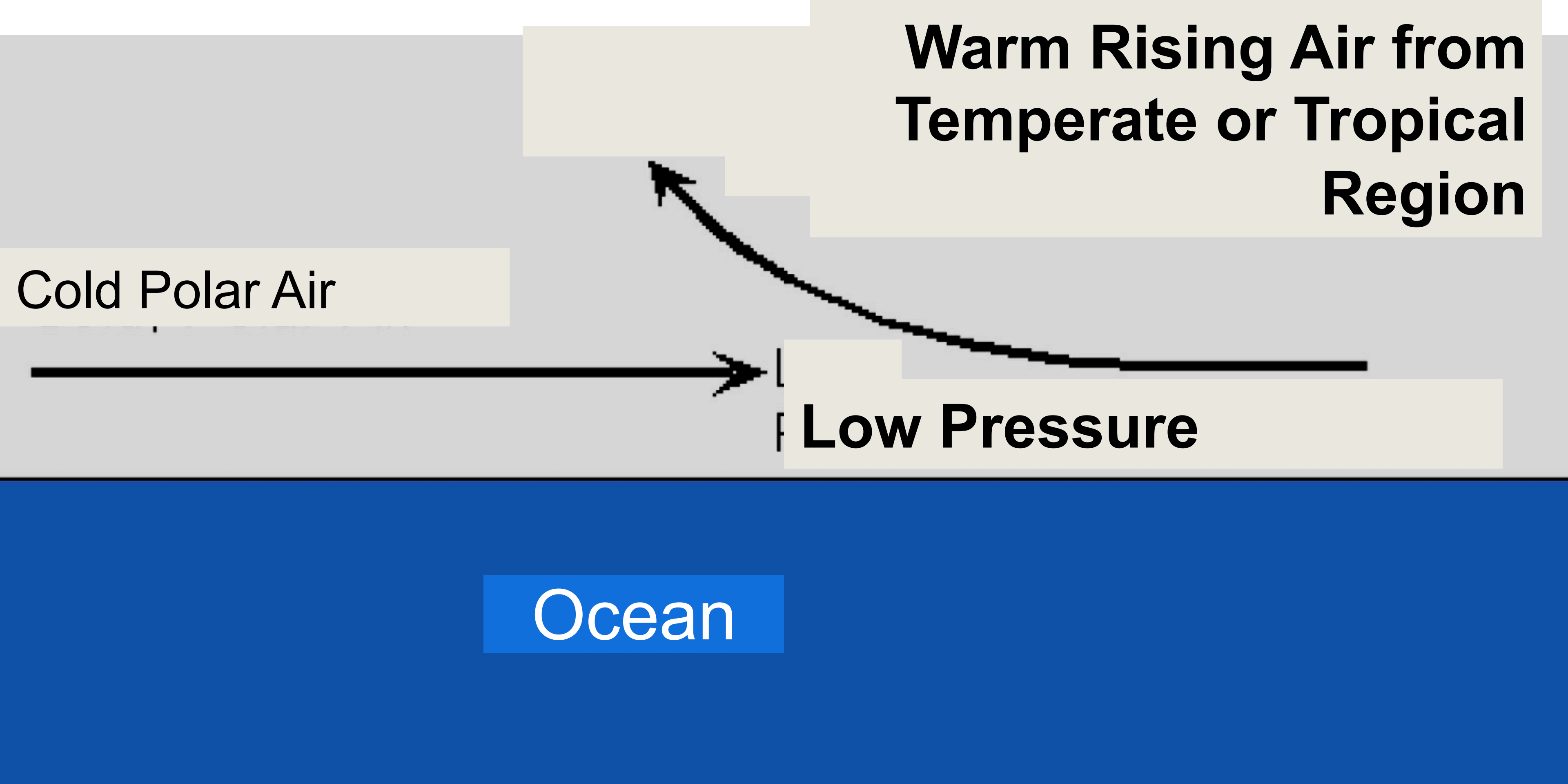
The regions colored in *blue are colder & higher pressures, than the green area nearer the equator.*



Wind & Rain

- **As well, land (even rocks or tree leaves) may heat up at different rates from a nearby ocean, so pressures can vary locally.**
- **Generally, high pressure moves to lower pressure.**
- **So you get wind!**
- **And when warm air masses and cooler ones collide, you get condensation, rain, storms.**

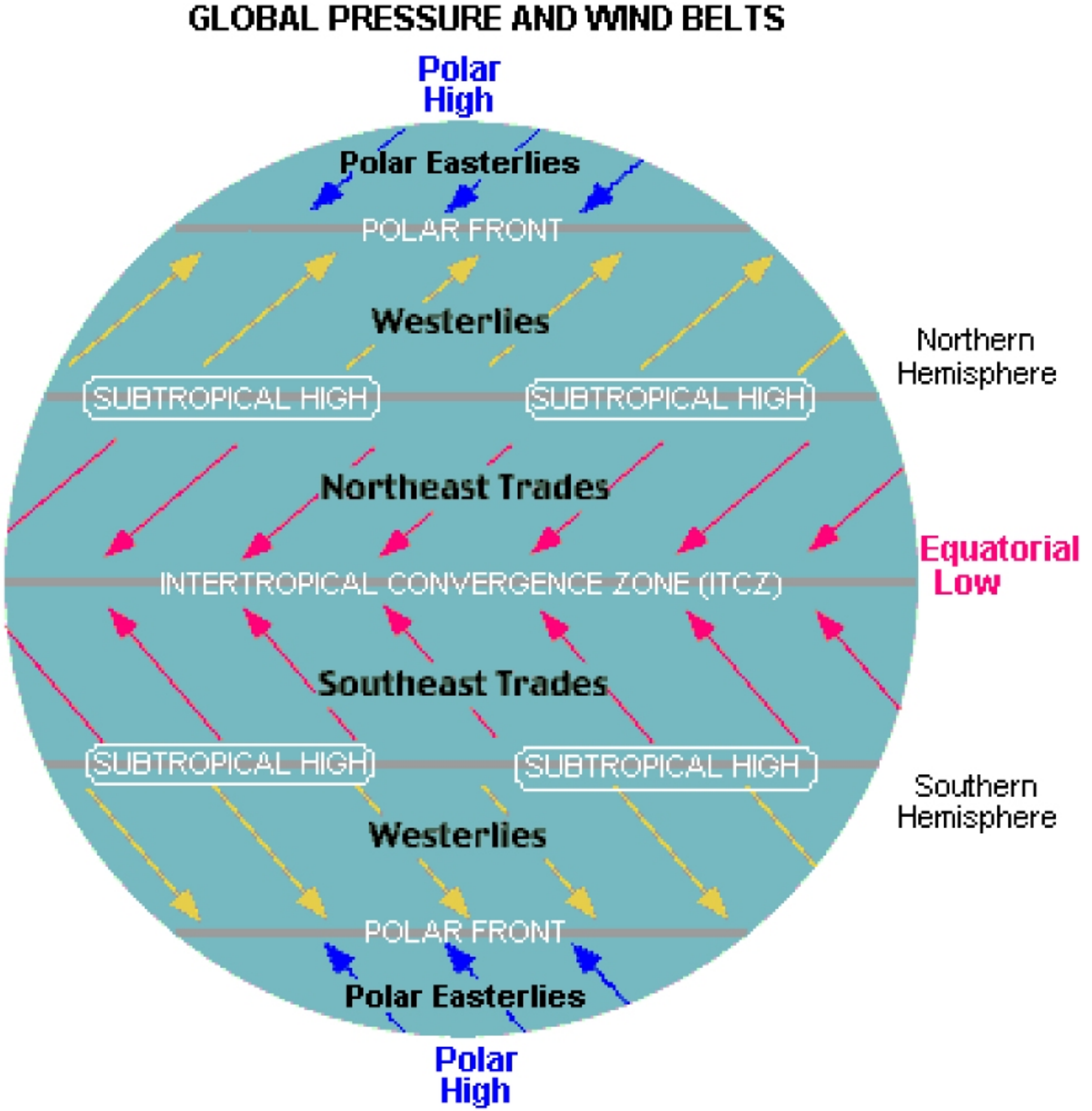
The interaction between warm tropical air and cold arctic air plus earth's spin creates regular wind and current patterns. Also, cold water sinks and warm water rushes in to take its place, so you get ocean currents that affect climate.

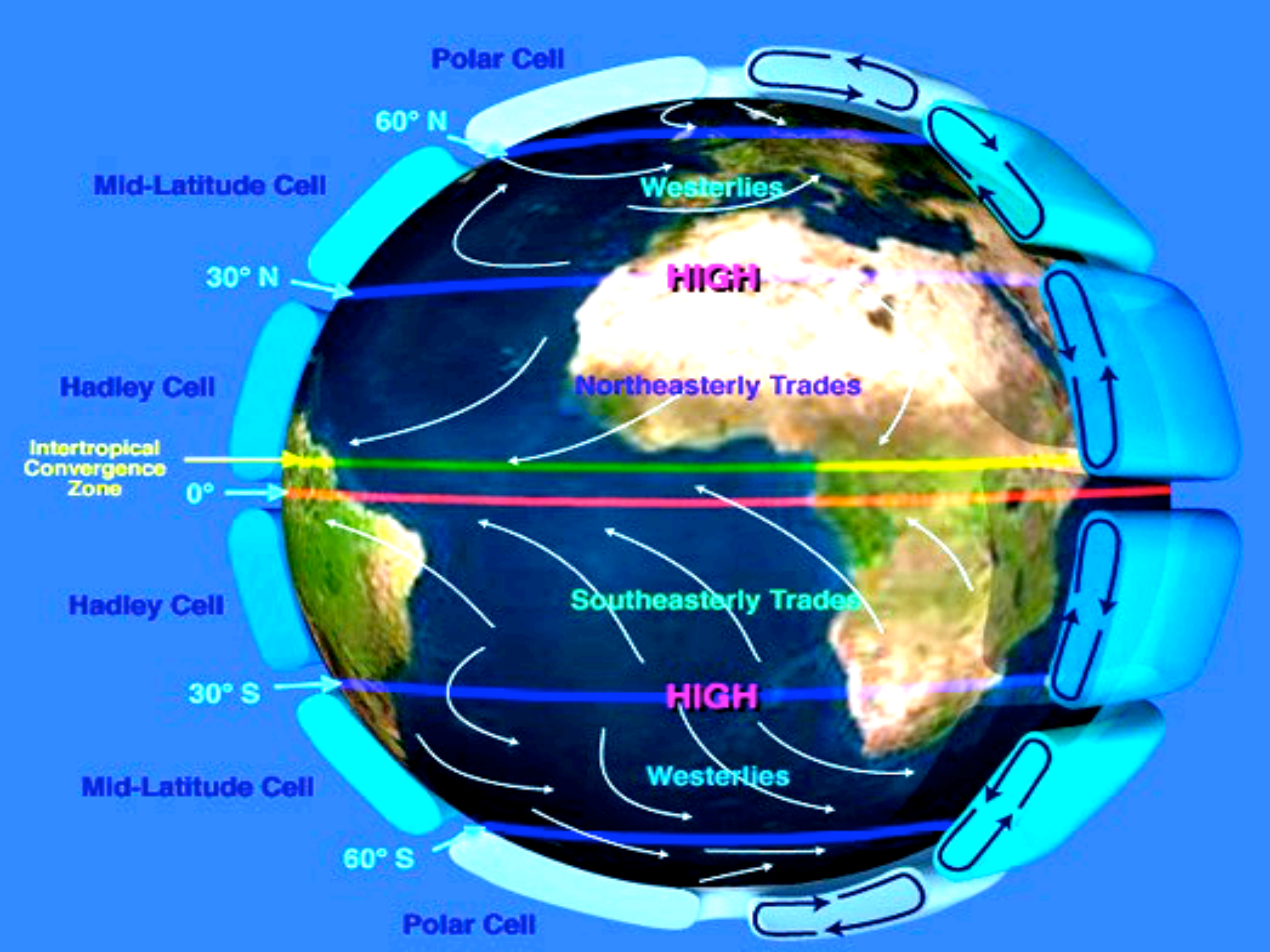


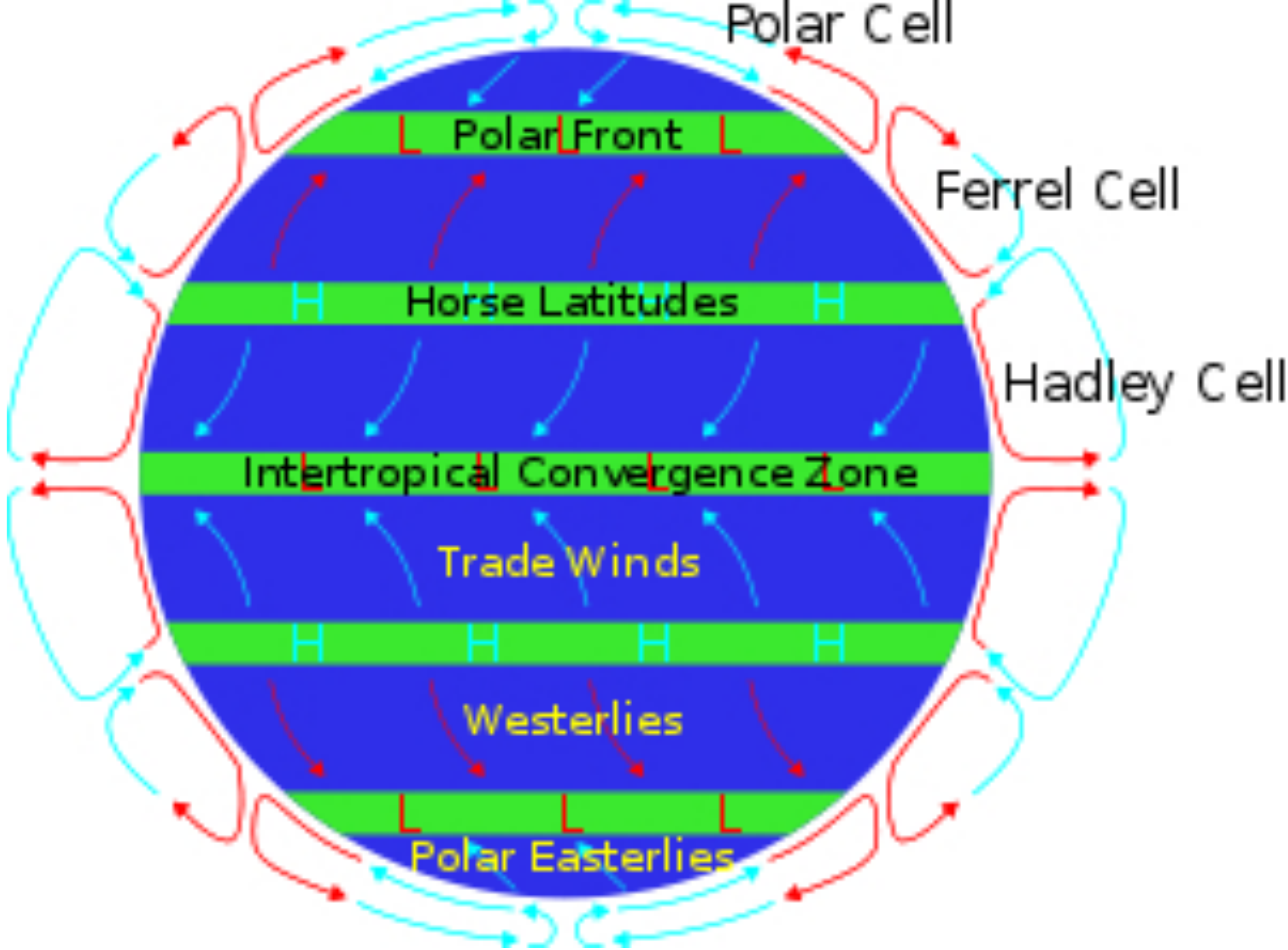
Polar high pressure air flows from the east (an easterly).

Contra low pressure flows towards the east (westerlies) out of sub-arctic.

Sub-tropical high air flows from the east

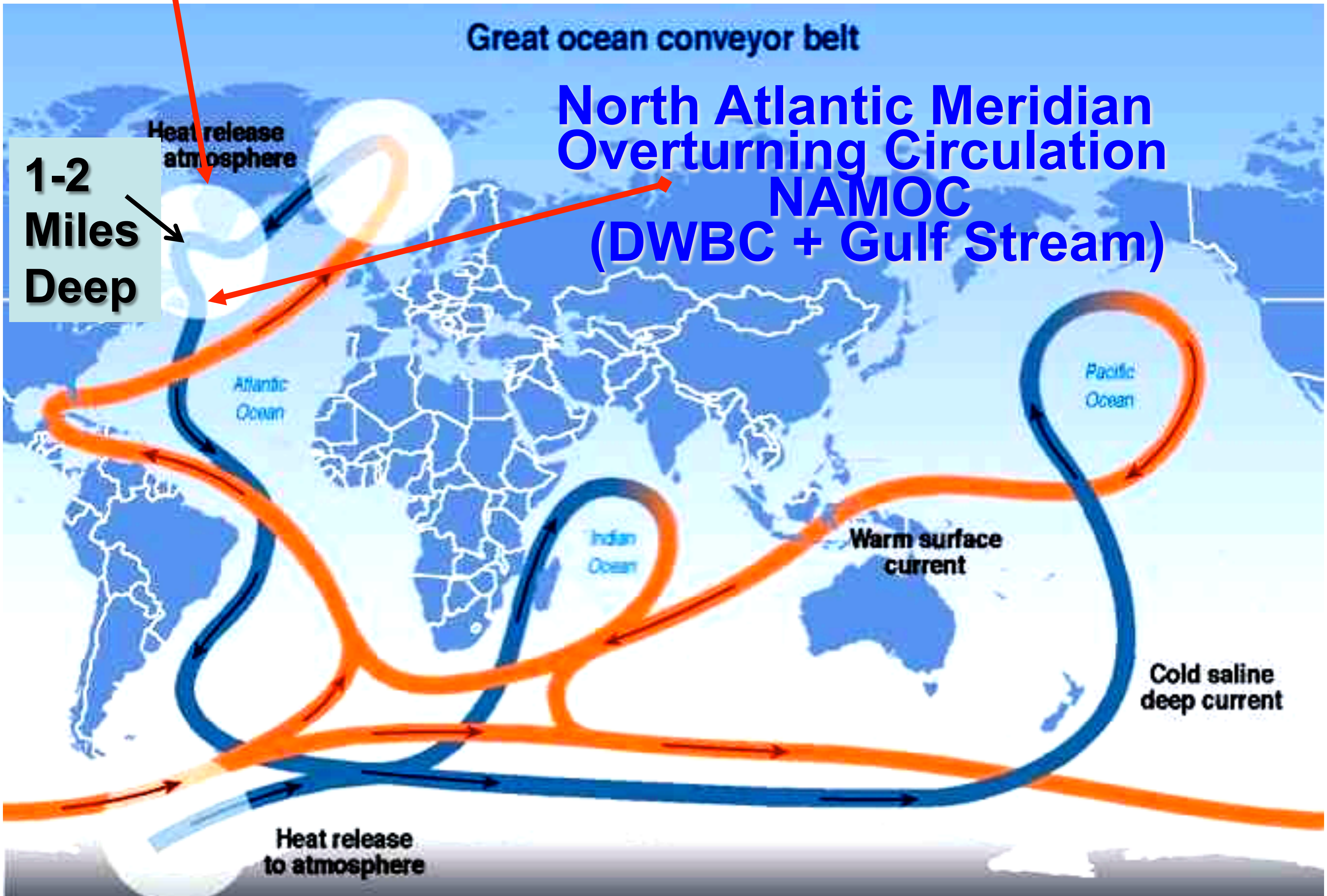



Polar Cell
60° N
Mid-Latitude Cell
Westerlies
30° N
HIGH
Hadley Cell
Northeasterly Trades
Intertropical Convergence Zone
0°
Hadley Cell
Southeasterly Trades
30° S
HIGH
Mid-Latitude Cell
Westerlies
60° S
Polar Cell



Polar Cell
Polar Front
Ferrel Cell
Horse Latitudes
Hadley Cell
Intertropical Convergence Zone
Trade Winds
Westerlies
Polar Easterlies

Deep Western Boundary Current



The Ocean Conveyor

Houston Wind Sector

- **Calm 7% of time spring & summer, 11% fall & winter.**
- **Winds out of south, east, or north but not west.**
- **Thus western winds are neither useful nor a problem, so can shade buildings from western sun without breeze worries.**
- **Except in the fall, easterlies (out of east) are not especially common either.**
- **Winds out of true southeast blow 10% of the time or more except in winter and they are even common then**

- **March to June**, true southeasterlies blow 14-17% of the time, and winds out of the south, south-southeast and southeast together blow almost 40% of the time.

- Vegetation & structures can provide a funnel or wind tunnel to a patio, porch, or house (or wherever you are) in these months.

- **April to August** winds out of southern directions more than half of time. In July $^{1}/_{4}$ of the winds come out of two directions: south and south southwest.

- **September to February**, winds from northern directions are more common than ones from the southern ones. Although September is a hot month, more of the winds are northerlies than southerlies.

- **December to February** winds out of true north most common (about 10% of time). But even then, winds from the various southern directions make up one quarter to one third of all winds, so our winter days are sometimes warm.

Pressure Oscillations

- There are pairs of places on the planet that predictably ***oscillate*** every few years between relatively high and relatively low air pressure.
- Over months or years or decades, oscillations go from positive (more pressure) to neutral to negative (less pressure) on a ratio scale.
- See http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/climwx.shtml

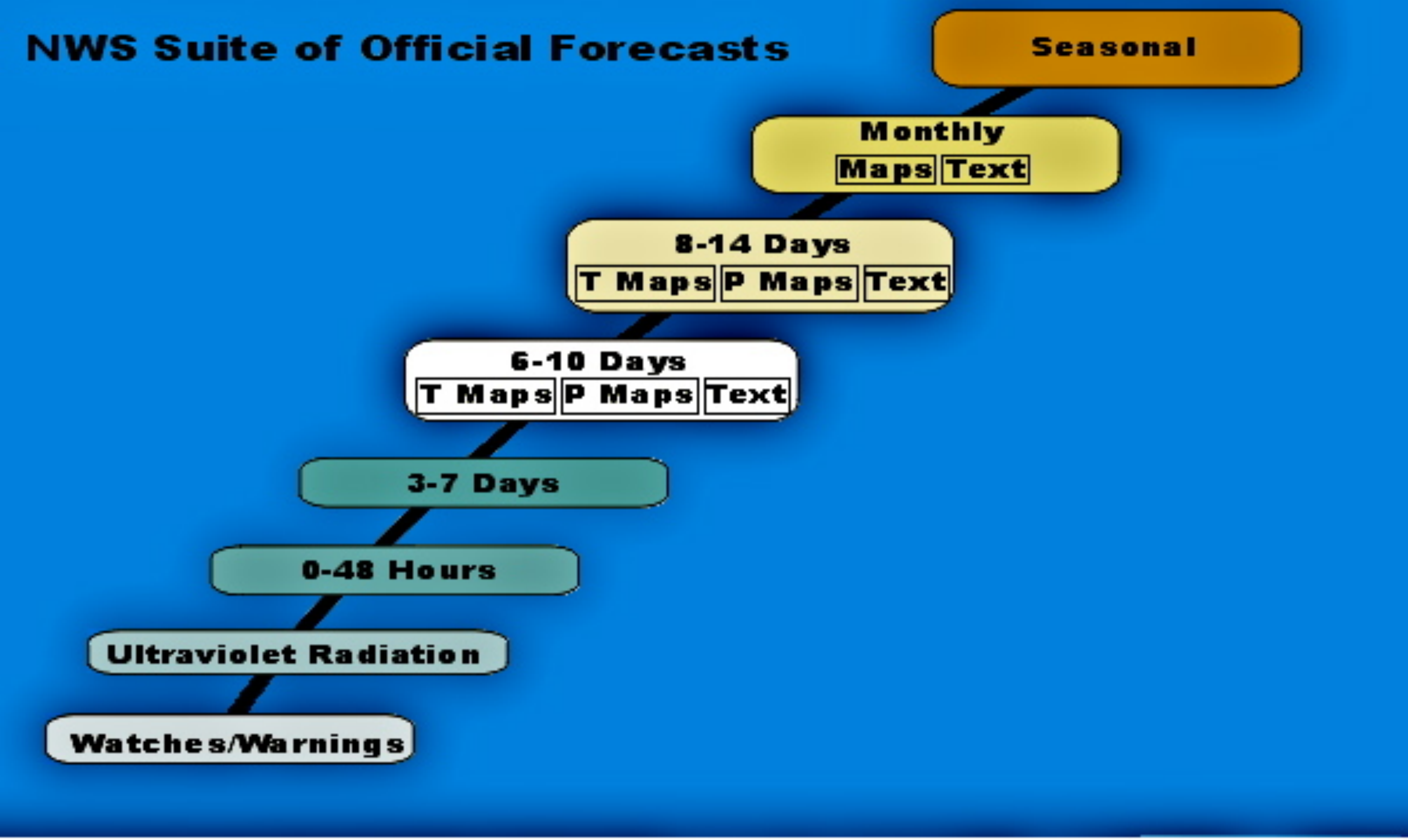
Pressure Oscillations

- **At many places on the earth's surface, air pressure has been measured over many years.**
- **With a lot of data, you can find a middle value.**
- **Some years at some dates, pressure will be below normal, and other years above normal.**
- **At *some* places on the earth's surface, for various reasons, whenever pressure is above normal in one place, there is a linked location very far away that is below normal.**
- **And vice versa.**

Temperature, precipitation, & hurricane forecasts beyond a few days are based on

- Historical experience with similar combinations of pressure oscillations, plus global warming observations, plus altitude, ocean, and urban heat island effects.

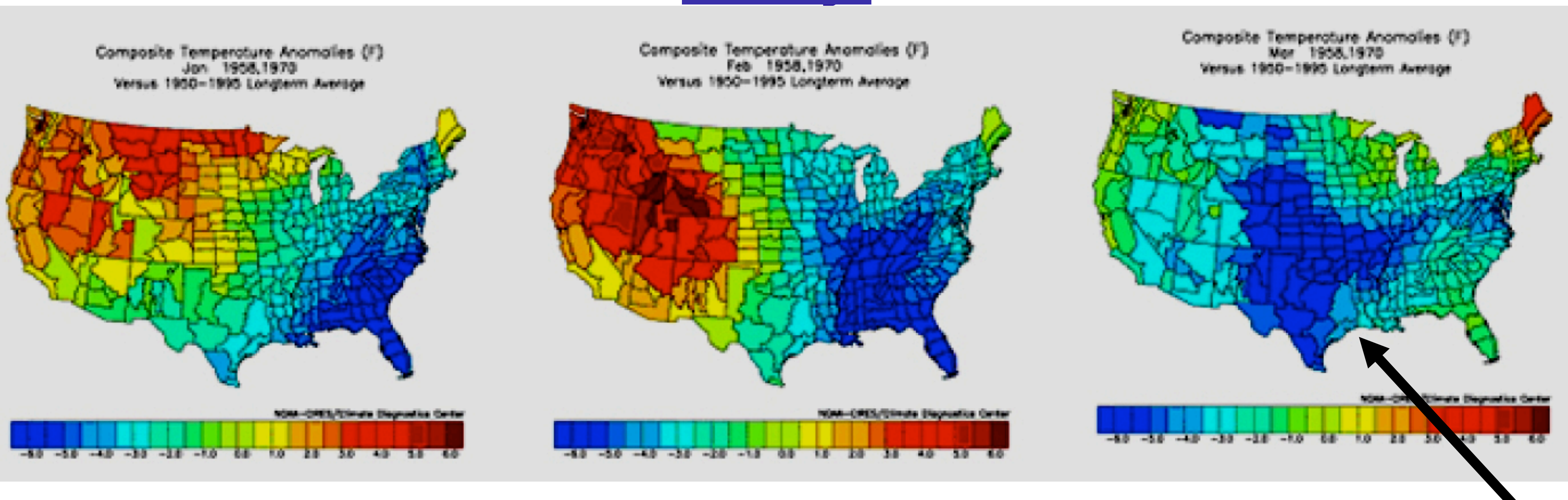
For an explanation see http://www.cpc.ncep.noaa.gov/products/predictions/long_range/fxus05.html



U.S. Hazards Assessment	Base-Period Means	Wind Chill Index	Monthly & Seasonal SST Forecasts Nino 3.4	Official SST Forecast	SST Base-Period Means

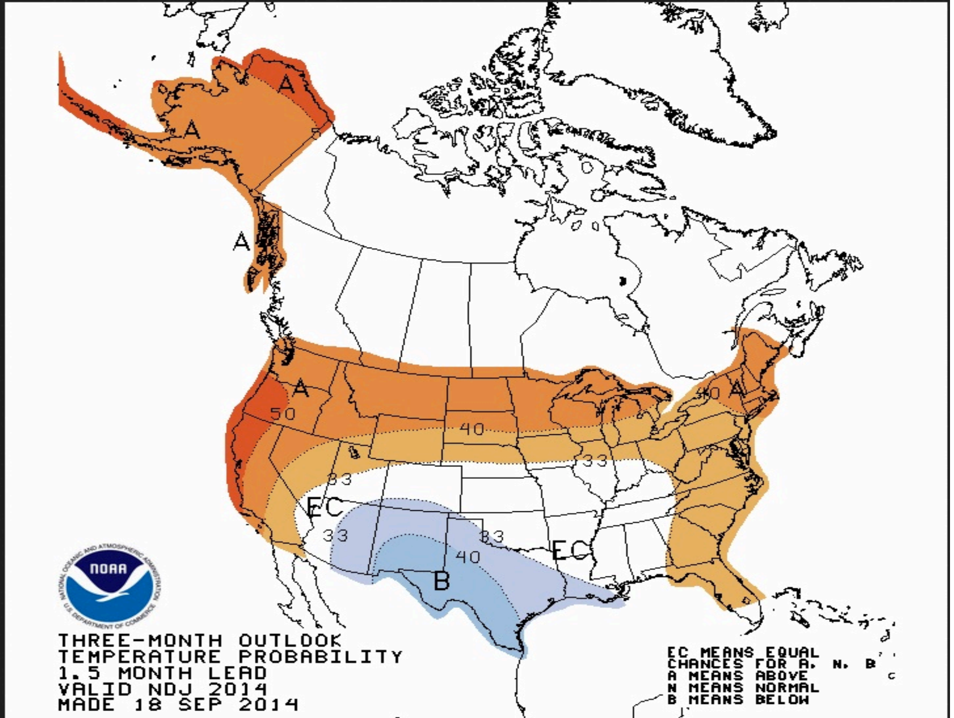
http://www.cpc.noaa.gov/products/forecasts/

For example, in spring 2003, pressure conditions in the atmosphere and ocean temperatures were similar to those in 1958 and 1970, so forecasters thought what happened in those years would repeat. They did! See http://www.cpc.ncep.noaa.gov/products/predictions/90day/

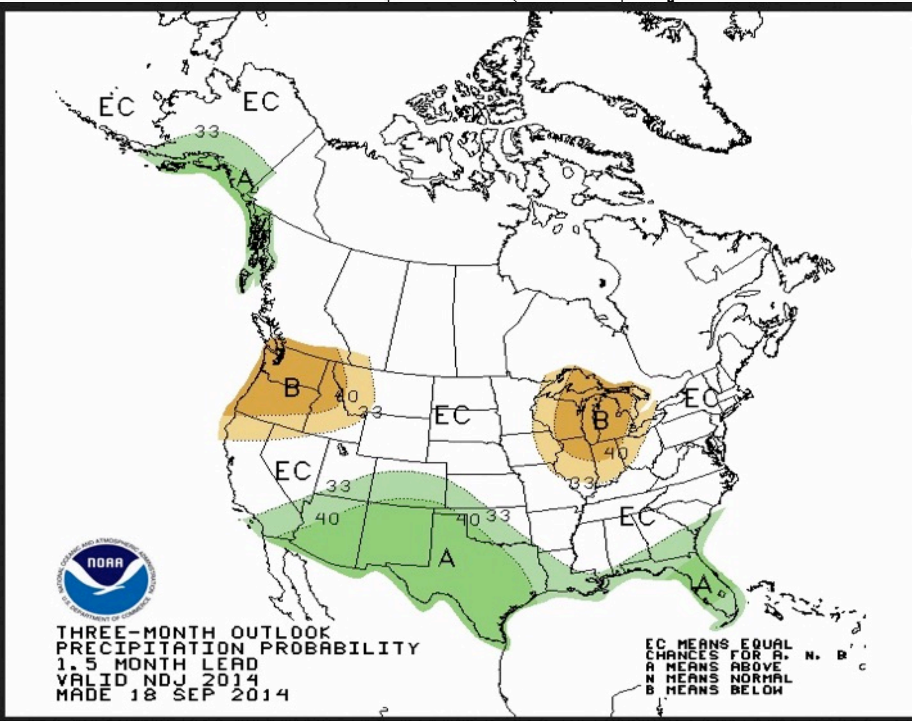


January, February, March 2003 Temp Predictions Colder or Hotter then Normal

Nov to Jan 2014-5



AVERAGE TEMPERATURES WILL BE A LITTLE COOLER THAN NORMAL



AVERAGE RAINFALL WILL BE MUCH HIGHER THAN NORMAL

Some Important Oscillations:

- North Atlantic Oscillation (NAO) part of Arctic Oscillation (A0)

El Niño!!

  - Southern Oscillation (ENSO)

- The Pacific Decadal Oscillation (PDO)

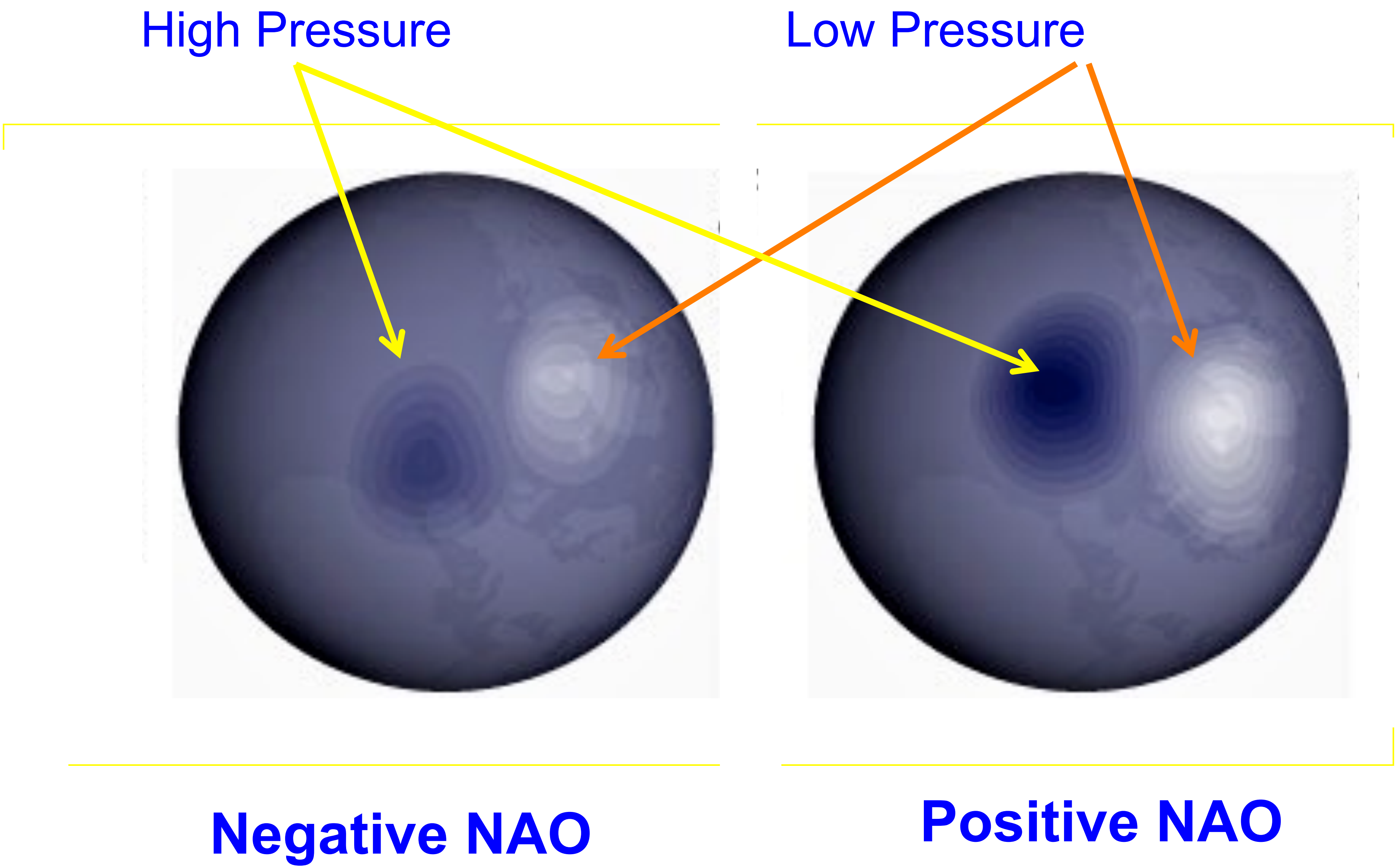
- Quasi-biennial Oscillation (QBO)

North Atlantic Oscillation

- ***NAO is important to us because it drains cold air out of North America or keeps it from leaving.***
- **Temperatures in Iceland and Greenland cycle back and forth.**
- **This is caused by a relatively low pressure area in Iceland and a relatively high pressure area in the Azores (off Spain and Portugal).**
- **There is a cyclic movement of air from the Icelandic area towards the sub-tropic belt near the Azores.**

The Arctic Oscillation

- NAO is part of a more basic cycle over the arctic called The Arctic Oscillation (AO).
- The Arctic oscillation (AO) is an index of of pressure variations in the polar region compared with opposite variations in mid-latitudes at 45˚N (Great Lakes).
- There is an Antarctic Oscillation version too.



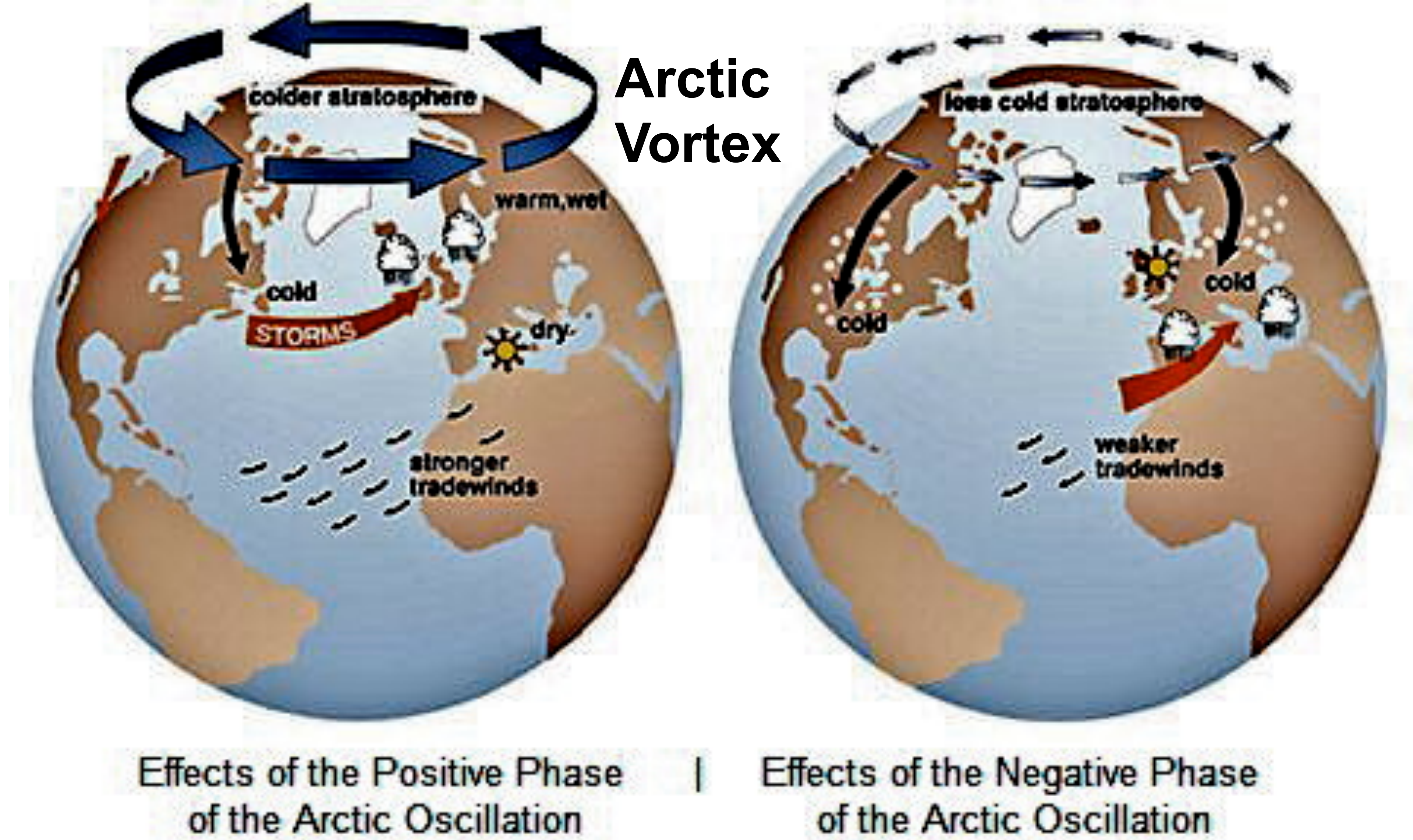
AO & NAO

Consequences

- During the positive NAO, westerly winds (from the west) tend to be stronger and wetter in Northern Europe
- And much weaker and drier heading over southern Europe and north Africa.
- During the negative NAO, pressure is stronger in the north and weaker in the south,
- So westerly winds track stronger and wetter in southern Europe and North Africa.

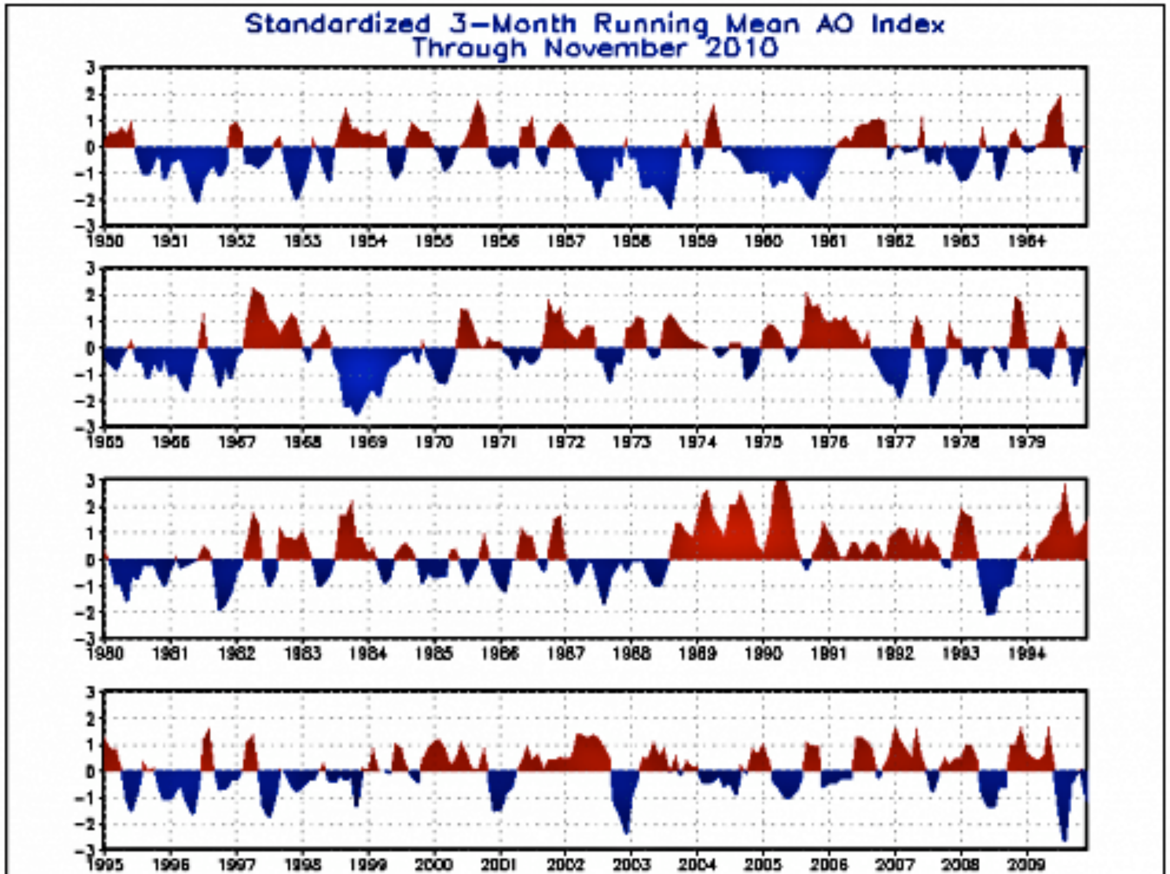
Consequences

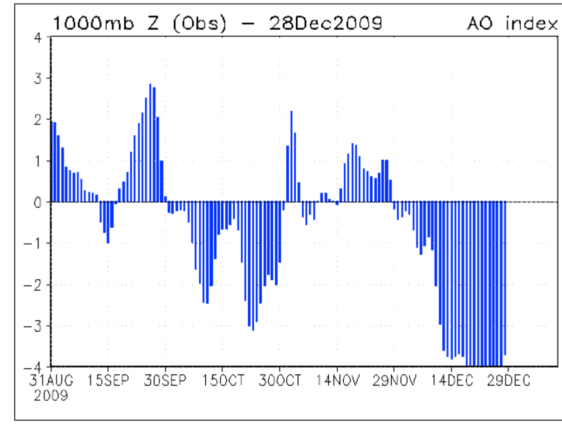
- **If NAO is positive, the northeastern US, southern Europe and North Africa are *hotter and drier*;**
    - **But the north central US is *wetter and colder*; northern Europe is *windier and wetter*.**
- **When the NAO is negative, the tropical Atlantic and Gulf Coast have *stronger hurricanes*;**
- **The northeastern US & the south central US are *colder*;**
    - **And southern Europe and North Africa is *wetter and windier*.**

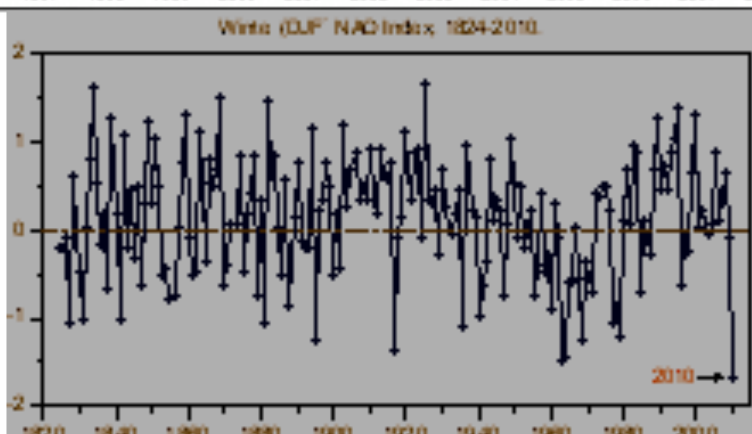


Positive Phase AO **Negative Phase AO**

NAO www.cpc.noaa.gov/data/teledoc/nao.shtml







Winter 2009-10 had the most negative index since records began in 1951 (-3.41 in Dec)

And the third coldest Houston temperature average**.**

The Southern Oscillation

- **There is *an inverse relationship between surface air pressure at two sites: Darwin (in Australia) and Tahiti (south central Pacific).***

- **Higher pressure than normal at one site is almost always correlated with lower pressure at the other, and vice versa.**

  - ***The pattern reverses every few years*.**

- **It represents a "see–saw," a mass of air oscillating back and forth across the International Date Line in the tropics and subtropics.**

Southern Oscillation:

- **When normal conditions exist *(La Nada)*, trade winds blow westward across the tropical Pacific, piling up warm surface water in Indonesia.**
- **Indonesian sea levels are about 20 in. higher than those in Ecuador!**
- **To replace water that went west, cool, nutrient–rich sea water "wells up" off the South American coast, supporting marine ecosystems and fisheries.**

- **Relatively cold sea temperatures also extend along the equator from South America towards the central Pacific.**
- **High rainfall occurs in the rising air over the warmest water to the west, whereas the colder eastern Pacific is relatively dry.**
- **See www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml**

Warmer & Drier During La Nada In The Houston Area

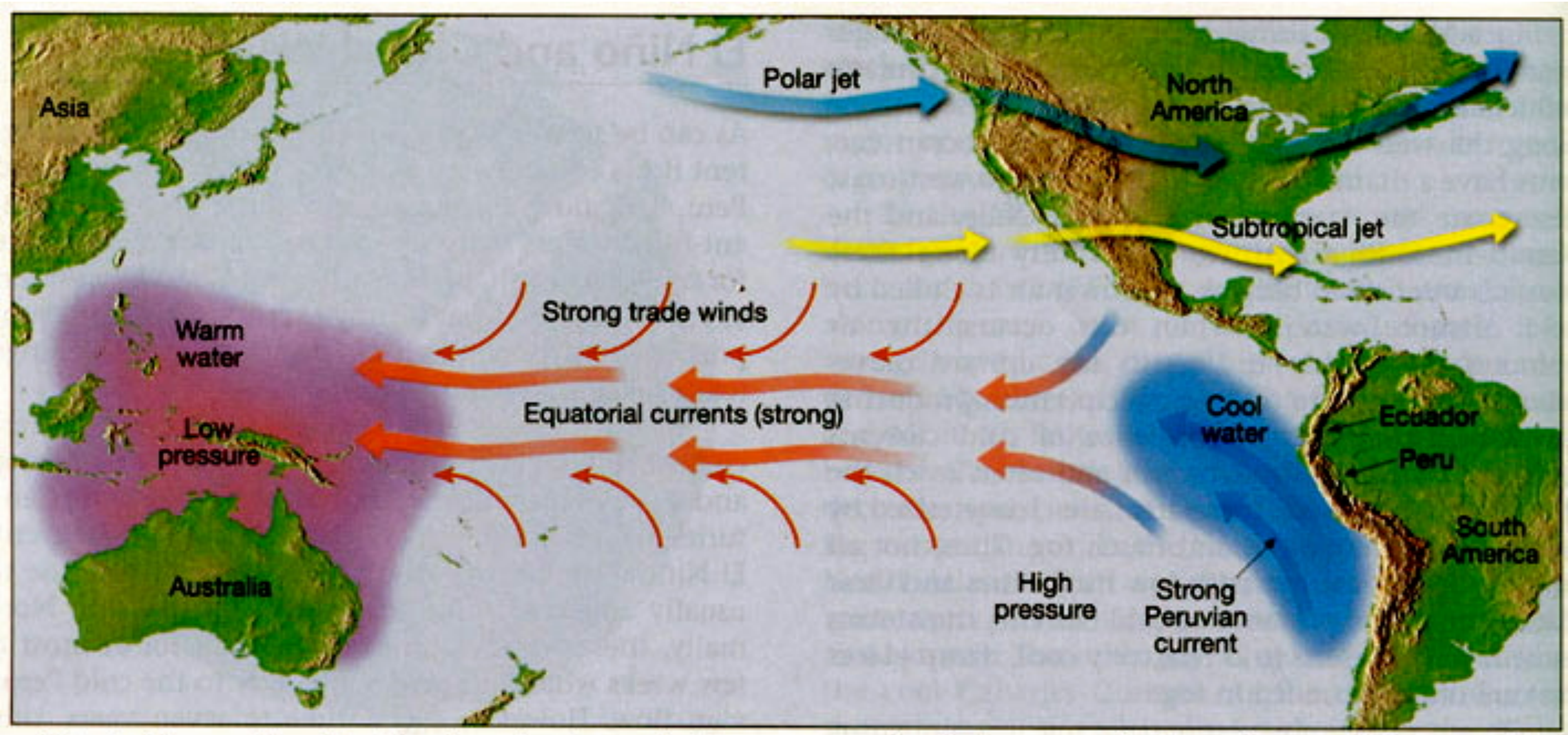


Fig.6 Normally, the trade winds and strong equatorial currents flow toward the west. At the same time, an intense Peruvian current causes upwelling of cold water along the west coast of South America.

La Nada And A Stronger Version *La Niña*

El Niño

- **When this process reverses, heavy rainfall and flooding occur over Peru, and drought over Indonesia and Australia.**
- **Nutrient rich water off the South American coast is reduced thus reducing fish catches.**
- **In the tropical South Pacific, the hurricane belt shifts eastward, so there are more hurricanes than normal in areas such as French Polynesia.**
- **When there is an El Niño, *in the Houston area in winter, it is wetter, less sunny, cold***

Wetter and because of clouds somewhat cooler in Houston

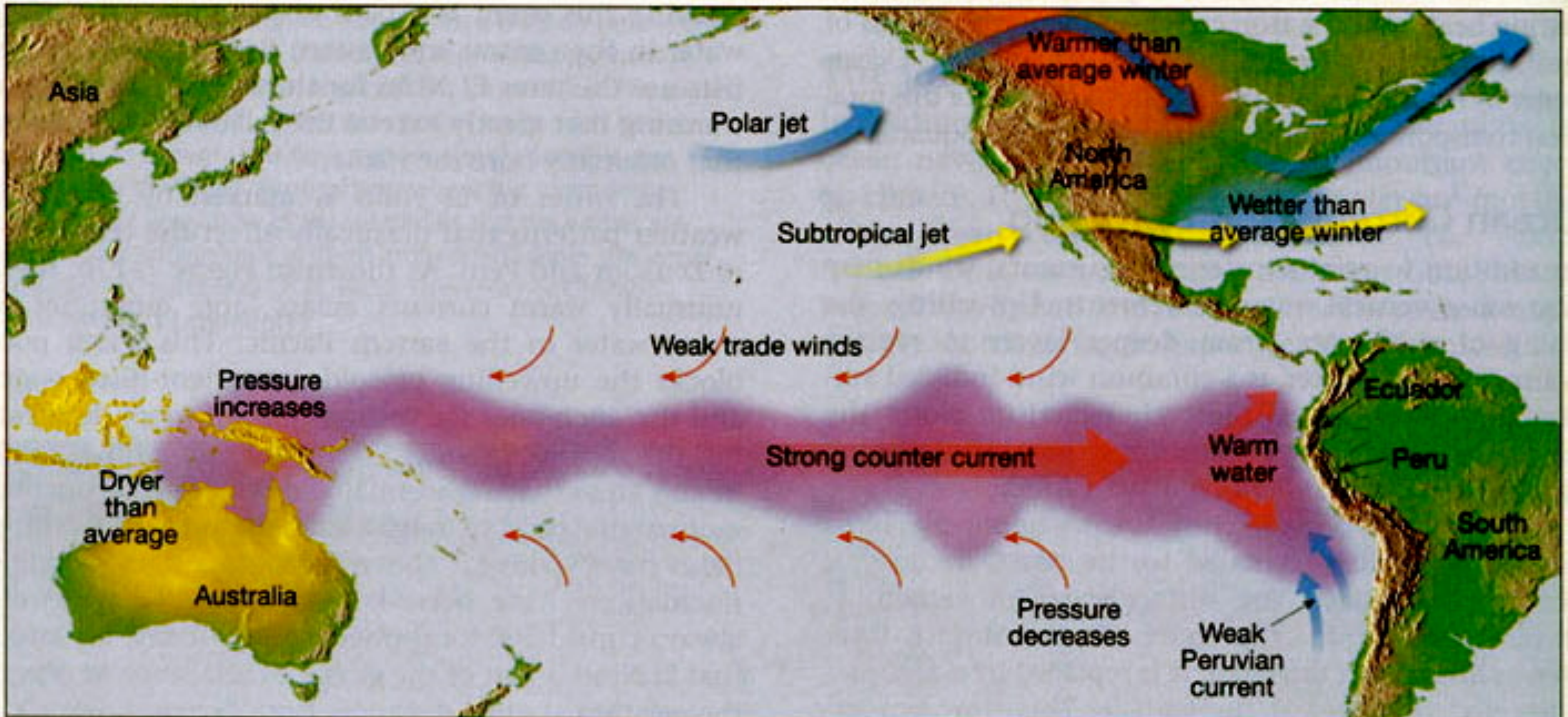
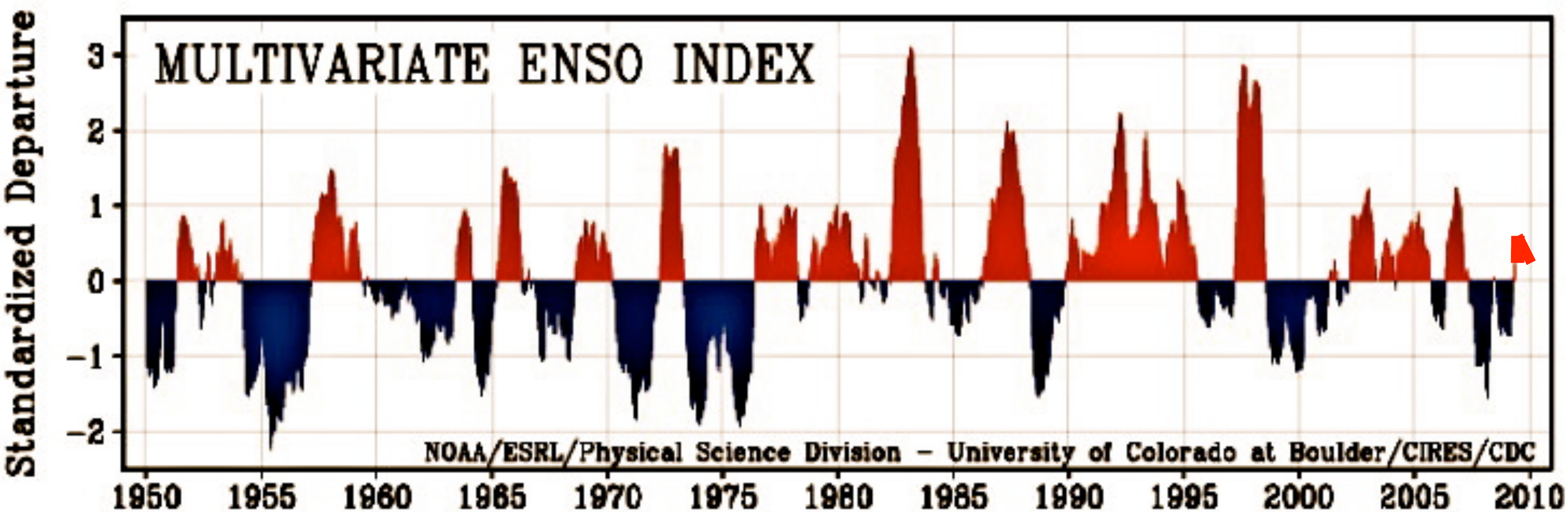


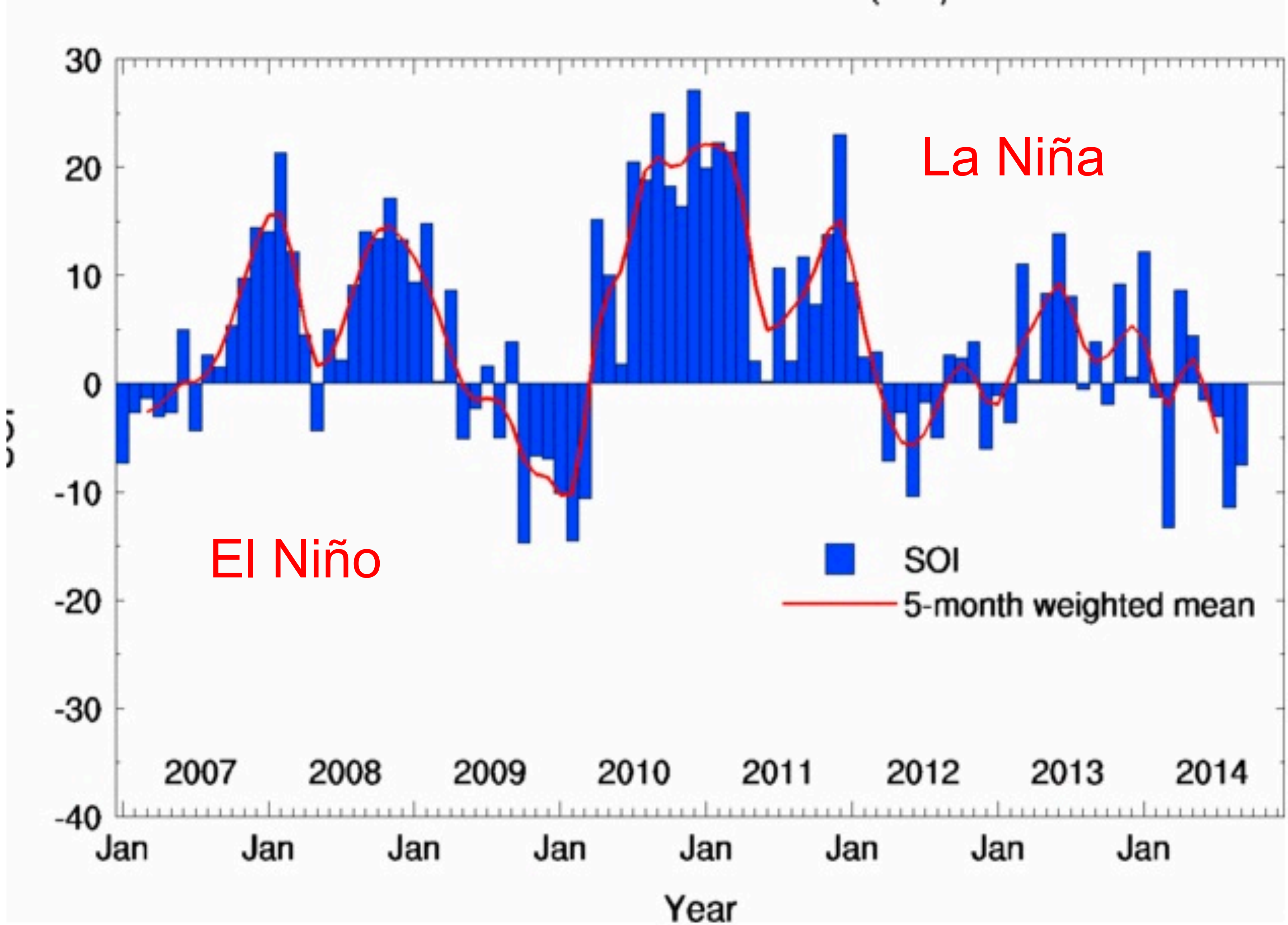
Fig.14 Upon the advent of an ENSO event, the pressure over the eastern and western Pacific flip-flops. This causes the trade winds to diminish, leading to an eastward movement of warm water along the equator. As a result, the surface waters of the central and eastern Pacific warm, with far-reaching consequences to weather patterns.

An El Niño Event

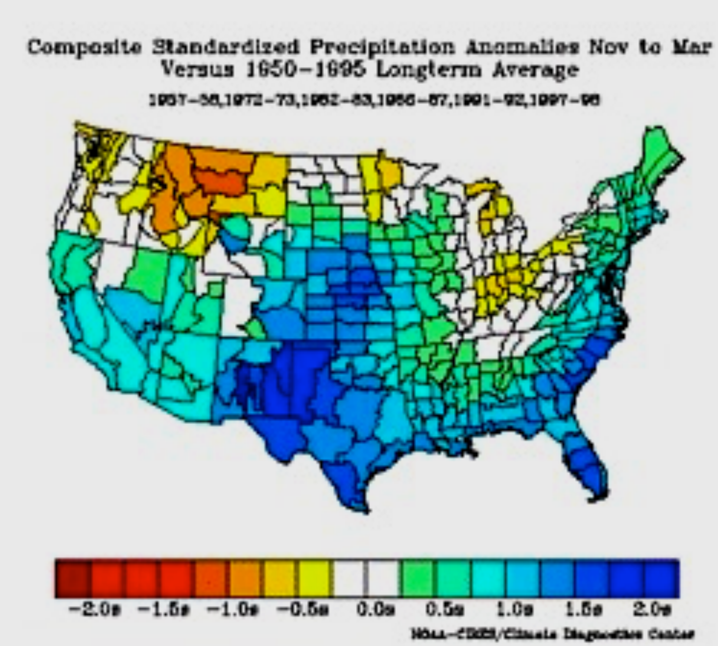
- We last had El Niño related effects over North America during the wet, cold Jan.-Mar. 2010.
- Winter 2010-11 was the strongest La Niña since the record drought years of the 1970’s and 1950’s.
- Winter 2011-2012 was a weak La Niña.

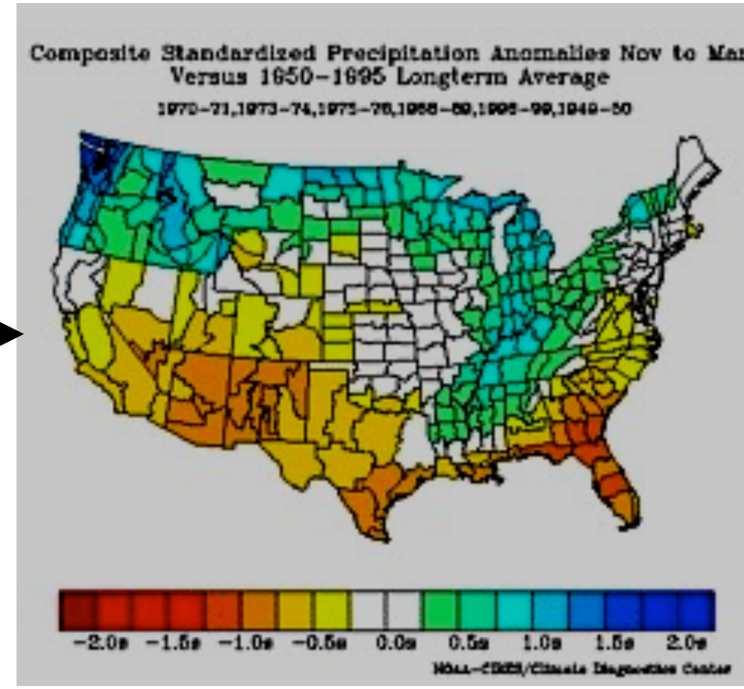


http://www.esrl.noaa.gov/psd/enso/mei/


La Niña
El Niño
SOI
5-month weighted mean
30
20
10
0
-10
-20
-30
-40
2007
2008
2009
2010
2011
2012
2013
2014
Jan
Jan
Jan
Jan
Jan
Jan
Jan
Jan
Year

"Normal" US *Winter* Weather

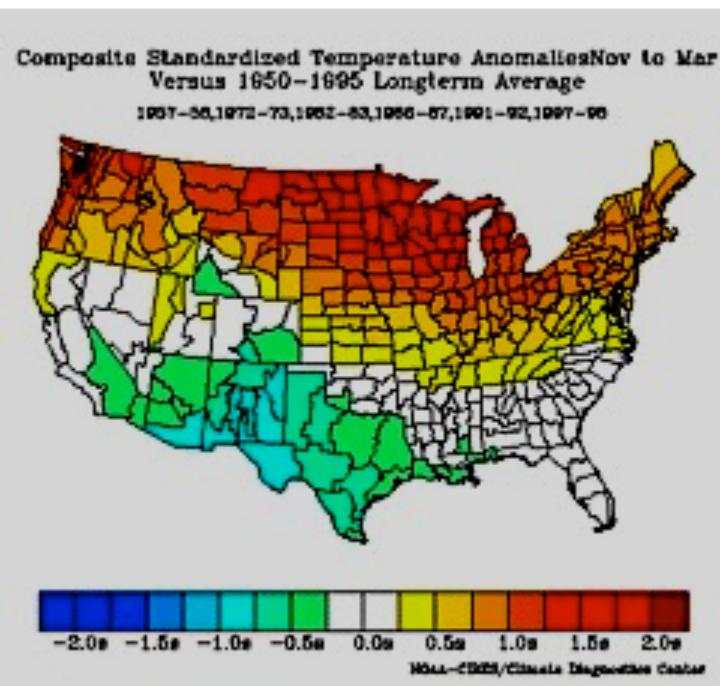




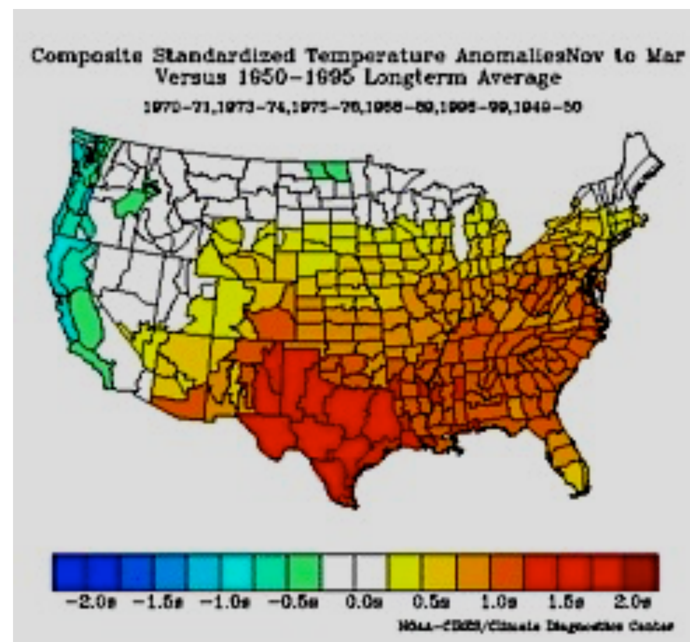
RAIN

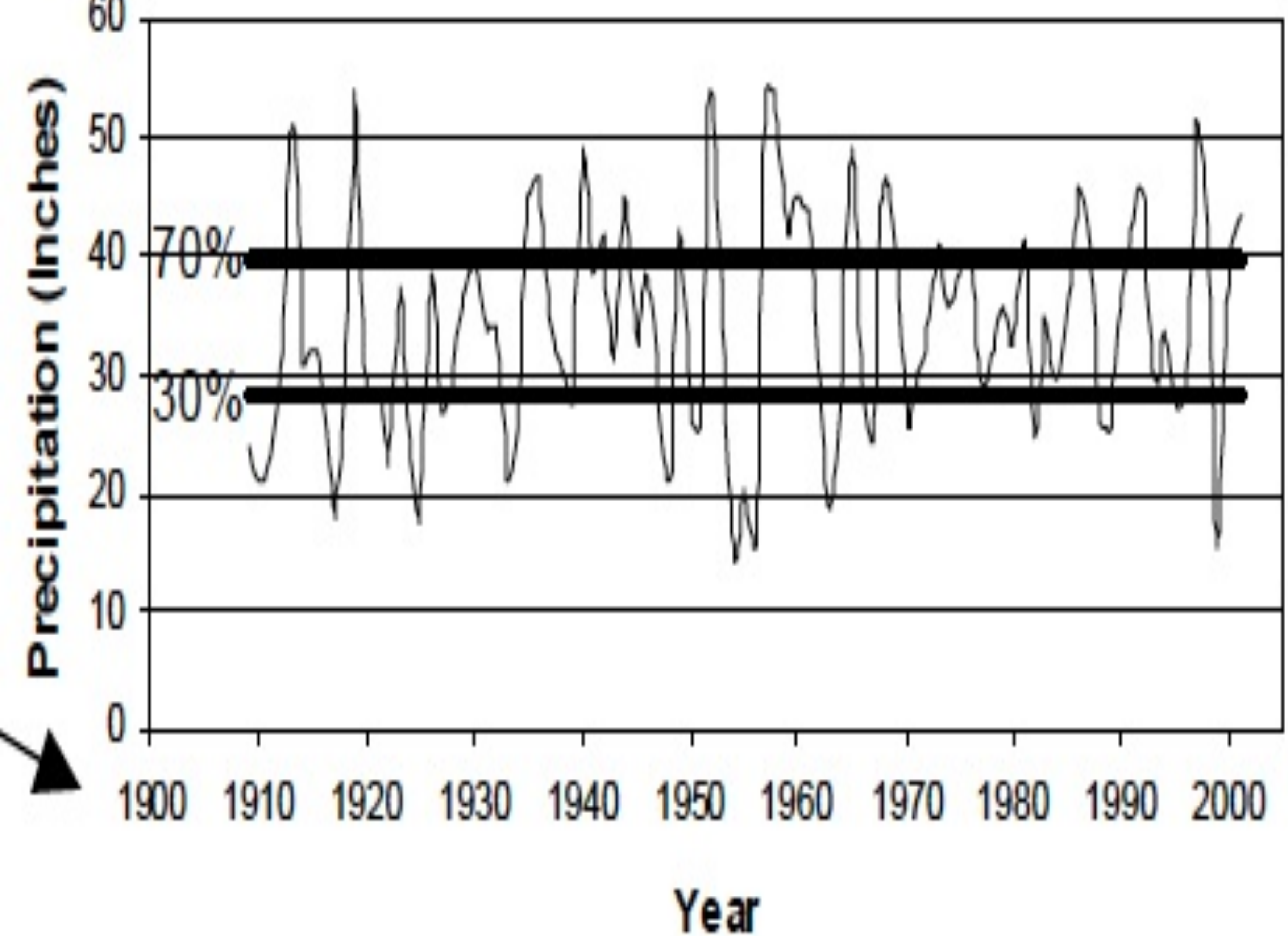
El Nino Years

La Nina Years



Temperature





Precipitation (Inches)
60
50
40
30
20
10
0
70%
30%
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Year

Sources on ENSO

- http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/
- http://www.cdc.noaa.gov/ENSO/enso.climate.html
- http://www.pmel.noaa.gov/tao/elnino/nino-home.html
- http://www.cpc.ncep.noaa.gov/data/indices/
- http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/ao_index.html

Pacific Decadal Oscillation

- **PDO is often described as a 20-30 year El Niño-like pattern of northern Pacific climate oscillation.**

- **Like ENSO, the extreme phases of the PDO are called either *warm* or *cool*.**

- ***They are defined by ocean temperature changes in the northeast Pacific and in the tropical Pacific Ocean*.**

- **The main effects of PDO are most visible in the northern Pacific & in North America, while secondary effects exist in the tropics.**

Pacific Decadal Oscillation

- This is the opposite of ENSO, which has main effects in the tropics, and secondary ones in North America.

- Like the Southern Oscillation, so-called "cool" phases are warmer & drier in our area; "warm" phases are cooler and wetter here.

- There have been just two full PDO cycles in the past century, and they may be part of the reason that whole decades seem to be drier or colder than other decades.

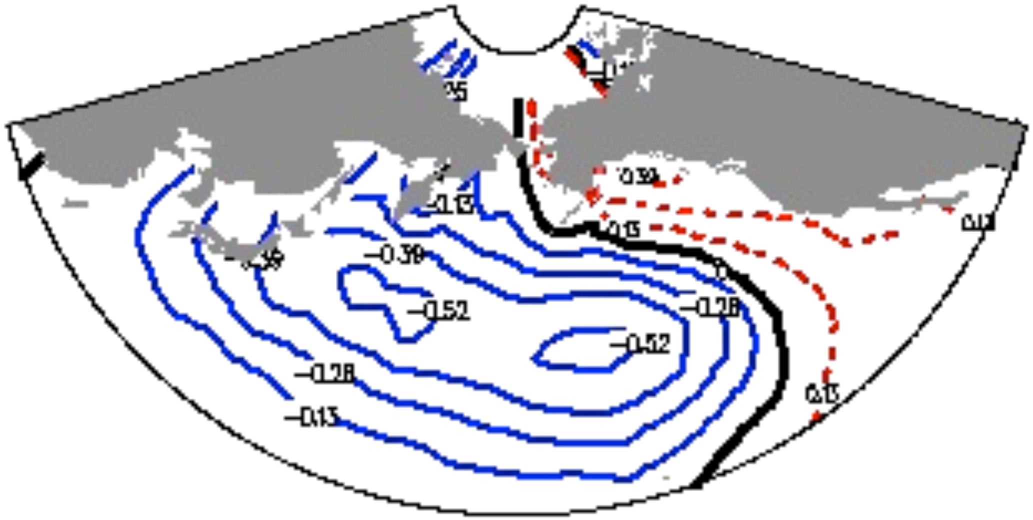
Pacific Decadal Oscillation

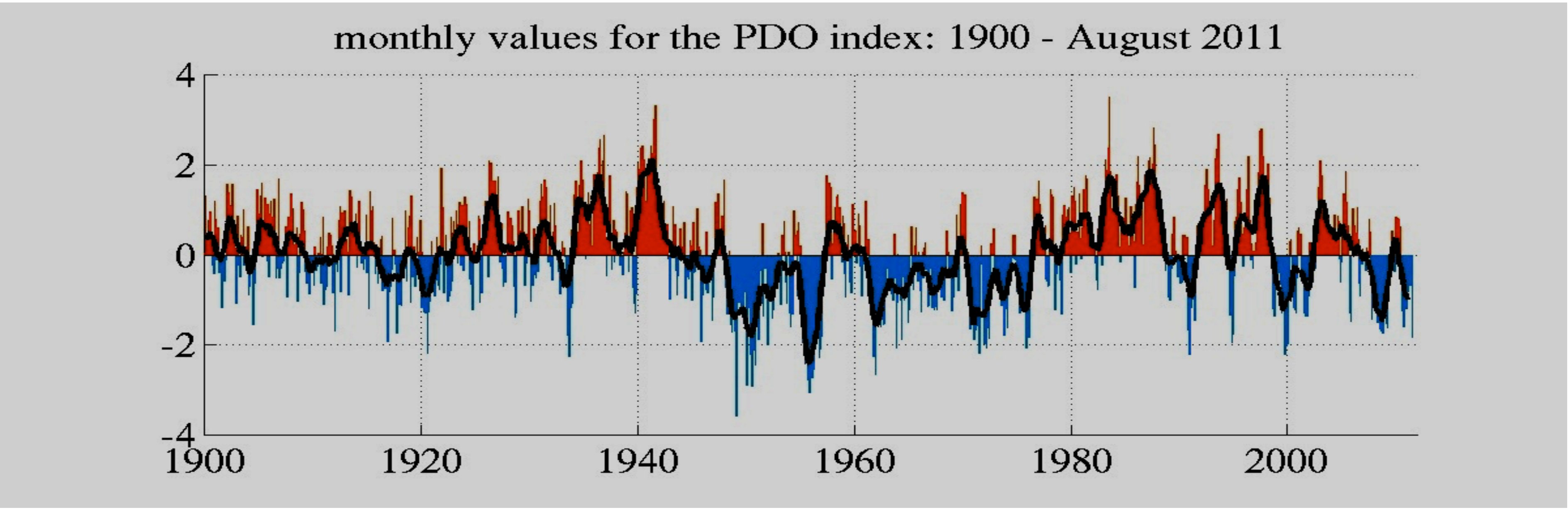
- **There was a cool PDO phase from 1890-1924 and again from 1947-1976.**

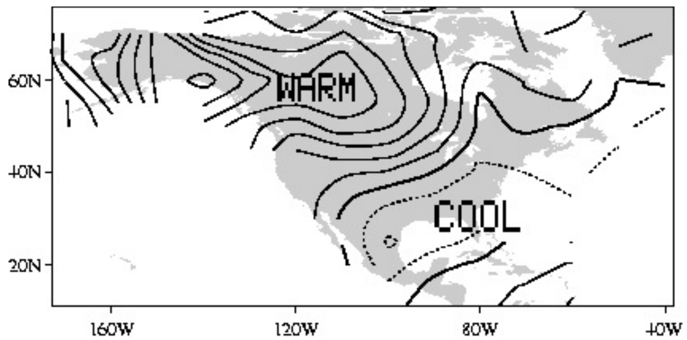
- **There was a warm PDO phase from 1925-1946 and from 1977 through the mid-1990's.**

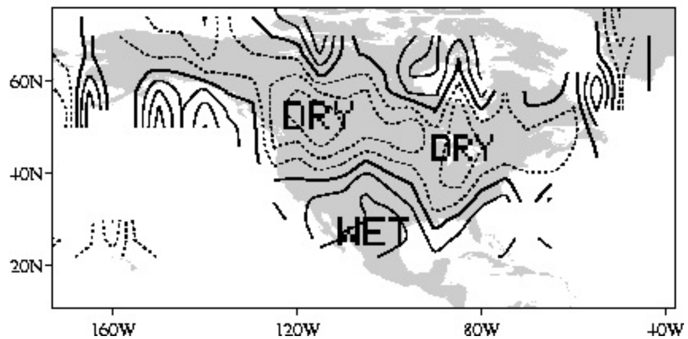
- **Recent changes in Pacific climate suggest a *possible* reversal to cool PDO conditions in 1998.**

Cool Phase PDO: Lower Temps and Higher Pressure in Northwestern Pacific









PDO Warm Phase October to March

Table 1: summary of North American climate anomalies associated with extreme phases of the PDO.

climate anomalies	Warm Phase PDO	Cool Phase PDO
Ocean surface temperatures in the northeastern and tropical Pacific	Above average	Below average
October-March northwestern North American air temperatures	above average	Below average
October-March Southeastern US air temperatures	below average	Above average
October-March southern US/Northern Mexico precipitation	Above average	Below average
October-March Northwestern North America and Great Lakes precipitation	Below average	Above average
Northwestern North American spring time snow pack	below average	Above average
Winter and spring time flood risk in the Pacific Northwest	Below average	Above average

Quasi-biennial Oscillation (QBO)

- **The wind above the equator about 15 km up in the stratosphere oscillates.**
- **For about 26- 28 months it comes out of the east and then it reverses and goes eastward.**
- **It is believed that large masses of water at the equator create “gravity waves” that create the momentum for these shifts.**

Why the QBO is important?

- **The QBO phase is often used to forecast hurricanes.**
- **Increased hurricane activity *in the Atlantic* occurs for westerly (or positive) phases (Ike); reduced hurricane activity for easterly (negative) phases**
- **This is because there is more variation of wind speed with height (wind shear) during easterly phases**
- **Update www.cpc.noaa.gov/data/indices/qbo.u30.index**

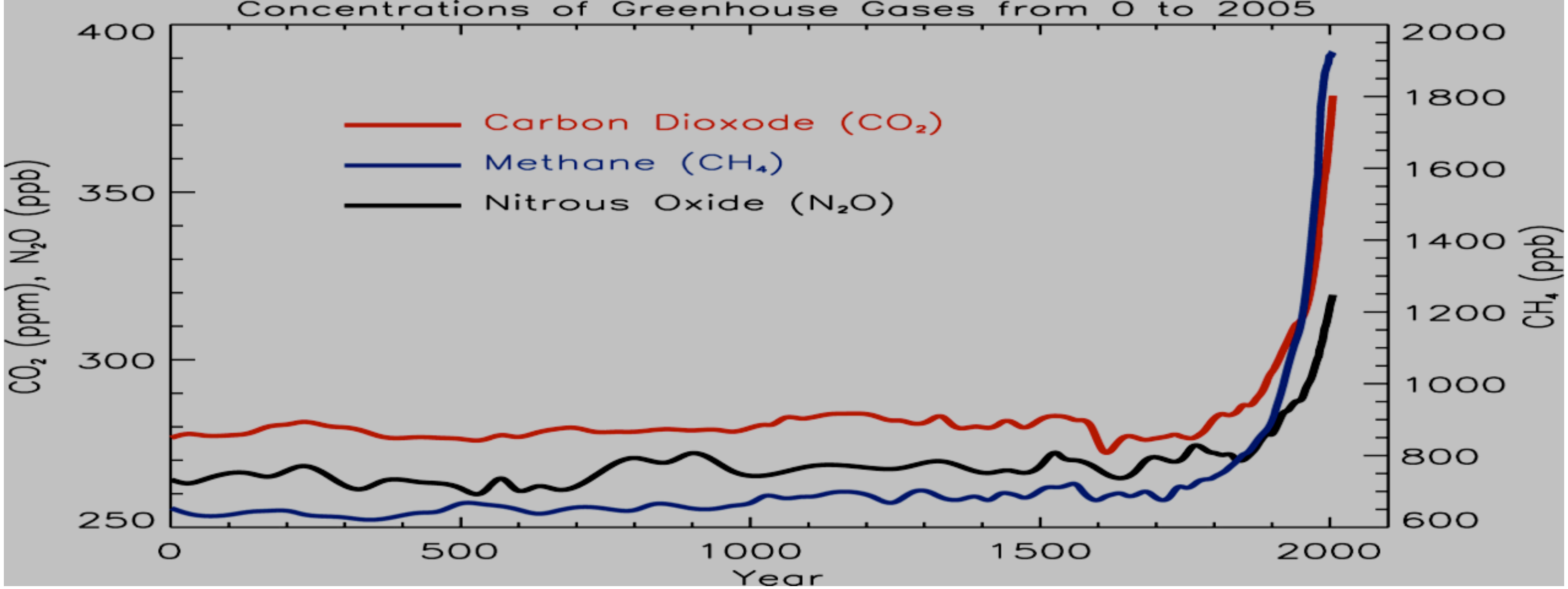
- **The QBO along with sea surface temperatures and El Niño Southern Oscillation (ENSO) are thought to affect monsoons (tropical wet then dry seasonal cycles).**

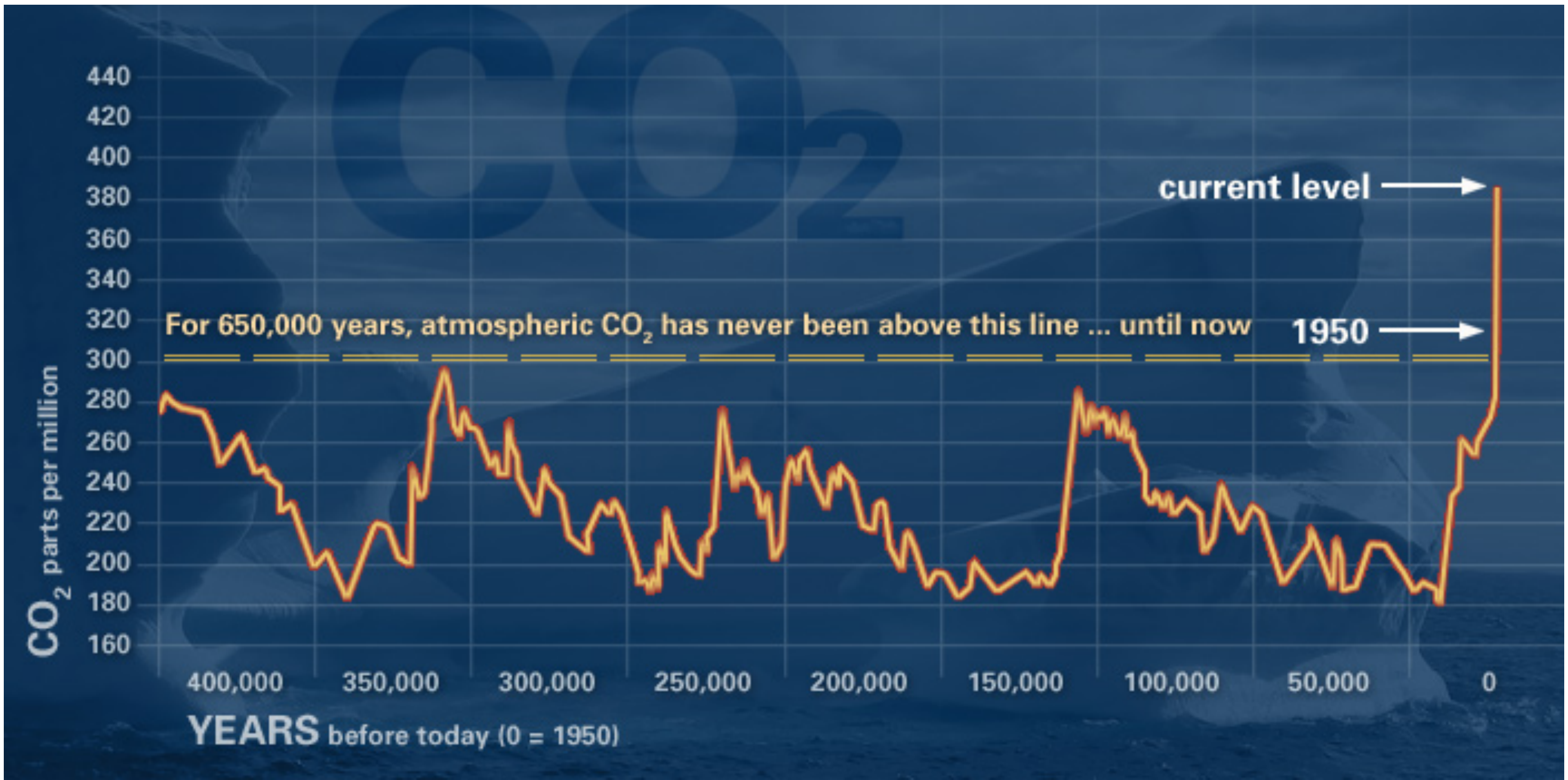
- **Tropical hurricane frequency in the northwest Pacific increases during the westerly phase of the QBO.**

- **Activity in the southwest Indian basin, however, increases with the easterly negative phase of the QBO.**

Houston Area Summary

	PDO	ENSO Winter	QBO	NAO/ AO
Usual, Westward, Warm or Positive Phase	Cooler, Wetter (1975-1995)	Drier, warmer -- La Niña (2011)	More hurri-canes (2008)	Wetter & Warmer central US Fewer arctic fronts
Less Common, Eastward, Cool or Negative Phase	Warmer Drier (1997-2011)	Wetter, colder --El Niño (2010)	Less Hurri-canes (2010)	More Hurricanes Colder fronts (2010, 2011)


Concentrations of Greenhouse Gases from 0 to 2005
Carbon Dioxode (CO_2)
Methane (CH_4)
Nitrous Oxide (N_2O)
CO_2 (ppm), N_2O (ppb)
CH_4 (ppb)
Year
400
350
300
250
0
500
1000
1500
2000
2000
1800
1600
1400
1200
1000
800
600


CO_2
current level
For 650,000 years, atmospheric CO_2 has never been above this line ... until now
1950
CO_2 parts per million
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
YEARS before today (0 = 1950)

Climate Change, Food, & Houston's Future

- **Why climate and weather are important.**
- **Main Causes of "Normal" weather & climate**
- ***What has been happening to the weather and climate.***
- **What may happen to the weather & climate**
- **Efforts to mitigate and their consequences**
- **Probable effects on our food supply**
- **Probable other effects on our area**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Starting at
$45

Well, We Were Warned by a Texan Who Knew Oil

- **Worried about the "storm of modern change" threatening "cherished landscapes," a president said:**

- **"This generation has altered the composition of the atmosphere on a global scale through… a steady increase in carbon dioxide from the burning of fossil fuels."**

--Lyndon B. Johnson

50 years ago in 1965

Carbon Dioxide Exchange Between Atmosphere and Ocean and the Question of an Increase of Atmospheric CO_2 during the Past Decades

By ROGER REVELLE and HANS E. SUESS, Scripps Institution of Oceanography, University of California, La Jolla, California

(Manuscript received September 4, 1956)

1956!

Abstract

From a comparison of C^{14}/C^{12} and C^{13}/C^{12} ratios in wood and in marine material and from a slight decrease of the C^{14} concentration in terrestrial plants over the past 50 years it can be concluded that the average lifetime of a CO_2 molecule in the atmosphere before it is dissolved into the sea is of the order of 10 years. This means that most of the CO_2 released by artificial fuel combustion since the beginning of the industrial revolution must have been absorbed by the oceans. The increase of atmospheric CO_2 from this cause is at present small but may become significant during future decades if industrial fuel combustion continues to rise exponentially.

Present data on the total amount of CO_2 in the atmosphere, on the rates and mechanisms of exchange, and on possible fluctuations in terrestrial and marine organic carbon, are inadequate for accurate measurement of future changes in atmospheric CO_2. An opportunity exists during the International Geophysical Year to obtain much of the necessary information.

Introduction

In the middle of the 19th century appreciable amounts of carbon dioxide began to be added to the atmosphere through the combustion of fossil fuels. The rate of combustion has continually increased so that at the present time the annual increment from this source is nearly 0.4 % of the total atmospheric carbon dioxide. By 1960 the amount added during the past century will be more than 15 %.

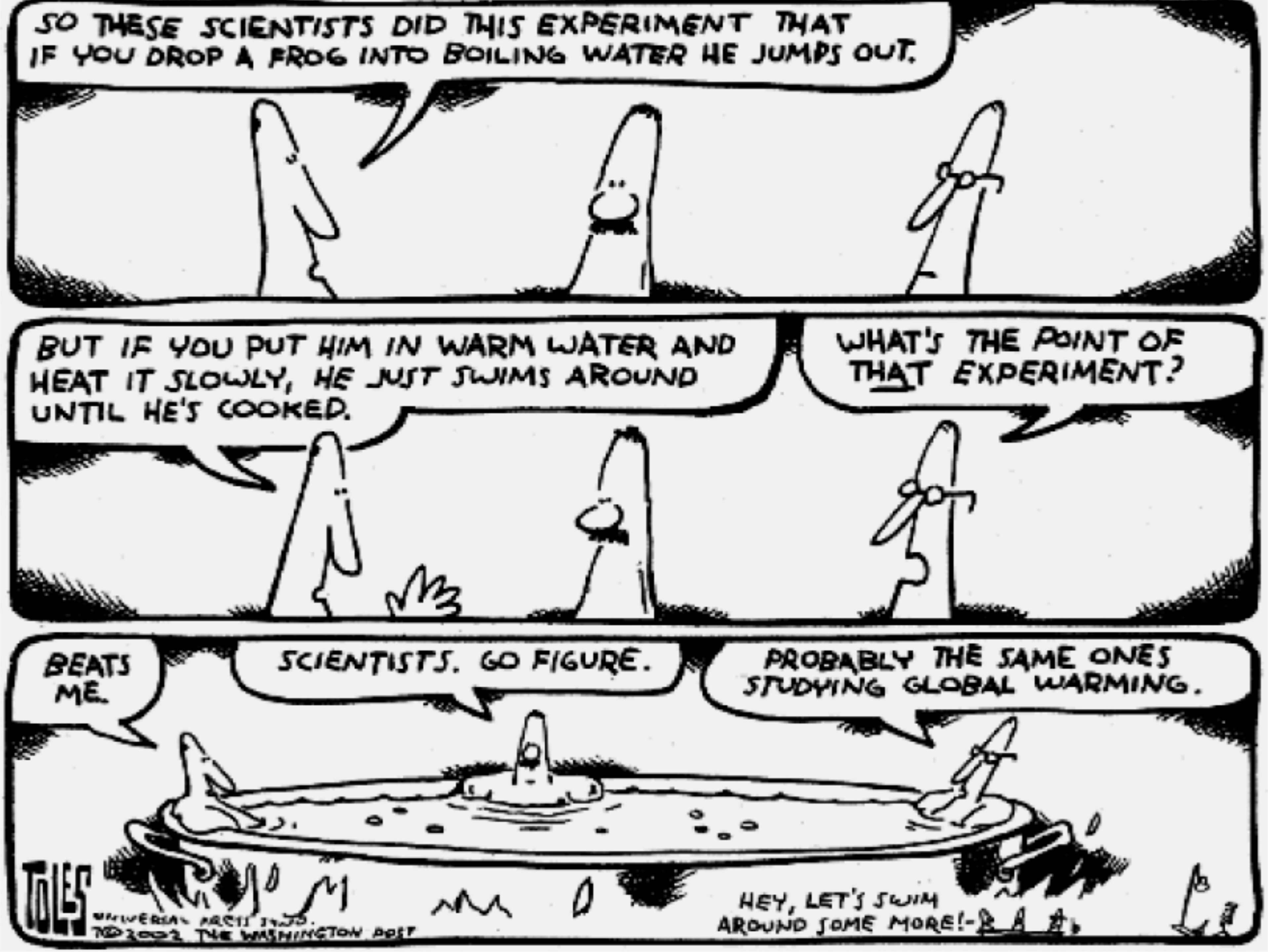
CALLENDAR (1938, 1940, 1949) believed that nearly all the carbon dioxide produced by fossil fuel combustion has remained in the atmosphere, and he suggested that the increase in atmospheric carbon dioxide may account for the observed slight rise of average temperature in northern latitudes during recent decades. He thus revived the hypothesis of T. C. CHAMBERLIN (1899) and S. ARRHENIUS (1903) that climatic changes may be related to fluctuations in the carbon dioxide content of the air. These authors supposed that an increase of carbon dioxide in the upper atmosphere would lower the mean level of back radiation in the infrared and thereby increase the average temperature near the earth's surface.

Subsequently, other authors have questioned Callendar's conclusions on two grounds. F...

Contribution from the Scripps Institution of Oceanog-

Climate & Weather Are Changing

- **There is ample evidence that human activity—especially fossil fuel and chemical fertilizer energy use--is destabilizing climate.**
- **And therefore much of the infrastructure we use worldwide to protect ourselves from climate is becoming obsolete quickly. $$$$$!!**
- **Based on past geology, all US climate scientists are now unanimous that this energy use must be radically transformed *quickly* to avoid catastrophe.**
- **So ALL our designs will need to change a lot.**

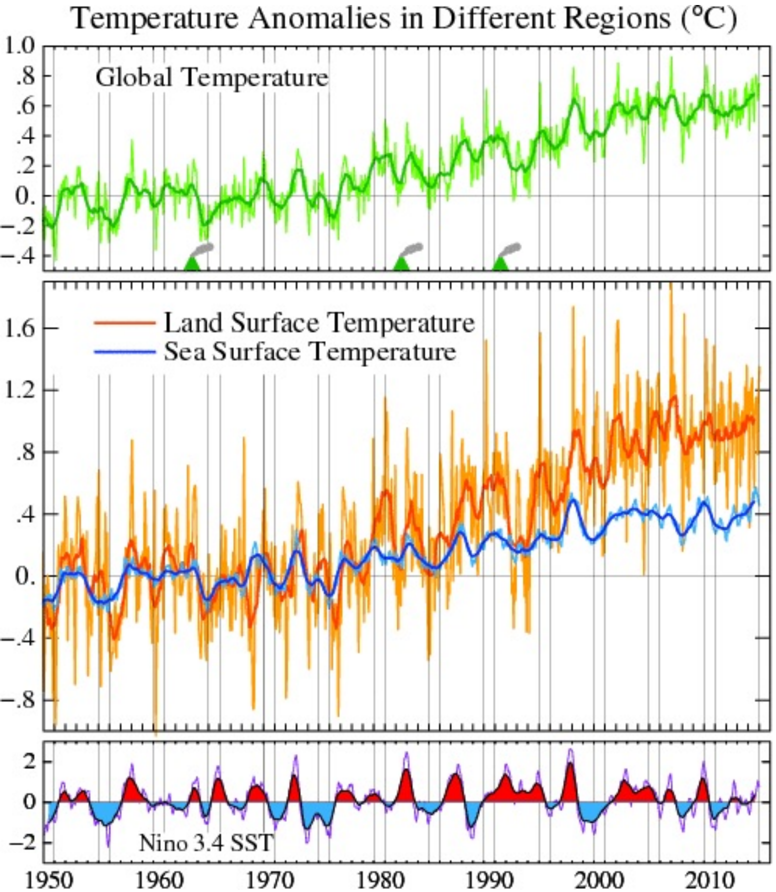

SO THESE SCIENTISTS DID THIS EXPERIMENT THAT IF YOU DROP A FROG INTO BOILING WATER HE JUMPS OUT.
BUT IF YOU PUT HIM IN WARM WATER AND HEAT IT SLOWLY, HE JUST SWIMS AROUND UNTIL HE'S COOKED.
WHAT'S THE POINT OF THAT EXPERIMENT?
BEATS ME.
SCIENTISTS. GO FIGURE.
PROBABLY THE SAME ONES STUDYING GLOBAL WARMING.
TOLES
THE WASHINGTON POST
HEY, LET'S SWIM AROUND SOME MORE!

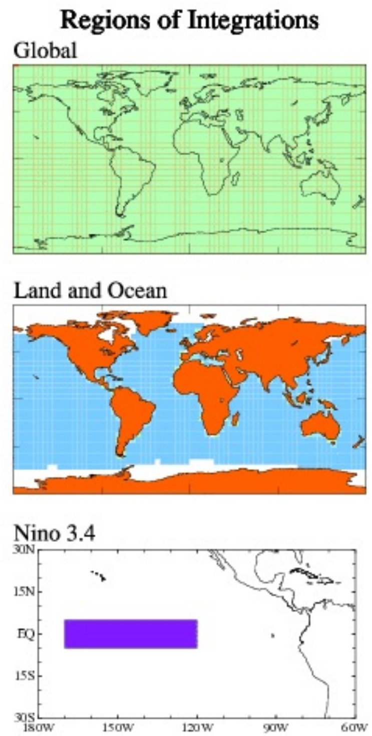
Is the planet warming?

Are humans responsible? These questions are settled as far as climate scientists in the US and worldwide are concerned.

Politically the questions are of course controversial because the costs of doing something and also of doing nothing are huge for producers and consumers of the emitting products.

But *scientifically* skeptics have the status of crackpots like "flat-earth" believers and "smoking doesn't cause cancer" zealots.





Global Top 13 Warmest Years (Jan-Dec) >1880

	+ °C	+°F
2014	0.69	1.24
2010	0.66	1.19
2005	0.65	1.17
1998	0.63	1.13
2013	0.62	1.12
2003	0.62	1.12
2002	0.61	1.10
2006	0.60	1.08
2009	0.59	1.07
2007	0.59	1.06
2004	0.57	1.04
2012	0.57	1.03
2011	0.51	0.92

http://www.ncdc.noaa.gov/sotc/global/

http://www.columbia.edu/~mhs119/Temperature/T_moreFigs/

Last decade was the warmest of the past thousand years, 1990s 2nd hottest.

For scientific refutation of common disinformation see especially

www.skepticalscience.com/argument.php

A Brief popular summary

www.washingtonpost.com/wp-dyn/content/article/2009/03/20/AR2009032002660.html .

Intergovernmental Panel on Climate Change

www.ipcc.ch/report/ar5/wg1/

www.youtube.com/watch?v=6yiTZm0y1YA

The World Meteorological Organization

http://www.wmo.int/pages/mediacentre/press_releases/pr_943_en.html

www. 350.org

- **American Association for the Advancement of Science**

http://whatweknow.aaas.org/get-the-facts/

- **American Geophysical Union**

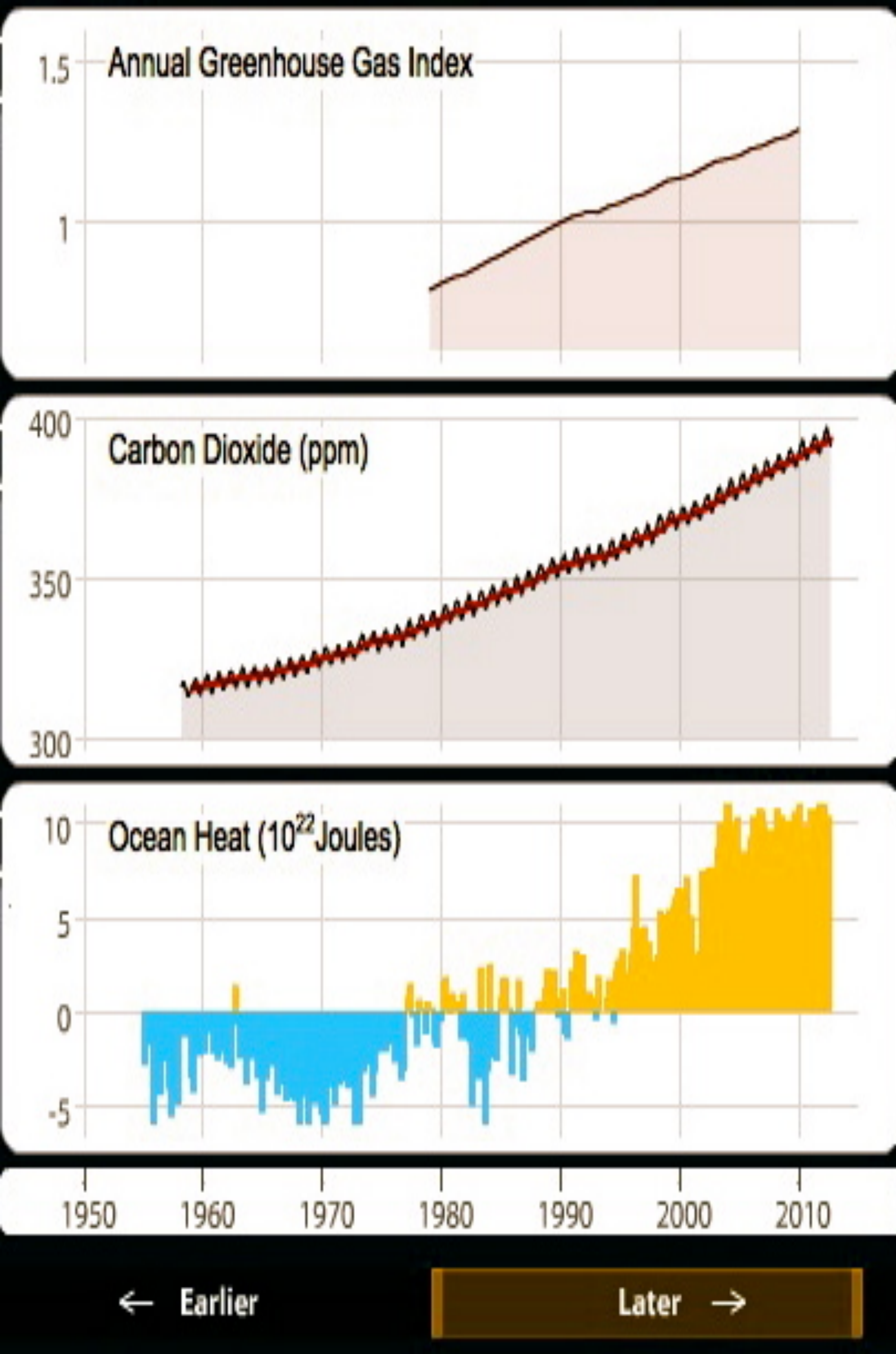
WWW.sciencepolicy.agu.org/files/2013/07/AGU-Climate-Change-Position-Statement_August-2013.pdf

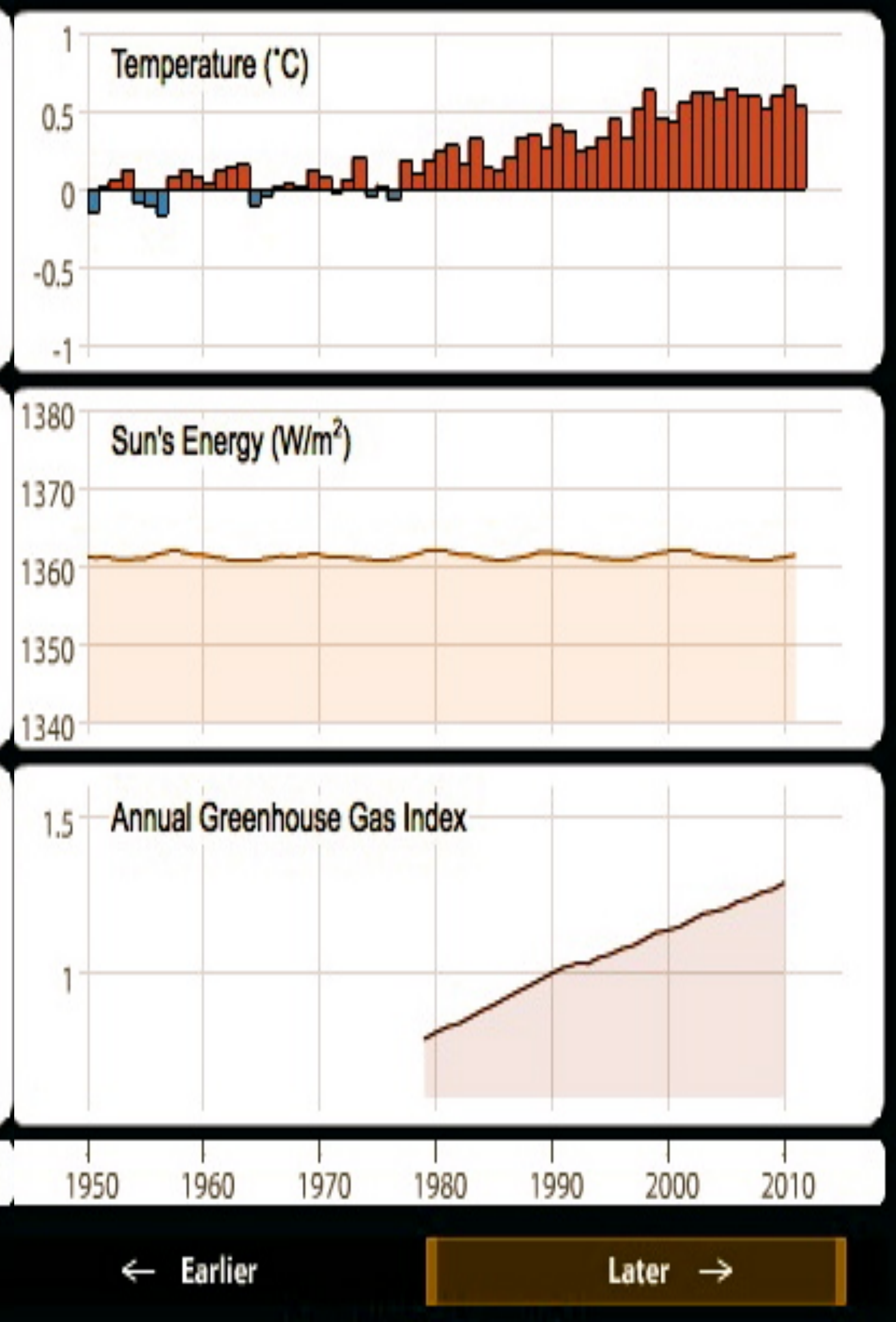
- **American Meteorological Society**

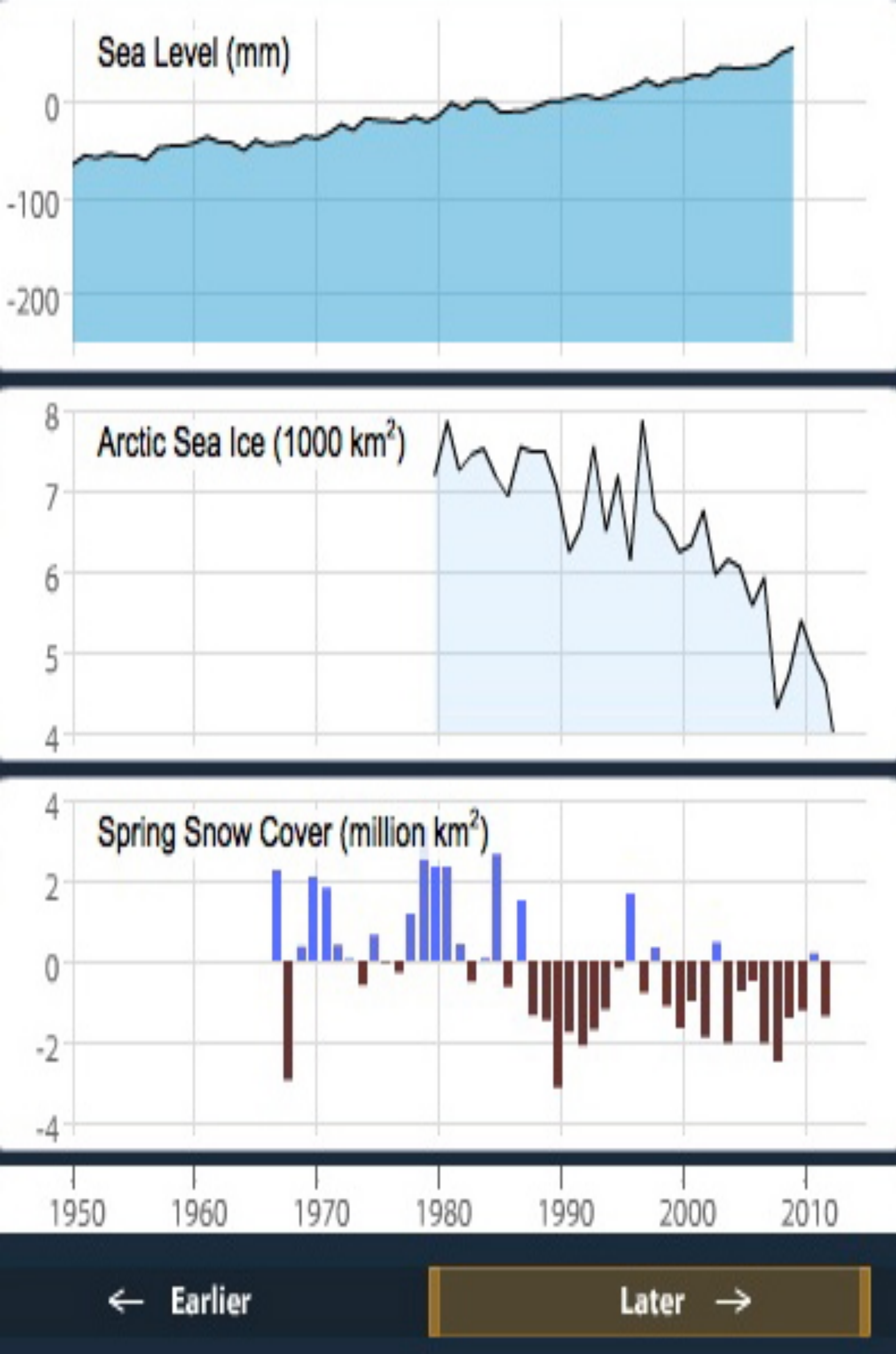
www.ametsoc.org/policy/2012climatechange.html

- **US National Academies of Science& UK Royal Society**

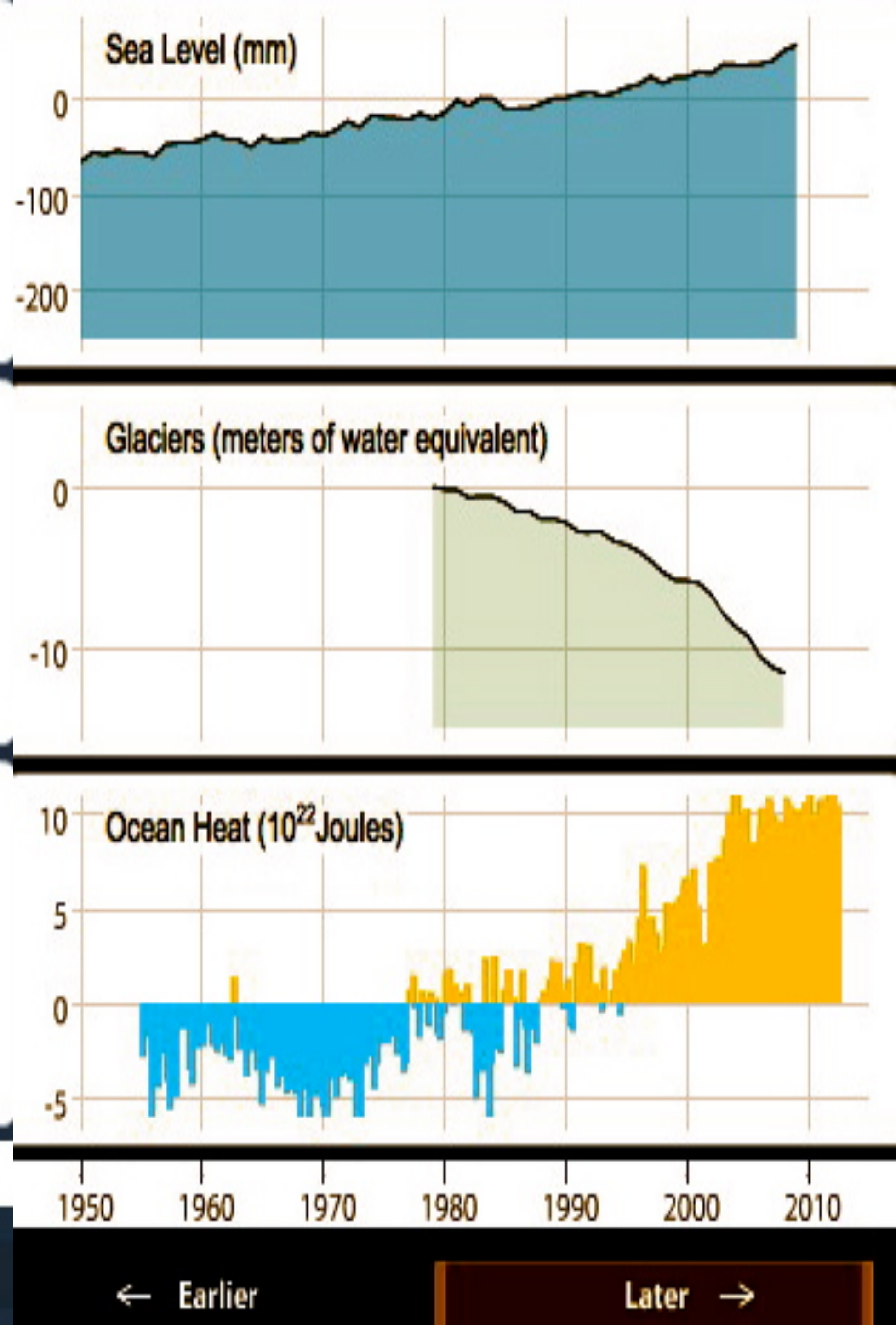
http://nas-sites.org/americasclimatechoices/events/a-discussion-on-climate-change-evidence-and-causes/


Annual Greenhouse Gas Index
1.5
1
Carbon Dioxide (ppm)
400
350
300
Ocean Heat (10^22 Joules)
10
5
0
-5
1950
1960
1970
1980
1990
2000
2010
← Earlier
Later →


Temperature (°C)
1
0.5
0
-0.5
-1
Sun's Energy (W/m²)
1380
1370
1360
1350
1340
Annual Greenhouse Gas Index
1.5
1
1950
1960
1970
1980
1990
2000
2010
← Earlier
Later →



Sea Level (mm)
0
-100
-200
Arctic Sea Ice (1000 km²)
8
7
6
5
4
Spring Snow Cover (million km²)
4
2
0
-2
-4
1950
1960
1970
1980
1990
2000
2010
← Earlier
Later →



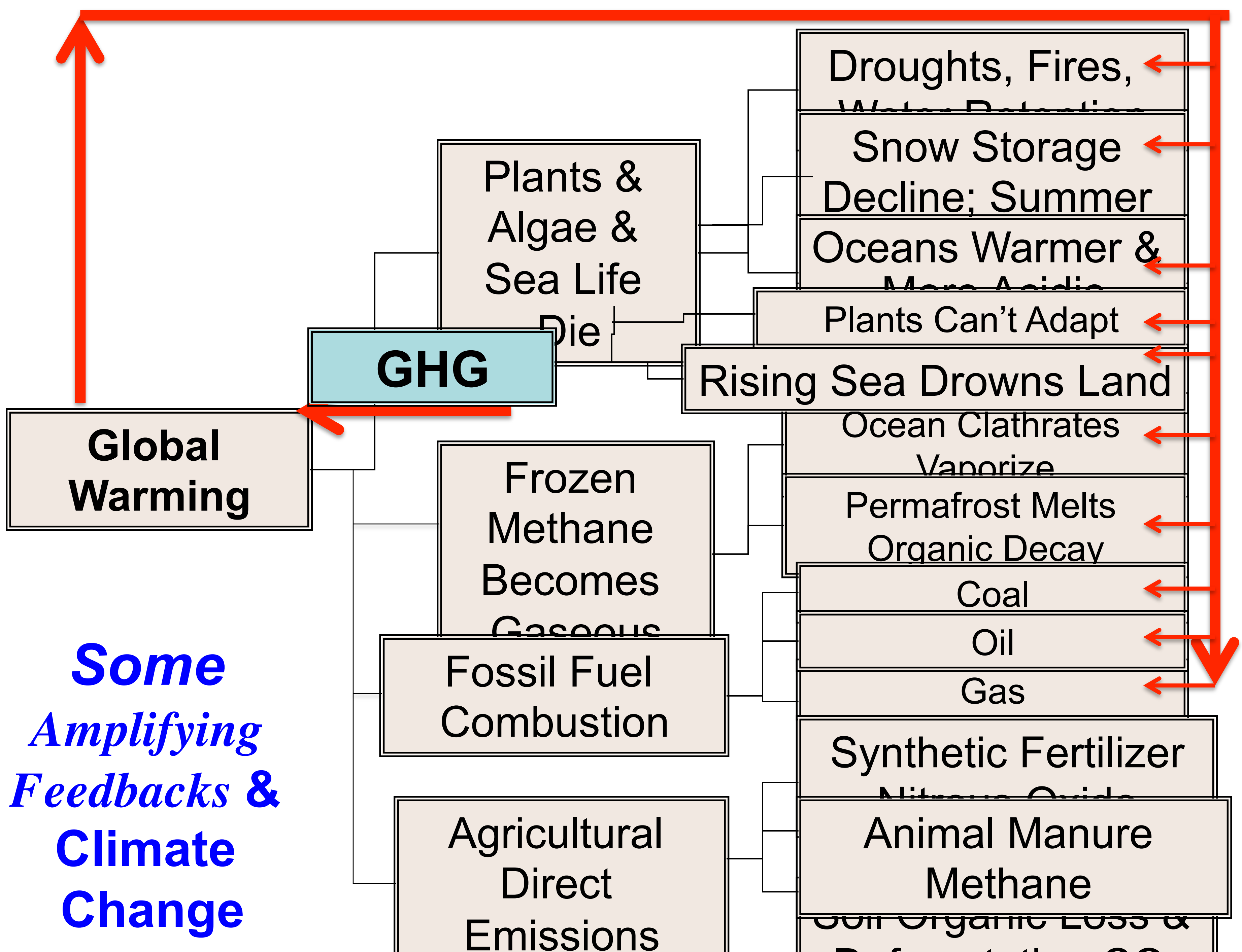
Sea Level (mm)
0
-100
-200
Glaciers (meters of water equivalent)
0
-10
Ocean Heat (10²² Joules)
10
5
0
-5
1950
1960
1970
1980
1990
2000
2010
← Earlier
Later →

Problem

- **Increasing greenhouse gases make temperatures hotter and these are leading to even more greenhouse gases.**
- **See Wake Up, Freak Out http://vimeo.com/1709110**

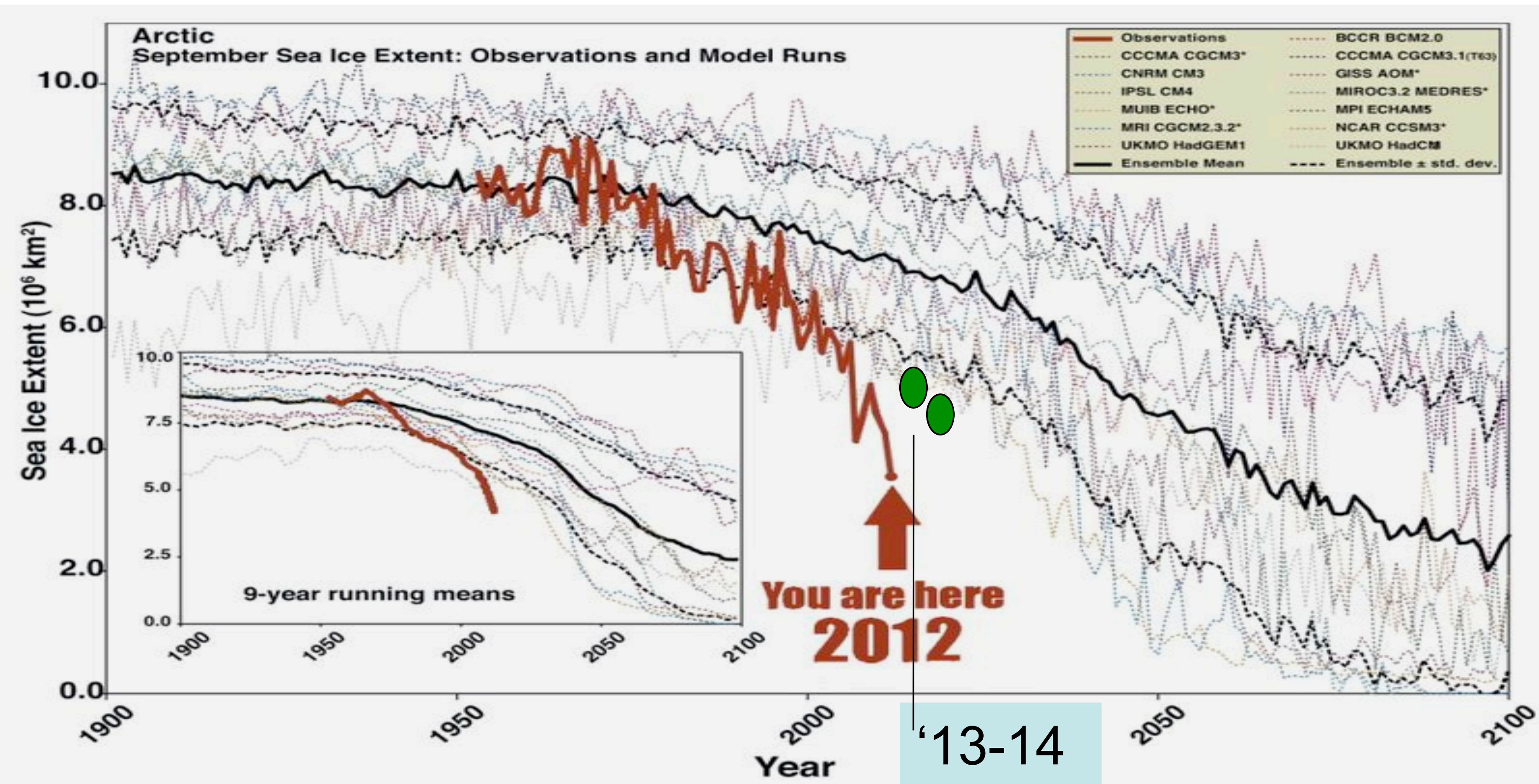
Problem

- **We are near a dangerous point where this "amplifying feedback" loop on a planetary scale will not be reversible because we have reached *a tipping point* where heat will create more heat.**
- **Or it will be dramatically more expensive in investment and taxes to reverse it.**

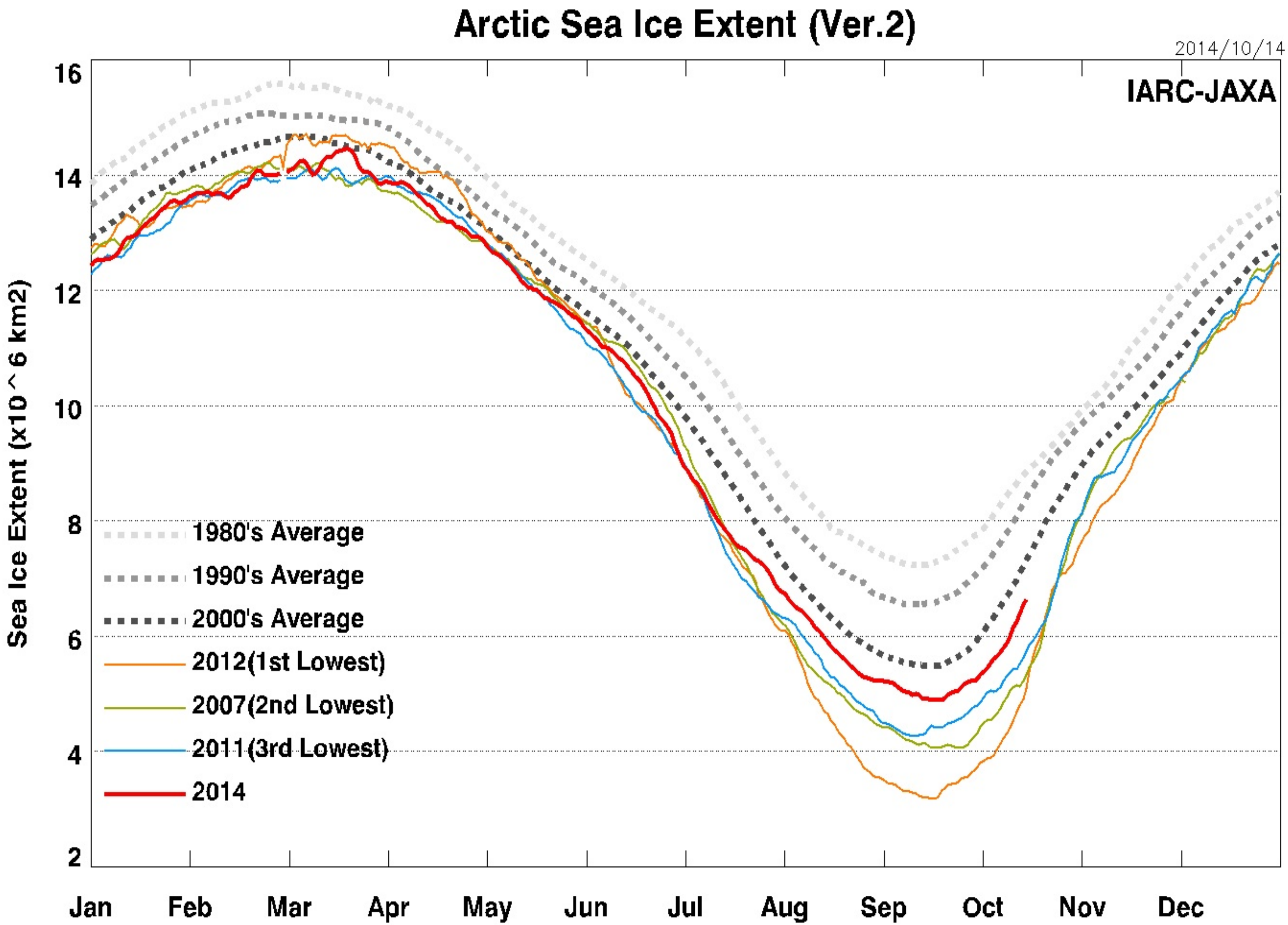

Some
Amplifying
Feedbacks &
Climate
Change
Global Warming
GHG
Plants & Algae & Sea Life Die
Frozen Methane Becomes
Fossil Fuel Combustion
Agricultural Direct Emissions
Droughts, Fires,
Snow Storage Decline; Summer
Oceans Warmer &
Plants Can't Adapt
Rising Sea Drowns Land
Ocean Clathrates
Permafrost Melts Organic Decay
Coal
Oil
Gas
Synthetic Fertilizer
Animal Manure Methane

Evidence of Amplifying Feedback?

Warming is happening much faster than even the most pessimistic forecasts of the Inter-governmental Panel on Climate Change a decade ago!



Methane Plume in Arctic


Arctic Sea Ice Extent (Ver.2)
2014/10/14
IARC-JAXA
Sea Ice Extent (x10^6 km2)
16
14
12
10
8
6
4
2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1980's Average
1990's Average
2000's Average
2012(1st Lowest)
2007(2nd Lowest)
2011(3rd Lowest)
2014

Houston Area Getting Hotter?

- **Hottest summer months ever over 130 years in Houston: ¼ in 65 years before 1947, ¾ in 65 years since.**
- **More of hottest months since 1996 than from 1880 to 1950!**
- **80% of the highest yearly average temperatures were in the last 20 years and 20% in the previous 110 years.**

Houston Area Getting Hotter?

- **For Galveston, all six of the hottest annual temperatures in the last 140 years have been since 1993.**
- **There has not been one of the coldest annual temperatures since 1979.**
- **At Hobby, all 10 of the hottest annual temperatures have been since 1998.**
- **Higher AC Bills!**

Houston Area Not so Cold?

- **The coldest part of the year is 31 days from December 15 to January 14.**

- **Over 130 years, each date has a record high temperature and record low.**

- **At the Houston station, 42% of record winter *highs* were in the last 20 years and 55% of record highs were in the previous 40 years.**

- ***Just 3% (1 of 31) of record high coldest daily temperatures occurred in the 70 years before 1950!***

Houston Area Not so Cold?

- Of the eleven coldest nights in Houston history (those less than 12˚F):
- 45% occurred before 1900,
- And the rest happened between 1900 and 1989.
- None of the 25 lowest temperatures ever (below 19˚) have occurred in the 25 years since 1989.
- No temperatures in the teens since 1996.

Galveston from 1872

Top 10 Warmest		Top 10 Coolest	
73.9	2012	67.6	1979
72.6	2006	67.6	1895
72.4	2011	67.8	1903
72.3	2005	68.1	1976
72.3	1999	68.1	1940
72.3	1994	68.3	1970
72.3	1933	68.3	1912
72.1	1927	68.4	1914
71.9	1998	68.5	1960
71.9	1995	68.6	1913

Should Average One Record Every 14.2 yr. (Galveston) Every 8.3 yr. (Hobby)

Hobby from 1931

Top 10 Warmest		Top 10 Coolest	
72.6	2012	66.8	1940
72.4	2011	67.1	1970
72.3	1998	67.2	1979
71.4	2006	67.5	1983
71.4	2005	67.5	1936
71.3	2008	67.6	1976
71.1	2009	67.8	1978
71.1	2000	67.8	1937
71.0	2007	68.0	1942
70.9	2004	68.1	1947

IAH/Downtown from 1889

Top 10 Warmest		Top 10 Coolest	
72.1	2012 ←	65.8	1976
71.9	1962	66.5	1983
71.8	2011 ←	66.5	1979
71.7	1933	66.7	1978
71.5	1965	66.9	1891
71.5	1927	67.1	1970
71.3	1954	67.4	1997
71.2	1956	67.5	1977
71.1	1950	67.5	1903
71.1	1921	67.5	1899

Should Average One Record Every 12.6 years

College Station from 1889

Top 10 Warmest		Top 10 Coolest	
71.6	2012 ←	65.2	1979
71.6	2011 ←	65.5	1983
70.9	1933	65.6	1976
70.7	1911	65.8	1968
70.4	1927	66.6	1919
70.4	1921	66.7	1970
70.3	1996	66.8	1997
70.2	2006 ←	66.8	1973
70.2	1934	66.8	1936
70.1	2009 ←	66.9	1975

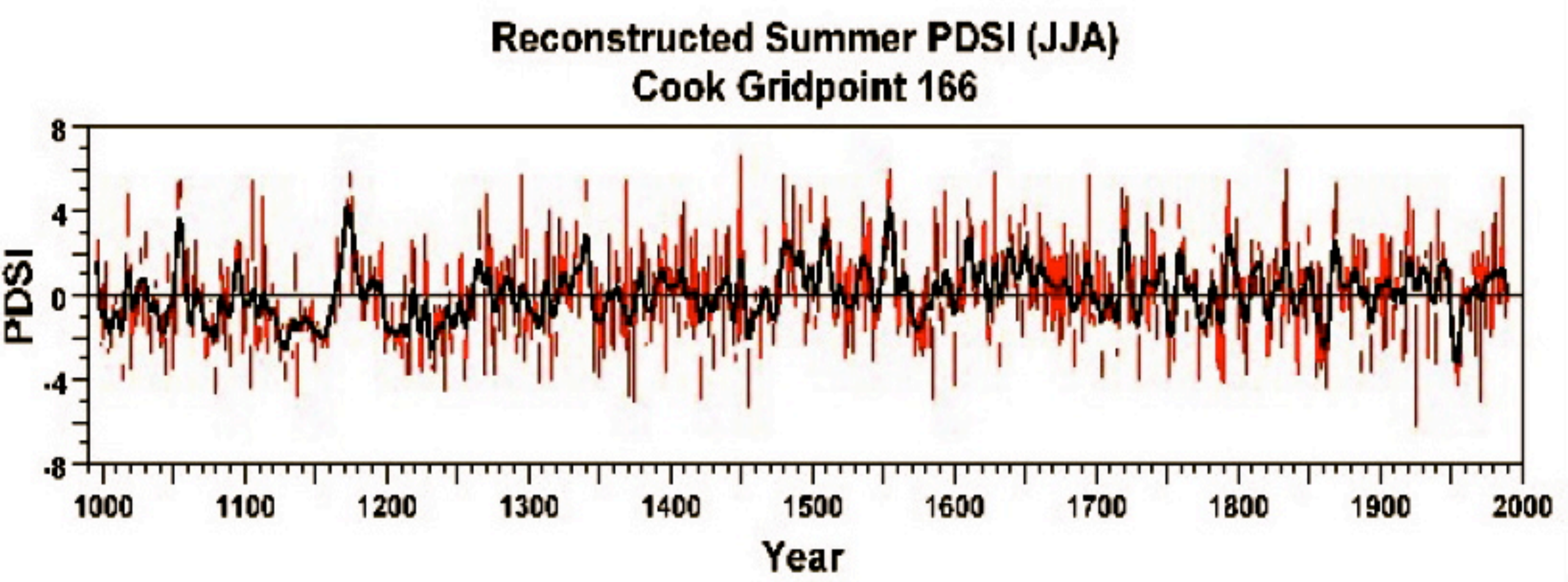
Record Area Temps 1990- Jan 2015	Galveston	Expected	Hobby	Expected	IAH/City	Expected	College Station	Expected	Total Observed	Total Expected
Warmest 10 Annual Temps	8	1.7	10	2.9	4	2.0	5	2.0	27	8.5
Warmest 10 Junes	7	1.7	10	2.9	7	2.0	4	2.0	28	8.5
Warmest 10 Julys	5	1.7	6	2.9	4	2.0	4	2.0	19	8.5
Warmest 10 Augusts	10	1.7	8	2.9	4	2.0	5	2.0	27	8.5
Daily High Temp Records December	19	5.4	17	9.2	17	6.2	8	6.2	61	27
Daily High Temp Records January	13	5.4	9	9.2	12	6.2	9	6.2	43	27
Heat Record Anomaly Totals	62	17.6	60	30	48	20.2	35	20.2	**205**	**88**
10 Lowest Annual Temps	0	1.7	0	2.9	0	2.0	1	2.0	1	8.6
Daily Low Temp Records December	0	5.4	3	9.2	2	6.2	4	6.2	9	27
Daily Low Temp Records January	0	5.4	1	9.2	1	6.2	3	6.2	5	27
Cold Anomaly Totals	0	12.5	4	21.3	3	14.4	8	14.4	**15**	**62.6**

Data from http://www.weather.gov/climate/local_data.php?wfo=hgx

There is Much that is Known About Weather History

Palmer Drought Severity

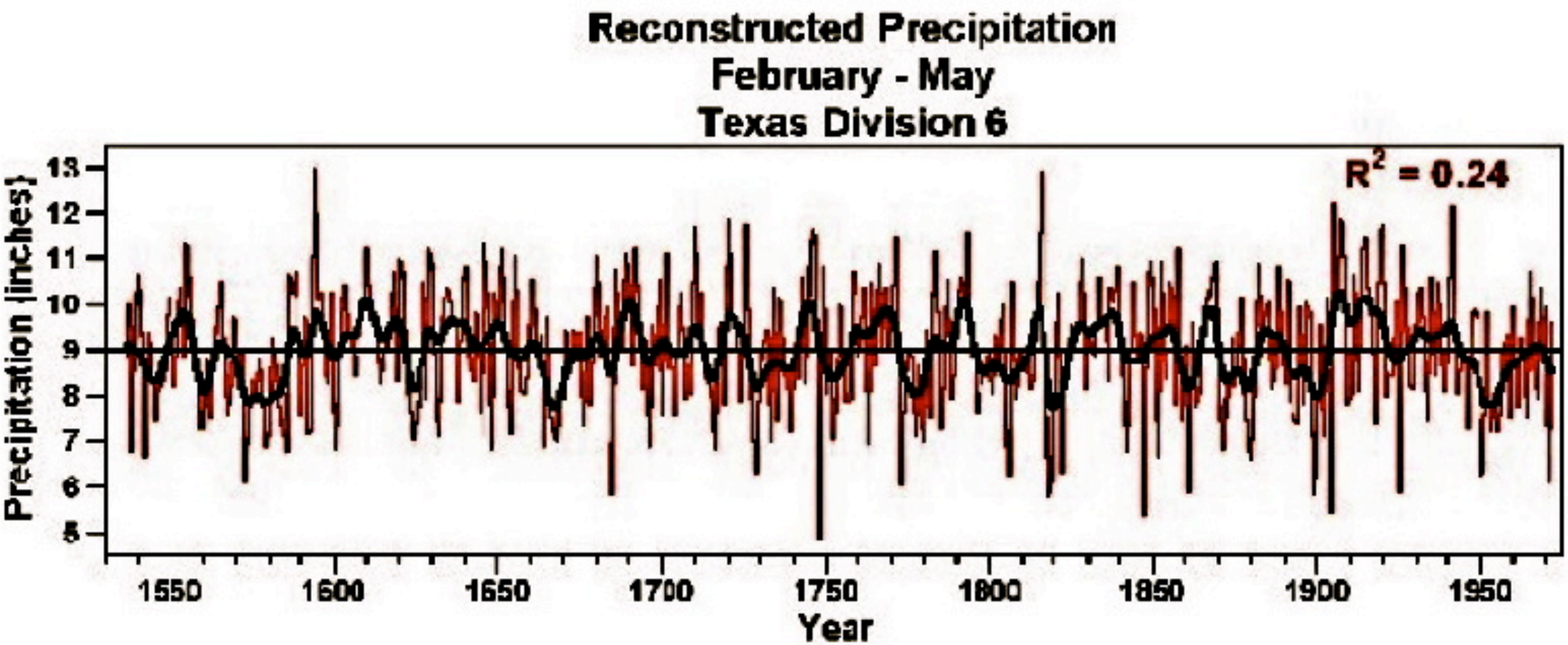
West of San Antonio



2000

1000

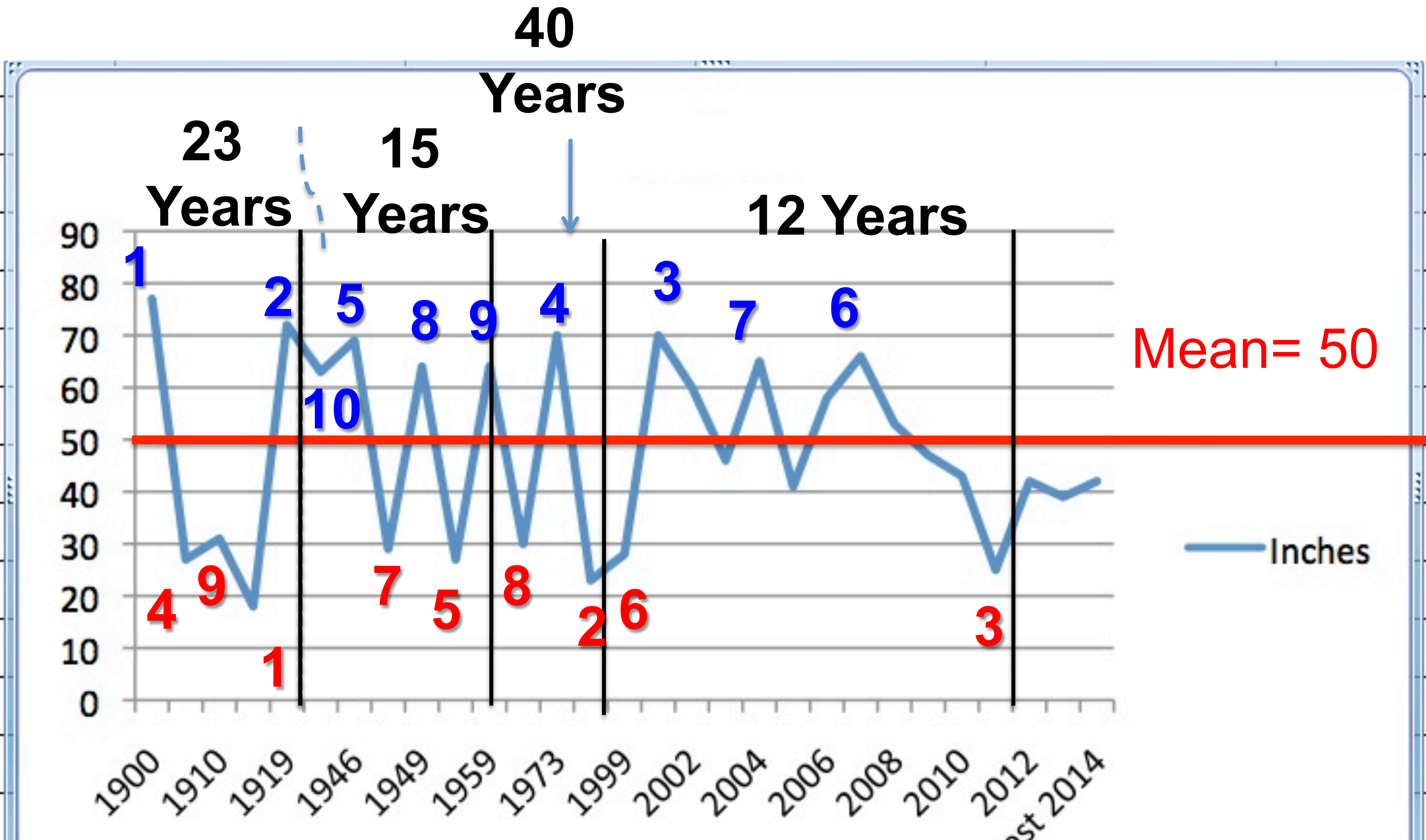
Spring Rain in Blanco-San Angelo-Uvalde Area Varies from 5 inches to 13



1550

1960

Annual Rainfall Houston Weather Station 1900-2014 in Inches



1537-1972 Feb-May Droughts

Table 5. Twenty … in the reconstruction of climatic division 6 (Edwards Plateau) Feb. – May total precipitation (inches), 1537-1972. The average Feb. – May precipitation over the 436-year reconstruction is 8.99 inches.

2011

Worst

1748

Case	1 Yr	2 yr	3 yr	4yr	5yr	10 yr.
1 (Worst)	1748/ 4.88	1818-1819/ 5.93	1818-1820/ 6.56	1817-1820/ 7.26	1818-1822/ 7.24	1571-1580/ 7.84
2	1847/ 5.39	1950-1951/ 6.38	1817-1819/ 7.08	1899-1902/ 7.39	1950-1954/ 7.57	1950-1959/ 7.84
3	1904/ 5.45	1684-1685/ 6.38	1583-1585/ 7.18	1950-1953/ 7.45	1666-1670/ 7.60	1576-1585/ 7.84
4	1818/ 5.75	1899-1900/ 6.46	1878-1880/ 7.28	1818-1821/ 7.48	1664-1668/ 7.71	1573-1582/ 7.91
5	1685/ 5.83	1728-1729/ 6.66	1666-1668/ 7.31	1666-1669/ 7.51	1819-1823/ 7.74	1572-1581/ 7.94
6	1899/ 5.85	1805-1806/ 6.73	1728-1730/ 7.33	1953-1956/ 7.52	1951-1955/ 7.76	1773-1782/ 7.99
7	1861/ 5.90	1879-1880/ 6.87	1879-1881/ 7.39	1573-1576/ 7.54	1622-1626/ 7.76	1575-1584/ 8.00
8	1925/ 5.90	1573-1574/ 6.94	1578-1580/ 7.40	1582-1585/ 7.56	1576-1580/ 7.79	1574-1583/ 8.05
9	1773/ 6.04	1819-1820/ 6.96	1573-1575/ 7.41	1878-1881/ 7.57	1573-1577/ 7.79	1949-1958/ 8.07
10	1971/ 6.08	1584-1585/ 7.02	1727-1729/ 7.42	1667-1670/ 7.58	1953-1957/ 7.81	1570-1579/ 8.08
11	1573/ 6.09	1579-1580/ 7.06	1667-1669/ 7.46	1819-1822/ 7.62	1572-1576/ 7.82	1577-1586/ 8.11
12	1819/ 6.12	1667-1668/ 7.14	1859-1861/ 7.47	1623-1626/ 7.64	1900-1904/ 7.85	1948-1957/ 8.12
13	1806/ 6.25	1592-1593/ 7.19	1623-1625/ 7.48	1777-1780/ 7.65	1817-1821/ 7.86	1871-1880/ 8.13
14	1950/ 6.27	1773-1774/ 7.24	1899-1901/ 7.49	1622-1625/ 7.67	1898-1902/ 7.86	1817-1826/ 8.14
15	1822/ 6.30	1559-1560/ 7.27	1953-1955/ 7.49	1559-1562/ 7.71	1558-1562/ 7.87	1946-1955/ 8.16
16	1729/ 6.33	1822-1823/ 7.27	1949-1952/ 7.50	1727-1730/ 7.73	1773-1777/ 7.88	1818-1827/ 8.16
17	1951/ 6.49	1870-1871/ 7.32	1950-1952/ 7.52	1870-1873/ 7.74	1571-1575/ 7.89	1775-1781/ 8.16
18	1880/ 6.59	1623-1624/ 7.34	1902-1904/ 7.54	1577-1580/ 7.75	1776-1780/ 7.89	1663-1672/ 8.18
19	1851/ 6.68	1846-1847/ 7.37	1683-1685/ 7.55	1571-1574/ 7.78	1581-1585/ 7.90	1664-1673/ 8.19
20	1542/ 6.68	1583-1584/ 7.38	1898-1900/ 7.55	1572-1575/ 8.78	1949-1953/ 7.90	1947-1956/ 8.19

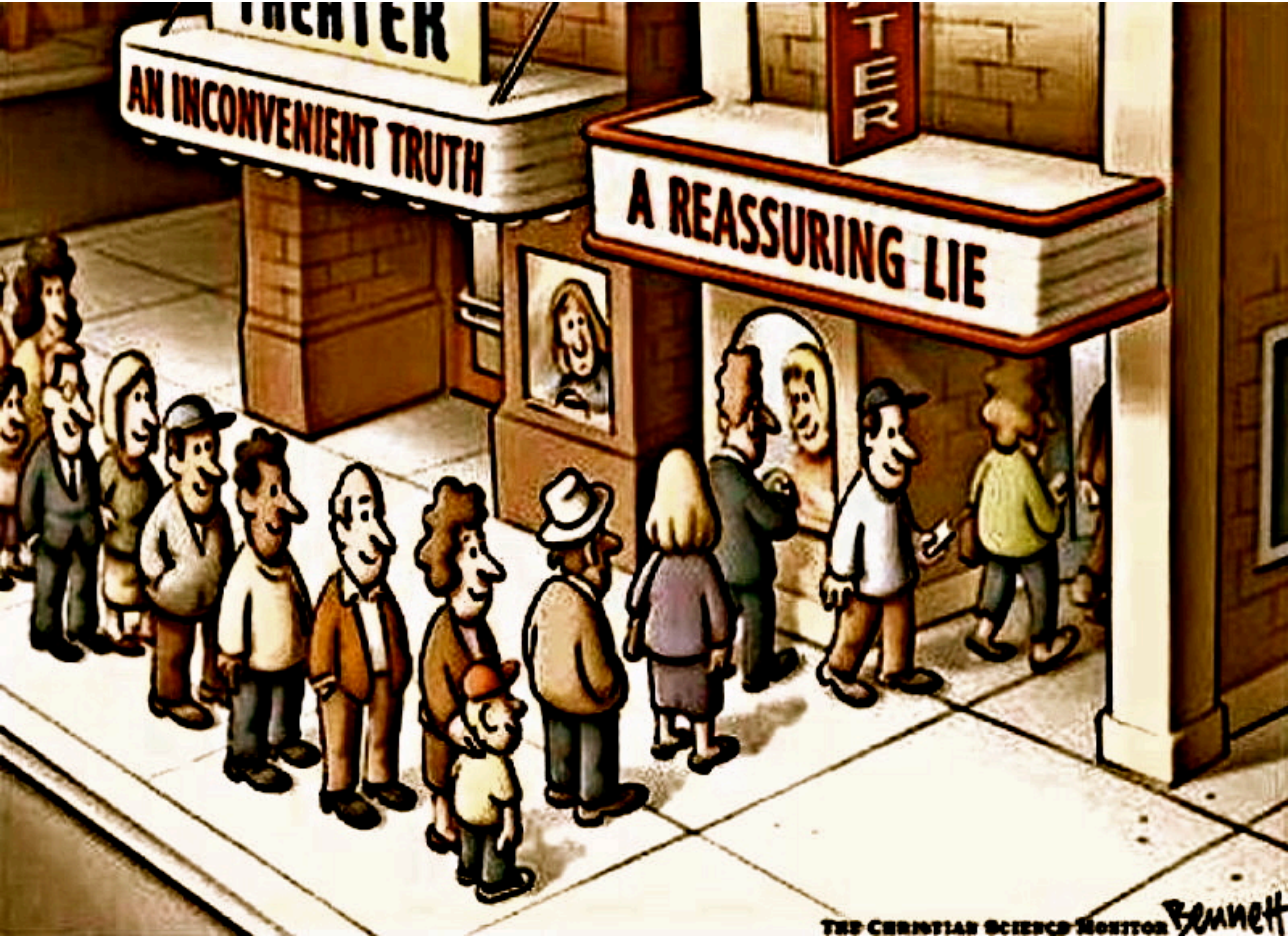
Since 1970

1940-1960

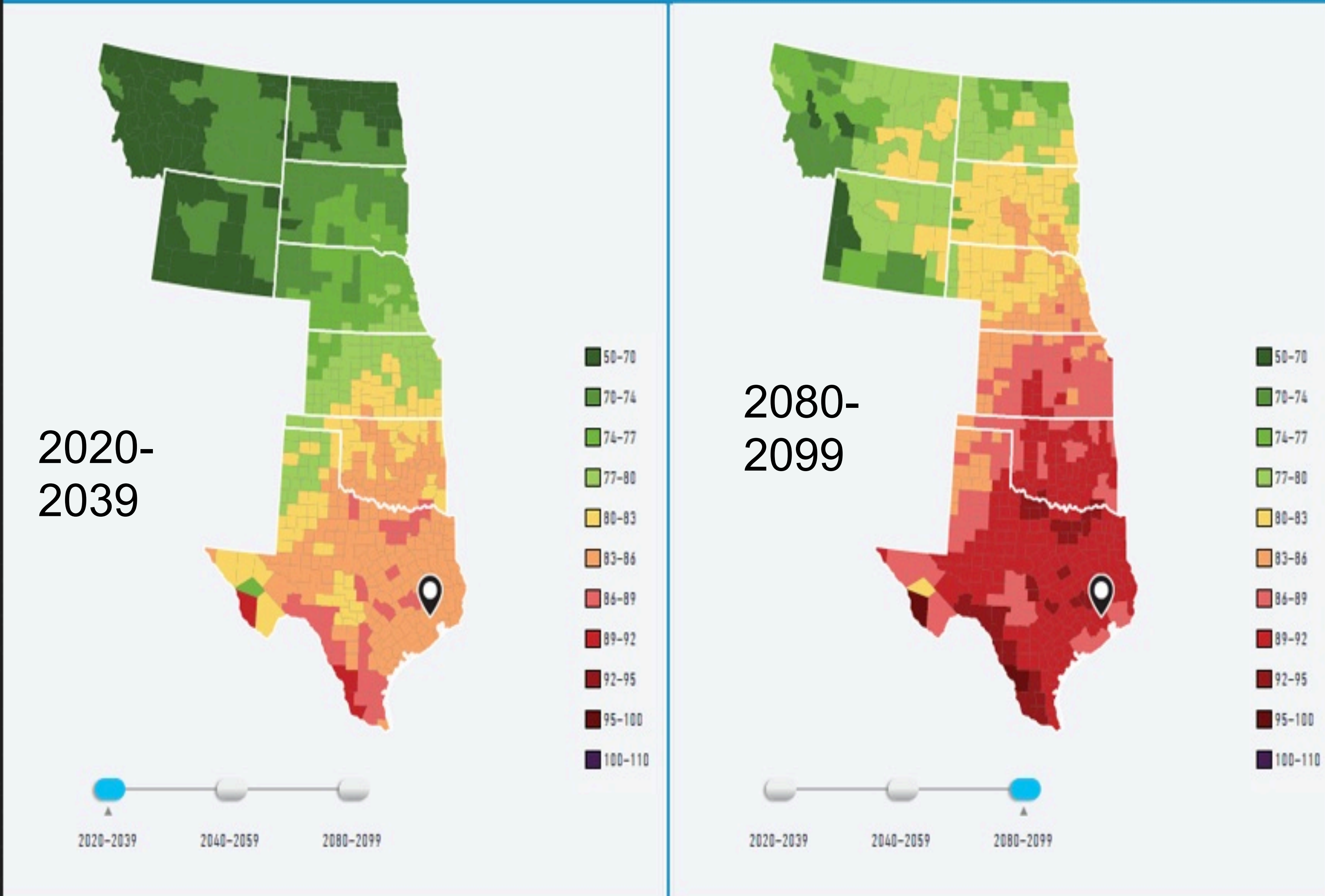
1900-1940

Climate Change, Food, & Houston's Future

- ***Why climate and weather are important.***
- **Main Causes of "Normal" weather & climate**
- **What has been happening to the weather and climate.**
- ***What may happen to the weather & climate***
- **Efforts to mitigate and their consequences**
- **Probable effects on our food supply**
- **Probable other effects on our area**


AN INCONVENIENT TRUTH
A REASSURING LIE
THE CHRISTIAN SCIENCE MONITOR
Bennett

GREAT PLAINS: AVERAGE SUMMER TEMPERATURE & KEY IMPACTS



Temperatures in the Arctic & the Tropics are changing,

- **So Weather and Therefore Food Supply will Change in Largely Unpredictable Ways.**

- **Very Rapid movement away from fossil fuel is essential across the planet *and especially here where there is large consumption per capita.***

- **We need to curb not only our direct use of energy, but also our indirect use.**

- **Items we purchase, need to not require lots of energy (embodied energy=EMERGY) in their life cycle from production to destruction.**
- **The easiest way to do this is to conserve materials and energy at a very high levels and move to local renewable production.**
- **We need to design better getting many uses out of all materials and energy.**
- **Some people advocate fourth generation nuclear, algae biofuels, lunar solar, agrochar or other carbon sequestration as alternatives. Lots could be done with better management of the arid tropics.**
- ***If everyone worked on it, much could be done*.**

Climate

- www.climate.gov
- *Storms of My Grandchildren—The Truth About the Coming Climate Change and Our Last Chance to Save Humanity* by James Hanson, Ph.D. Clearly explains the science
- http://en.wikipedia.org/wiki/Global_warming is a good overall view with lots of links.
- http://climatechangenationalforum.org/ Good articles by Texas state climatologist & others
- http://www.skepticalscience.com/ Good explanations of climate science and science fiction

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Not being weather literate or *climate responsible* could be VERY costly!

Be Your Own Weather Person!

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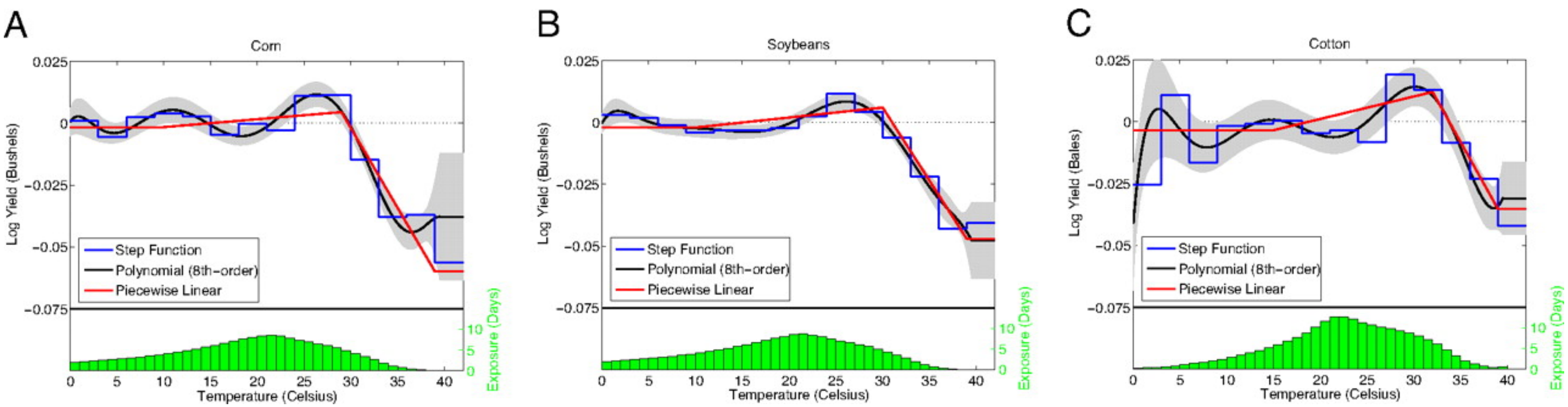
Plants & Climate

- Tomatoes and corn only pollinate at certain different temperatures (55-85; 70-90);
- Lettuce and okra seed only sprout at certain different temperatures (<75, >70);
- Mangoes and tangerines have different lower temperature limits (25, 18)
- Particular apple varieties, olives, and peonies need different winter temperatures for different periods of time in order to flower.
- Differences in one yard or region may be important.

Cold Temperatures & Plants

- **To be successful growing fruit, you need to figure out how cold and how cool it gets in winter *where you live*.**
- **How cold it gets on the coldest nights determines what semi-tropicals will do well at your place.**
- **Different semi-tropicals can tolerate different low temperatures--papayas to 30˚, mangoes to 27˚, oranges on trifoliate roots to 22˚, etc..**
- **Very urban inner city Houston, especially immediately south and southwest of downtown (like Hermann Park) is much warmer on cold nights than more rural areas. So too are Gulf Coast barrier islands. Galveston rarely goes below freezing, and Conroe often goes below 20˚.**

Nonlinear relation between temperature and yields.



Schlenker W , and Roberts M J PNAS 2009;106:15594-15598

PNAS

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