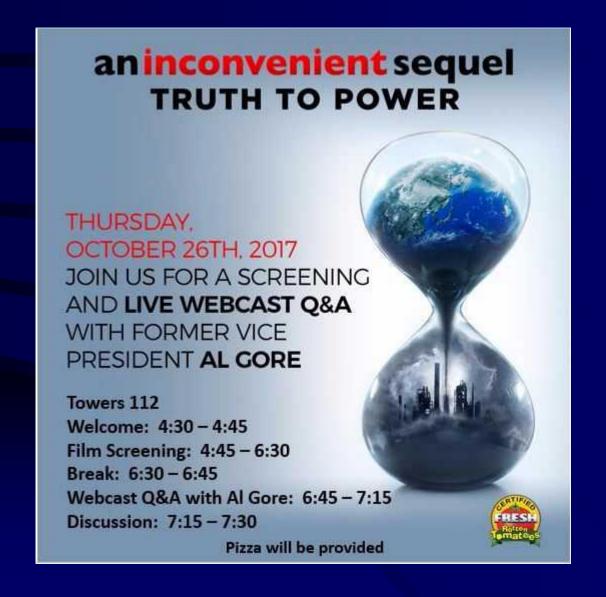
## The Greenhouse Effect

## A timely IS Event on Thursday



- Fairly bright, generally not too hard to see
- Smaller than Earth
- Density similar to that of the moon
- Surface temperature
   150–250 K
- Day ~ 24.6 hours
- Year ~ 2 Earth years
- Thin atmosphere, mostly carbon dioxide
  - 1/150 the pressure of Earth's atmosphere
- Tiny magnetic field, no magnetosphere

## Mars



## Mars

- Northern Hemisphere basically huge volcanic plains
  - Similar to lunar maria
- Valles Marineris –
   Martian "Grand Canyon"
  - 4000 km long, up to 120 km across and 7 km deep
  - So large that it can be seen from Earth



## Martian Seasons: Icecaps & Dust Storms



## Martian Surface

Iron gives the characteristic Mars color: rusty red!

Sojourner View of Viking 1 1 m rock

## Martian Panorama

Note: the sky is not black as on the moon, but pale pink of the dust in the atmosphere!

Video: Curiosity Landing

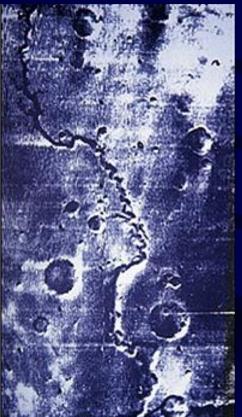
"Twin Peaks" – about 1-2 km away



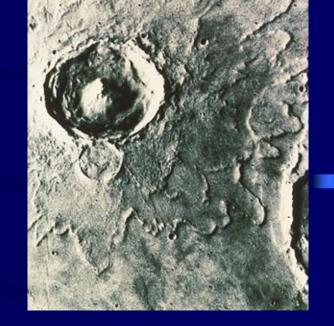
## Water on Mars?

Mars

Louisiana





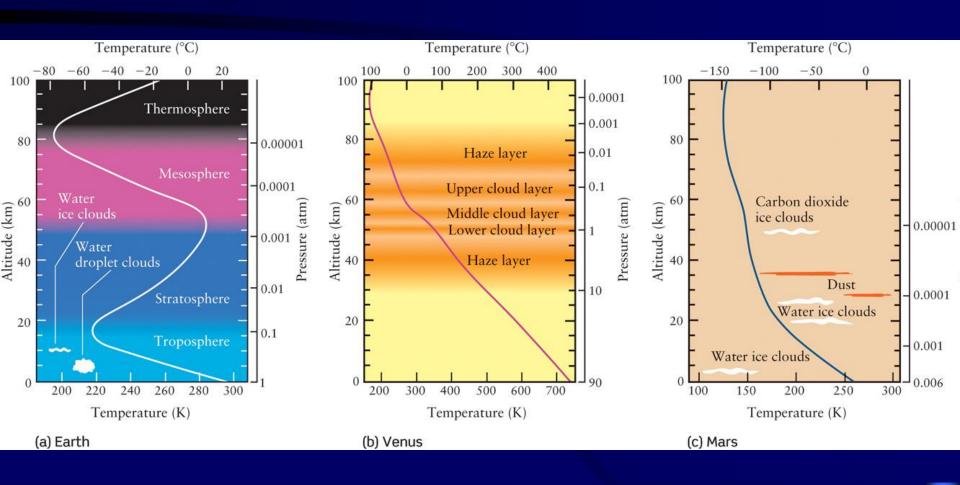




Runoff channels

**Outflow Channels** 

## Terrestrial Atmospheres



## Atmospheric Histories

- Primary atmosphere: hydrogen, helium, methane, ammonia
  - Too light to "stick" to a planet unless it's very big → Jovian Planets
- Secondary atmosphere: water, CO<sub>2</sub>, SO<sub>2</sub>, ...
  - Outgassed from planet interiors, a result of volcanic activity

## Atmospheric Histories - Venus

- Venus is closer to Sun than Earth →hotter surface
- Not a lot of liquid water on surface initially
- CO<sub>2</sub> could not be absorbed by water, rocks because of higher temperatures
- → run-away Greenhouse effect: it's hot, the greenhouse gases can't be be stored away, it gets hotter ...

## Earth's Atmospheric History

- Volcanic activity spews out water steam
- Temperature range allowed water to liquify
- CO<sub>2</sub> dissolves in oceans, damping greenhouse effect
- More water condenses, more CO<sub>2</sub> is absorbed
- If too cold, ice forms → less cloud cover → more energy
- No oxygen at this point, since it would have been used up producing "rust"
- Tertiary atmosphere: early life contributes oxygen
  - 1% 800 Myrs ago, 10% 400 Myrs ago

## Mars – Freezing over

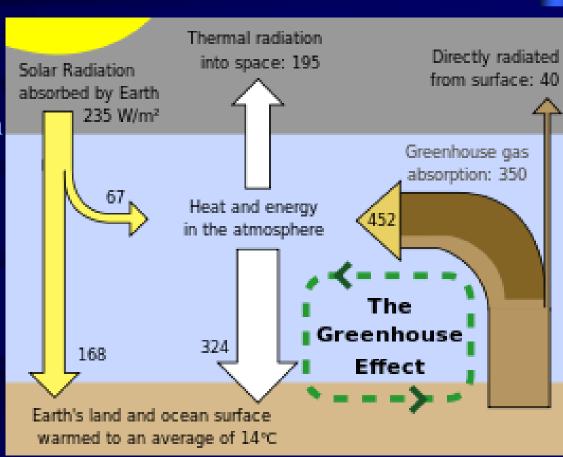
- Mars once had a denser atmosphere with liquid water on the surface
- As on Earth, CO<sub>2</sub> dissolves in liquid water
- But: Mars is further away from the Sun
  - → temperature drops below freezing point → inverse greenhouse effect
- permafrost forms with CO<sub>2</sub> locked away
- Mars probably lost its atmosphere because its magnetic field collapsed, because Mars' molten core cooled down

#### COSMIC CONNECTIONS Evolution of Terrestrial Atmospheres Earth, Venus, and Mars formed with similar original atmospheres. However, these atmospheres changed dramatically over time due to factors such as planetary size and distance from the Sun. Earth: active plate tectonics "recycles" gases and maintains a moderate atmosphere. 6. Plants convert CO2 to O2; bacteria 2. H2O falls as rain; CO2 and 1. H2O, CO2, SO2, and N2 are convert nitrates to N2 and O2. SO2 dissolve in the oceans; outgassed from Earth volcanoes N2 goes into nitrates. on an ongoing basis. Clouds Oceans 5. The liberated H2O, 3. CO2, SO2, and some CO2, and SO2 rise upward H<sub>2</sub>O are incorporated into sedimentary rocks. by volcanic action. - Sediment 4. Sedimentary rocks are eventually subducted to great depths, where heat liberates the gases. Venus: no plate tectonics and more intense sunlight gives a thick atmosphere. S Ultraviolet light 2. Sunlight warms Venus more than Earth, H<sub>2</sub>O, CO<sub>2</sub>, SO<sub>2</sub>, and N<sub>2</sub> are outgassed from Venusian so H2O does not fall as rain. There are no volcanoes on an ongoing basis. oceans, so CO2 remains in the atmosphere 3. Ultraviolet light from the and intensifies the greenhouse effect. sun breaks apart some H2O Atmosphere molecules; hydrogen escapes into space. 4. H2O that does not escape combines with SO2 to make H2SO4 (sulfuric acid) in Venus's clouds. Surface 5. Remaining SO2 is locked up in sulfate minerals. Mars: no plate tectonics, weak gravity, and feeble sunlight gives a thin atmosphere. S Ultraviolet light 1. H2O, CO2, SO2, and N2 were 2. Sunlight warms Mars less than outgassed from Martian volcanoes; Earth, so H2O fell as rain; CO2 3. Ultraviolet light from the sun broke this stopped billions of years ago and SO2 dissolved in the water. apart some H2O and N2 molecules; as the planet's interior cooled. the weak gravity allowed H, N, and O atoms to escape into space. 4. Removing CO2 and H2O from the atmosphere reduced the greenhouse effect, lowering temperatures. H<sub>2</sub>O froze beneath the surface, while CO<sub>2</sub> and SO<sub>2</sub> Permafrost went into rocks and the regolith. 5. There is no plate tectonics on Mars thanks to its small size. Gases that go into the surface are not recycled into the atmosphere.

#### NASA Jet Propulsion Laboratory

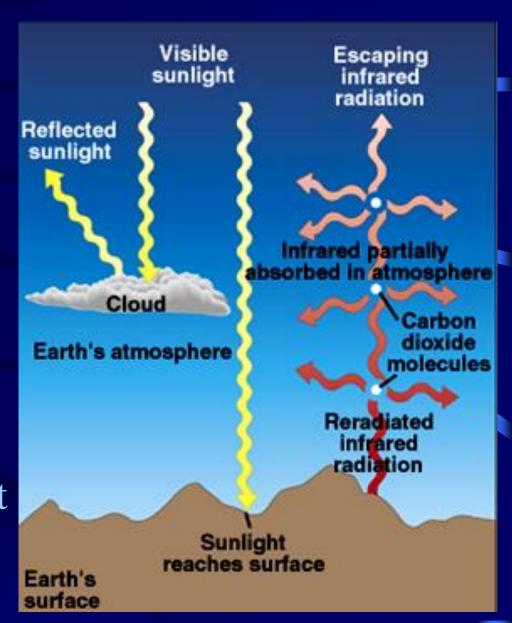
## Greenhouse Effect

- Earth absorbs energy from the Sun and heats up
- Earth re-radiates the absorbed energy in the form of infrared radiation
- The infrared radiation is absorbed by carbon dioxide and water vapor in the atmosphere
- Heats earth by about 40K, up from 250K without greenhouse effect. Significant because it makes surface temp above the freezing point of water

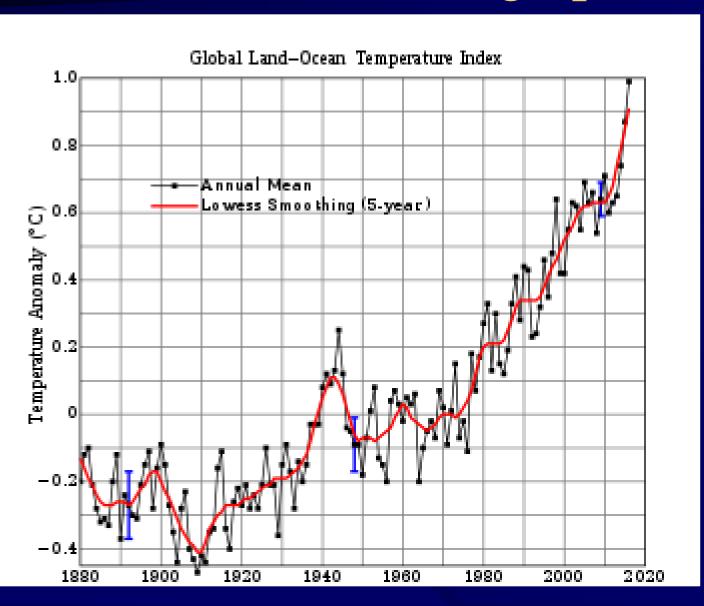


## Global Warming

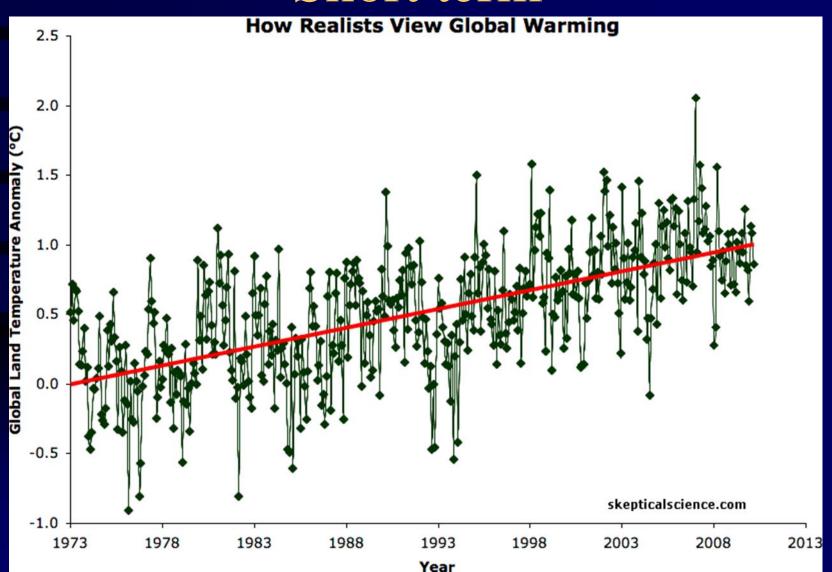
- Excessively "politicized" topic
- Very complex problem scientifically
- Slow changes over long periods of time
- Sources of heating, sources of cooling themselves are temperature dependent



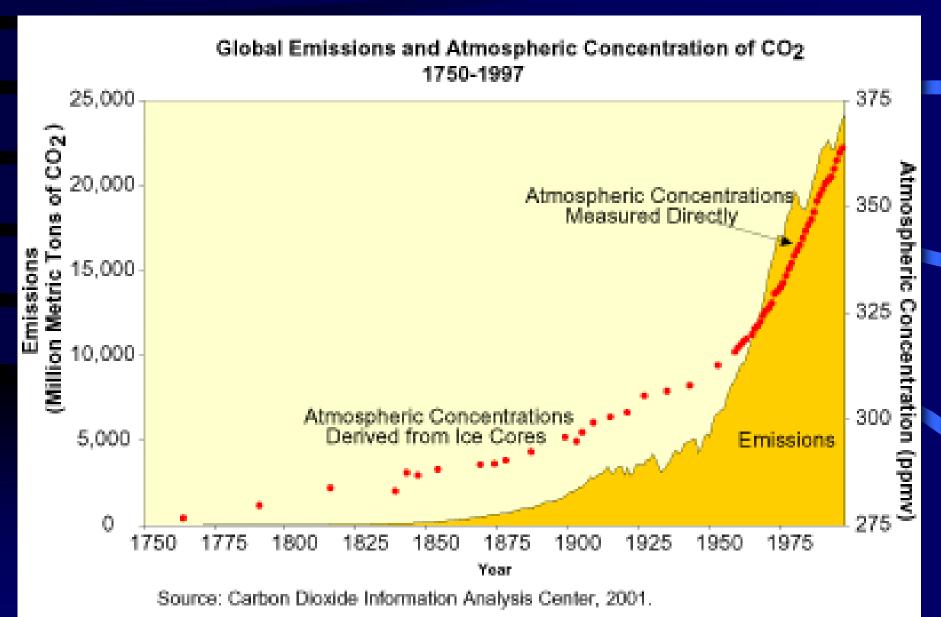
## The Earth is warming up!



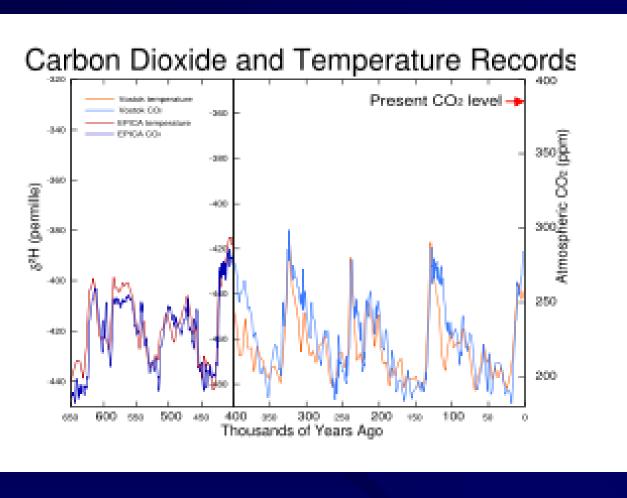
## Noise vs Signal, Long term vs Short term



## Man-made CO<sub>2</sub> in the Atmosphere goes up



## Correlation: Temperatures rise when Carbon Dioxide levels rise



• This is true since prehistoric times

## More evidence of global warming



This is what Whitechuck Glacier in Glacier Peak Wilderness in the U.S. state of Washington looked like in 1973.

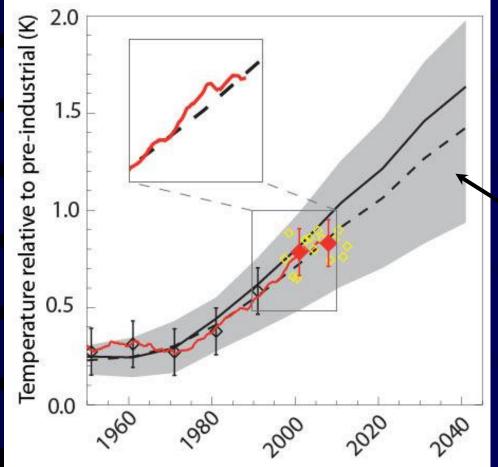


In a similar view of Whitechuck as seen in 2006, where this branch of glacier retreated 1.9 km (1.2 mi).

http://en.wikipedia.org/wiki/Retreat\_of\_glaciers\_since\_1850



Boulder Glacier, Washington state



# Predictions are observed to be correct — climate model supported! prediction in 1999

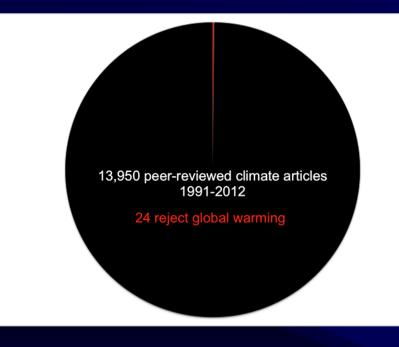
*Nature Geoscience* **6**, 243–244 (2013)

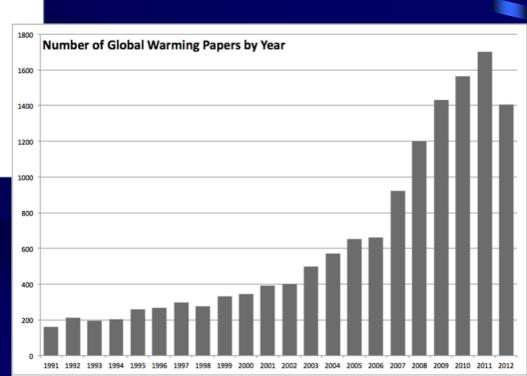
doi:10.1038/ngeo1788

Published online 27 March 2013

The climate forecast published in 1999 is showed by the dashed black line. Actual temperatures are shown by the red line (as a 10-year mean) and yellow diamonds (for individual years). The graph shows that temperatures rose somewhat faster than predicted in the early 2000s before returning to the forecasted trend in the last few years.

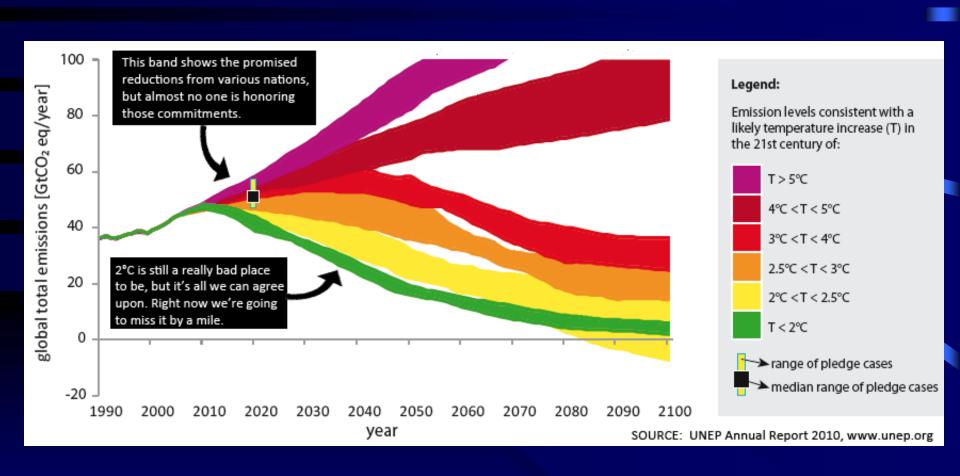
# Overwhelmingly, scientists agree that global warming is real





Summary of global warming impacts											
	Increase in global mean temperature relative to the late 20th century										
-	0	1	2	3	4	5	6	7	8	9 °F	
Physical	(A)	The risks associated with some extreme weather events increase with temperature									
	-Other effects include sea level rise and ocean acidification. Warming could be irreversible for several millennia.										
The larger the increase in temperature, the more species will be at risk of extinction											
				20-30% at risk of			furti	ner extinc	tions		
Social	-Mix of positive and negative impacts. Developing countries are the most vulnerable to negative impacts										
	The negative impacts of climate change tend to increase with temperature.  Larger temperature increases will be more difficult to adapt to.										
Large- scale impacts	The risk of large-scale and/or abrupt impacts increases with temperature  Partial deglaciation of Greenland and West Antarctic ice sheets adds 4-6 m (13-20 ft) or more to sea level rise										
	0	1	io I	2		3		4		5 °C	

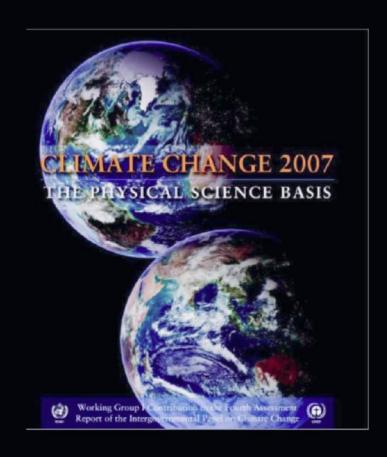
## We're not doing nearly enough!



## Indicators of a Warming World



#### THIS is the consensus:



**IPCC 2007** 

"The observed widespread warming of the atmosphere and ocean, together with ice mass loss, support the conclusion that it is extremely unlikely that global climate change of the past fifty years can be explained without external forcing, and very likely [90%] that it is not due to known natural causes alone."