Types of Climate Change
(or timescales of variability)
Change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer.

May be due to:

(1) internal processes

(2) external forcing

Distinguishing between external influences and internal climate variability: Detection and Attribution
Climate change takes place at various timescales or frequencies.

Observational and numerical data often represent the resultant of more than one process acting on a given location.

A satellite snapshot of sea surface temperature (SST) contains information which results from the superposition of several physical phenomena in the ocean.

Analogously, buoys that record time series of current speed and direction also contain information from different timescales.
Example of some timescales (aka frequencies) of oceanic variability

<table>
<thead>
<tr>
<th>Time Scale</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal</td>
<td>~ 12 to 24 hs</td>
</tr>
<tr>
<td>Daily</td>
<td>~ day-night</td>
</tr>
<tr>
<td>Annual</td>
<td>~ 1 year</td>
</tr>
<tr>
<td>Biennial</td>
<td>~ 2 years</td>
</tr>
<tr>
<td>Interannual (e.g., El Nino)</td>
<td>3 to 8 years</td>
</tr>
<tr>
<td>Decadal</td>
<td>9 to 12 years</td>
</tr>
<tr>
<td>Interdecadal</td>
<td>18 and longer</td>
</tr>
<tr>
<td>Centennial</td>
<td>100 years</td>
</tr>
<tr>
<td>Trends</td>
<td>Global Warming</td>
</tr>
</tbody>
</table>
1. Internal Variability (ENSO, PDO, AO, NAO)

2. External Variability (solar, volcano)

3. Climate change (GHGs)
1. El Niño

(T ~ 4-6 y)
El Nino Southern Oscillation

El Nino

La Nina
Nino3.4 Index - **SST anomalies** (=Total SST – Mean SST)

**How many timescales can your eye pick?**
Global Impacts of El Niño

WARM EPISODE RELATIONSHIPS  DECEMBER - FEBRUARY

WARM EPISODE RELATIONSHIPS  JUNE - AUGUST
2. Pacific Decadal Oscillation (T~ 20-30 y)
The "Pacific Decadal Oscillation" (PDO) is a long-lived El Niño-like pattern of Pacific climate variability. While the two climate oscillations have similar spatial climate fingerprints, they have very different behavior in time.
Leading principal component of North Pacific monthly sea surface temperature variability (poleward of 20N)
3. **Arctic Oscillation (AO)**

T~???
Arctic Oscillation (AO)

The dominant pattern of non-seasonal sea-level pressure variations north of 20N latitude, characterized by pressure anomalies of one sign in the Arctic with the opposite anomalies centered about 37-45N. High Index= Below normal Arctic SLP
Arctic Oscillation (AO)

The standardized 3-month running mean value of the AO index. The departures are standardized using the 1950-2000 base period statistics.
Arctic Oscillation (AO)

Land air temperature and precipitation response to “high index” polarity of AO
4. **Atlantic Multidecadal Oscillation (AMO)**
   $T \sim 60-70 \text{ y}$
Mean ocean temperature anomalies in the Atlantic from 0 to 70N
AMO and Atlantic Hurricanes

The hurricane data superimposed on the AMO index
AMO and PDO and Droughts in the US

Time series and complimentary modes of the Pacific Decadal Oscillation (PDO) and Atlantic Multidecadal Oscillation (AMO). Note -PDO, +AMO modes in the 1950s and 1999-2003, when severe drought gripped much of the western U.S.
high (red > 25%) and
low (blue < 25%)
drought frequencies

25% = normal drought frequency
4. Antarctic Circumpolar Wave (ACW) (T ~ 8 y)

Travels westward, *against* the massive circumpolar current. Affects the overlying atmosphere (temperature and winds over the southern seas) + weather of the three southern continents bordering these seas.
A Significant Component of Unforced Multidecadal Variability in the Recent Acceleration of Global Warming (Internal Multidecadal Pattern: IMP)

- Trend in the spatially averaged "well observed" forced SST ~ 0.1K/decade
- IMP can contribute about 0.08K/decade for a 30-year trend
- The warming and cooling of the IMP matches that of the Atlantic Multidecadal Oscillation
- IMP can explain the acceleration in warming during 1977-2008 as compared to 1946-1977, in spite of the forced component increasing at the same rate during these two periods
- The amplitude and time scale of the IMP are such that its contribution to the trend dominates that of the forced component on time scales less than 16 years, implying that the lack of warming trend during the past ten years is not statistically significant
- While the IMP can contribute significantly to trends for periods of 30 years or less, it cannot account for the 0.8°C warming trend that has been observed in the twentieth century spatially averaged SST
Applied novel statistical method that decomposes variables by time scale, where time scale is measured by Average Predictability Time (APT).

IMP:
The component that maximizes the average predictability time of SST in 14 climate models run with fixed forcing ("control runs")

From DelSole, Tippet & Shukla (2010)
**FIG. 2.** The pattern of the expected response to climate forcing, obtained by maximizing the ratio of variances between the forced and control simulations.
Estimates of the amplitude of the forced component and the IMP

*blue dashed line=years of the most significant volcanic eruptions*
We cannot reject the hypothesis that the forcing does not influence IMP.
Trend for the observed SST, and for the reconstruction based on IMP plus forced component, are statistically indistinguishable.

Observations (green dots), as reconstructed by:
(black dots) = forced component + IMP
(red dots) = forced component only
Relative to 1901-1950 mean.
<table>
<thead>
<tr>
<th>Period</th>
<th>Data Set</th>
<th>Trend (K/decade)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1946 - 1977</td>
<td>Total Observations</td>
<td>0.0378 ± 0.0372</td>
</tr>
<tr>
<td>1946 - 1977</td>
<td>Forced + IMP</td>
<td>0.0486 ± 0.0291</td>
</tr>
<tr>
<td>1946 - 1977</td>
<td>Forced Only</td>
<td>0.112 ± 0.0355</td>
</tr>
<tr>
<td>1977 - 2008</td>
<td>Total Observations</td>
<td>0.145 ± 0.029</td>
</tr>
<tr>
<td>1977 - 2008</td>
<td>Forced + IMP</td>
<td>0.166 ± 0.0319</td>
</tr>
<tr>
<td>1977 - 2008</td>
<td>Forced Only</td>
<td>0.122 ± 0.0314</td>
</tr>
<tr>
<td>1946 - 2008</td>
<td>Total Observations</td>
<td>0.0909 ± 0.0137</td>
</tr>
<tr>
<td>1946 - 2008</td>
<td>Forced + IMP</td>
<td>0.096 ± 0.0133</td>
</tr>
<tr>
<td>1946 - 2008</td>
<td>Forced Only</td>
<td>0.103 ± 0.012</td>
</tr>
</tbody>
</table>

**TABLE 1.** Trends in annual-mean, spatially-averaged SST for different reconstructions and periods. “Total observations” refers to well-observed HadSST2, “Forced + IMP” refers to best fit SST using forced component plus IMP, and “Forced only” refers to best fit SST using the forced component only. Trends are expressed in K/decade plus-minus the 95% confidence interval.
5. Global Warming trend

\[ T \sim ?? \]
IPCC 4th assessment report:
T increased by
$0.74 \pm 0.18 \, ^\circ C$
Most of increase was caused by GHGs.
T is likely to rise by 1.1-6.4 \, ^\circ C
In 21-st century
Global Warming Attribution

Contribution of external forcing to global temperature anomalies
Global Warming Attribution

Comparison of Modeled and Observed Temperature

1890 - 2000

Change in risk of mean European summer temperatures exceeding a threshold of 1.6°C (relative to 1961-1990) in the presence (red) and absence (green) of anthropogenic change.

Fraction of attributable risk (FAR) to anthropogenic forcing. The shift from the green to the red distribution in (a) implies a FAR distribution with mean 0.75, corresponding to a four-fold increase in the risk of such an event (b).
Histogram of the linear trend C/decade in volume ave temp from control (black) and anthropogenically forced ensemble members (gray), compared to observed (X)

*** = probability that grey and black are drawn from the same distribution < 0.01
**  = probability that grey and black are drawn from the same distribution < 0.05
* ** = probability that grey and black are drawn from the same distribution < 0.1
Global Warming Attribution

Strength of the ensemble common model fingerprint of ocean warming.
Global Warming Attribution

Strength of observed and model-simulated warming signal by depth for the World Ocean and for each ocean basin individually. **Red** dots/bars = observations & 2std. **Blue** crosshatched swaths = 90% confidence limits of the natural internal variability strength. **Green** crosshatched swaths represent the range of the anthropogenically forced signal estimates. Grey triangles = strength of the warming signal with solar + volcanic forcing.

http://www.grist.org/tags/How+to+Talk+to+a+Climate+Skeptic
Climate Change:

✓ Observed trends in:
  ▪ temperature
  ▪ sea ice
  ▪ Precipitation
  ▪ sea level
  ▪ extreme weather events

✓ Radiative forcing and feedbacks

✓ Solar variability and climate cycles

✓ Global climate models
Hockey Stick Controversy

The hockey stick graph as shown in the 2001 IPCC report. This chart shows the data from Mann et al. 1999. The blue lines are temperatures estimated from proxy indicators, red lines are temperatures from thermometers, and the gray shaded region represents estimated error bars.
Increase in solar activity should warm the stratosphere while an increase in greenhouse gases should cool the stratosphere. Temperatures in the stratosphere have been cooling since 1979.
Water Vapor and Greenhouse System

Water vapor is 99.999% of natural origin.
H2O in the troposphere is a feedback effect, it is not a forcing agent.
Ice in the Arctic

Percentage difference in ice extent (area in millions of sq km) relative to the mean for the period (1979-2009). Sea ice minimum is decreasing faster than the sea ice maximum.
Sea ice minima and maxima for the periods of 1972-2008 vs SST anomaly. We expect the annual loss of sea ice to accelerate & discrepancy between sea ice minimum and sea ice maximum to continue increasing (until the sea ice minimum reaches zero).
CO2 and Temperature

Changes in orbital parameters => greater amounts of summer sunlight fall in the northern hemisphere. This (small) forcing, causes ice to retreat in the north => changes the albedo => further warmth, in a feedback effect. Some number of centuries after that process started, CO2 concentrations in the atmosphere began to rise => amplified the warming trend.