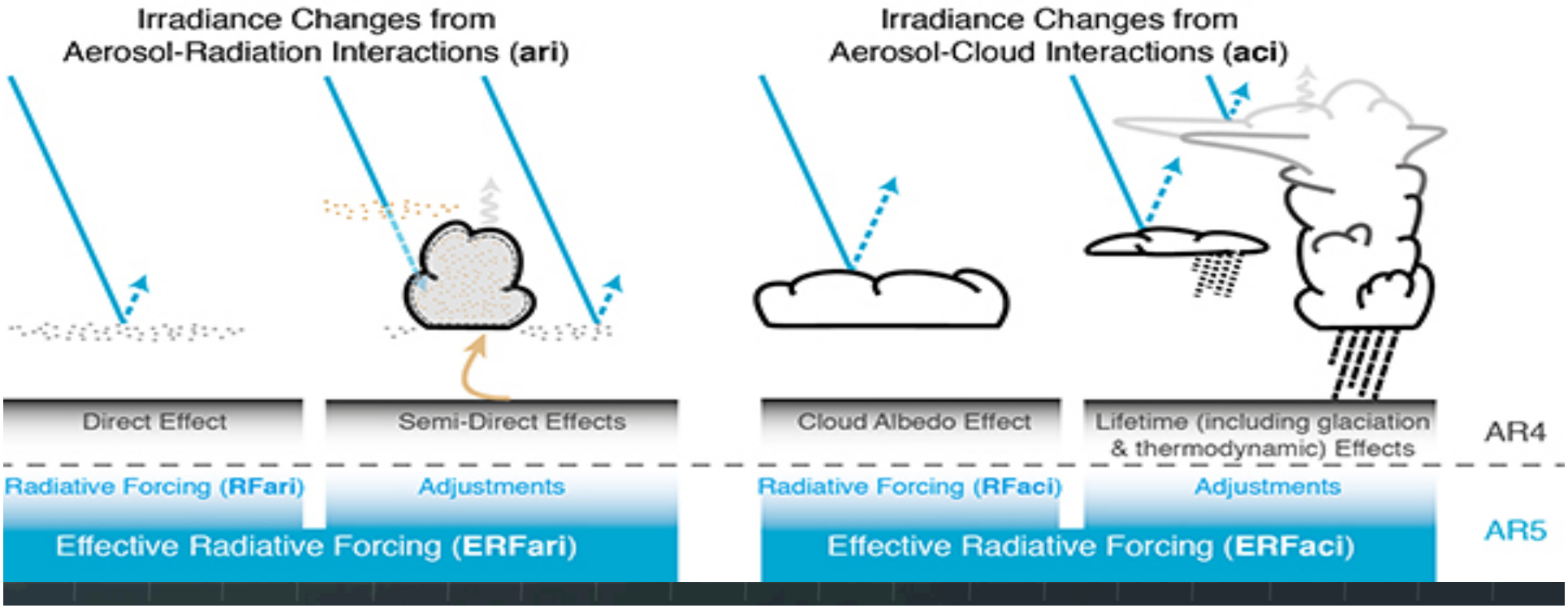
# Global Dimming and Drought in the Sahel

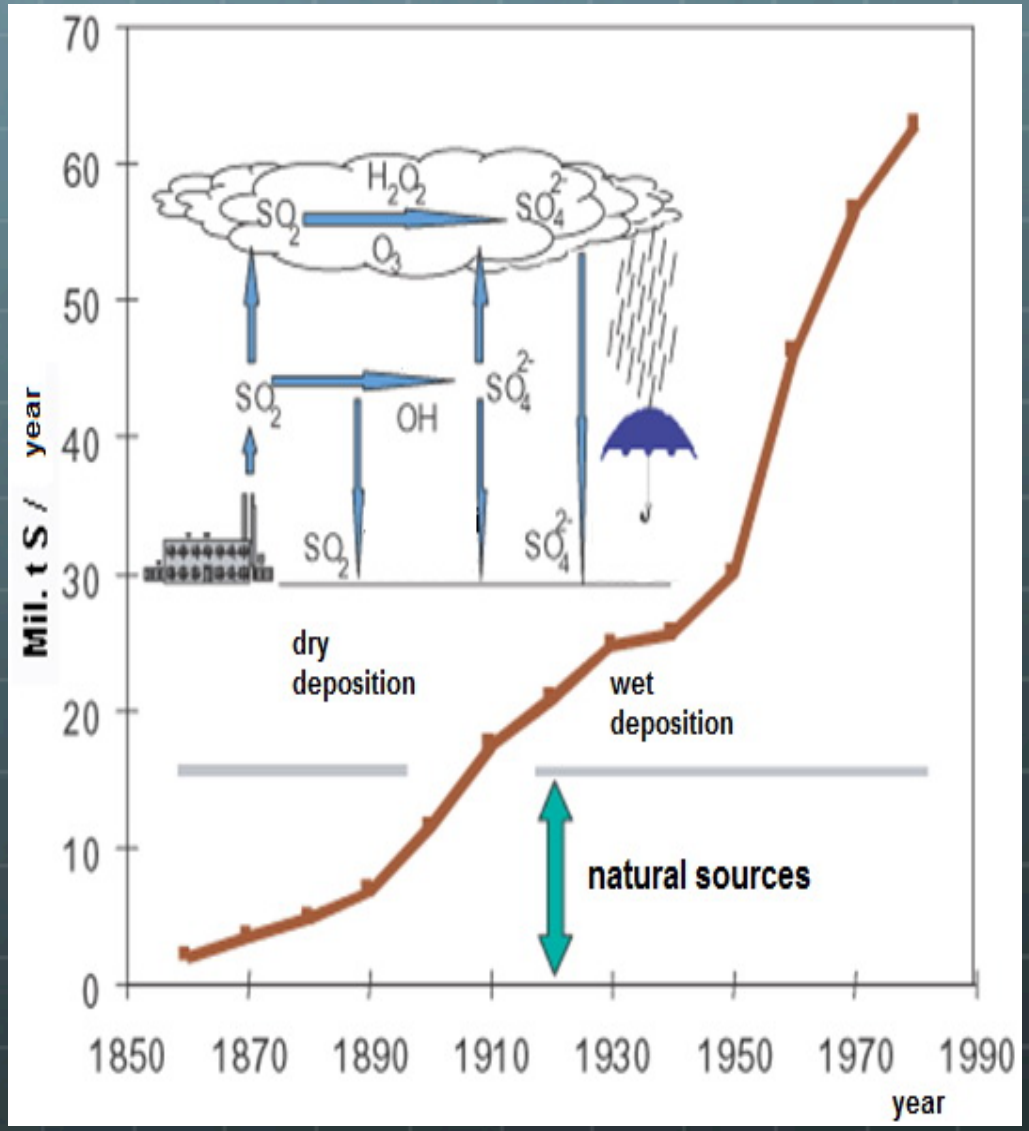
## The Effects of $SO_2$ (Sulfur Dioxide) Pollution from Northern Countries and the Sahel Decadal Drought

# What is Global Dimming?

**Solar dimming is a reduction of solar radiation that reaches the Earth's surface. This is caused by tiny aerosol particles suspended in the atmosphere. Aerosols may scatter, reflect or absorb sunlight impeding it from reaching the Earth's surface. This has a cooling effect on Earth's surfaces.**



# What is $SO_2$ ?




Sulfur Dioxide is a gas. Its' chemical composition consists of the elements Sulfur and Oxygen.

SO2 is a soluble colorless gas that is produced by natural and anthropogenic sources.

When SO2 is emitted into the atmosphere it is converted into sulfates through the oxidation process. SO2 also dissolves with water droplets and precipitates as acid rain.

# How Sulfate Aerosols Form?

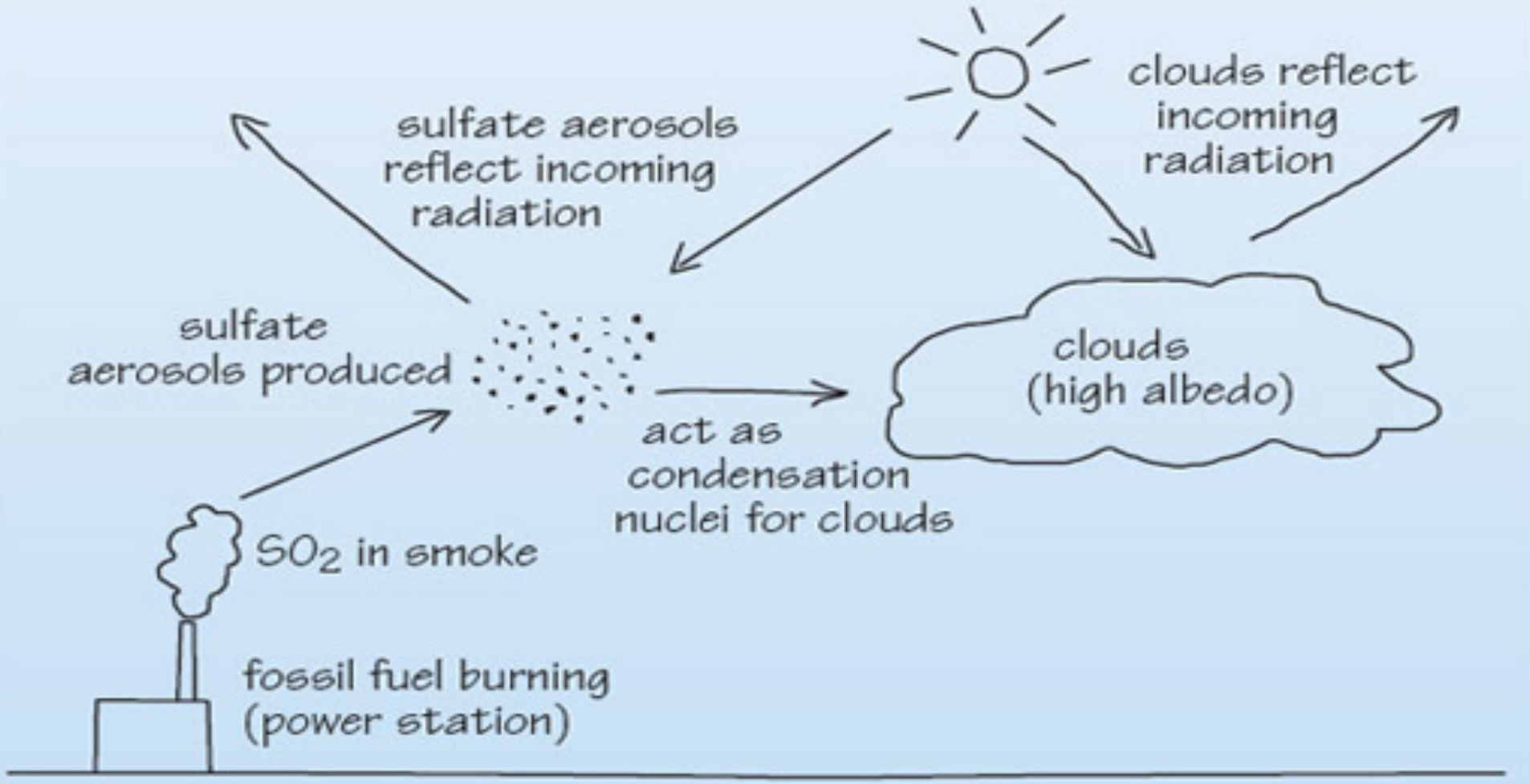
## Natural Sources

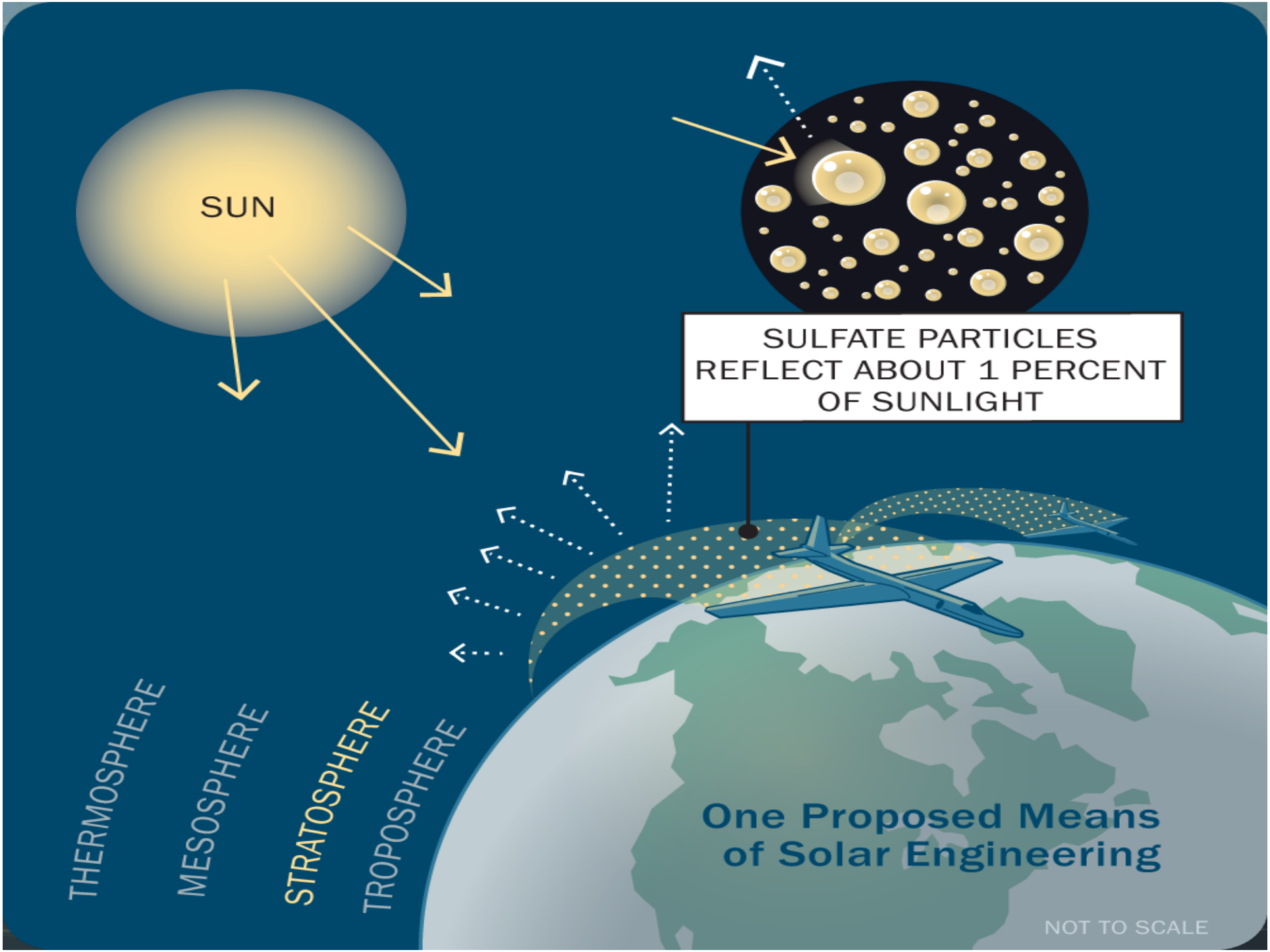
- Volcanic Eruptions
- Ocean Spray
- Decaying Vegetation


## Anthropogenic Sources: Burning of Materials that Contain Sulfur

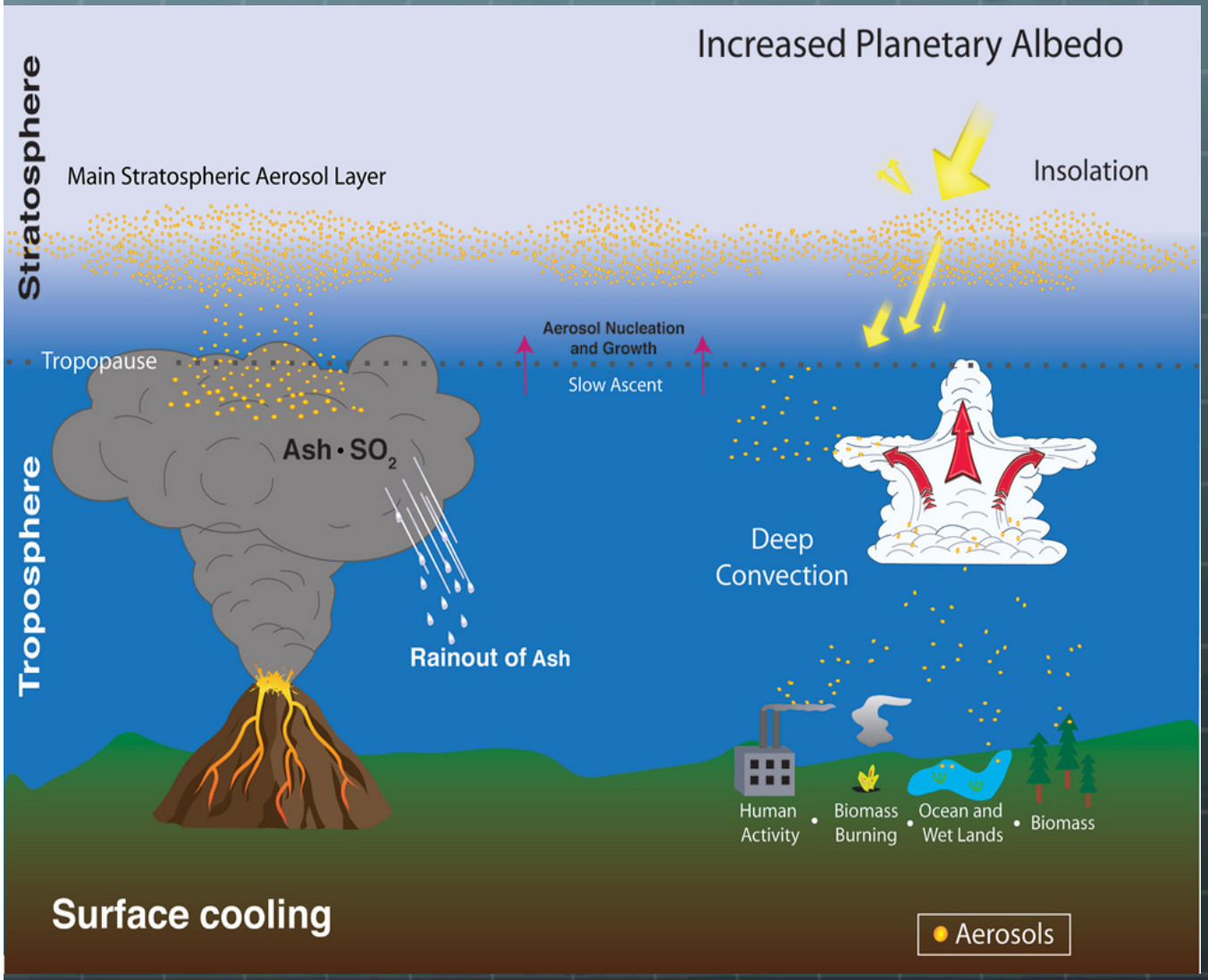
- Burning of Fossil Fuels
- Power Plants
- Refining Oil
- Metal Smelting
- Chemical Manufacturing
- Industrial Processing
- Ship Exhaust
- Vehicles
- Airplanes

# How Sulfate Aerosols Reflect Sunlight?




SUN
SULFATE PARTICLES REFLECT ABOUT 1 PERCENT OF SUNLIGHT
THERMOSPHERE
MESOSPHERE
STRATOSPHERE
TROPOSPHERE
One Proposed Means of Solar Engineering
NOT TO SCALE

# Effect of $SO_2$ Aerosols on the Atmosphere




Aerosols are transferred into the atmosphere by deep convective currents from atmospheric winds.

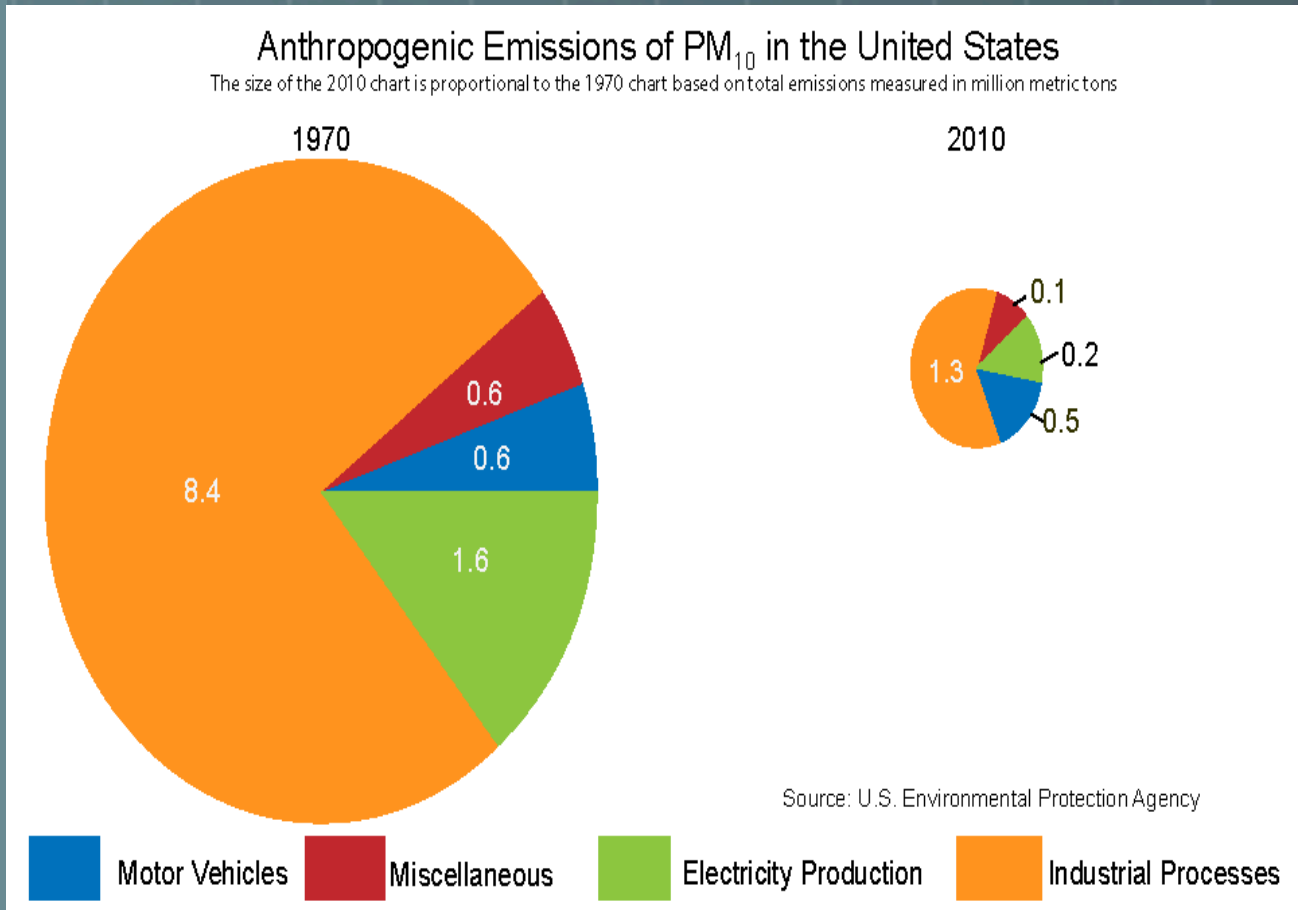
Once in the Atmosphere aerosols reflect solar radiation. This effect is localized only affecting the geographical area where $SO_2$ is concentrated in. This increases the insolation, therefore the Earth's Albedo causing a cooling effect.

Once in the atmosphere aerosols are dispersed by prevailing winds of the region and can travel far.

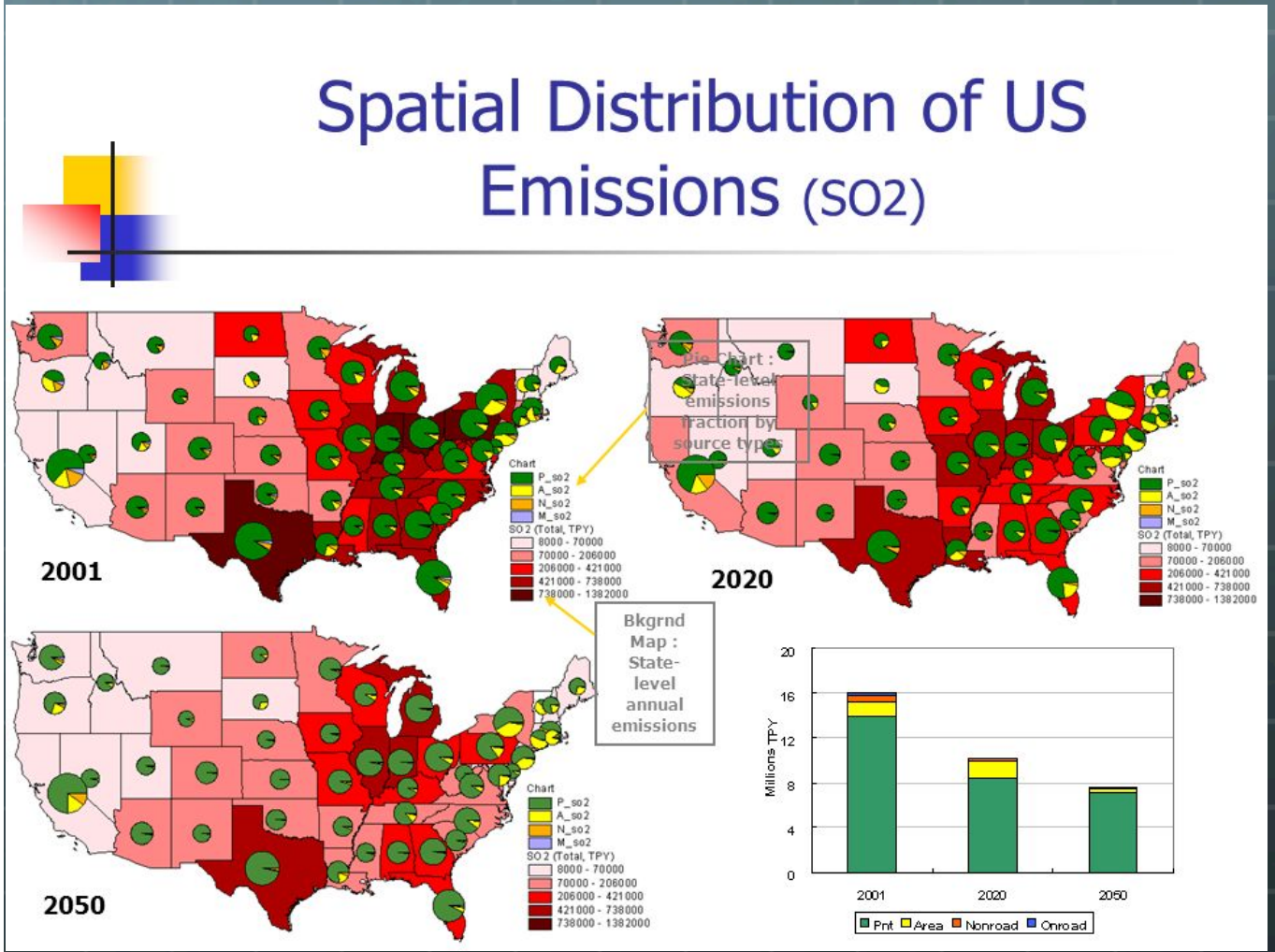
# Industrial Revolution Fossil Fuel Burning

$SO_2$ has been identified as a major player in Global Dimming.

Since the beginning of the Industrial Revolution thousand s of megatons of $SO_2$ have been released into the atmosphere. Mostly by Northern Nations; United States, Europe and China. The emissions peaked during the early 1970's.

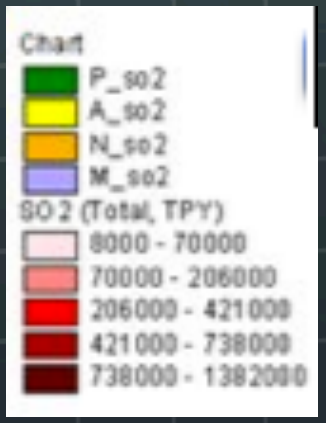


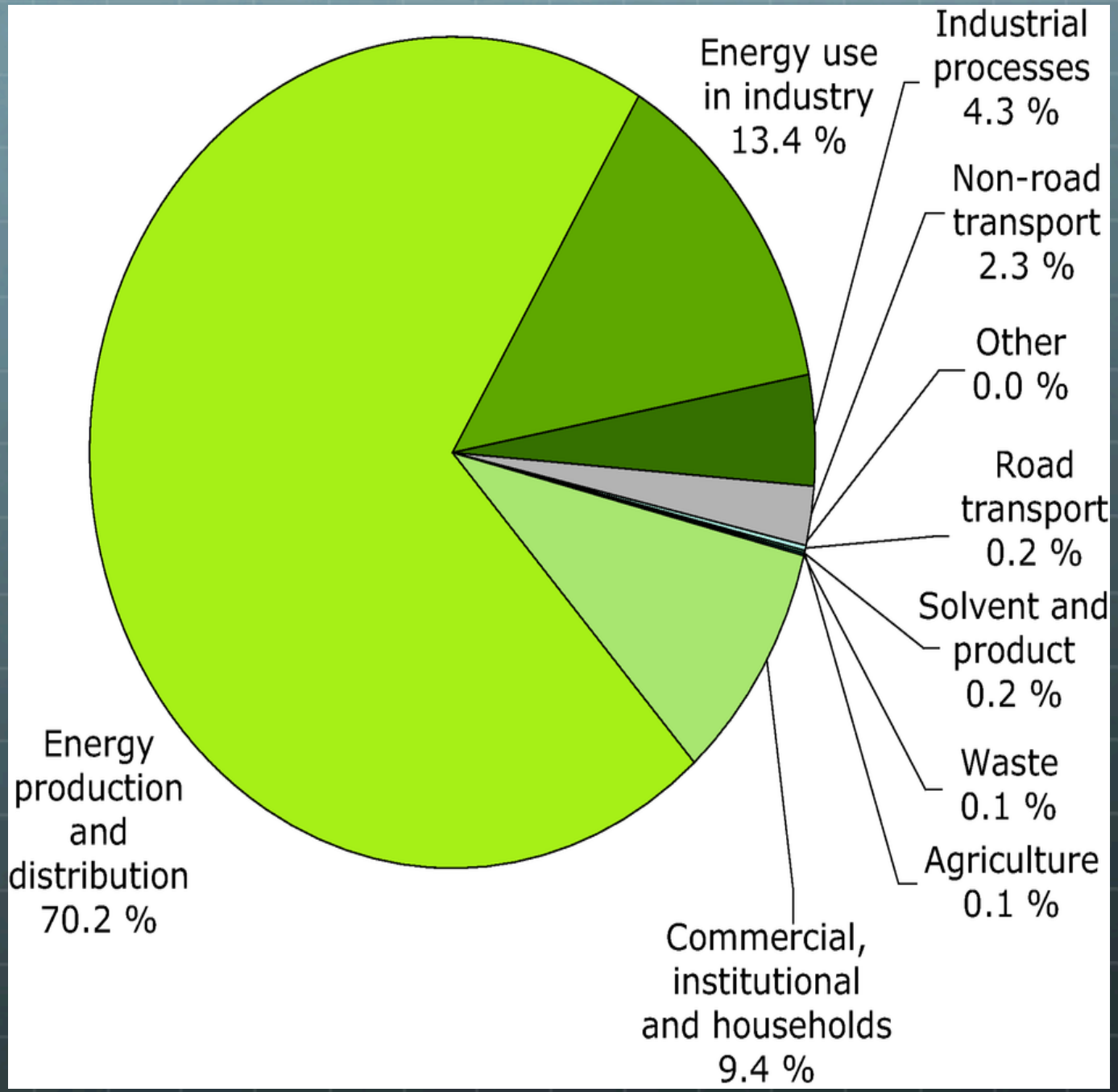
# $SO_2$ Emissions in the US




Where are the $SO_2$ emissions most prominent in U.S.?

In your opinion why is there is a successive projected decrease in $SO_2$ emissions from 2001 – 2020 – 2050?

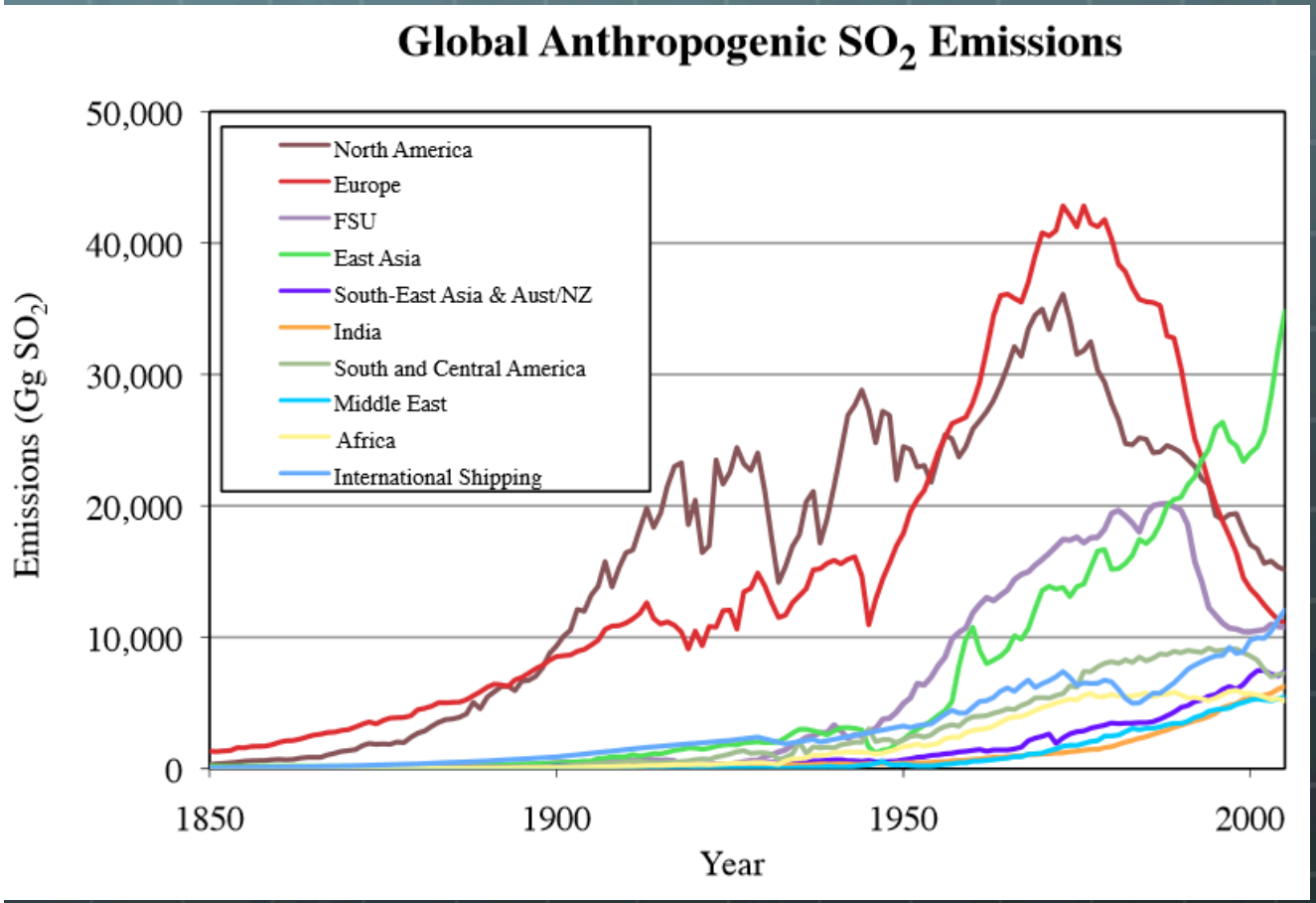





# Sector Share of $SO_2$ Emissions in the European Union in 2009

Which industry is the highest contributor to $SO_2$ emissions?

# 1850 – 2000 SO2 Global Emissions




What countries had the most elevated levels of $SO_2$.?

During what Period?

List the Countries that had the least elevated levels of $SO_2$?

How do you think the $SO_2$ emissions from the polluting countries may affect others?

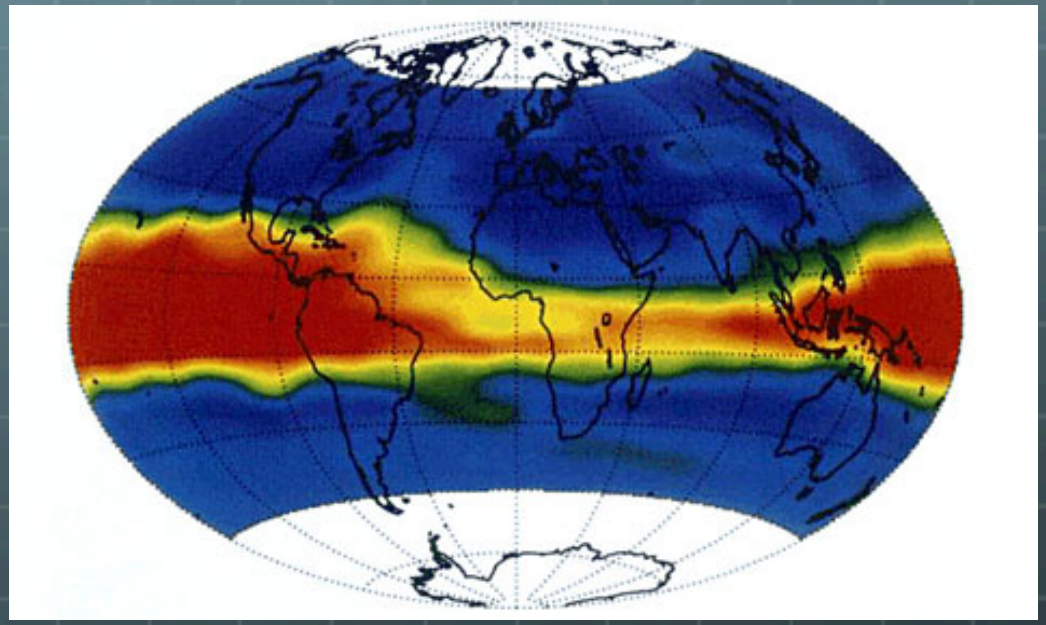
# Aerosol Climate Interference in the Sahel

The effect of Global Dimming caused the North Atlantic Ocean surface temperatures to cool three tenths of a degree Celsius (0.3°C ) below its' historical average. This was due to large quantities of Sulfate Aerosol Emissions in the U.S. and Europe.

The subtle change in temperature set in motion a sequence of climatic events that caused the worst drought of the 20th Century in the Sahel Region of Africa. The Sahel lost 30% of its' annual precipitation which comes form Monsoon weather systems in the summer months of Jul through September. The Sahel depends on these systems to bring the much needed rainfall for its subsistence.

The Sahel is located in a climate transition zone between the dry Sahara Desert and above Central South Africa that enjoys of tropical weather. The geography of the Sahel makes it vulnerable to sudden changes in weather patterns.

# How do We Know $SO_2$ Aerosols Cause Global Dimming and Cooling of Earth Land/Sea Surface Temperatures?

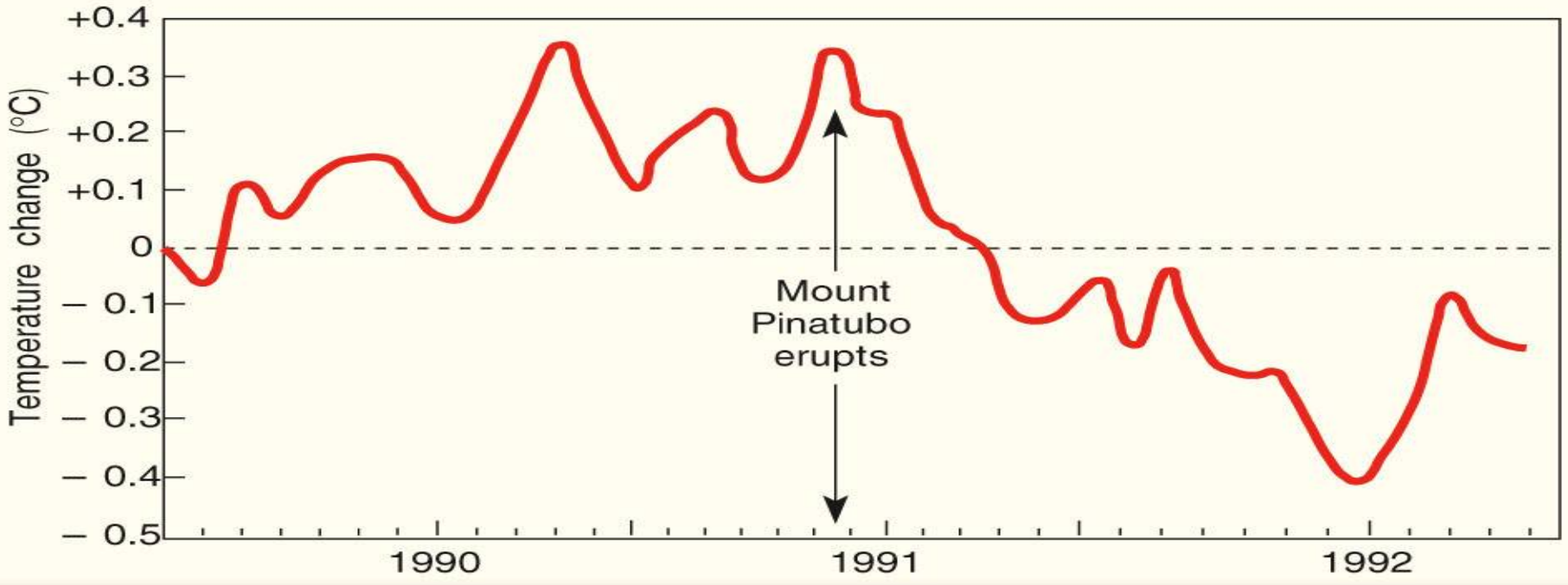


This Satellite Image shows Mt. Pinatubo's $SO_2$ gas and dust aerosol plume (red and yellow) between June 14 and July 26th of 1991. The plume completely circled the Earth circulating and formed a band 20 to 50° wide.

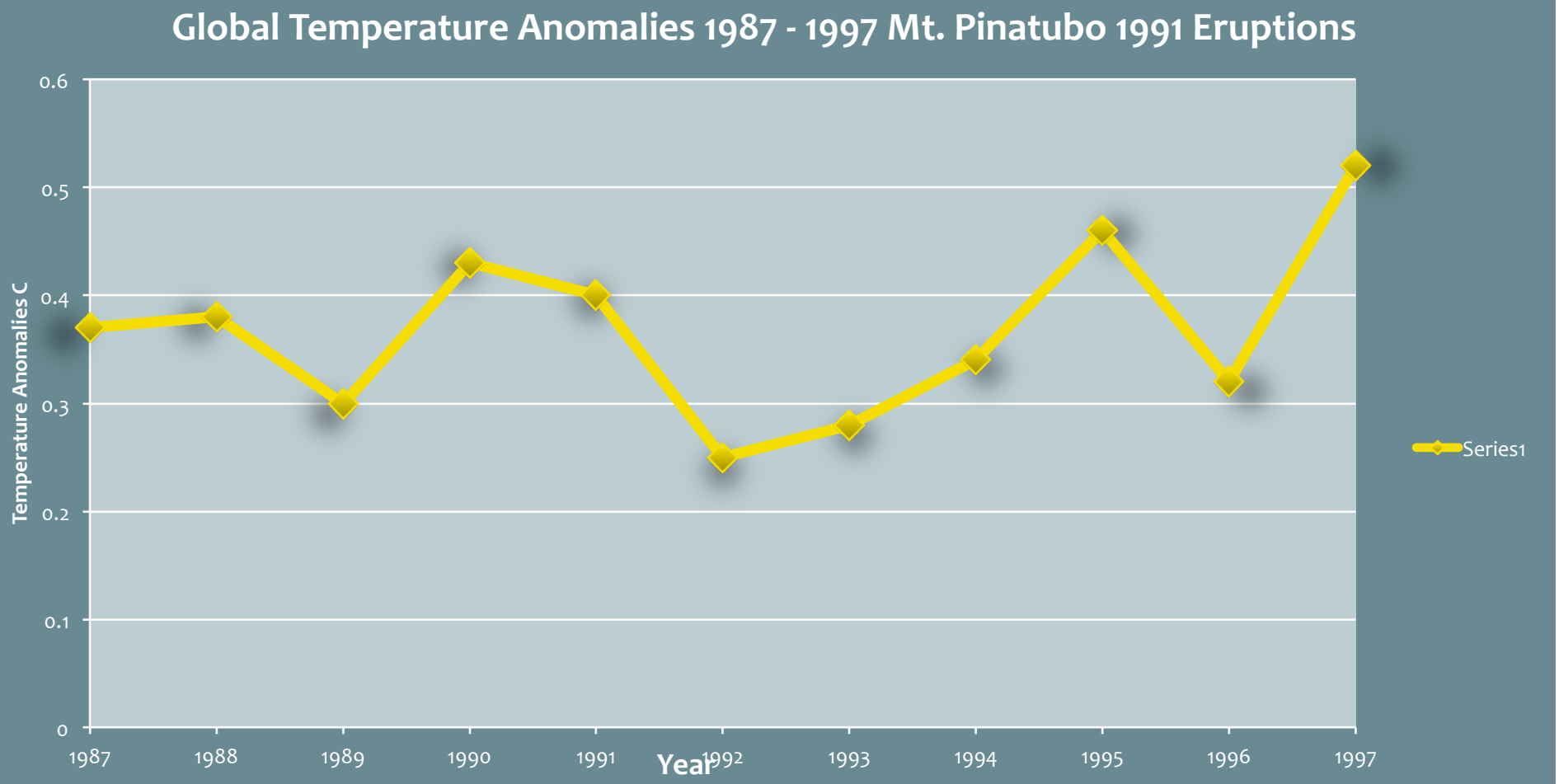
Mt. Pinatubo Eruption ejected 20 million tons of $SO_2$ Gas into the Stratosphere.

# How do We Know Aerosols Cause Global Dimming and Cooling of Earth Land/Sea Surface Temperatures?

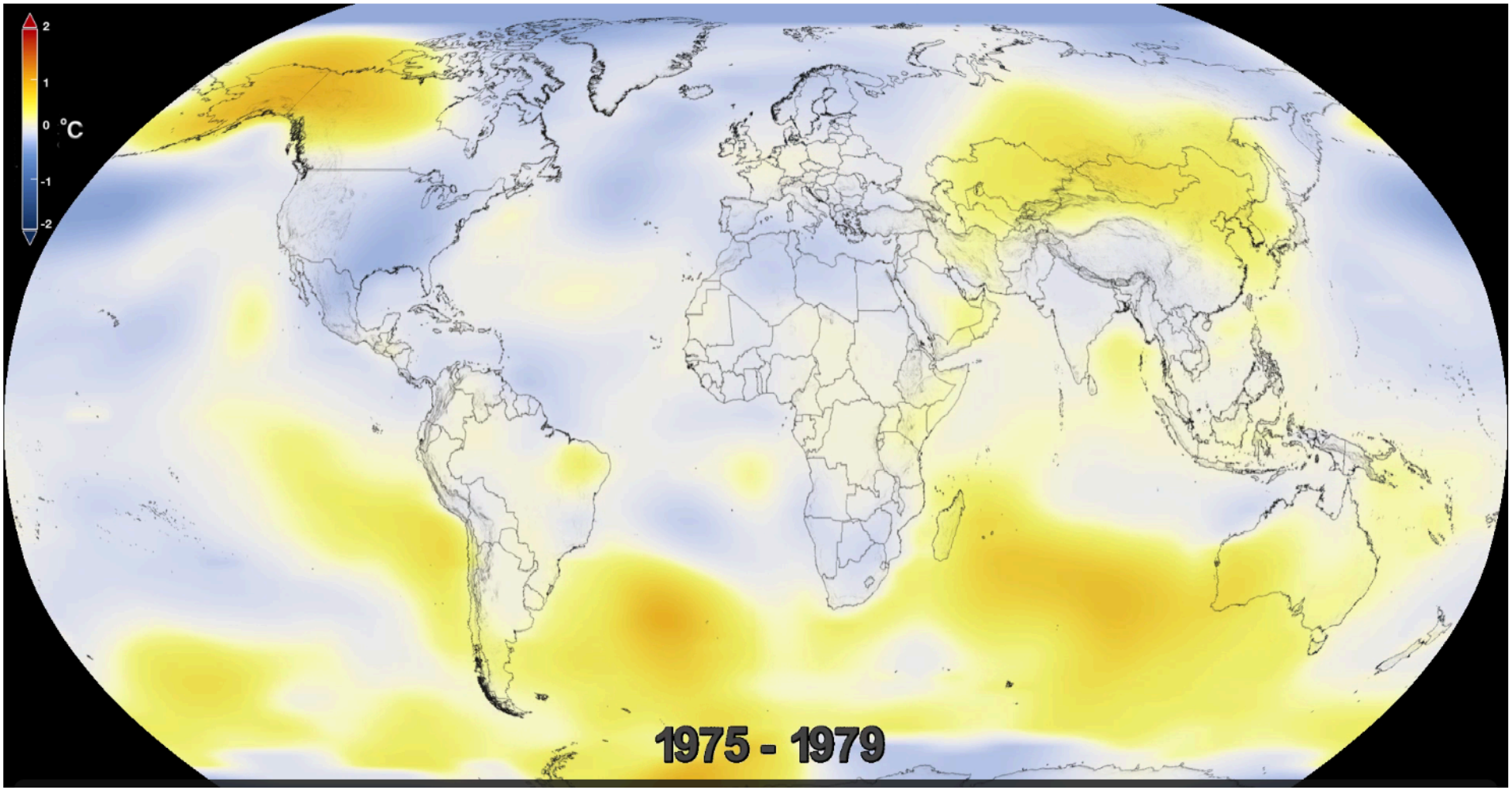
There was a significant drop of the northern hemisphere surface average temperatures of .5 to .6°C (.9 to 1° F). The effect lasted for 1 to 3 years.



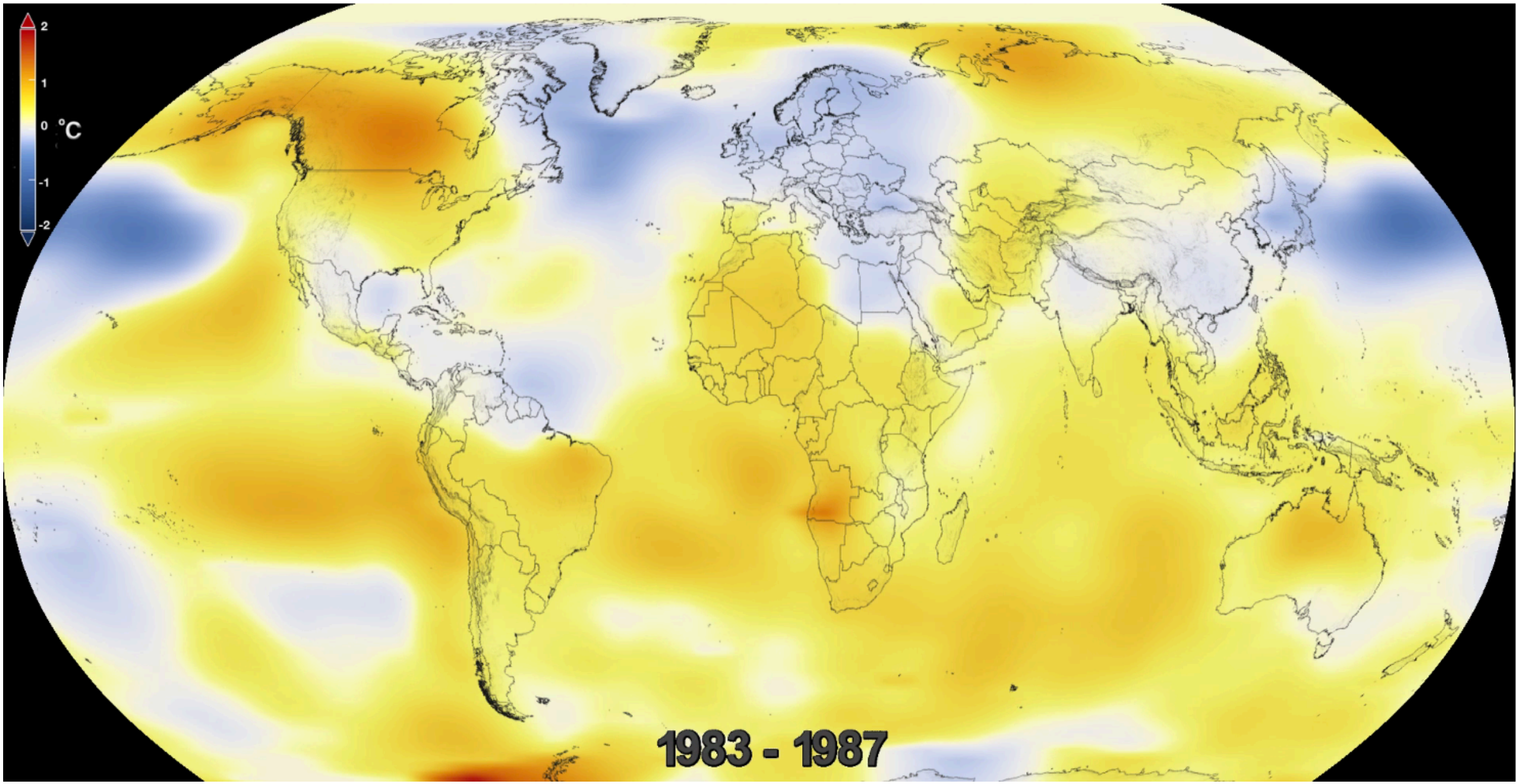
# Global Land and Ocean Temperature Anomalies Student Data Analysis



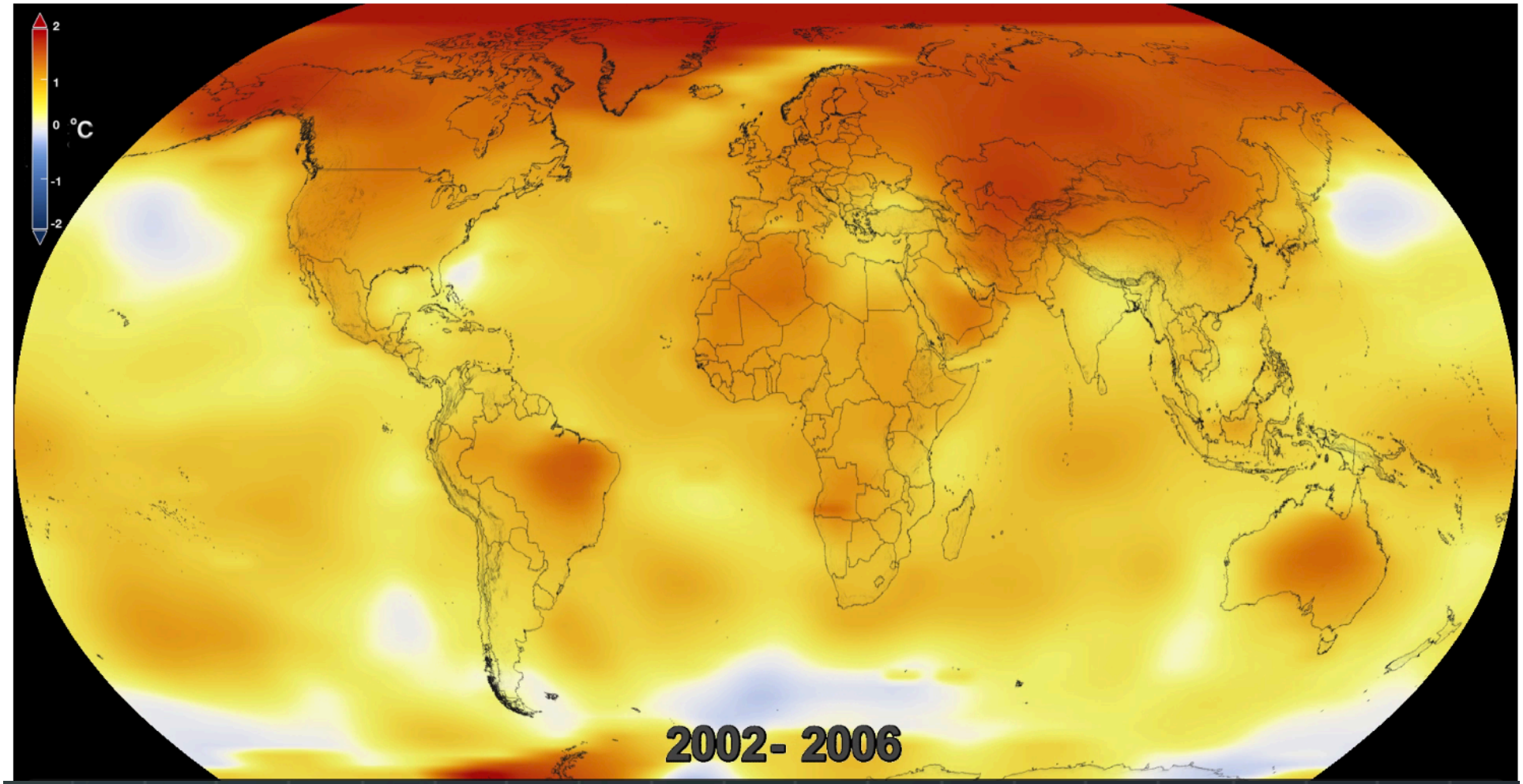
# Five Year Global Temperature Anomalies 1975 - 1979



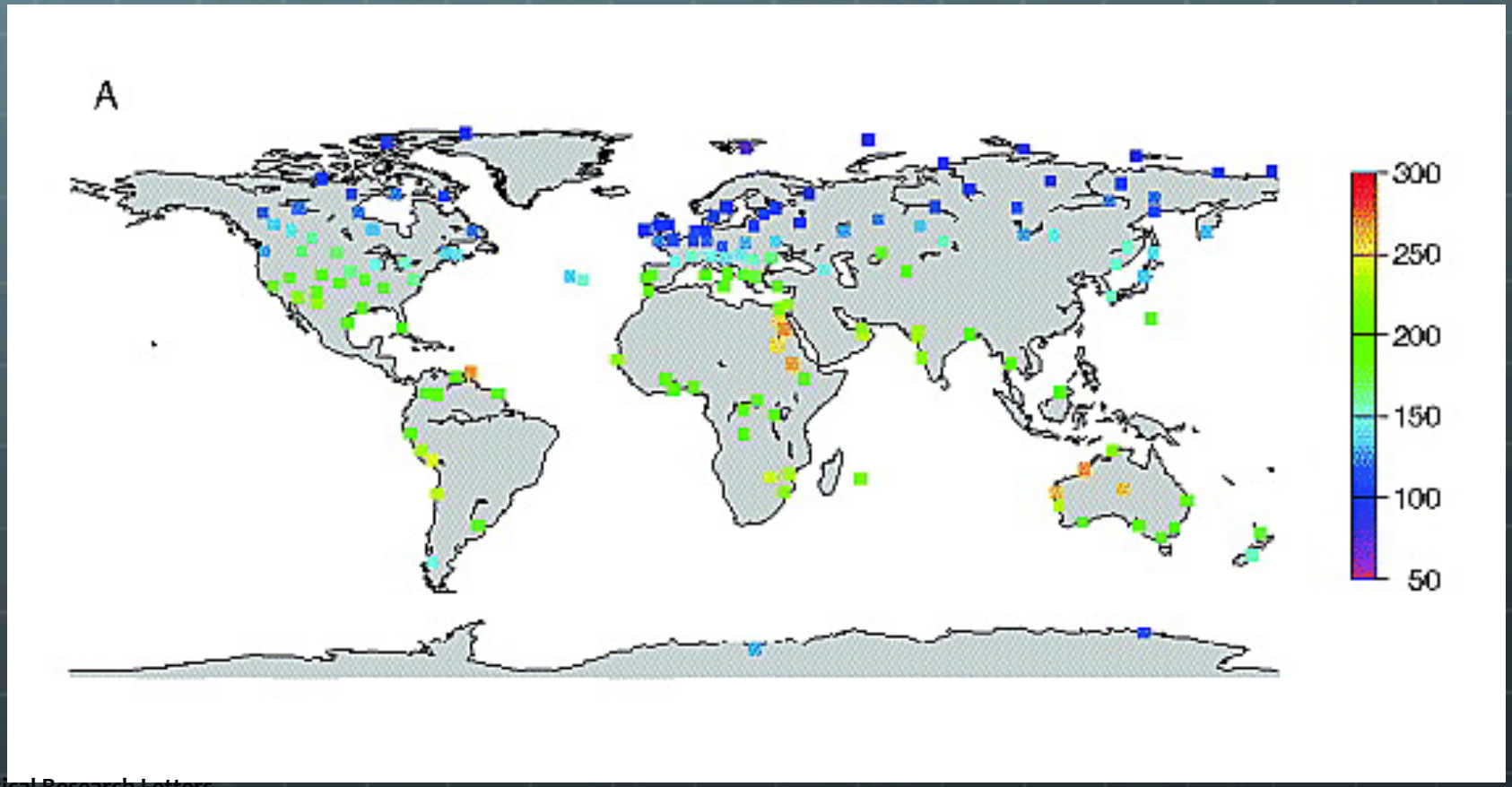
# Five Year Global Temperature Anomalies 1983 - 1987



# Five Year Global Temperature Anomalies 2002 - 2006

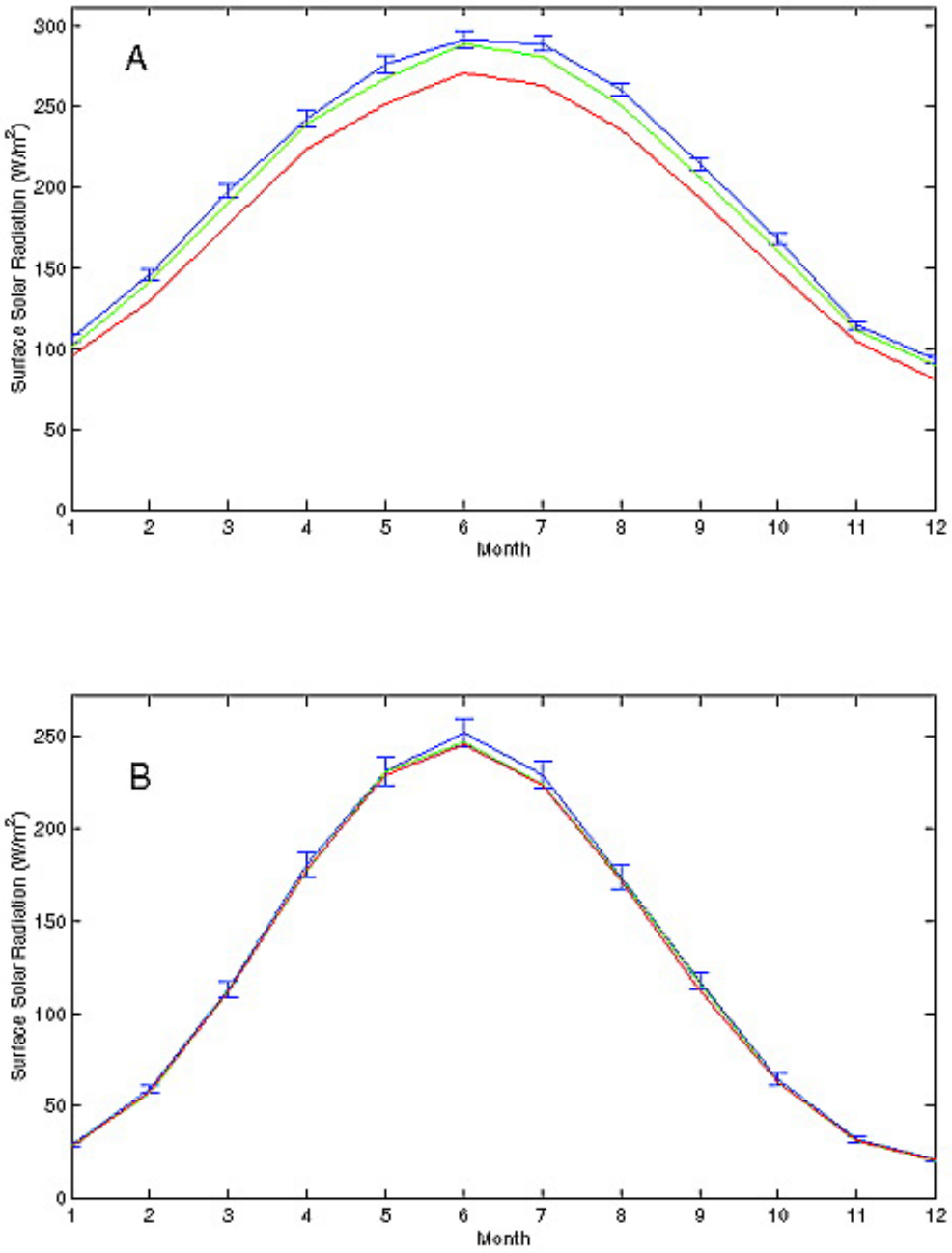


# Observed reductions of surface solar radiation United States and worldwide from 1961 to 1990 due to $SO_2$ Emissions



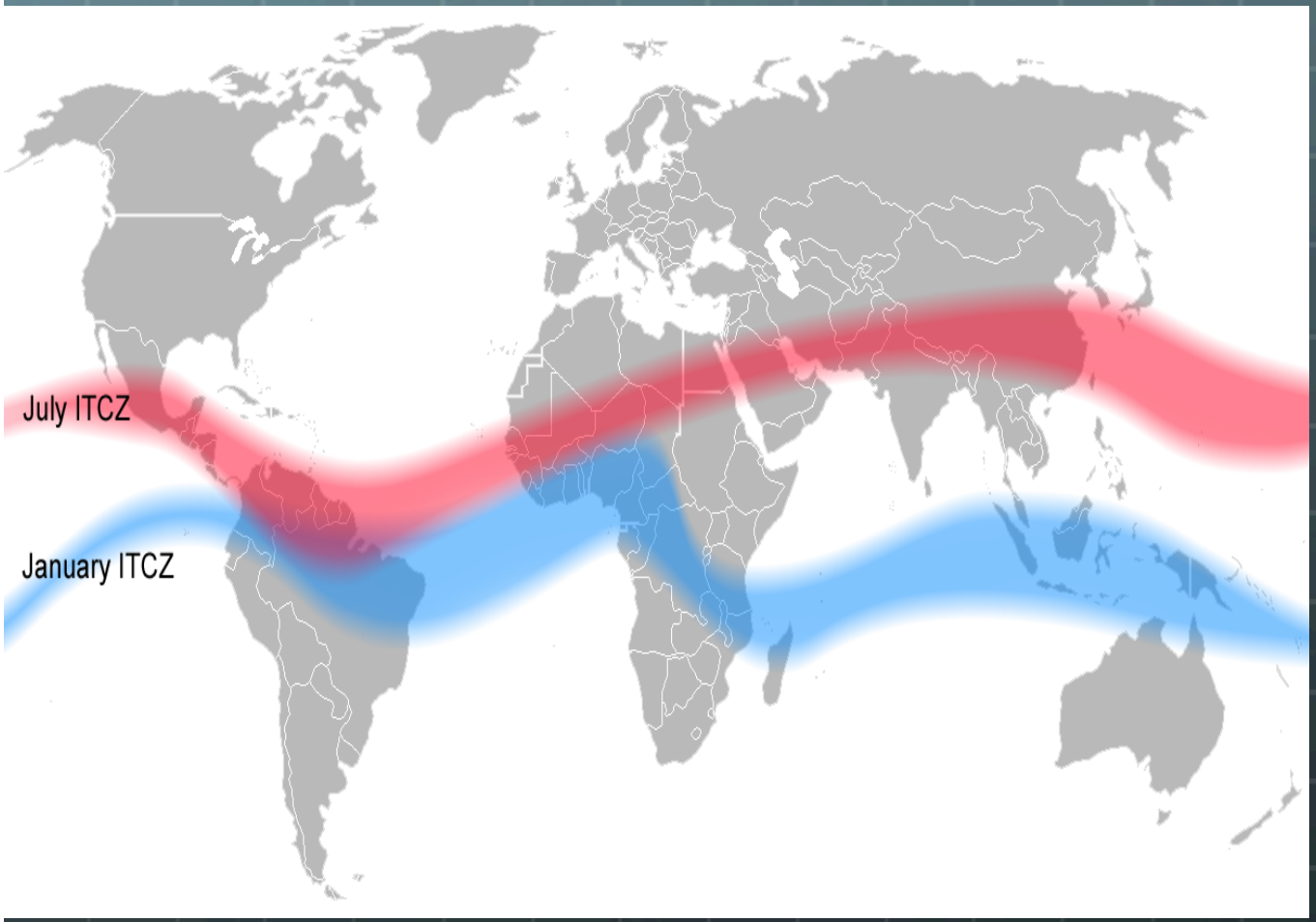

**Geophysical Research Letters**
Volume 29, Issue 10, pages 61-1-61-4, 24 MAY 2002 DOI: 10.1029/2002GL014910
http://onlinelibrary.wiley.com/doi/10.1029/2002GL014910/full#grl15787-fig-0001

# Observed reductions of surface solar radiation at sites in the United States and worldwide from 1961 to 1990




**Geophysical Research Letters**
Volume 29, Issue 10, pages 61-1-61-4, 24 MAY 2002 DOI: 10.1029/2002GL014910
http://onlinelibrary.wiley.com/doi/10.1029/2002GL014910/full#grl15787-fig-0002

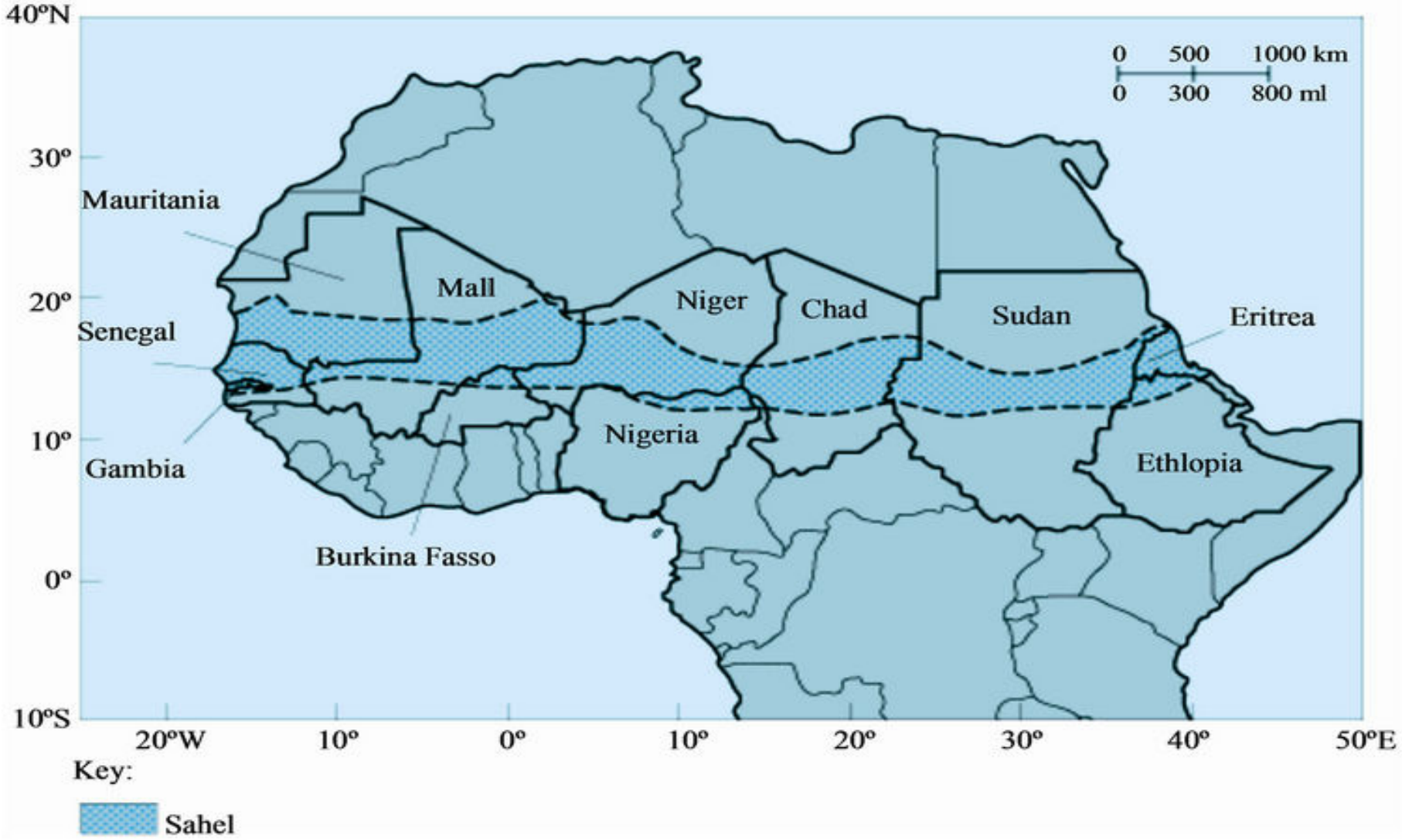
# Intra-Tropical Convergence Zone and Precipitation in the Sahel




ITCZ is an equatorial system powered by convective wind currents of converging northern and southern hemisphere trade winds.

The ITCZ migrates between north of the equator during the northern hemisphere summers and south of the equator during the northern hemisphere winters.

# Where is the Sahel?

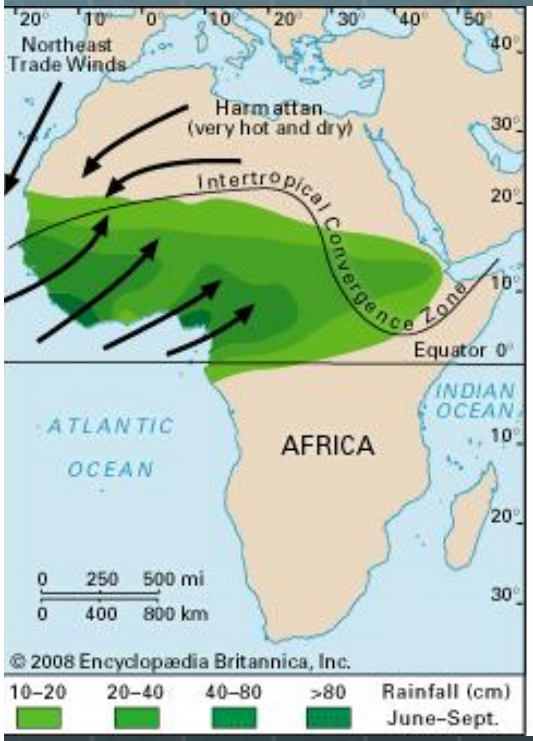


# Oscillation of Water Vapor

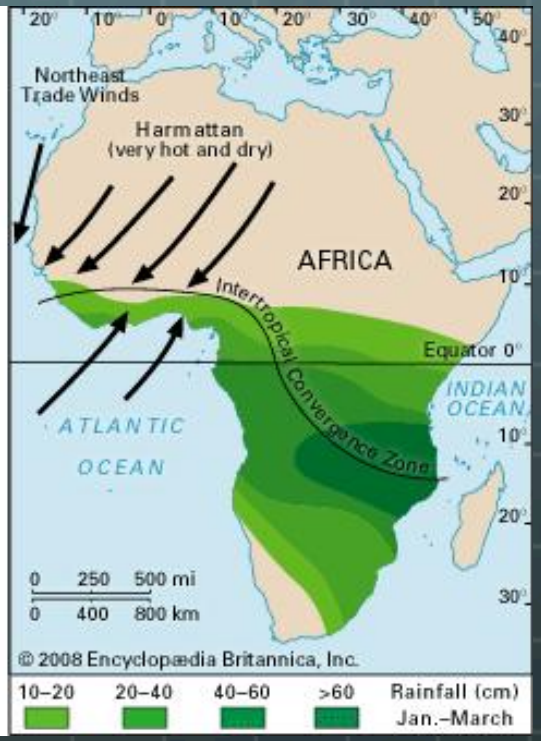
# Water Vapor Relative to Sea Surface Temperature

# The Dimming Effect and Changes in the ITCZ Oscillation

## Summer ITCZ




## Winter ITCZ

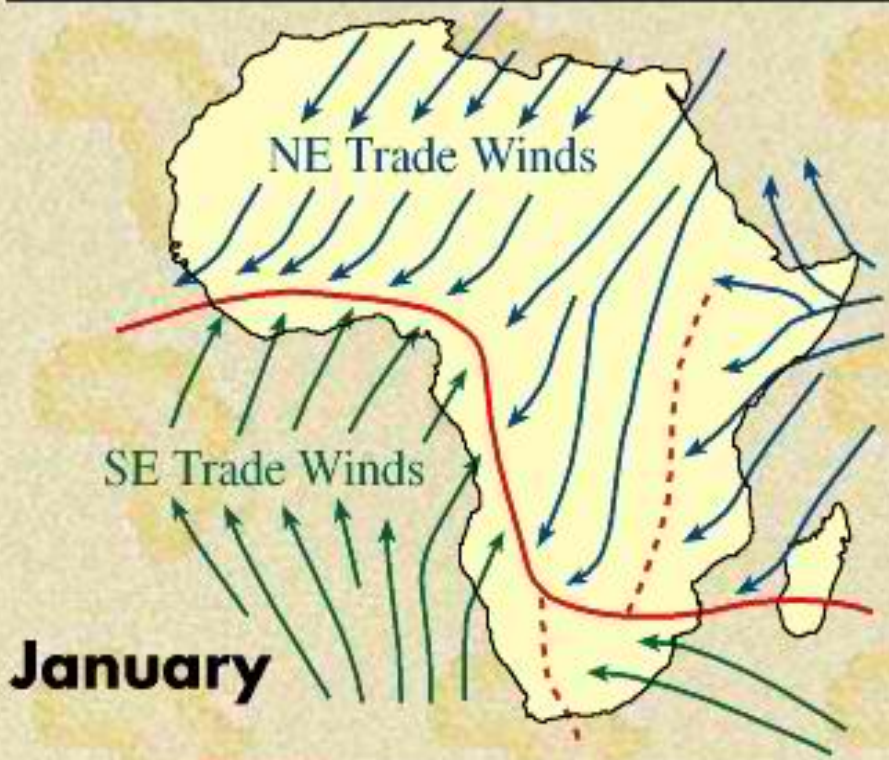


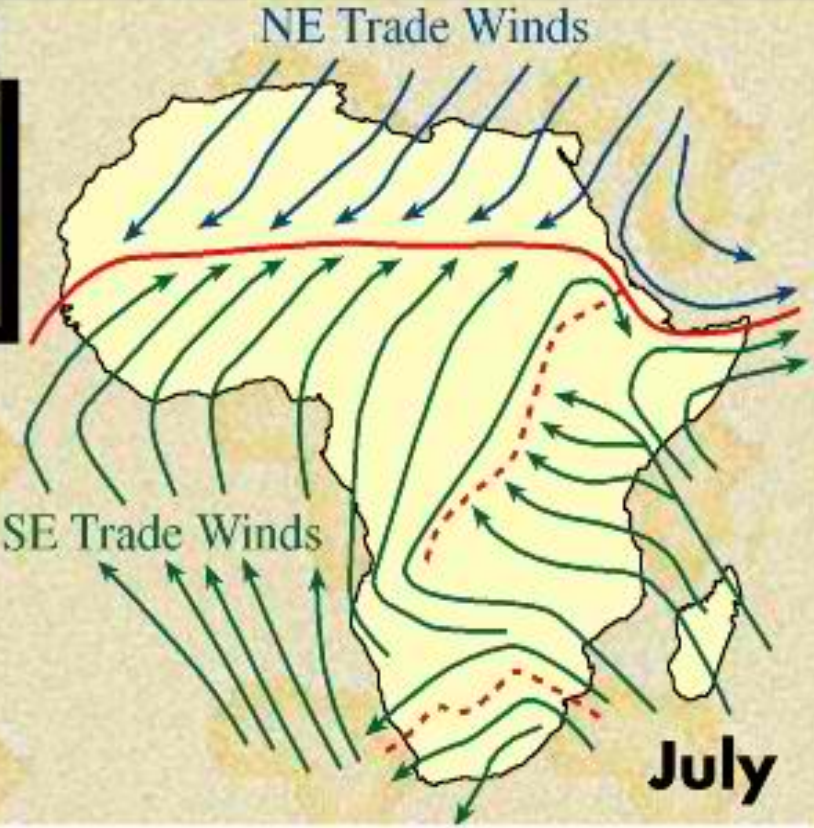

The Sahel Region of Africa depends on the Monsoon type weather for its water. It lies within the Inter Tropical Convergence Zone. The Sahel has suffered a dramatic decrease in rainfall since the late 1960's until today.

# Intertropical Convergence Zone

## Definition

The Intertropical Convergence Zone (ITCZ) is an area of low pressure where the trade winds converge. Changes in air pressure over land cause a seasonal shift in the location of the ITCZ. Occasionally, the ITCZ stagnates over the ocean near the Equator. When this occurs, some refer to the lack of movement in the air mass as "The Doldrums."

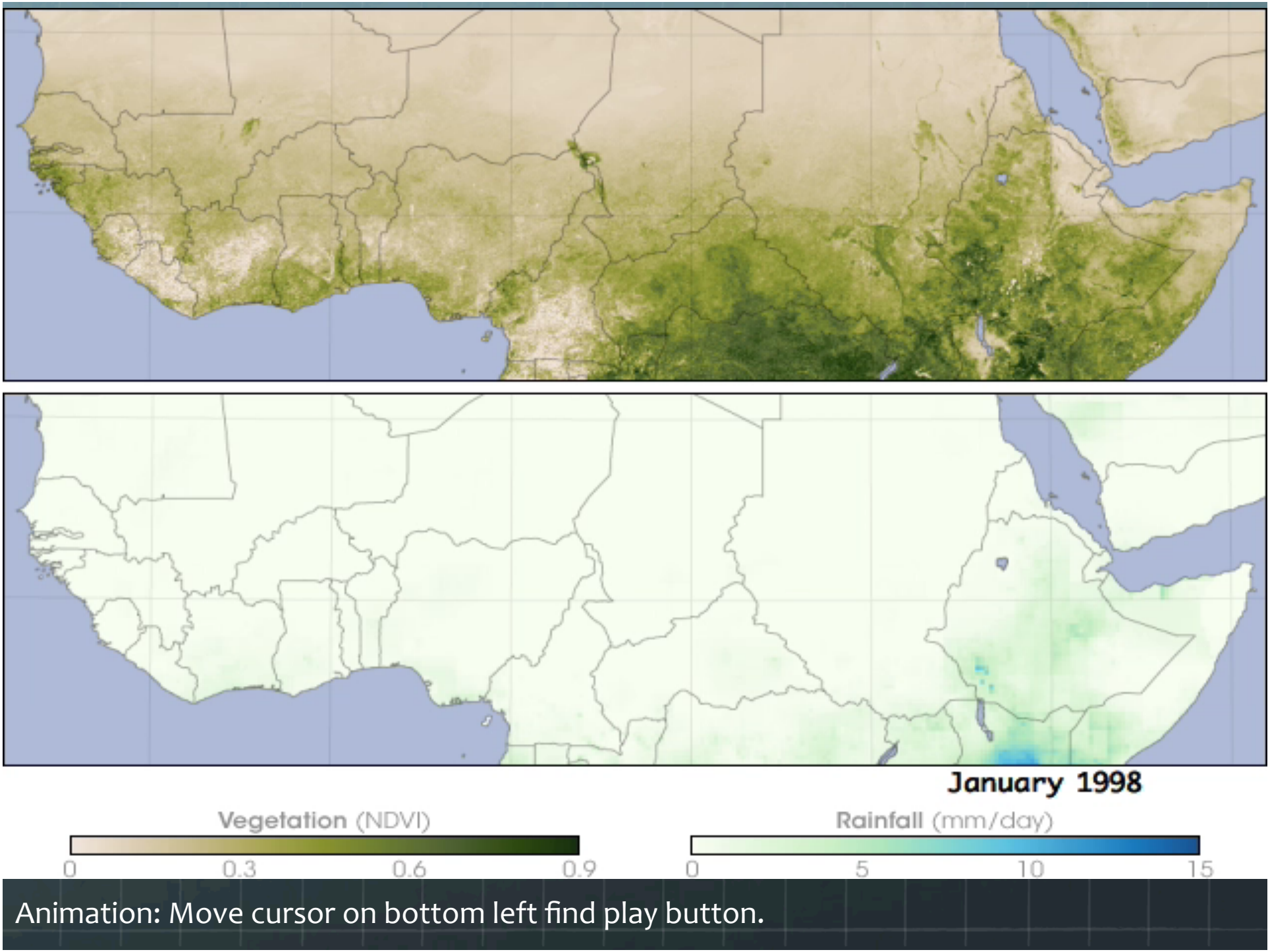


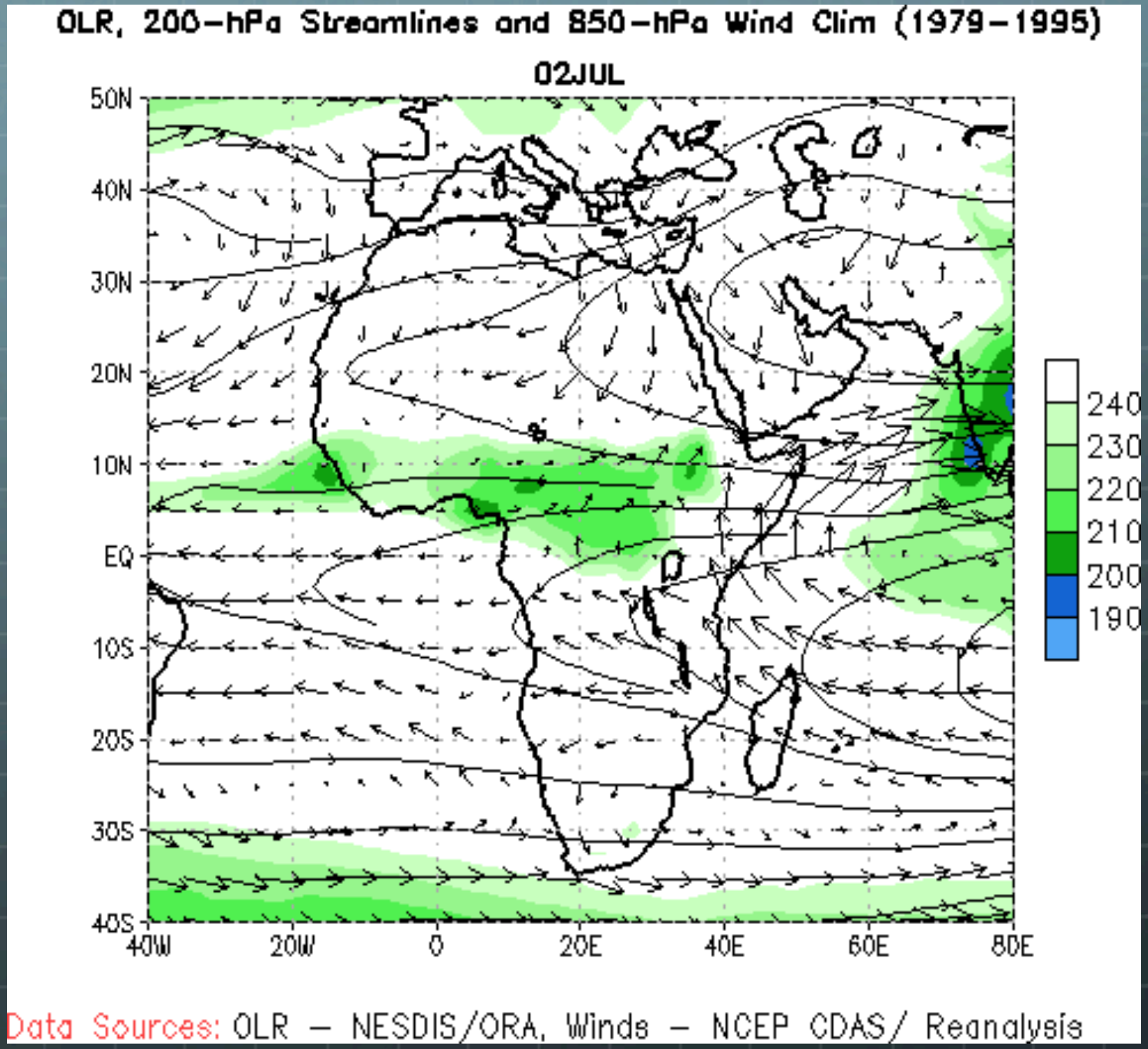

Intertropical Convergence Zone
Other Zones of Convergence
Wind Currents

## Points of Interest

- The ITCZ shifts significantly from January to July.
- The ITCZ is one of Africa's principal rainmaking mechanisms.
- The movement of the ITCZ causes wet and dry seasons across Africa.
- Farmers plan their planting and harvesting according to the rain from the ITCZ.
- When the ITCZ does not follow its normal schedule, it affects the farming and pastoral life, causing both droughts and floods.



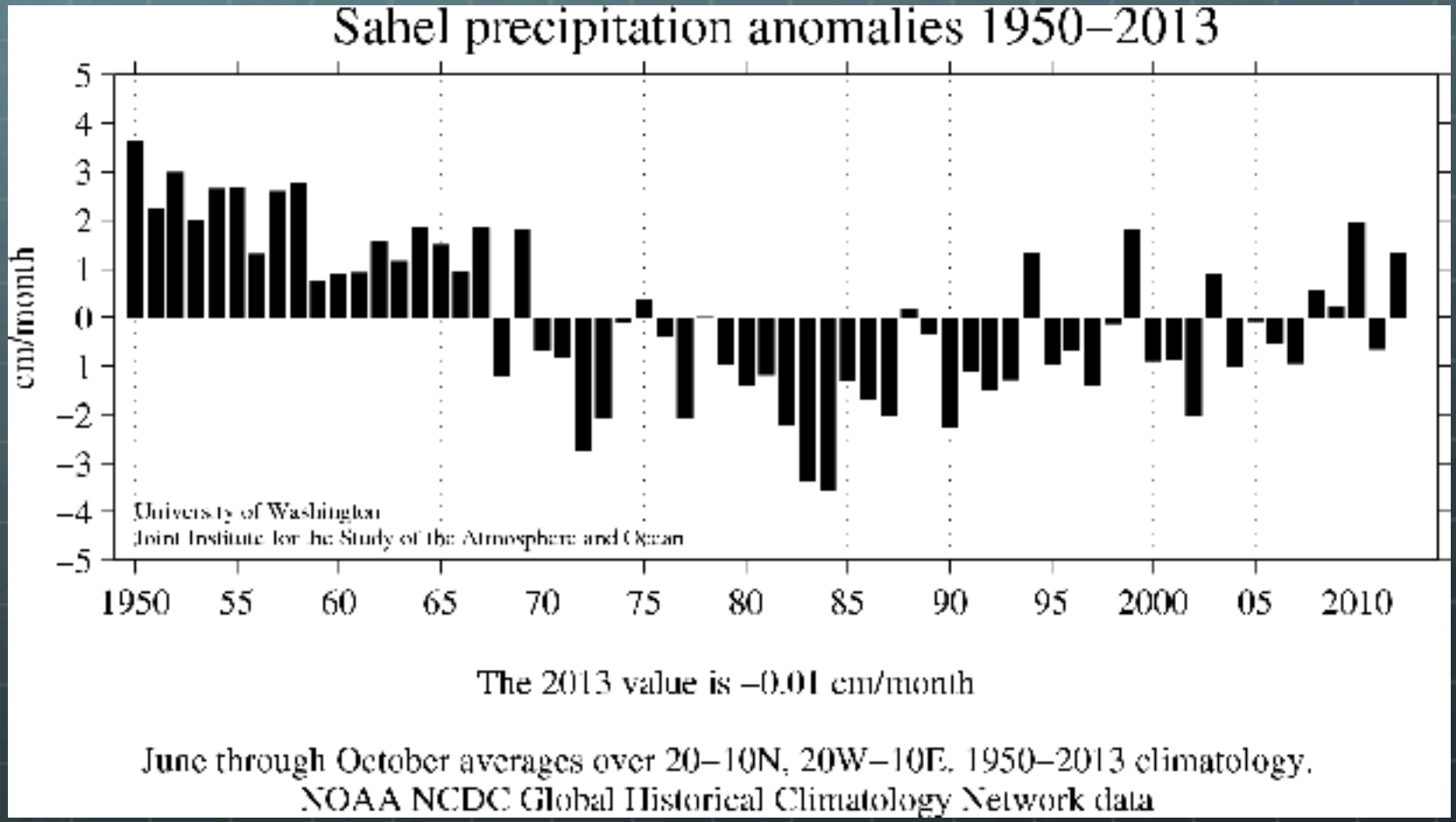

Animation: Move cursor on bottom left find play button.



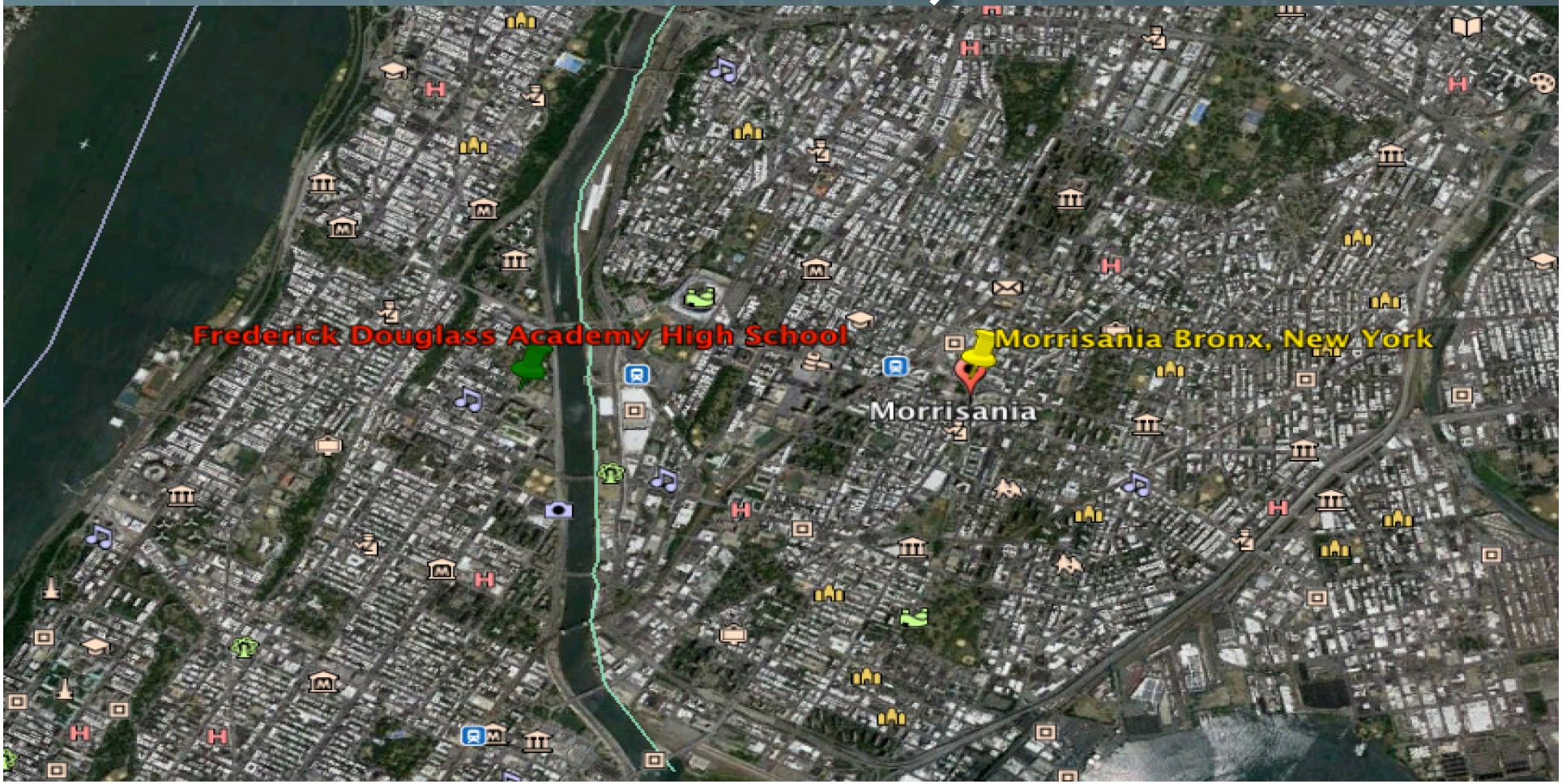

Wind Patterns and the ITCZ (Inter Tropical Convergent Zone) Summer Oscillation during the Multi-decadal Drought of the Sahel.

The Animation shows the ITCZ further south than it would normally be for the summer season. This shift limited the amount of rain reaching the thirsty Sahel.

# Sahel Precipitation Anomalies Graph 1950 - 2013



# Analysis of $SO_2$ Emissions from M monitoring Site in Morrisania Bronx, New York



# $SO_2$ Data Analysis

- To access the $SO_2$ data open the excel file: $SO_2$_DATA_Aerosols_BRONX.xlsx
- There are several sheets in the data file. The fist spreadsheet shows the daily average values of $SO_2$ by month and year.
- Open the second sheet it has the total $SO_2$ readings per month.
- The data was obtained for the Bronx air quality monitoring station.

# $SO_2$ Data Analysis

| A | B | C |
|---|---|---|
| Date | Site ID | Sulfur Dioxide AQI Daily Value |
| 1/1/80 | 36-005-0003 | 109 |
| 1/2/80 | 36-005-0003 | 103 |
| 1/3/80 | 36-005-0003 | 92 |
| 1/4/80 | 36-005-0003 | 106 |
| 1/5/80 | 36-005-0003 | 69 |
| 1/6/80 | 36-005-0003 | 117 |
| 1/7/80 | 36-005-0003 | 107 |
| 1/8/80 | 36-005-0003 | 84 |
| 1/9/80 | 36-005-0003 | 84 |
| 1/10/80 | 36-005-0003 | 96 |
| 1/11/80 | 36-005-0003 | 127 |
| 1/12/80 | 36-005-0003 | 39 |
| 1/13/80 | 36-005-0003 | 99 |
| 1/14/80 | 36-005-0003 | 54 |
| 1/15/80 | 36-005-0003 | 69 |
| 1/16/80 | 36-005-0003 | 100 |
| 1/17/80 | 36-005-0003 | 103 |
| 1/18/80 | 36-005-0003 | 123 |

Daily Average Readings of Sulfur Dioxide in the Bronx, NY

# Calculate the SO2 Monthly Average

$SO_2$ Monthly Values = SUM of Daily Readings of $SO_2$ from Column F

January 1980 =SUM(F2:F32)

| B | C | D | E | F |
|---|---|---|---|---|
| SO2/Monthly Values | | Months | Readings/Month | Monthly Average |
| 2593 | | Jan-80 | 31 | |
| 2087 | | Feb-80 | 24 | |
| 1853 | | Mar-80 | 27 | |
| 1440 | | Apr-80 | 30 | |
| 1223 | | May-80 | 31 | |
| 1237 | | Jun-80 | 30 | |
| 1283 | | Jul-80 | 29 | |
| 1341 | | Aug-80 | 31 | |
| 960 | | Sep-80 | 30 | |
| 1087 | | Oct-80 | 26 | |
| 1890 | | Nov-80 | 28 | |
| 2579 | | Dec-80 | 31 | |
| 2704 | | Jan-81 | 31 | |
| 1799 | | Feb-81 | 22 | |
| 2177 | | Mar-81 | 31 | |
| 0 | | Apr-81 | 0 | |
| 404 | | May-81 | 18 | |
| 722 | | Jun-81 | 28 | |
| 1283 | | Jul-81 | 2 | |
| 873 | | Aug-81 | 30 | |
| 834 | | Sep-81 | 29 | |
| 1792 | | Oct-81 | 31 | |
| 1890 | | Nov-81 | 27 | |
| 2579 | | Dec-81 | 25 | |
| 2427 | | Jan-82 | 30 | |
| 2262 | | Feb-82 | 27 | |
| 2063 | | Mar-82 | 27 | |
| 1622 | | Apr-82 | 28 | |
| 1064 | | May-82 | 27 | |
| 1091 | | Jun-82 | 29 | |
| 1651 | | Jul-82 | 31 | |
| 1169 | | Aug-82 | 26 | |
| 952 | | Sep-82 | 26 | |
| 1979 | | Oct-82 | 31 | |

Calculate the Monthly Average

$SO_2$ Monthly Total/ Reading/Month = Monthly Average

=SUM(B2/E2)

The Readings/Month
The total readings of $SO_2$ per month.
The total of readings does not necessarily match the total of days months. A (0) value means no readings.

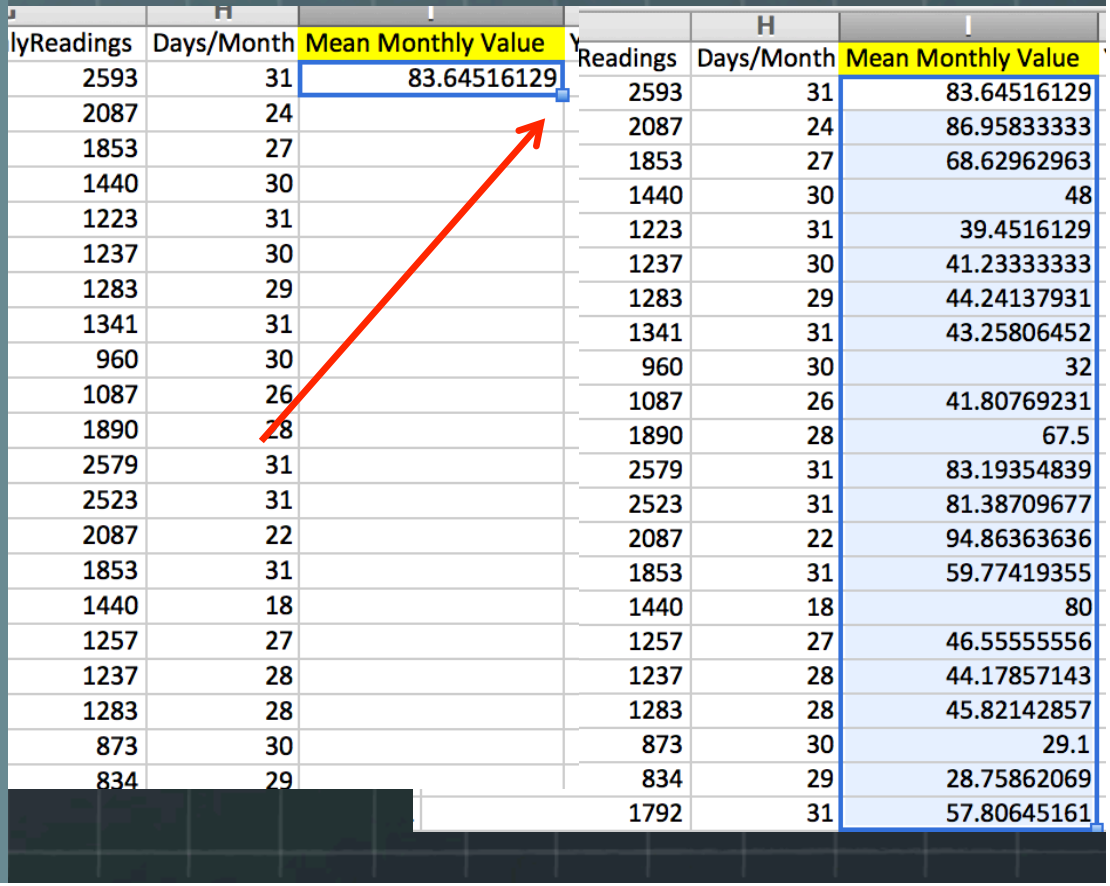
# Find Mean of Monthly Values

To find the mean of the monthly values enter the formula =SUM(G2/H2) in cell I2.

There is a short cut in Excel so that the formula doesn't have to be entered one cell at a time.

Place the cursor on the blue box, it will turn into a cross, click on it and drag it down.

The mean monthly values will appear on the column. You can check the formulas by clicking on a cell to verify it's dividing Column G by Column H.



| lyReadings | Days/Month | Mean Monthly Value |
|---|---|---|
| 2593 | 31 | 83.64516129 |
| 2087 | 24 | |
| 1853 | 27 | |
| 1440 | 30 | |
| 1223 | 31 | |
| 1237 | 30 | |
| 1283 | 29 | |
| 1341 | 31 | |
| 960 | 30 | |
| 1087 | 26 | |
| 1890 | 28 | |
| 2579 | 31 | |
| 2523 | 31 | |
| 2087 | 22 | |
| 1853 | 31 | |
| 1440 | 18 | |
| 1257 | 27 | |
| 1237 | 28 | |
| 1283 | 28 | |
| 873 | 30 | |
| 834 | 29 | |

| Readings | Days/Month | Mean Monthly Value |
|---|---|---|
| 2593 | 31 | 83.64516129 |
| 2087 | 24 | 86.95833333 |
| 1853 | 27 | 68.62962963 |
| 1440 | 30 | 48 |
| 1223 | 31 | 39.4516129 |
| 1237 | 30 | 41.23333333 |
| 1283 | 29 | 44.24137931 |
| 1341 | 31 | 43.25806452 |
| 960 | 30 | 32 |
| 1087 | 26 | 41.80769231 |
| 1890 | 28 | 67.5 |
| 2579 | 31 | 83.19354839 |
| 2523 | 31 | 81.38709677 |
| 2087 | 22 | 94.86363636 |
| 1853 | 31 | 59.77419355 |
| 1440 | 18 | 80 |
| 1257 | 27 | 46.55555556 |
| 1237 | 28 | 44.17857143 |
| 1283 | 28 | 45.82142857 |
| 873 | 30 | 29.1 |
| 834 | 29 | 28.75862069 |
| 1792 | 31 | 57.80645161 |

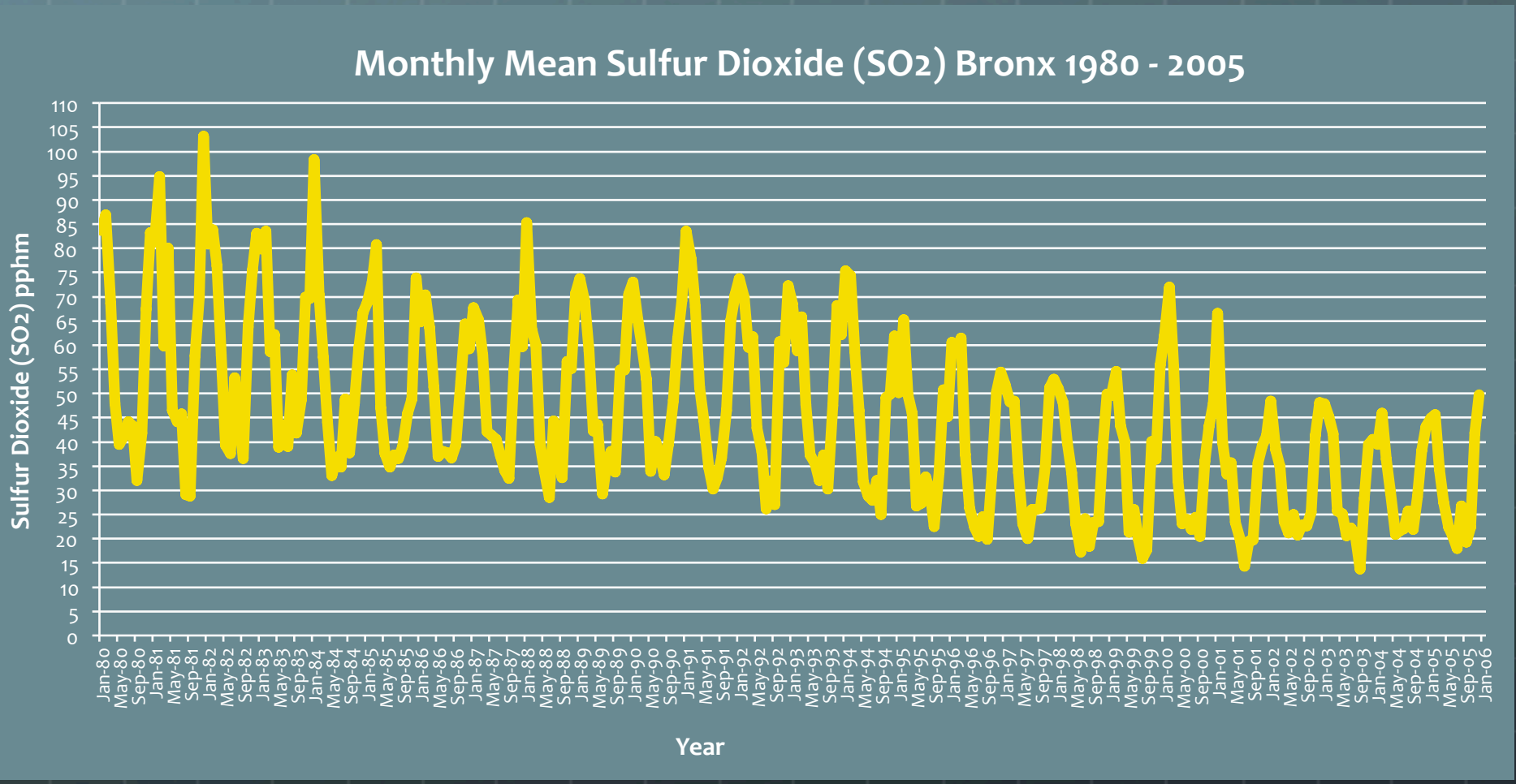
# Graphing $SO_2$ Mean Monthly Value

- Highlight all values in Column F Month/Year list beginning with cell 2 to the end of the of the list.
- With the command button pressed down (for Mac or Ctrl. for PC) highlight the Column I (Mean Monthly Value) beginning with cell 2 to the end of the list.
- Go to Insert or the Charts Bar on the Bar Menu and select Line, on the line Menu select Marked Line.
- A time series graph will appear. The x axis should have the months and the y axis the $SO_2$ monthly average.

# Labeling Graph and Changing X-Y Axis Values

- X-Axis: Select Chart Layout and click on X-Axis. On the Chart a Text Box will appear write in Year. On a PC go to Layout and you will see the label icon for the task.
- X-Axis: Change the angle of the year labels in the X-Axis in order to read them better. Click twice on the X-Axis, in the pop up format box go to Text Box and change the text direction to 90° counter clockwise
- Y-Axis: Make sure the Y-axis is properly labeled with the type of Data and Units: Sulfur Dioxide ($SO_2$) pphm. PPHM means parts per hundred million, this is the units used to measure $SO_2$ in the AQI (Air Quality Index). Select Chart Layout and click on Y-Axis.
- Label your Graph with an appropriate title as well. Click on Chart Format and click on Chart Title.
- What title do you think is appropriate for the Graph? The Title needs to take into consideration type of data, values used, location and dates.

# $SO_2$ Monthly Average Graph



# Graph Annual Mean SO2

Calculate the annual means for $SO_2$. In column K enter the formula =SUM(I2:/I13)/12 – this will add all the monthly means for the year 1980.

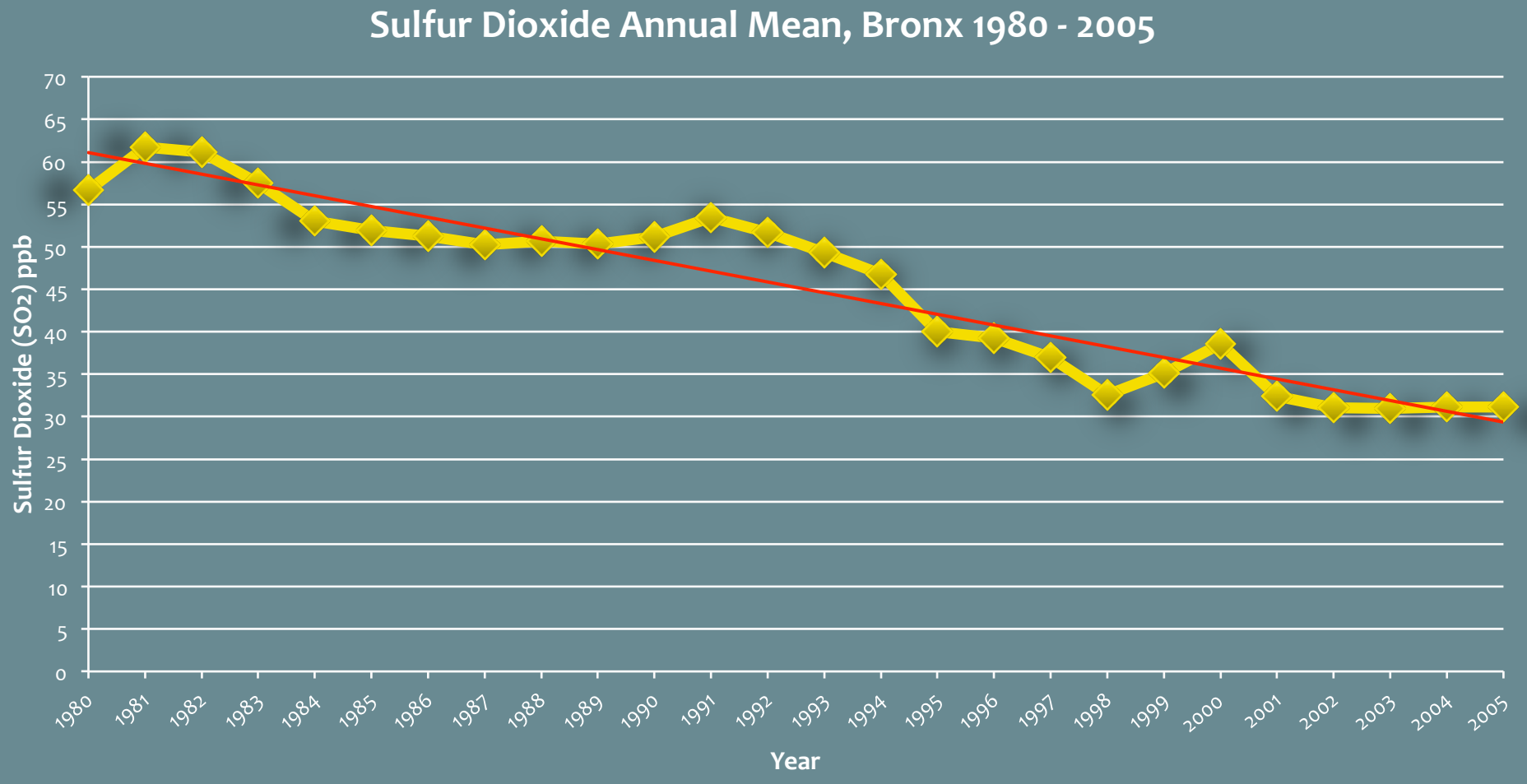
There is no easy short cut for the calculation of the other years. To add annual values enter the formula and place the cursor in between the two parenthesis and go to Column I and highlight it by clicking on Jan – 81 and hold down cursor to Dec – 81 and press enter.

If this is to hard, write down the beginning cell number for January (for each year) and the cell number for December for each year. Enter these values in between the parenthesis in each formula between. Do the same for each year.

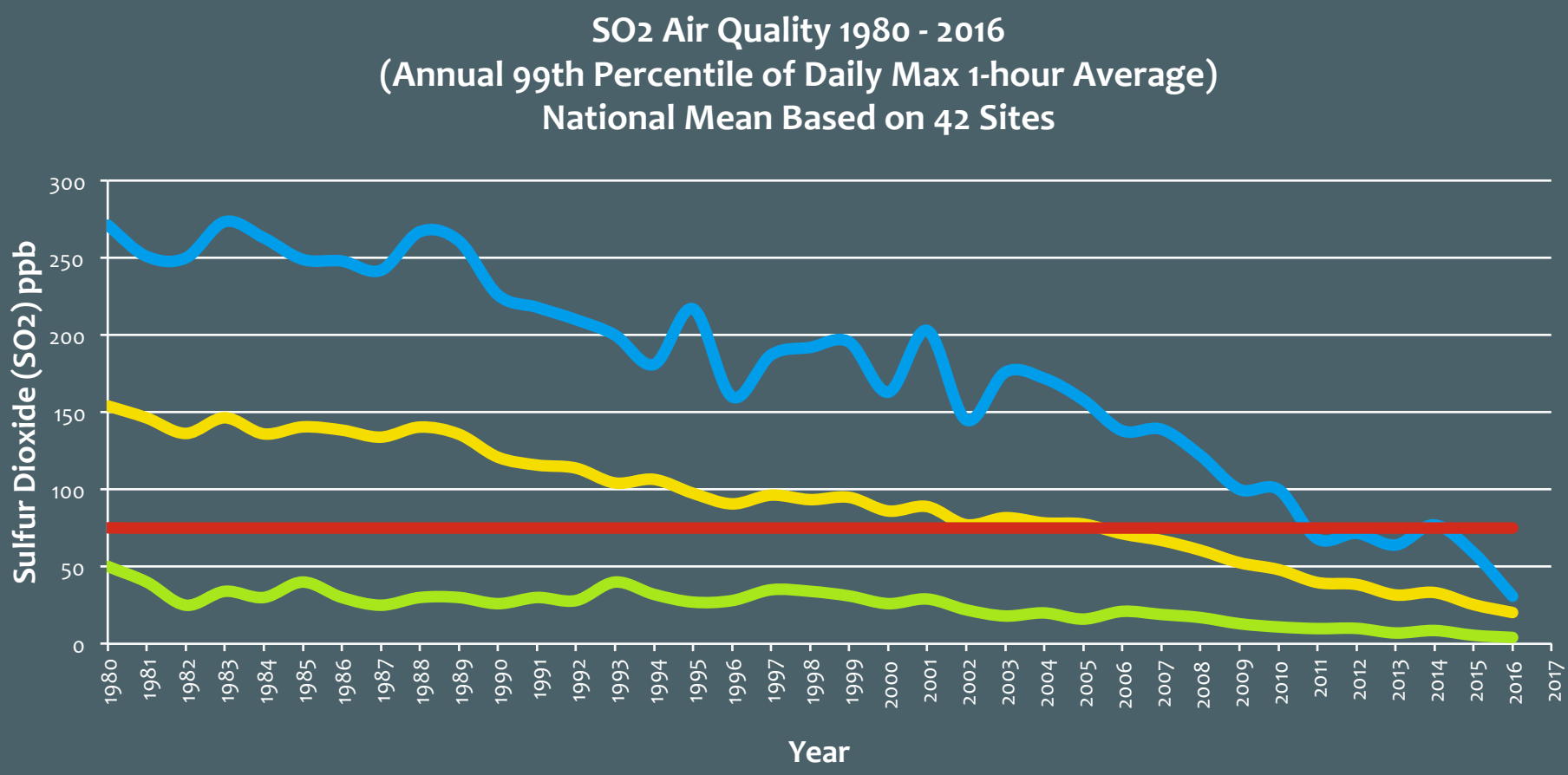
# Graph Annual Mean for SO2

- Highlight Columns K and J simultaneously.
- To create the graph, go to Insert or Chart and select Scatter, under Scatter select Straight Market Scatter. The chart will appear. Notice that X-Axis scale will have to be changed.
- Change X-Axis so that it begins on the year 1980 instead of 1979. To do so click twice on the X-Axis on the graph. A Format Axis Box will open, if not go to Format and select Axis.
- Once the Axis Box opens select Scale. Change the Minimum value to 1980 and the Maximum Value to 2005. Change Major Unit to 3 this will change the axis intervals to every 4 months. It can be change to every month, 2 months, 4 months.
- Label the graph and the axis using the same commands as in the previous graph.
- Insert a trendline: Go to Chart Layout select Trendline and in the menu select Linear Trendline.

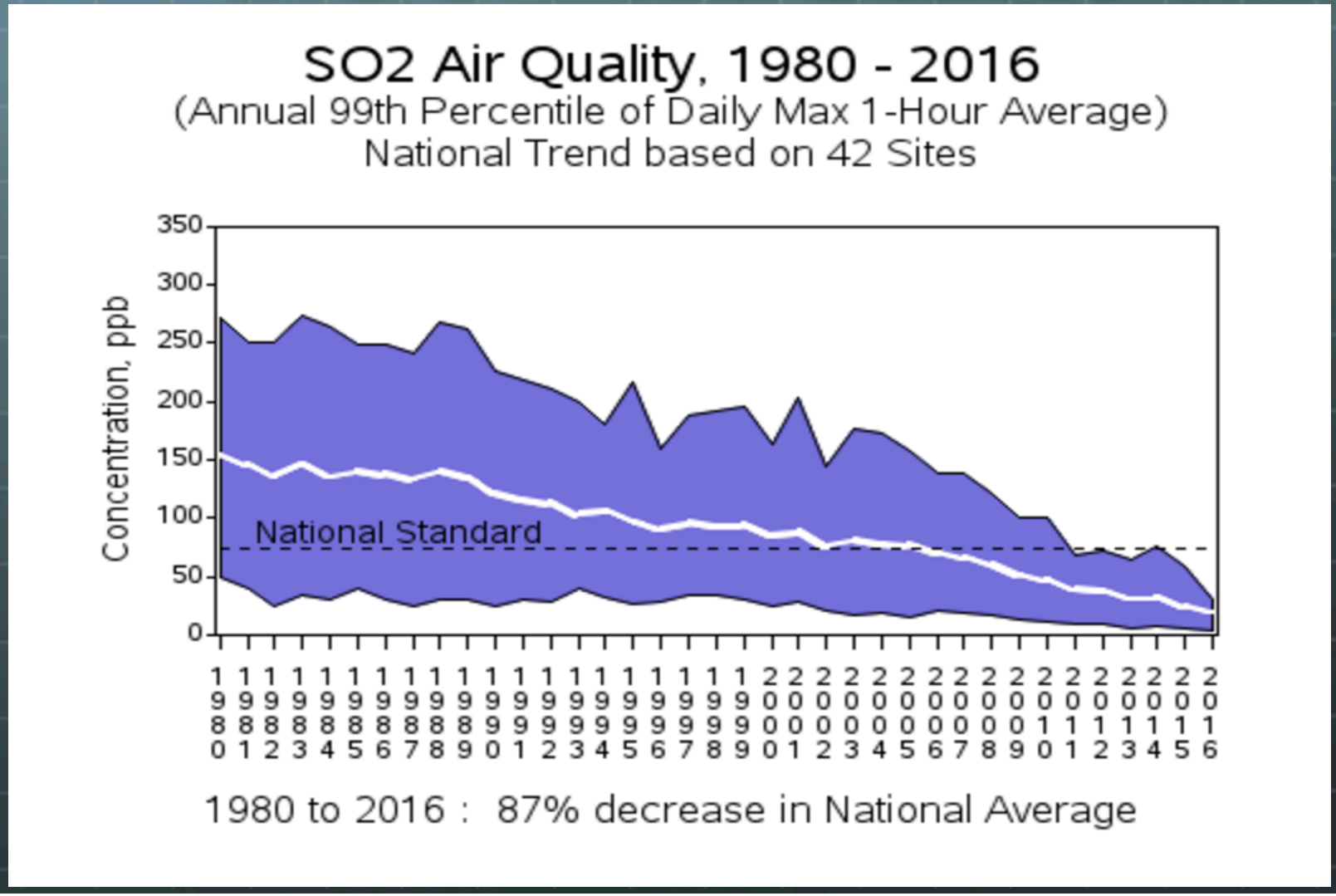
# What happened to the levels of SO2?



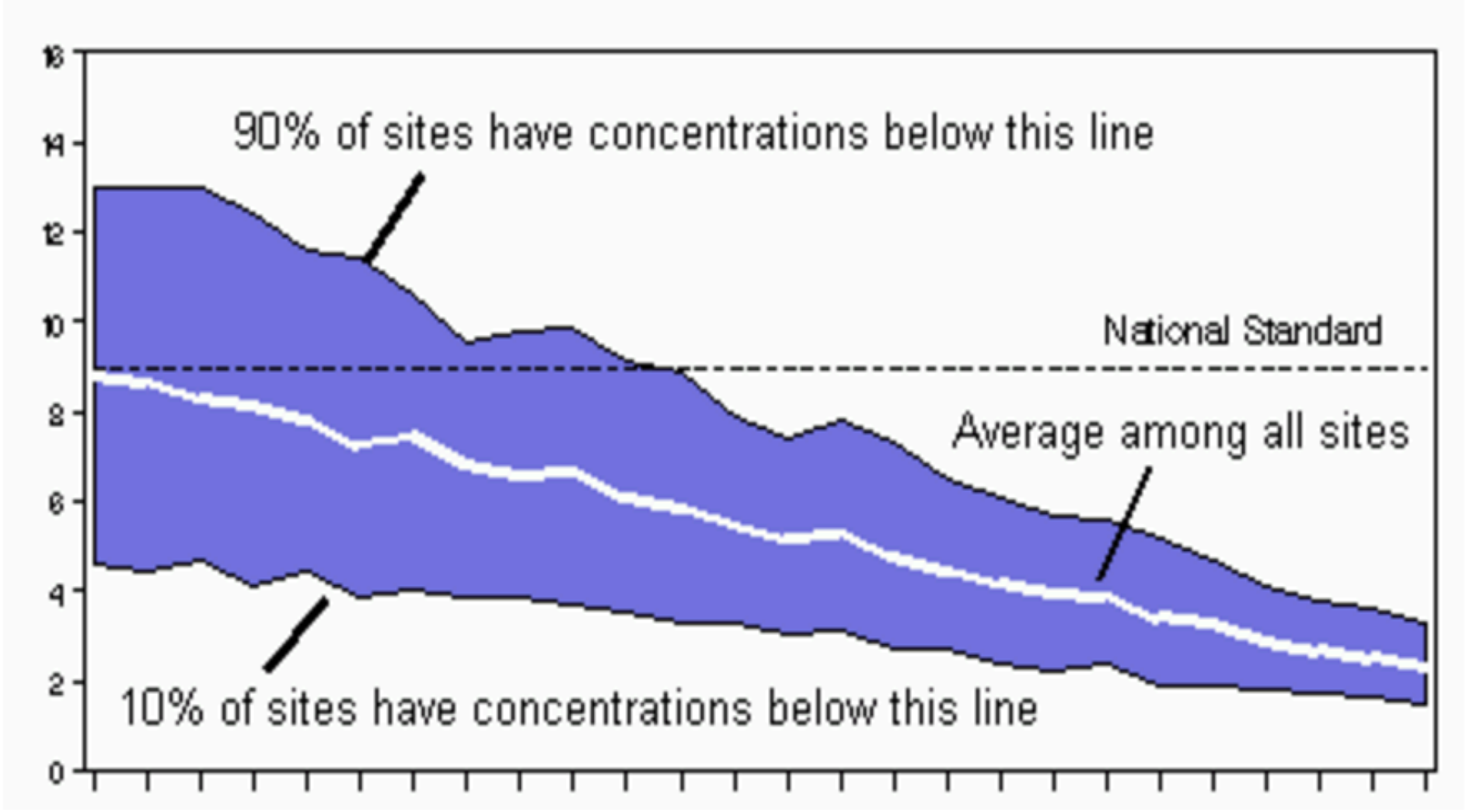
# $SO_2$ Emissions National Mean



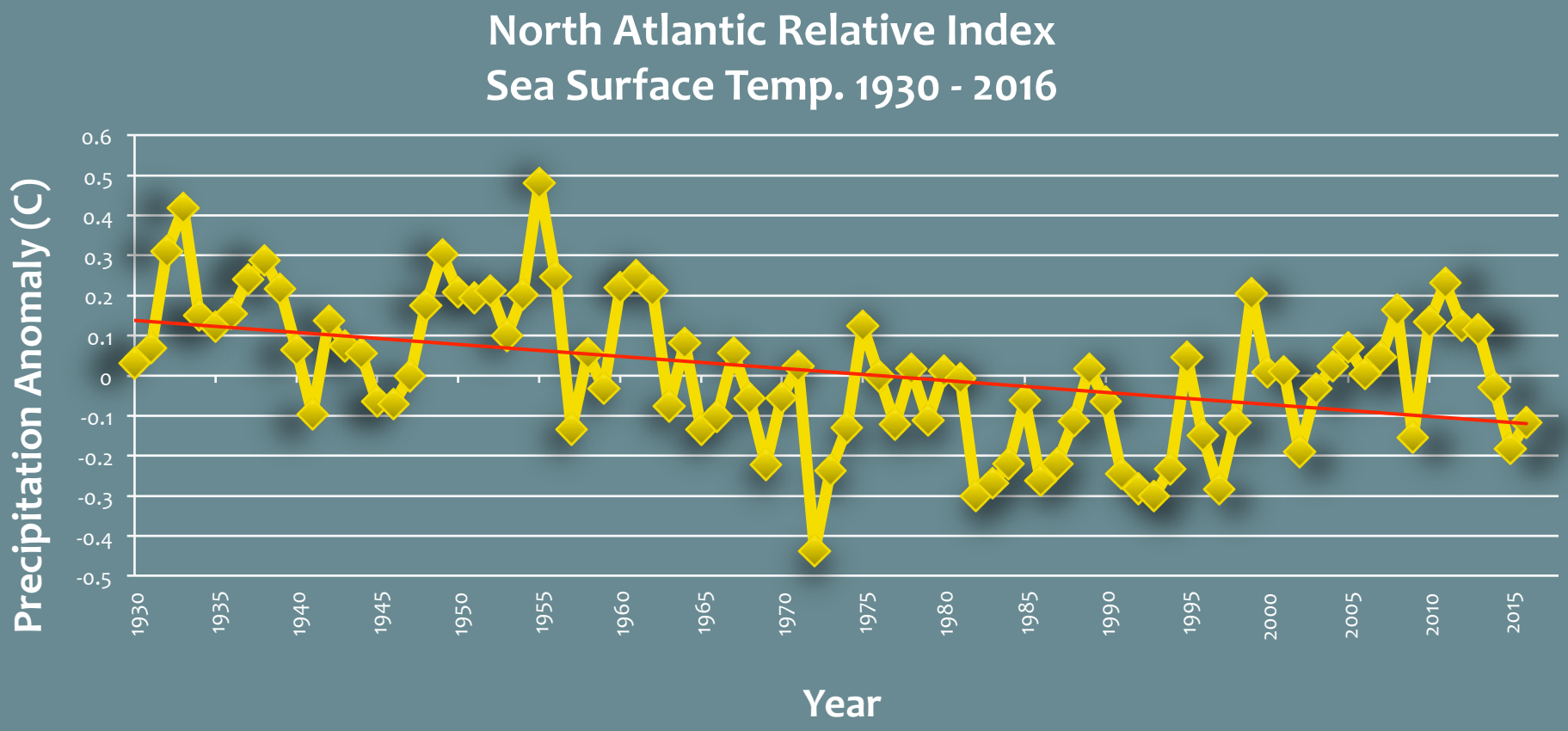
# Sulfur Dioxide Trend in the United States



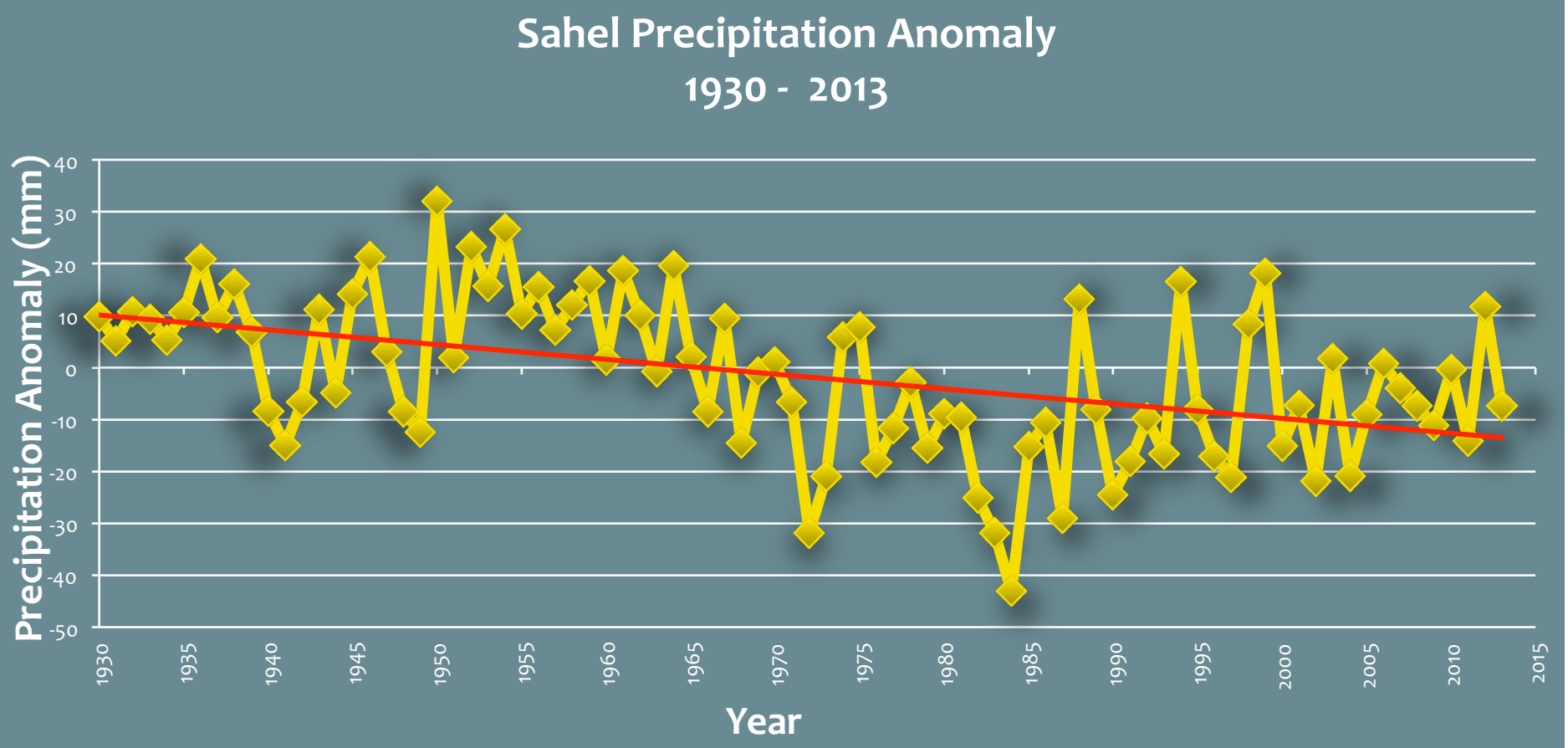
# How to Interpret the Graph



# North Atlantic Relative Index
# Sea Surface Temperature
# Sahel 1930 - 2016



# Time Series Sahel Precipitation Graph 1930 – 2013 Baseline



# Environmental Research Letters

## Video Abstract

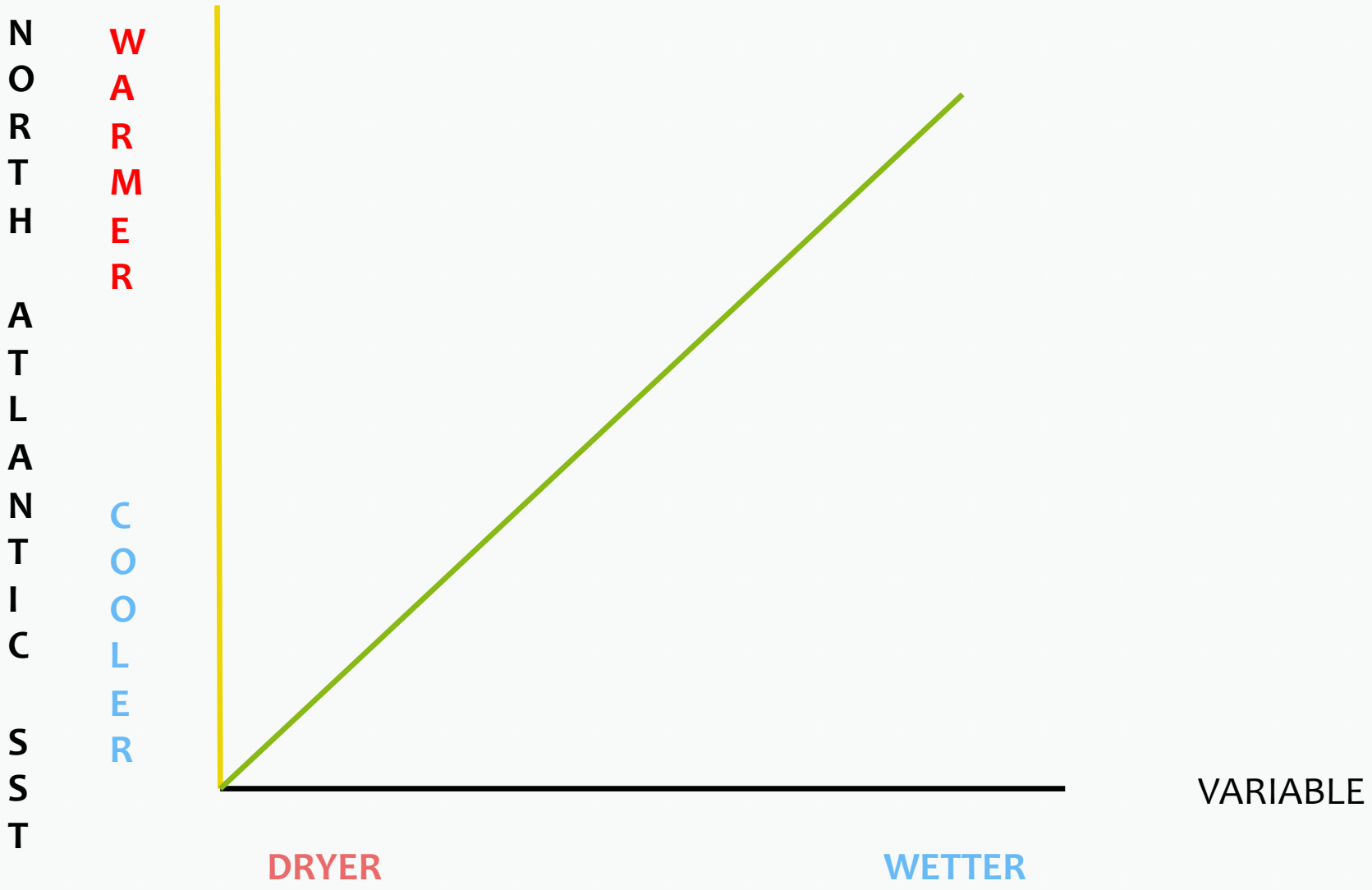
## A unifying view of climate change in the Sahel linking intra-seasonal, interannual and longer time scales

A Giannini et al 2013 Environ. Res. Lett. 8 024010

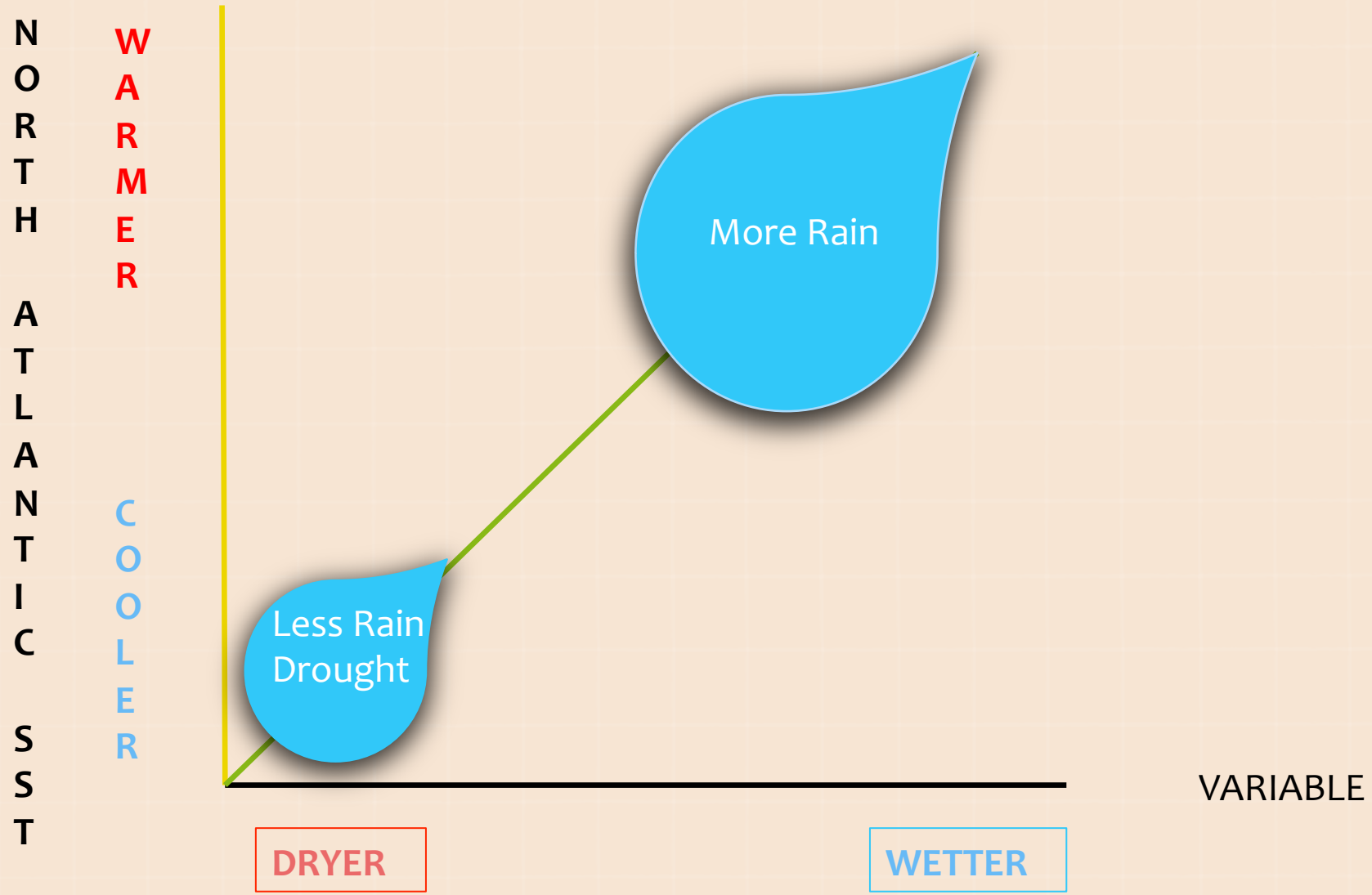
iopscience.iop.org/1748-9326



Video: Move cursor to the bottom left to find play button.

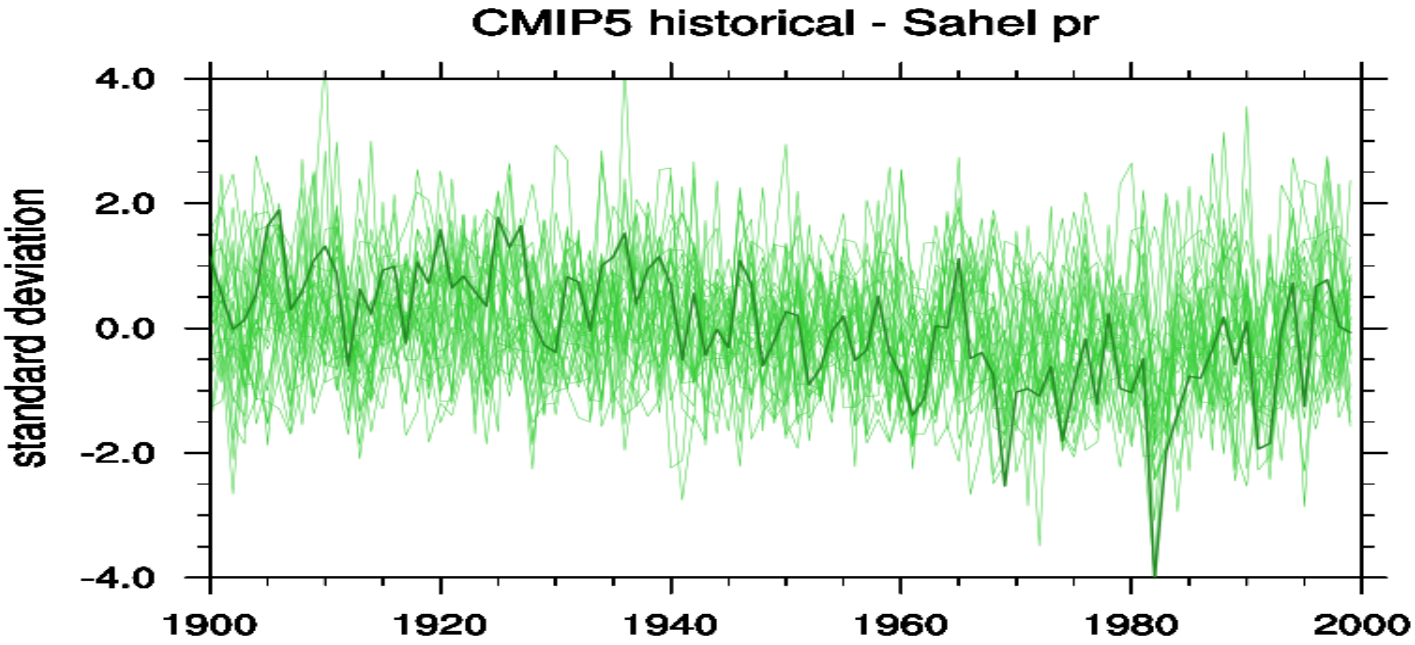



SAHEL REGION, NORTH AFRICA




SAHEL REGION, NORTH AFRICA

# What do Computer Climate Model Simulations Look Like? - What is it Telling Us about The Sahel Climate?



# Why Climate Model Simulations?

They are used to help us further develop our knowledge about how climate systems evolve, vary and change.

These models produce long-term historical climate simulations and projections into the future informed by how forcings interact with physical climate processes.

Climate Model Simulations may help forecast future climate changes and variability.

# How are computer climate models are created?

To generate the computer model simulations data related to climate forcings (natural and or anthropogenic) are set to vary (fluctuate at the same rates) they did in the real world to the best of the scientists knowledge. The historical climate data is obtained from observations measurements and or from climate proxies – paleoclimate data.

**Natural Forcings:**

**They are natural influences on climate for example:**

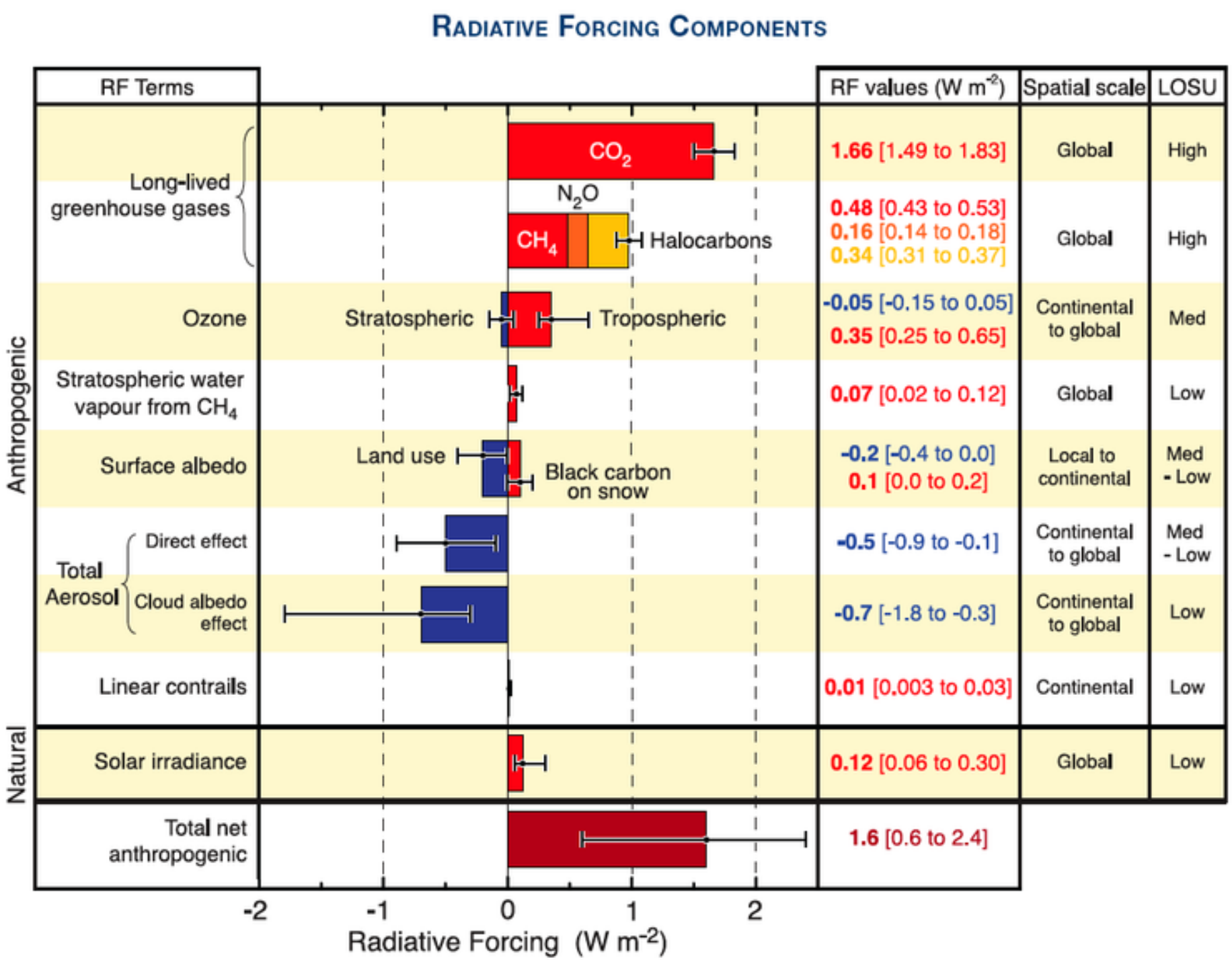
***Solar Insolation at the top of the atmosphere*** **– the amount of solar radiation the reaches a certain area, in this case the atmosphere.**

***Volcanic Eruptions*** **(like Mt. Pinatubo eruption in the Philippines in 1991)**

**Athnropogenic Forcings or human influences are chemicals that can affect the Earth's Energy Budget:**

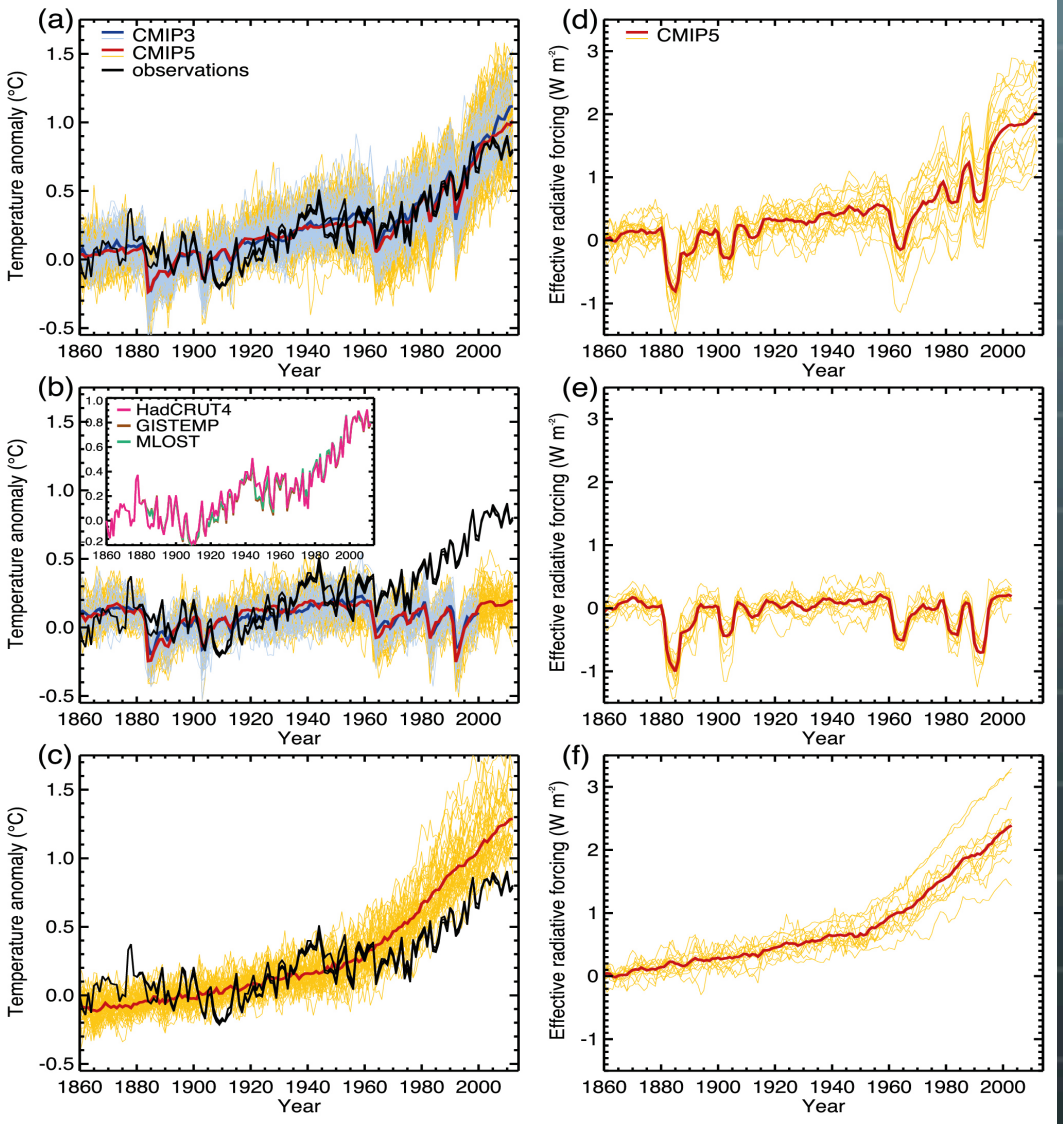
- ***Concentrations of Greenhouse Gases*** **– $CO_2$, Methane, water vapor.**
- ***Aerosols*** **– $SO_2$, Soot, Carbon, others.**
- ***Ozone***
- ***Other Chemical Compounds that enter the Atmosphere***

## Radiative Forcing Components



# Radiative Forcing Video

# How do these Models Work?




Models can run climate data with all forcings – natural and anthropogenic – that influence climate patterns and changes: for example not limited to surface temperature or precipitation.

They also run climate computer simulations with:

- Only Natural forcings.
- One anthropogenic forcing.
- Many anthropogenic forcings.

This is called parallel modeling. They do this to compare one model with another.

What climate parameter are the graphs on the left modeling?

Some are modeling climate forcings.

# Modeling Mean Global Temperature Anomalies

## What is a mean global temperature anomaly?

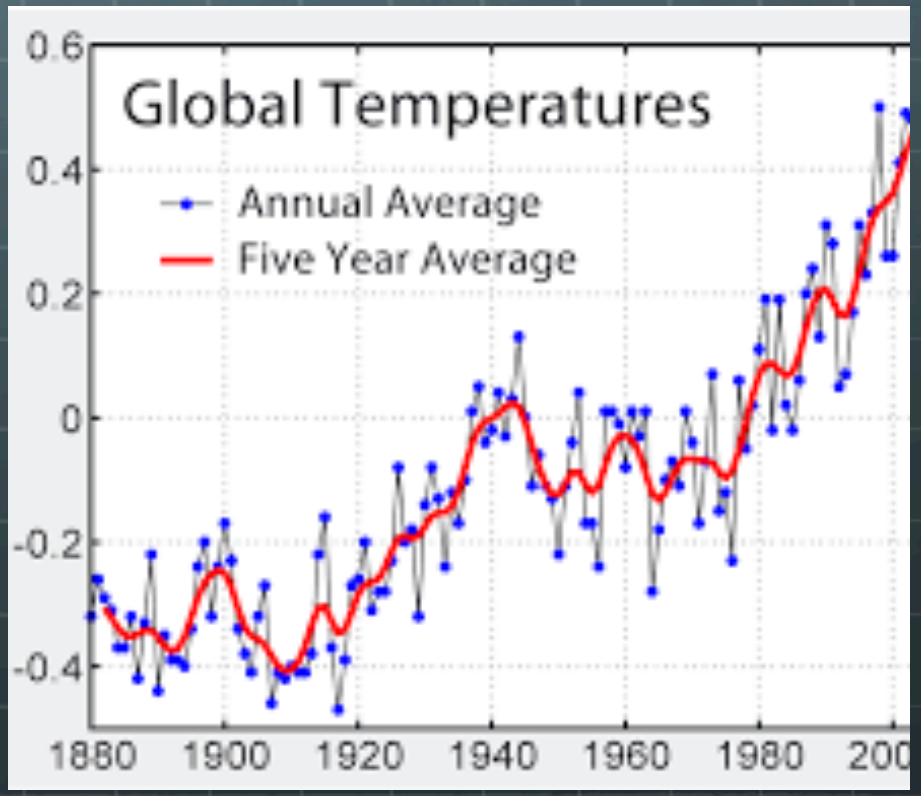
An anomaly is when some thing breaks from the norm.

The norm in climate mean global temperatures is measured by averaging the sea-surface and land temperatures over a specific time scale depending what is being studied. The time scale generally exceeds a decade.

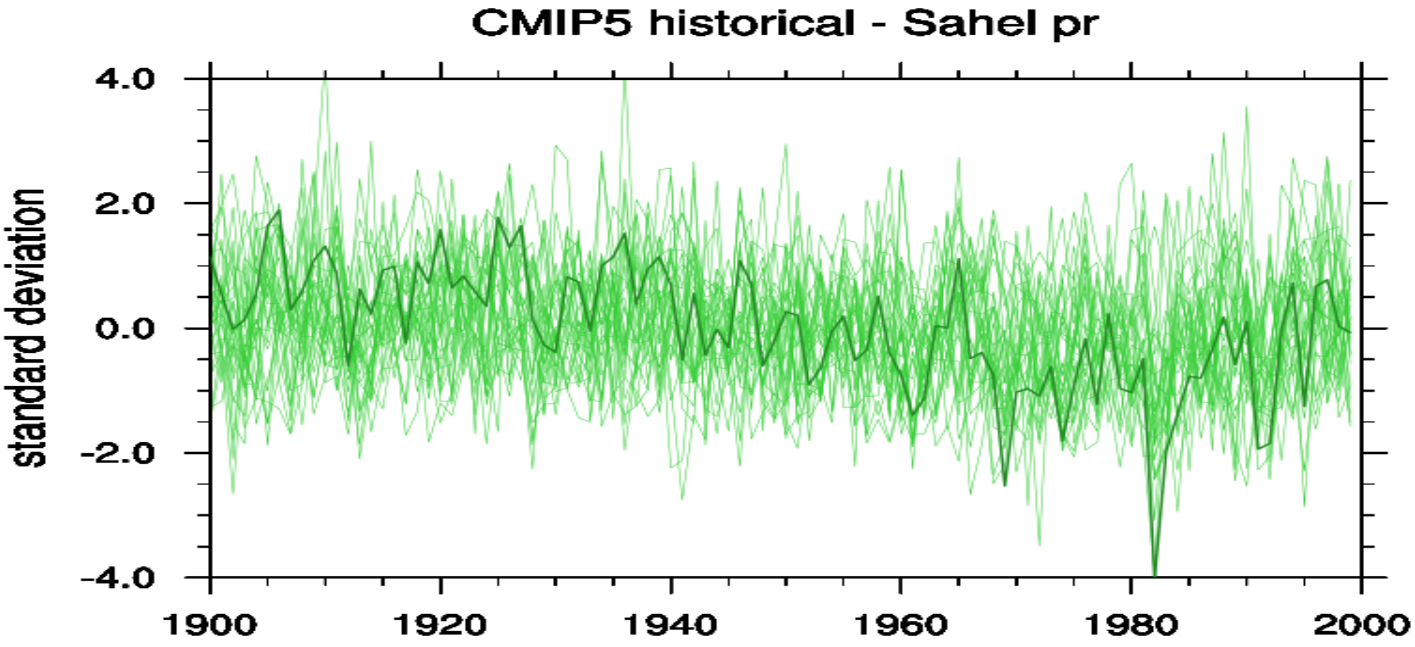
Positive number indicate warming above the norm (baseline); and negative numbers indicate cooling below the norm.

Example: 1880 - 2013

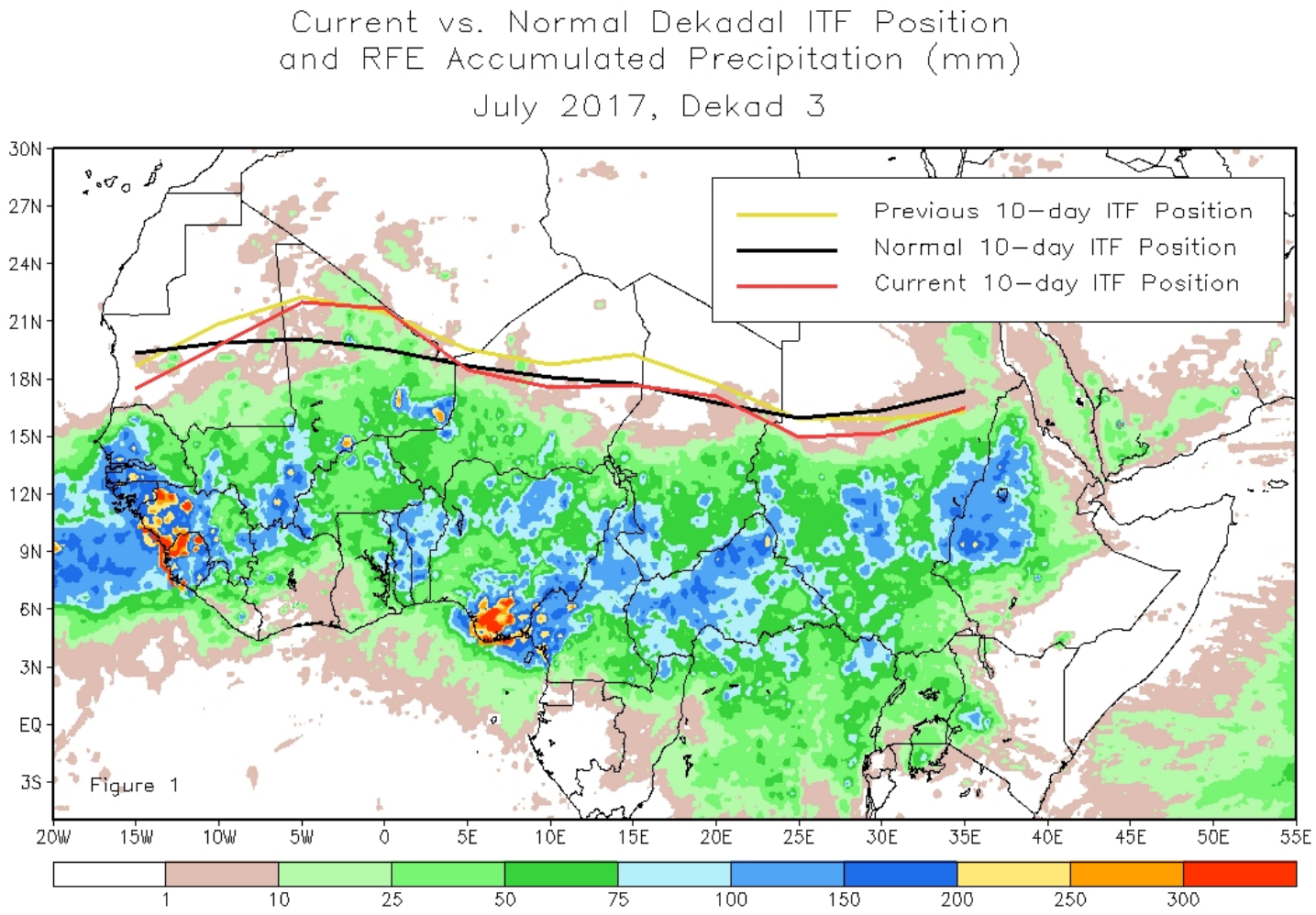
## Global Mean Temperature Curve



# What does this Simulation Model is Telling Us?



# The Sahel's Climate Forecast

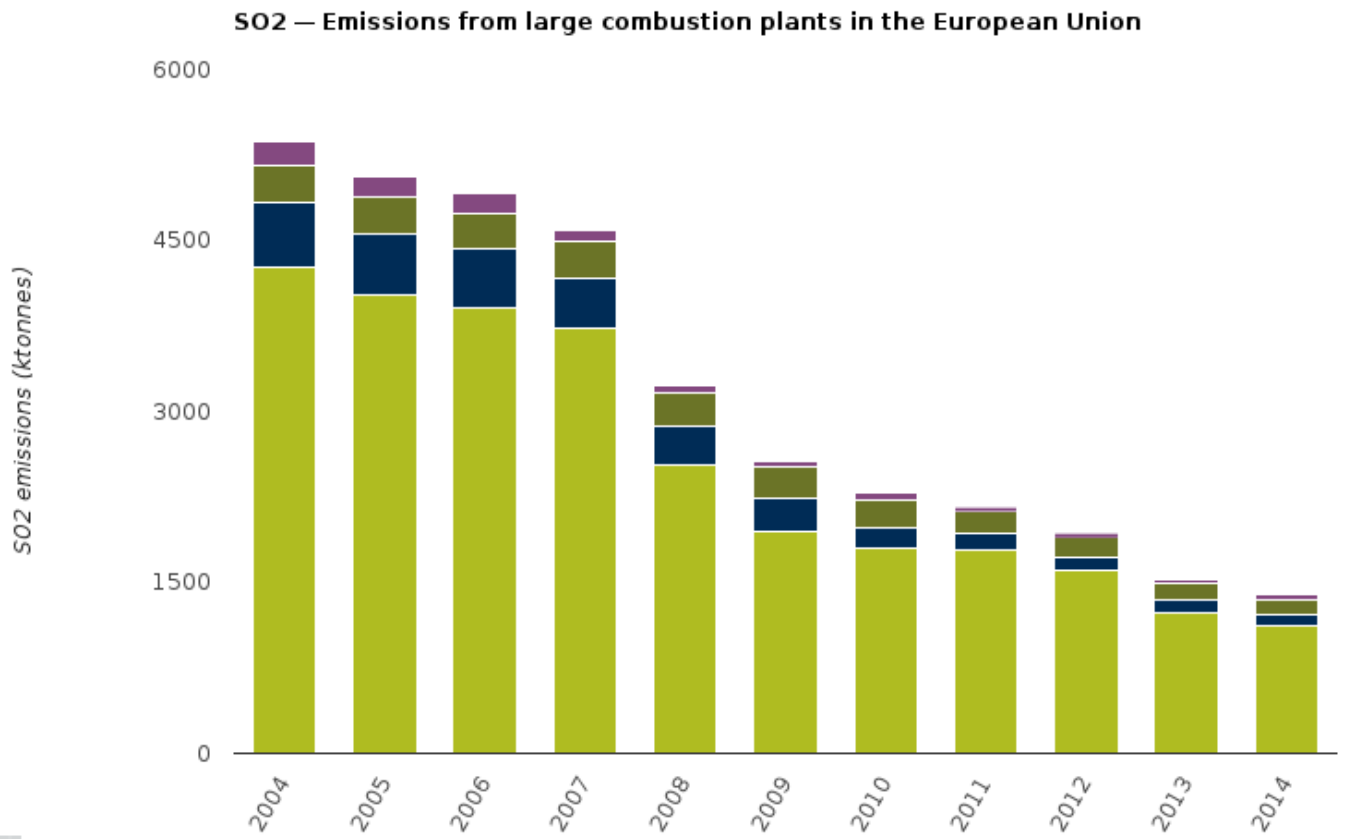



**Is the Sahel showing signs of changes in precipitation patterns ?**

**How can this question be answered?**

**What would be needed?**

# European Union SO2 Emissions



# What caused significant reductions in SO2?

## United States

- Clean Air Act – Federal Law enacted in 1970 to establish federal and stat regulations to limit emissions .
- NAAQS – National Ambient Quality Standards – were established for common air pollutants: PM (particulate matter); Carbon Monoxide; Lead; $SO_2$; $NO_x$(Nitrogen Oxide); Ozone ($O_3$).

## European Union

Clean Air Policy Package – The European Union enacted a series of policies in 1970's which significantly reduce emissions pollution.

The currently have a very ambitions plan of further reducing emissions by 2020. Under the current regulations they have managed to reduce $SO_2$ emissions by 80%.

# $SO_2$ Emissions on the Rise in Asia