**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 +/- 0.15°C

**The impacts of ENSO**

- ENSO alters the climate on a global scale. For example, ENSO impacts
  - Rainfall in Indonesia
  - 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

**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 0.5C -- that can last for up to two years

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Mount Pinatubo, Philippines (1991)

... resulted in a reduction insolation (sunlight) reaching the surface of 2-3 W/m² for about a year
Volcanic Eruptions and Global Temperature

- Suggestion that the typical large volcano can cool the planet by ~0.2ºC for about a year or so
- After ENSO and another major pattern of natural variability is removed

Thompson et al. 2008

The impact of Mount Pinatubo eruption: Precipitation

- Mount Pinatubo also caused about 5% less global averaged precipitation

Trenberth and Dai 2007

Mechanism of Volcanic Perturbation

- Sulphate particles in the stratosphere reflect sunlight, hence increase the albedo of Earth
- Process is well understood but ...
  - Amount of sunlight scattered depends greatly on size and amount of aerosol particles
  - The global monitoring of aerosols began in ~1980
- Hence, the history of the amplitude of the ‘forcing’ before 1980 is poorly known

The impact of Mount Pinatubo eruption: Model vs Observations

- Pinatubo caused the planet to be about 0.3ºC cooler for about 18 months

Houghton Fig. 5.21

Major Volcanic Eruptions in the past

- Estimates from two different groups

IPCC 2007 Fig 2.18

Volcanic Eruptions and Global Temperature

- Suggestion that the typical large volcano can cool the planet by ~0.2ºC for about a year or so

Thompson et al. 2008

IPCC 2007 Fig 6.14
Forced Change: Changes in the Sun’s output

- Sunspots are associated with a small increase in energy coming from the Sun
  - Sunspot numbers vary (11 year cycle, and other poorly understood time scales)
- Direct estimates of the change in insolation since 1978
  - The solar constant varies by +/- 0.05% over the sunspot cycle, or about +/- 0.5W/m², or about +/-0.125 W/m² averaged over the whole Earth
- Changes are too small to explain correlated variability in global temperature, so exotic theories are often involving cosmic rays and clouds to amplify forcing.
  - Expect ~0.05°C changes in global temperature

The Solar Constant

Sunspot observations

25 BC: First sunspot records in China
1611: Sunspots discovered by Europeans (with telescopes)

How to view sunspots

NO !!!

Yes

focus solar image onto a screen

www.spaceweather.com
Sunspot Evolution

The Solar Constant in the past

Climate Variability and Climate Change

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Next: How we determine which changes are due to natural variability and which changes are due to forcing (natural and human induced)?