Physics 112
Star Systems

Lecture 11
The Terrestrial Worlds
Earth

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There’s no place like home…
  There’s no place like home…
  There’s no place like home…

Frank L. Baum “The Wizard of Oz”
Worlds of Rocks and Ice
Metals, Rocks and Ices

Density of Ice is 1 gram/cm$^3$

Density of Rock (Silicates) 3 gram/cm$^3$

Density of Metals 8 gram/cm$^3$
Comparative Planetology

Venus
- Mass: $4.87 \times 10^{24}$ kg
- Diameter: 12,104 km
- Density: 5.25 gm/cm$^3$
- 0.72 AU from the Sun
- Rotation: - 243 days (retro)
- Revolution: 224.7 days

Earth
- Mass: $5.97 \times 10^{24}$ kg
- Diameter: 12,756 km
- Density: 5.52 gm/cm$^3$
- 1.0 AU from the Sun
- Rotation: 1 day
- Revolution: 365.26 days

Mars
- Mass: $6.42 \times 10^{23}$ kg
- Diameter: 6,794 km
- Density: 3.94 gm/cm$^3$
- 1.52 AU from the Sun
- Rotation: 1.03 days
- Revolution: 687 days
Studying Terrestrial Worlds

Three Main Areas of Study
Lithosphere: Surface Rock
Hydrosphere: Liquids
Atmosphere: Gases

PLUS!
Magnetic Fields
Space-Weathering
Processes that Shape the Lithosphere

**Tectonism:** Forces affecting the Crust

**Volcanism:** Activity involving molten rock

**Impacts:** The effect of meteors or comets hitting the planet

**Gradation (Erosion):** The effect of wind or liquids
Planetary Interiors

Calvin J. Hamilton
Earth

Mass: $5.97 \times 10^{24}$ kg
Diameter: 12,756 km
Density: 5.52 gm/cm³

1.0 AU from the Sun
Rotation: 1 day
Revolution: 365.26 days

Surface Gravity: 9.8 m/s²
Surface Temp: 58.7° F
Atmos. Pressure: 1 atm

Atmospheric Composition:
- $N_2$ 78% nitrogen
- $O_2$ 21% oxygen
- Ar 0.9% argon
- $CO_2$ 0.04% carbon dioxide
- $H_2O$ 3% water vapor
The Earth itself is about 4.5 billion years old. We know this mainly from studying isotope ratios (radioisotope dating), although there is much other evidence from other sources, other bodies in the solar system, accumulation of the lunar regolith, etc.

The Earth’s surface is affected by geological processes and so many of its features are much younger. This is what we mean when we talk about the age of the surface.

The age of Earth’s surface is about 100-300 million years.
Earth’s Lithosphere

(picture from Glencoe text, Earth Science)
Plate Tectonics

The Earth’s crust is shattered into a set of plates that float and move on the molten rock below.

http://en.wikipedia.org/wiki/Continental_drift
Continental Drift

In 1596 by the Dutch map maker Abraham Ortelius in the third edition of his work *Thesaurus Geographicus* suggested that the continents had once been joined and were separated by earthquakes and floods.

This idea was proposed again by Alfred Wegener, a German meteorologist and geologist in his book "Origin of Continents and Oceans."

He estimated that 200 million years ago the continents were joined together, forming a large supercontinent he called Pangaea, meaning "All-earth".

NASA's Goddard Space Flight Center monitors Earth crustal movements using satellite laser ranging measurements. Maui Hawaii is moving northwest toward Japan at about 3 inches per year.

Alfred Wegener (1880-1930),

http://en.wikipedia.org/wiki/Continental_drift
Continental Drift

http://pubs.usgs.gov/gip/dynamic/historical.html
http://en.wikipedia.org/wiki/Continental_drift
Continental Drift

Fossil distributions of various animal species confirm the continental drift hypothesis.

The Atlas Mountains in Morocco are in fact the same mountain range as the Appalachians in upstate New York!

Formation of the Himalayas

http://en.wikipedia.org/wiki/Continental_drift
Earthquakes

1906 San Francisco earthquake
damage at 7th and Mission

"The street was like a heaving sea,
frozen in one of its wildest contortions."

http://www.cr.nps.gov/seac/earthqke.htm

2002 Upstate NY earthquake
April 20, 2002. M 5.1 (Richter Scale)
Impact Craters on Earth

There are approximately 172 identified impact craters on Earth. Erosion rapidly destroys the evidence of such impacts, so that evidence of only the largest impacts remain.

Recently, amateur enthusiasts have discovered new craters using Google Earth.

http://www.gearthblog.com/kmfiles/impacts.kmz

Lac à l'Eau Claire (Clearwater Lakes) in Quebec is the result of a double impact of a pair of asteroids over 290 million years ago.
Barringer Meteorite Crater in Arizona

Approximately 50,000 years ago a nickel-iron meteorite about 150 feet across weighing about 300,000 tons slammed into Arizona at a speed of 28,600 miles per hour. The explosion created by its impact was equal to 2.5 megatons of TNT, or about 150 times the force of the atomic bomb that destroyed Hiroshima.

http://www.nationalgeographic.com
The crater is about 0.8 mile wide, 570 feet deep. The rim rises about 150 above the surrounding plain.
Anatomy of the Crater

Crater Rim

Original Surface

Gullies formed by erosion from rain

Crater Floor

Photo: KH Knuth
What Caused the Crater?

In the late 1800s, no one knew what caused the crater. People had always known about meteorites, but no one had ever seen one big enough to make a significant hole.

In 1891 Grove Karl Gilbert, the chief geologist for the U.S. Geological Survey, set out to test the two hypotheses about the crater.

- the crater was created by the impact of a giant meteorite
- the crater was the result of an explosion of superheated steam, caused by volcanic activity

A large meteorite was not found. Although small ones were found around the crater. Nor were compass needles affected, again ruling out a buried meteorite.

Gilbert concluded that it must have been a steam explosion, even though there were no volcanic rocks.

In 1902 Daniel Moreau Barringer, a mining engineer heard about the crater. The fact that the small meteors were found with the ejected rocks, but not buried in the original rock layers made him believe that it was a meteorite, but that it had been destroyed.

He presented his arguments for the impact theory to the Academy of Natural Sciences in Philadelphia in 1906 and 1909.

“The evidence included:

A. The presence of millions of tons of finely pulverized silica, which could only have been created by enormous pressure.
B. The large quantities of meteoritic iron, in the form of globular "shale balls", scattered around the rim and surrounding plain.
C. The random mixture of meteoritic material and ejected rocks.
D. The fact that the different types of rocks in the rim and on the surrounding plain appeared to have been deposited in the opposite order from their order in the underlying rock beds.
E. The absence of any naturally occurring volcanic rock in the vicinity of the crater.”

http://www.barringercrater.com/science/
The Barringer Meteorite Impact

Under the impact site a layer of rock fused by the impact is formed. This is called impact breccia as it consists of fragments of the previous rock structure fused into a new matrix.

The layers of rock blasted out of the crater are folded over forming the crater rim.

http://www.barringercrater.com/science/
The origin of the Moon’s craters was thought to be volcanic. Ironically, Gilbert, who thought Meteor Crater was not due to an impact was in 1893 the first to suggest that the Moon’s craters were the remains of impact events.

Scientists were sharply divided until the work of Gene Shoemaker in 1963 who wrote a seminal paper comparing the geology of Meteor Crater to the craters created by nuclear tests in Nevada.

Gene Shoemaker was to be the geologist on Apollo 17, but could not go due to a medical condition.

“Not going to the Moon and banging on it with my own hammer has been the biggest disappointment in life”

http://www2.jpl.nasa.gov/sl9/news82.html
When Gene Shoemaker died in 1997, his ashes were launched in a memorial capsule aboard Lunar Prospector to the moon. The capsule was carried in a vacuum-sealed, aluminum sleeve deep inside the spacecraft. It was wrapped in a piece of brass foil inscribed with an image of a Comet Hale-Bopp, an image of Meteor Crater, and a passage from William Shakespeare's "Romeo and Juliet":

"And, when he shall die,
Take him and cut him out in little stars,
And he will make the face of heaven so fine
That all the world will be in love with night,
And pay no worship to the garish sun."
- Romeo and Juliet

http://www2.jpl.nasa.gov/s19/news82.html
Impact Mechanics (from Shoemaker)

2. Meteorite enters ground, compressing and fusing rocks ahead and flattening by compression and by lateral flow. Shock into meteorite reaches back side of meteorite.

3. Rarefaction wave is reflected back through meteorite, and meteorite is decompressed, but still moves at about 5 km/sec into ground. Most of energy has been transferred to compressed fused rock ahead of meteorite.

4. Compressed slug of fused rock and trailing meteorite are deflected laterally along the path of penetration. Meteorite becomes liner of transient cavity.

5. Shock propagates away from cavity, cavity expands, and fused and strongly shocked rock and meteoritic material are shot out in the moving mass behind the shock front.

6. Shell of breccia with mixed fragments and dispersed fused rock and meteoritic material is formed around cavity. Shock is reflected as rarefaction wave from surface of ground and momentum is trapped in material above cavity.
7. Shock and reflected rarefaction reach limit at which beds will be overturned. Material behind rarefaction is thrown out along ballistic trajectories.

8. Fragments thrown out of crater maintain approximate relative positions except for material thrown to great height. Shell of breccia with mixed meteoritic material and fused rock is sheared out along walls of crater; upper part of mixed breccia is ejected.

9. Fragments thrown out along low trajectories land and become stacked in an order inverted from the order in which they were ejected. Mixed breccia along walls of crater slumps back toward center of crater. Fragments thrown to great height shower down to form layer of mixed debris.

Fig. 4—Diagrammatic sketches showing sequence of events in formation of Meteor Crater, Arizona.
You can see the crater from space.

Note the crater rim and the shadow it casts on the crater floor. This would allow you to determine the height of rim and depth of the crater.

Note the remains of the ejecta blanket.

What other features are observable in this image?
The crater is a half a mile across. It was originally about 400 feet deep. Over the past 300,000 years the wind gradually filled it with sand and today the crater floor is only about 170 feet below the rim, which rises 80 feet above the flat desert.

The floor of the crater formed its own ecosystem since the ground is more porous than the original desert and the rim offers some shade. Trees grow on the crater floor.

Manicouagan Crater, Ontario

This is the remains of an ancient impact that took place about 200 million years ago.

The crater is 40 miles in diameter, and due to erosion has become an annular lake.

The fin of the Space Shuttle Columbia can be seen in the image.
Volcanism
Volcanism

Kilahuea Hawaii
Volcan Osorno, Chile
Volcanism

Car embedded in hardened lava.
Photo: Univ. of Iowa, Dept of Geoscience
Volcanism
Mount St. Helens 1980 Eruption

http://www.britannica.com
http://www.ccrh.org/comm/moses/image/mosel/ashclds.jpg

Ash Clouds

Photographer Reid Blackburn's car after the eruption.
Mount St. Helens 1980 Eruption

Photo: Jim Nieland, U.S. Forest Service, Mount St. Helens National Volcanic Monument

Photo: Lyn Topinka

http://www.cet.edu/ete/modules/volcanoes/eruptanimation1.html
Mount St. Helens in Washington

Before and After an Earthquake

October 21, 2006
Volcanoes from Space

Krakatau, Indonesia

Mt. Vesuvius, Italy

http://volcano.und.edu/vwdocs/current_volcs/ikonos/ikonos.html
Volcanoes from Space

Nyaragongo, Dem. Rep. of Congo

Mt. St. Helens, USA

http://volcano.und.edu/vwdocs/current_volcs/ikonos/ikonos.html
Erosion: Water, Waves, Ice, Wind
Erosion

The Grand Canyon  (277 miles long, 1 mile deep, 10-18 miles wide)
Deer Creek Slicing Through Sandstone

Here you can see the effect of a river slowly eroding through sandstone.

http://www.kaibab.org/geology/gc_geol.htm
Rock Layers of the Grand Canyon

This image and the history that follows is from: http://www.kaibab.org/geology/gc_geol.htm
History of the Grand Canyon

The Earth was formed approximately 5 billion years ago.

The roots of the ancient mountain range that now lies at the bottom of the Grand Canyon were formed about 1.7 billion years ago.

There is then an unconformity of about 450 million year in which the rocks are missing.

At 1.25 billion years ago the first sedimentary layer, the Bass Formation, was laid down. Ancient coastal dwelling colonies of algae known as Stromatolites are preserved within this layer and indicate that the area was coastal at that time.

At 1.2 billion years ago the sea retreated leaving mud flats behind which eventually became the Hakatai Shale.

At 1.19 billion years a similar layer was deposited which is known as the Dox Formation. This was again formed of mudstones and shales and contains ripple marks as well as other features that indicate that it was close to the coast.

Between 1.25 and 1.1 billion years ago there was also some volcanic activity with the region of the Grand Canyon and this is when the Cardenas Basalts were formed.

Between 1 billion and 825 million years ago additional coastal and shallow sea formations, which are now classified as the Chuar group, were deposited.

There is then another unconformity of about 250 million years in which new rock layers were probably laid down but were completely eroded away.
History of the Grand Canyon

The Tapeats Sandstone was then deposited around 550 million years ago along long vanished coastline. There are places in the Canyon in which off shore islands have been found imbedded within this layer.

The Bright Angel Shale was deposited 540 million years ago and indicates that the ocean was again advancing.

The Muav Limestone was deposited around 530 million years ago at the bottom of a shallow sea.

The thick layer of Redwall Limestone which began to deposited around 330 million years ago indicates that the land was submerged for a great deal of time.

The Supai Group which rests atop the Redwall is dated at 300 million years ago and indicates that it was formed in an above water and coastal environment.

The Hermit Shale which was deposited around 280 million years ago contains many plant fossils which indicate that it was also above water.

The Coconino Sandstone represents the remains of a vast sea of sand dunes which was blown down from the north around 270 million years ago.

The layers found within Toroweap Formation contains both sandstone and limestone, indicating that it was sometimes coastal and sometimes submerged. These layers date to around 260 million years.

The top layer of the Grand Canyon, the Kaibab Limestone, contains many marine fossils which indicate that it originated at the bottom of the sea. This layer is around 250 million years old.

Rock layers younger than 250 million years have been eroded away and no longer exist in the immediate vicinity of the Grand Canyon.

The Rocky Mountains begin to form 60-70 million years ago and at some point later the Colorado River is born.
Grand Canyon from Space

http://www.spaceimaging.com/gallery/iowEEK/archive/05-04-24/grand_canyon_06_19_04_800.jpg
Rivers from Space

Mississippi Delta, Louisiana

Lake Nassar, Egypt
Wave Erosion

Wave erosion of cliffs at Southerndown near Bridgend, South Wales.
Glaciers are rivers of ice that slowly carve out valleys. River valleys are V-shaped. Glacial valleys are U-shaped.
Wind (Aeolian) Erosion

http://www.sunsetcities.com/Valley-of-Fire/Photos/DSCF0004-beehives-00.jpg
http://web.umr.edu/~rogersda/phd_research/arches_np.htm
Wind (Aeolian) Erosion: Dunes

Dunes along Kuiseb River, Namibia

http://photo.net/photo/pcd0738/great-sand-dune-hills-light-15

Frozen Dunes in Antarctica
Studying Terrestrial Worlds

Three Main Areas of Study
Lithosphere: Surface Rock
Hydrosphere: Liquids
Atmosphere: Gases

PLUS!
Magnetic Fields
Space-Weathering
The Earth has a magnetic field much like a bar magnet. Note that the North Pole is actually a south magnetic pole. This is why the north pole of your compass is attracted to it.
Currents in the spinning outer liquid iron core create a magnetic field that looks very much like a bar magnet.
Further from the Earth, the winds of electrically charged particles moving at 200 km/sec “blow” the field back forming a shock front and a magnetotail.
Anatomy of the Earth’s Magnetic Field

- Magnetopause
- Shock wave
- Magnetic field lines
- Solar wind
- Van Allen belts

Scale: 100,000 km
The Effect of Charged Particles

Electrically charged particles from the Sun (electrons, protons, and Helium nuclei) can become trapped by the magnetic field.

They spiral in along the field lines to the poles.

The regions where they are trapped are called the Van Allen Radiation Belts.
Auroras

When the Solar Winds are strong, these particles can collide with atoms in the Earth’s upper atmosphere. These collisions excite the air atoms resulting in the emission of light.

We call these lights:
Aurora Borealis
(Northern Lights)

Aurora Australis
(Southern Lights)
Auroras

An Aurora on Earth. Photo taken from the ISS
Auroras

An Aurora on Earth. Photo taken from the Space Shuttle
Auroras

An Aurora on Earth. Photo taken from the Space Shuttle
Auroras

An Aurora from the surface of Earth
Auroras

An Aurora from the surface of Earth
As the plates separate magma flows in to fill the space forming the Mid-Atlantic Ridge. Iron oxide in the lava aligns with the Earth’s magnetic field and is frozen into place as the lava hardens into rock. By observing the magnetic polarity of the rock along the growing ridge, we find that the Earth’s field has changed polarity 170 times in 100 million years. Currently the field is decreasing and it is thought a reversal is possible in as little as 2000 years from now.
Studying Terrestrial Worlds

Three Main Areas of Study
Lithosphere: Surface Rock
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PLUS!
Magnetic Fields
Space-Weathering
Space-Weathering

Space-weathering is the process of erosion due to interactions with celestial objects.

Solar wind enrichment and micrometeor impact erosion are two examples. This does not affect the Earth because the surface is shielded from these effects by both the magnetic field which deflects the solar wind and the atmosphere which vaporizes micrometeorites.

The lunar regolith however is due to space-weathering.
Studying Terrestrial Worlds

Three Main Areas of Study
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PLUS!
Magnetic Fields
Space-Weathering
Oceans (Typical Image of Earth)
Mountain Height and Ocean Depth

Water covers 71% of Earth’s surface.

The oceans are no more than 6.8 miles deep. Typical depths are about 5 miles, which is about the height of Mount Everest above sea level.
Oceans also Transport Heat

Thermohaline Circulation

- Deep water formation
- Surface current
- Deep current

Salinity (PSS)

32 34 36 38
The Hydrosphere

The Water Cycle

- Water storage in ice and snow
- Precipitation
- Snowmelt runoff to streams
- Infiltration
- Ground-water discharge
- Streamflow
- Spring
- Freshwater storage
- Surface runoff
- Water storage in the atmosphere
- Sublimation
- Evapotranspiration
- Evaporation
- Condensation
- Water storage in oceans

USGS

http://ga.water.usgs.gov/edu/watercycle.htm
Evolution of an Ocean

While exploring Continental drift, we saw the generation of The Atlantic Ocean.

The rifts generated by divergence of two plates is eventually flooded and becomes a new ocean.
Studying Terrestrial Worlds

Three Main Areas of Study
Lithosphere: Surface Rock
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PLUS!
Magnetic Fields
Space-Weathering
Atmospheric Profile

Earth's atmosphere

- temperature (°F)
- altitude (km)
- ozone layer (main concentration)
- stratosphere
- mesosphere
- thermosphere
- ionosphere, magnetosphere begin
- mesopause
- stratopause
- tropopause
- troposphere
- Mount Everest 8.85 km, 28%
- 90 km, 0.0001%
- 50 km, 0.1%

% at selected altitudes are percentages of sea-level pressure.

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Earth’s Upper Atmosphere
Atmospheric Circulation on Earth

Solar heating is greatest in the equatorial region.

The Poles are cooler.

So there is a temperature gradient from the equator to the poles.

Nature does not like gradients, and will work to equalize to.

Hot air will rise and cool by radiating infrared light into space. This forms **convection cells** that transport heat and air.
Coriolis Force

Because the equator is moving faster than the higher latitudes, air that moves northward races ahead of the surface and moves east. This force is called the **Coriolis Force**.

These simple convection cells break apart and form vortices and eddys.
Winds

The combination of the convection cells formed by hot rising air and the Coriolis Force, create winds that flow across the surface of the Earth in well-defined patterns.

Turbulent Flow caused by an Island
Air Motions due to High and Low Pressure

In the northern hemisphere, low pressure variations lead to counterclockwise wind flow; whereas high pressures lead to clockwise winds.

Storms are characterized by a Low Pressure system. They are generally called cyclones.
Hurricane Ivan
Anatomy of a Hurricane

http://serc.carleton.edu/research_education/katrina/understanding.html
Typhoon Nabi
Hurricane Eyewall

Hurricane as a Heat Engine (Carnot)

A-B. Warm Sea surface air is drawn toward the low pressure region at the center of the hurricane undergoing isothermal expansion.

B-C. It is lifted high into the atmosphere and expands adiabatically.

C-D. The air cools by radiation into space and is compressed isothermally.

D-A. The air drops from D to A and compresses adiabatically.

The net result is that the hot sea surface is cooled with the heat energy going into the high speed winds and radiation into space.

http://www.physicstoday.org/vol-59/iss-8/p74.html
Hurricane Katrina: 28 August 2005
Movie of 2005 Hurricanes
New Orleans in July 2006 (1 Year Later)
Dust Storm in Australia

12.11.2002
Gobi Desert Dust Storm in Beijing

http://www.lakepowell.net/asiandust.htm
Temperature of Earth

Sunlight heats the planet’s surface.

The upper atmosphere radiates away heat in the form of infrared radiation into space.
Temperature of Earth

Sunlight heats the planet’s surface.

The upper atmosphere radiates away heat in the form of infrared radiation into space.

These processes alone would lead to an average temperature of 0°F (-18°C)
Greenhouse Effect

Sunlight heats the planet’s surface.

The upper atmosphere radiates away heat in the form of infrared radiation into space.

Water and other gases like Carbon Dioxide (CO2) absorb infrared radiation and slow the rate at which heat radiates into space.
Greenhouse Effect

Sunlight heats the planet’s surface.

The upper atmosphere radiates away heat in the form of infrared radiation into space.

Water and other gases like Carbon Dioxide (CO2) absorb infrared radiation and slow the rate at which heat radiates into space.

These three processes keep Earth at an average temperature of 58.7° F
Carl Sagan (November 9, 1934 – December 20, 1996)

Carl Sagan was born in Brooklyn, New York in 1934.

Sagan was a prominent figure in the U.S. space program since its beginning in the 1950s and was an adviser to NASA.

He introduced the idea of a Greenhouse Effect as an explanation for the surface temperatures of Venus, Earth, and Mars. He was the first to recognize that Earth is undergoing a Human-induced Greenhouse warming, and that the effects are potentially catastrophic. He also predicted the effect known as Nuclear Winter.

He championed the idea of exobiology as a respectable field of study and popularized these areas of science through his TV documentary Cosmos.
Rhone Glacier
Muir Glacier, Alaska

1941

2004
Temperatures are Rising

2005 was warmest year in over a century. 2006 was 5th warmest year ever.

2007 is predicted to be warmer than 2006.

Note that the bar in 2001 goes up to 2.8°C, whereas it is 3.8°C in 2006.
El Nino and Volcanoes

El Nino significantly increases the global temperature.
La Nina significantly reduces the global temperature.
Major volcanoes have an overall cooling effect.
Note that the increasing trend is not related to any of these effects.
Vostok Ice Core Samples of CO$_2$

By measuring the concentration of Carbon Dioxide in air bubbles trapped in Antarctic Ice, one can get a picture of CO$_2$ levels over time.

The low periods are the Glacial Ages when NY was under 1 mile of ice.

The high points correspond to subtropical climates---like today. The spike at the end is the rise due to the burning of fossil fuels.
Mauna Loa

Carbon Dioxide levels measured from Mauna Loa in Hawaii.

$\text{CO}_2$ levels oscillate seasonally with plant growth in the northern hemisphere.

They have been rising steadily for 50 years now.

The rise in $\text{CO}_2$ is the same magnitude as the difference between tropical weather and a glacial period!!!
Melt Zone of Greenland Ice Shelf Growing

While the Greenland Ice Shelf does not appear to have significantly changed, the Melt Zone (which is the area that melts in summer) is increasing.

The rate of loss of ice from Greenland has doubled from 1996 – 2006.

When Greenland melts, the sea levels will rise by 20 feet. Lower Manhattan will be underwater.
Earth's grim future

UN report says poor will suffer most unless measures taken to cut greenhouse gases

By SETH BORENSTEIN, AP

BRUSSELS -- As the world gets hotter, millions of people will suffer from hunger, thirst, floods and disease unless drastic action is taken, the bleakest report yet on global warming said yesterday.

"Don't be poor in a hot country, don't live in hurricane alley, watch out about being on the coasts or the Arctic, and it's a bad idea to be on high mountains with glaciers melting," Stephen Schneider, a Stanford University scientist and study co-author, said.

All regions of the world will change, with the risk that nearly a third of the Earth's species will vanish if global temperatures rise just 2 C above the average temperature in the 1980s and '90s.

FIERCE DEBATE

Yet those grim predictions were toned-down from the scientists' original wording -- a compromise brokered in a fierce debate. Researchers accused governments -- namely China, Russia and Saudi Arabia -- of ignoring science and watering down the report to avoid action.
Climate Change: NOT a Political Issue

The scientific claim (for which you have seen only some of the evidence) is that CO2 from burning organics (coal, oil, wood, etc) is causing this rise in atmospheric CO2 and hence temperature.

The problem is that those who make a living off of selling fossil fuels stand to lose a lot of potential income.

The critics claim that scientists are inventing this crisis to divert taxpayer dollars into scientific research.

Science aside: consider how much money a scientist would get as opposed to an oil executive, and now you understand the motives.
Climate Change: How Do You Know?

BE INFORMED

- Look closely at the evidence. Consider which hypothesis gives a more consistent picture and explains ALL of the data.

- Think for yourself, but if something confuses you, ask someone who might know. Think about what their explanation is and WHY it does or does not make sense.

- Consider the motives behind those who are telling you what to believe.
Climate Change: What Does it Predict?

The phrase Global Warming refers to the Earth’s **AVERAGE** temperature rising.

- An exceptionally warm day in January is NOT evidence (by itself) for Global Warming.
- A snowy day in May is also NOT evidence (by itself) AGAINST Global Warming.

**The Predictions are:**
- The **AVERAGE** temperatures will rise
- The polar ice will melt flooding the coastlines
- The Earth’s weather will become more extreme and unpredictable
- Droughts, Wild Fires, Floods, Tornadoes, Hurricanes will on average increase in frequency. Where? No one can predict.
What are the Uncertainties?

The 15 or so advanced climate models in the world all agree that the weather will become more extreme and chaotic. They do not agree on what will happen where and when.

Clouds can change the picture
1. Increasing temperatures result in more evaporation
2. IF this water vapor forms clouds, the cloud cover on Earth will increase on average.
3. Increasing cloud cover will reflect more sunlight back into space resulting in a cooling effect. This could save us. Or it could run rampant and cool us to much too fast throwing us into another glacial age.
4. If more clouds do not form, the fact that water vapor is a Greenhouse Gas will result in even greater temperature increase.
Climate Change: What Can We Do?

If you decide that Global Warming is a significant problem here is what you can do:

Take Personal Action to reduce your energy consumption.
- Conserve Heat
- Drive Less, walk and ride bikes more
- Buy a fuel efficient car

Encourage Community Action to move to clean energy
- Encourage Carpooling
- Make sure public buildings are energy efficient

Influence US Action
- Write your local newspaper
- Write your Representative or Senator
- Work to pass laws to enforce energy efficiency
- Run for Office yourself!!!

Union of Concerned Scientists
http://www.ucsusa.org/
Why Earth’s Sky is Blue…and not so Blue
Scattering Processes

Rayleigh Scattering

Light polarizes molecules and makes them radiate like an antenna.

Mie Scattering

Mie scattering occurs when the particles are greater than 1/10 the wavelength of the light. Water vapor in the form of clouds or fog results in Mie scattering.

Raman Scattering

Raman scattering results from photons being absorbed and re-emitted. The emitted light is of a lower frequency than the incident light as energy is transferred to the molecule in the collision. This is not an essential process for the color of our skies.
Rayleigh Scattering

Rayleigh Scattering is due to an electromagnetic interaction between atoms and molecules and an electromagnetic wave. As the electromagnetic wave passes by a molecule, it polarizes the molecule which creates an oscillating dipole. The dipole then radiates like an antenna re-transmitting the light. This process dominates for particles less than 1/10 the wavelength of the light.

Rayleigh Scattering Physics

Because the degree of scattering is inversely proportional to the fourth power of the wavelength, shorter wavelengths (or higher frequencies) scatter more. Thus the Blue Light scatters more: 400 nm (blue) scatters 9.4 times more intensity than 700 nm (red).

http://hyperphysics.phy-astr.gsu.edu/hbase/atmos/blusky.html#c2
Rayleigh Scattering Physics

In this equation $\alpha$ is the polarizability of the atom or molecule. Different air molecules have different polarizabilities.

\[
I = I_0 \frac{8\pi^4 N \alpha^2}{\lambda^4 R^2} (1 + \cos^2 \theta)
\]

Polarizability of Various Atmospheric Constituents

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Polarizability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N$_2$)</td>
<td>11.74 x 10$^{-24}$ cm$^3$</td>
</tr>
<tr>
<td>Oxygen (O$_2$)</td>
<td>10.59 x 10$^{-24}$ cm$^3$</td>
</tr>
<tr>
<td>Carbon Dioxide (CO$_2$)</td>
<td>2.911 x 10$^{-24}$ cm$^3$</td>
</tr>
<tr>
<td>Water (H$_2$O)</td>
<td>0.041 x 10$^{-24}$ cm$^3$</td>
</tr>
</tbody>
</table>

Since Nitrogen comprises 80% of our atmosphere and has the largest polarizability, our skies can accurately be described as Blue Nitrogen Skies.

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The Blue Sky is not Uniform in Intensity

The Sky is a lighter blue at directions perpendicular to your line-of-sight to the Sun.
Mie Scattering

Mie scattering occurs with larger particles such as water vapor, dust, aerosols, salt spray, etc.

The scattering pattern is mainly in the forward direction, and is not sensitive to the wavelength of the light.

Mie scattered light looks white.
Now for Mie Scattering

The Sky is a lighter blue at directions perpendicular to your **line-of-sight** to the Sun.
Putting the Two Together

Mie Scattering Dominates near the Sun - white

Rayleigh Scattering dominates elsewhere, but is weakest perpendicular to the Sun – light blue

Rayleigh Scattering dominates - blue
Why Earth’s Sky is Blue...and not so Blue
Why Earth’s Sky is Blue…and not so Blue

Rayleigh Scattering
Why Earth’s Sky is Blue…and not so Blue

Rayleigh Scattering

Rayleigh Scattering

Mie Scattering
Why Earth’s Sky is Blue…and not so Blue

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Rayleigh Scattering

Mie Scattering

Mie Scattering

Rayleigh Scattering weaker perpendicular to Sun
Why Earth’s Sky is Blue…and not so Blue

Rayleigh Scattering

Mie Scattering

Reflected Light with little Blue because of Rayleigh Scattering
Venus, Earth and Mars