FINAL EXAM: MONDAY MARCH 17 3-6PM

- cumulative (will cover entire quarter)
- material since second midterm emphasized more
- all multiple choice

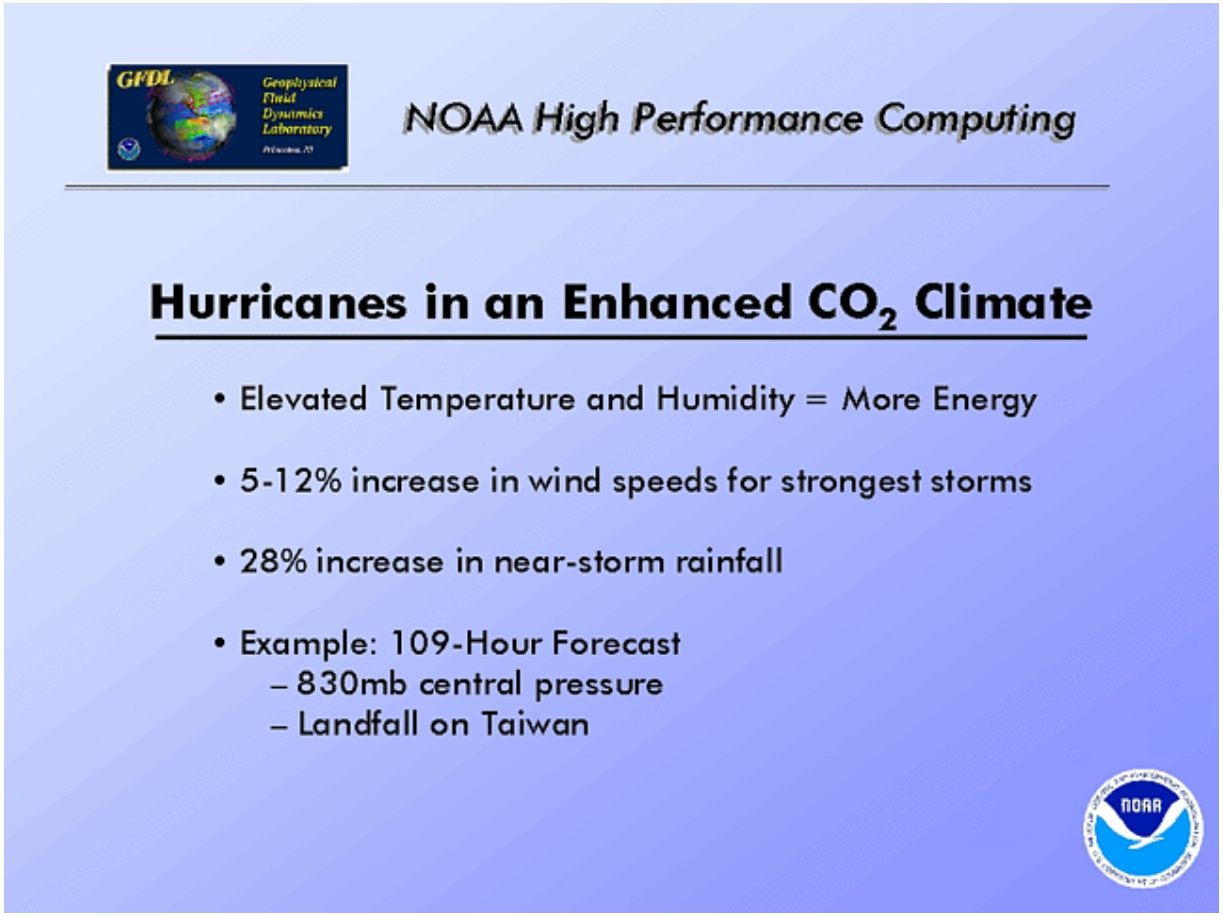
REVIEW SESSION: THURSDAY MARCH 13
6:30 – 8:00 PM
HSS 1330

Midterm 2:

45 Possible
High Score = 45
Average = 34.4

Approximate Grades

A = 38.0 – 45.0
B = 30.5 – 37.5
C = 20.0 – 30.0
NP < 20



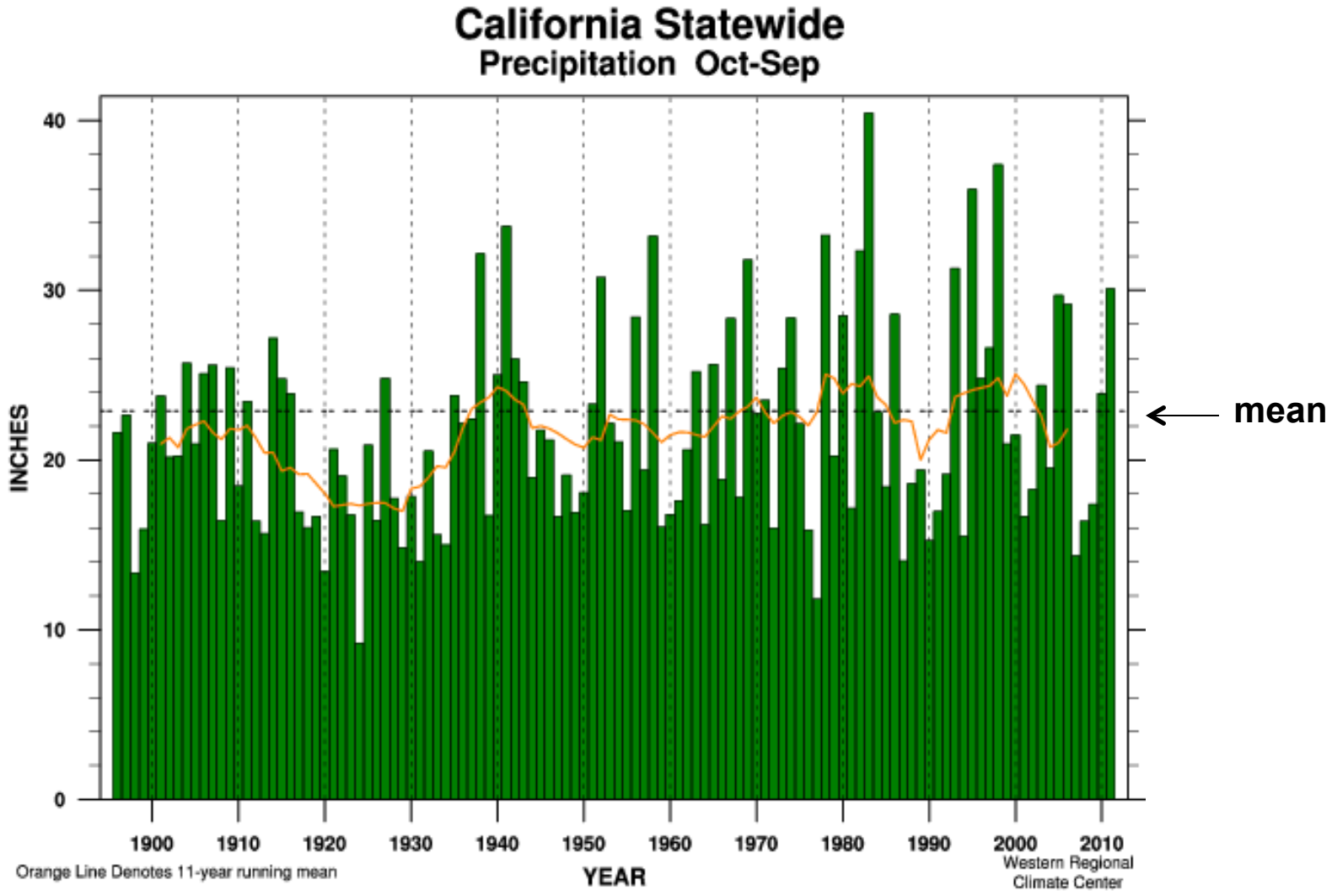
Expect warmer ocean water in future....

However, still not sure about future hurricanes since upper level winds may change as well

Climate vs. Weather

Weather: Atmospheric state at a particular time

Climate: Weather averaged over many times (30 or more)



Would get wrong impression if only look at a couple of years

Climate Change

- Climate has always been changing during Earth's history
- In past, change was usually slow
  ==> 10,000 years or more to see change
- Now, might be in period where climate is changing much faster
  ==> 50-100 years
  ==> probably due to human activities

How do we measure climate change?

- **Temperature**
  - **most common, but not necessarily best measure**
- **Precipitation (amount and timing)**
  - **important for farming and food production**
- **Sea Level**

Clicker Question

Set Frequency to "AD"

As global temperatures increase, how would you expect the sea level to change?

(A) sea level will increase

(B) sea level will decrease

(C) sea level will remain essentially unchanged

Clicker Question

Set Frequency to "AD"

As global temperatures increase, how would you expect the sea level to change?

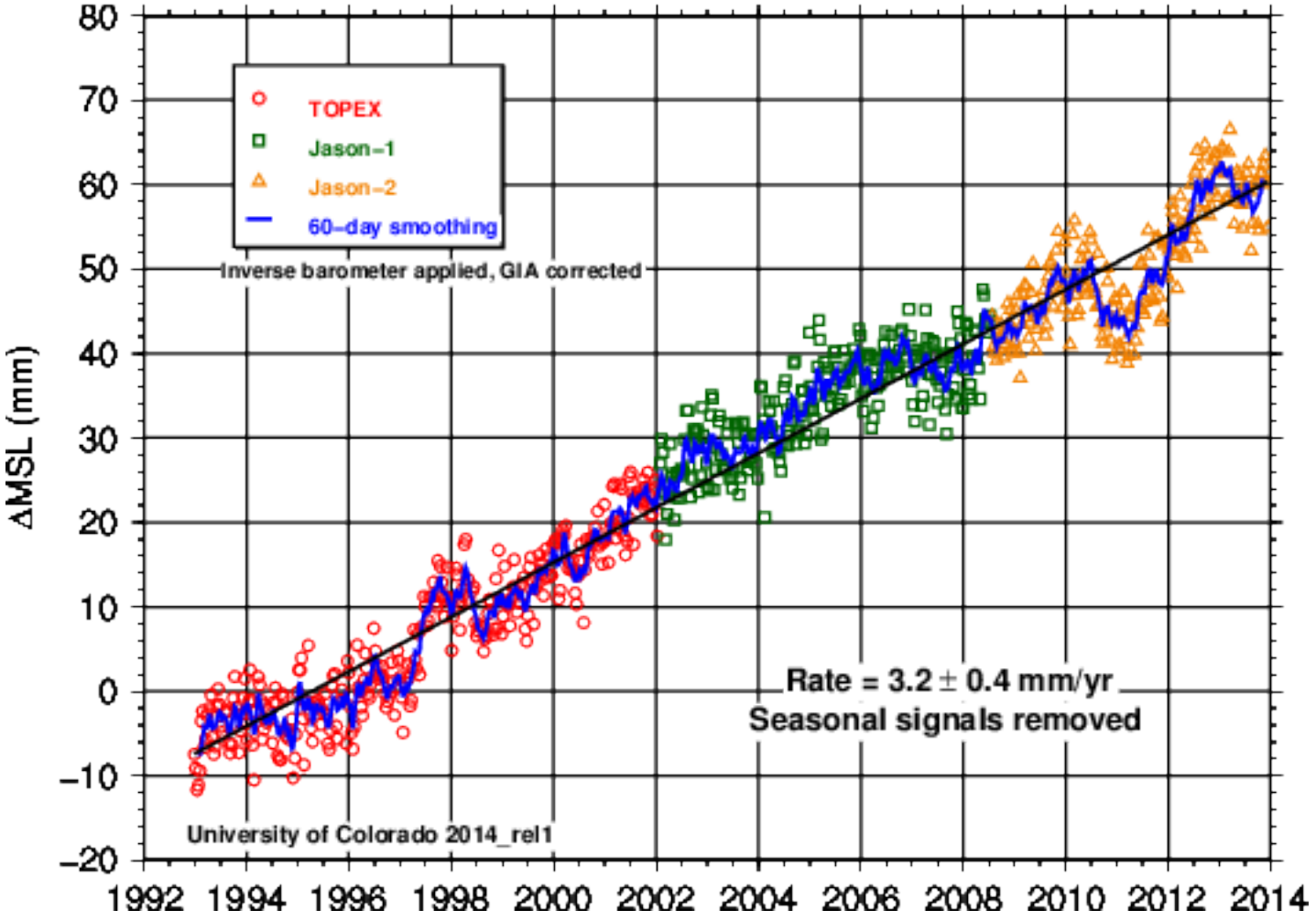
(A) sea level will increase

Sea Level expected to INCREASE because:

1) as water warms it expands

2) melting ice from glaciers and ice caps

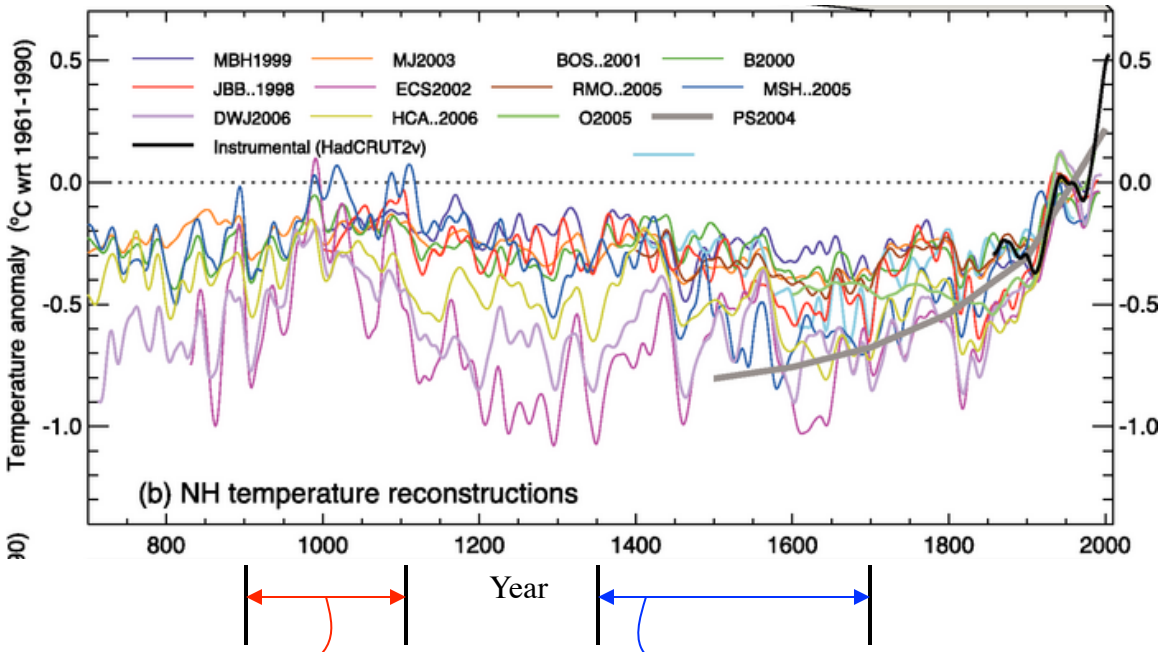
Global Mean Sea Level



How do we measure climate change?

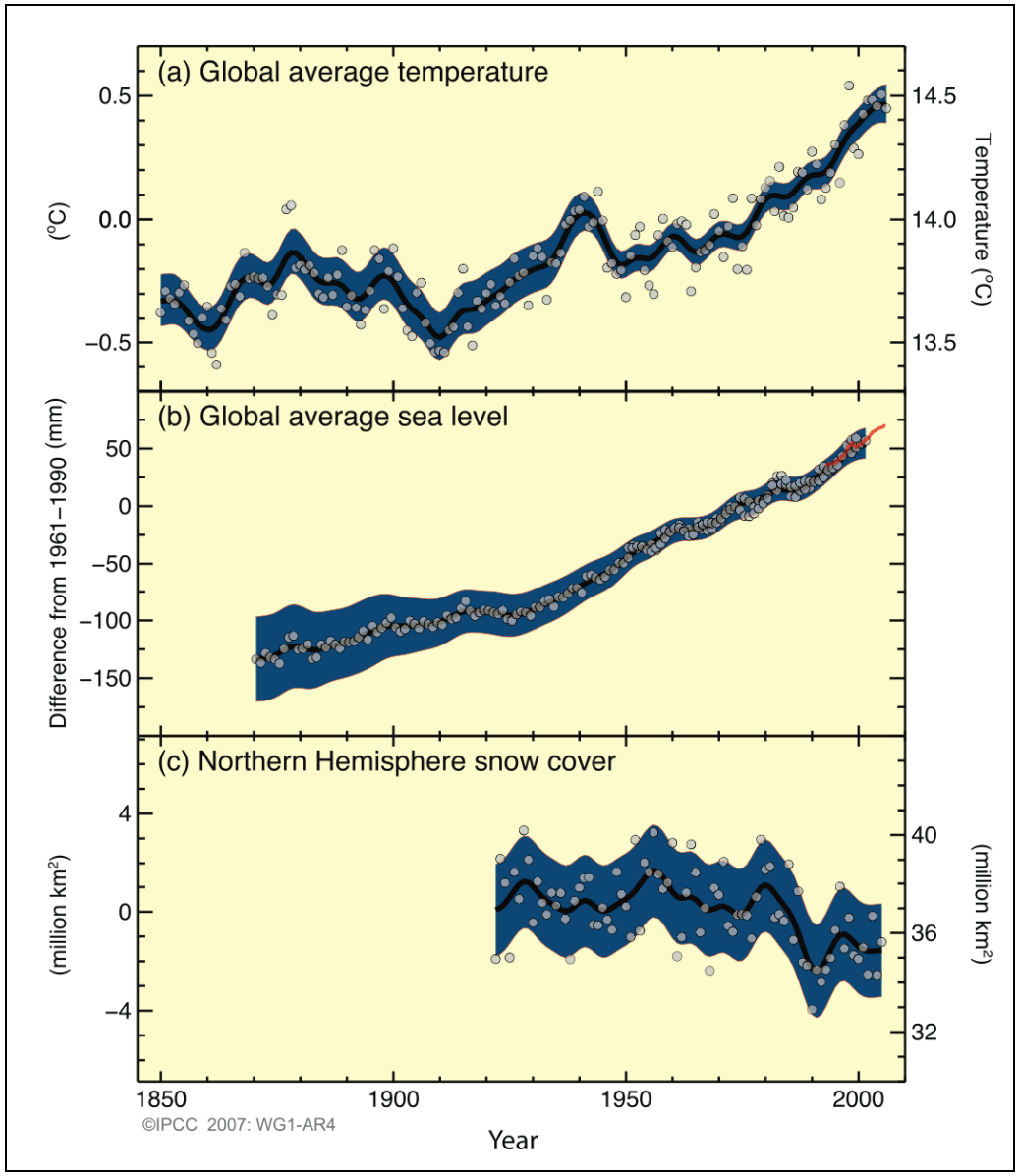
- **Temperature**
  - **most common, but not necessarily best measure**
- **Precipitation (amount and timing)**
  - **important for farming and food production**
- **Sea Level**
  - **important for island nations**
  - **also some major cities near sea level (London, New Orleans, ...)**

From 2007 IPCC Report



Medieval Climatic Optimum (~ 900 - 1100)
- relatively milder climate (at least in N. Europe)
- led to increased farming and exploration
- era of Vikings

Little Ice Age
- cooler climate (at least in N. Europe)
- glaciers advanced
- farming declines and many famines
- exploration of new world delayed

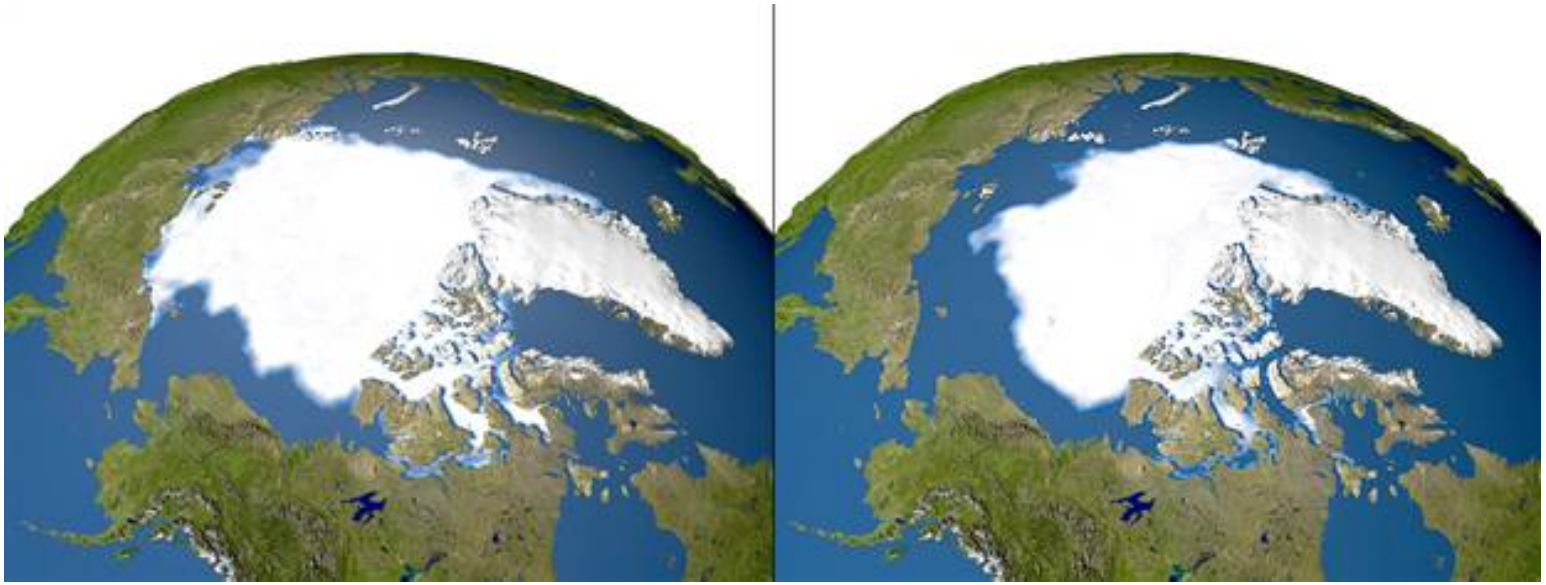


1900-1940: warming

1940-1970: slight cooling

1970-present: warming

ARCTIC SEA ICE MINIMUM FROM SATELLITE OBS.



1979 2005

NATURAL CLIMATE CHANGE

Period	Timescale
Ice Ages	Millions of years
Interglacial Periods	10,000's of years
"Little Ice Age"	100's of years
20th Century warming/cooling	~30 years

Possible Natural Causes

- Continental Drift
- Variations in Earth's Orbit
- Volcanic Activity
- Solar Cycles
  - sunspots (~ 11 year cycle)
  - magnetic field (~22 year cycle)

Continental Drift

- continents are slowly moving (few cm per year)

Different arrangement of land masses could affect:

- ice formation (albedo)
- ocean currents
- sea level

250 Mio years ago

200 Mio years ago

150 Mio years ago

100 Mio years ago

50 Mio years ago

Now

Continental Drift

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ALBEDO = Amount of solar radiation reflected by surface

Typical Albedos

Ocean	**~5-10%**
Global Avg	**~30-35%**
Snow/Ice	**~80-90%**

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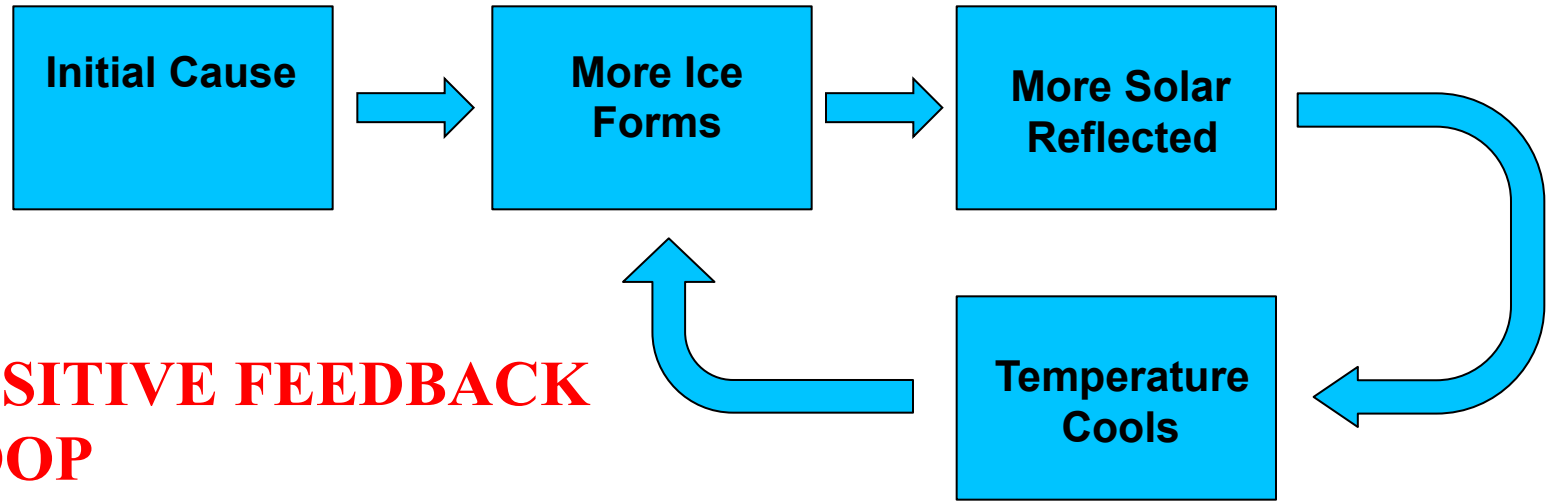
ICE-ALBEDO FEEDBACK:



POSITIVE FEEDBACK LOOP

Continental Drift

- continents are slowly moving (few cm per year)

Different arrangement of land masses could affect:

- ice formation (albedo)
- ocean currents
- sea level

Periods of fast and slow drift

fast drift => more CO_2 via degassing

Clicker Question

Set Frequency to "AD"

During periods of fast continental drift more CO_2 is emitted to the atmosphere. In general, how would you expect atmospheric temperatures to respond?

(A) temperatures would decrease

(B) temperatures would increase

(C) no impact on temperatures

Clicker Question

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Periods of fast and slow drift

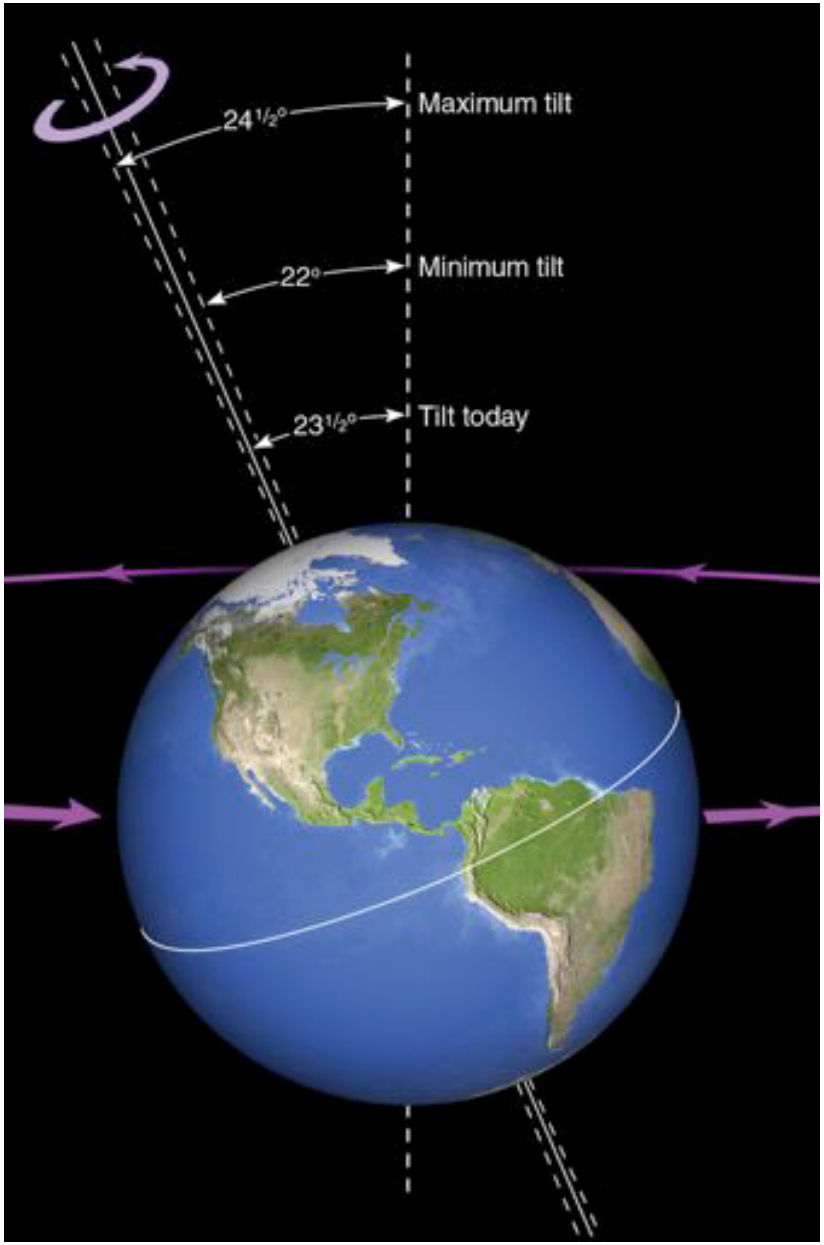
fast drift => more CO_2 via degassing => warmer temps

Slow processes: timescale = millions of years

Might help explain Ice Ages

Changes in Earth's Orbit “Milankovitch Theory”

- Tilt of Earth's axis


24½°
Maximum tilt
22°
Minimum tilt
23½°
Tilt today

Changes in Earth's Orbit "Milankovitch Theory"

- Tilt of Earth's axis
  - currently at 23.5°
  - varies between 22 and 24.5° (41000 year period)

    less tilt = less seasonal variation

Impact of Seasonal Temperature Variation

Less Variation: Cooler Summers and Warmer Winters

Summer still warmer than winter, but difference between seasons not as strong

Warmer Winter:

- in polar areas temperatures are warmer but still below freezing

Clicker Question

Set Frequency to "AD"

If temperatures increased but were still below freezing, in general how would this impact the amount of snow at a location?

(A) reduced snow amounts

(B) increased snow amounts

(C) will not change snow amounts

Clicker Question

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Impact of Seasonal Temperature Variation

Less Variation: Cooler Summers and Warmer Winters

Summer still warmer than winter, but difference between seasons not as strong

Warmer Winter:

- in polar areas temperatures are warmer but still below freezing
- more water vapor in warmer air ==> MORE SNOW in polar areas

Cooler Summer:

- cooler temperatures mean less snow melts during summer
- some snow still on ground as next winter begins

  ==> SNOW DEPTHS BUILD and GLACIERS/ICECAPS FORM

  ==> ALBEDO FEEDBACK

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    = glaciers increase (no summer melt)

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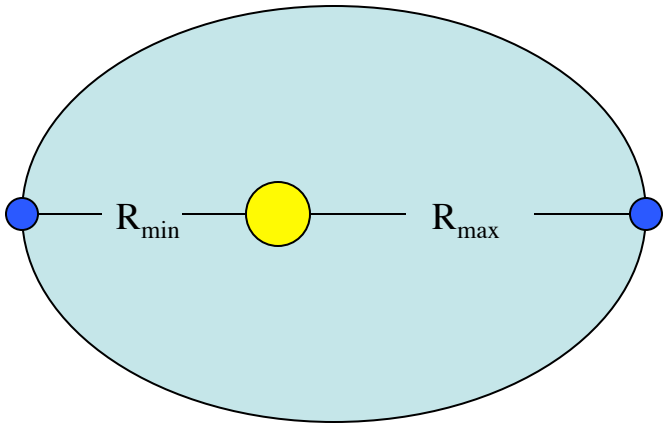
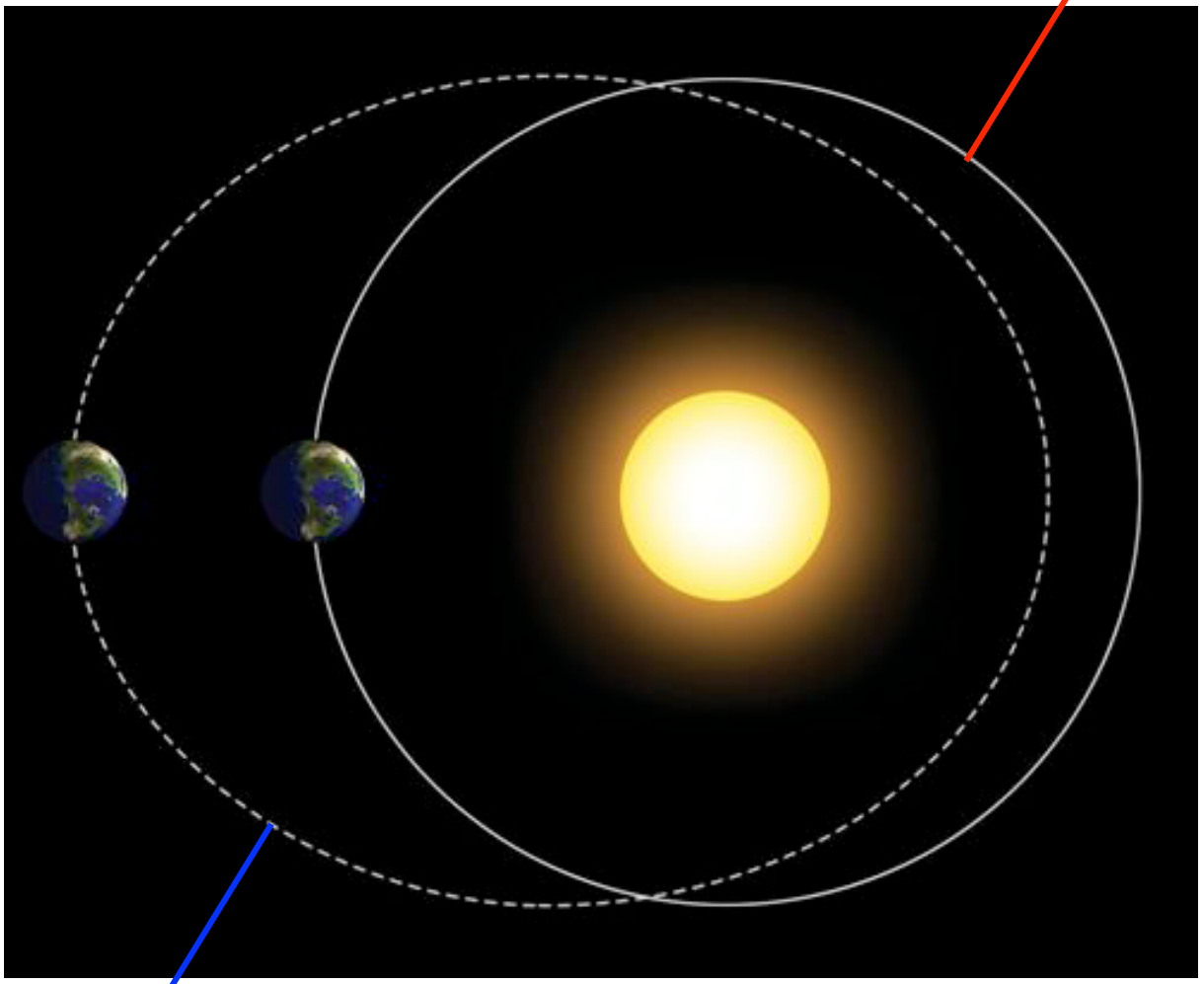
- Eccentricity of Orbit



Low Eccentricity



High Eccentricity

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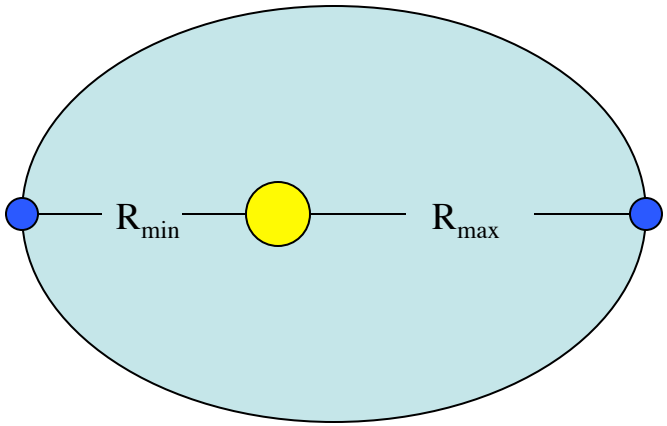
  - varies between 22 and 24.5° (41000 year period)

    less tilt = less seasonal variation

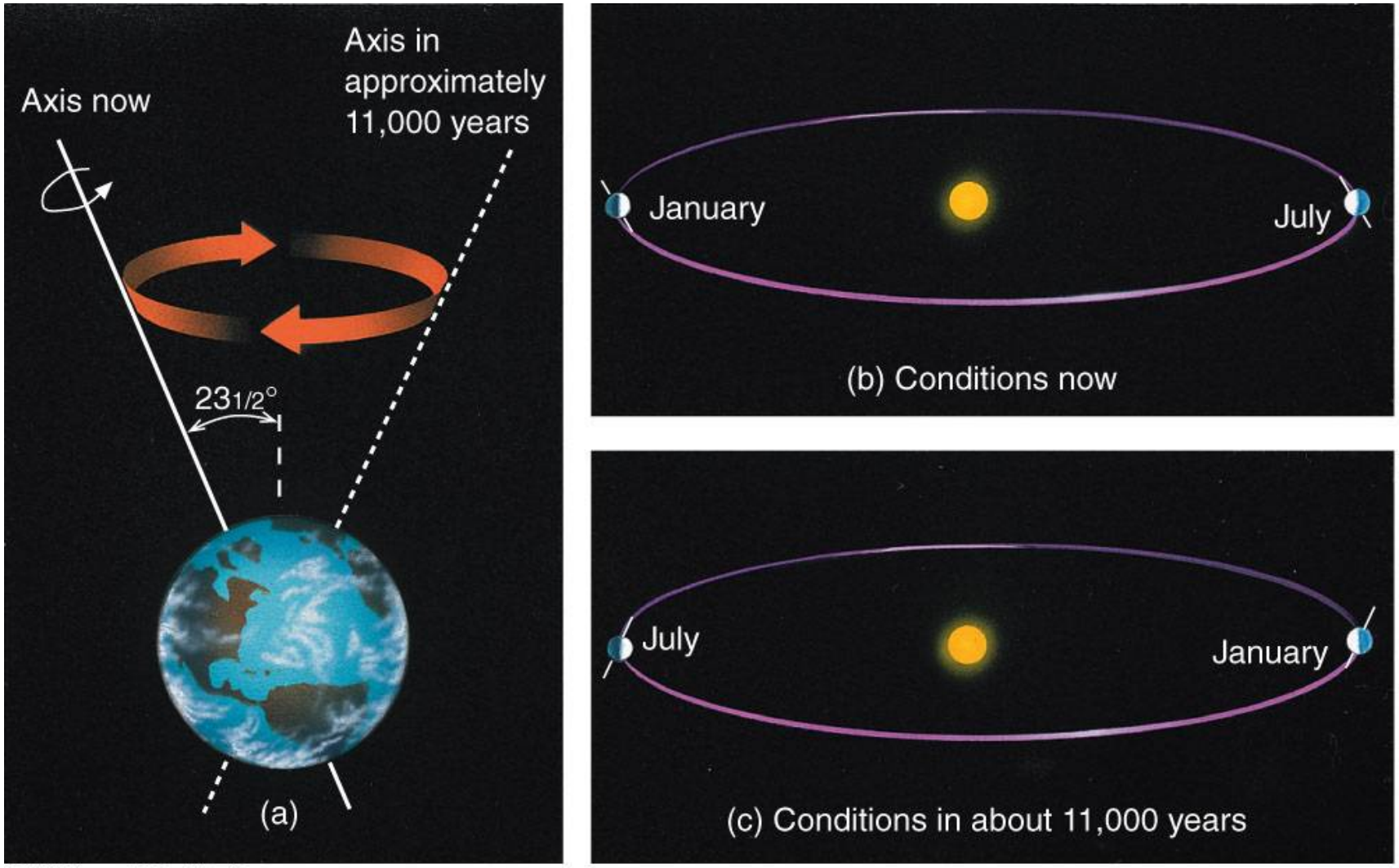
    = glaciers increase (no summer melt)

- Eccentricity of Orbit
  - $R_{min}/R_{max} = 0.97$ (currently low eccentricity)
  - $R_{min}/R_{max} = 0.91$ (50000 years from now high eccentricity)

    high eccentricity => solar energy will vary more during year



- Precession
  - currently closest to sun in January
  - in 11500 years, closest to sun in July



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- Precession
  - currently closest to sun in January
  - in 11500 years, closest to sun in July
    => NH seasons will vary **more** than present
    => SH seasons will vary **less** than present
  - in 23000 years closest to sun in January again

Orbital cycles vary from 10000 to 100000 years
=> may help explain interglacial periods

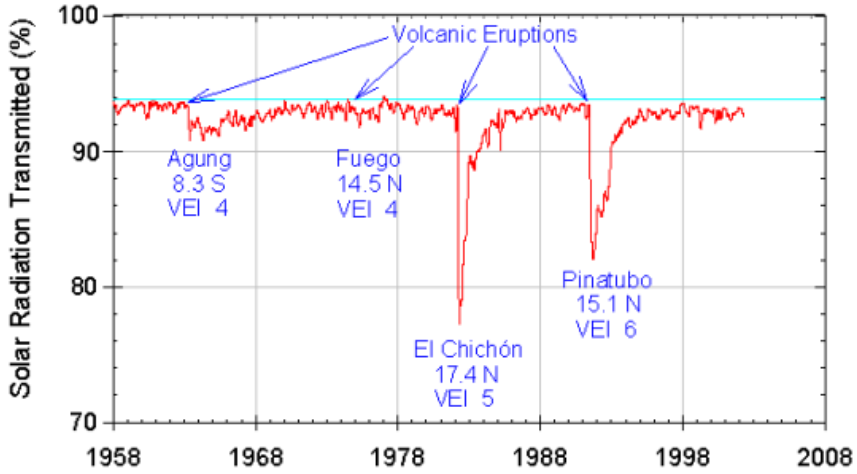
Volcanic Activity

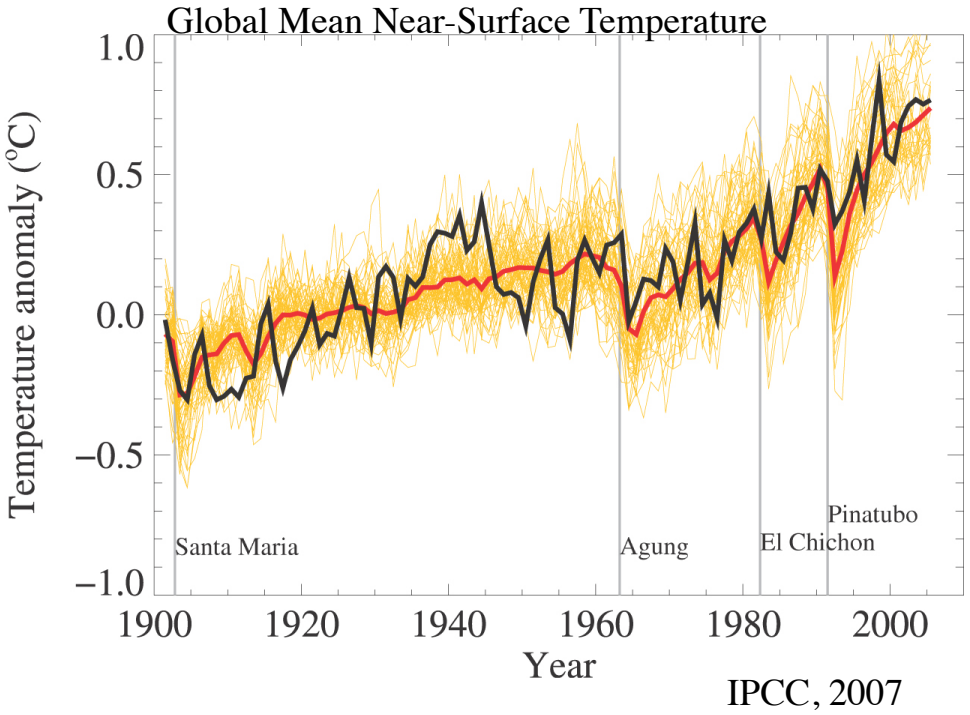
- some eruptions inject sulfur gas into stratosphere
- combines with water vapor to form aerosol haze
  => absorbs and backscatters solar radiation
  => net effect is a cooling of the Earth's surface

1992 Mt. Pinatubo
- global mean T decreased ~1°F within 1 year

Observations note sharp drop in solar transmission and average global temperature shortly after last 4 major volcanic eruptions.

Mauna Loa Observatory
Atmospheric Transmission
===>





IPCC, 2007

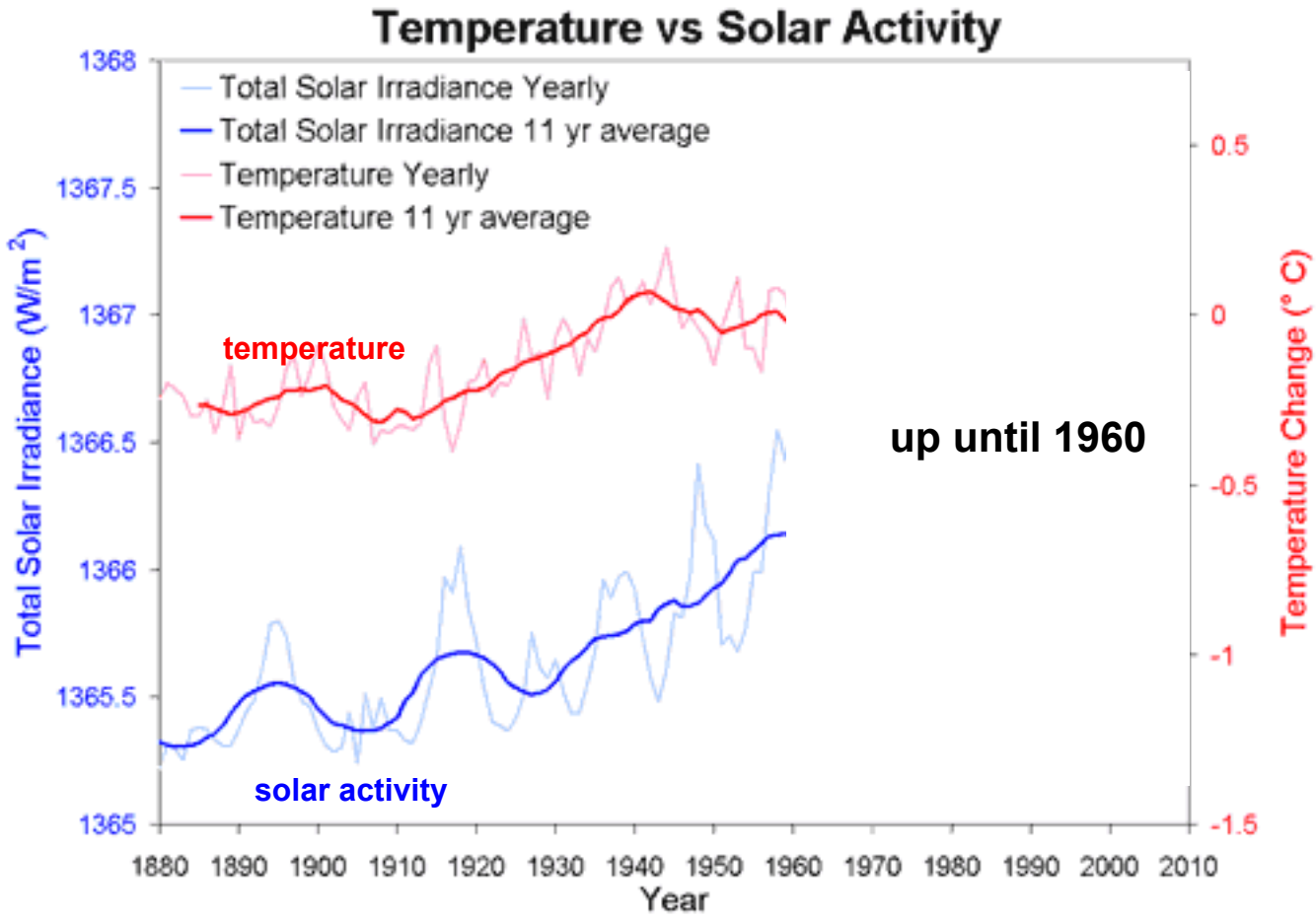
58 simulations from
14 different models

mean of all model runs
"ensemble mean"

observations

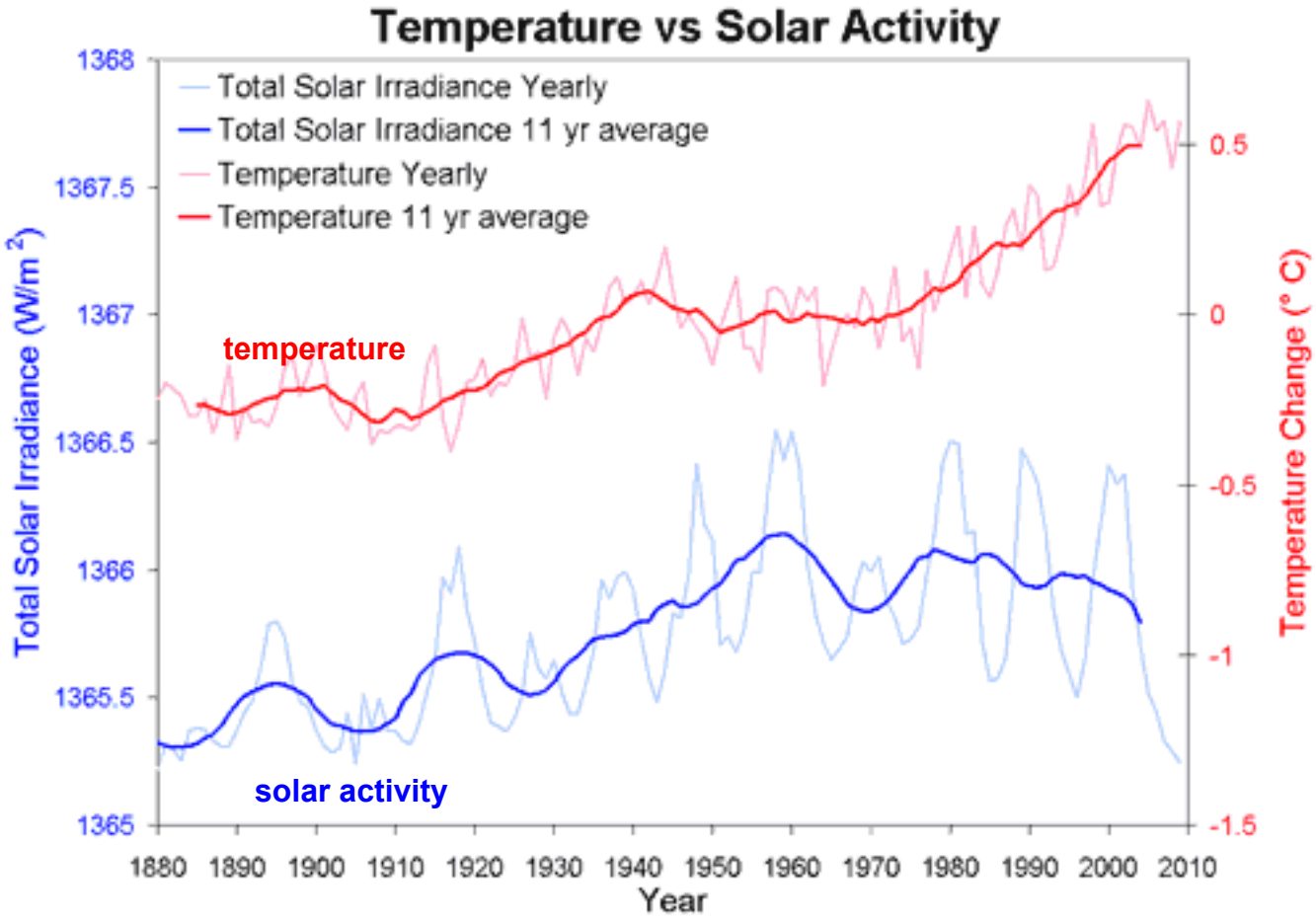
Models included both natural
and human-induced changes

Solar Activity



From Cook (2010)

Solar Activity



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How are we (humans) changing the climate?

- Fossil fuel burning
  increased CO2, etc = warmer temps

- Release of CFCs
  destroyed stratospheric ozone = increased UV radiation

- Deforestation/Biomass burning
  short term impact = large release of CO2 & aerosols
  long term impact = albedo change; CO2 uptake

- Cities/Urban heat islands
  more asphalt/concrete = warmer temps around cities

Why all the fuss now?

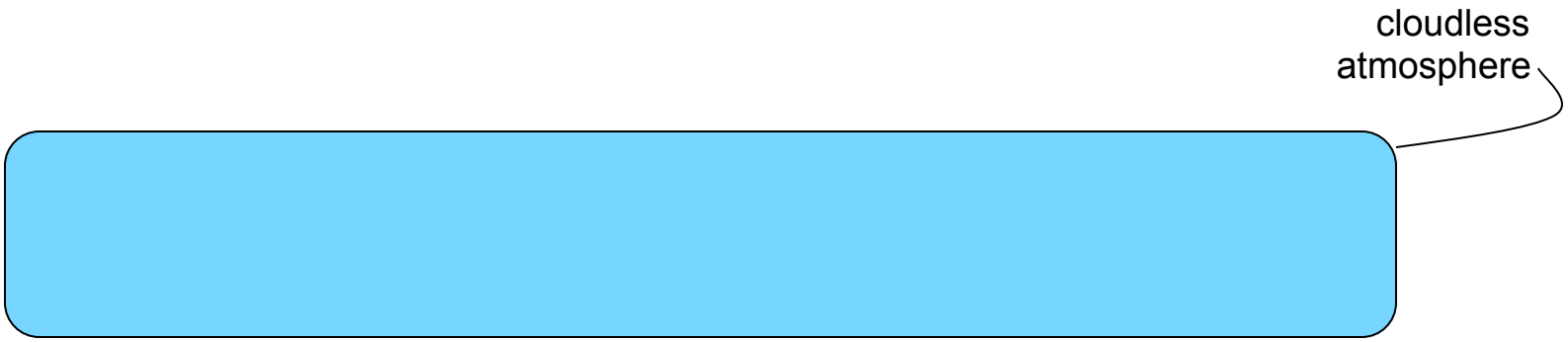
- population growing faster than ever
- we use more energy (per person) than ever

90% of population growth in developing countries

However, not just a third world problem:

	Population		Energy/person		Total Energy
U.S.	250 million	x	280×10^9 J	=	70×10^{18} J
India	835 million	x	8×10^9 J	=	7×10^{18} J

ATMOSPHERIC GREENHOUSE EFFECT



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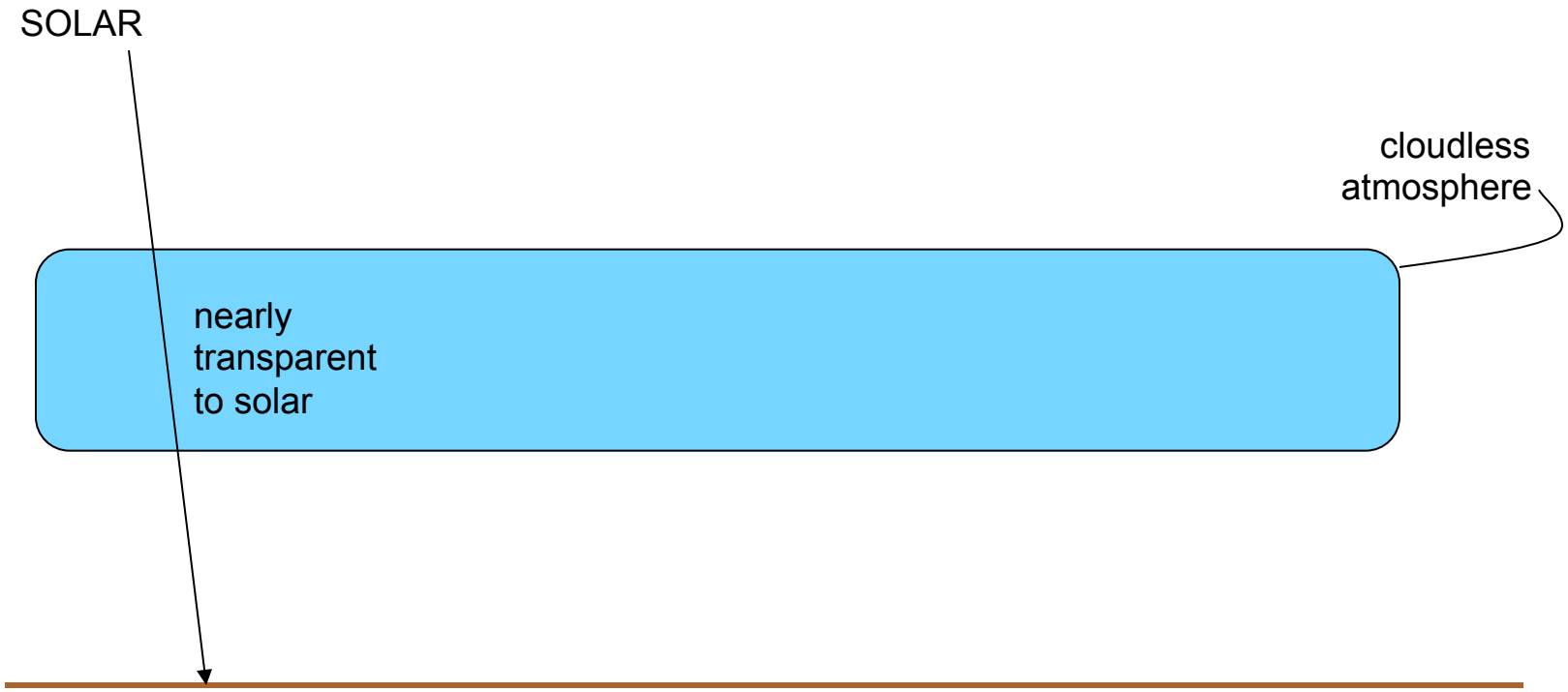

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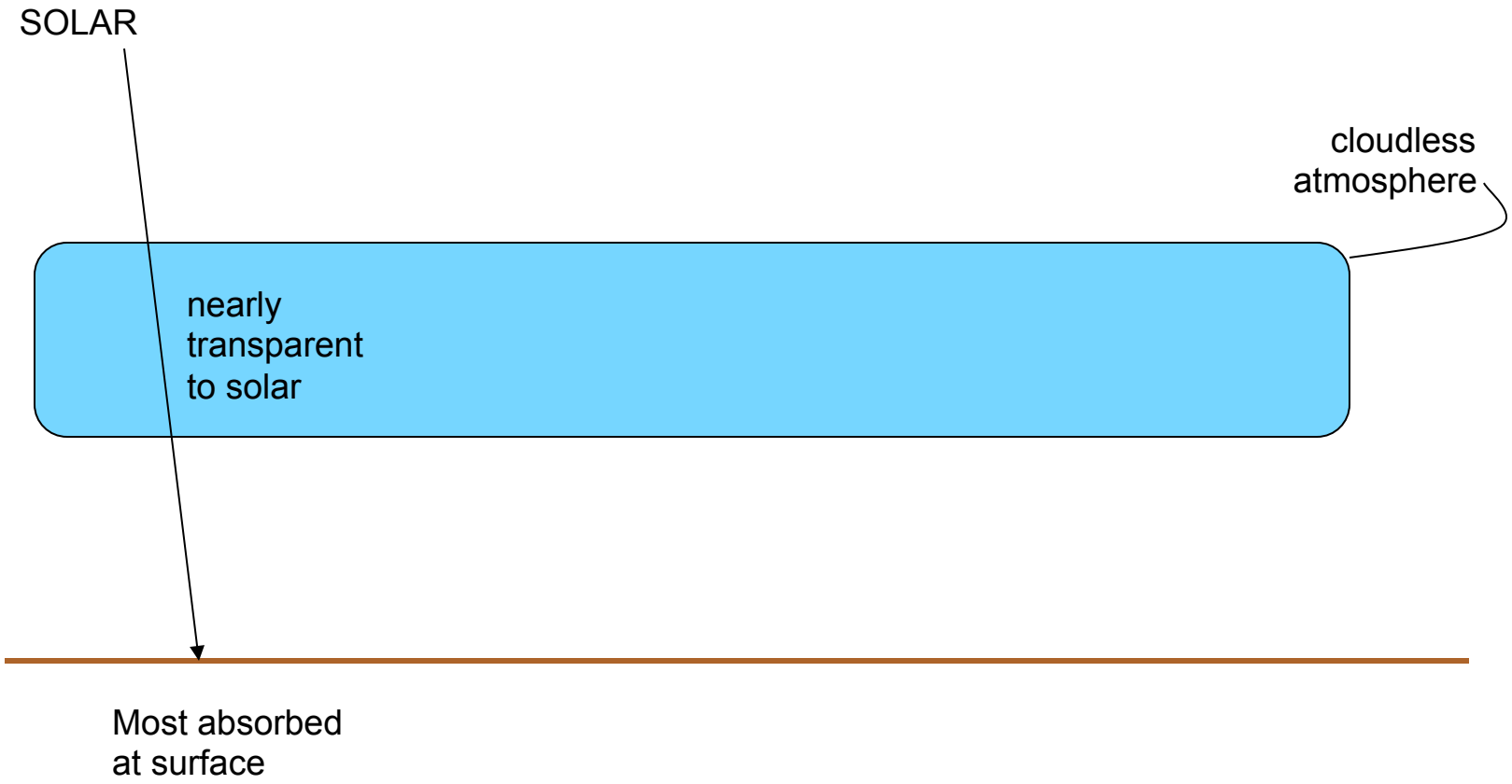

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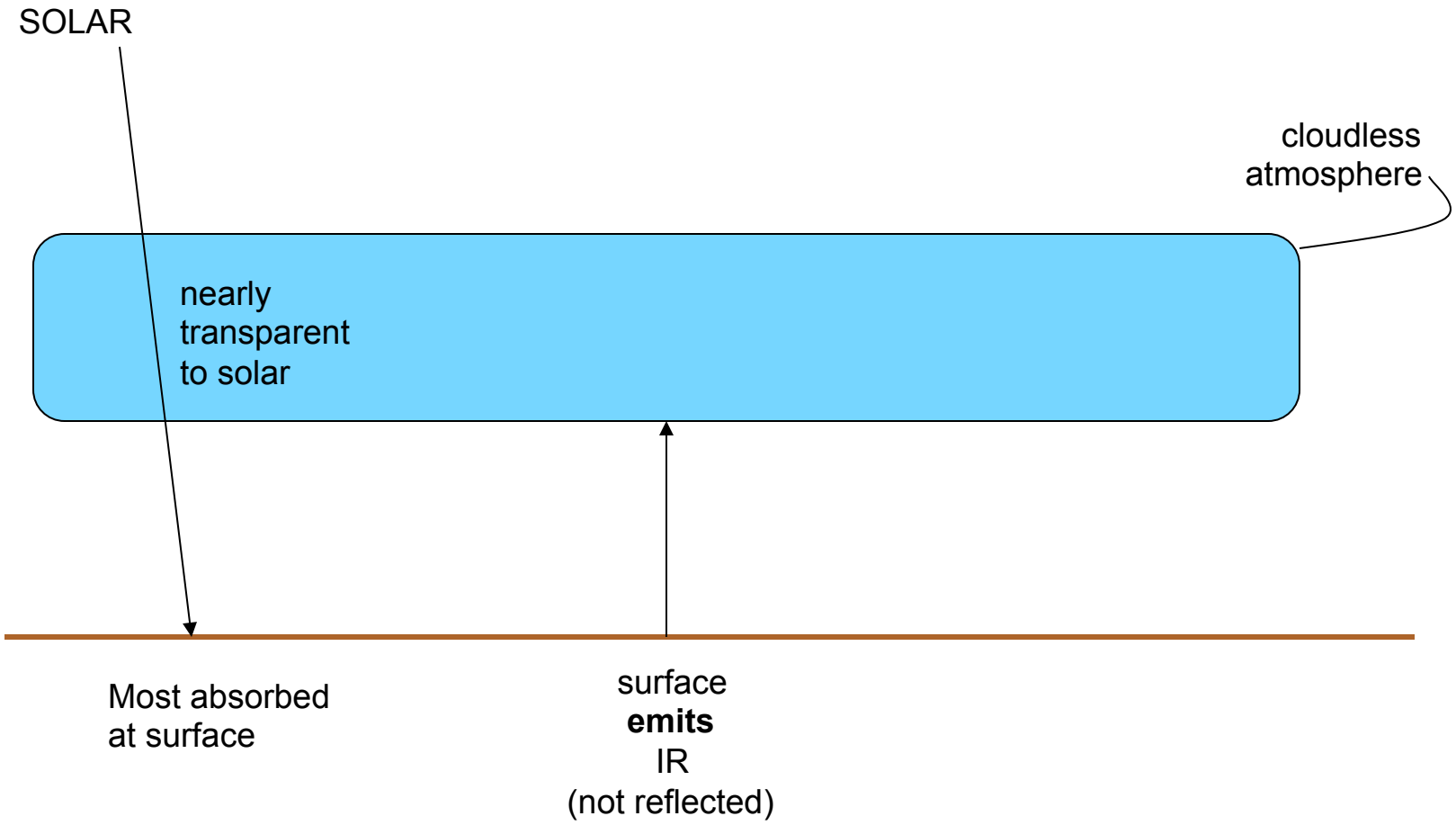

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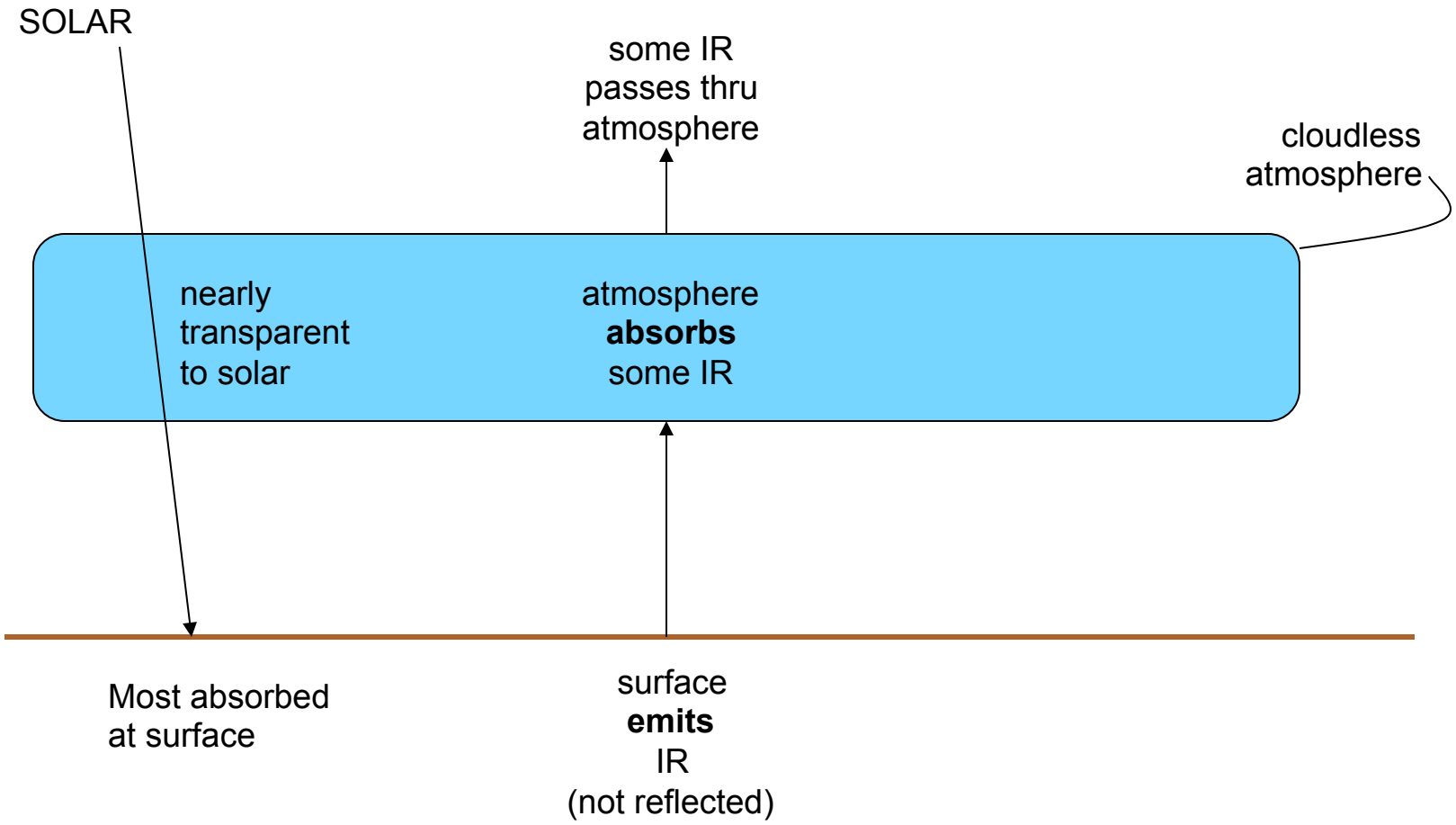

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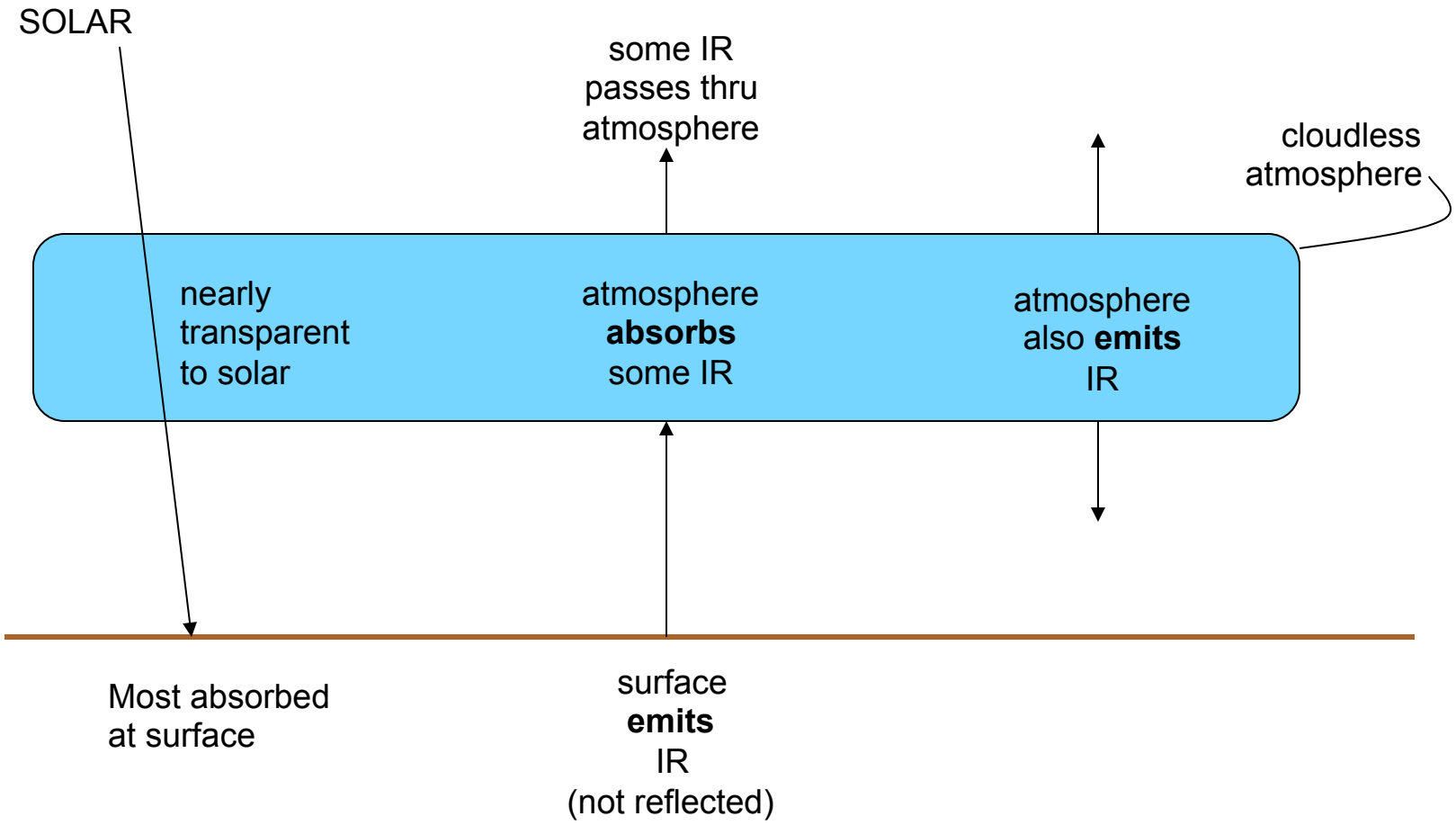

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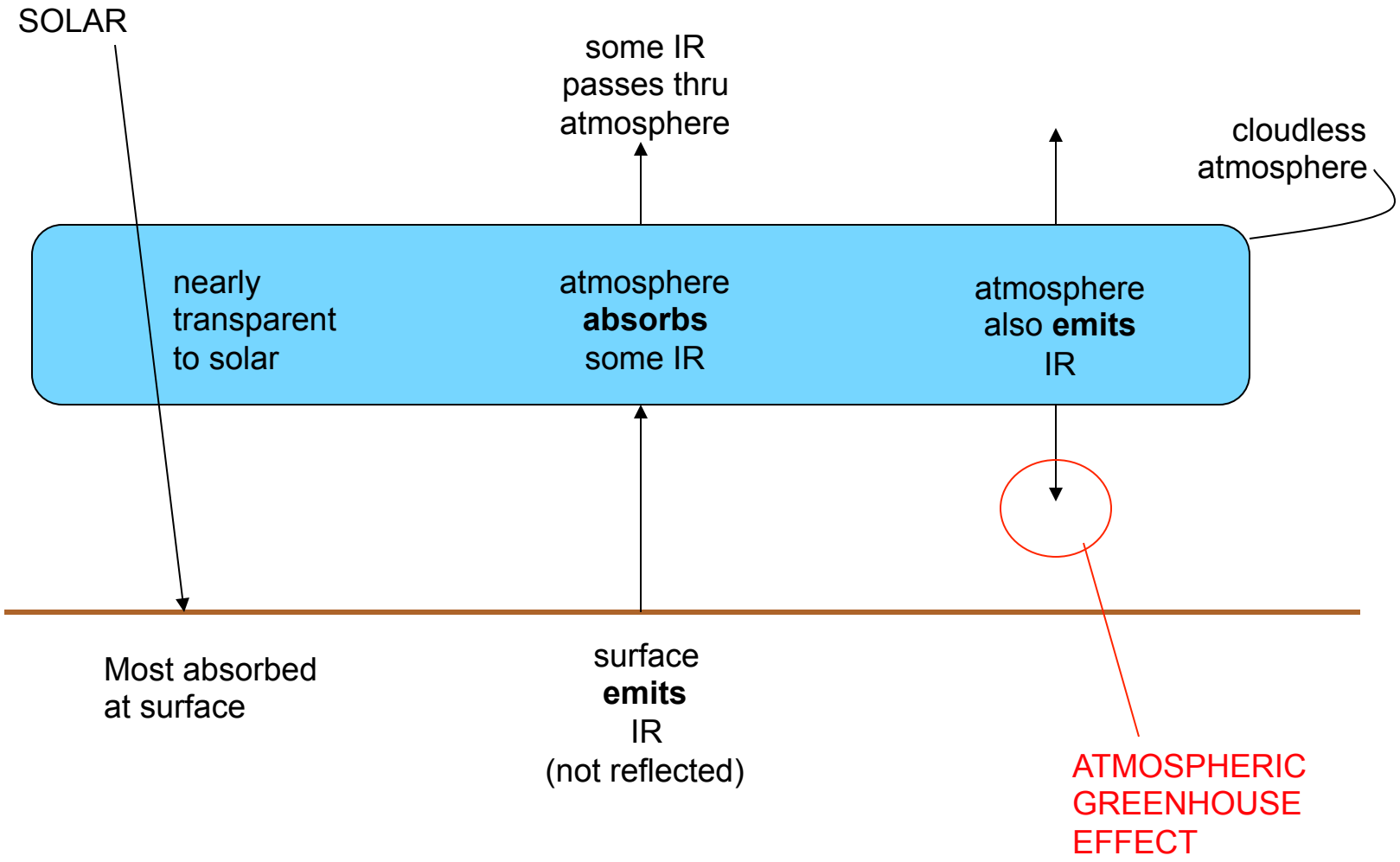

ATMOSPHERIC GREENHOUSE EFFECT