

## 1. Definitions:

### • **The Climate system**

- What is included: the coupled atmosphere, ocean, land surface, and sea ice system
- What usually isn't included:
  - things that don't have much effect on the "climate system"
  - things that change on very long (geologic) time scales are usually considered external to the climate system
    - Examples: changes in location of continents and oceans, changes in land topography)

### • **Natural Variability**

- Variations in climate that are due to *internal* interactions between the atmosphere, ocean, land surface and sea ice.
  - Examples: year-to-year differences in storminess in the Pacific Northwest, drought, the El Niño/Southern Oscillation (ENSO) phenomenon, the North Atlantic Oscillation, etc.

## “Radiative Forcing”

- **Radiative Forcing** (RF) is a measure of the change in the energy balance of the Earth-atmosphere system when factor(s) that affect climate are altered. (IPCC '07)
  - The RF is calculated instantaneously to the alteration (ie, before the atmosphere adjusts to the change)
  - Called 'radiative' because the process that communicates the net change in energy is electromagnetic radiation
- A positive Radiative Forcing results in a net increase in downward energy and thus will lead to a warming of the surface. Examples of RF:
  - increase in the solar luminosity
  - increase in greenhouse gas concentration
- RF allows one to assess and compare the relative importance of different natural and human-induced forcings on climate

## Agents of Climate Change: Forcing

Climate can change due to *external forcing*

### • **Natural Forcing**

- Examples:
  - Volcanoes (scattering particles, albedo  $\alpha$ )
  - changes in the Earth's orbit
  - changes in the solar luminosity ( $S_0$ )

### • **Human Forcing**

- Examples:
  - emissions of greenhouse gases (emissivity  $\epsilon$ )
  - aerosols (tiny particles,  $\alpha$ )
  - land use changed ( $\alpha$ , etc)

## Climate Variability and Climate Change

### 1. Definitions

- The Climate System; Natural and Forced Variability

### 2. Natural Variability

- North Atlantic Oscillation, El Niño/Southern Oscillation

### 3. Forced Change (natural)

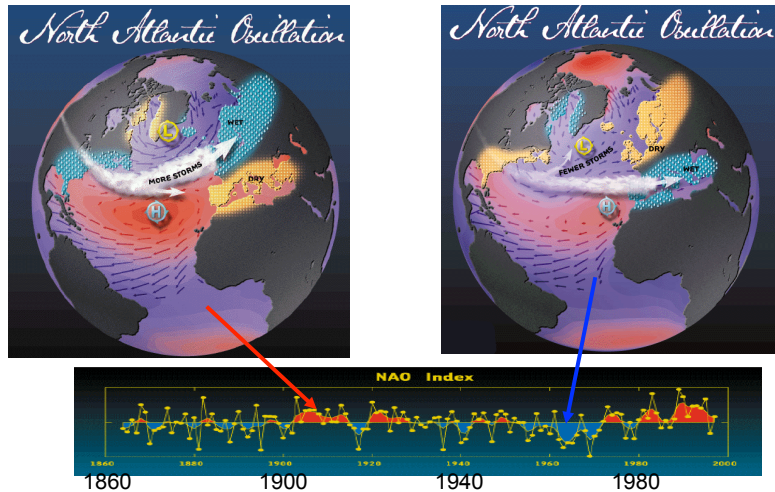
- Volcanic Eruptions (scattering particles)
- Changes in the Solar Luminosity

### 4. Forced Change (human)

- Burning of fossil fuels (increasing GH gases)
- Burning of biomass (scattering particles)

## 2. Examples of Natural Variability

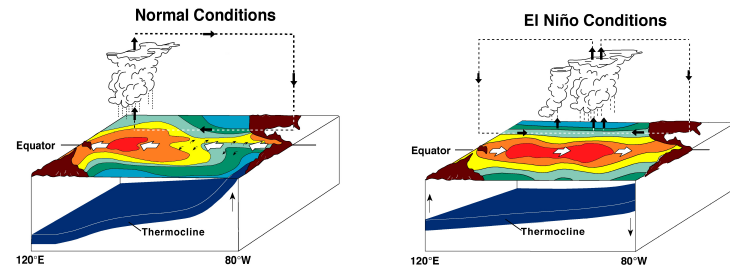
- The North Atlantic Oscillation (NAO)
  - (year to year variations in the wintertime storminess in the N. Atlantic)



## 2. Examples of Natural Variability

### El Niño/Southern Oscillation (ENSO)

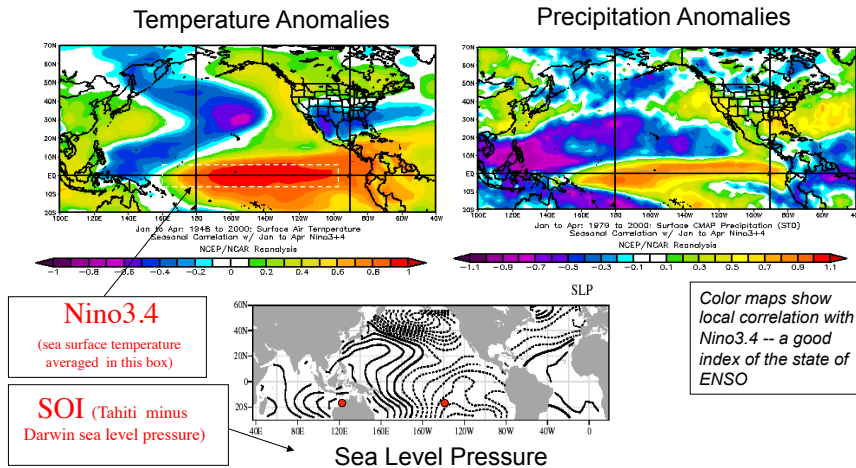
- El Niño/Southern Oscillation(ENSO) is the dominant pattern of climate variability on year-to-year time scales



- The physics responsible for ENSO are localized in the tropical Pacific, but ENSO causes global climate anomalies

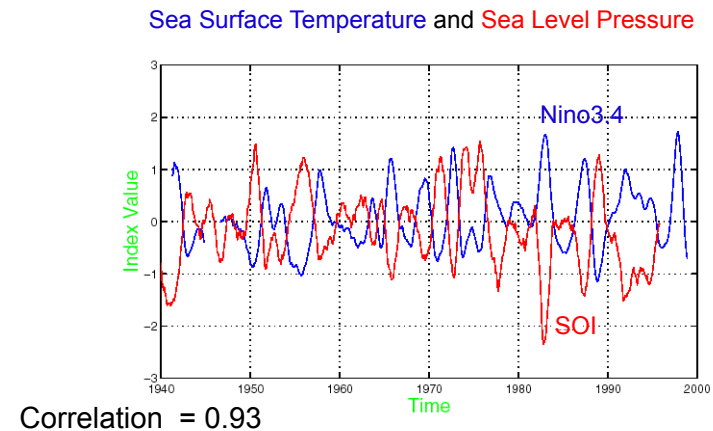
## ENSO

Changes in the distribution of sea surface temperature are coordinated with changes in atmospheric circulation and rainfall patterns



## ENSO

There is a tight coupling between the atmosphere & ocean

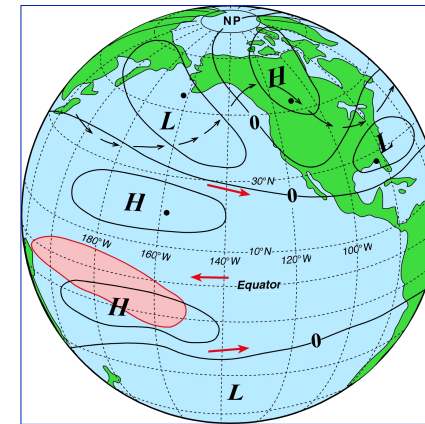


## ENSO

- El Nino is the warm phase of ENSO
  - The tropical Pacific ocean is warmer than usual; rainfall moves from the western Pacific to the central Pacific
- La Nina is the cold phase of ENSO
- El Ninos
  - occur every 3-7 years or so and last about one year
  - El Nino is usually followed by one year of La Nina conditions
- The state of the tropical Pacific (ENSO) is predictable up to one year in advance
  - For example, the average skill for a six month forecast is about 0.85 (perfect forecast =1, no skill =0)
- ENSO causes the global average temperature to change by +/- 0.15°C

ENSO affects the global climate through atmosphere and ocean teleconnections

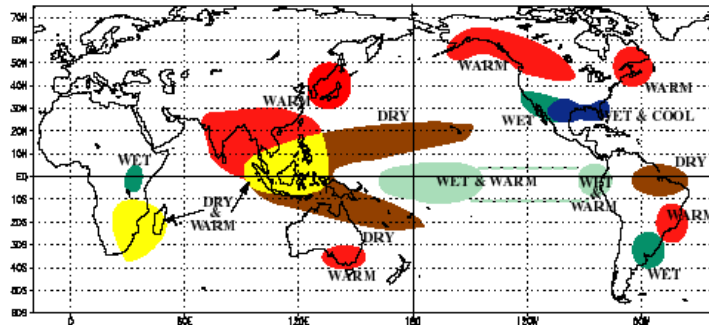
Anomalies during El Nino: the “warm phase” of ENSO



Upper level circulation changes

## The impacts of ENSO

### WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



- ENSO alters the climate on a global scale. For example, ENSO impacts
  - Rainfall in Indonesia (correlation 0.7)
  - about 1/4 of the variability in wintertime temperature and storminess in the western US
  - the probabilities of extreme weather events on a global scale

## Current Tropical Pacific Ocean Temperature Anomalies

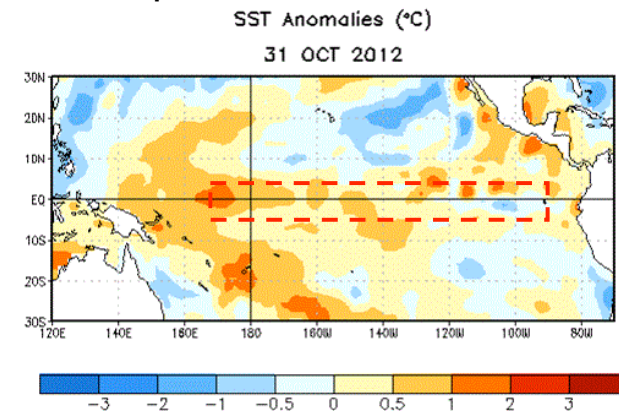


Figure 1. Average sea surface temperature (SST) anomalies (°C) for the week centered on 31 October 2012. Anomalies are computed with respect to the 1981-2010 base period weekly means.

# Most recent El Nino Forecasts

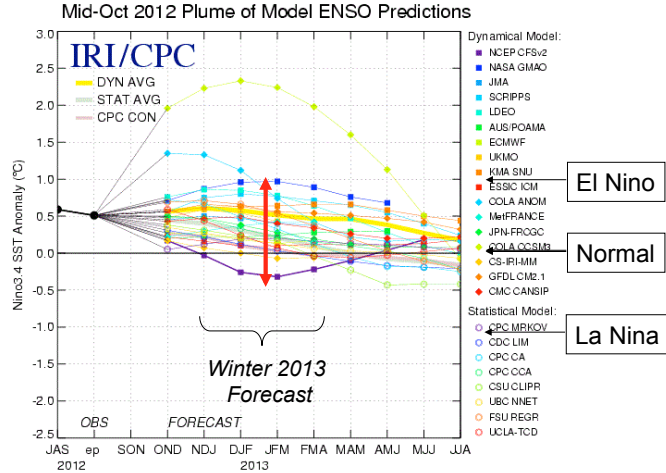


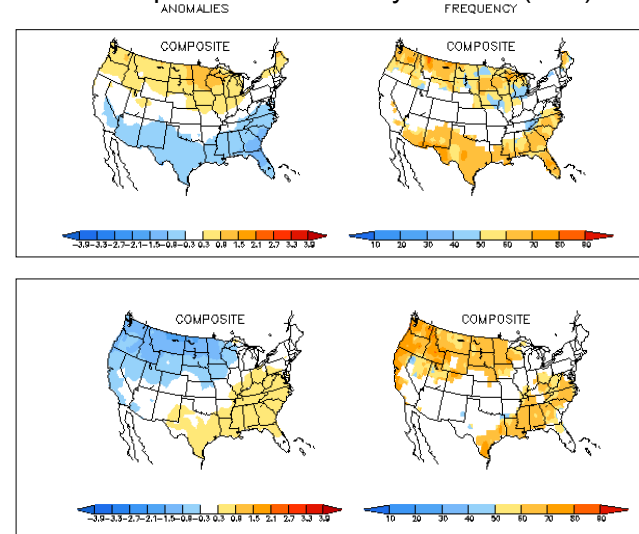
Figure 6. Forecasts of sea surface temperature (SST) anomalies for the Niño 3.4 region (5°N-5°S, 120°W-170°W). Figure courtesy of the International Research Institute (IRI) for Climate and Society. Figure updated 15 October 2012.

[http://iri.columbia.edu/climate/ENSO/currentinfo/SST\\_table.html#figure](http://iri.columbia.edu/climate/ENSO/currentinfo/SST_table.html#figure)

# Historical Impact of ENSO on the US

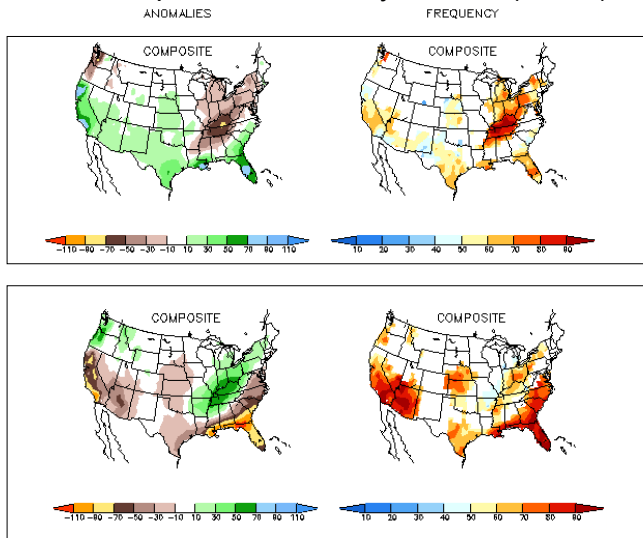
<http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml>

## Temperature in January - March (in C)



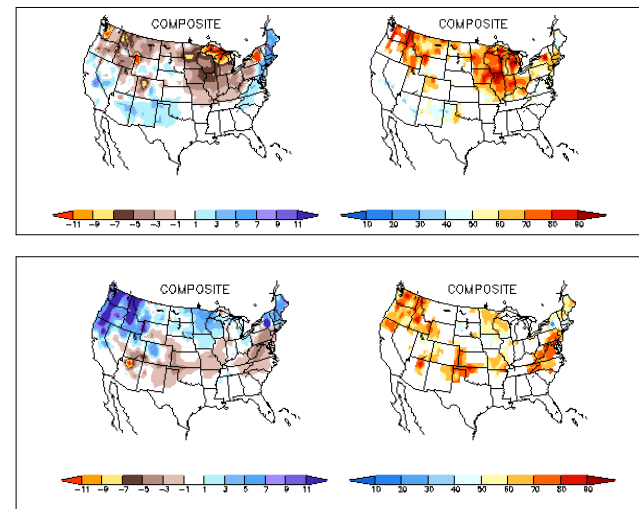
# Historical Impact of ENSO on the US

## Precipitation in January - March (in mm)



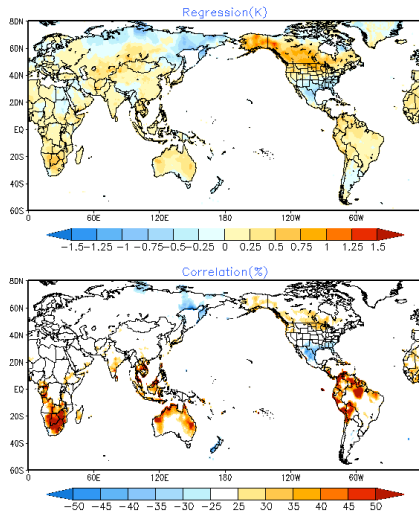
# Historical Impact of ENSO on the US

## Snowfall in January - March (in inches)



## Historical Impact of ENSO

### Temperature in December – February

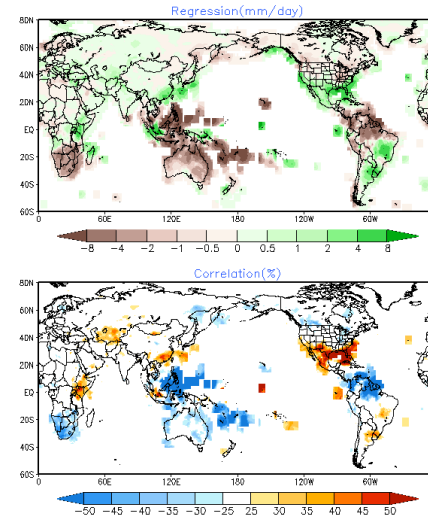


Regression  
(how much change  
in a modest El Nino)

Correlation

## Historical Impact of ENSO

### Precipitation in December – February



Regression  
(how much change  
in a modest El Nino)

Correlation

## Climate Variability and Climate Change

### 1. Definitions

- The Climate System; Natural and Forced Variability

### 2. Natural Variability

- North Atlantic Oscillation, El Nino/Southern Oscillation

### 3. Forced Change (natural)

- Volcanic Eruptions (scattering particles)
- Changes in the Solar Luminosity

### 4. Forced Change (human)

- Burning of fossil fuels (increasing GH gases)
- Burning of biomass (scattering particles)

## 3. Forced Change: Natural

### Volcanoes

- Emit sulfur dioxide into atmosphere
- The most explosive eruptions can loft sulfur dioxide 20-30km -- into the stratosphere, where it turns into sulphate particles (aerosols)
- Once in the stratosphere, the winds distribute the sulphate aerosols globally
- The smallest particles fall-out in one or two years
- Climate Impact:
  - Small sulphate particles reflect radiation in the visible band; hence they reduce the insolation arriving at the surface
  - This causes a cooling of the planet -- as much as 0.5°C -- that can last for up to two years

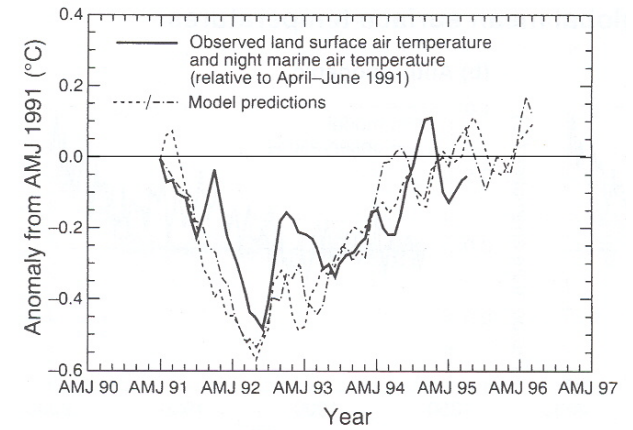
## Mount Pinatubo, Philippines (June 1991)



.... resulted in a reduction insolation (sunlight) reaching the surface of 2-3 W/m<sup>2</sup> for about a year

## The impact of Mount Pinatubo eruption: Model vs Observations

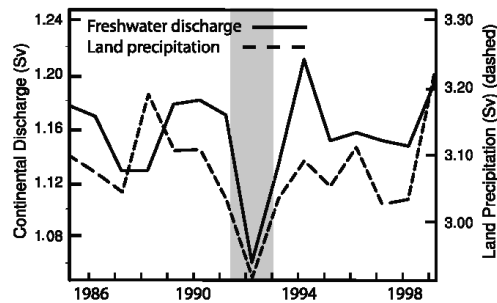
Departure of Global Average Temperature from April-June 1991 average



Pinatubo caused the planet to be about 0.35°C cooler for about 18 months

Houghton Fig. 5.21

## The impact of Mount Pinatubo eruption: Precipitation



Mount Pinatubo also caused about 5% less global averaged precipitation

Trenberth and Dai 2007