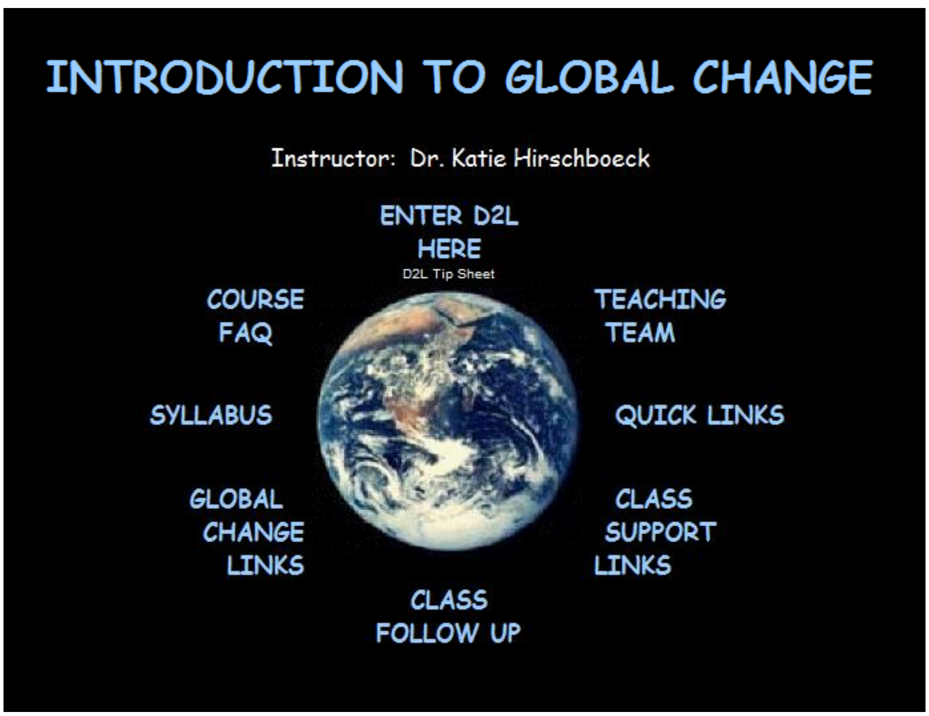
GC170A-1 The Earth & Its Environment
Lecture Sections 001+002
FALL 2014

INTRODUCTION TO GLOBAL CHANGE

INSTRUCTOR: Dr. Katie Hirschboeck

CLASS NOTES PACKET



Fall 2014

UA GENERAL EDUCATION
FOUNDATION FOR SUCCESS
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HOW TO USE THIS
CLASS NOTES PACKET

Welcome to GC-170A1, Sec 001+002! This CLASS NOTES packet is designed to be a companion to the classroom portion of **GC-170A-1 Introduction to Global Change**, taught by Dr. Katie Hirschboeck. **You should bring this packet with you to every class.** (You do NOT need to bring the textbooks: *The Science of Global Change: An Introduction* and *Dire Predictions* with you to class, unless announced in advance.)

This packet contains the following:

- **Selected notes with definitions**, **key points**, & **figures** to accompany Dr. H's lecture presentations on the **course topics**.
- Some **fill-in-the-blank interactive sections** that accompany a few of the lectures
- Several **blank pages** for entering your own outlines, notes, sketches and summaries as you review each topic after class while studying.
- Your **own copy** of handout materials used in class during many of the **group activities**, so you can take your own notes while working together as a group and refer to the activity later.
- More detailed **background reading material** that isn't in your regular textbook to supplement some of the topics.
- **Appendices** that include items needed for specific activities and assignments at different points during the semester.
- **Directions** on how to find **Dr. H's office** in the Bryant Bannister Tree-Ring Building **(last page).**

See Dr H's GC-170A-1 WEBPAGE & D2L site
for the latest versions of:

Course Syllabus, Semester-on-a-Page, Textbook Reading Schedule, Readiness Quiz Due Dates,
Test and Exam Dates, the Course Policies FAQ,
and all other information on assignments, due dates, and grading:

Dr H's GC-170A-1 WEBPAGE: http://www.ltrr.arizona.edu/kkh/natsgc/

(The course number for this course was formerly NATS 101,
*for "natural sciences" – so the course is often abbreviated as "**natsgc**")*

INTRODUCTION TO GLOBAL CHANGE
CLASS NOTES PACKET
FALL 2014

TABLE OF CONTENTS

ADDITIONAL NOTES

[Get semester-on-a-page updates online in D2L and tape or staple here as needed]

GC 170A1 SEMESTER-ON-A-PAGE – FALL 2014

NOTE: This schedule may need to be revised as the semester progresses – updates will be posted online

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
AUGUST	AUG 24	25 *First day of classes*	**26** #1 –-Overview + Science **RQ-A**	27	**28** #2 – Quantifying Global Change **RQ-B**	29	30
		SEP 1 *Labor Day - no classes*	**2** #3 – Quantifying Global Change II	3 *Change of Schedule Form needed to ADD*	**4** #3 – Energy & Matter Overview **RQ-1 CUTOFF**	5	6
SEPTEMBER	7	8	**9** #4 – Electromagnetic Radiation	10	**11** #5 – The Radiation Laws - I **RQ-2 CUTOFF**	12	13
	14	15	**16** **TEST #1**	17	**18** #5 – The Radiation Laws - II	19	20
	21 *Last day to drop via UAccess w/o grade of W or E on transcript*	22	**23** #6 Atmo Structure & Chemical Composition - I **RQ-3 CUTOFF**	24	**25** #6 - Atmo Structure & Chemical Composition - II	26	27
	28	29	**30** #7 – Thermodynamics & Energy Transformations - I **RQ-4 CUTOFF**	OCT 1	**2** #7 – Thermodynamic & Energy Transformations - II	3	4
OCTOBER	5	6	**7** **TEST #2**	8	**9** #8 – The Global Energy Balance - I	10	11 Family Weekend
	12	13	**14** #8 – The Global Energy Balance - II	15	**16** **MIDTERM EXAM**	17 *Last day for registration changes w/o Dean's signature*	18
	19	20	**21** #9 – Systems & Feedbacks **RQ-5 CUTOFF**	22	**23** #10 – How Climate Works - I	24	25
	26	27	**28** #10 – How Climate Works - II **RQ-6 CUTOFF**	29	**30** #11 Natural Climatic Forcing	31	NOV 1
NOVEMBER	2	3	**4** **TEST #3**	5	**6** #12 – Ozone Depletion - I **RQ-7 CUTOFF**	7	8
	9	10	**11** *Veteran's Day* - no classes	12	**13** #12 – Ozone Depletion - II	14	15
	16	17	**18** #13 – Global Warming & Anthropogenic Forcing – I **RQ-8 CUTOFF**	19	**20** #13 – Global Warming & Anthropogenic Forcing - II	21	22
	23	24	**25** **TEST #4**	26	27 *Thanksgiving*	28 *Break*	29
DECEMBER	30	DEC 1	**2** #14 – Climate Change: Impacts & Choices - I	3	**4** #14 – Climate Change: Impacts & Choices - II	5	6
	7	8	**9** Global Change Wrap-Up **RQ-9 CUTOFF**	10 *Last day of classes*	11 *Reading Day*	12 *Finals Begin*	13
	14	15	16	17	18 **FINAL EXAM** 10:30 am - 12:30 pm	19	20 *Semester Ends*

Online Self Test & Readiness Quiz (RQ) Topics

** NOTE: RQ A + RQ B are practice quizzes*

- ❑ *RQ-A – Syllabus & FAQ **
- ❑ *RQ-B – Global Change Overview **
- ❑ RQ 1 – Energy & Matter
- ❑ RQ 2 – Electromagnetic Spectrum
- ❑ RQ 3 – Atmo Structure & Composition
- ❑ RQ 4 – Thermodynamics & Laws of Motion
- ❑ RQ 5 – Systems & Feedbacks
- ❑ RQ 6 – Natural Climatic Processes & Forcing
- ❑ RQ 7 – Ozone Depletion
- ❑ RQ 8 – Global Warming

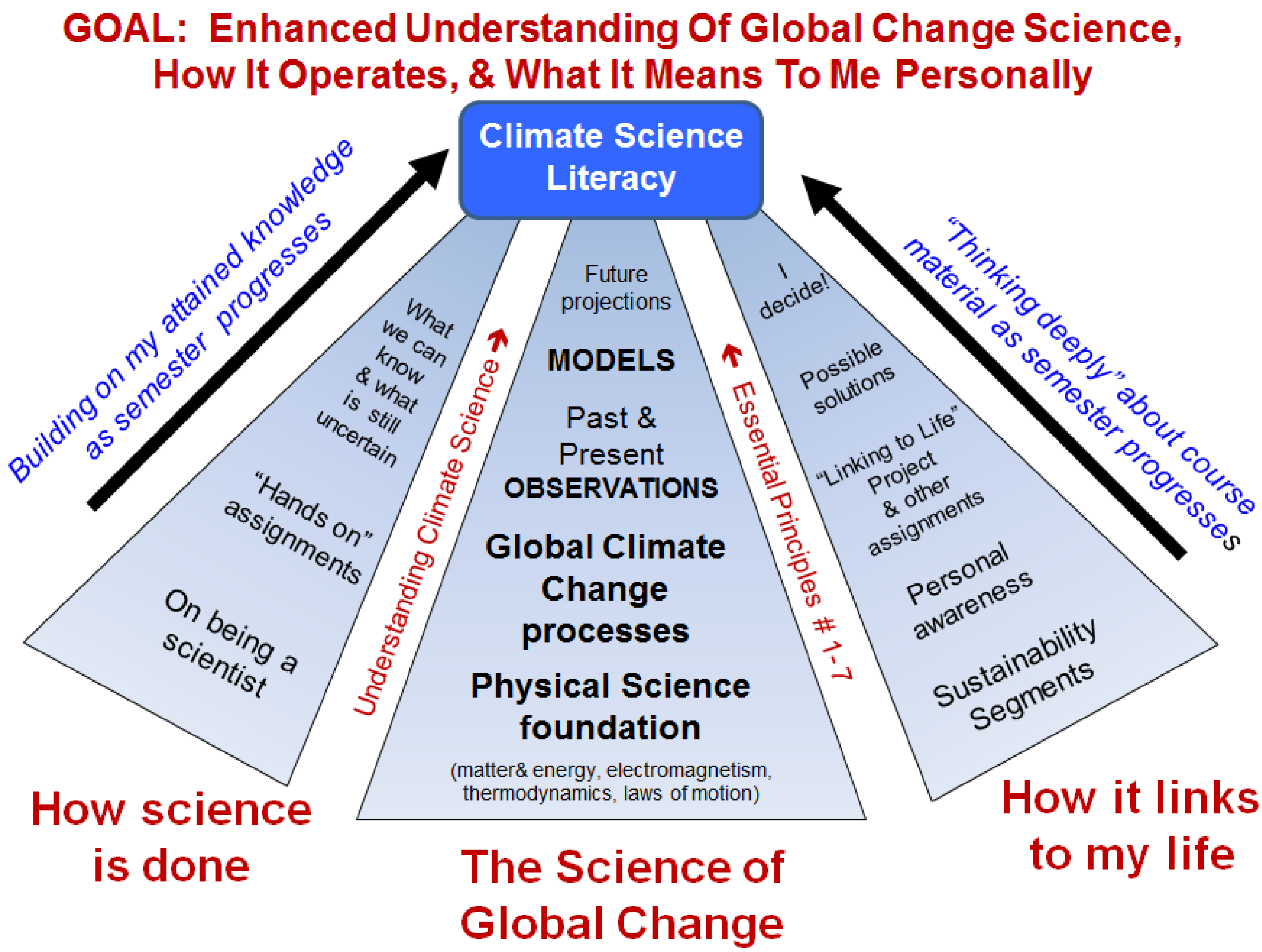
☑ check off the RQs as you complete them – CUTOFF DATES are listed in calendar above

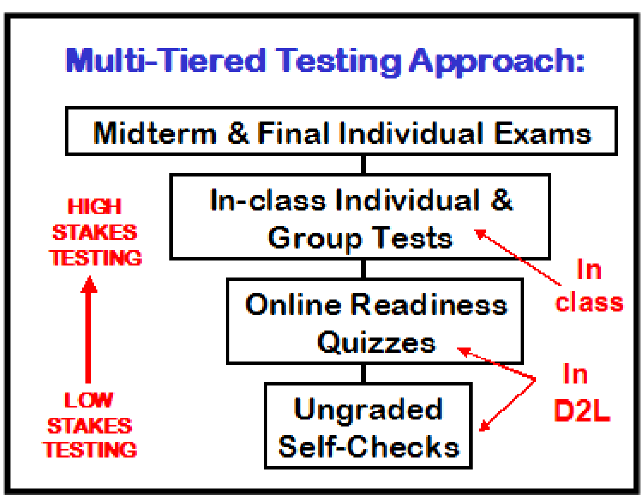
GC-170A-1 Introduction to Global Change – Fall 2014
TEXTBOOK READING ASSIGNMENTS & SELF-TEST / READINESS QUIZ SCHEDULE

Class Topic		SGC E-Text *The Science of Global Change – An Introduction*	DP Text *Dire Predictions*	Other e.g., Class Notes & PDF links in the Weekly Checklist	Self Test + Readiness Quiz (RQ)
1	Course Overview and Science Background	Ch 1 (1-20)	Pt 1 (36-59)	Class Notes	*Syllabus & FAQ*
2	Quantifying Global Change	Graph Review: Box Fig 2-2on p 28		Class Notes	
3	Matter & Energy Overview	Last Ch in E-text on *Atoms: The Nature of Things*		Class Notes & Appendix	1– Energy & Matter
4	Electromagnetic Radiation	Ch 3 (36-39)		Class Notes	2 –Electro-magnetic Radiation & Spectrum
5	The Radiation Laws	Ch 3 (39-44, 48-50)	Pt 1 (22-23)	Class Notes	
6	Atmospheric Structure & Composition	Ch 3 (44-50)	Pt 1 (26-29) (32-33)		3- Atmospheric Structure & Composition
7	Thermodynamics & Energy Transformations			Class Notes & Checklist links	4- Thermo-dynamics
8	The Global Energy Balance	Ch 3 (review 43-44) Ch 3 (48-52)	Pt 1 (64-65)	Class Notes Appendix	
9	Systems and Feedbacks	Ch 2 (21-27 only) Ch 3 (53-55)	Pt 1 (24-25)		5 – Systems & Feedbacks
10	How Climate Works	Ch 4 (57-83)	Pt 1 (10-15)	Class Notes & Checklist links	
11	Natural Climatic Forcing	Ch 15 (295- top of 303)	Pt 1 (18 + 40) (60-63)	Class Notes	6-Climate & Natural Forcing
12	Ozone Depletion in the Stratosphere	Ch 1 (review 9 -11)	Pt 1 (30-31)	Class Notes & Checklist link	7 – Ozone Depletion
13	Global Warming & Anthropogenic Forcing	Ch 15 (303-320)	Pt 1 (66 – 75) (94-97)	Class Notes & Checklist Links	8 – Global Warming
14	Climate Change Impacts & Choices	Ch 16 (321—339)	Intro (6-9) Pt 1 (20-21) Pt 2 (77-105) Pt 3 (107-139) Pt 4 (141-153) Pt 5 (155-197)	Class Notes & Checklist Links of IPCC documents	
	Global Change Wrap-Up	Re-read Ch 1 (1-17)			9-Global Change Recap

TOPIC # 1 COURSE OVERVIEW & BACKGROUND

> Science is simply common sense at its best.
> *- Thomas Huxley*





BACKGROUND OVERVIEW ON SCIENCE & GLOBAL CHANGE

> Science is demonstrating that this planet is more vulnerable than had previously been thought.
> *- Richard Benedick*

WHAT ARE THE BIG QUESTIONS IN GLOBAL CHANGE?

1-Global Climate Change = How do we <u>know</u> it's happening and what is causing it (human vs. natural)? How will it affect regions, people, plants, animals? Can we do anything about it?

2- Sustainability (ecological) = How do we use our natural resources without depleting their stocks or irrevocably damaging ecosystems and the climate for future generations?

3-Sustainability (economic) = How can economic activity progress at a rate that meets (or surpasses) the needs of the planet and its population?

4. Choices & Solutions = Are (2) and (3) above at cross-purposes? What realistically effective actions can individuals and institutions take to address these issues?

This semester we will examine the observations pointing to each of these statements:

THE BASICS: WHAT THE SCIENCE IS SAYING

1. Climate Change is real: change has happened, change is happening, change will continue to happen in the future

2. The Earth is warming

3. Humans are causing a significant portion of this recent warming

4. The warming will continue

5. Globally the net result will be bad for people, plants, and animals

6. There are legitimate unresolved questions

7. There are related -- but distinctly different -- global change processes of great concern: specifically, ozone depletion & biodiversity loss

This semester we will critically examine and evaluate many of these arguments about climate change – Then it will be up to YOU to decide how to respond.

HOW MUCH OF A CONCERN IS CLIMATE CHANGE?

Here are the most used "climate myths" and "denier" arguments about the causes and effects of climate change

From: http://www.skepticalscience.com/

Climate's changed before
It's the sun
It's not bad
There is no consensus
It's cooling
Models are unreliable
Temp record is unreliable
Animals and plants can adapt
It hasn't warmed since 1998
And so forth . . . . .

BACKGROUND READING: ON SCIENCE & BEING A SCIENTIST

> Do not become a mere recorder of facts, but try to penetrate the mystery of their origin.
> *- Ivan Petrovich Pavlov (1849-1936) Russian physiologist*

Review Of Key Elements Of Science

(1) SCIENTIFIC METHOD(S)

The traditional approach is typically stated as:
observation➔ hypothesis ➔ prediction ➔ testing
. . . but there are actually many ways of doing science!
All approaches contain the key steps of **OBSERVATION**, **ANALYSIS** and drawing **CONCLUSIONS** which must be **repeatable** and able to be **substantiated** by others.

"In practice" scientists tend to "weave back & forth" between **inductive** & **deductive** reasoning in their approaches:
IN-duction: individual observations ==> general conclusion
DE-duction: the big picture (theory) ==> conclusion or prediction about individual observations

(2) IMPORTANT TERMS:

HYPOTHESES are "tentative guesses" based on observations, *in contrast to . . .*

THEORIES have met extensive observational and experimental tests. A **long-standing THEORY** (which has not been disproven) is the closest thing we have to a law!
(The derisive phrase "just a theory" does not apply to a well-substantiated theory that has stood the test of time!)

LAWS apply everywhere in the universe and are overarching statements about how the universe works.

(3) HOW SCIENCE PROCEEDS "IN ACTION":

- is driven by curiosity, but often needs great persistence
- is sparked by rare joys of discovery
- is kept "honest" by reproducibility of results
- is kept "honest" by communal review
- gets closer to the truth by accumulation of knowledge
- gets closer to the truth by collaborative efforts
- avoids becoming "theory laden" by being both open-minded and skeptical at the same time
- must be ethical by recognizing and reporting conflicts of interest that could influence results
- must be ready to change any preconceived ideas if evidence shows otherwise
- improves over time as error and fraud get weeded out
- is filled with wonder-awe-joy-mystery!

Quotes by Scientists about Science

Science is the best tool ever devised for understanding how the world works.

a. Science is a very human form of knowledge. We are always at the brink of the known.

b. Science is a collaborative enterprise spanning the generations.

c. We remember those who prepared the way . . . seeing for them also.

d. If you're scientifically literate, the world looks very different to you – and that understanding empowers you.

e. There's real poetry in the real world; science is the poetry of reality.

f. We can do science, and with it, we can improve our lives.

g. The story of humans is the story of ideas that shine light into dark corners.

h. Scientists love mysteries; they love not knowing.

i. Scientists don't feel frightened by not knowing things; they think it's much more interesting.

j. There's a larger universal reality of which we are all a part.

k. The further we probe into the universe, the more remarkable are the discoveries we make.

l. The quest for the truth – in and of itself – is a story that's filled with insights.

m. From our lonely point in the cosmos, we have – through the power of thought – been able to peer back to a brief moment after the beginning of the universe.

n. Science changes the way your mind works. . . . to think a little more deeply about things.

o. Science replaces private prejudice with publicly verifiable evidence.

Quotes from The Poetry of Reality (An Anthem for Science)
at: http://www.symphonyofscience.com/

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Get a good understanding of "science in action" by reading these

QUOTES BY SCIENTISTS ABOUT THE SCIENTIFIC PROCESS

Which ones resonate with you?

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[All quotes are from: The Mind of God & Other Musings -- The Wisdom of Science, ed. by Shirley A. Jones, 1994.]

FACTS

1. Facts are the air of science. Without them you never can fly. *Ivan Petrovich Pavlov (1849-1936) Russian physiologist*

2. Sit down before fact like a child, and be prepared to give up every preconceived notion, follow humbly wherever and to whatever abyss Nature leads, or you shall learn nothing. *Thomas H Huxley (1825-1895) British biologist*

3. Science is built up with facts, as a house is with stones. But a collection of facts is no more a science than a heap of stones is a house. *Jules Henri Poincare' (1854-1912) French scientists*

4. It is the fate of theories to be washed away . . . I hold them all very lightly, and have used them chiefly as convenient pegs on which to hang my collection of facts. *James G. Frazier (1854-1941) British anthropologist*

5. Science is organized common sense where many a beautiful theory was killed by an ugly fact. *Thomas H. Huxley (1825-1895) British biologist*

DISCOVERY

6. We are more easily persuaded, in general, by the reasons we ourselves discover than by those which are given to us by others. *Blaise Pascal (1623-16662) French physicist*

7. . . . I think that the context of discovery is very different from the context of explanation or explication. But you don't discover things the way you write them down. There are subterranean processes which occur, and only at a certain point suddenly do things begin to gel and you know where you're going. *Jule Charney quoted in: The Atmosphere -- A challenge, The Science of Jule Gregory Charney by Lindzen et al., eds., 1990*

8. Any scientist who is not a hypocrite will admit the important part that luck plays in scientific discovery. *Sir Peter Brian Medawar (1915-1987) British zoologist*

9. In the fields of observation, chance favors only the mind that is prepared. *Louis Pasteur (1822-1895) French chemist-microbiologist*

10. Don't laugh . . . I felt I was born for that moment. To stand there, on that street in Paris in the middle of the night, with this idea at last clarified in my mind, Oh, that clarification! It was as though the idea had come into my head so that one day I would know the incredible joy of the clarification. Nothing else can touch that experience for me. Let me tell you, there's not an "I love you" in the world that can touch it. Nothing. *Laura Levin, US biophysicist (discovering the muscle mechanism of the clam)*

11. Besides learning to see, there is another art to be learned -- not to see what is not. *Maria Mitchell (1818-1889) US Astronomer*

12. There is no logical way to the discovery of . . elemental laws. There is only the way of intuition, which is helped by a feeling for the order lying behind the apparatus. *Albert Einstein (1879-1955) Swiss-American physicist*

13. It is like finding the handwriting of God. *Joe Primack (b. 1945) US astrophysicist (on discovering "ripples" in space)*

PERSEVERANCE

14. Results! Why, man, I have gotten a lot of results. I know several thousand things that won't work. *Thomas Alva Edison (1847-1931) US Scientist*

15. If I have ever made any valuable discoveries, it has been owing more to patient attention, that to any other talent. *Sir Isaac Newton (1642-1727) British physicist*

AWE

16. The joy of insight is a sense of involvement and awe, the elated state of mind that you achieve when you have grasped some essential point; it is akin to what you feel on top of a mountain after a hard climb or when you hear a great work of music. *Victor Weisskopf (b. 1908) Austrian-American physicist*

17. The most beautiful experience we can have is the mysterious . . . He to whom this emotion is a stranger, who can no longer pause to wonder and stand rapt in awe, is as good as dead. *Albert Einstein (1879-1955) Swiss-American physicist.*

18. Do not become a mere recorder of facts, but try to penetrate the mystery of their origin. *Ivan Petrovich Pavlov (1849-1936) Russian physiologist*

19. In one pool, on the right side of the path, is a family of otters; on the other side, a family of beavers . . . . I was transfixed. As I now recall it, there was only one sensation in my head: pure elation mixed with amazement at such perfection . . . I wished for no news about the physiology of their breathing, the coordination of their muscles, their vision, their endocrine systems, their digestive tracts. I hoped never to have to think of them as collections of cells. All I asked for was the full hairy complexity, then in front of my eyes, of whole, intact beavers and otters in motion. *Lewis Thomas (1913-1993) US biologist*

CURIOSITY

20. Those who do not stop asking silly questions become scientists. *Leon Lederman (b. 1822) US Nuclear physicist*

21. Ask questions. Don't be afraid to appear stupid. The stupid questions are usually the best and the hardest to answer. They force the speaker to think about the basic problem. *Paul Ehrenfest (1880-1933) Austrian physicist*

22. The equations we seek are the poetry of nature. . . . Why is nature that way? Why is it possible for these powerful manifestations of forces to be trapped in a very simple, beautiful formula? This has been a question which many people have discussed, but there is no answer. *Chen Ning Yang (b. 1922) US physicist*

CHANGE

23. The one universal ever-operating law throughout has been the law of change. Nature never stands still and never duplicates herself. Life is always in the process of becoming something else. *Laurence M. Gould (b. 1896-1995), US scientist*

FALSIFICATION

24. A null result would kill off the whole present crop of theories. *Philip Lubin (b. 1953) US Astrophysicist*

25. No amount of experimentation can ever prove me right; a single experiment may at any time prove me wrong. *Albert Einstein (1879-1955) Swiss-American physicist*

26. I have steadily endeavored to keep my mind free so as to give up any hypothesis, however much beloved (and I cannot resist forming one on every subject), as soon as the facts are shown to be opposed to it. *Charles Darwin (1809-1882) British biologist*

ADDITIONAL NOTES

TOPIC #2 QUANTIFYING GLOBAL CHANGE
SCALE, RATES OF CHANGE & TIME SERIES PLOTS

> Yes, we have to divide up our time like that, between our politics and our equations. But to me our equations are far more important, for politics are only a matter of present concern. A mathematical equation stands forever.
> - *Albert Einstein*

WHAT IS THE LINK TO GLOBAL CHANGE?

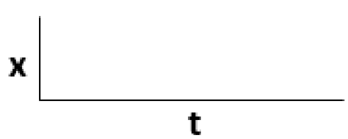
It is a huge challenge to define CHANGE ON A GLOBAL SCALE!

Scientists are faced with a major problem when they try to quantify nature. Earth / global change phenomena and processes occur over an enormous range of **SPATIAL AND TEMPORAL SCALES**. There is also an enormous range in the numbers of things. In addition, things in nature **CHANGE at different RATES**.

SPATIAL & TEMPORAL SCALES: "POWERS OF 10 VIDEO" – illustrates the above problem. It is important to develop a sense of the RELATIVE SCALES in physical phenomena

Q. How do we express such vast ranges in numbers???

TIME SERIES CHANGE: a time series is a plot of value of some *variable* (x) at each point in *time* (t)



RATES OF CHANGE: Change in some variable (x) per change in time (t) d(x) / d(t)
where d = "delta" = "change in," x = a variable, t = time

e.g.: "the average rate of increase of CO^2 concentration since 1958 has been 43 ppm / 37 yr (or about 1.2 ppm/yr)"
ppm = parts per million

NOTE: Powers of 10 can be used to express **exponential rates of change**

THE TOPICS IN THIS CLASS WILL ADDRESS A HUGE RANGE OF SCALES
We need "Powers Of Ten" to describe and quantify them !

Watch the POWERS OF TEN video at: http://www.powersof10.com/film

1×10^{0}	1 meter (m)	blanket
1×10^{1}	10 m	blanket a dot
1×10^{2}	100 m	tiny cars, boats
1×10^{3}	1,000 m = 1 km	
1×10^{4}	10,000 m	most of Chicago, edge of Lake Michigan
1×10^{5}	100,000 m	
1×10^{6}	1,000,000 m = 1 million m	Great Lakes, Florida, ocean
1×10^{7}	10 million m	whole globe 🌎
1×10^{8}	100 million m	orbit of moon
1×10^{9}	1,000 million m	
1×10^{10}	10,000 million m	orbits of planets
1×10^{11}	100,000 million m	sun enters field of view
1×10^{12}	1 million million m	orbits of outer planets
1×10^{13}	10 million million m	whole solar system
1×10^{14}	100 million million m	solar system just one of stars
1×10^{15}	1,000 million million m	
1×10^{16}	1 light year *(a distance unit)*	
1×10^{17}	10 light years	
1×10^{18}	100 light years	
1×10^{19}	1,000 light years	Milky Way galaxy
1×10^{20}	10,000 light years	outskirts of galaxy
1×10^{21}	100,000 light years	
1×10^{22}	1 million light years	our galaxy a dot among others
1×10^{23}	10 million light years	
1×10^{24}	100 million light years	mostly emptiness
➔ **1×10^{-0}**	**1 meter (m)**	***starting point of video*** 🡐
1×10^{-1}	10 cm (.1 m)	zoom in on hand
1×10^{-2}	1 cm (.01 m)	
1×10^{-3}	1 mm (.001 m)	just about to enter skin
1×10^{-4}	100 microns (.0001 m)	
1×10^{-5}	10 microns (.00001 m)	enter a white blood cell
1×10^{-6}	1 micron (.000001 m = 1 micrometer)	see cell nucleus with DNA coils
1×10^{-7}	1,000 Ångstroms	Molecule of DNA
1×10^{-8}	100 Ångstroms	
1×10^{-9}	10 Ångstroms (=1 nanometer)	three hydrogen atoms bonded to one carbon atom
1×10^{-10}	1 Ångstrom (.0000000001 m)	outer electron shell of C atom, then 2 in inner shell
1×10^{-11}	0.1 Ångstrom	draw towards center B mostly space
1×10^{-12}	0.01Ångstrom (= 1 picometer)	carbon atom nucleus w/ 6 protons & 6 neutrons
1×10^{-13}	0.001 Ångstrom	carbon atom nucleus
1×10^{-14}	0.0001 Ångstrom	single proton fills screen
1×10^{-15}	0.00001 Ångstrom	

LENGTH OF ENTIRE JOURNEY: 1×10^{40}

Scientific Notation Review

- Any large (or small) number can be expressed as the product of two terms: (a) the *prefactor* = a number with a value between 1 and 10 that gives the precision or accuracy of the original number, & (b) an *exponent* (e.g., power of 10)
- To multiply numbers in scientific notation, multiply the prefactors and add the exponents (
- To divide numbers in scientific notation, divide the prefactors and subtract the exponent of the number in the denominator from the exponent of the number in the numerator

The one universal ever-operating law throughout has been the law of change.
Nature never stands still and never duplicates herself. Life is always in the process of becoming something else. - *Laurence M. Gould (b. 1896-1995) U.S. geologist*

TIME SERIES PLOTS: PLOTTING CHANGE OVER TIME

Recognizing & Describing Different Types of Change As Depicted in Time Series Plots

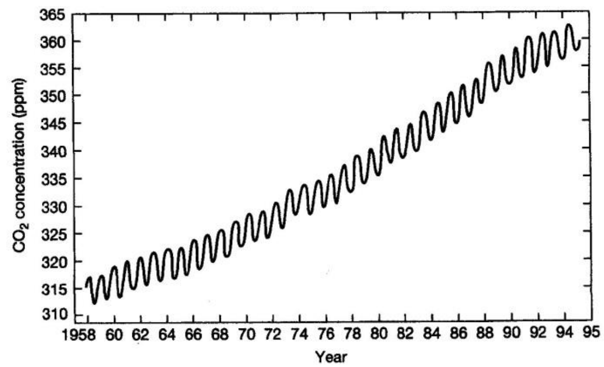
For a quick review of graphs, see E-Text p 28 Box Figure 2-2

☐ Look carefully at each of the time series plots # 1-7 and compare and contrast them.

☐ Then in the space to the right of each graph, briefly describe the kind of time series change that the plot is depicting. (Use the hints in the box below to write your descriptions.)

☐ Lastly, select the plot below (#1-7) that you think best represents the type of change depicted by the **Keeling Curve** ==>

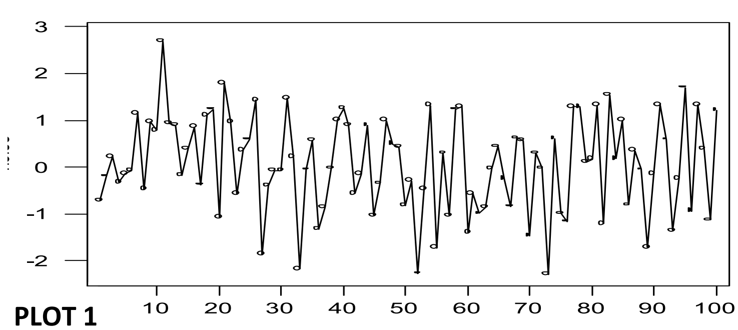
Your answer: Plot #_____ is the most like the Keeling Curve



HINTS: Here are some terms that will help you describe time series changes more precisely in fewer words:

- **Mean** = average (a "constant mean" for a time series can be represented by a horizontal line with roughly the same amount of variation above and below the line in the data series)
- **Variance** = the range of fluctuations (wiggles) above and below the mean (statistically the variance is the square of the standard deviation about the mean)
- **Periodic** = perfect oscillations (fluctuations) (going up and down regularly or in a perfect wave-like motion)
- **Quasi-periodic** = almost regular oscillations (in nature things are quite often quasi-periodic rather than perfect oscillations)
- **Trend** = a line of general direction (increasing or decreasing)

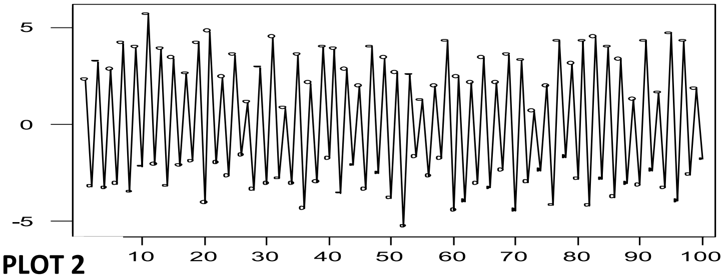
PLOTS: Different Types of Change As Depicted In Time Series Plots



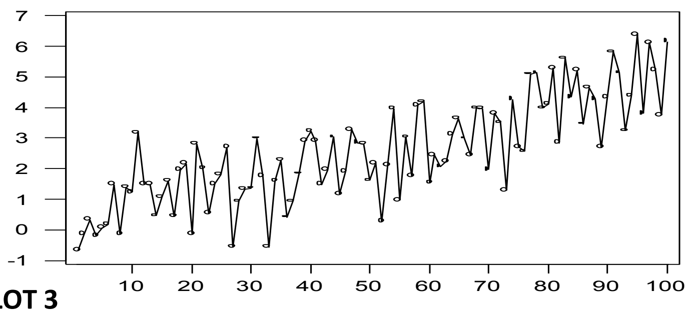
PLOT 1

Description:

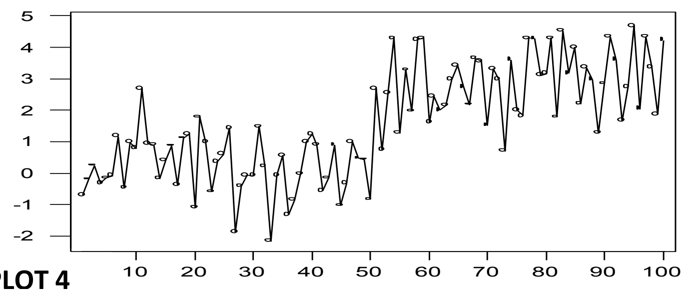
This plot appears to go up and down without any regular pattern (e.g., randomly); there are about as many points above the time series mean (average) as below; and the range of wiggles above and below the mean seems to be about the same over time.



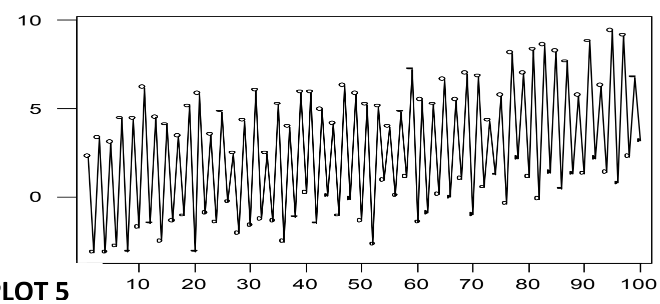
PLOT 2



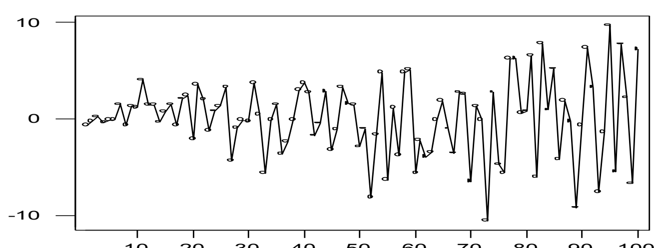
PLOT 3



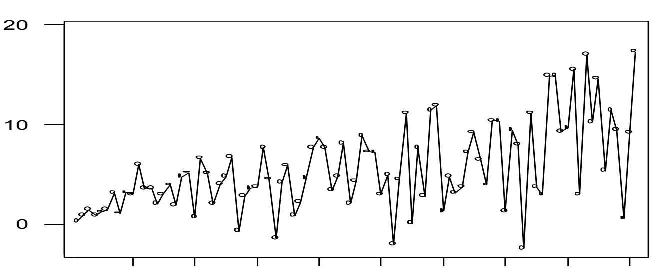
PLOT 4



PLOT 5



PLOT 6

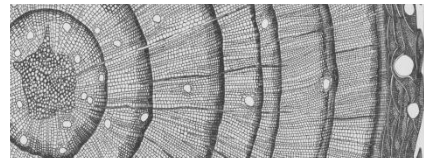


PLOT 7

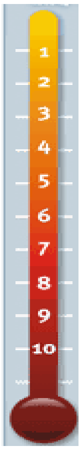
🌎 WHAT IS THE LINK TO GLOBAL CHANGE?

Introducing: **GLOBAL-CHANGE RELATED TIME SERIES!**

You'll see a lot of them this semester – including plots based on TREE RINGS ➔



EXPLORING THE FIRST "MYTH" . . .



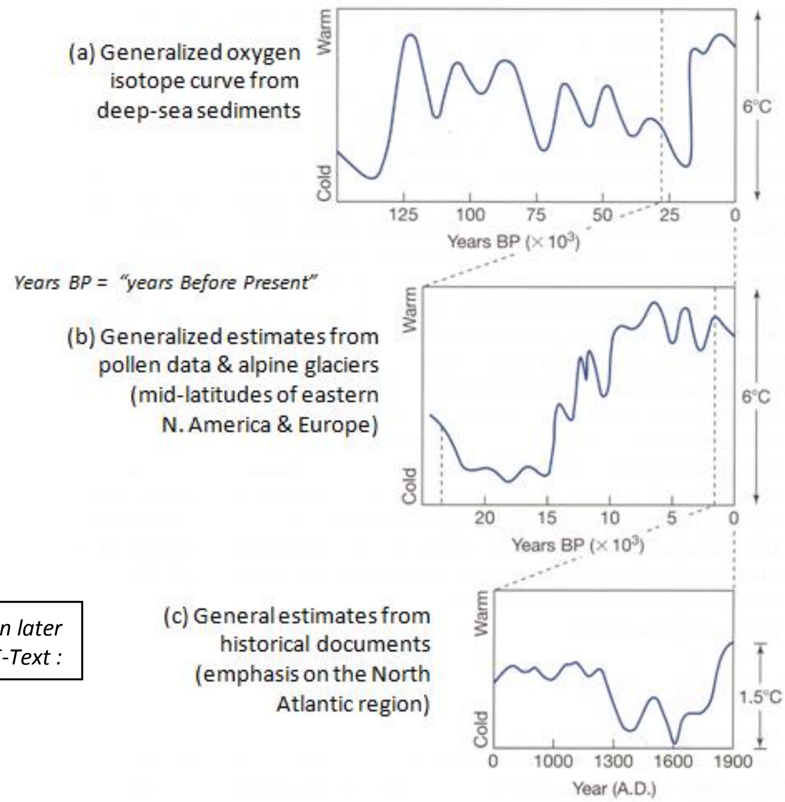
Climate Myth #1:

"Climate's changed before"

. . . therefore recent conditions are not unprecedented when compared to past climatic changes!

See more "Climate Myths" at: www.skepticalscience.com

MEAN GLOBAL TEMPERATURE CHANGE TIME SERIES
Since the Last Glacial Maximum
("telescoping" time scales)



You'll see these graphs again later in Chapter 15 of the E-Text :

RESPONSE TO MYTH #1: Yes, the climate has changed before! (Duh!) See the times series plots above!

Paleoclimate scientists have studied this thoroughly for decades and no one disputes this. Natural climate change in the past proves that climate is sensitive to an energy imbalance. If the planet accumulates heat, global temperatures will go up. Currently, increased amounts of CO_2 are imposing an energy imbalance due to the enhanced greenhouse effect.

Past climate change actually provides evidence for our climate's sensitivity to CO_2.

➔ BUT to make an incontrovertible case about the role that humans play in global warming/climate change, what do scientists need?

In order to make an incontrovertible case for global warming, you'd have to have a long-term temperature record, centuries, that was over a large part of the globe. And so you have to look over a long term and say, "What's the average been for several hundred years, and is this a significant departure from that?" And that's very difficult to do. - James Trefil, physicist

Tree rings and other "natural archives" that are indicators of past climate actually make it possible to do this! We'll look at the evidence this semester . . . .

ADDITIONAL NOTES:

TOPIC # 3 MATTER & ENERGY OVERVIEW

> *Science shows us that the visible world is neither matter nor spirit;*
> *the visible world is the invisible organization of energy.*
> - Heinz R. Pagels (b. 1939), U.S. Physicist

MATTER: QUICK REVIEW OF TERMS

Atom: consists of a positively charged nucleus and negatively charged electron(s) in orbit; the smallest particle that retains its chemical identity e.g. oxygen (O), hydrogen (H)

Element: made from a single type of atom that cannot be broken down any further

Ion: an electrically charged (+ or -) atom or group of atoms *(+ or - charge)*

Molecule: any collection of two or more atoms bound together; the smallest part of any substance that has all the chemical properties of the substance, e.g. H_2O moelcule

Electron: tiny negatively charged particles with very low mass; circle in orbits around a positively charged nucleus of an atom *(- charge)*

Nucleus: small but massive central part of an atom; made up of elementary particles that are even smaller; the *Strong Force* operates over extremely short distances to hold the nucleus particles together

Proton: positively charged nuclear particle *(+ charge)*

Neutron: electrically neutral nuclear particle, approx equal in mass to a proton; both protons and neutrons have much greater relative mass than electrons *(neutral charge)*
The # neutrons can vary, leading to isotopes

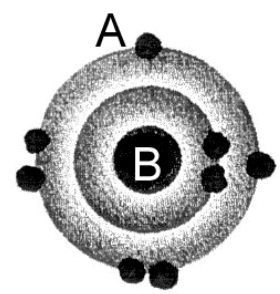
Isotope: atoms of a given element that have different numbers of neutrons in their nuclei (hence slightly different masses) e.g. carbon-12 (^{12}C) & carbon-13 (^{13}C) **

The ***atomic number*** = # protons (+) in nucleus

Neutral *(no charge)* when # protons = # electrons
Ion (+ or -) when # protons ≠ # electrons

The ***mass number*** = # protons + # neutrons in the nucleus of the atom

"DOT DIAGRAM" of an atom of OXYGEN (O)



Q1. What is the small circular black feature at A called? ________________

Q2. What is the large circular black feature in the center at B called? _____________

Q3. How many electrons does the atom have? ______

Q4. How many protons does the atom have (if the atom has <u>no charge</u>)? _______

Q5. How many neutrons does the atom have? ____

Q6. What is the atomic number of oxygen? ____

Q7. What is the mass number of oxygen? ____

Q8. Is the oxygen isotope ^{18}O lighter or heavier than the isotope ^{16}O? _____________

** **MORE ON ISOTOPES:** the most common form of carbon atoms has a **mass number** of 12 and an atomic number of 6. If mass number = # protons + # neutrons, then to find out the number of neutrons, subtract the number of protons from the mass number, e.g. 12 (mass number) minus 6 (atomic number) = 6 neutrons.

Atoms that have the same atomic number but different mass numbers are called ***isotopes***. So the example just given is for an isotope of carbon called "carbon-12" or ^{12}C. A carbon atom with 7 neutrons (instead of 6) would be carbon-13 or ^{13}C (and would be heavier due to the mass of the additional neutron).

THE PERIODIC TABLE: THE ELEMENTS OF GLOBAL CHANGE

The periodic table of chemical elements arranged in order of atomic number, usually in rows, so that elements with similar atomic structure (and hence similar chemical properties) appear in vertical columns.

ELECTRON CONFIGURATION OF ELEMENTS 1 to 18*

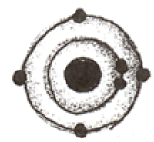
** Among the heavier elements, the distribution of electrons becomes more complicated because of the division of shells into sub-shells*

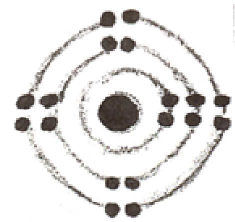
Atomic #	Element & Symbol	# of Electrons in Each Shell			Total # of Electrons
		1st	2nd	3rd	
1	**HYDROGEN, H**	**1**			***1***
2	*Helium, He*	2 (Full)			*2*
3	*Lithium, Li*	2	1		*3*
4	*Beryllium, Be*	2	2		*4*
5	*Boron, B*	2	3		*5*
6	**CARBON, C**	**2**	**4**		***6***
7	**NITROGEN, N**	**2**	**5**		***7***
8	**OXYGEN, O**	**2**	**6**		***8***
9	**FLUORINE, F**	**2**	**7**		***9***
10	*Neon, Ne*	2	8 (Full)		*10*
11	*Sodium, Na*	2	8	1	*11*
12	*Magnesium Mg*	2	8	2	*12*
13	*Aluminum, Al*	2	8	3	*13*
14	**SILICON, SI**	**2**	**8**	**4**	***14***
15	*Phosphorus, P*	2	8	5	*15*
16	**SULFUR, S**	**2**	**8**	**6**	***16***
17	**CHLORINE, CL**	**2**	**8**	**7**	***17***
18	**ARGON, AR**	**2**	**8**	**8 (Full)**	***18***

WHAT IS THE LINK TO GLOBAL CHANGE?

BOLDED elements in the table at left
← play especially important roles in Global Change!
Be sure you are familiar with them.

Q. Which element does each of these dot diagrams represent?



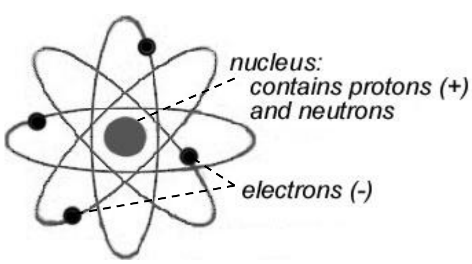


(a) ______________ (b) ______________

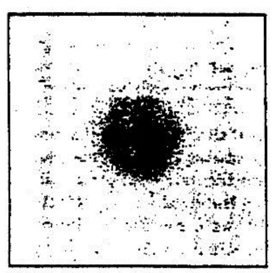
CONCEPTUAL MODELS OF ATOMIC BEHAVIOR

Conceptual model = Definition of a phenomenon in terms of features recognizable by observations, analysis or validated simulations

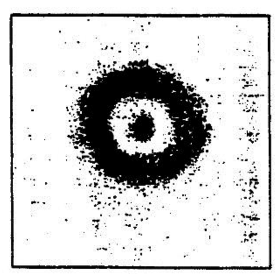
PLANETARY MODEL



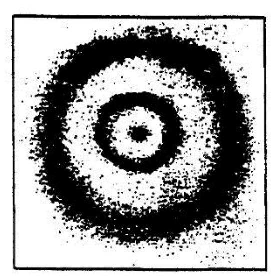
QUANTUM (BOHR) MODEL



Electron "cloud" of H in ground state



Electron cloud of H in 1st excited state



Electron cloud of H in 2nd excited state

- Electrons can exist only in discrete “allowed orbits” within shells (or energy levels) and not in between.
- Electrons move -- not according to Newtonian laws of motion -- but according to quantum mechanics
- The “empty” spaces represent areas with *little likelihood* of finding an electron
- Dark areas represent places (or energy levels) where electrons are “allowed” to be

KEY CONCEPT FOR THIS CLASS: ENERGY & MATTER INTERACT WITHIN THE ATOM

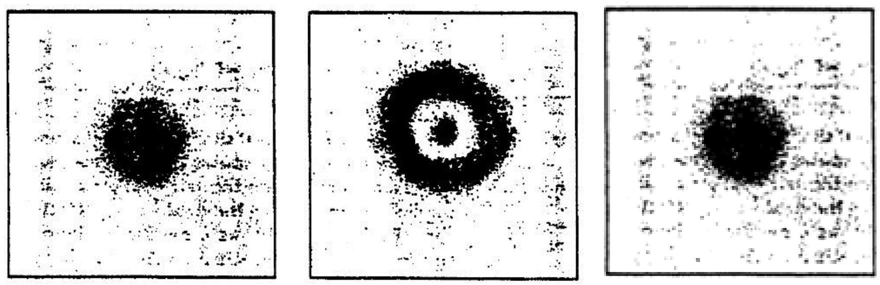
- In an "allowed orbit" (shell) an electron can exist for long periods of time without giving off radiation; energy is in a fixed state (designated by quantum or shell numbers, (n = 1, 2, 3, etc.)

- The electron in the lowest energy level (n = 1) is called the *ground state*, levels above are called *excited states (1st excited state, 2nd excited state* . . .)

- Each electron energy level can accommodate only a limited number of electrons, then it is "full"

- The higher the shell number (n) the more distant are its electrons from the nucleus and the greater the energy of the electrons.

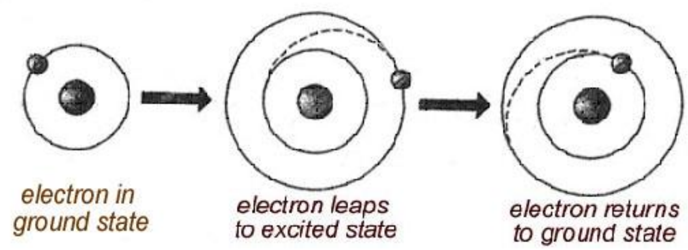
- The electron that can be separated most easily from its atom is an electron in the highest shell.



Electron cloud of H in ground state

Electron cloud of H in 1st excited state

Electron cloud of H back in in ground state



ENERGY: QUICK REVIEW

WHAT IS THE LINK TO GLOBAL CHANGE?

The basic physical concepts of **energy,** and the ways **matter and energy** interact, link to Global Change because they provide the 'foundation' for understanding: a) the important energy fluxes (transfers) in the Sun-Earth-Atmosphere system, and b) the important moisture fluxes and phase changes of water (H_2O) at the Earth-Atmosphere interface (i.e., where sky meets earth!).

ENERGY TERMS & UNITS

Energy - the quality of an object that enables it to do "work;" the capacity to exert force over a distance.

Mass - Mass (m) is the amount of matter in a particle or object; standard unit = kilogram (kg)

Force - A push or pull that, acting alone, causes a change in acceleration of the object on which it acts.

Force is expressed in units called **newtons (N)**. A newton is a unit of force needed to accelerate a mass of 1 kilogram by 1 meter per second squared.

Work - Work (W) is done whenever a force (F) is exerted over a distance (d). Work is equal to the force that is exerted times the distance over which it is exerted (i.e. the product of the force applied to an object and the distance through which the object moves). ***W = F x d***

Work is expressed in units called **joules**. A joule is the amount of work done when you exert a force of one newton through a distance of one meter.

Power - Power (P) is equal to work (W) done divided by the time (t) it takes to do it. *P = W/t*

Power can be expressed in joules/sec = **watts**

1 watt of power = (1 joule of energy) ÷ (1 second of time)

***Energy* can therefore also be expressed in terms of power and time:**

energy (in joules) = power (in watts) x time (in seconds)

Term	Definition	Units
Force	mass x acceleration	newtons
Work	force x distance	joules
Energy	ability to do work	joules
Energy	power x time	joules
Power	work/time	watts

A **kilowatt** = one thousand (10^3) watts
A surface area of one square meter on Earth receives typically one kilowatt of sunlight from the sun (on a clear day at midday).

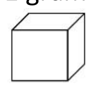
Your electric bill is based on the **kilowatt-hour** (kWh)
1 kWh = a unit of energy equal to 1000 watt hours
or 3.6 megajoules

LINKING "ENERGY" TO YOUR LIFE:

A *calorie* is a common unit of energy that may be easier to relate to your everyday life.

1 calorie = the amount of energy required to raise 1 gram of room-temperature water 1 degree Celsius in temperature.

1 gram = ~ 1 cubic centimeter of H_2O liquid

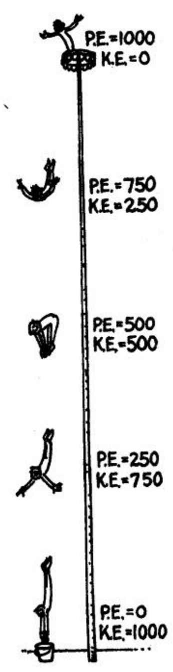


1 calorie = 4.186 joules
1 calorie per second = 4.186 joules per sec
= 4.186 watts
1 calorie per minute = 0.07 watts

FORMS OF ENERGY

KINETIC ENERGY (KE) - *Energy of motion*; the ability of a mass in motion to do work. The type of energy associated with moving objects.

Kinetic energy is equal to the mass of the moving object times the square of the object's velocity, multiplied by the constant ½. $KE = (½)\ m\ v^2$



POTENTIAL ENERGY (PE) – The energy a system possesses if it is capable of doing work, but is not doing work now.

Quick summary of different forms of potential energy:

Gravitational - Energy associated with the position of a mass in a gravitational field; *energy stored by virtue of its position*.

Elastic - Energy stored in a flexed muscle, a coiled spring, a stretched rubber band, etc.

Chemical - Energy stored in the electrical bonds that bind together the molecules or atoms of a substance. In any process in which atoms rearrange to form different molecules, a chemical reaction occurs, during which energy is absorbed or released by matter.

Electrical - Energy associated with the position of a charge in an electric field; an electric charge is an excess or deficit of electrons on an object.

Magnetic - Energy stored in a magnetic field. Magnetic fields can be created by the motion of electrical charges.

Of special importance for this class are:
ELECTROMAGNETIC & THERMAL ENERGY *(see box below)*

PREVIEW: TWO IMPORTANT FORMS OF ENERGY UNDERLYING KEY GLOBAL CHANGE ISSUES

➔ **Electromagnetic Energy** - a self-propagating **electric** and **magnetic** wave. Electromagnetic energy includes an entire spectrum of wavelengths (and their associated frequencies), e.g., visible light, ultraviolet, infrared, microwave, etc. [More details: **Electromagnetic radiation** is technically defined as: *self-sustaining oscillating electric and magnetic fields at right angles to each other and to the direction of propagation. It does not require a supporting medium and travels through empty space at the speed of light*.

WHAT IS THE LINK TO GLOBAL CHANGE? *Electromagnetic energy does not need matter as a medium for transferring the energy, hence it can easily travel through space, as does all the electromagnetic energy we (on Earth) receive from the Sun*.

Ultimately, Electromagnetic Energy gives us CLIMATE! *(more on this later!)*

➔ **Thermal Energy (called "Heat" to simplify)** - A measure of the quantity of **atomic kinetic energy** contained in every object; the total kinetic energy of molecules in matter. The molecules of every substance are constantly "jiggling" in some sort of back-and-forth vibratory motion. The greater this molecular kinetic energy is in a substance, the hotter the substance is (relates to temperature & warming!)

ENERGY TRANSFORMATION: 2 Important Concepts

"Everything that happens can be described as energy transformation."

CONCEPT #1: CONSERVATION OF ENERGY & ENERGY TRANSFORMATIONS

THE LAW OF CONSERVATION OF ENERGY:

**Energy cannot be created or destroyed—
It may be transformed from one form to another, but the total amount of energy never changes.**

WHAT IS THE LINK TO GLOBAL CHANGE?

*Although energy may not be destroyed,
it can become **INEFFICIENT**
i.e., not easily used or available to do work!*

Efficiency = work done / energy used

Finding more energy-efficient approaches to "fueling" human activities is a one of the most fundamental ways we can have a positive impact on the environment.

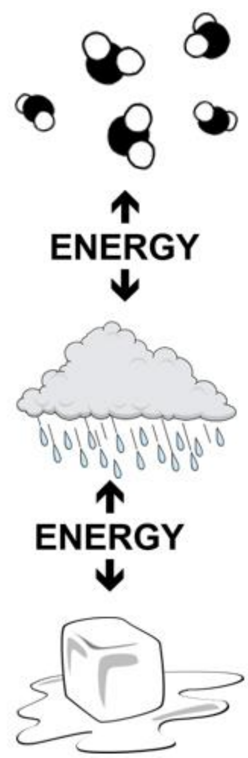
CONCEPT #2: ENERGY & MATTER INTERACT IN PHASE CHANGES

The change in the state of a substance from a **SOLID** to a **LIQUID**, or from a **LIQUID** to a **GAS**, (or vice versa) is called a **<u>change of state</u>** or **<u>phase change</u>.**

Energy in the form of heat, i.e., **thermal energy** is involved in phase changes.

WHAT IS THE LINK TO GLOBAL CHANGE?

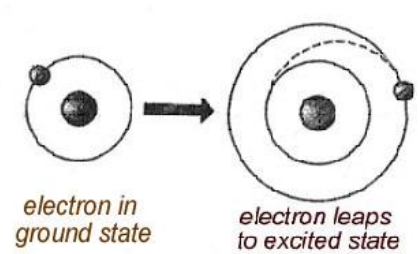
The phase changes in water — during which energy is either absorbed or released — are involved in every aspect of the Earth's **WEATHER & CLIMATE** . . as well as in **CLIMATE CHANGE!**



*MORE ON THIS in
the THERMODYNAMICS topic. . . .*

TOPIC # 4 – ELECTROMAGNETIC RADIATION

> Not only is the universe stranger than we imagine, it is stranger than we can imagine.
> *~Arthur Eddington*



But what "causes" the leap??

Electrons can be promoted to higher energy levels or even knocked free from their atoms in a variety of ways – **one way that is critical to global change processes involves a packet of energy called a PHOTON.**

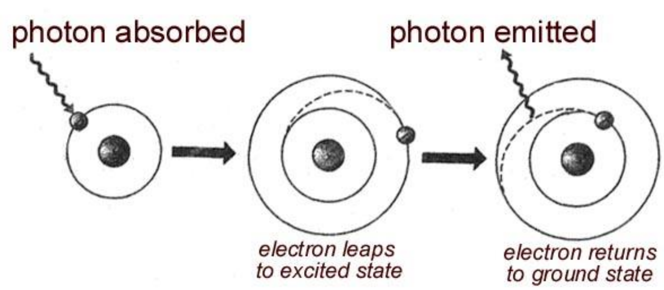
PHOTON = A particle-like unit of *electromagnetic energy* (light), **emitted or absorbed** by an atom when an electrically charged electron changes state.

A *photon* is also the form of a single packet of **ELECTROMAGNETIC RADIATION.**

- Electrons can make transitions between the orbits allowed by quantum mechanics by **absorbing or emitting exactly the energy difference** between the orbits.
- **The energy that is absorbed or emitted during** the quantum leaps between their electron shells is called **electromagnetic energy ---** which can be viewed either as pulses of energy traveling in **waves** (of certain wavelengths and speeds) or as bundles of particle-like energy called **photons.**
- All matter emits (gives off) radiant energy.
- **LIGHT** is composed of ***photons***, the basic packet of electromagnetic radiation.
- Electromagnetic energy <u>does not NEED matter</u> to be transferred, but when it DOES **react with matter,** it can be:
    - **ABSORBED (and EMITTED)**
    - **TRANSMITTED**
    - **SCATTERED**, or
    - **REFLECTED . . .**
      . . . . through -- or by -- the matter

More on this in later topics . . .

THE QUANTUM BEHAVIOR of ELECTRONS in ATOMS produces ELECTROMAGNETIC RADIATION



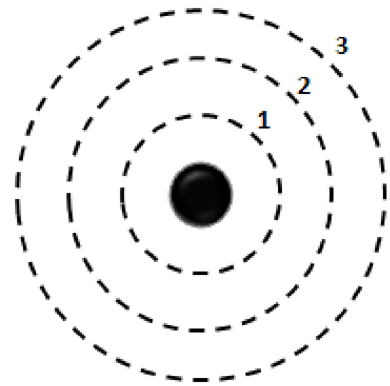
🌎 WHAT IS THE LINK TO GLOBAL CHANGE?

Nearly all the ENERGY we have on EARTH in different forms (including energy derived from oil, gas, coal – and even the food we eat) ultimately comes from the SUN and the SUN's energy arrives in the form of PHOTONS!

SKETCH IT YOURSELF: On the diagram at right, illustrate the **photon behavior** and **electron behavior** that takes place ***when a photon is emitted by an electron***.

HINT: *the black sphere in the middle represents the nucleus and the dashed lines represent energy levels 1, 2, 3. Draw in an electron at level 2, then show what happens to the electron's position after it emits (radiates) a photon of energy.*

Then **LABEL** your sketch to identify the names of the features you have drawn in (e.g., photon, electron) and write out what is happening to them (being absorbed, being emitted, leaping to a lower/higher level, etc.)

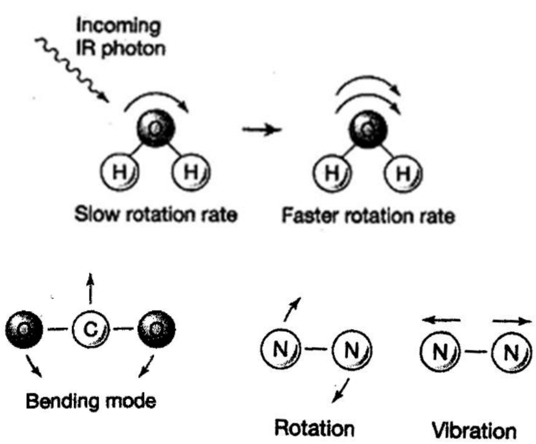


QUANTUM BEHAVIOR
in MOLECULES

Quantum leaps of electrons between discrete energy levels (shells) *within atoms* involve photons which are absorbed or emitted, but **quantum theory also involves the molecular-scale motion (i.e., rotation, bending, & vibration) of molecules!**

MOLECULAR QUANTUM BEHAVIOR
➔ KINETIC ENERGY / MOTION:
rotation, vibration, & bending!

> Anyone who says that they can contemplate quantum mechanics without becoming dizzy has not understood the concept in the least. *~ Niels Bohr*

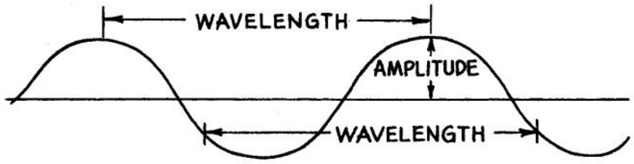


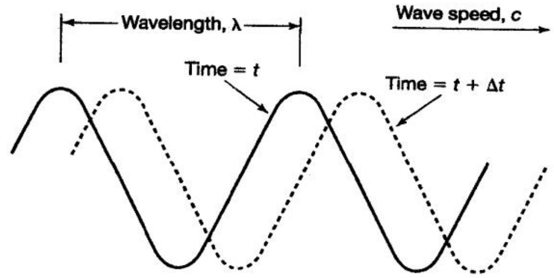
WHAT IS THE LINK TO GLOBAL CHANGE?

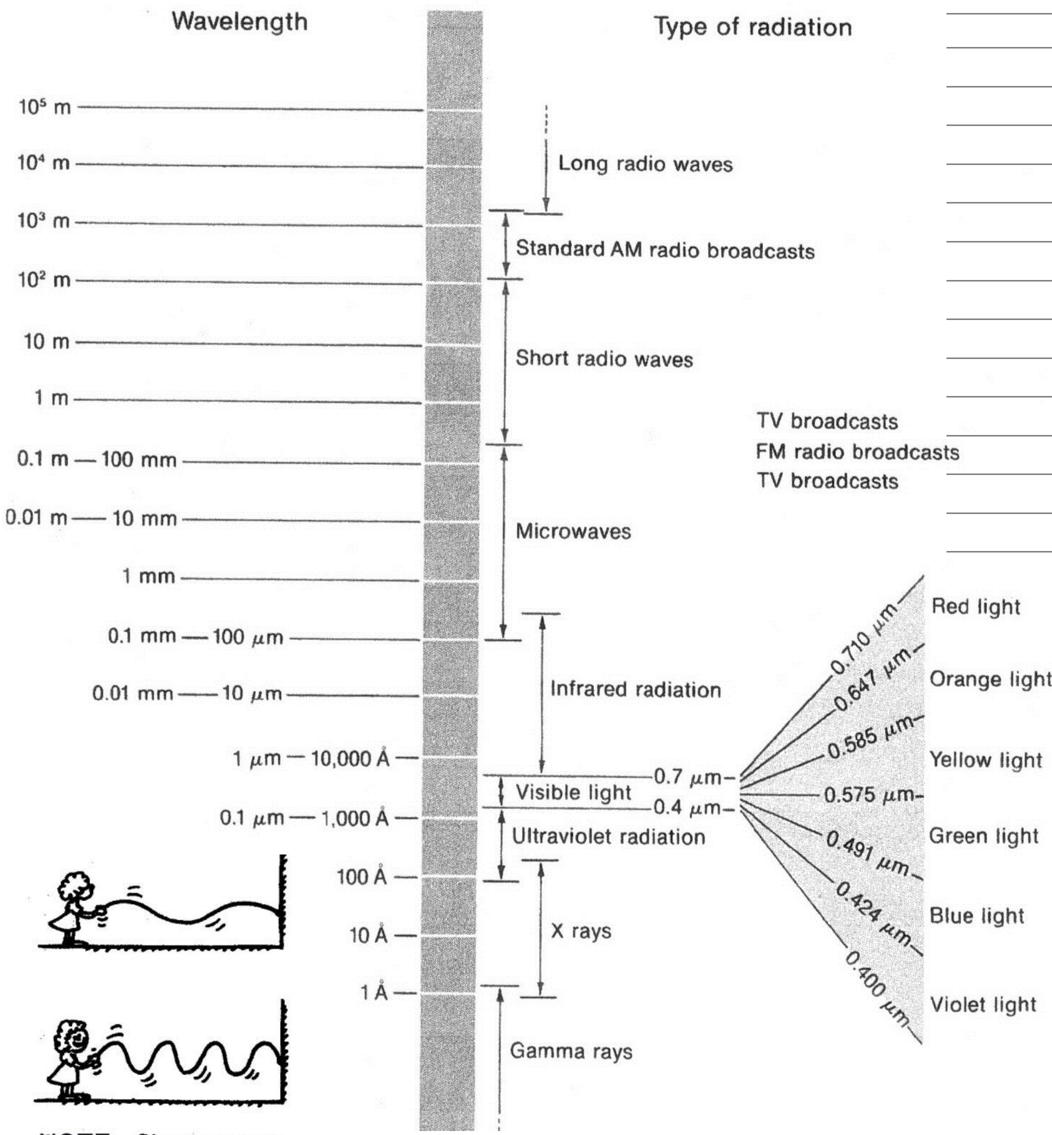
Molecular quantum behavior motions in certain types of gases like WATER VAPOR and CARBON DIOXIDE (H_2O and CO_2) explain why some gases (e.g., H_2O, CO_2) contribute to the **GREENHOUSE EFFECT and GLOBAL WARMING** and other gases (e.g., O_2, N_2) do not!!

The Electromagnetic Spectrum

> Come forth into the light of things. Let nature be your teacher. ~ *William Wordsworth*





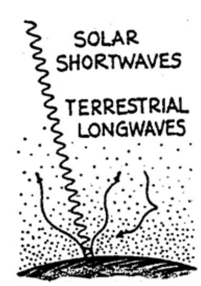


NOTE: **Shorter wavelengths are produced when the rope is shaken more vigorously.**

> *"The shorter the wavelength the greater the energy & the higher the frequency"*

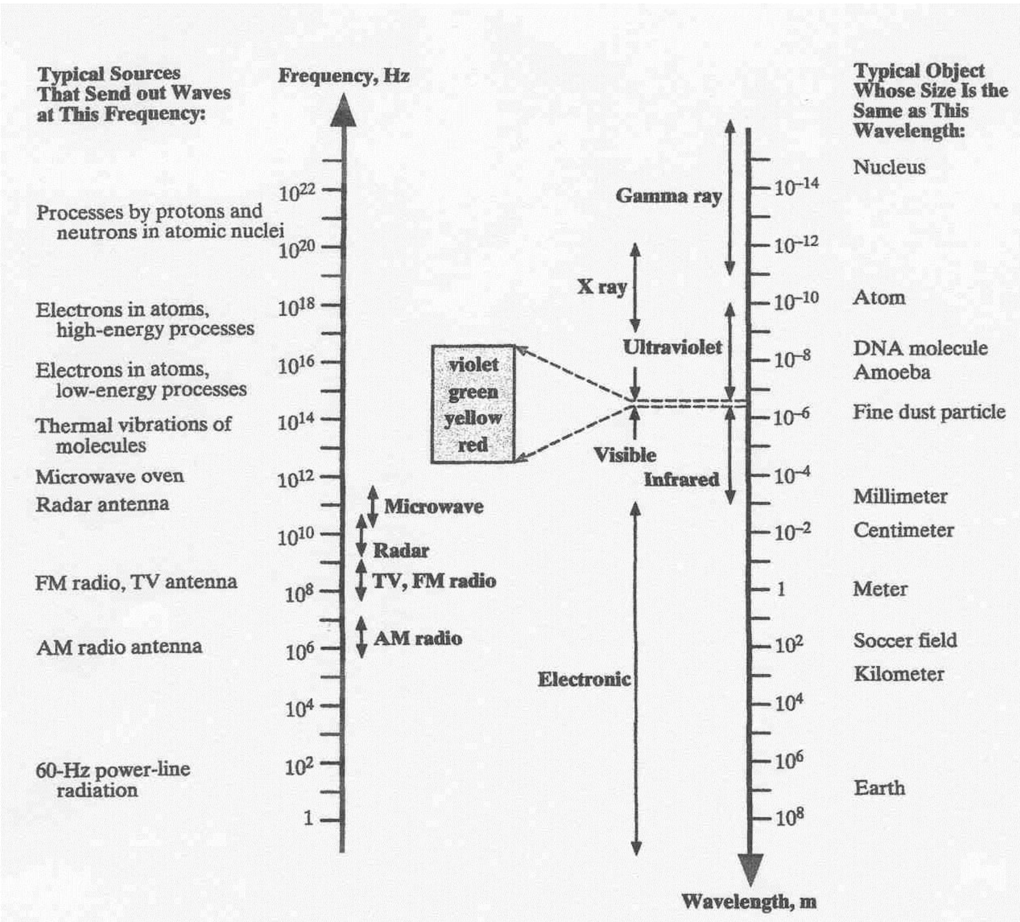
🌎 WHAT IS THE LINK TO GLOBAL CHANGE?

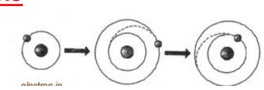
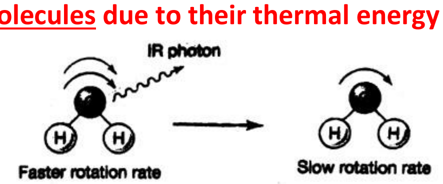
The differences in solar and terrestrial wavelengths of energy are the underlying basis for the **GREENHOUSE EFFECT** and our concerns about **GLOBAL WARMING**



ANOTHER VIEW OF THE ELECTROMAGNETIC SPECTRUM

(in this view the longest wavelengths are at the BOTTOM)



Type of Electromagnetic Radiation	Range of Wavelengths (in units indicated)	Additional Information
Gamma rays	**10^{-16} to 10^{-11}** in meters (m) using scientific notation	**Involve high-energy processes <u>within a nucleus</u> caused by the strong force**
UV Ultraviolet radiation UVC .20 - .29 UVB .29 - .32 UVA .32 - .40	**.0001 to 0.4** in micrometers (µm)	**Involve electrons moving (quantum leaps) <u>within atoms</u>** 
VIS Visible light	**0.4 to 0.7** in micrometers (µm)	
IR Infrared radiation	**0.7 to ~30 (up to 1000)** in micrometers (µm)	**Involve chaotic thermal <u>kinetic motion</u> of <u>molecules</u> due to their thermal energy** 
IR Near Infrared radiation	**0.7 - 1.0** in micrometers (µm)	
IR Far Infrared	**1.0 - ~30 (up to 1000)** in micrometers (µm)	
Microwaves	**10^{-4} to 10^{-2}** in meters (m) using scientific notation	**occur in nature & also electronically produced by a "magnetron" in a microwave oven**
AM Radio waves	**10 to 10^{2}** in meters (m) using scientific notation	**occur in nature & also electronically produced in human-made electrical circuits**

TOPIC # 5 - THE RADIATION LAWS

🌎 WHAT IS THE LINK TO GLOBAL CHANGE? Why and how the Greenhouse Effect works!

> The equations we seek are the poetry of nature. . . . Why is nature that way? Why is it possible for these powerful manifestations of forces to be trapped in a very simple, beautiful formula? This has been a question which many people have discussed, but there is no answer. *- Chen Ning Yang (b. 1922) US physicist*

<u>LAW # 1</u> Emission of radiation:

All substances emit radiation as long as their temperature is above absolute zero (-273.15°C or 0 K).

Blackbody (def): A body that **emits equally well at all wavelengths** (i.e. radiates with 100% efficiency.)

<u>LAW # 2</u> The Plank function

(relates energy & wavelength)

Blackbodies exhibit a *defined relationship* between **the amount of radiation energy (E)** they emit (give off) and the **wavelength (λ)** of that radiation.

This relationship is called the *Planck function:*

E = h * speed of light / wavelength

$$E = h\,c / \lambda$$

where h is Planck's constant, c = speed of light, λ = wavelength of radiation

<u>LAW # 3</u> The Stefan-Boltzmann Law

(relates energy & temperature)

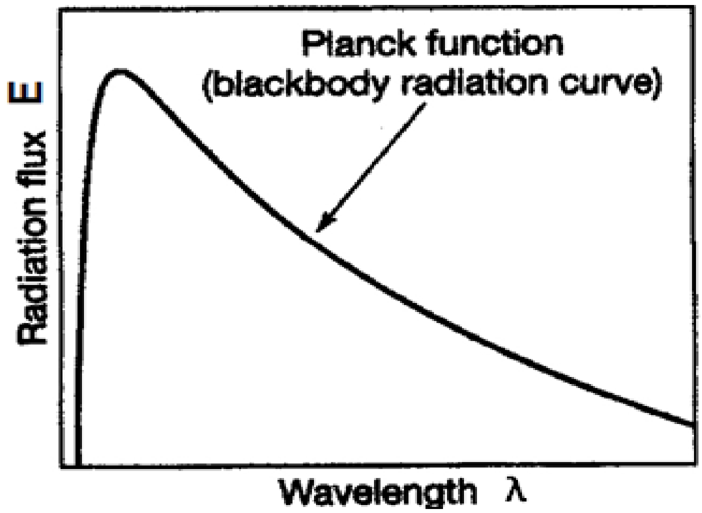
If the substance is an ideal emitter (i.e., a black body), the **amount of radiation emitted (E)** is proportional to the fourth power of its **absolute temperature (T).**

[Note: E = the total radiation flux of energy emitted by a substance at a given wavelength λ]

This is known as the *Stefan-Boltzmann law*:

$$E = \sigma T^4$$

*where **σ is a constant** (the Stefan-Boltzmann constant) which has a value of 5.67×10^{-8} W/m^{-2} K^4 and **T is the absolute temperature**. (in Kelvin)*



LAW # 4 Wien's law

(relates temperature & wavelength)

As substances get hotter, the wavelength at which radiation is emitted will become shorter.

This is known as Wien's law:

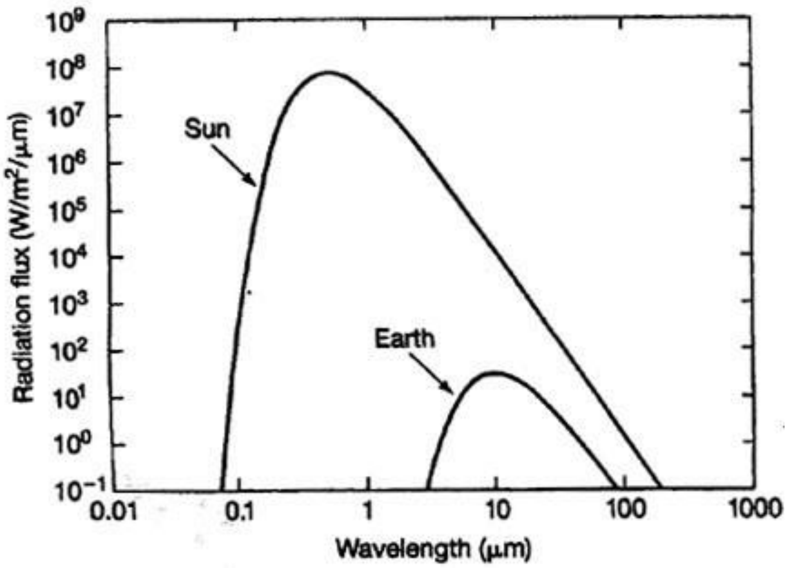
$$\lambda_m = a/T$$

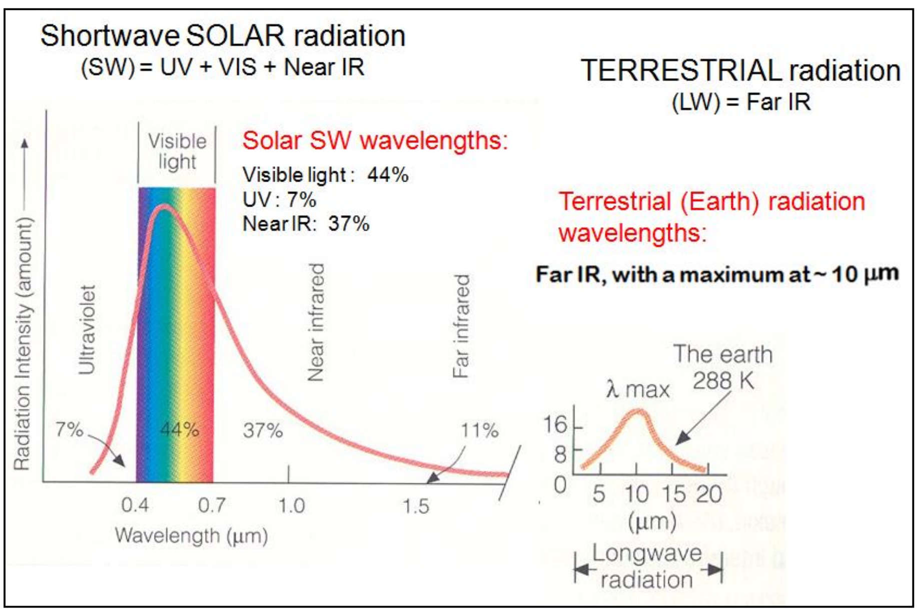
where:

***λ_m is the wavelength** at which the peak occurs*

***T is the absolute temperature** of the body (in Kelvin)*

***a is a constant** with a value of 2898 if λ_m (in micrometers)*





The **Sun** radiates <u>most</u> of its energy at **~0.5 µm**
(right in the middle of the **<u>visible light</u>** part of the spectrum)

But the Sun also radiates a fair amount in the **UV** (7%) and **Near IR** (37%) parts of the spectrum, plus other wavelengths

The cooler **Earth** radiates entirely in the **<u>Far IR</u>** part of the spectrum with a peak at **~10 µm.**

QUICK REVIEW: *match each equation at right with the correct "mantra" bellow & fill in the name of the law*

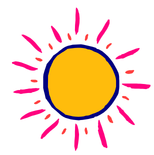
(a) $E = \sigma T^4$ (b) $E = hc/\lambda$ (c) $\lambda_m = a/T$

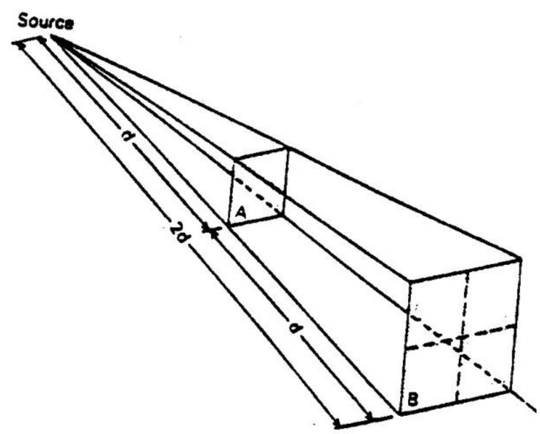
Equation		Name of Law:
_____	"The <u>hotter</u> the body, the <u>shorter</u> the wavelength" "The <u>cooler</u> the body, the <u>longer</u> the wavelength"	______________________
_____	"the hotter the body, the (much) greater the amount of energy flux"	______________________
_____	"SHORTER wavelengths have HIGHER intensity radiation than LONGER wavelengths"	______________________

<u>LAW # 5</u> The Inverse-Square law

(relates amount of radiation intercepted to the distance from source)

The amount of radiation passing through a particular unit area is inversely proportional to the square of the distance of that area from the source ($1/d^2$).





Remember, when Electromagnetic radiation interacts with matter, it can be:

- **ABSORBED (and EMITTED)**
- **TRANSMITTED**
- **SCATTERED, or**
- **REFLECTED . . . .**

  . . . through -- or by -- the matter

<u>LAW # 6</u> Selective Absorption and Emission

(relates different gases to the wavelengths of energy they can absorb & emit)

There are two parts to this law:

(a) Some substances emit and absorb radiation at certain wavelengths only.

(This is mainly true of gases.)

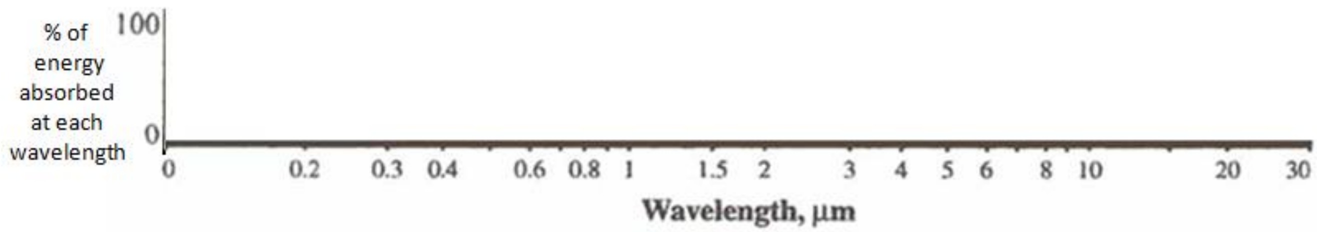
(b) These substance absorb <u>only</u> radiation of wavelengths they can emit:

HANDS-ON PRACTICE to better understand LAW #6

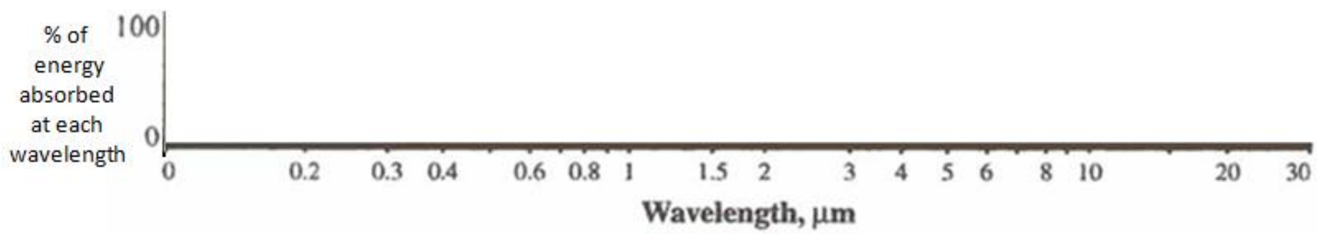
ABSORPTION CURVES (diagrams that show *which* wavelengths of energy different gases selectively absorb)

We use an **absorption curve** (graph) to show the relationship between **wavelengths** of the electromagnetic spectrum (along the horizontal axis) and the **% of energy at each wavelength** that is absorbed by a particular gas (vertical axis)

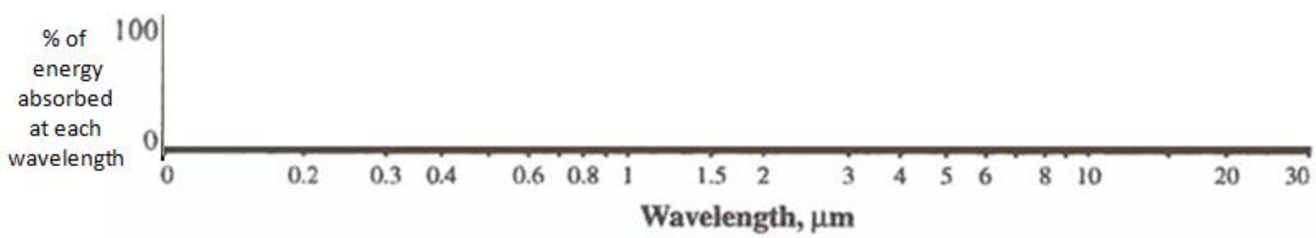
Q 1. *Draw an absorption curve for a hypothetical gas that can absorb <u>ALL</u> UV radiation but <u>zero</u> visible light and IR radiation:*



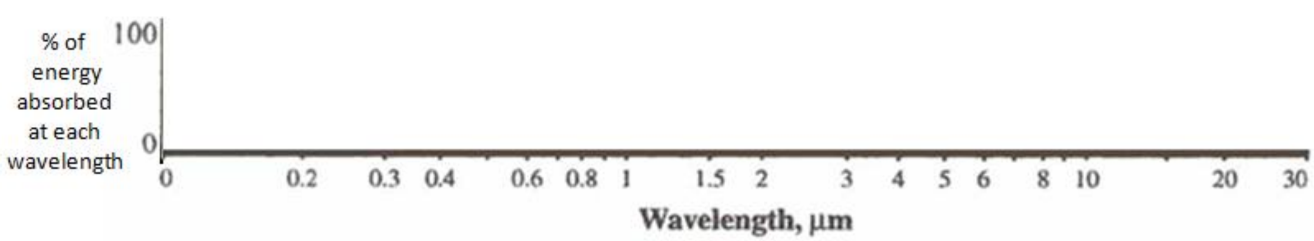
Q 2. *Draw an absorption curve for a "perfect" greenhouse gas that absorbs ALL IR radiation, but no visible or UV:*



Q 3. *Draw an absorption curve for a hypothetical gas that absorbs ALL UV radiation and ALL IR radiation, but leaves a "WINDOW" open for visible light, allowing the visible light wavelengths to pass through the gas unimpeded <u>without</u> being absorbed:*



Q 4. *Draw an absorption curve for a hypothetical gas that can absorb 100% of the IR radiation in these three wavelength bands*: **band from 2 to 2.5 µm** **band from 3 to 4 µm** **band from 13 to 20 µm**



Q 5**.** Is the hypothetical gas in Q4 likely to be a GREENHOUSE GAS? WHY or WHY NOT?

WHAT IS THE LINK TO GLOBAL CHANGE?

LAW #6 explains why the OZONE LAYER PROTECTS US and why GREENHOUSE GASES warm the Earth!

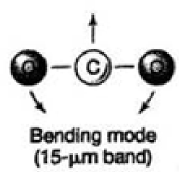
a) The frequency & wavelength of a photon **absorbed** by a given electron, atom, molecule will be the same as the frequency/wavelength with which it is **emitted.**

b) **O_3 (ozone)** selectively **absorbs ultraviolet (UV) radiation** at wavelengths < ~ 0.3 µm
This is how the ozone layer in the stratosphere protects us from harmful, high energy radiation.

c) **GREENHOUSE GASES** both **absorb and emit electromagnetic radiation in the infrared (IR)** part of the spectrum – once IR is absorbed by the greenhouse gases in the atmosphere, it can be emitted back to the Earth's surface to heat it all over again!!
(**This is called the GREENHOUSE EFFECT**.)

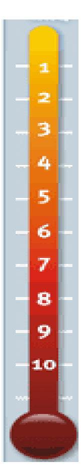
d) The **IR absorbed in the atmosphere** by the GHG's can also be **emitted upward to outer space**, where it will be lost from the Earth-Atmosphere system altogether.

e) **CO_2 is a triatomic molecule**, and one way that CO_2 vibrates is in a "bending mode" that has a frequency that allows CO_2 to absorb IR radiation at wavelengths of 2.5 - 3.0 µm, at ~ 4 µm, and especially at a wavelength **of about 15 µm.** *(the "15 µm CO_2 band")*



f) **Since 15 µm is close to the peak of Earth's outgoing radiation, (10 µm), this absorption band keeps a lot of Earth's longwave radiation from escaping to space**.

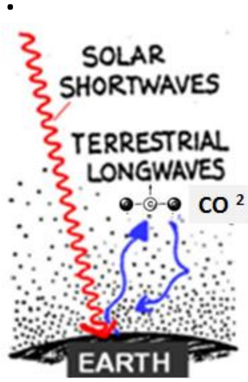
g) If a gas absorbs radiation of any wavelength, the **amount absorbed** will be **proportional to (a) the number of molecules of gas** and (b) the **intensity of radiation** of that wavelength.



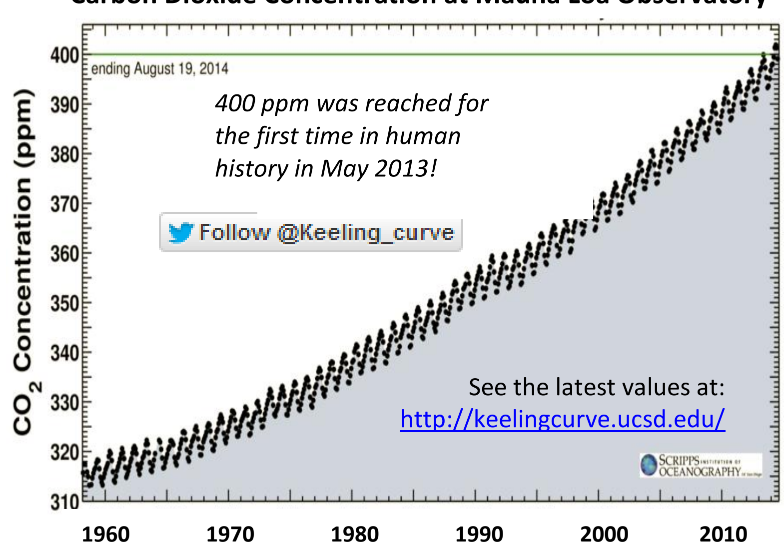
EXPLORING ANOTHER MYTH . . .

CLIMATE MYTH #30:

"Increasing CO_2 has little to no effect"



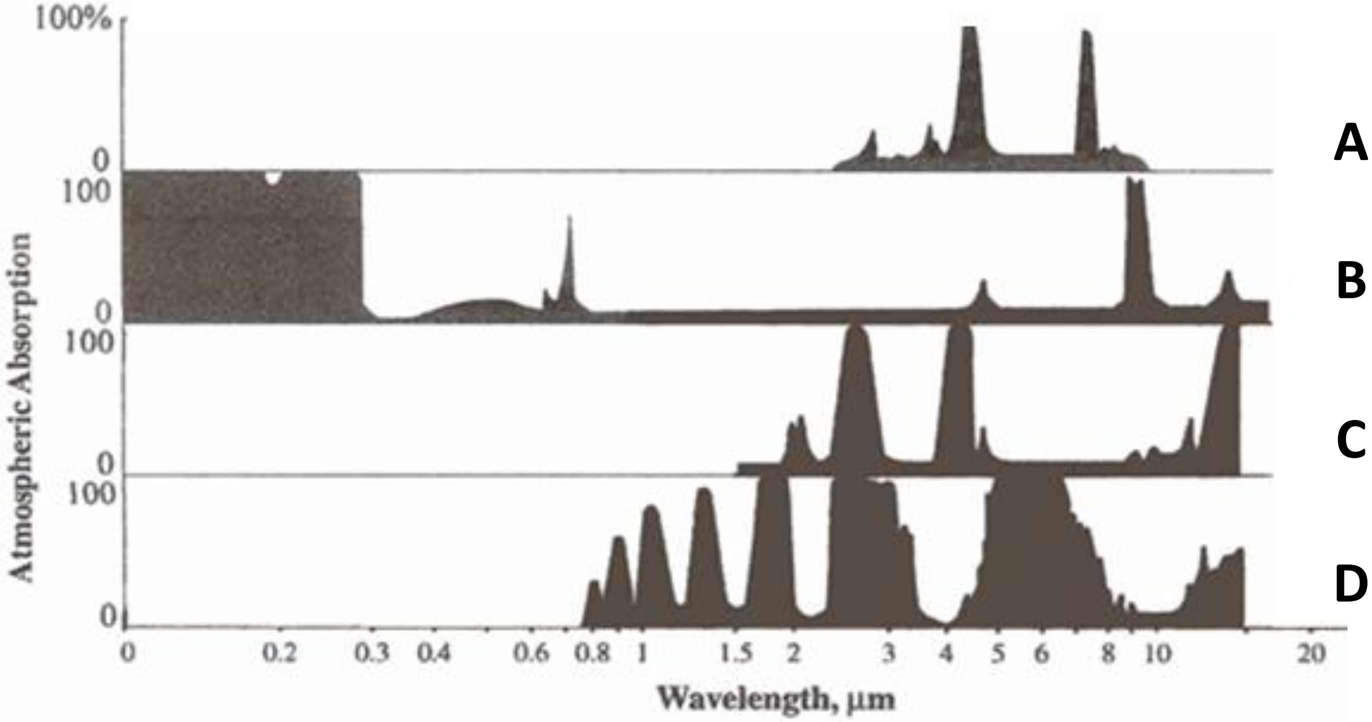
Carbon Dioxide Concentration at Mauna Loa Observatory



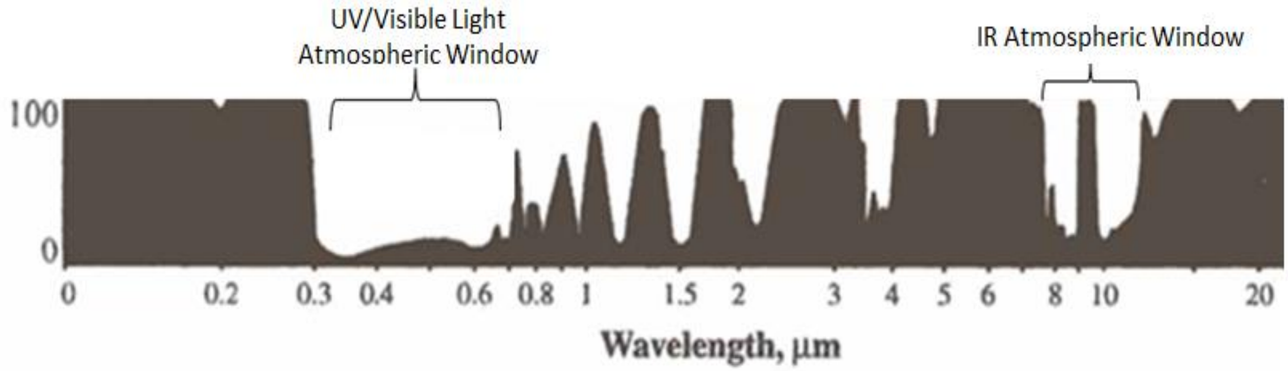
Q 6. IDENTIFYING THE ABSORPTION CURVES OF INDIVIDUAL GASES

Gas	Primary absorption wavelengths *(in micrometers)*	
Water vapor (H_2O)	0.8 1 1.5 2 to 3.5	4 to 7 9 to 10 11 to 20
Molecular oxygen (O_2) and Ozone (O_3)	0.0001 to 0.280 8.5 to 10	
Nitrous oxide (N_2O)	4 to 5 7 to 7.5	
Carbon dioxide (CO_2)	2 to 2.5 3 to 4 13 to 20	

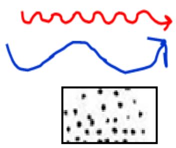
Based on the primary absorption wavelengths of each of gas shown in the table above, match the gases with their corresponding absorption curves below:



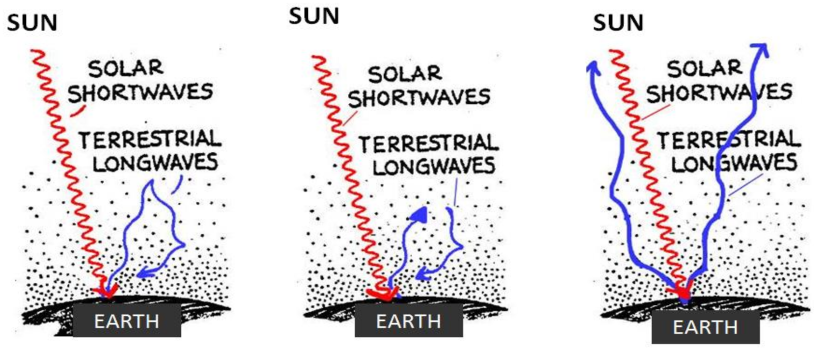
ABSORPTION CURVE FOR THE WHOLE ATMOSPHERE:



SOLAR vs TERRESTRIAL RADIATION CLASS CONCEPTS SELF TEST

KEY: 

= represents Solar shortwave (SW) radiation
= represents Terrestrial longwave (LW) (infrared IR radiation)
= represents the atmosphere and its gases (which can absorb and emit certain kinds of radiation)



A B C

Q 7. Which diagram above shows **<u>shortwave</u> (SW) radiation** being **<u>reflected</u>** back to space?

Diagram A   Diagram B   Diagram C   None of them

Q 8. Diagram A shows LW radiation "bouncing off" the gases in the atmosphere (i.e. being reflected back to the surface by the gases without being absorbed by them.) **Is this an accurate depiction of how Greenhouse Gases produce the "Greenhouse Effect?** ________ Why or why not?

Q 9. Diagram B shows LW radiation being absorbed and them emitted by the gases in the atmosphere. **Is this an accurate depiction of how Greenhouse Gases produce the "Greenhouse Effect?** ________ Why or why not?

Q 10. Diagram C shows LW radiation going right through the atmosphere out to space. **Is this an accurate depiction of how Greenhouse Gases produce the "Greenhouse Effect?** _______ Why or why not?

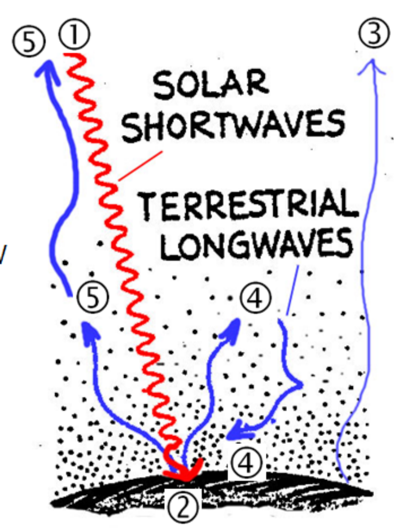
Q 11. On the diagram that you think **<u>best</u> depicts the processes involved in the GREENHOUSE EFFECT,** <u>**circle**</u> the **specific part of the diagram** that represents <u>where</u> the **Greenhouse Gases "do their thing," i.e. produce the "Greenhouse Effect."**

Modified Cartoon of Solar (SW) & Terrestrial (LW / IR) wavelengths of radiation:

① Some Incoming SW radiation from the SUN goes right <u>through</u> the atmosphere to Earth (w/o being absorbed)

② The Earth absorbs SW that reaches the surface

③ Some IR radiation is emitted from the Earth's surface right <u>out</u> to space through "IR window"



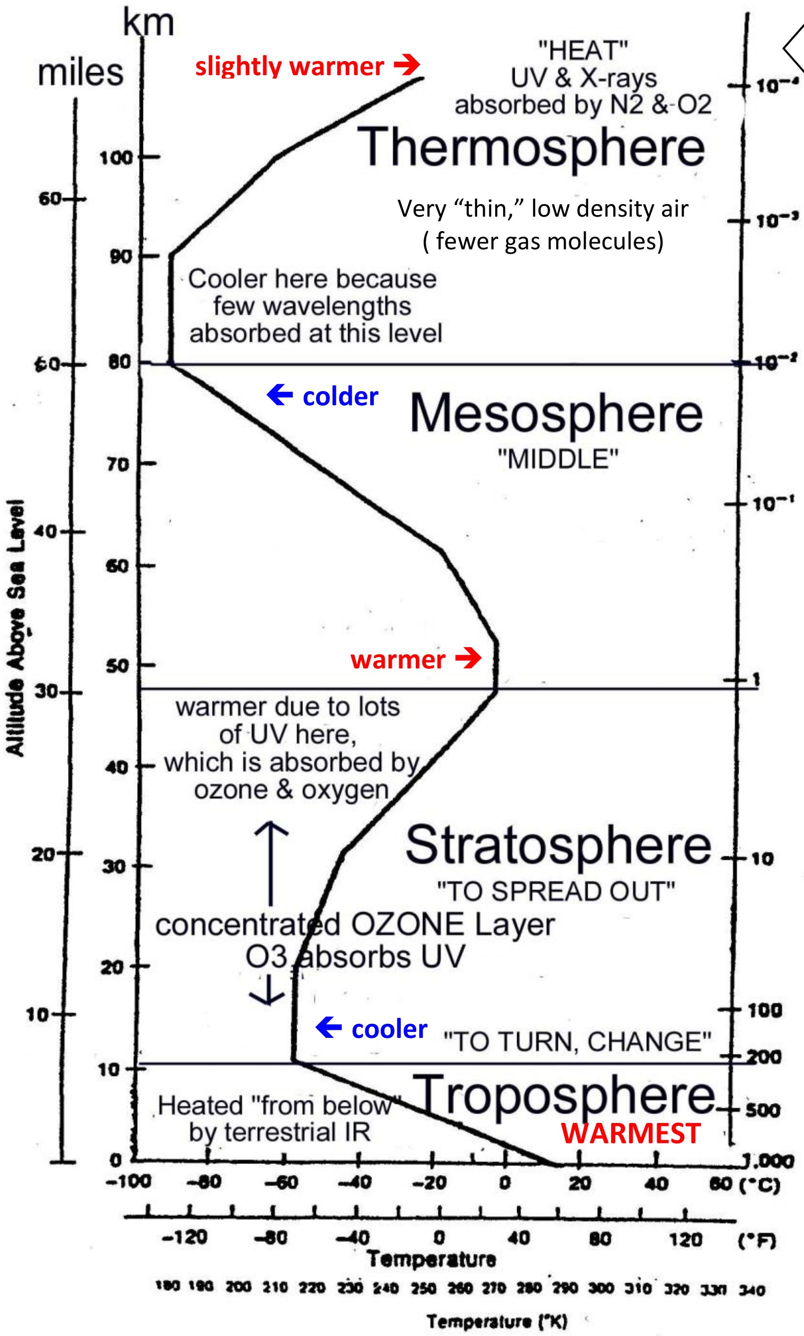
④ Some IR radiation is absorbed by GH gases in the atmosphere and emitted <u>back</u> to Earth

⑤ Some IR radiation is absorbed by GH gases in the atmosphere, but is emitted <u>out</u> to space (not back to Earth)

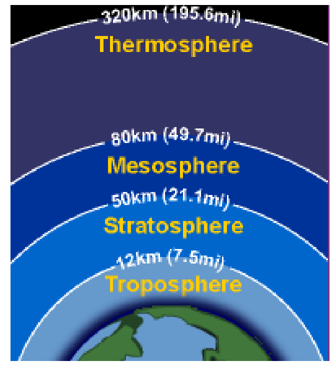
ADDITIONAL NOTES:

TOPIC # 6 ATMOSPHERIC STRUCTURE & CHEMICAL COMPOSITION

> We travel together, passengers in a little space-ship, dependent on its vulnerable supplies of air and soil. - Adlai Stevenson



How Solar radiation of different wavelengths gets transferred or absorbed on its way to the Earth's surface.



THERMOSPHERE: 80 - 320 km

MESOSPHERE: about 50 to 80 km

STRATOSPHERE: 10-15 to about 50 km

TROPOSPHERE: surface to 10-15 km

WHAT IS THE LINK TO GLOBAL CHANGE?

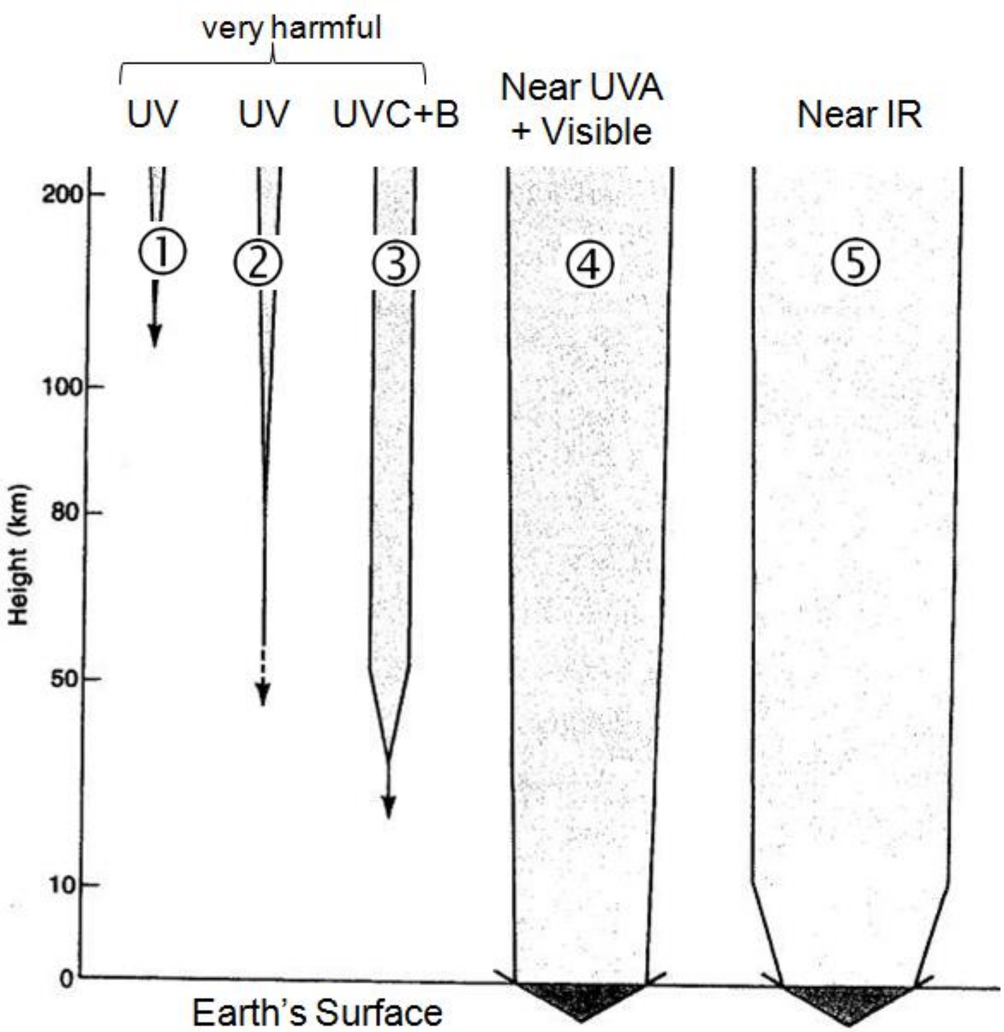
The atmosphere is divided into layers and two of them, the **Troposphere and the Stratosphere, are where most of the Global Change "action" is occurring!** The atmosphere's **vertical structure** is defined by **TEMPERATURE CHANGES.** As you move up from the Earth's surface (which has the warmest temperatures) to the very top of the atmosphere (which has low density and fewer gas molecules), the different layers are defined by changes or reversals in the trend of atmospheric temperature

These changes in temperature are the result of differential absorption (Radiation Law #6) of shortwave (SW) and longwave (LW) radiation at different levels by the gases concentrated there.

Transfer of Incoming Solar Radiation toward Earth's Surface

An application of the Radiation Laws!

It doesn't all get transmitted – some wavelengths are absorbed by gases in the atmosphere on the way down!



KEY:
1. **UV, $\lambda < 0.12$ µm, absorbed by N_2 and O_2 in upper atmosphere**
2. **UV, 0.12 µm $\leq \lambda < 0.18$ µm absorbed by O_2**
3. **UV, 0.18 µm $\leq \lambda < 0.34$, µm absorbed by O_3 in ozone layer**
4. **Near UV and visible, 0.34 µm $\leq \lambda < 0.7$ µm transmitted nearly undiminished except for scattering**
5. **Near IR, 0.7 µm $\leq \lambda < 3.0$ µm , absorbed slightly by O_2 and in troposphere by H_2O**

Reminder: ***Ultraviolet radiation: UVC = 0.20 - 0.29 UVB = 0.29 - 0.32 UVA = 0.32 - 0.40*** **µm**

➔ **DO THE FOLLOWING: ON THE DIAGRAM ABOVE DRAW IN THE TROPOPAUSE, STRATOPAUSE & MESOPAUSE**

Q1. The GREATEST amount of **incoming solar energy** (represented by the width of the arrows) is transferred to Earth via **which wavelength(s)** of electromagnetic radiation? ________________________

Q2. Why does ARROW #3 get narrow and then disappear below 50 km?

Q3. Why does ARROW #5 get slightly more narrow below 10 km?

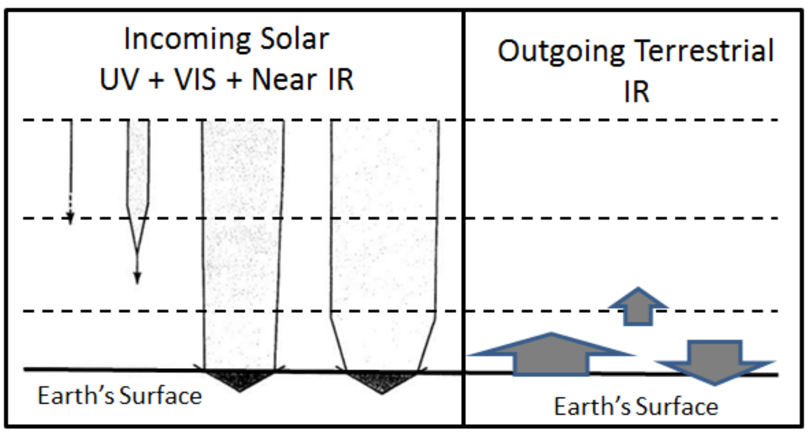
ATMOSPHERIC COMPOSITION

*** = Greenhouse Gas (GHG)** **RF = Radiative Forcing of GHG's in Wm^{-1}**

Gas	Symbol	Percent Concentration (by volume dry air)	Concentration in Parts per Million (ppm)	*RF W/m^2
Nitrogen	N_2	78.08	780,800	
Oxygen	O_2	20.95	209,500	
Argon	Ar	0.93	9,300	
*** Water Vapor**	**H_2O**	0.00001 *(South Pole)* – 4 *(Tropics)*	0.1 *(South Pole)* – 40,000 *(Tropics)*	*varies*
*** Carbon Dioxide**	**CO_2**	0.0390 – 0.0400 *and rising*	390 – 400 *and rising* http://co2now.org/	1.66
*** Methane**	**CH_4**	0.0001774 *and rising*	1.774 *and rising*	0.48
*** Nitrous Oxide**	**N_2O**	0.0000323 *and rising*	0.323 *and rising*	0.16
*** Ozone**	**O_3**	0.0000004 *(in 70s)*	0.01 *(at the surface)*	*varies*
*** CFCs** (e.g. Freon-12) (Chlorofluorocarbons)	**CCl_2F_2**	0.0000000538	0.000538 *RF for all CFC Totals:*	0.170 0.268
*** HCFCs** (e.g., HCFC-22) (Hydrochlorofluorocarbons)	**$CHClF_2$**	0.0000000169	0.000169 *RF for all HCFC Totals:*	0.033 0.039
Neon, Helium, Hydrogen, Krypton, Xenon	Ne, He, H, Kr, Xe	0.0018 – 0.000009	18 – 0.09	
Particles (dust, soot)	--	0.000001	0.0001	

GHG

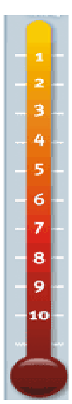
For current GHG concentrations see: http://cdiac.ornl.gov/pns/current_ghg.html
http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf Table 2.1



WHAT IS THE LINK TO GLOBAL CHANGE?

Radiative Forcing (RF) - Radiative forcing is the change in the net, downward (incoming) minus upward (outgoing), **irradiance** (expressed in W/m^2) at the ***tropopause*** due to a change in an external driver of *climate change*, such as, for example, a change in the concentration of *carbon dioxide* or the output of the Sun.

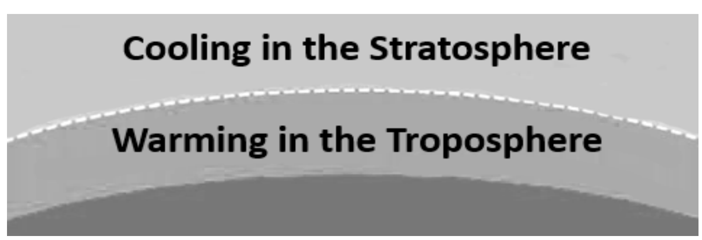
Calculating **Radiative Forcings** helps us pinpoint which factors lead to warming or cooling in the troposphere and stratosphere.



EXPLORING THE EVIDENCE . . .

The Greenhouse Warming Signature:
"Increasing CO2 warms the Troposphere and cools the Stratosphere"

The "Greenhouse Effect" Warming Signature:

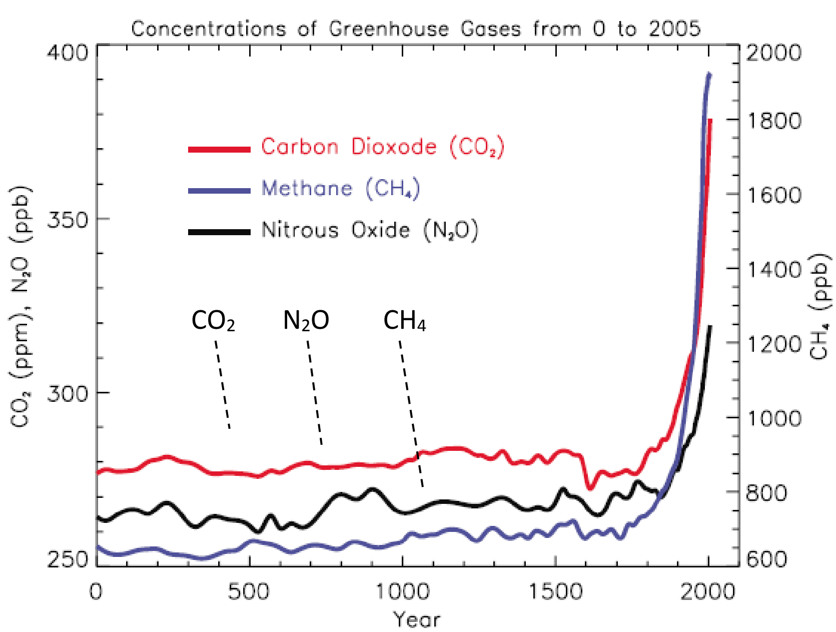


What would a "SOLAR Warming" Signature look like?

GREENHOUSE GASES OVERVIEW

Water vapor H_2O 0.1 to 40,000 ppm	Arrives in atmosphere **naturally through evaporation** Due to unique quantum rotation frequency, H_2O molecules are excellent absorbers of IR wavelengths of 12 µm and longer; virtually 100% of IR longer than 12 µm is absorbed by H_2O vapor (and CO_2) H_2O has variable concentration & residence time in atmosphere depending on location & atmospheric circulation Not globally increasing in direct response to human-induced factors, but if global temperatures get warmer, H_2O vapor will increase due to more evaporation
Carbon dioxide CO_2 280 ppm (pre-1750) 360 ppm (1997) 379 ppm (2005) 390+ ppm (2011)	Arrives in atmosphere **naturally through the natural carbon cycle** **Has increased dramatically** since the 1800s due to (1) **fossil fuel consumption**: oil, coal, gas -- especially coal, and (2) **deforestation** -- which has the effect of increasing the amount of carbon in the atmospheric "reservoir" by reducing the photosynthesis outflow and increasing the respiration inflow. (Deforestation also accelerates forest decomposition, burning, etc. adding to the overall respiration inflow.) Residence time in the atmosphere of carbon atoms in the carbon cycle = ~12.7 years; but residence time of CO_2 gas molecules is estimated at about 100 years and it takes 50 to 100 years for atmospheric CO_2 to adjust to changes in sources or sinks. Due to unique quantum bending mode vibration behavior, CO_2 molecules are excellent absorbers of electromagnetic radiation of about 15 µm (close to the wavelength of 10 µm, at which most of Earth's radiation is emitted.)
Methane CH_4 1.774 ppm	Produced naturally in **anaerobic processes** (e.g., decomposition of plant material in swamps & bogs) **Has increased** due to: **raising cattle / livestock, rice production, landfill decomposition, pipeline leaks** Has relatively short atmospheric residence time because it reacts with OH (~12 years)
Nitrous oxide N_2O 0.319 ppm	Produced **naturally in soils** **Has increased** due to **fossil fuel combustion, forest burning, use of nitrogen fertilizers** Has long atmospheric residence time (~ 115-150 years)
Ozone O_3 0.01 ppm (surface)	Produced **naturally in photochemical reactions in stratospheric ozone layer** "good ozone" **Has increased in troposphere** due to **photochemical smog** reactions "bad ozone" Absorbs IR radiation of 9.6 µm, close to wavelength of maximum terrestrial radiation (10 µm)
CFCs, HCFC, & others	**Human-made** CFCs (didn't exist in atmosphere prior to 1950s) **Have increased** at rates faster than any other greenhouse gas; used in **refrigerants, fire retardants, some aerosol propellants & foam blowing agents** Absorb at different wavelengths than H_2O and CO_2 (in 8 –12 µm part of spectrum), hence a single molecule can have great effect (residence time varies by specific gas; up to 100 yrs; This group of gases has extremely large **Global Warming Potentials (GWP's)** *[see p 29 in DP]*

NATURAL vs. ANTHROPOGENICALLY ENHANCED CONCENTRATIONS OF GHG's



← Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. **Increases since about 1750 are attributed to human activities in the industrial era.**

Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gasper million or billion air molecules, respectively, in an atmospheric sample.

Source: IPCC AR4: http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf

TOPIC #6 SUMMARY: ATMOSPHERIC STRUCTURE & CHEMICAL COMPOSITION

Key Climate Science & Global Change Concepts

1. Four gases N_2, O_2, A, & CO_2 comprise about 99% of the volume of the atmosphere. These are the major gases. However, even the "minor" gases by % volume can be extremely important to us, especially H_2O (water vapor!), CH_4 (methane), and O_3 (ozone), which -- together with CO_2 -- are the main **GREENHOUSE EFFECT** gases. Even smaller amounts of other trace gases such as CFC's and halons can play an important role by disrupting stratospheric **OZONE**.

2. **Most of the mass of the atmosphere is in the bottom few kilometers.** Traces of the earth's atmospheric gases can be detected up to 60,000 km above the earth's surface, but 99% of the mass of the atmosphere lies below 50 km (near top of stratosphere) and 50% of the mass lies below about 6 km (middle troposphere).

3. Different gases are abundant at certain levels in the atmosphere. Because gases absorb and emit only certain wavelengths of radiation, different wavelengths are absorbed at different altitudes, depending on which gas is abundant at that level. **Wherever radiation is absorbed by these gases, the atmosphere heats up, leading to variations in the vertical temperature profile of the atmosphere.**

   N_2, N, O and O_2 are very effective in absorbing very short wave radiation that is harmful (e.g. x-rays and the shorter ultraviolet wavelengths). Since these gases are abundant at high altitudes, much of this harmful radiation never reaches the earth's surface. Similarly, **O_3** in the concentrated **OZONE LAYER** (at about 25 - 35 km in the mid-stratosphere) absorbs additional amounts of the harmful ultraviolet shortwave radiation.

   H_2O and CO_2 are most abundant close to the earth's surface in the lower troposphere. Being greenhouse gases, they are transparent to incoming solar shortwave radiation, but they absorb terrestrial <u>longwave</u> radiation emitted from the earth's surface. **They then re-radiate much of this energy back to the surface, keeping the earth comfortably warmer than it would be without a "Greenhouse Effect."**

4. **The differential absorption of wavelengths of radiation by atmospheric gases at various elevations leads to the "vertical structure" of the atmosphere:** troposphere, stratosphere, mesosphere, thermosphere. The boundaries separating these layers of the atmosphere are defined by temperature changes and are referred to as “pauses,” i.e., tropopause, stratopause, and mesospause.

TOPIC # 7 – THERMODYNAMICS & ENERGY TRANSFORMATIONS

WHAT IS THE LINK TO GLOBAL CHANGE? ENERGY TRANSFER, CONSERVATION & EFFICIENCY

> In this house, we OBEY the laws of thermodynamics! *-Homer Simpson*

PART A - THERMAL ENERGY BACKGROUND

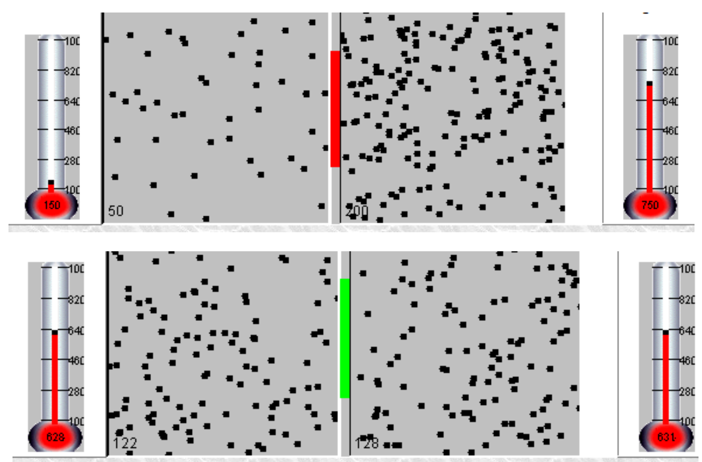
The molecules of every substance are constantly "jiggling" in some sort of back-and-forth vibratory motion. The greater this molecular kinetic energy is in a substance, the hotter the substance is.

THERMAL ENERGY (internal energy) = **the total kinetic energy of molecules in matter**.

(Specifically, a measure of the quantity of atomic **kinetic & potential energy** contained in every object.)

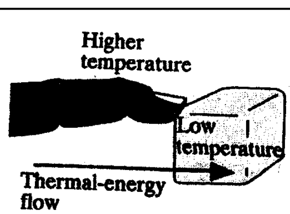
TEMPERATURE = is a measure of the average kinetic energy of each molecule in a body.

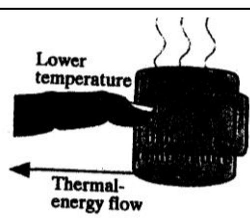
- It tells how warm or cold a body is with respect to some standard (e.g., Fahrenheit, Celsius, or Kelvin standard scales).
- If a body has a high temperature, each of its molecules has, *on the average*, a large amount of kinetic energy;
- if a body has a low temperature, each of its molecules has, *on the average,* a small amount of kinetic energy.
- When atoms and molecules cool so much that they *lose all their kinetic energy*, they reach the "absolute zero" of temperature (-273.15°C = -459.69°F = 0 Kelvin)



HEAT = the **thermal energy that is *transferred*** from one body to another because of a temperature difference.

Heat will always pass from a substance of higher temperature to a substance of lower temperature, until both come to a common temperature.





PART B - TEMPERATURE RESPONSE & THERMAL ENERGY STORAGE IN DIFFERENT SUBSTANCES

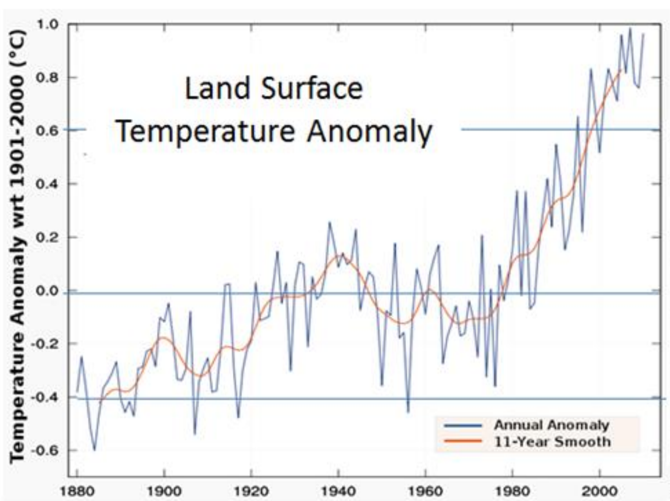
HEAT CAPACITY (Thermal Capacity) = the amount of thermal energy required to change a substance's temperature by a given amount (*joules* or *calories)*

SPECIFIC HEAT = the heat capacity per unit mass of a material (e.g. amount of energy (in calories) required to raise the temperature of 1 gram of *a substance* by 1°C)

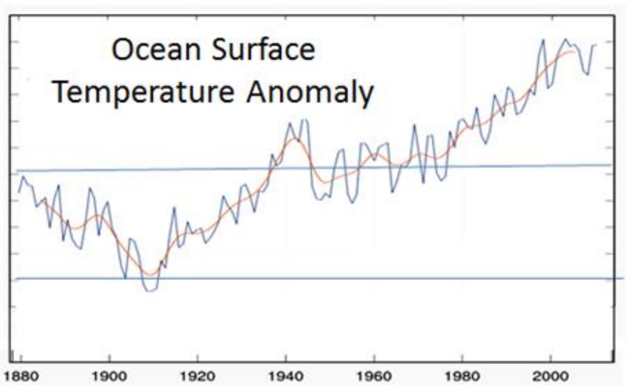
Substance	Specific Heat *calories*	*joules*	Heat Capacity *(calories per cubic cm)*
water	1.00	4.186	1.00
air	0.24	1.005	0.00024 - 0.00034
concrete	0.21	.879	0.5
sand	0.20	.837	0.1 - 0.6 (higher if wet)
rock	0.185	.774	
iron	0.105	.440	0.82
silver	0.056	.234	0.59

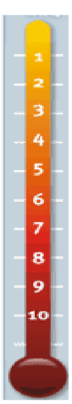
Why will he burn his tongue??

Heat capacity represents the capacity of a substance to <u>absorb</u> and <u>store</u> heat in relation to its *volume* and *density.*



NOAA Global land & ocean surface temperature anomaly 1880-2010.
Data source: http://www.ncdc.noaa.gov/cmb-faq/anomalies.php



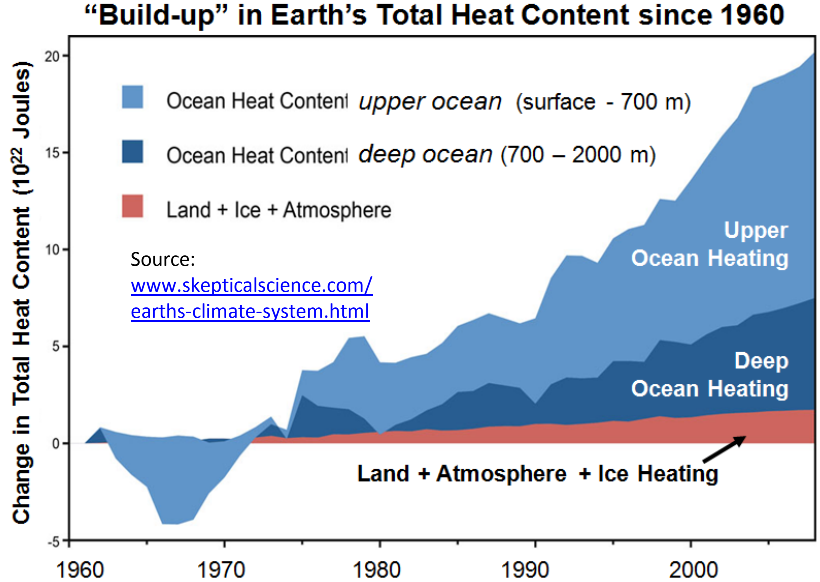


EXPLORING THE EVIDENCE . . .

Q1. Why does the <u>land</u> <u>surface</u> WARM faster than the <u>ocean surface</u>?

Q2. Why is the total heat <u>CONTENT</u> of the ocean so much greater than the land?

"Build-up" in Earth's Total Heat Content since 1960



PART C – THERMAL ENERGY TRANSFER

(aka " Heat Transfer")

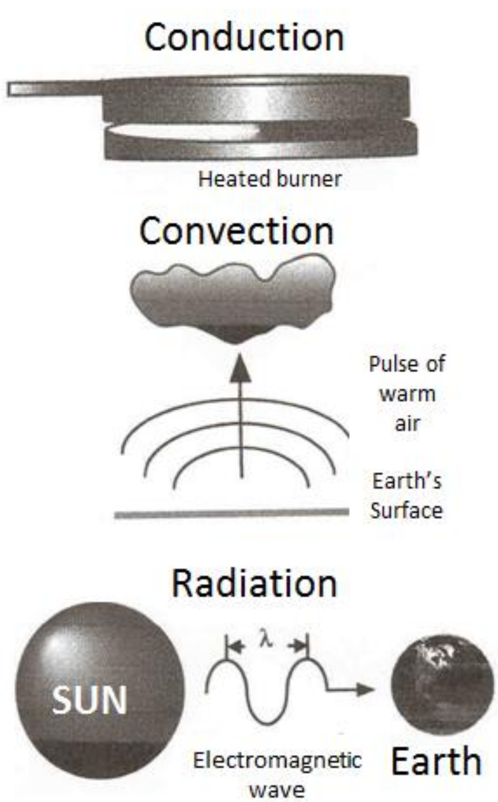
HEAT TRANSFER is the process by which thermal energy *moves from one place to another*;
This transfer occurs through three different mechanisms: ***conduction*, *convection*** or ***radiation*.**

CONDUCTION = passage of thermal energy through a body **without large-scale movement of matter** within the body. Occurs through the transfer of **vibrational energy from one molecule to the next** through the substance. In general, solids (esp. metals) are good conductors & liquids and gases (esp. air) are poor conductors.

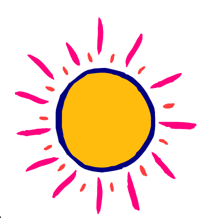
CONVECTION = passage of thermal energy through a fluid (liquid or gas) **by means of large-scale movements of material within the fluid,** as in a ***convection cell.***

RADIATION = the transfer of thermal **energy in a wave or pulse of *electromagnetic radiation*** (as in a photon) or IR wavelength. The only one of the three mechanisms of heat transfer that **does *not* require atoms or molecules (matter)** to facilitate the transfer process.

IMPORTANT: ***Electromagnetic energy (radiation) is energy that does not involve molecular motion.*** *It does not become measurable heat (jiggling molecules) until it strikes an object, is absorbed by the object and sets the molecules in the object in motion, thereby raising the temperature of the object*



WHAT IS THE LINK TO GLOBAL CHANGE?



The sun's energy comes in as radiant electromagnetic) energy, and is converted to measurable heat that can be sensed *only after* it is absorbed (e.g., by the surface of the earth, by certain gases in the atmosphere – the GREENHOUSE GASES!)

PART D - THE LAWS OF THERMODYNAMICS

"Everything that happens can be described as energy transformation."

All of the energy transformations related to THERMAL ENERGY, are governed by LAWS!

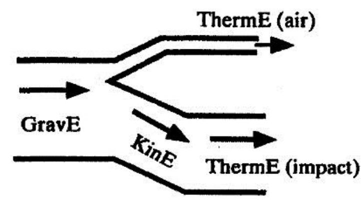
THE FIRST LAW OF THERMODYNAMICS

(aka "Law of Conservation of Energy)

The total energy of all the participants in any process must remain unchanged throughout the process. There are no known exceptions.

- Energy can be transformed (changed from one form to another), but the total amount always remains the same.
- Heat added to a system = increase in thermal energy of the system + external work done by the system.

Energy flow diagram for a falling book, with air resistance. The widths of the pipes correspond to the amounts of energy involved in different parts of the process. Since energy is conserved in each stage of the process, the pipe widths match up at each intersection.



SECOND LAW OF THERMODYNAMICS

Heat will not flow spontaneously from a cold to a hot body. Heat never of itself flows from a cold object to a hot object. Thermal energy flows spontaneously (without external assistance) from a higher temperature object to a lower-temperature object. It will not spontaneously flow the other way.

- *Stated as the "Law of Heat Engines" =* Any process that uses thermal energy as input to do the work must also have a thermal energy output (or exhaust). In other words, **heat engines are always less than 100% efficient.**
- *Stated as the "Law of Increasing Entropy" =* The second law of thermodynamics says that **energy of all kinds in our material world disperses or dissipates if it is not hindered from doing so.**

WHAT IS THE LINK TO GLOBAL CHANGE?

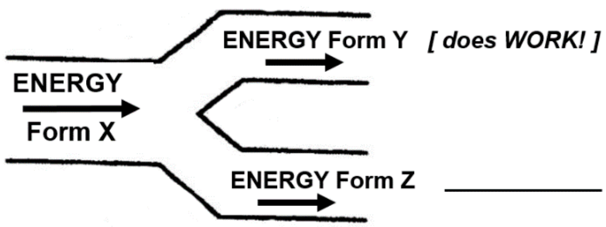
IMPROVING ENERGY EFFICIENCY depends on how we harness and use THERMAL ENERGY because of IRREVERSIBILITY: Once a system creates thermal energy, that system will never by itself (spontaneously) be able to return to its previous condition (and eventually can end up as "wasted energy!"). **The 2^{nd} Law (aka "The Law of Increasing Entropy" tells us that there is an irreversibility about any process that creates thermal energy!**

NOTE: for an excellent site with more detail on the SECOND LAW and ENTROPY see Professor Frank Lambert's "Entropy is Simple" site: http://entropysimple.oxy.edu/

PART E – ENERGY TRANSFORMATIONS & ENERGY EFFICIENCY
Applying The Laws of Thermodynamics & The Laws of Motion

RECAP: Different ways of stating the two Laws of Thermodynamics:

The 1st Law of Thermodynamics	The 2nd Law of Thermodynamics
• Energy is conserved (knows as The Law of Conservation of Energy) • The amount of energy in the universe is constant. • Energy can be neither created nor destroyed. • It is impossible to build a machine that produces <u>more</u> energy than it uses	• Heat cannot flow from a cold object to a hot object on its own. • With each energy conversion from one form to another, some of the energy becomes unavailable for further use. • It is impossible to convert heat energy into work with 100 percent efficiency. • It is impossible to build a machine that produces <u>as much</u> energy as it uses. • The entropy of the universe tends to a maximum.



SELF CHECK:

Q1: In the energy flow diagram above, <u>which Law of Thermodynamics</u> tells us that the amount of energy (represented by the width of the "pipes") in **X** must be equal to the amount of energy in **Y+Z**? #1 or #2

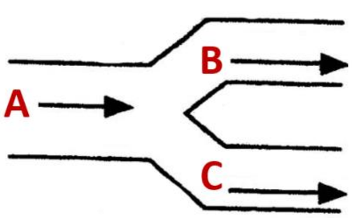
Q2. In the energy flow diagram above, <u>which Law of Thermodynamics</u> tells us that it would be impossible for **Energy Form Z** to do as much work as **Energy Form Y ?** #1 or #2

Q3. What form of energy do you think Z is? Is it doing work? Is it useable, or not?____________________

[Hint, think about the flow diagram of the falling book. Which pipe is Z most like in that diagram?]

Now let's transfer these concepts to LIGHT BULB EFFICIENCY!

Here is a simple and unlabeled **ENERGY FLOW DIAGRAM to show how a LIGHT BULB works** . . . you flip on the switch to start the energy flow, and the light comes on, right? [Since we don't know what kind of bulb it is, the width of the "pipes" has <u>not</u> yet been adjusted to show the relative amounts of energy in each type of energy flow.]



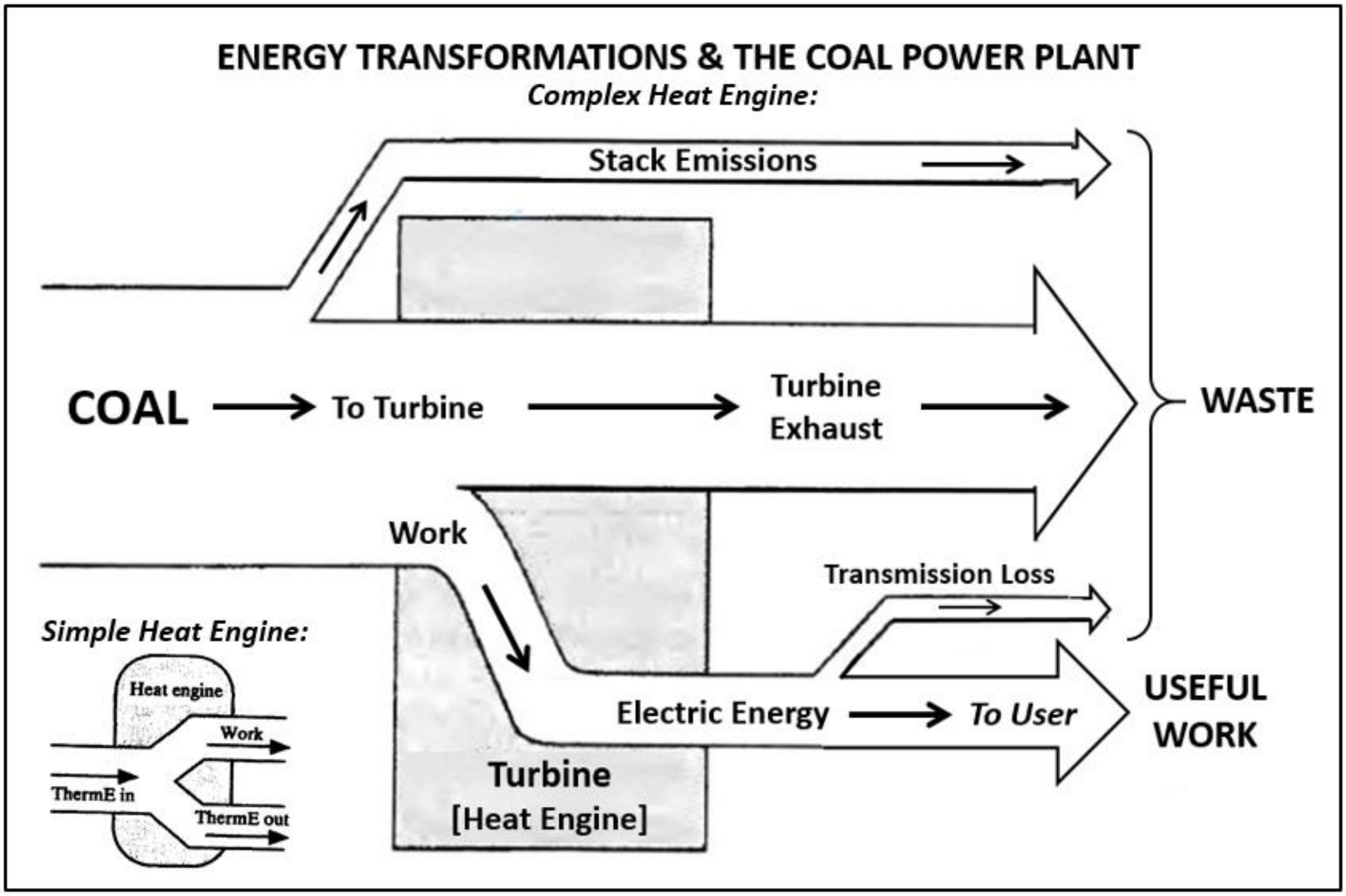
A = ______________________

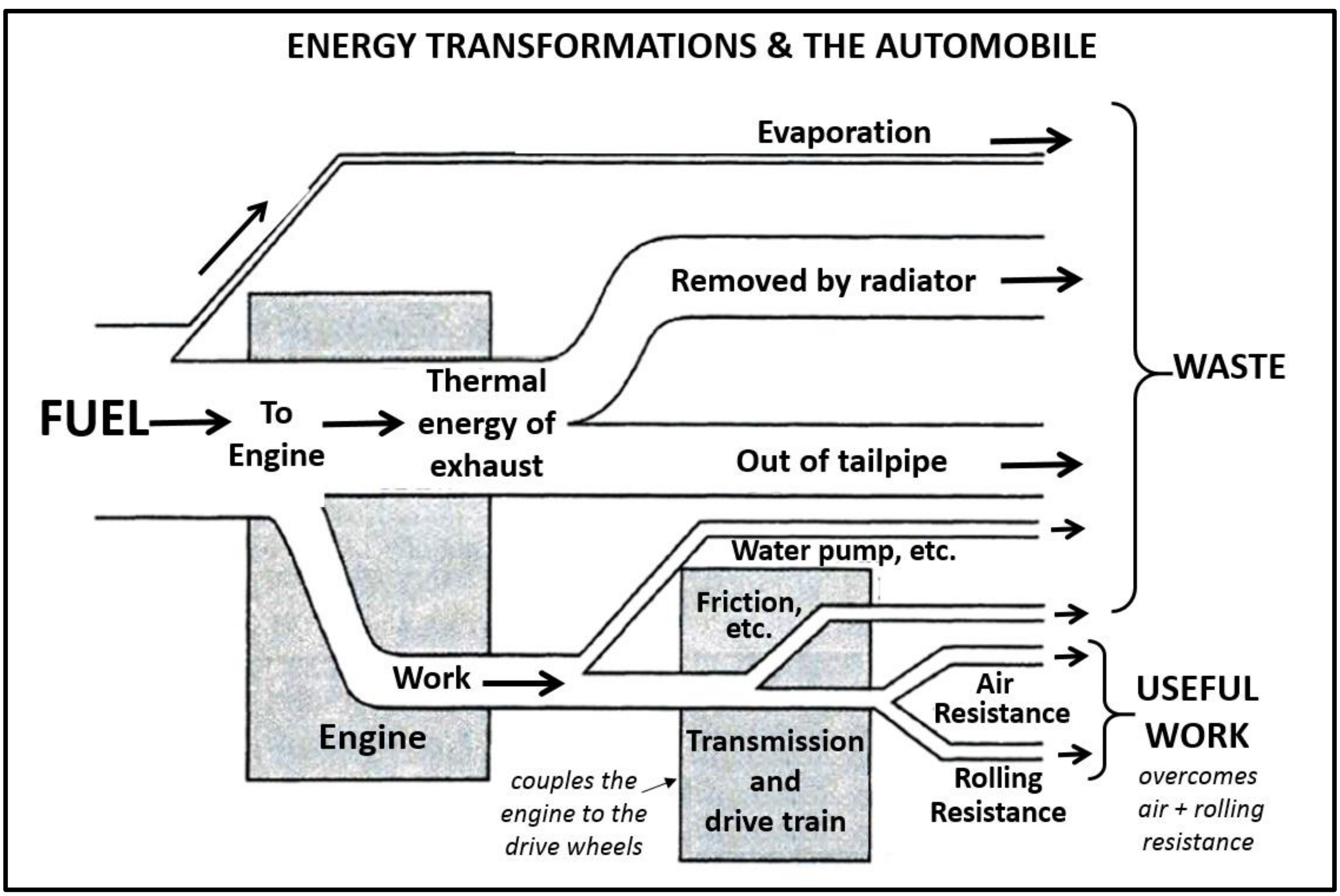
B = ______________________

C = ______________________

Label each pipe with one of the **<u>UNDERLINED CHOICES</u>** below to match the pipes with the form of energy flowing in that pipe:

Choices:
<u>LIGHT</u> *(electromagnetic energy)*
<u>ELECTRICITY</u> *(electrical energy)*
<u>HEAT</u> *(thermal energy)*


ENERGY TRANSFORMATIONS & THE COAL POWER PLANT
Complex Heat Engine:
Stack Emissions
COAL
To Turbine
Turbine Exhaust
WASTE
Work
Transmission Loss
Simple Heat Engine:
Heat engine
Work
ThermE in
ThermE out
Electric Energy
To User
USEFUL WORK
Turbine [Heat Engine]


ENERGY TRANSFORMATIONS & THE AUTOMOBILE
Evaporation
Removed by radiator
FUEL
To Engine
Thermal energy of exhaust
WASTE
Out of tailpipe
Water pump, etc.
Friction, etc.
Work
Air Resistance
USEFUL WORK
overcomes air + rolling resistance
Engine
Transmission and drive train
Rolling Resistance
couples the engine to the drive wheels

ENERGY & MOTION GLOSSARY FOR REFERENCE:

Force (F) = any influence that can cause a body to be *accelerated*. The common force unit is the *newton.* A force is an *action*, not a thing. Every force is similar to a push or a pull.

Acceleration (a) = change in velocity (Δv) / t (time interval) **Velocity** = distance (d) / time (t)

Inertia = The tendency of a body to resist a change in motion, or a body's ability to stay at rest or to maintain an unchanging velocity. A body's inertia is its degree of resistance to acceleration, or its **mass.**

Mass (M or m) = **The quantity of matter in a body**. More specifically, it **is the measurement of the inertia** or sluggishness that a body, in the absence of friction, exhibits in response to any effort made to start it, or stop it, or change in any way its state of motion.

Weight = The force due to gravity upon a body.

Momentum (*p*) = inertia in motion; the product of mass of an object and its velocity.

Momentum = mass x velocity or **Momentum = *m v***

Newton's Laws of Motion

NEWTON'S 1ST LAW OF MOTION *(also called "The Law of Inertia")*

- **A moving object will continue moving in a straight line at a constant speed and a stationary object will remain at rest; unless acted on by an unbalanced force.**

or

- **All bodies have inertia** *[inertia* = the tendency of a body to resist a change in motion: body's ability to stay at res or maintain an unchanging velocity; a body's **mass** is the measurement of the inertia]

NEWTON'S 2ND LAW OF MOTION: *(can be expressed as:* Force = mass x acceleration of F = ma)

- **The ACCELERATION of a body is directly proportional to the NET FORCE acting on the body and inversely proportional to the MASS of the body.**

or

- $\mathbf{a \propto F/m}$ $\mathbf{a = F/m}$ (with appropriate units of m/s^2 for ***a***, newtons for ***F***, kilograms for ***M***)

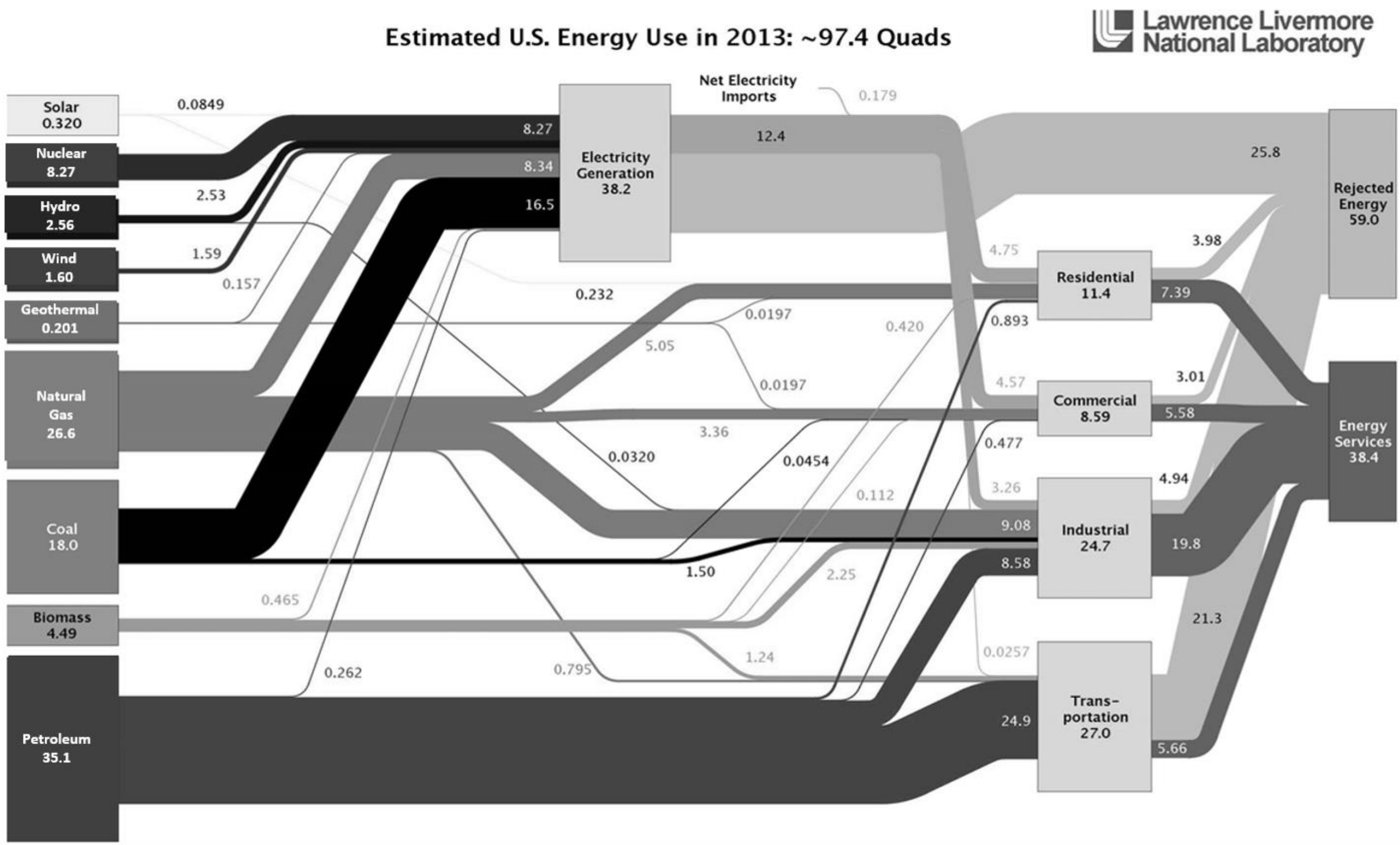
NEWTON'S 3RD LAW OF MOTION *(also called "The Law Of Force Pairs")*

- **Forces always occur in pairs; an action and a reaction. To every action force there is an equal and opposite reaction force; whenever one body exerts a force on a second body, the second body exerts an equal and opposite force on the first body. The two forces are equal in strength but opposite in direction. There is never only a single force in any situation.**

or

- **For every action there is an equal and opposite reaction**

Estimated U.S. Energy Use in 2013: ~97.4 Quads



Source: LLNL 2014. Data is based on DOE/EIA-0035(2014-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Source: https://www.llnl.gov/news/newsreleases/2014/Apr/NR-14-04-01.html#.U_U3ncVdXyA

ADDITIONAL NOTES:

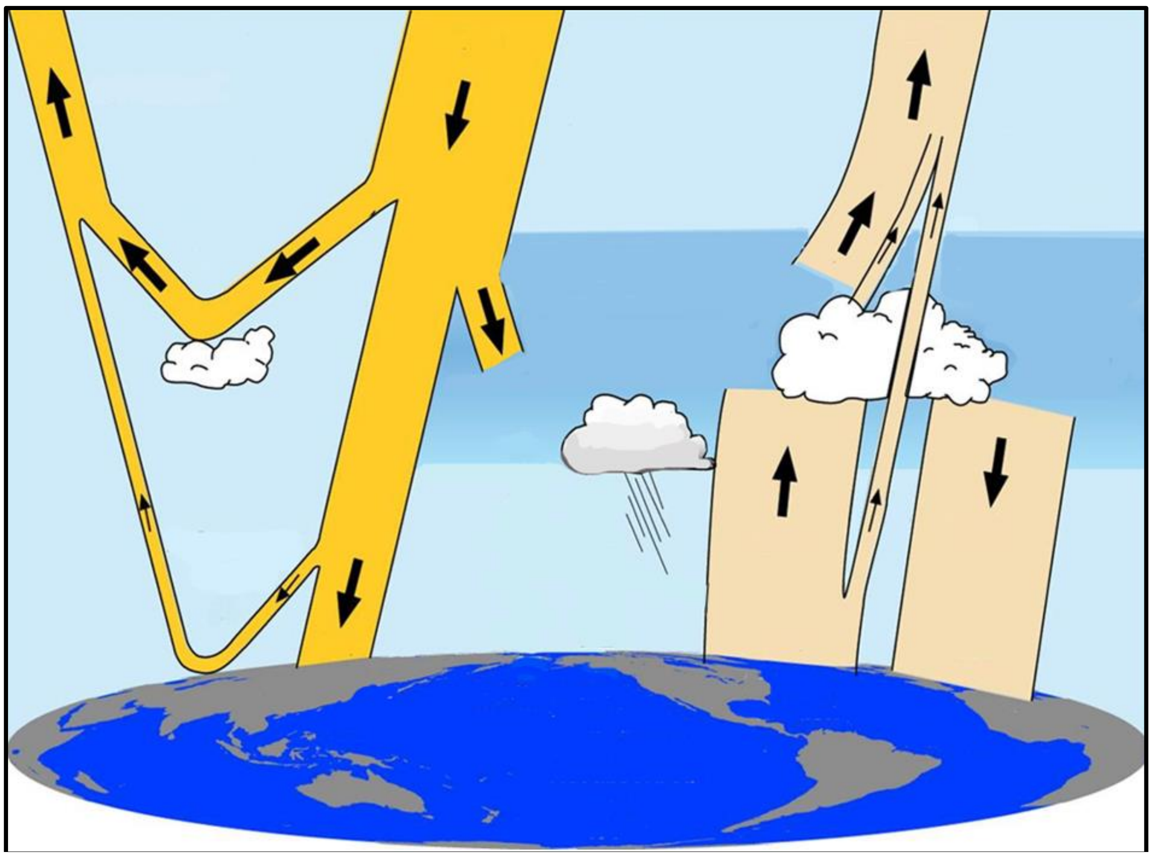
TOPIC # 8 – THE GLOBAL ENERGY BALANCE

> Look at life as an energy economy game. Each day, ask yourself, Are my energy expenditures (actions, reactions, thoughts, and feelings) productive or nonproductive? During the course of my day, have I accumulated more stress or more peace? - *Doc Childre and Howard Martin*

$$R_{NET} = \overset{SW}{\downarrow} + \overset{SW}{\downarrow} - \overset{SW}{\nearrow} - \underset{LW}{\uparrow} + \overset{LW}{\downarrow} = H + LE + G$$

Representation of the Energy Balance & Energy Pathways

Throughout the whole Earth-Atmosphere system, the energy units balance out, energy is conserved, and the 1st Law of Thermodynamics applies.



ALBEDO = reflectivity of a surface

Represented as:
a decimal from 0 to 1.0 or %

100 % = perfect reflectivity.

The amount *absorbed* = (1.0 – albedo)

Albedos of Some Common Surfaces

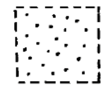
Type of Surface	*Albedo*
Sand	0.20–0.30
Grass	0.20–0.25
Forest	0.05–0.10
Water (overhead Sun)	0.03–0.05
Water (Sun near horizon)	0.50–0.80
Fresh snow	0.80–0.85
Thick cloud	0.70–0.80

ADDITIONAL NOTES:

THE ENERGY BALANCE

$$R_{NET} = \overset{SW}{\downarrow} + \overset{SW}{\downarrow} - \overset{SW}{\nearrow} - \underset{LW}{\uparrow} + \overset{LW}{\downarrow} = H + LE + G$$

GUIDE TO THE "CARTOON" SYMBOLS WE'LL USE:

EARTH'S SURFACE:  **CLOUDS:**  **ATMOSPHERE:** 

DIRECT SOLAR SHORTWAVE: $\overset{SW}{\downarrow}$ **DIFFUSE SOLAR SHORTWAVE:** $\overset{SW}{\downarrow}$ **REFLECTED SOLAR SHORTWAVE:** $\overset{SW}{\nearrow}$

UPWARD LONGWAVE (IR): $\underset{LW}{\uparrow}$ **DOWNWARD LONGWAVE (IR) :** $\overset{LW}{\downarrow}$

SUCCINCT SUMMARY OF THE ENERGY BALANCE COMPONENTS

1. Scientists generally assume that **the atmosphere-earth system is in "balance**," i.e., **energy in = energy out**. If it isn't, the earth should be getting gradually warmer or colder over time! That's why understanding the components of the Energy Balance is so important for Global Change Science! **Is the balance changing???**

2. About **30% of the total incoming energy gets reflected back out to space** without ever being absorbed by the surface of the earth. **About 70% gets absorbed in the atmosphere or at the surface of the earth** and then is **radiated back out to space in the form of longwave (infrared) radiation.**

3**. Shortwave solar radiation** $\overset{SW}{\downarrow} \overset{SW}{\downarrow} \overset{SW}{\nearrow}$ entering the Earth's atmosphere from the Sun can be: (1) **reflected** back to space by the atmosphere or by the surface, (2) s**cattered back out to space or scattered down to the Earth's surface** by atmospheric gases, dust, etc., (3) **absorbed by gases and clouds** in the atmosphere or, (4) **beamed directly to the surface where it is absorbed.** The **amount** of direct and diffuse shortwave radiation that is actually **absorbed at the earth's surface is about 1/2 the amount** that arrives initially **at the top of the atmosphere**.

4. **Longwave radiation** $\underset{LW}{\uparrow} \overset{LW}{\downarrow}$ radiated from the Earth or atmosphere can be: (1) **emitted from the Earth's surface directly to space** through the "atmospheric window," (2) **emitted from the Earth's surface and absorbed in the atmosphere by greenhouse gasses**, (3) **emitted from the atmosphere escaping to space,** or (4) **emitted from the atmosphere back to the Earth's surface**, where it can be absorbed and emitted to the atmosphere again (**re-radiation**).

5. At the **Earth's surface**, there is a **net surplus of energy:** called **"net radiation"** R_{NET} that **drives** energy transfers or exchanges in the form of ***convection***, ***conduction***, and ***phase changes*** ➔ **weather & climate**!

The amount of energy transferred in these different forms: **sensible heat** **H** **, latent heat (or latent energy)** **LE** and **"ground" (land + water) heat flux** **G** -- varies from place to place on the earth.

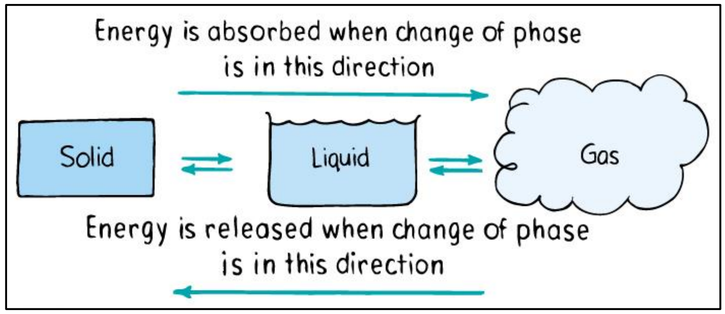
UNDERSTANDING THE RIGHT SIDE OF THE EQUATION: H + LE + G

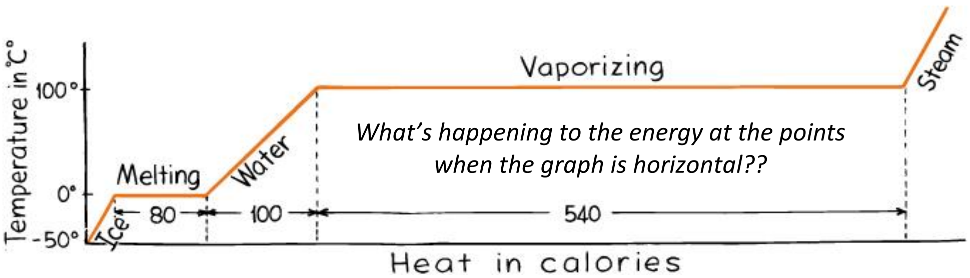
SENSIBLE HEAT (H) & LATENT ENERGY (LE)

SENSIBLE HEAT (H) = the amount of energy released or absorbed by a substance during a **change of temperature.**

LATENT ENERGY (LE) = the amount of energy released or absorbed by a substance during a **change of phase,** such as when water evaporates.

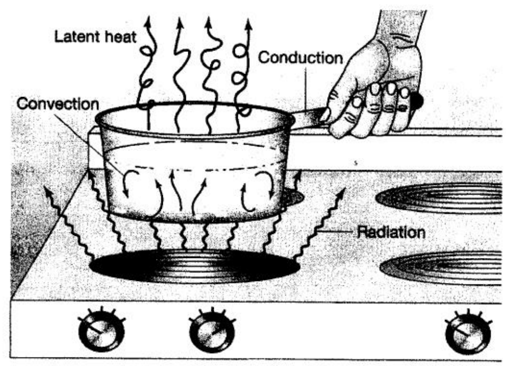
H + LE: Energy & Phase Changes In Matter





Explanation of H and LE:

H = sensible heat transfer



Sensible heat is the energy or heat of molecular motion. It can be "sensed" with a thermometer, and we "feel" it as heat, unlike LE. It is transferred by ***conduction*** from warmer to cooler objects (most common in solids); and by ***convection*** (large scale, mostly vertical, motion of gases or liquids)

LE = latent energy (latent heat) transfer

Latent energy is energy needed for ***phase changes*** in H_2O: LE is removed from the environment and "hidden" in H_2O during the evaporation of water and melting of ice => environment cools. LE is released to the environment from H_2O during condensation of water vapor and freezing of ice => environment warms.

Explanation of G:

G = "ground storage," i.e. transfer of heat into the "ground" = the continental OR oceanic surface of Earth!

G is energy ***conducted*** into **land (in soil, rock) or water (in ocean, lakes)** and **temporarily stored there to be released later as H or LE.** On a daily time scale, G is usually stored during the day and released at night. On an annual basis, G tends to be stored during the warm season and released during the cold season. Averaged over several years, G stored and G released balances out to be zero.

Review: **HEAT CAPACITY** = the capacity of a substance to absorb and store heat in relation to its *volume* and *density.* **HEAT CAPACITY is critically important for G!**
The differences in the heat capacity of **land vs water** result in differences in:
(a) how much total energy can be stored
(b) how quickly energy can be transferred into storage, and
(c) how quickly energy can be released from storage.

APPLYING THE ENERGY BALANCE TERMS TO YOUR EVERYDAY LIFE

Following is a list of things you might observe at one time or another in your daily lives. Each has something to do with one or more components of the Energy Balance Equation**.**

➔ **Your task is to decide which Energy Balance component (or components working together) *are most directly related to* or *responsible for* the observed phenomenon.**

Divide up the 20 items in your group so that each student has 2 or 3, then pair up to work out the answers together. A preceptor, GTA, or Dr H will help you if you have questions. When your "pair sharing" is done, explain your answers to the whole group so that **everyone has the entire sheet answered** and knows how to respond to questions like this on a test!

Phenomena related primarily to the LEFT side of the equation:

$$\overset{SW}{\downarrow} + \overset{SW}{\downarrow} - \overset{SW}{\nearrow} - \underset{LW}{\uparrow} + \overset{LW}{\downarrow}$$

Practice Q: You see the sky as blue.

1) People wear sunglasses on the ski slope.

2) There is still brightness on a day completely overcast by clouds.

3) You can get a better tan (and skin cancer!) at midday, lying flat on the ground; rather than early or late in the day, standing up. *(NOTE: in both cases your body is perpendicular to the sun's rays)*

4) The Greenhouse effect.

5) Red sunsets (especially after large and explosive volcanic eruptions!)

6) Infrared photographs of the land surface can be taken at night using special infrared cameras, whereas a regular camera needs daylight or a flash to work.

7) You can see your shadow distinctly on a sunny day, but not on a cloudy day.

8) You see the colors of a rainbow.

9) Football and baseball players sometimes put black streaks under their eyes for games.

10) You park your car on a blacktop parking lot on a hot, sunny day

Phenomena related primarily to the RIGHT side of the equation:

$$H + LE + G$$

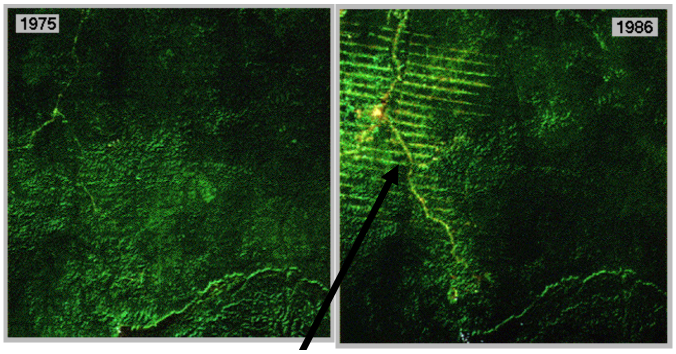
11) a hot air balloon

12) pigs have no sweat glands so they wallow in the mud to cool themselves

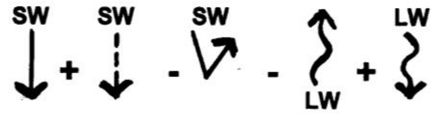
13) In Arizona, swamp coolers (evaporative coolers) work well in hot, dry June but may not work as well in the more humid months of July and August.

WHAT IS THE LINK TO GLOBAL CHANGE?
Thinking Through Global & Regional Changes In The Energy Balance

TROPICAL DEFORESTATION
(satellite imagery)



Striped pattern of deforestation due to construction of logging and access roads



How would the left side of the equation change after deforestation?

Q1. Will albedo **INCREASE or DECREASE** after deforestation? Why?

Q2. Would this lead to local **COOLING or WARMING** ? Why?

H + LE + G

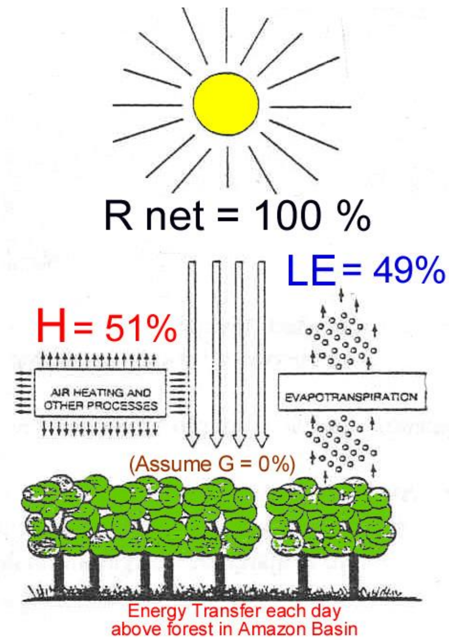
HOW MIGHT H + LE CHANGE AFTER DEFORESTATION?

Estimates from the Amazon Basin indicate that ~ ½ of its precipitation is derived from recycled water (after trees take in H_2O it is returned to the atmosphere as water vapor through transpiration.)

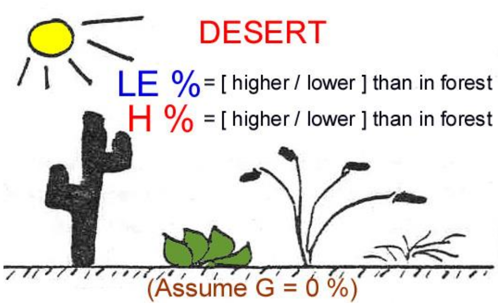
Deforestation therefore has a dramatic effect on the local hydrologic cycle (i.e., evaporation, transpiration, & precipitation) of the rainforest, which **affects the amount of energy stored in either H or LE** and therefore can affect local climate. Deforestation also affects soil moisture & runoff.

Q3. Will the proportion of energy stored in **LE** (at the expense of H) **INCREASE** or **DECREASE** after deforestation? Why?

Q4. Would this lead to local **COOLING or WARMING** ? Why?



How does the ENERGY BALANCE differ in an arid environment?



H + LE + G

How would the distribution of energy in the right side of the equation differ in the Sonoran desert vs. the Amazon rainforest?

Q5. Choose the correct response below. Why?
(a) In the desert, **LE** will be **higher** and **H** will be **lower**
(b) In the desert, **LE** will be **lower** and **H** will be **higher**

Q6. Which environment do you think can reach the **highest temperatures** during its warm season? Why?
(a) The Amazon Rain Forest? (b) The Sonoran Desert?

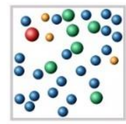
Through reasoning like the above, based on the Energy Balance,
YOU can develop conceptual models about the directions future Global Changes will take us!

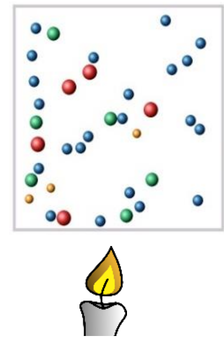
WHAT IS THE LINK TO GLOBAL CHANGE?

H + LE + G ARE THE DRIVERS OF LOCAL & GLOBAL WEATHER & CLIMATE

H (Sensible Heat) can be "sensed" as hot and cold temperatures due to the kinetic energy of the gas molecules ➔

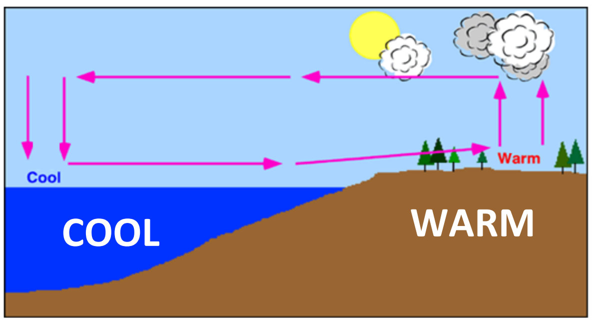
Cold air is more dense and tends to sink



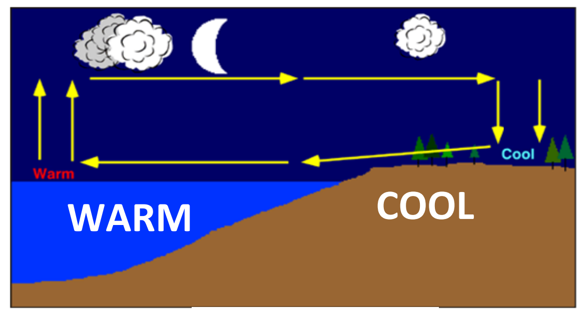


Warm air is less dense, will expand and rise

Example of how **H + G** *can affect local climate:*



LAND BREEZE



SEA BREEZE

TEMPERATURE is determined by: **H + LE + G** together

ATMOSPHERIC CIRCULATION, CONVECTION and LAND & SEA BREEZES are determined by:

- Thermally driven DENSITY difference of AIR **(related to H)**

  \+

- HEAT CAPACITY differences of LAND vs. WATER **(related to G)**

PRECIPITATION (clouds, rain , snow) + DROUGHT are determined by:

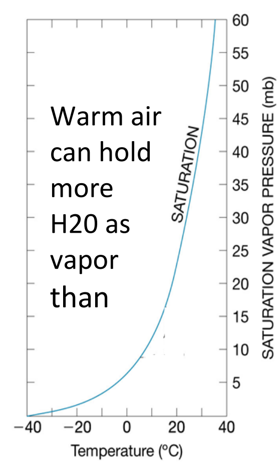
- Amount of MOISTURE IN THE AIR **(related to evaporation: LE)**

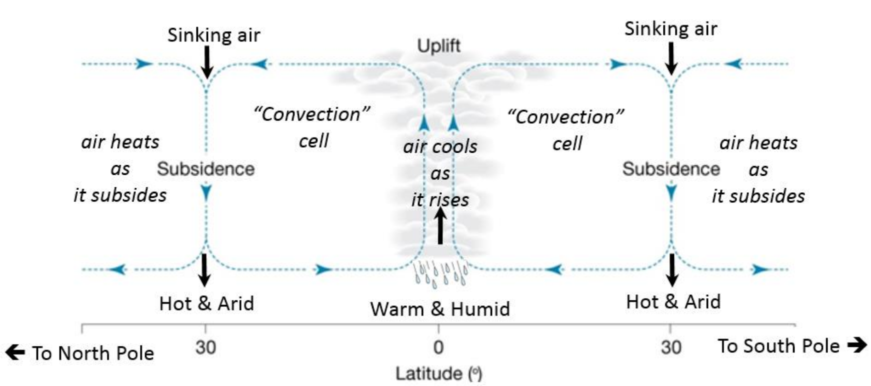
  \+

- TEMPERATURE of the AIR: **warmer air holds more moisture ➔**

  \+ **(related to H)**

- ATMOSPHERIC CIRCULATION PROCESSES interacting with above **(related to H, LE, G, plus land vs. water distribution, latitude, topography, etc.)**





ADDITIONAL NOTES:

TOPIC #9 SYSTEMS & FEEDBACKS

"When one tugs at a single thing in nature, one finds it attached to the rest of the world."
- John Muir

WHAT IS A SYSTEM?

SYSTEM = a set of interacting components

SYSTEM MODEL = a set of assumptions, rules, data and inferences that define the interactions among the components of a system and the significant interactions between the system and the "universe" outside the system

SYSTEM DIAGRAM = A diagram of a system that uses graphic symbols or icons to represent components in a depiction of how the system works

Component *(def)* =

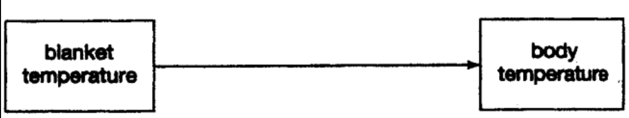
An individual part of a system. A component may be a reservoir of matter or energy, a system attribute, or a subsystem.

Coupling *(def):*

The links between any two components of a system.

Couplings can be positive (+) or negative (-)

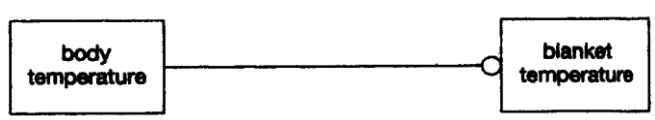
A coupling between an electric blanket temperature component and a body temperature component:



If the electric blanket's temperature INCREASES . . .

The person's body temperature will ______________

A coupling between a person's body temperature and an electric blanket's temperature



If the person's body temperature INCREASES and he gets too hot . . .

The electric blanket's temperature control will be turned down and the blanket temperature __________

Feedback mechanism *(def):*

a sequence of interactions in which the final interaction influences the original one.

Feedbacks occur in loops ➔

Feedback Loop *(def)* =

A linkage of two or more system components that forms a ROUND-TRIP flow of information.

Feedback loops can be positive (+) or negative (-).

A ***positive feedback*** is an interaction that amplifies the response of the system in which it is incorporated

(self-enhancing; amplifying)

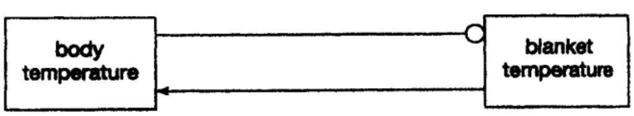
A ***negative feedback*** is an interaction that reduces or dampens the response of the system in which it is incorporated

(self-regulating; diminishes the effect of perturbations)

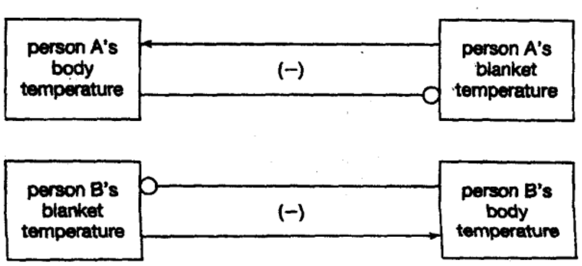
FEEDBACK LOOP

What kind of FEEDBACK LOOP IS IT?

Positive (+) or Negative (-) ???

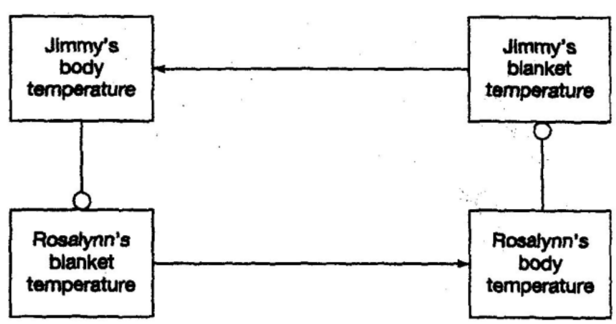


Proper alignment of dual control electric blanket:



Improper alignment:

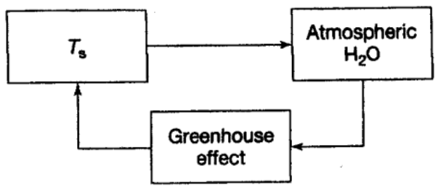
What kind of FEEDBACK LOOP IS IT?



A _________ FEEDBACK LOOP that ___________ the effect!

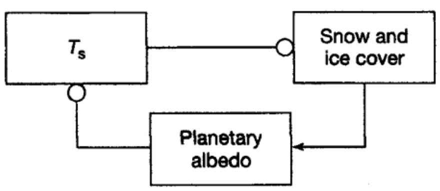
WATER VAPOR Feedback in the Earth-Atmosphere

What kind of FEEDBACK LOOP IS IT?



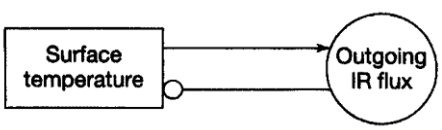
SNOW AND ICE ALBEDO Feedback

What kind of FEEDBACK LOOP IS IT?



OUTGOING INFRARED ENERGY FLUX / TEMPERATURE Feedback

What kind of FEEDBACK LOOP IS IT?



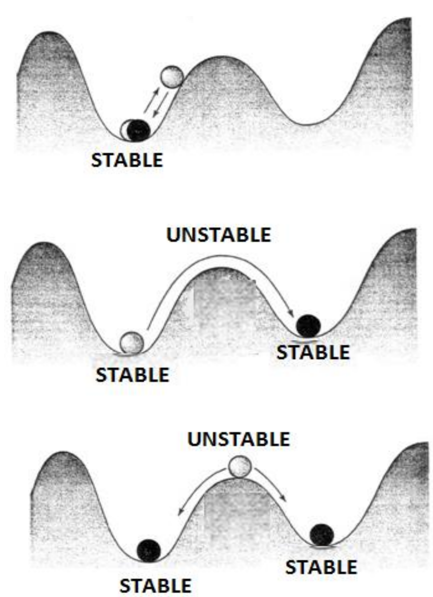
EQUILIBRIUM STATES

*The presence of **FEEDBACK LOOPS** leads to the establishment of **EQUILIBRIUM STATES***

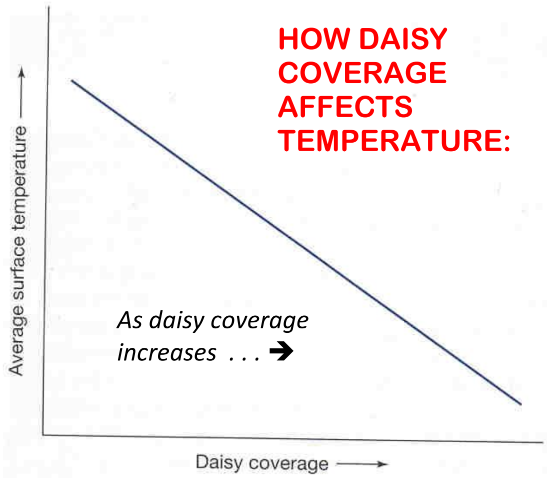
Negative (self-regulating) feedback loops establish **STABLE** equilibrium states that are resistant to a range of perturbations; the system responds to modest perturbations by returning to the stable equilibrium state

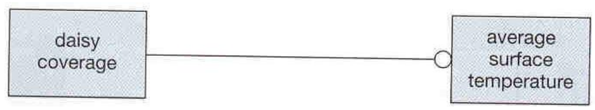
Positive (amplifying) feedback loops establish **UNSTABLE** equilibrium states. A system that is poised in such a state will remain there indefinitely. However, the slightest disturbance carries the system to a new state.

The equilibrium states of a schematic system, represented as peaks (unstable states) and valleys (stable states)

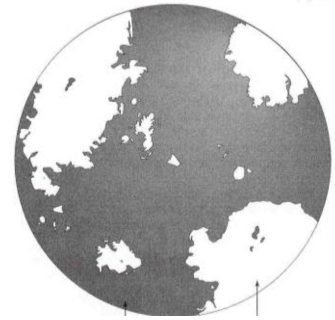


DAISYWORLD MODELING:



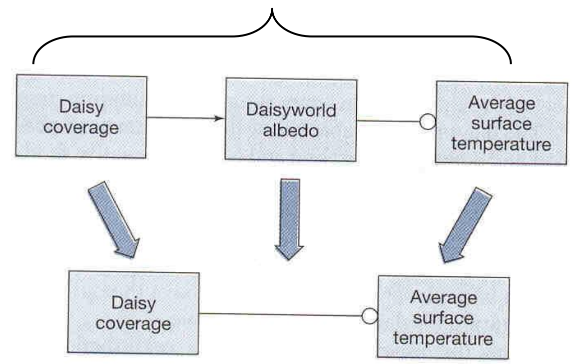


White daisies = high albedo



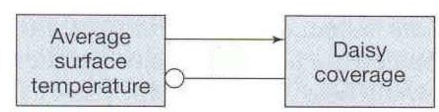
Gray soil = low albedo

These are the "in between" processes that explain the Daisy Coverage/ Temp coupling relationship at left

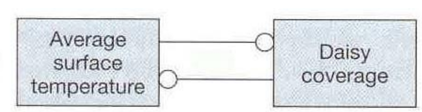


The key lessons of the Daisyworld example are:

- As the temperature increases, Daisyworld can adapt at first because as the daisies increase, their high albedo reflects back the sunlight and regulates the temperature, cooling things off and slowing down the temperature increase.



- This is a **[negative & self-regulating / positive & self-amplifying**] feedback loop.
- **In the example above, the Daisyworld system [IS / IS NOT] in equilibrium.**
- However, if increased warming occurs and the temperature increases to a point where it **warms too much** for the daisies (i.e., beyond the optimum temperature for daisy survival), then the daisies will start to die off.
- As the daises die off, the albedo will decrease, more sunlight will be absorbed instead of reflected back, and the temperature will get even hotter, killing off more daisies.



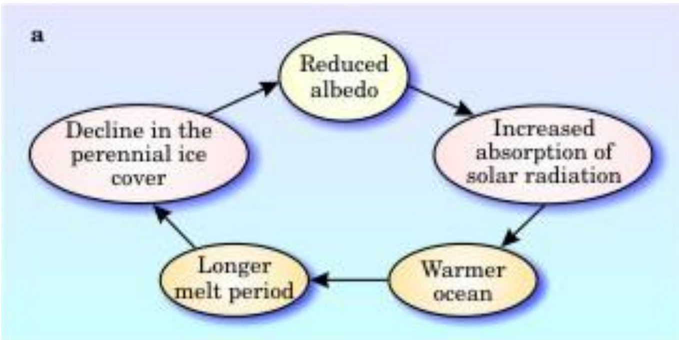
- This is a **[negative & self-regulating / positive & self-amplifying**] feedback loop.
- **In the example above, the Daisyworld system [IS / IS NOT] in equilibrium**
- Therefore, severe consequences can occur on a planet like Daisyworld when adapting to temperature change if certain thresholds are crossed and the negative feedback loops that normally regulate temperature are replaced by positive feedback loops that amplify temperature!

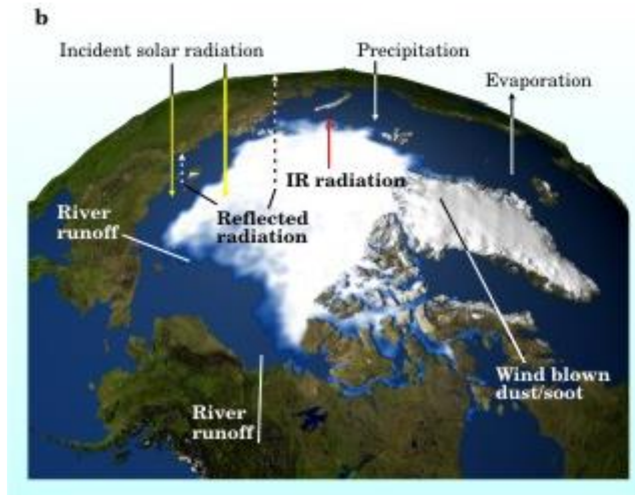
THOUGHT QUESTION: Could this happen on OUR PLANET EARTH?? Why or Why not?

More details about Daisyworld modeling are given in Chapter 2 of the E-Text, for students who want to dig deeper.

SELF-TEST: Is this multi-component feedback loop positive or negative?

ARCTIC SEA ICE FEEDBACK LOOP





Note that the arrows in (a) above all look alike and do not use the same "coupling" symbols you've learned on the previous pages and in your E-Text. Nevertheless, the principles of how couplings and feedback loops work are universal, regardless of how they are depicted in a diagram.

Test your understanding of couplings and feedback loops by sketching in the E-Text arrow symbols to indicate positive or negative couplings between each of the components set up for you in the boxes at right.

When your sketch is completed, **state whether the entire loop is:**

+ POSITIVE (self-enhancing) or
- NEGATIVE (self-regulating)

albedo

extent of sea ice cover

SW radiation absorbed *(by ocean)*

amount sea ice of melting

ocean temperature

ADDITIONAL NOTES:

TOPIC # 10   HOW THE CLIMATE WORKS

> The earth [as viewed from space] . . . has the organized, self-contained look of a live creature, full of information, marvelously skilled in handling the sun. - Lewis Thomas

We'll start our exploration with the ultimate driver of Earth's Climate:

EARTH-SUN RELATIONSHIPS

INSOLATION (def) = the solar radiation incident on a unit horizontal surface at the top of the atmosphere. (aka **solar irradiance**) *The latitudinal variation of INSOLATION drives the general circulation of the atmosphere and its resulting weather & climate*

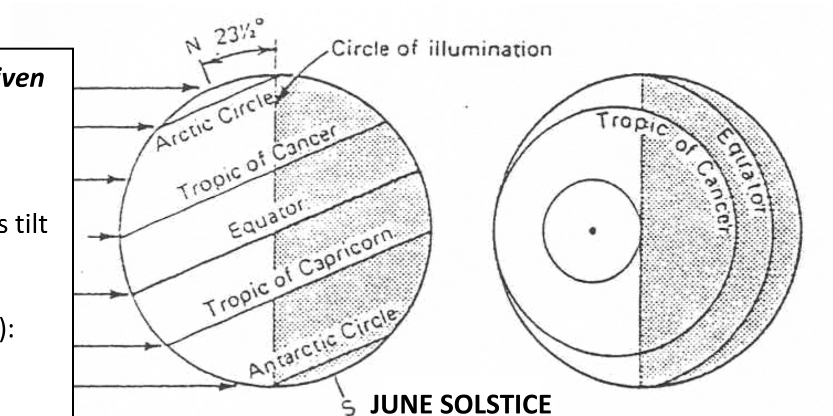
The total daily insolation received at a given latitude is a factor of:

INTENSITY + DURATION

INTENSITY of sun's rays: depends on axis tilt and how earth intercepts sun's rays

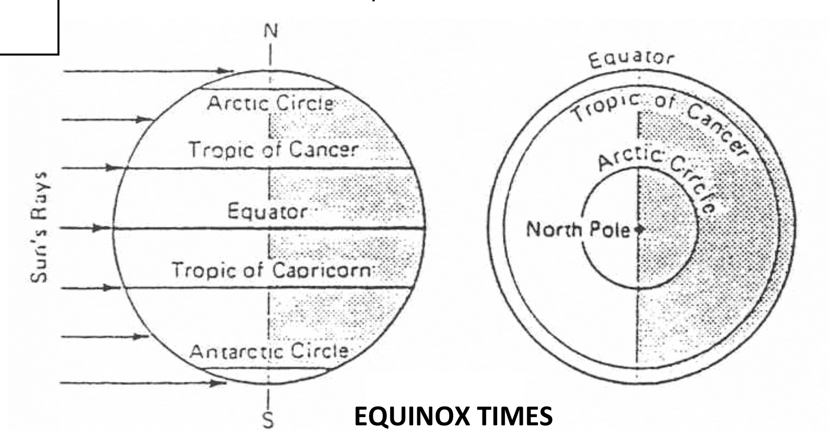
DURATION of daily insolation (day length): depends on where circle of illumination intersects latitude band

Intensity & Duration vary with latitude and with the time of year



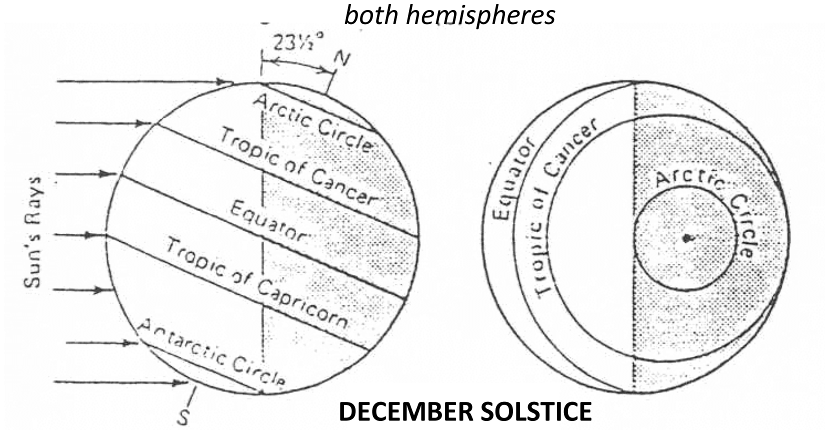
JUNE SOLSTICE

uneven receipt of insolation between hemispheres N.H. > S.H.



EQUINOX TIMES

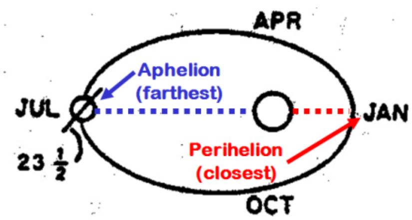
fairly even receipt of insolation in both hemispheres



DECEMBER SOLSTICE

uneven receipt of insolation between hemispheres S.H. > N.H.

Earth's Axis Tilt & Elliptical Orbit ➔ Contrast in Northern vs. Southern Hemisphere:



In its elliptical orbit around the Sun, currently the Earth is:

-- **closest to the Sun (= perihelion) in January** (just after the Dec Solstice)
-- **farthest from the Sun** (= **aphelion**) **in July** (just after the June Solstice)

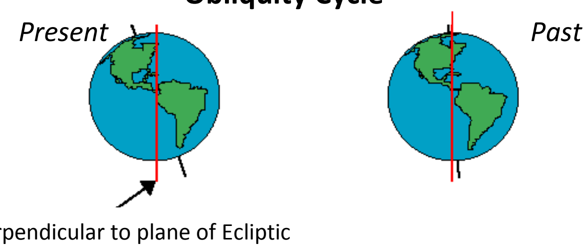
Thought Question: *What are the implications of the seasonal timing of the perihelion and aphelion for current climate in the Northern vs. the Southern Hemisphere?*

EARTH-SUN Relationships vary over time

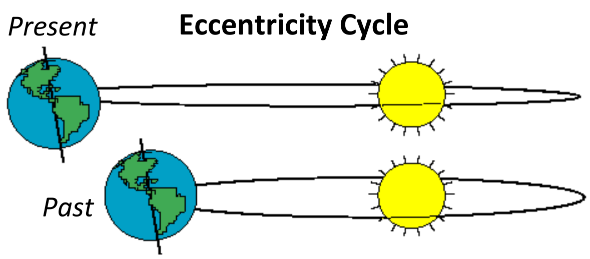
(variations are defined by the Milankovitch cycles – more on the cycles in upcoming topic)

1. OBLIQUITY OF EARTH'S AXIS
Axis "tilts" 23.5 degrees from plane of ecliptic; causes the seasons; tilt angle varies over time

Obliquity Cycle



Eccentricity Cycle



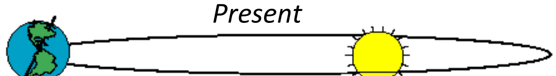
2. ECCENTRICITY OF ORBIT
Earth's orbit around sun is not symmetrical; varies from elliptical => circular shape over time

3. Timing of Seasons in Relation to Orbit: PRECESSION OF THE EQUINOXES
Earth is currently is closest to the Sun in January and farthest in July; varies over time

Precession of the Equinoxes

A

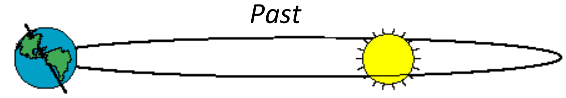
Present



Northern hemisphere tilted toward the sun at aphelion.

C

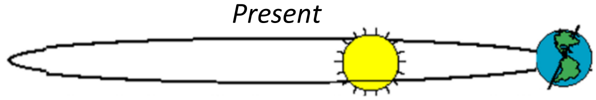
Past



Northern Hemisphere tilted away from the sun at aphelion.

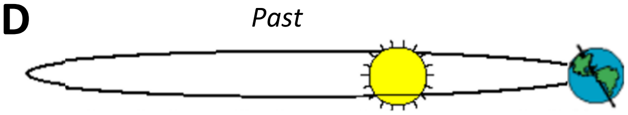
B

Present



D

Past



SELF TEST: *For each of the figures above, decide if it represents <u>Northern Hemisphere **SUMMER**</u> or <u>Northern Hemisphere **WINTER**</u>, based on how the figure depicts the Earth's orbit and titled axis.*

THE ENERGY BALANCE ➔ THE GENERAL CIRCULATION OF THE ATMOSPHERE

HOW IT ALL FITS TOGETHER:

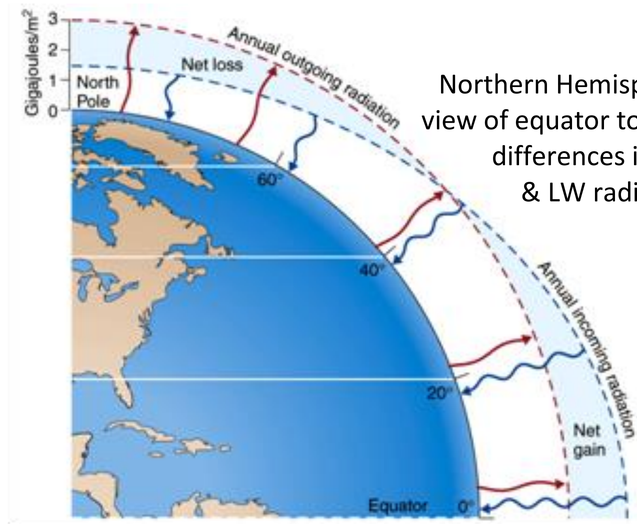
- INCOMING **SOLAR SW** (Insolation) varies by latitude *(more comes in near the equator, less near the poles)*

- OUTGOING **TERRESTRIAL LW** radiation varies by latitude *too (more LW emitted at warmer tropical latitudes, less in the cooler high latitudes)*

- The **EQUATOR–POLE DIFFERENCES** in how much LW radiates out are not as great as the equator-pole differences in how much SW comes in. Hence more comes in than goes out at the low latitudes and more goes out than comes in at the high latitudes.

- The result is a **NET SURPLUS** of energy in the low latitudes and a **NET DEFICIT** in the high latitudes.

- This energy imbalance leads to large **THERMAL DIFFERENCES** between low and high latitudes that drive the **GENERAL CIRCULATION OF THE ATMOSPHERE**, which moves surplus energy from the tropics to the deficit areas in the colder latitudes via **SENSIBLE HEAT (H) and LATENT HEAT (LE)** transport of energy.



Northern Hemisphere view of equator to Pole differences in SW & LW radiation

Pole-to-Pole view of differences in SW & LW radiation:

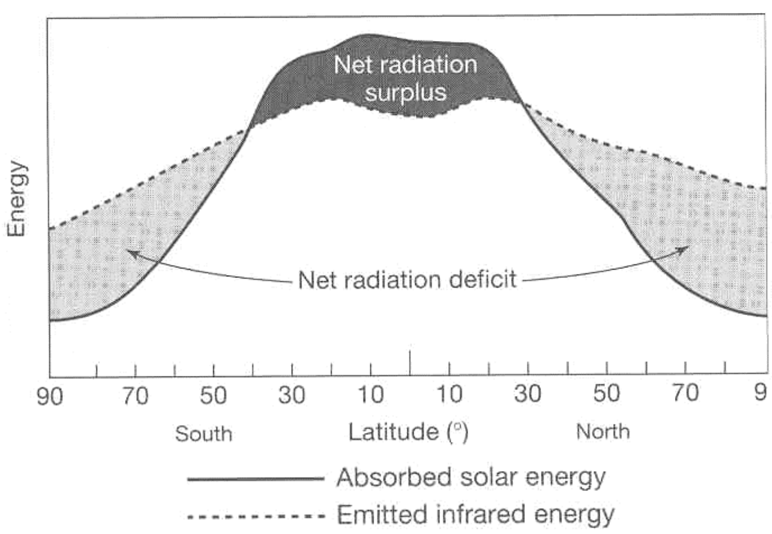
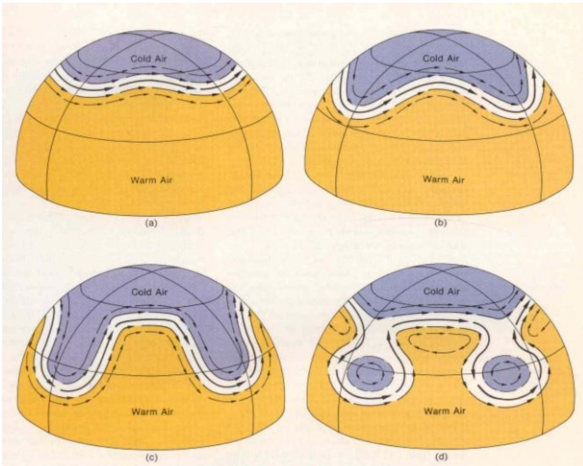
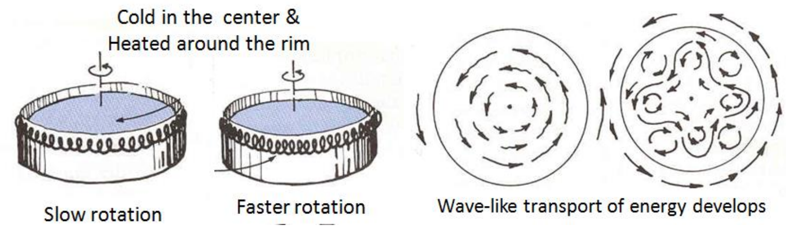


Fig 4-2 in E-Text

MORE ON ATMOSPHERIC CIRCULATION & THE ENERGY BALANCE





The “DISHPAN EXPERIMENT” -- a “wave-like” circulation (called **Rossby waves**) are needed to balance out the thermal differences in the pan

The Rossby wave pattern of the CIRCUMPOLAR VORTEX changes from day-to-day and season-to-season.

(TOP) In **summe**r (and during warmer climatic regimes) the **vortex is contracted** and the storms steered by the upper level westerly winds are shifted further north so that more of the hemisphere is affected by warm air masses.

(BOTTOM) In **winter (**and during colder climatic regimes) the **vortex tends to expand** more often into deep waves and the storms and cold polar air steered by the upper level westerly winds (jet stream) can dip down into low latitudes

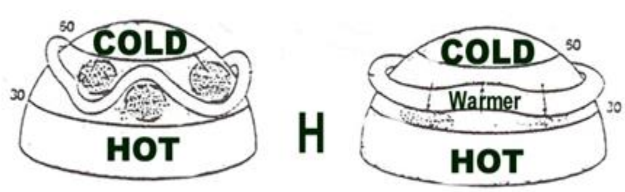
HOW HIGH LATITUDE ENERGY DEFICITS & LOW LATITUDE ENERGY SURPLUSES ARE BALANCED OUT:

A. When **large scale transport of warm or cold air masses** occurs, steered by Hadley cell and Rossby wave circulation, the **sensible heat (H)** component of net radiation (R_n) is being transferred across latitudes.

B. Large amounts of **energy also can be transferred** across latitudes in the **form of latent heat (LE).**

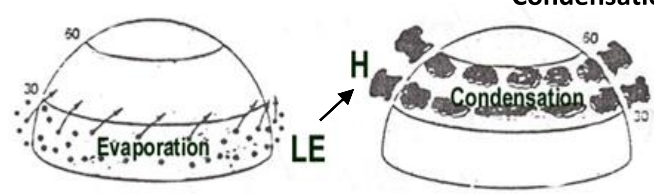
- **evaporation** takes place in the low, warmer latitudes ==> LE stored in atmosphere
- winds and circulation **transport water vapor** to high, cooler latitudes
- water vapor **condenses** and leaves atmosphere in the form of **precipitation** ==> LE released from atmosphere and becomes sensible heat **H**

A. Sensible Heat Transport:



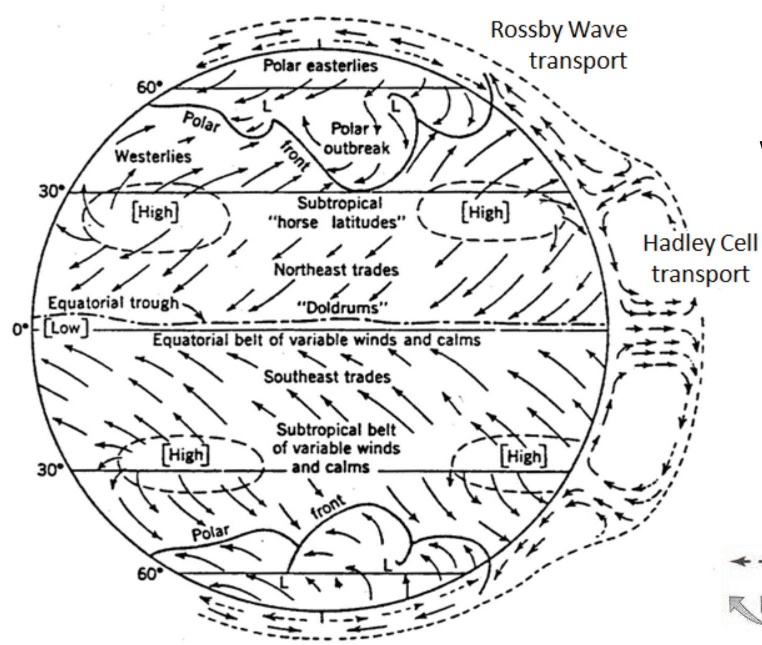
B. Latent Heat Transport:

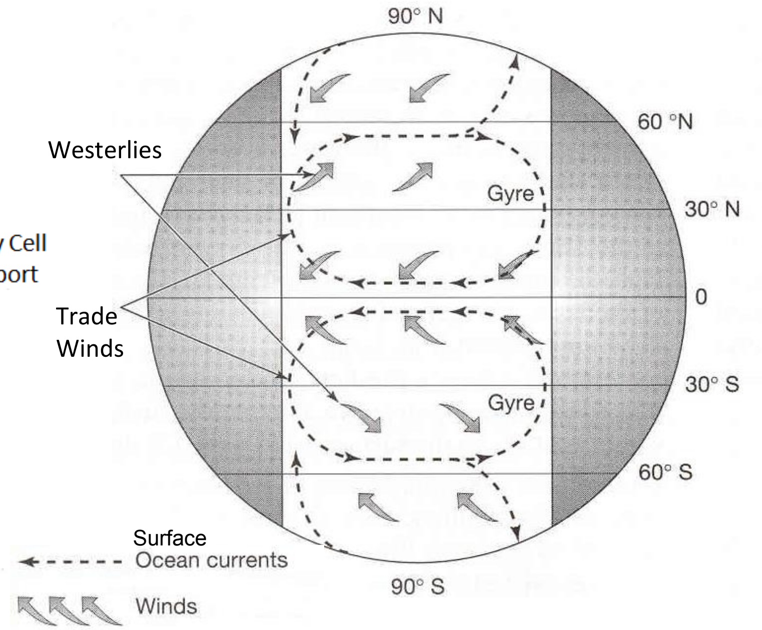
Condensation



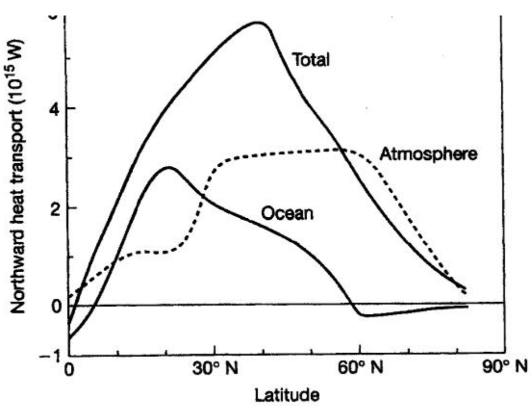
Evaporation

THE GENERAL CIRCULATION OF THE ATMOSPHERE & OCEANS

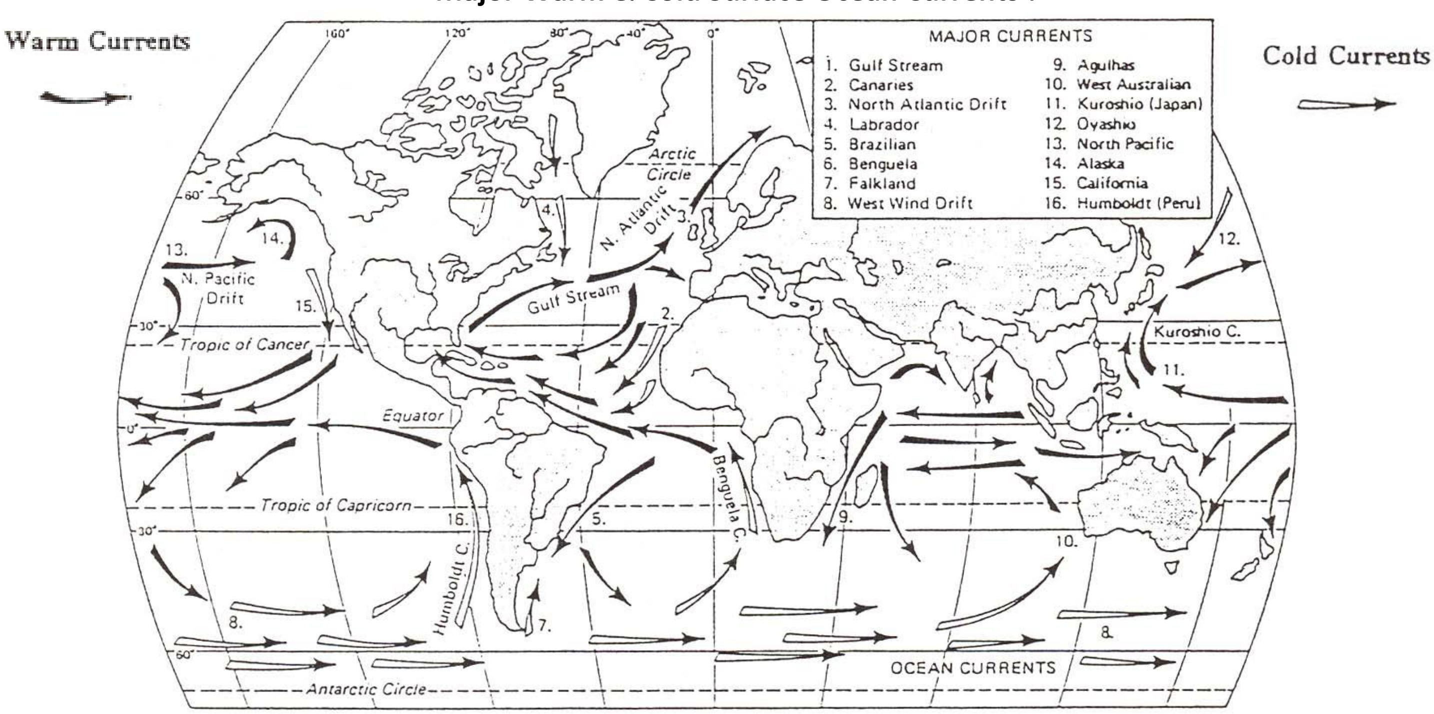




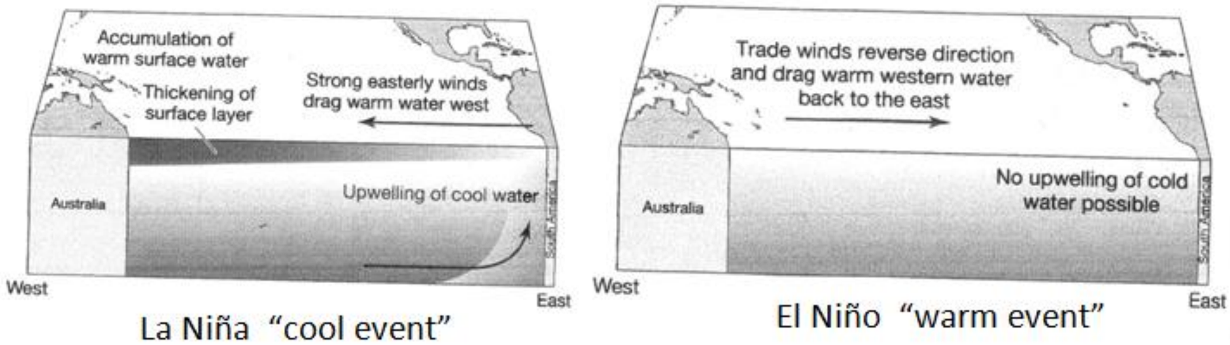
Poleward heat transport in the N. Hemisphere :



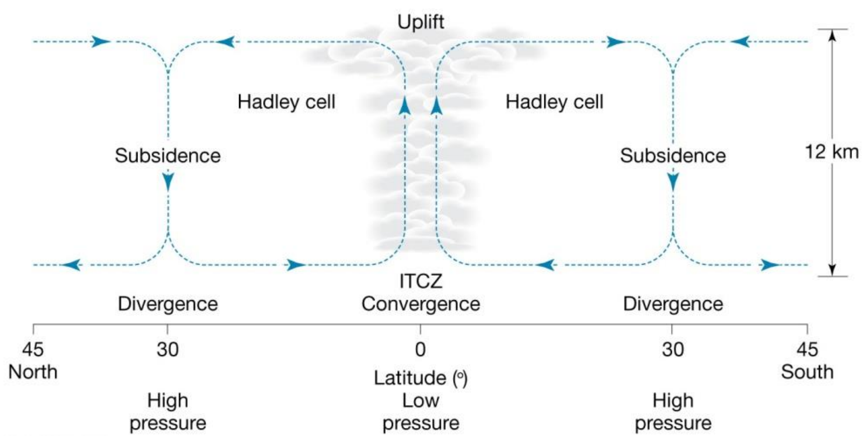
Major Warm & Cold Surface Ocean Currents :

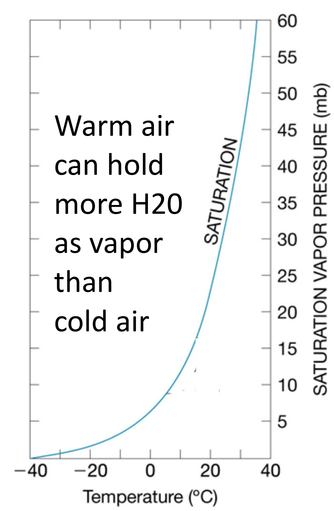


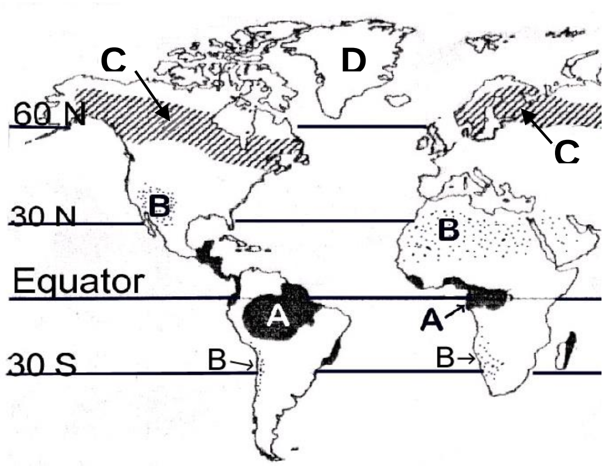
El Niño & La Niña Ocean Circulations



GLOBAL CLIMATE PATTERNS – BRIEF OVERVIEW





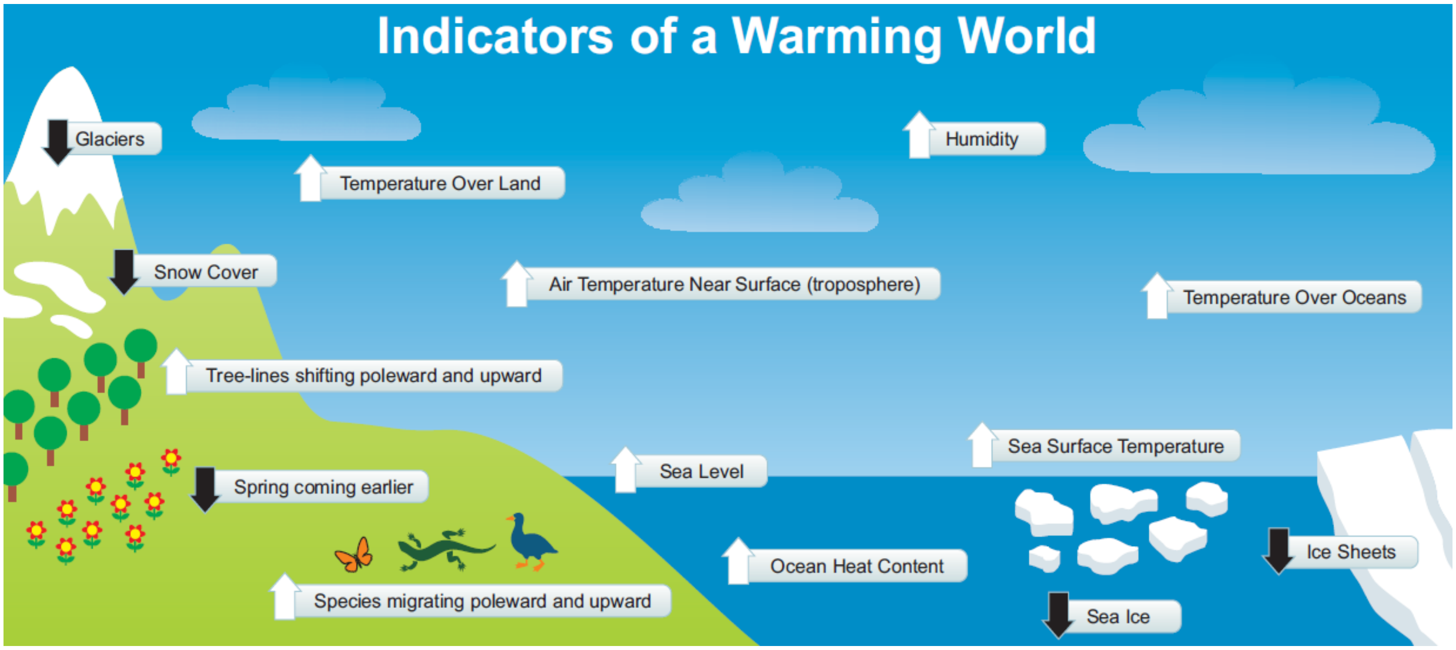


Q. What kind of climate and vegetation will you find in the areas marked A, B, C, & D ?

A ______________________ C______________________

B ______________________ D ______________________

TO PONDER: Can you begin to explain how each of the processes involved in these climate change indicators would occur with a warming world?



Global climate variability and change are caused by changes in the ENERGY BALANCE that are "FORCED"

Natural Climatic Forcing = due to natural earth-atmosphere-sun processes

- Earth-Sun orbital relationships
- solar variability
- changing land-sea distribution (due to plate tectonics)
- volcanic eruptions

VS.

Anthropogenic Climatic Forcing = humans cause or enhance the processes involved

- enhanced Greenhouse Effect due to fossil fuel burning
- land use changes due to human activity (deforestation, etc.)
- soot and aerosols from industry
- chemical reactions in stratosphere involving human-made compounds

KEY QUESTION: How much is due to natural forcing and how much to anthropogenic forcing? Can we even know?

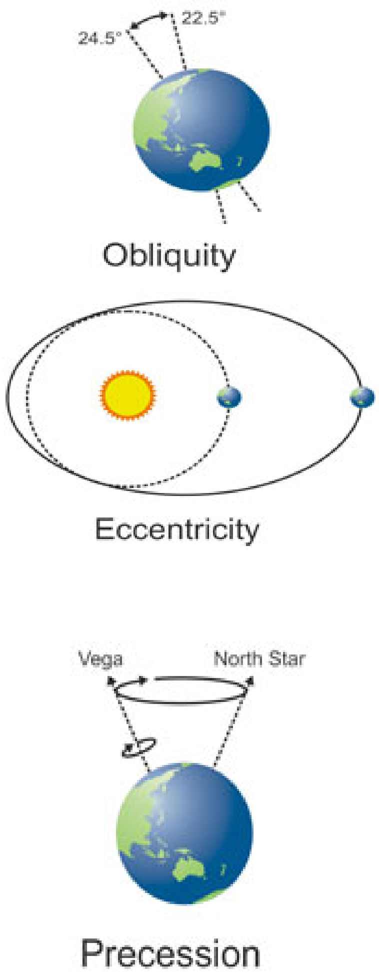
ADDITIONAL NOTES:

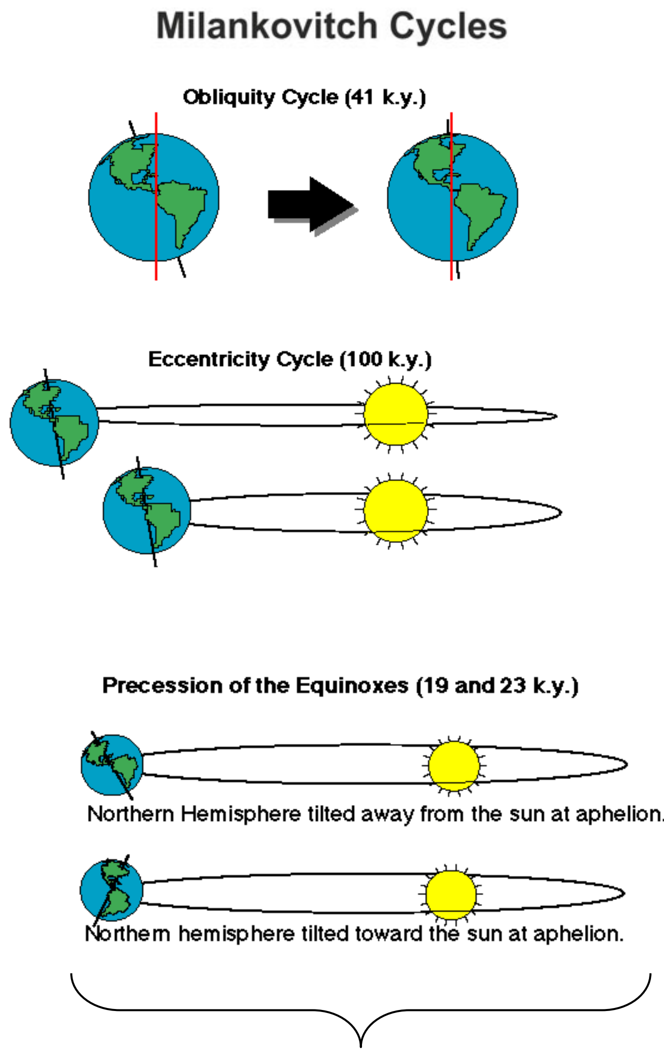
TOPIC # 11   NATURAL CLIMATIC FORCING

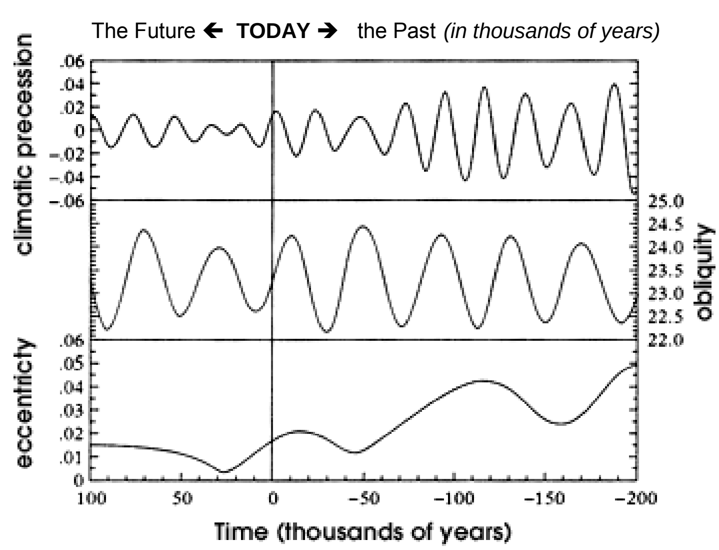
SOLAR "ASTRONOMICAL" FORCING OF CLIMATE CHANGE

due to "Earth-Sun Orbital Relationships"

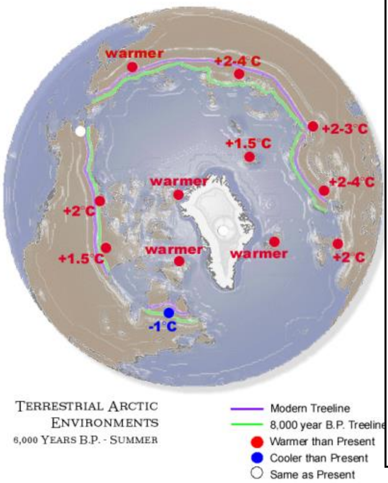
Astronomical Forcing drives natural climate variability (ice ages, etc.) on LONG time scales (5,000 to 1 million years)







SOLAR VARIABILITY FORCING – ANCIENT & RECENT

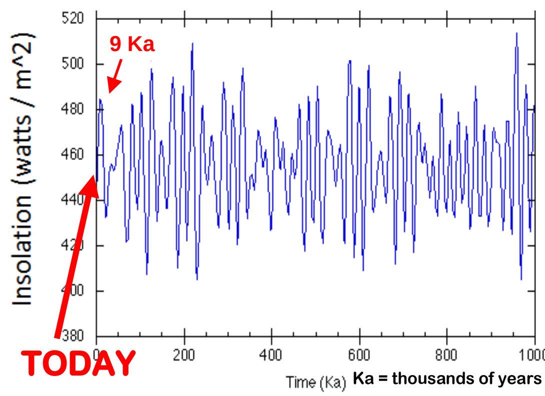


Mid-Holocene warm period
(~ 6,000 years ago)

Was generally warmer than today, but only in summer and only in the Northern Hemisphere

Cause = "astronomical forcing"

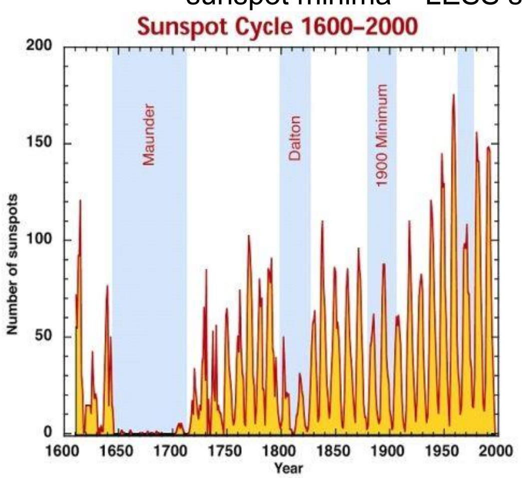
SOLAR INSOLATION calculated for 65° N latitude



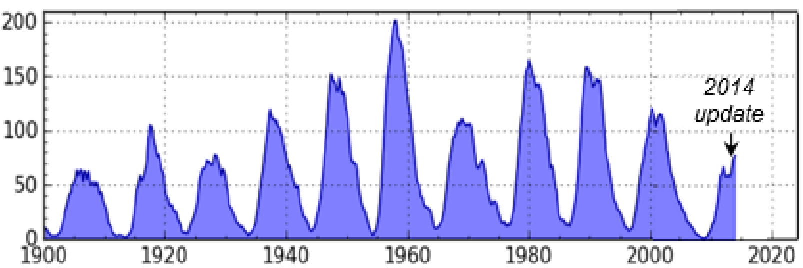
Over the last 100,000 years, in the Northern Hemisphere, peak summer insolation occurred about 9,000 years ago (9 Ka BP) when the last of the large ice sheets melted. Since that time, Northern Hemisphere summers have seen less solar radiation.

MORE RECENT SUNSPOT VARIATIONS & SOLAR VARIABILITY

sunspot minima = LESS solar brightness / Sunspot cycles (quasi-periodic)



http://www.sidc.be/sunspot-index-graphics/sidc_graphics.php



Sunspot Frequency

RECENT SUNSPOT VARIATIONS:

Maunder Minimum (1645-1715) linked to "Little Ice Age" (1600-1800) but uncertainties remain about what MECHANISM transfers brightness drop ➔ lower temperatures

Dalton Minimum (1795 – 1825) also cooler, but lots of large volcanic eruptions then as well.

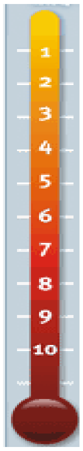
Since the Dalton Minimum, the Sun gradually brightened: the "Modern Maximum" (max in 2001)

But increase in solar brightness accounted for only:

- about ½ of the temperature increase since 1860, and
- less than 1/3 since 1970

The rest is attributed to <u>greenhouse-effect warming</u> by most experts in solar forcing.

Exploring Another Myth . . .

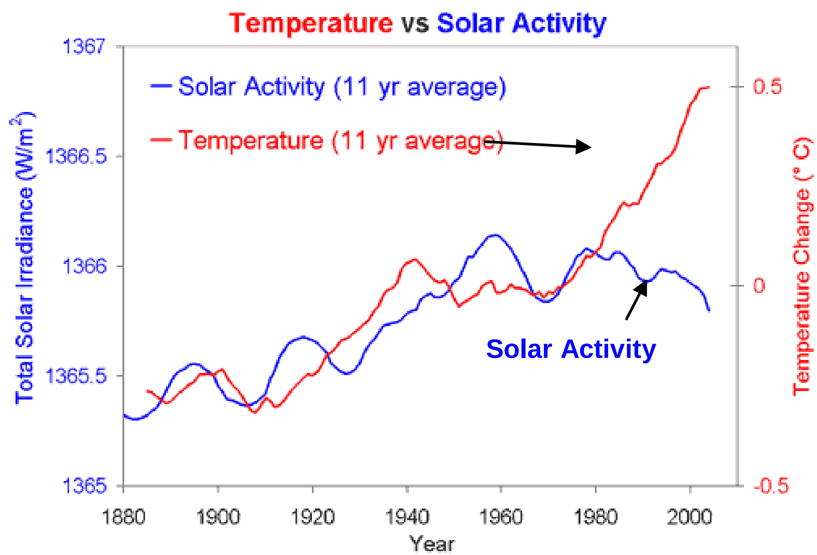


Climate Myth #2:

"It's the Sun"

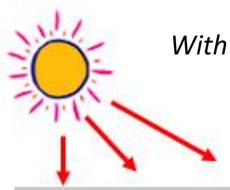
(i.e., the recent warming is from natural solar variability)

Figures from skepticalscience.com

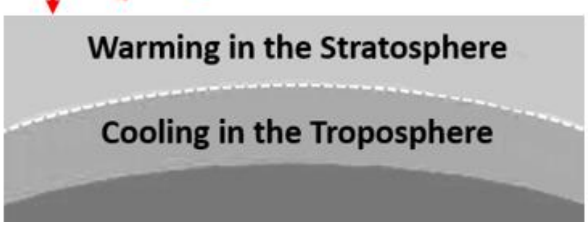


Global temperature (NASA GISS) and Total solar irradiance (1880 to 1978 from Solanki, 1979 to 2009 from PMOD).

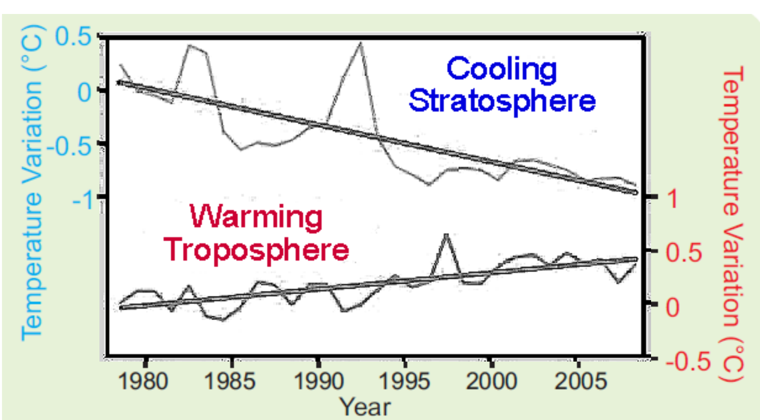
The Solar Irradiance Signature:



With increased Solar Activity we would expect to see "top down" warming:



What has actually been observed:

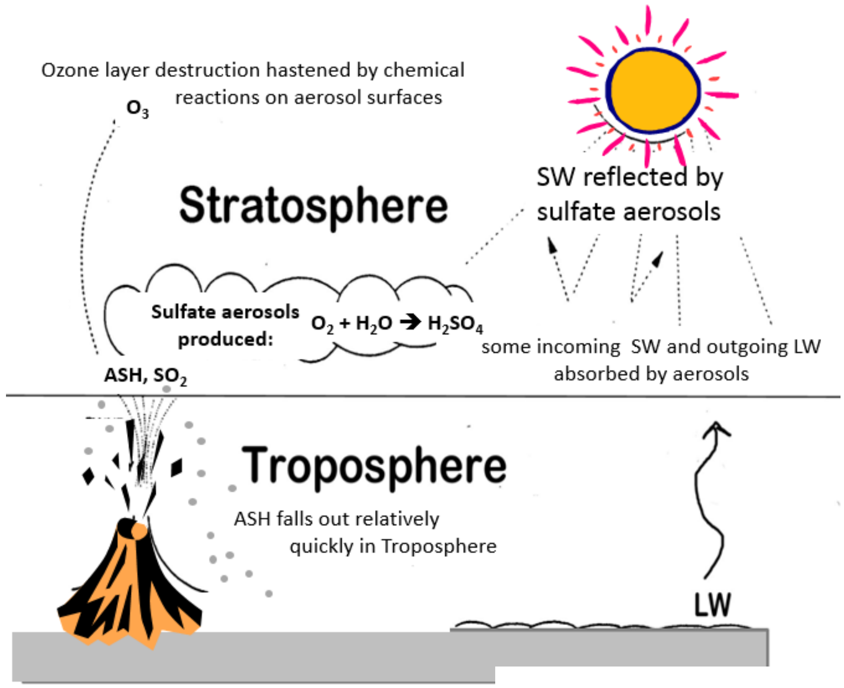


Graphs showing temperature variations (degrees C) in the stratosphere and troposphere
(measured by satellites)

Irradiance = *the flux of radiant energy per unit*

VOLCANIC FORCING

"Volcanoes are one way Earth gives birth to itself." - Robert Gross

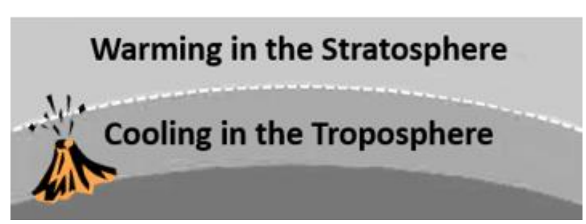


HOW ERUPTIONS FORCE CLIMATE CHANGE
(through the RADIATION BALANCE of course!)

Large volcanic eruptions inject **sulfur gases** into the **stratosphere**, which **convert to sulfate aerosols** with a residence time of 1-3 years:

- Ash quickly falls out of the atmosphere within 10s to 100s of km from eruption
  hence the albedo of ash is not the reason for cooling after an eruption!
- SO_2 remains gaseous, converts to **sulfuric acid (H_2SO_4)** which condenses in a mist of fine particles (**sulfate aerosols**).
- the sulfate aerosols ***reflect*** some of the incoming solar SW radiation back to space, **COOLING THE TROPOSPHERE**
- aerosols also ***absorb*** some wavelengths of the incoming SW radiation and some of the Earth's outgoing LW radiation, **WARMING THE STRATOSPHERE**
- the volcanic aerosols also serve as surfaces for chemical reactions **that destroy stratospheric ozone**.
  Q. How would this affect the radiation balance?

The Volcanic Aerosol Signature:



Which Eruptions are Climatically Effective?

Eruptions that:

- are **explosive**
- have **high sulfur content** in their magma
- have eruption clouds that inject gases into the **stratosphere**

The **geographic location** of the eruption influences its climatic effectiveness because of the **General Circulation of the Atmosphere**:

- **Low latitude** eruptions:
  aerosols ➔ into both hemispheres

- Mid-to-high latitude eruptions:
  Aerosols ➔ same hemisphere
-

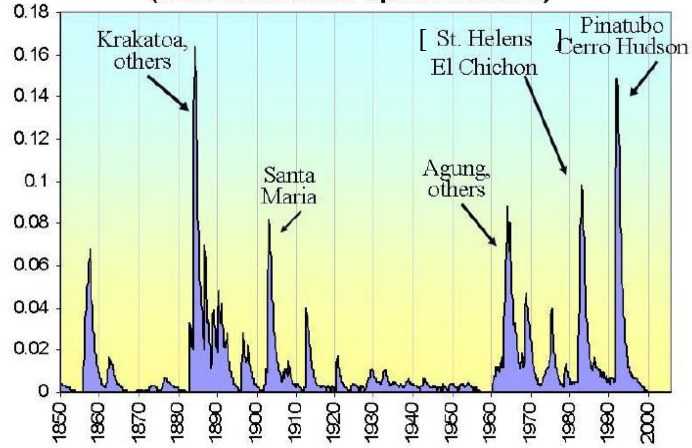
How Much Tropospheric Cooling Can Occur and How Long Does It Last?

- a 1-to-3 year cooling of average surface temperatures of 0.3 to 0.7º C.

How Important is Explosive Volcanism as a Forcing Mechanism for Past and Future Climate Changes?

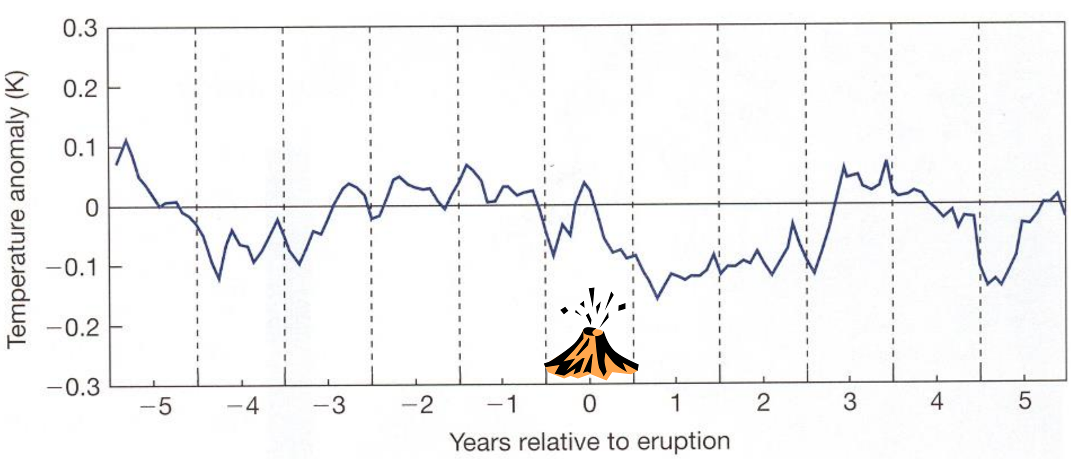
- Intervals of high explosive volcanic activity can play a large role in interdecadal climate change, such as that of the "Little Ice Age" which took place from the late 1500s through the mid 1800s .
- Individual years, such as 1816, the "Year without a Summer" after the eruption of Tambora in 1815, provide evidence of the significant effects a single large eruption can have.

Stratospheric Volcanic Aerosol
(NASS GISS Aerosol Optical Thickness)



Volcanic aerosols in the high atmosphere block solar radiation and increase cloud cover leading to widespread cooling, especially significant in summer

TYPICAL GLOBAL COOLING PATTERN AFTER A VOLCANIC ERUPTION
The global mean temperature changes for 5 years before (-) and after a large eruption (at year zero).



ACTIVITY ON VOLCANISM AND CLIMATE

COMPARISON TABLE OF ERUPTIONS

Eruption & Latitude	Year	Amount of Magma Erupted (km^2)	Stratospheric Aerosol (Mt) S.H.	N.H.	H_2SO_4 estimate (Mt)	Estimated N.H. Temp change (°C)
Tambora (8°S)	1815	50	150	150	52	-0.4 to -0.7
Krakatau (6°S)	1883	10	~34	55	2.9	-0.3
Santa Maria (15°N)	1902	9	22	<20	0.6	-0.4
Katmai (86°N)	1912	15	0	<30	12	-0.2
Agung (8°S)	1963	0.6	30	20	2.8	-0.3
Mt St. Helens (46°N)	1980	0.3	0	*no info*	0.08	0 to -0.1
El Chichón (17°N)	1982	~ 0.3	<8	12	0.07	-0.2
Pinatubo (15°N)	1991	~ 5	*no info*	~25	~0.3	-0.5
		(Large eruption if lots of magma)	*(How much got into each hemisphere)*		*(Sulfur-rich if high)*	

1. **List at least 4 reasons** why the eruption of **Tambora in 1815** resulted in the largest GLOBAL cooling effect of all the eruptions listed in the table.

#1 ____

____

#2 ____

____

#3 ____

____

#4 ____

____

2. **Give at least two reasons** why the eruption of **Mt. St. Helens was not a very climatically effective** eruption:

#1 ____

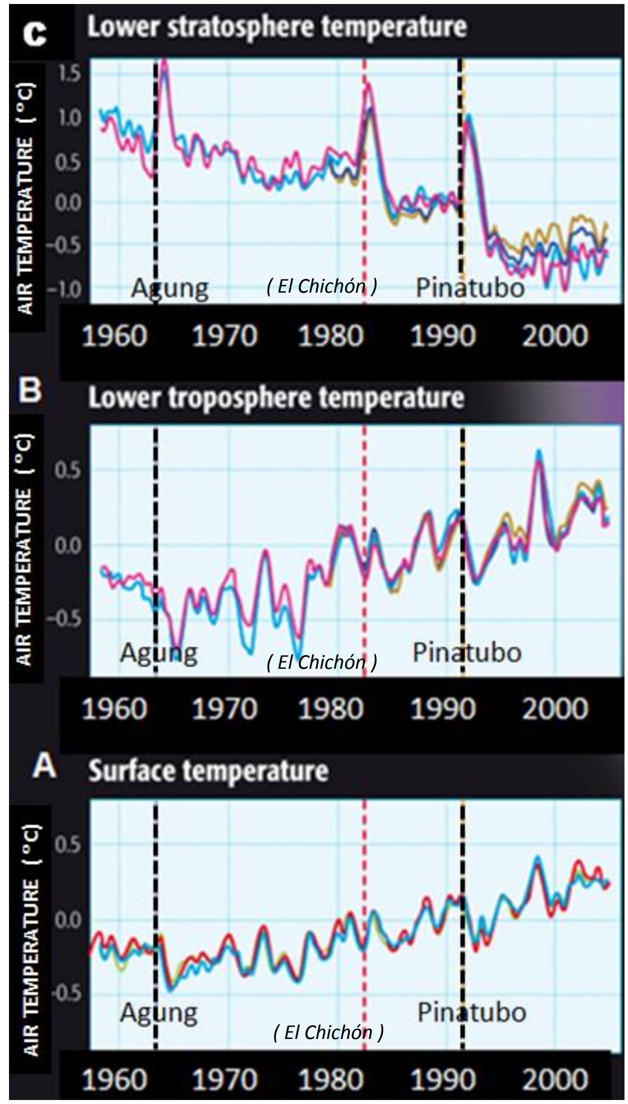
____

#2 ____

____

3. The figure at right shows the global temperature response after the eruptions of **Agung in 1963, El Chichón in 1982, and Pinatubo in 1991** at different levels in the atmosphere from the surface up to the lower stratosphere.

Since El Chichón's climatic effect was influenced strongly by an El Niño, we'll focus on ***AGUNG*** ***&*** ***PINATUBO*** *only* ➔



3a. **Which levels** (A = Surface, B = Lower Troposphere, C = Lower Stratosphere) show a **COOLING response** immediately after the eruptions of Agung and Pinatubo?
(circle all that apply):

A-Surface B-Lower Troposphere C-Lower Stratosphere

3b. **Which levels** show a **WARMING** response immediately after the eruptions of Agung and Pinatubo?
(circle all that apply):

A-Surface B-Lower Troposphere C-Lower Stratosphere

4. **Describe HOW** the temperature at the three different levels in the atmosphere responded to the effects of Agung's and Pinatubo's sulfate aerosol veils and **explain WHY** by referring to specific processes of the **Radiation Balance:**

A-Surface ____

____

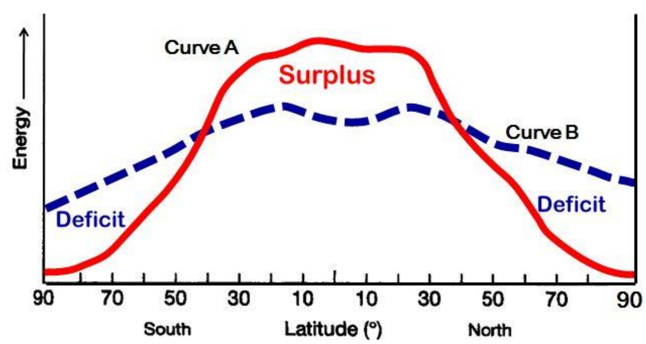
B-Lower Troposphere______________________________

____

C- Lower Stratosphere______________________________

____

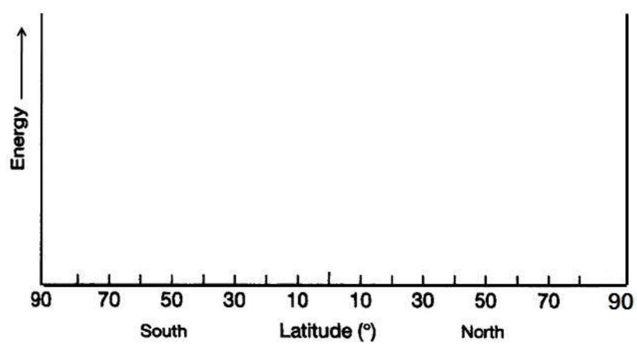
5. At right is the graph showing annual incoming SW solar radiation absorbed in the **troposphere's** earth-atmosphere system and outgoing LW terrestrial radiation **leaving the tropospheric** earth-atmosphere system at various latitudes.



A = solid curve = incoming **shortwave** (solar) radiation SW

B = dashed curve = outgoing **longwave** (terrestrial) radiation LW

SKETCH IN A NEW GRAPH to show how the energy balance in the troposphere would change if **a major volcanic eruption** (like Krakatau or Tambora) occurred.



HINTS:

Which curve should be most affected by the eruption? **A** *or* **B**
For the curve you picked, should it be sketched as moving **UP** *or* **DOWN***?*

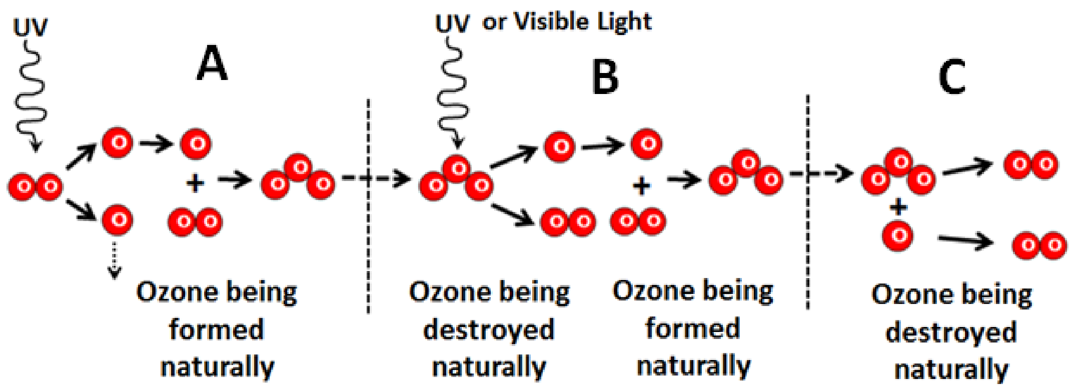
ADDITIONAL NOTES:

TOPIC # 12 - OZONE DEPLETION IN THE STRATOSPHERE
A Story of Anthropogenic Disruption of a Natural Steady State

> [The Ozone Treaty is] the first truly global treaty that offers protection to every single human being
> *- Mostofa K. Tolba, Director of the UN Environment Programme*

THE CHAPMAN MECHANISM: produces & destroys ozone in stratosphere through photochemical reactions:

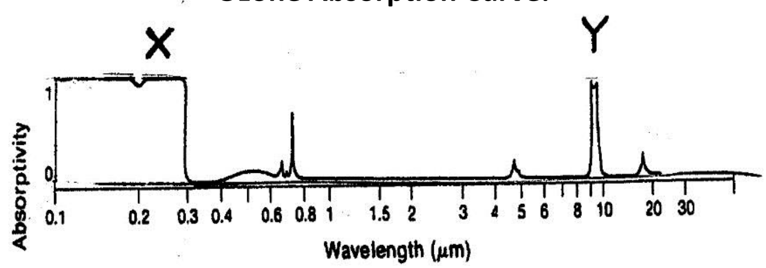
A. Ozone (O_3) is created when a highly energetic UV photon strikes an oxygen molecule (O_2), freeing its atoms (O) to combine with other nearby oxygen molecules to form O_3.
B. Ozone is repeatedly broken apart by photons of UV or visible light and quickly re-formed, ready to absorb more incoming solar radiation.
C. Ozone "dies" or is destroyed when an oxygen atom (O) collides with an ozone molecule (O_3) and forms two oxygen molecules (O_2)



WHY THE OZONE LAYER MATTERS TO US!

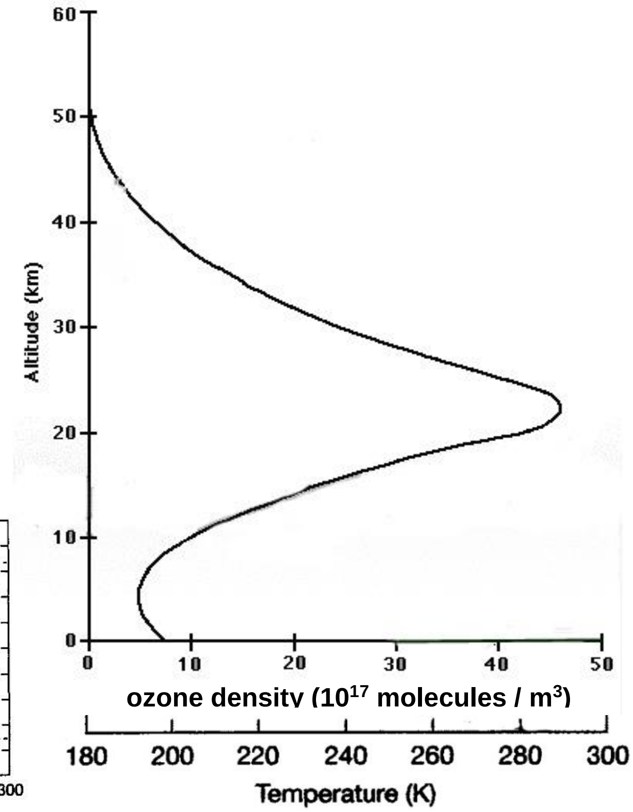
Wavelength Range	Name	Biological Effect
.32 to .4 µm (320-400 nm)	**UVA**	once thought to be relatively harmless, BUT causes wrinkles, premature aging and associated sun-related skin damage; new research indicates possible skin cancer link
29 to .32 µm (290-320 nm)	**UVB**	harmful, causes sunburn, skin cancer, and other disorders
.20 to .29 µm (200 - 290 nm)	**UVC**	extremely harmful, damages DNA -- but almost completely absorbed by ozone

Ozone Absorption Curve:



IN-CLASS ACTIVITY TO CONNECT CONCEPTS TOGETHER:

1. The graph to the right represents **ozone density changes with altitude**. On the graph, do the following:



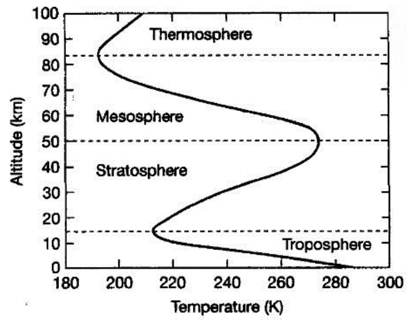
(a) D*raw in horizontal lines* to indicate the **boundary between**:

- **the troposphere & the stratosphere**
- **the stratosphere & the mesosphere**

(b) Then *LABEL these 3 levels of the atmosphere*:

- **troposphere**
- **stratosphere**
- **mesosphere**

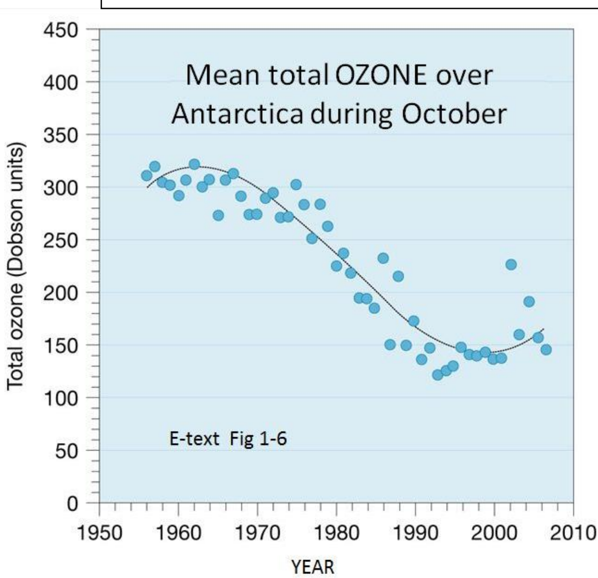
(c) Using this graph of ➔ temperature & altitude to guide you, *roughly* sketch in the vertical temperature profile on the ozone graph to indicate how temperature varies with altitude.

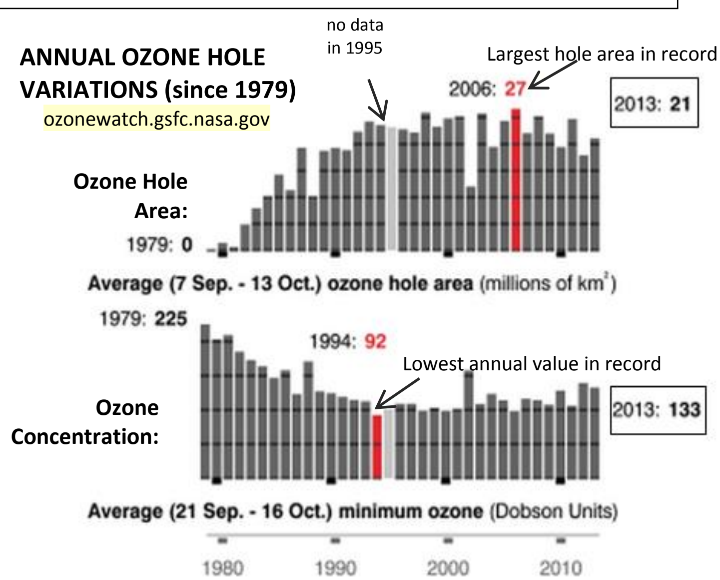


Q**, Does the temperature of the atmosphere INCREASE or DECREASE with increasing altitude in the stratosphere***? (circle one)* **Why?** ____

____

THE OZONE HOLE – Seasonal Depletion of Ozone over Polar Areas





Dobson units (DU) = O_3 gas per unit area between Earth's surface and top of the atmosphere.

The "Ozone Hole" is defined as the area with ozone concentrations less than 290 Dobson Units (DU).
What year did the hole begin forming? ________

____

____

____

____

____

OZONE DEPLETION: What, Why & Where

- The “Ozone Hole" is a depletion of ozone in the lower stratosphere (12-25 km) that occurs each spring. Discovered after systematic measurements began over Antarctica in the mid-1970s, it is typically defined as the area with O_3 concentrations less than 290 DU.
- The hole forms because the steady state balance of O_3 in the stratosphere (due to the Chapman mechanism) is disrupted when UV breaks apart CFCs to release free chlorine (Cl) or NO atoms.
- A single Cl atom can destroy 100,000s of O_3 molecules in the stratosphere, acting as a catalyst without being destroyed itself.
- The hole is most severe over Antarctica in S.H. spring (Sep-Oct); a less severe hole occurs over the Arctic in N.H. spring (Feb-Mar).
- Depletion is most severe over polar regions (esp. Antarctica) because:
  (a) the unique circumpolar vortex circulation in winter isolates the stratosphere and acts like a "containment vessel" in which chemical reactions may occur in near isolation
  (b) chemical reactions are more efficient and faster on surfaces of extremely cold *polar stratospheric ice cloud* (PSC) particles
- Ozone is *increasing* in the troposphere (e.g., due to photochemical reactions with car exhaust) but only at the rate of about 1% per year. Stratospheric levels are going down faster than ozone is being added in the troposphere.

Ozone formation (with uv)

$O_2 \rightarrow O + O$

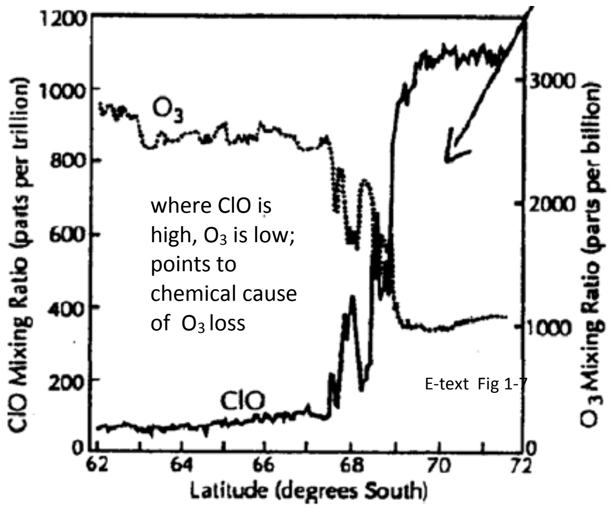
$O + O_2 \rightarrow O_3$

Ozone loss

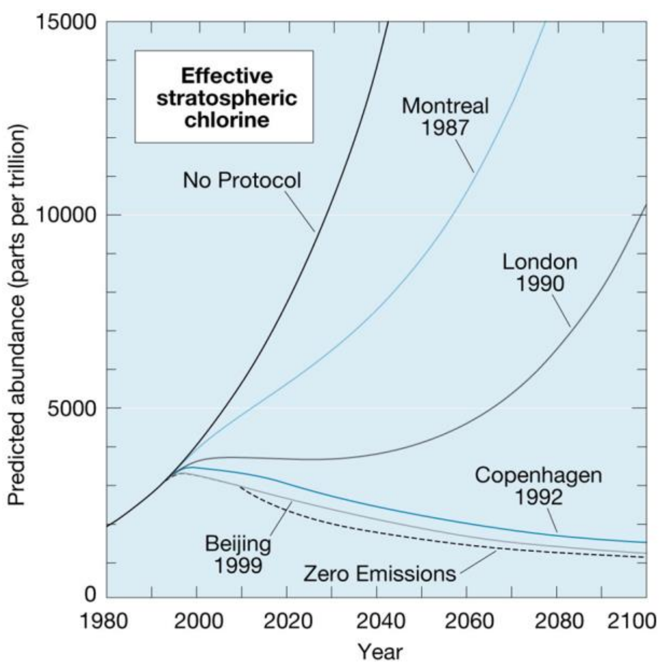
$O_3 + O \rightarrow O_2 + O_2$
Chapman's scheme

$O_3 + NO \rightarrow O_2 + NO^2$
$O + NO_2 \rightarrow O_2 + NO_2$
NO as catalyst

$O_3 + Cl \rightarrow O_2 + ClO$
$O + ClO \rightarrow O_2 + Cl$
Cl as catalyst



Projected stratospheric chlorine concentrations under the various international agreements

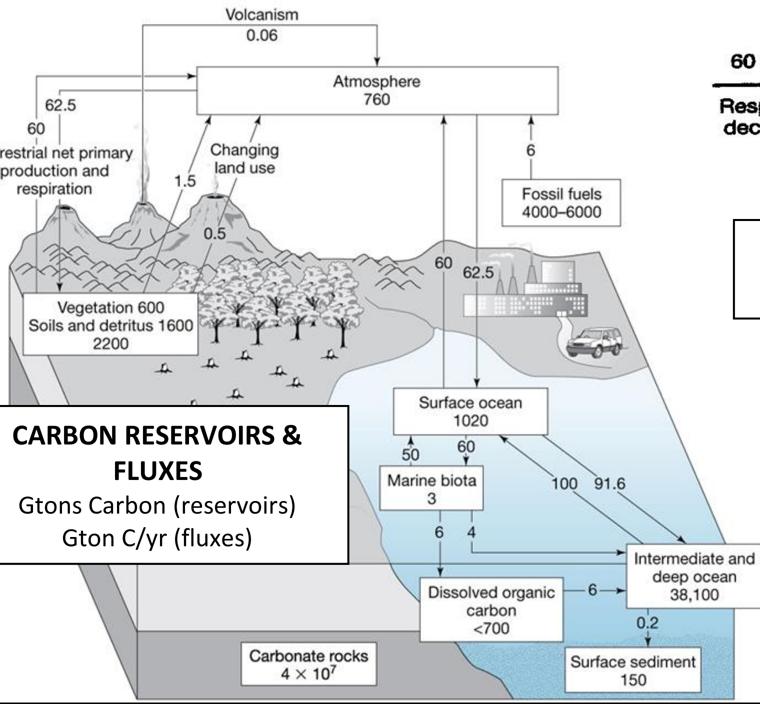


ADDITIONAL NOTES:

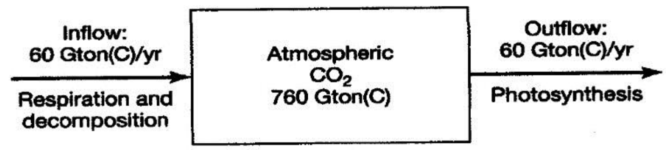
TOPIC # 13 GLOBAL WARMING & ANTHROPOGENIC FORCING

> We are playing Russian roulette with our climate . . . The Earth's climate system is an angry beast subject to unpredictable responses, and by adding carbon dioxide to the atmosphere we may be provoking the beast.
>
> – *Wally Broecker, paleoclimatologist*

A. Carbon Reservoirs & Fluxes: Natural vs. Anthropogenically Enhanced



CARBON RESERVOIRS & FLUXES
Gtons Carbon (reservoirs)
Gton C/yr (fluxes)



The atmospheric carbon reservoir
inflows and outflows (fluxes) in a steady state

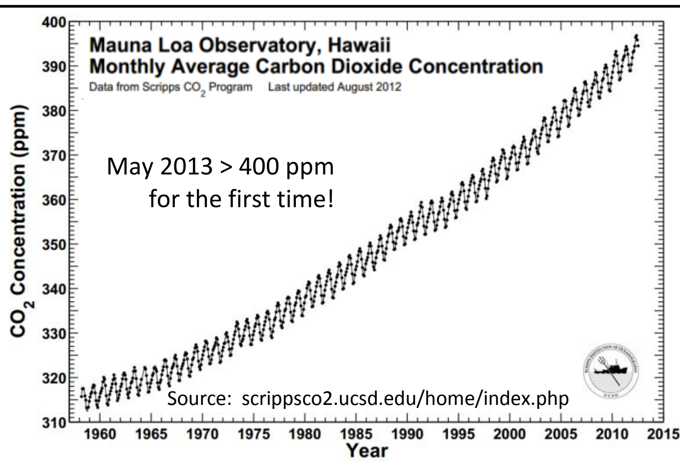
NATURAL FLUXES INTO & OUT OF THE ATMOSPHERIC CARBON RESERVOIR:

LARGE FLUX IN:

Respiration: $\underset{\text{carbohydrate}}{CH_2O} + \underset{\text{oxygen gas}}{O_2} \longrightarrow \underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O}.$

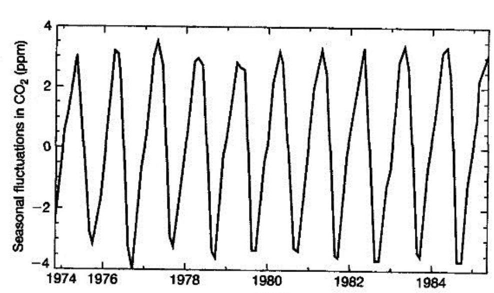
LARGE FLUX OUT:

Photosynthesis (Primary Production): $\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} \longrightarrow \underset{\text{carbohydrate}}{CH_2O} + \underset{\text{oxygen gas}}{O_2}.$

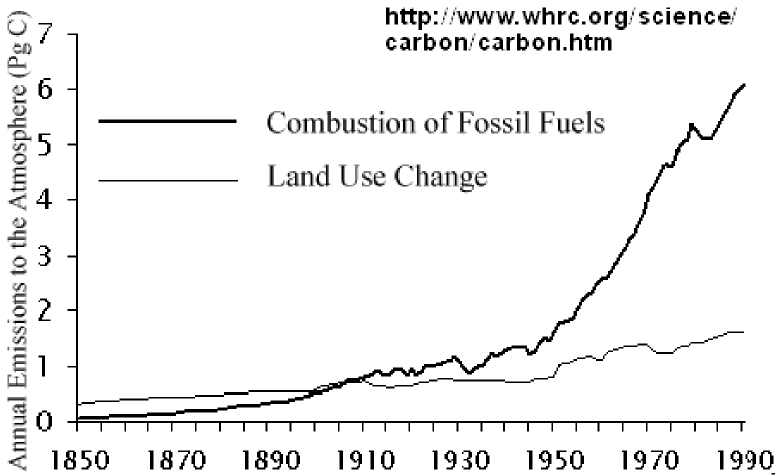


KEELING CURVE ZIG-ZAGS = seasonal fluctuations driven by the balance between respiration and photosynthesis in Northern Hemisphere forests. *[Tick marks are at Jan]*

Photosynthesis > Respiration (CO_2 goes down in summer)
Respiration > Photosynthesis (CO_2 levels rise in fall/winter)



ANTHROPOGENIC INFLUENCES ON CARBON IN THE ATMOSPHERE

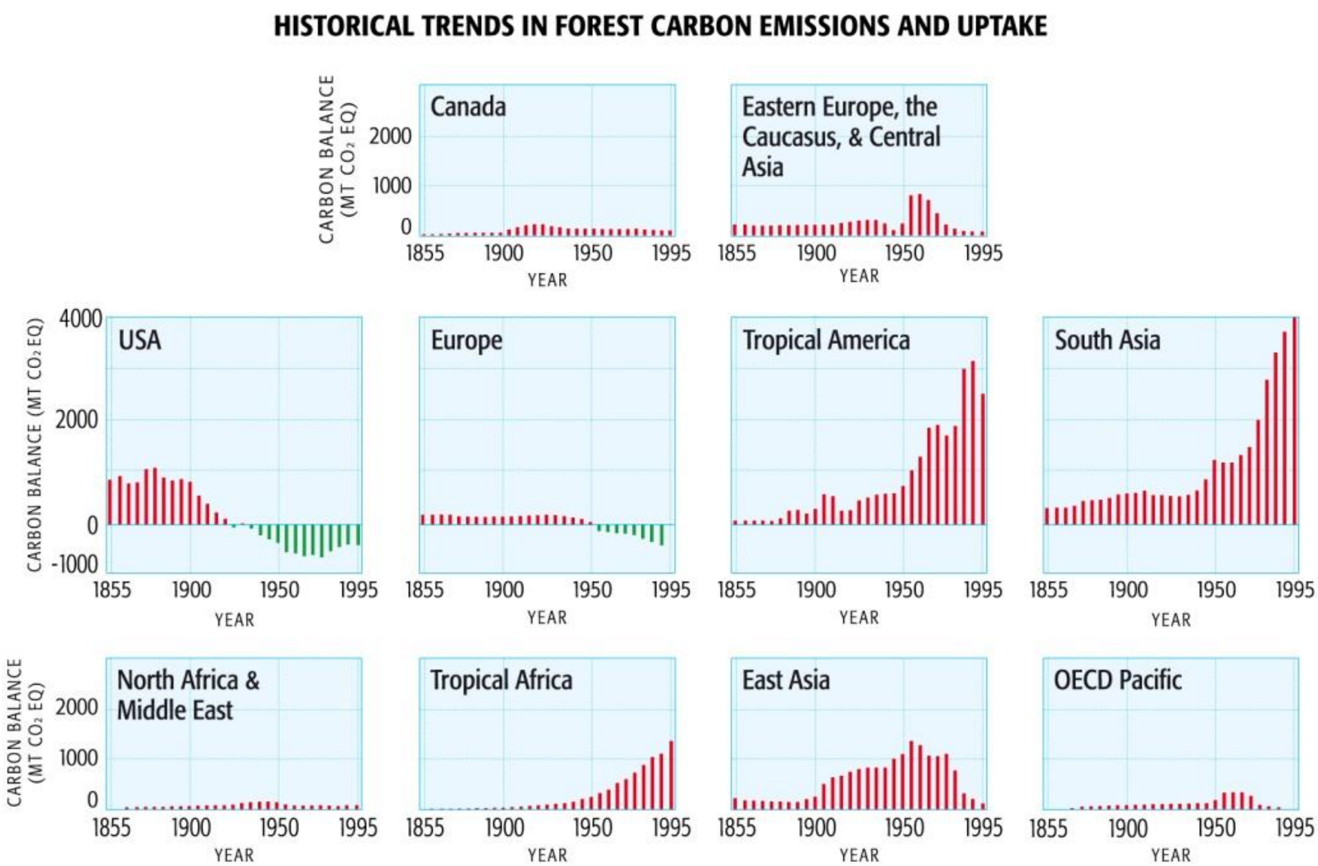


Anthropogenic-Driven Change

The darker line is emissions of carbon into the atmosphere from burning of fossil fuels; the lighter line is emissions due to land use change (e.g. deforestation, etc.).

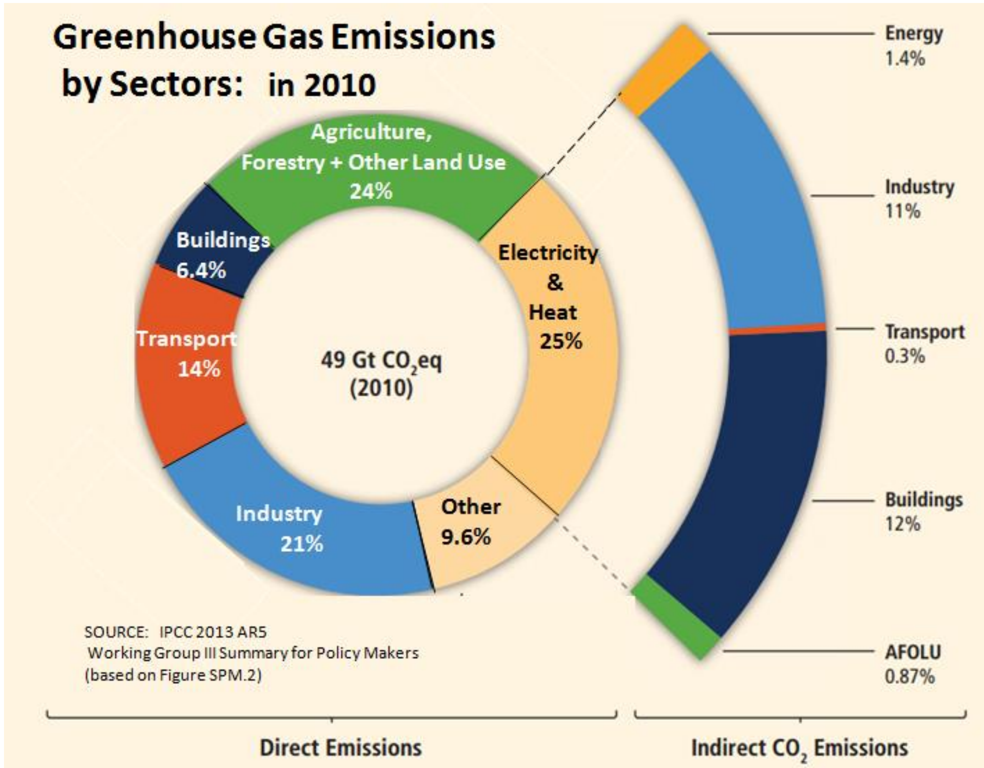
Which process emits more carbon into the atmosphere and how do the trends compare over time?

See also: http://www.epa.gov/climatechange/ghgemissions/global.html http://co2now.org/

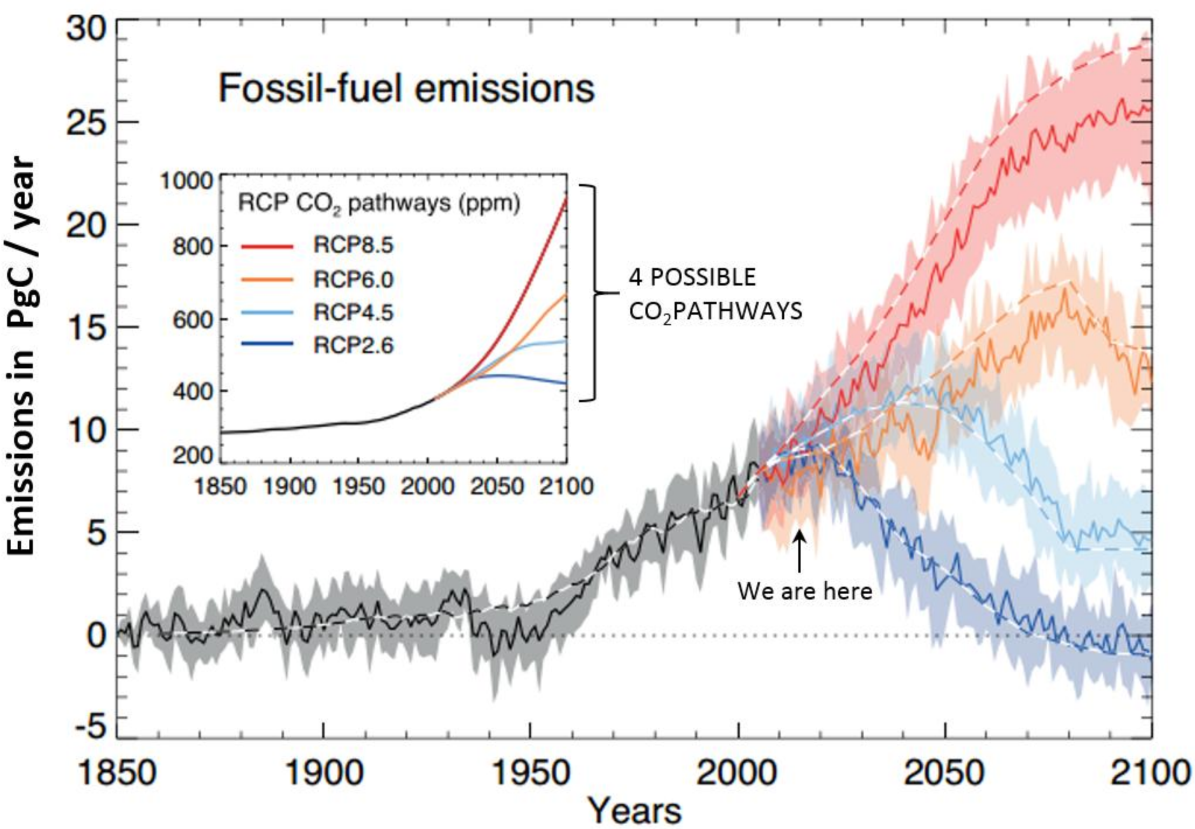


Carbon emissions (into the atmosphere) are due to deforestation. Uptakes (in Europe and the U.S.) are due to a shift to being a net carbon sink after a long history of deforestation. Below: GHG emissions by sector (both figures from IPCC AR4)

ANTHROPOGENIC TO GREENHOUSE GAS EMISSIONS BY SECTORS



IPCC 2013 AR5 SCENARIOS OF FUTURE FOSSIL-FUEL EMISSIONS:



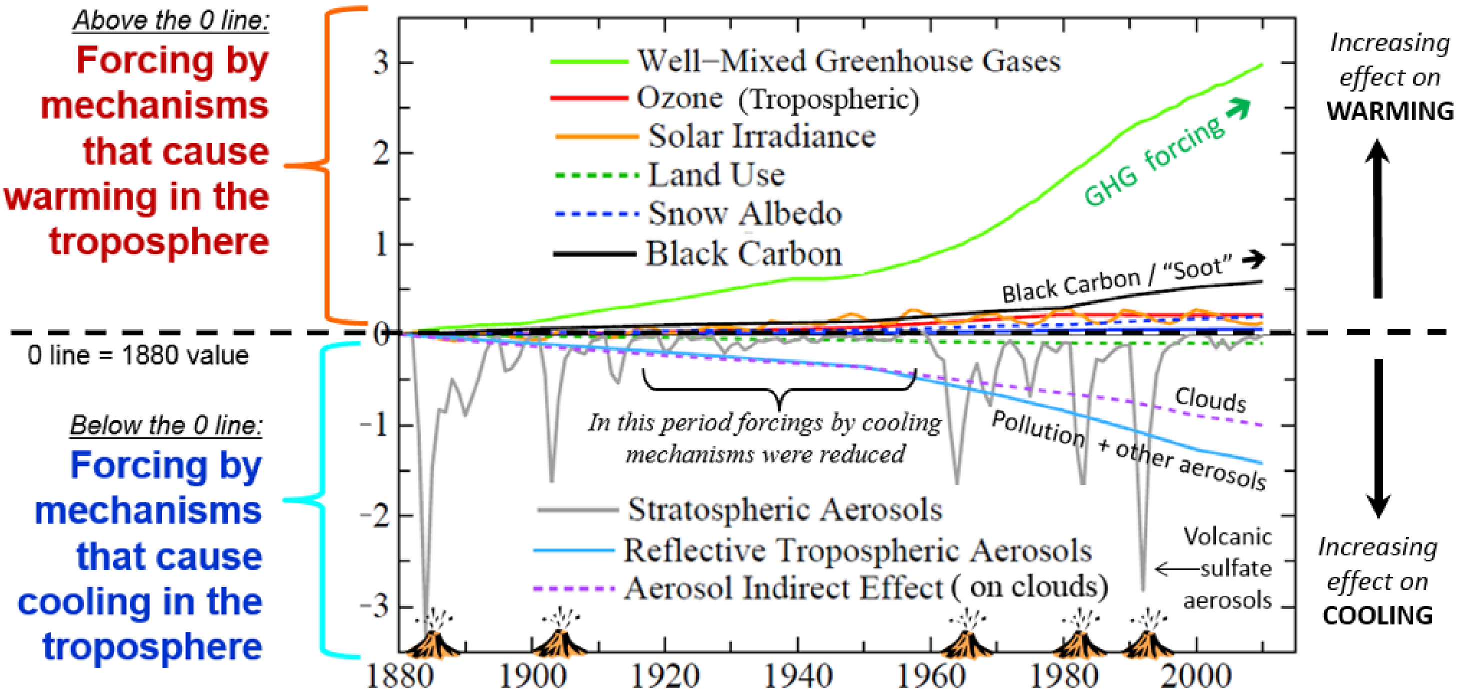
PgC/yr = (1 Petagram Carbon equals 10^{15} gC, or 1 billion metric ton C, or 3.67 billion metric ton CO_2),

B. *The Key To It All:* Sorting Out RADIATIVE FORCING & Its Effect on Climate

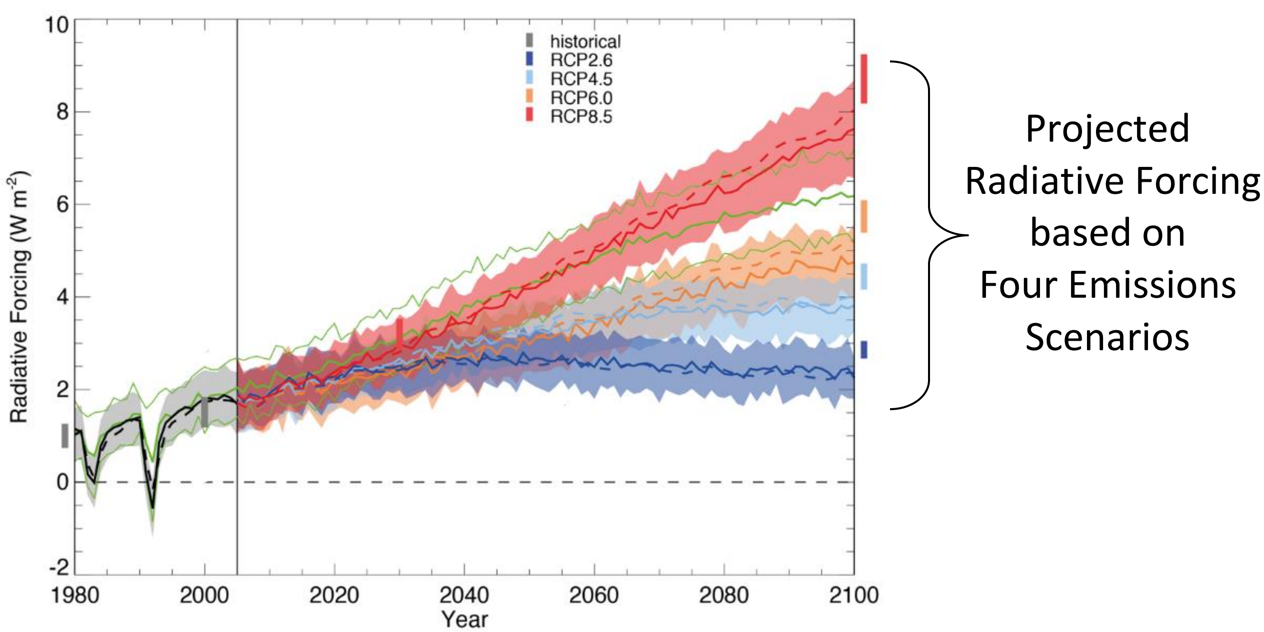
RADIATIVE FORCING = a measure of the influence a factor has in altering the balance of incoming ↓ and outgoing ↑ energy in the Earth-atmosphere system

- It is an index of the importance of a factor as a potential climate change mechanism.
- It is expressed in Watts per square meter (Wm^{-2}).
- *Another more technical definition* = the change in the net downward ↓ minus upward ↑ irradiance (expressed in W m^{-2}) at the tropopause due to a change in an external driver of climate.

RADIATIVE FORCING MECHANISMS

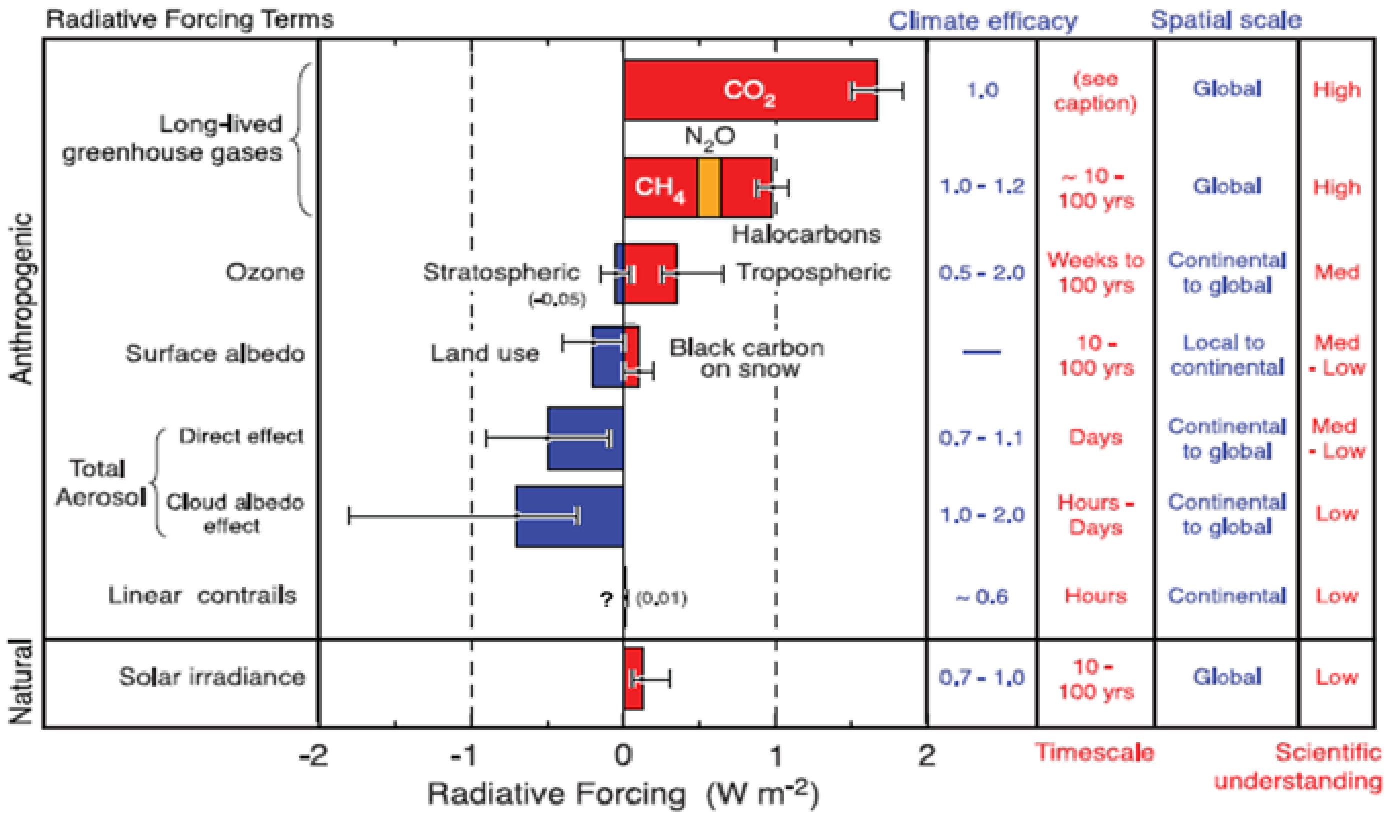


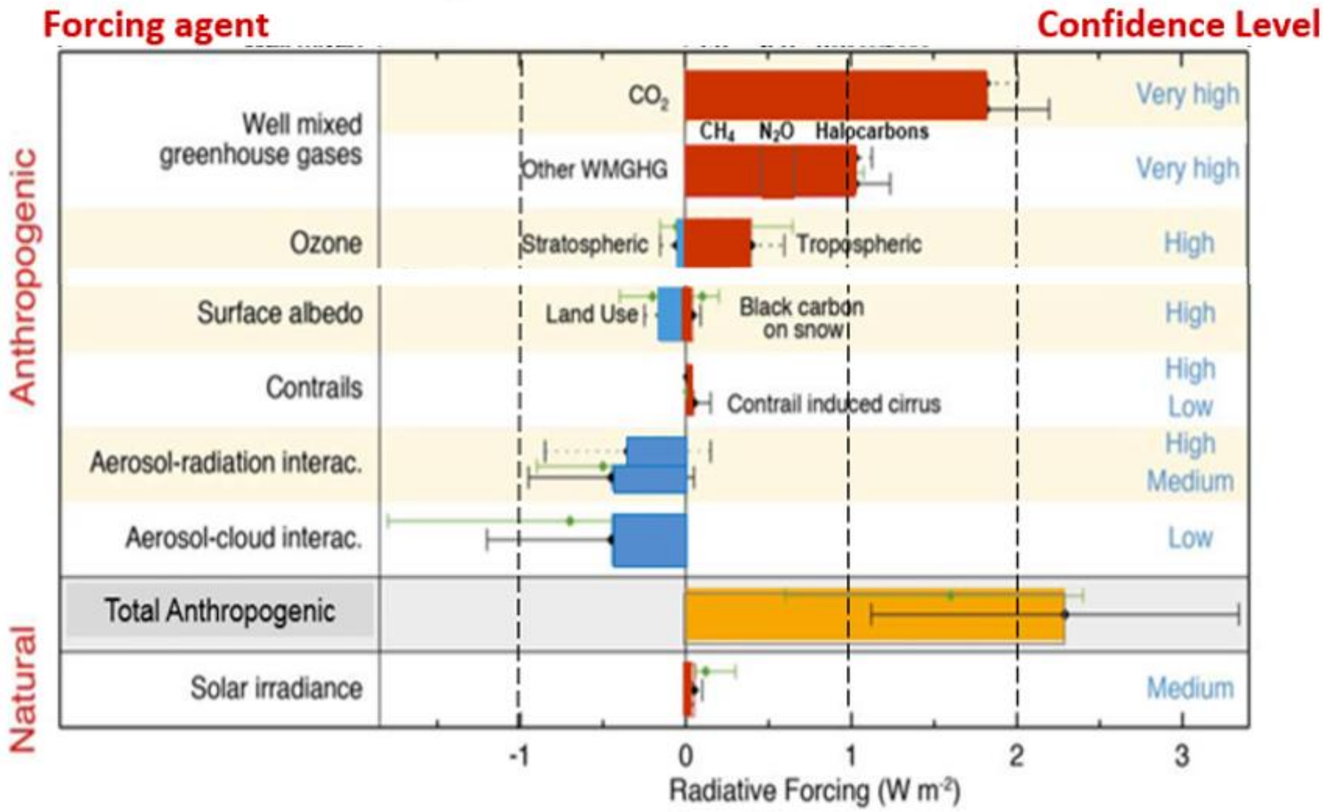
Effectiveness of various global climate forcings (+ or -) relative to their 1880 value (in W/m^2)



Radiative forcing of climate between 1750 and 2005

Based on IPCC 2007 AR4 WG-I: Chapt 2, Figure 2.20





Based on IPCC 2013 AR5 WG-I Technical Summary Fig TS.6

http://www.climatechange2013.org/images/report/WG1AR5_TS_FINAL.pdf

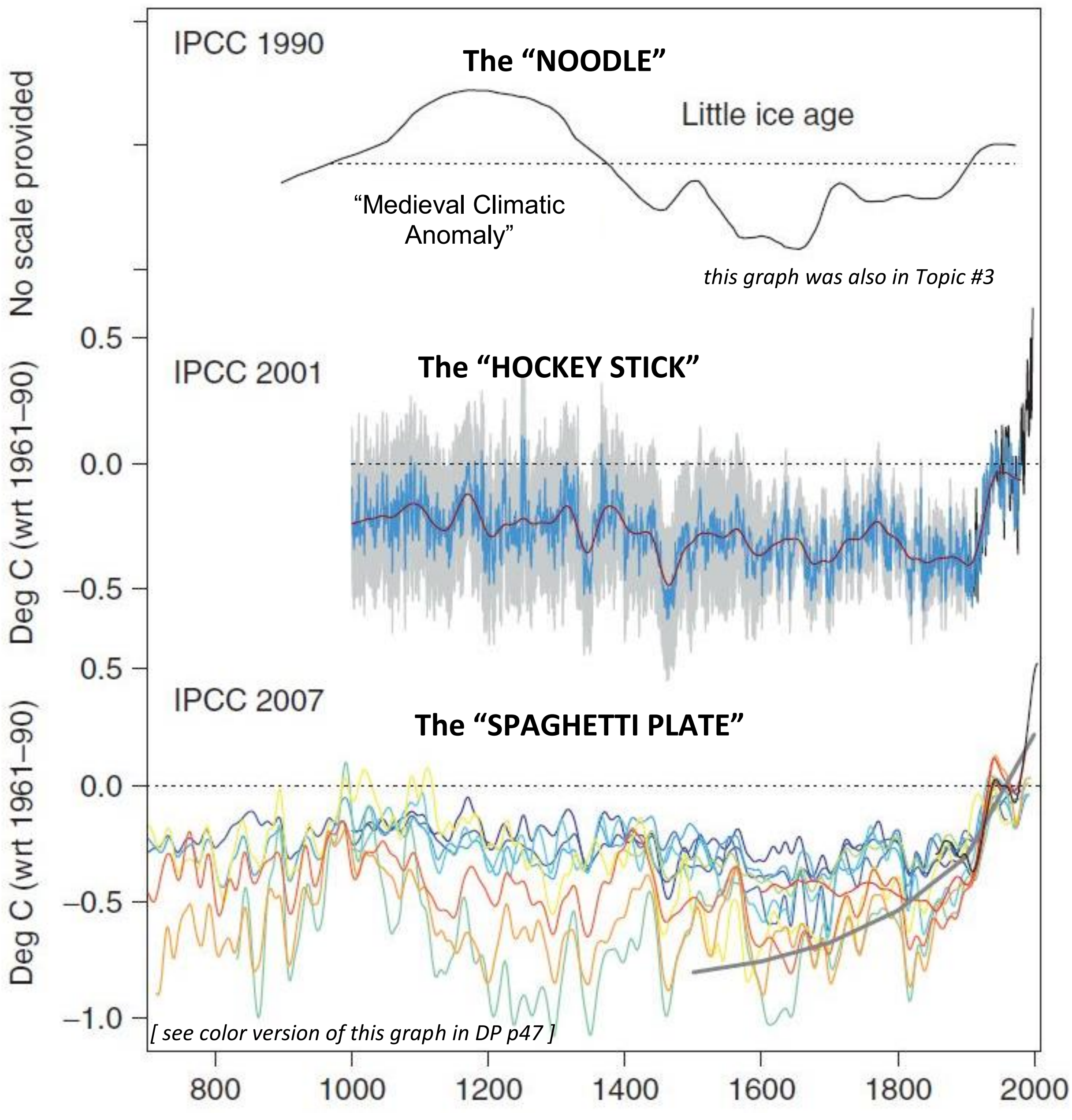
C. Evidence From Natural Archives

> *"The farther backward you can look, the farther forward you are likely to see."*
> *- Winston Churchill*

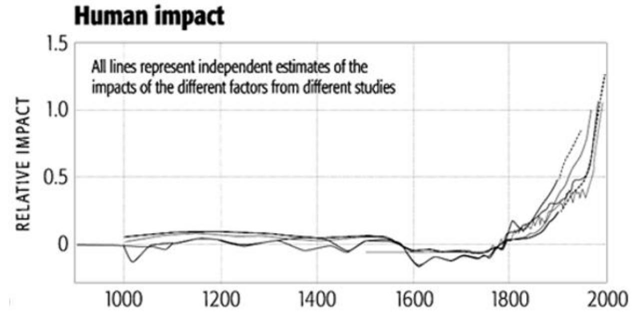
The most recent warming is without precedent for at least the past millennium.

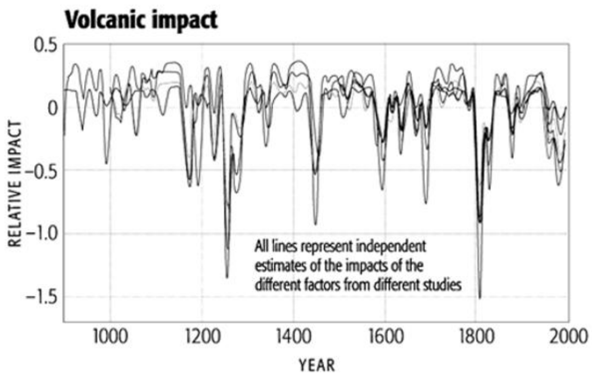
Over much longer geologic time, the 20th & 21st centuries may not necessarily be the warmest time in Earth's history . . . **but what is unique is that the recent warmth is global and cannot be explained by natural forcing mechanisms.**

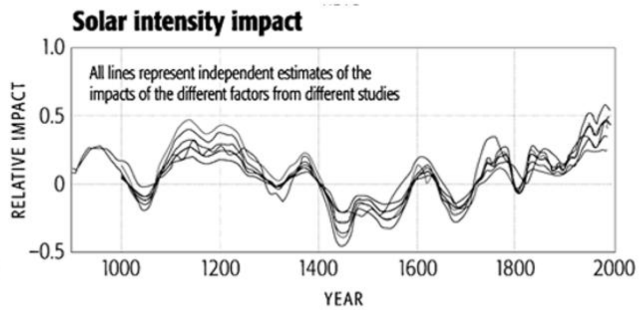
Three "ICONIC" GRAPHS: NORTHERN HEMISPHERE TEMPERATURE CHANGES OVER THE PAST MILLENNIUM



D. Using Models to Sort Out Natural vs. Anthropogenic Forcing



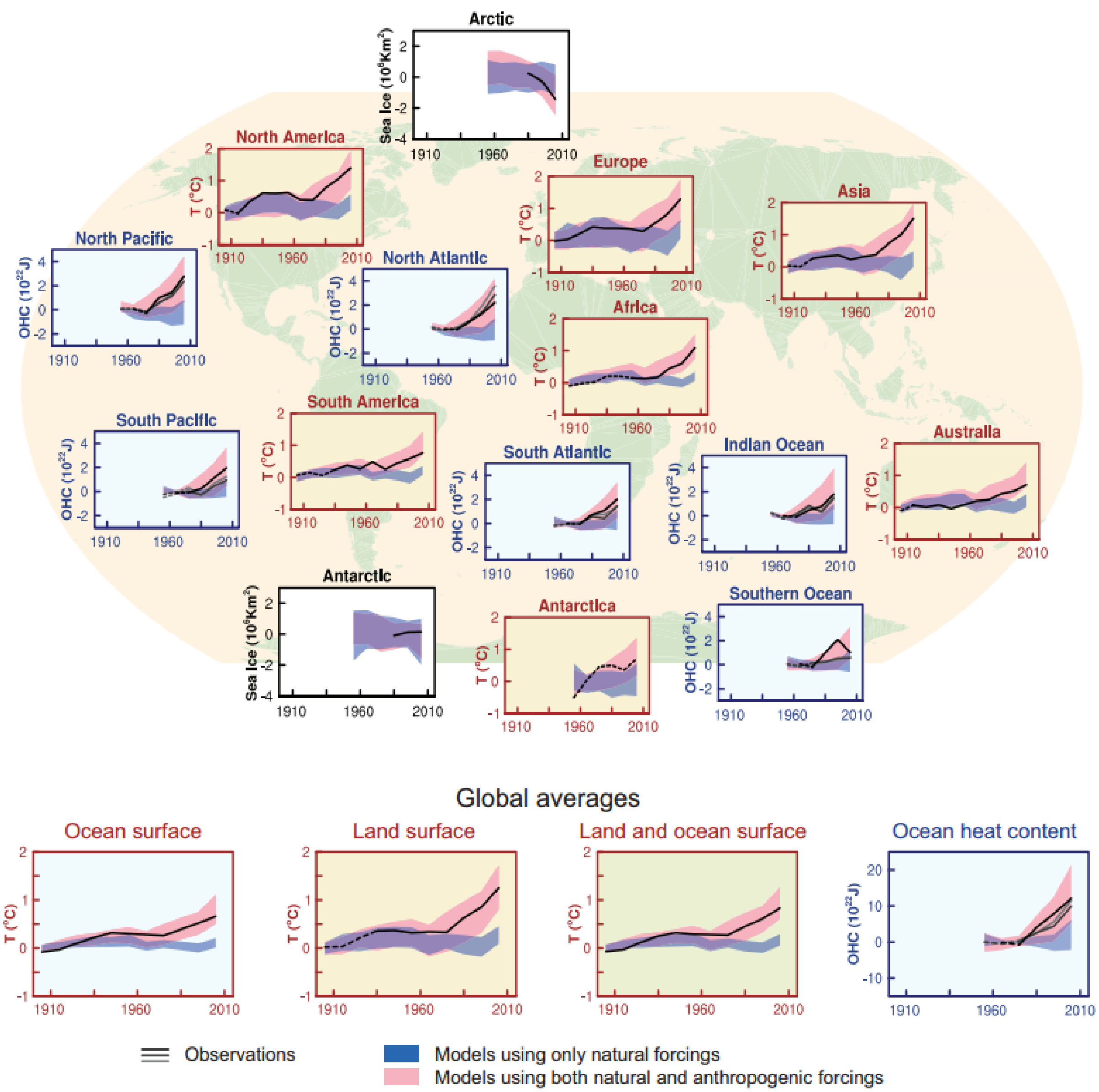




Model Comparisons of Natural vs. Anthropogenic Forcing on All Continents

IPCC AR5 WG I Technical Summary Fig TS 12

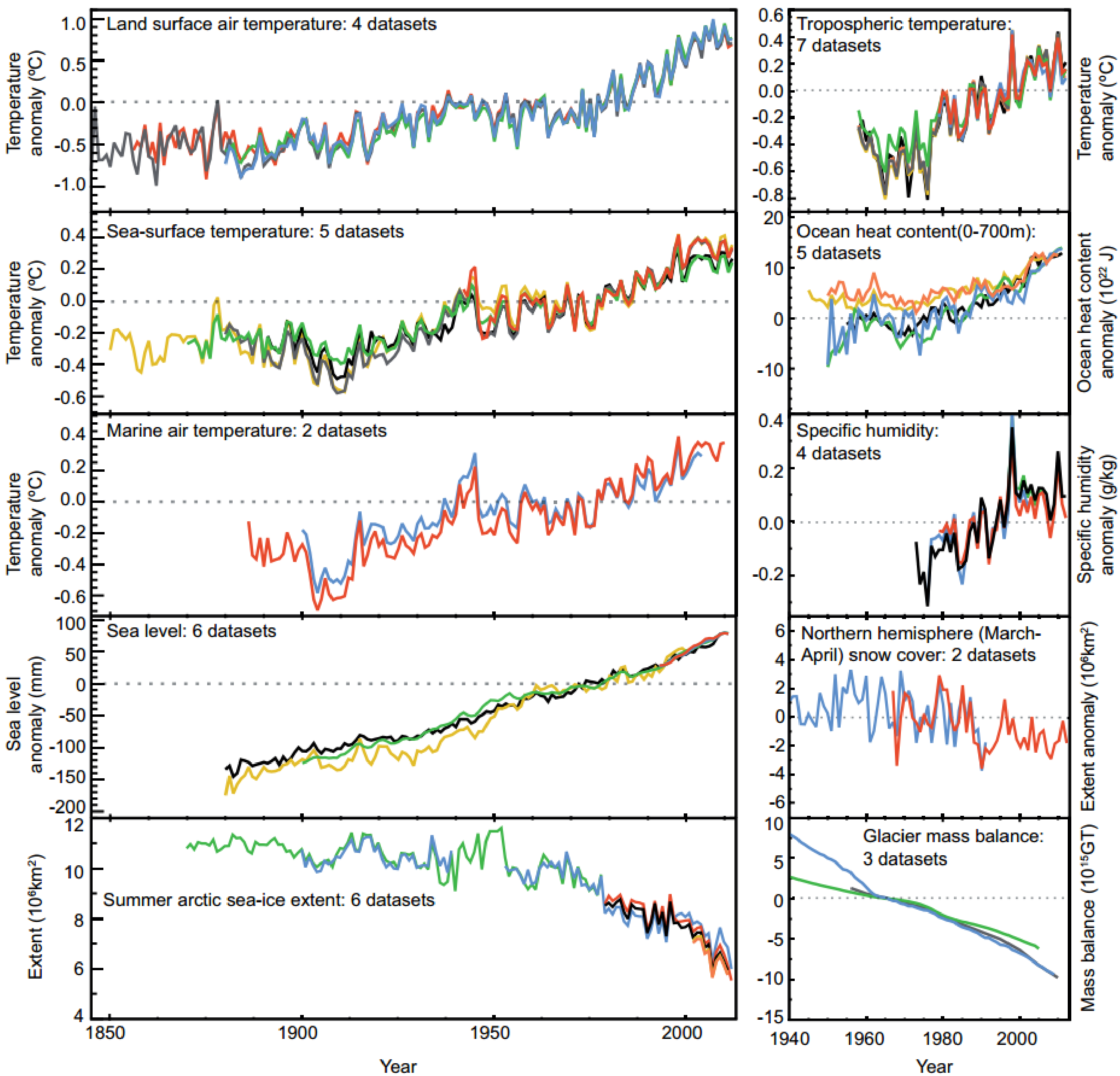
http://www.climatechange2013.org/images/report/WG1AR5_TS_FINAL.pdf



AN ARRAY OF TIME SERIES PLOTS SHOWING MULTIPLE OBSERVED INDICATORS OF A CHANGING GLOBAL CLIMATE

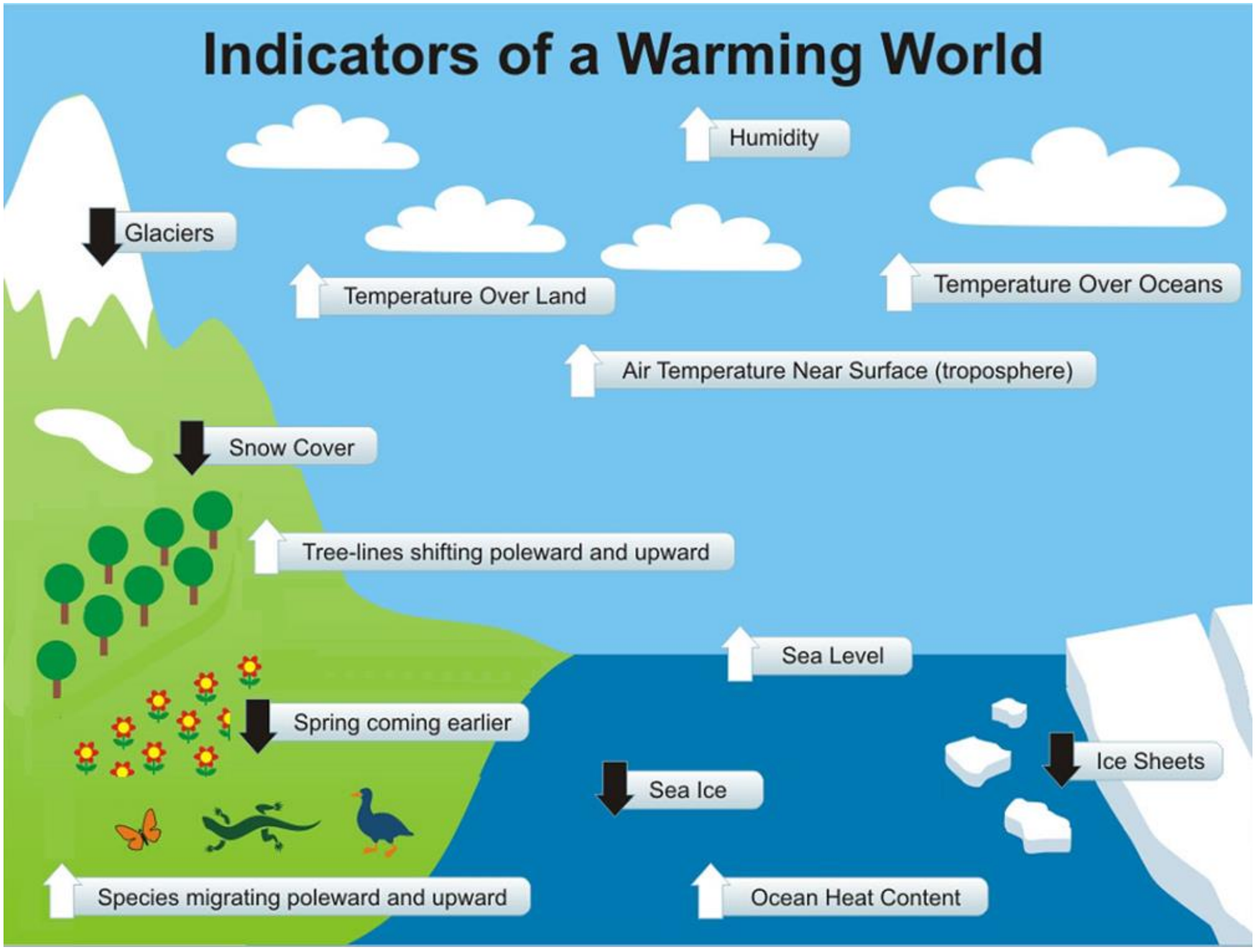
(Source: IPCC 2013 Working Group I Technical Summary)

http://www.climatechange2013.org/images/report/WG1AR5_TS_FINAL.pdf

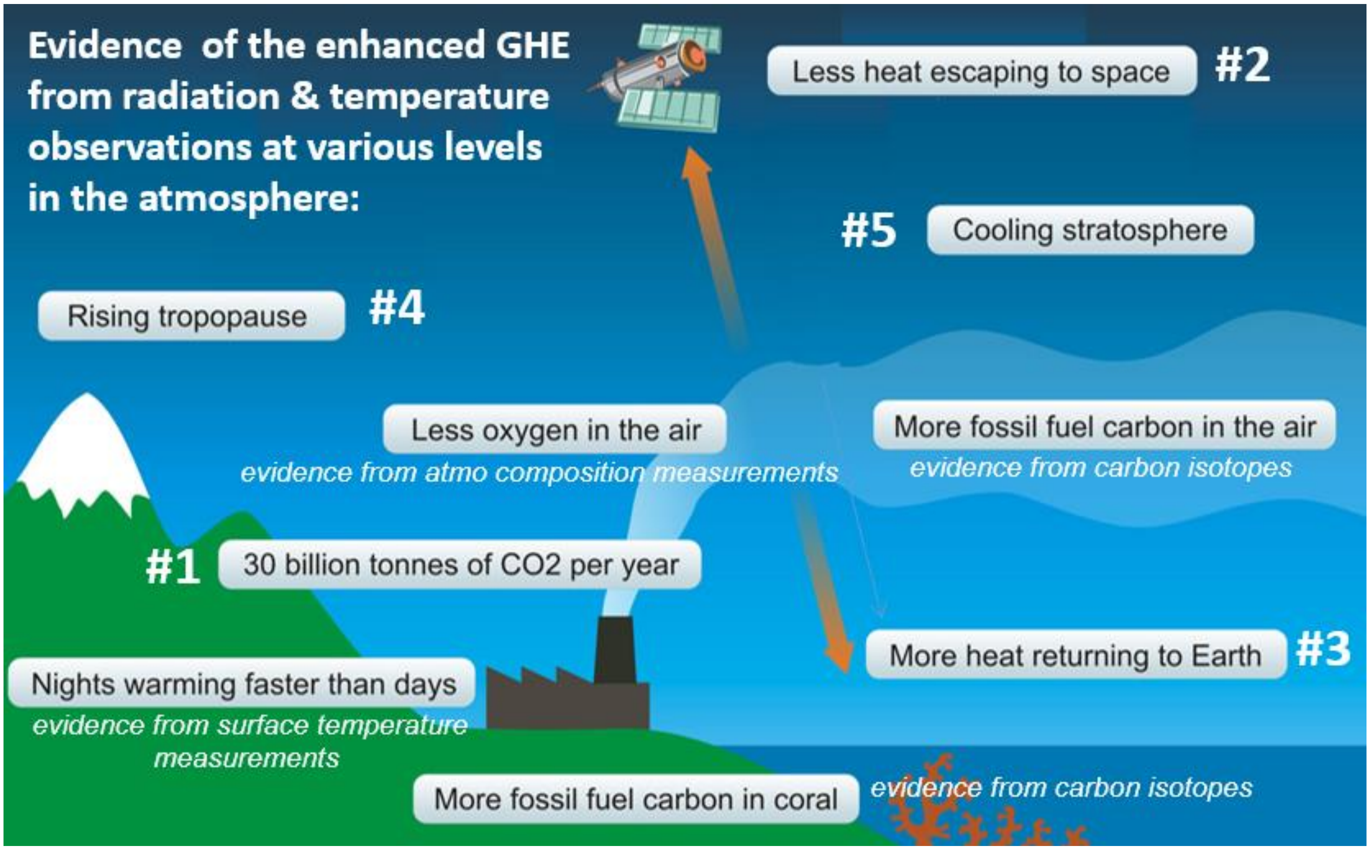


Each line represents an independently derived estimate of change in the climate element. In each panel all data sets have been normalized to a common period of record.

EVIDENCE FROM OBSERVATIONS RECAP



Some Indicators of a
<u>Human</u> Fingerprint on Climate Change:



Can you link the indicators in the figure with processes we've covered this semester that are linked to an ANTHROPOGENIC influence?

(Some are already noted in the figure]

1. 30 billion tonnes of CO_2 emitted into the atmosphere per year:

2. Less heat escaping to space at the top of the atmosphere:

3. More heat returning to Earth:

4. Rising tropopause:

5. Cooling stratosphere:

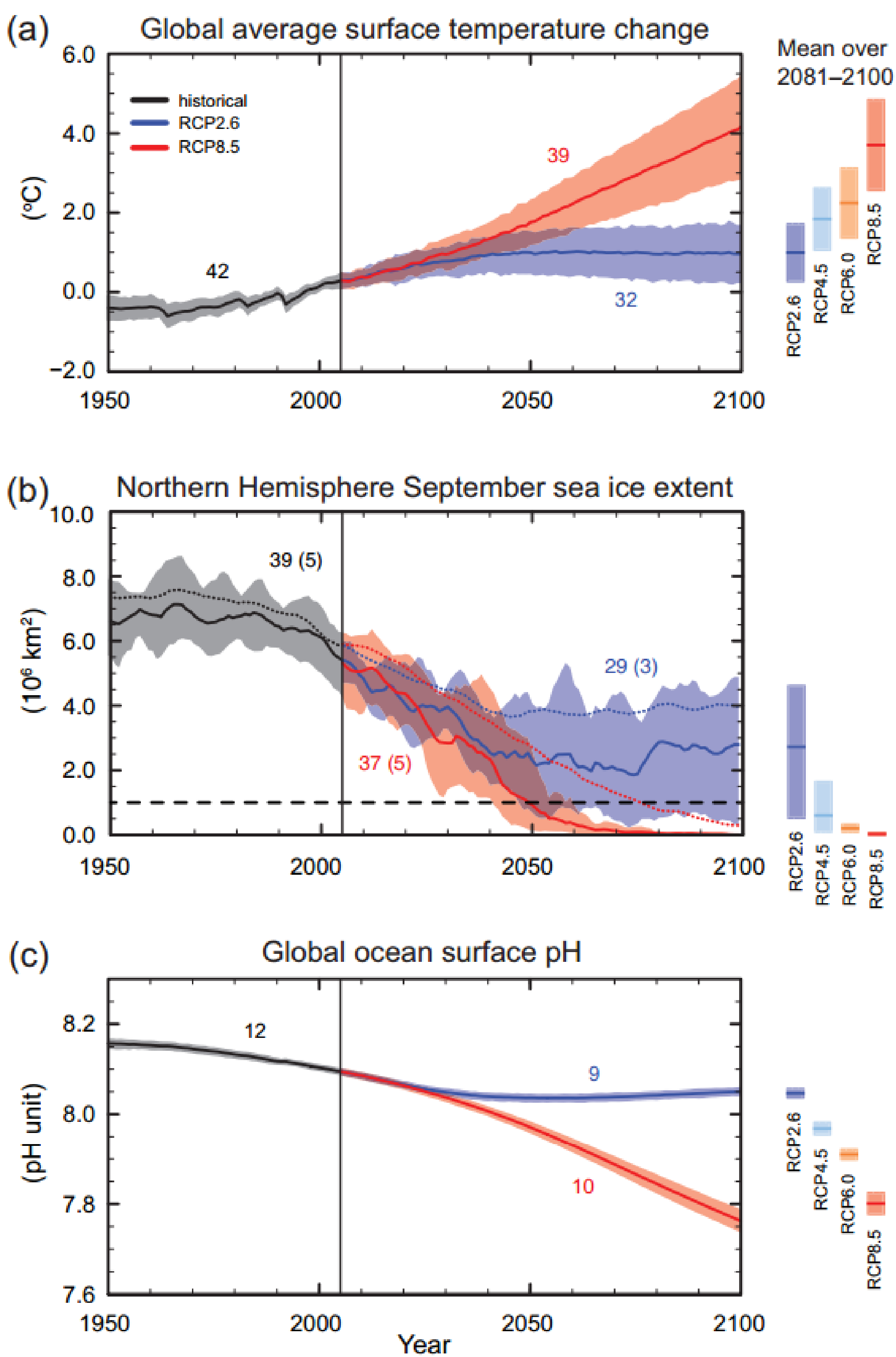
TOPIC #14 – CLIMATE CHANGE IMPACTS & CHOICES

> There is a paradoxical gulf between the importance of Earth's climate and the level of public interest in it. . . . We're in the middle of a large uncontrolled experiment on the only planet we have.
>
> *- Donald Kennedy, editor-in-chief of the journal Science*

IPCC 2013 (AR5): Projected Climate Change for Different Emissions Scenarios

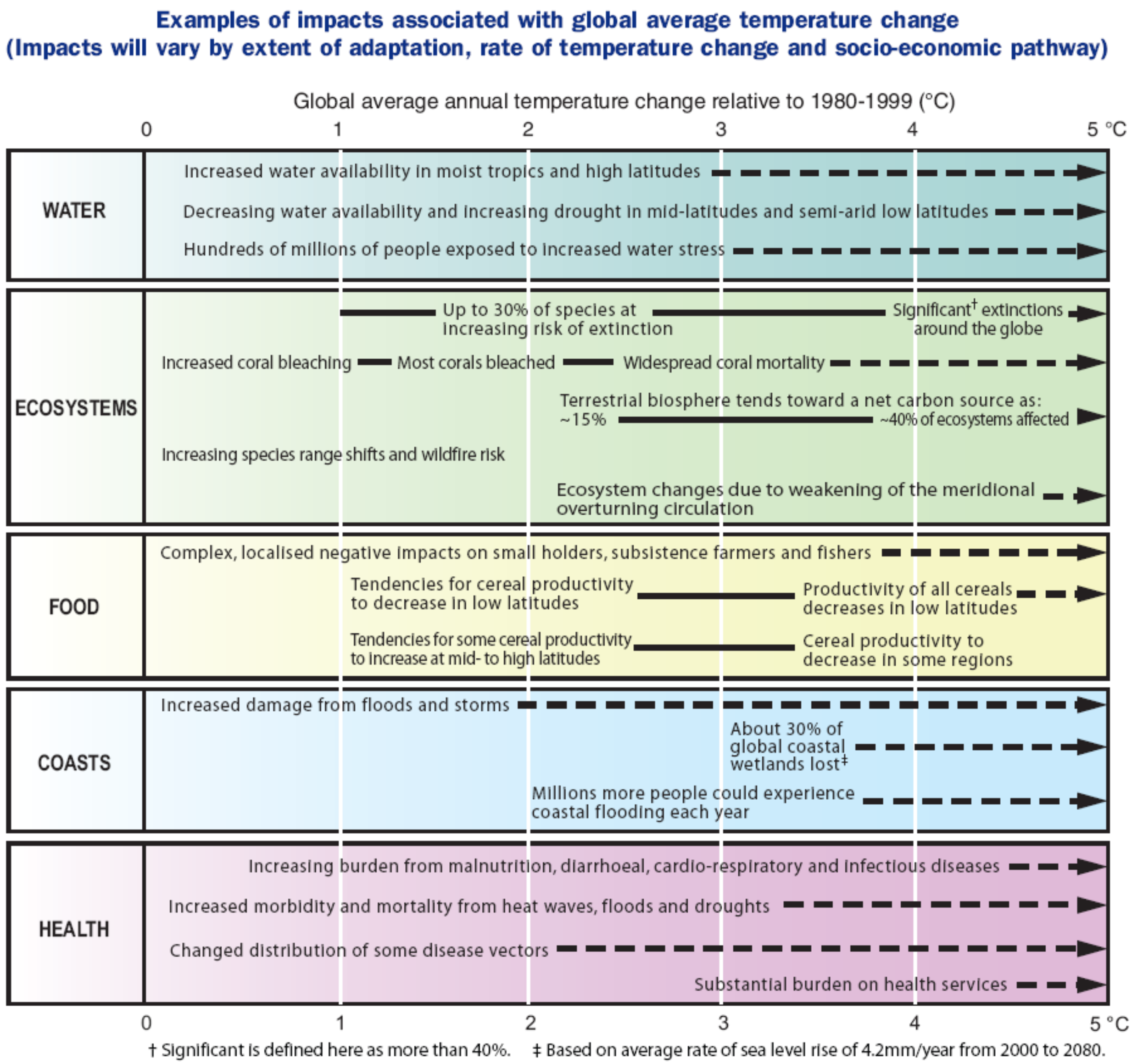
IPCC 2013 AR5 WG I Summary for Policy Makers Fig SPM.7

http://www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf



PROJECTED IMPACTS OF CLIMATE CHANGE

(based on AR4 Report; many are already being observed!)

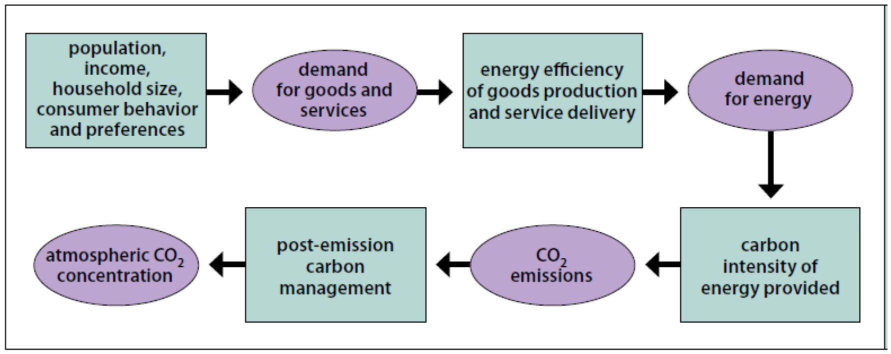


CLIMATE CHANGE: MITIGATION & ADAPTATION

> A world civilization able to envision God and the afterlife, to embark on the colonization of space, will surely find the way to save the integrity of this magnificent planet and the life it harbors because quite simply it's the right thing to do, and ennobling to our species. -E. O. WIlson

QUESTION: To Mitigate or Adapt? ANSWER: We need both! *(see DP p 144)*

Mitigation: An *anthropogenic* intervention to reduce the anthropogenic forcing of the *climate system*; it includes strategies to reduce *greenhouse gas sources* and emissions and enhancing *greenhouse gas sinks*.



The chain of factors that determines how much CO2 accumulates in the atmosphere. The boxes represent factors that can potentially be influenced to affect the outcomes in the circles.

Adaptation: Adjustment in natural or *human systems* in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Adaptive capacity (in relation to climate change impacts): The ability of a system to adjust to *climate change* (including *climate variability* and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Adaptive management: An approach to management of natural resources that emphasizes how little is known about the dynamics of ecosystems and that as more is learned management will evolve and improve

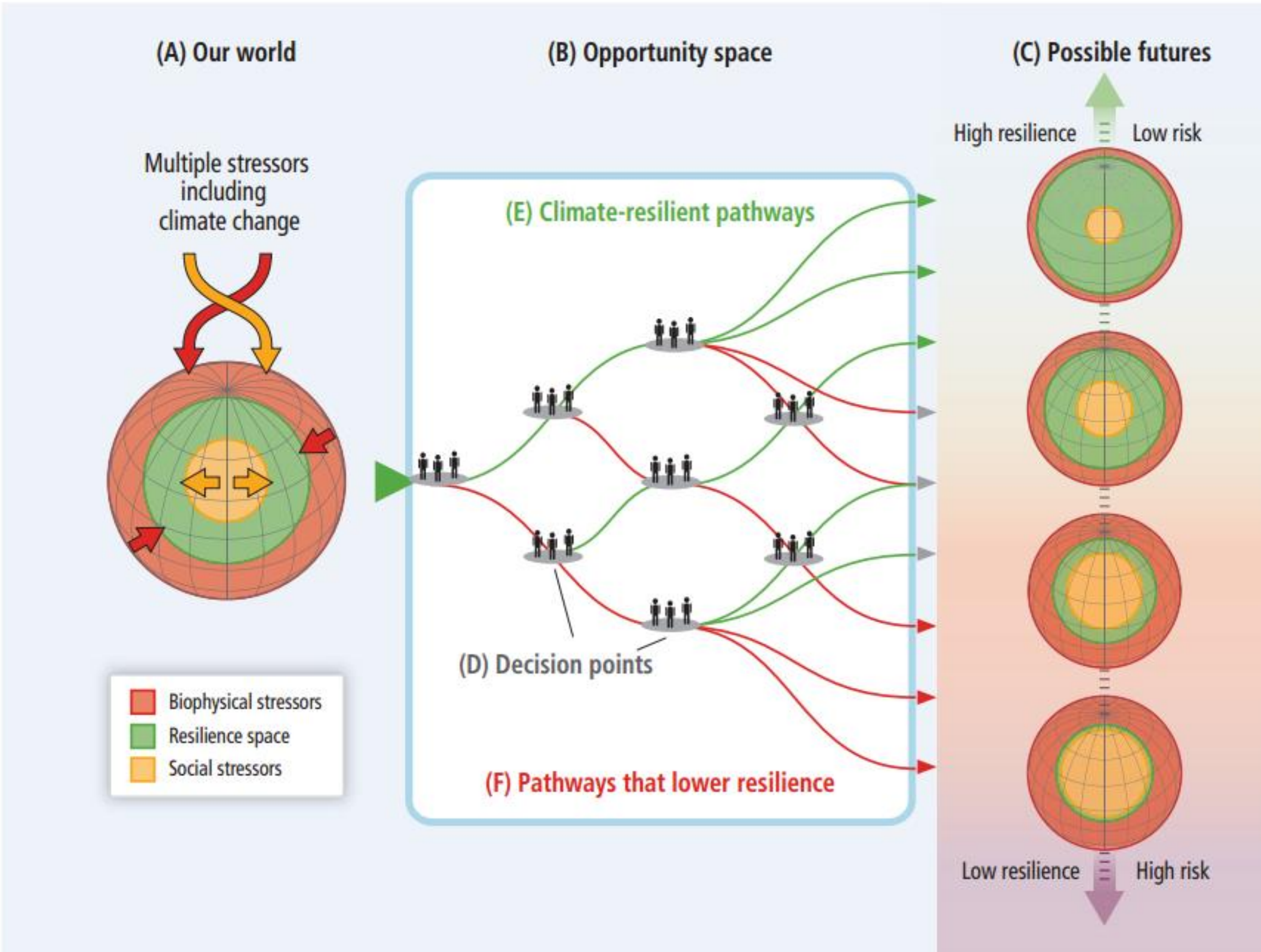
EXAMPLES*:*

Conservation
Energy efficiency
Alternative energy (solar, wind, geothermal, hydropower, nuclear)
Green economy
geoengineering,
footprint reduction
management solutions
forest stewardship /certification
international agreements on emissions targets (e.g., Kyoto, etc.)
national policies (cap & trade vs. carbon tax)
local initiatives (e.g., rainwater harvesting)
sustainable lifestyles . . . and more!

CHOICES & CLIMATE-RESILIENT PATHWAYS: Which paths will we take?

Source: IPCC 2013 AR5 Working Group III Summary for Policy Makers

http://report.mitigation2014.org/spm/ipcc_wg3_ar5_summary-for-policymakers_approved.pdf



OPPORTUNITY SPACE AND CLIMATE-RESILIENT PATHWAYS

(A) **Our world is threatened** by multiple stressors that impinge on resilience from many directions, represented here simply as biophysical and social stressors. Stressors include climate change, climate variability, land-use change, degradation of ecosystems, poverty and inequality, and cultural factors.

(B) **Opportunity space** refers to decision points and pathways that lead to a range of (C) possible futures with differing levels of resilience and risk.

(D) **Decision points result in actions or failures-to-act** throughout the opportunity space, and together they constitute the process of managing or failing to manage risks related to climate change.

(E) **Climate-resilient pathways** (in green, pointing upward) within the opportunity space lead to a more resilient world through adaptive learning, increasing scientific knowledge, effective adaptation and mitigation measures, and other choices that reduce risks.

(F) **Pathways that lower resilience** (in red, pointing downward) can involve insufficient mitigation, maladaptation, failure to learn and use knowledge, and other actions that lower resilience; and they can be irreversible in terms of possible futures.

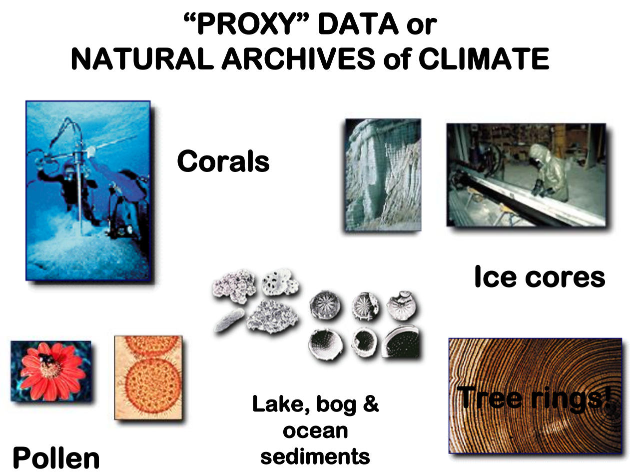
APPENDIX

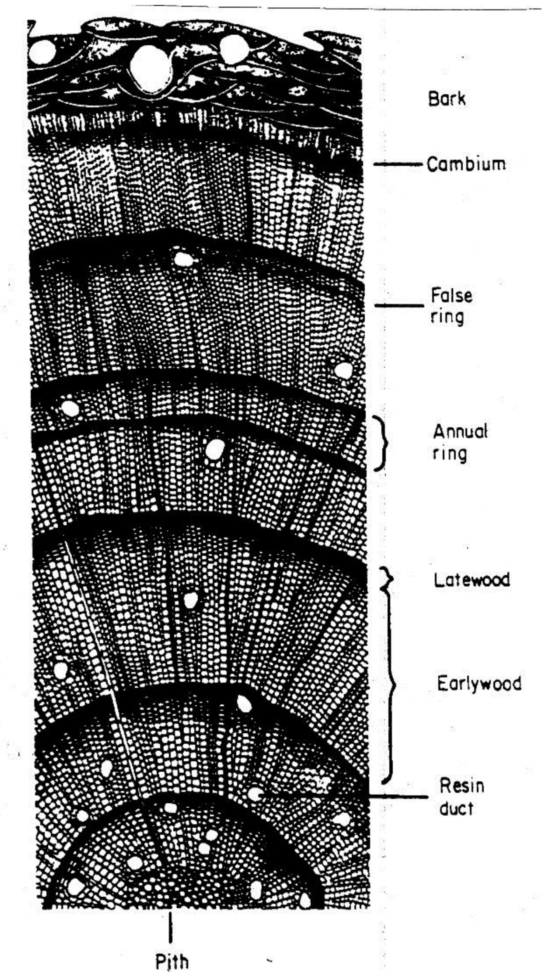
Supplementary Materials
for Background & Use in Class Activities

NOTES

APPENDIX A: INTRODUCTION TO TREE RINGS & DENDROCHRONOLOGY

> Trees and stones will teach you that which
> You can never learn from masters. ~ *St. Bernard of Clairvaux*





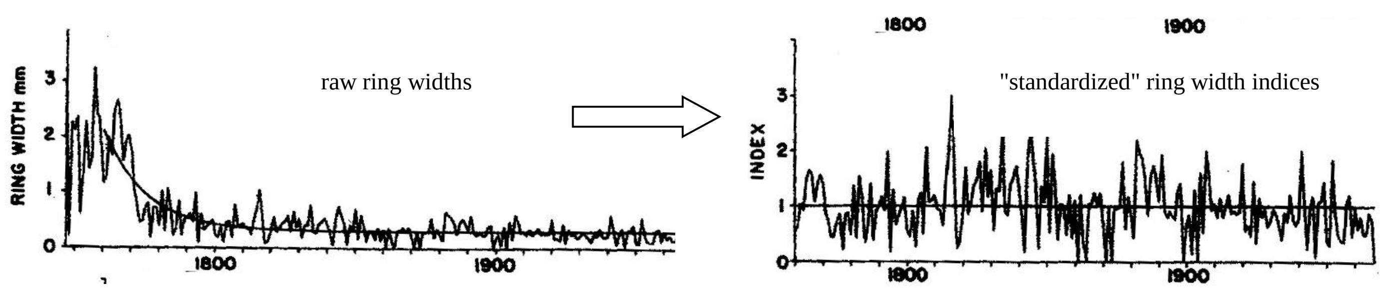
How old is the tree shown above? _____ years

Dendrochronology (def): The science that uses tree rings dated to their exact year of formation to answer questions pertaining to various fields in the earth sciences.

Tree ring: A layer of wood cells produced by a tree or shrub in on year

- *Earlywood* (thin-walled cells formed early in the growing season)
- *Latewood* (thicker-walled cells produced later in the growing season)

Tree-ring chronology: A series of measured tree-ring properties, such as ring width, that has been converted to dimensionless indices through the process of standardization:



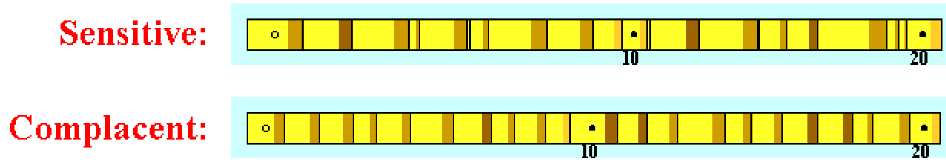
Key Principles of Dendrochronology

- *Uniformitarianism* --"the present is the key to the past;" can reconstruct past based on present linkages
- *Limiting Factors* --growth can occur only as fast as allowed by factor that is most limiting (e.g. rainfall)
- *Site Selection* -- sites are selected based on criteria of tree-ring sensitivity to an environmental variable
- *Crossdating* -- matching patterns in rings of several tree-ring series allow precise dating to exact year
- *Replication* -- "noise" minimized by sampling many trees at a site + more than one core per tree
- *Ecological Amplitude* -- trees more sensitive to environment at latitudinal /elevational limits of range

Key Scientific Issues in Dendrochronology:

- Locally absent rings & false rings can occur (need a “master chronology” to sort these out)
- Species limitations (some trees have no rings, non-annual rings, poorly defined rings)
- Trees must crossdate! (can’t develop a chronology or link to climate without this)
- Geographical limitations (tropics, deserts and other treeless areas, oceans, etc.)
- Age limitations (old trees hard to find; oldest living trees = Bristlecone Pines almost 5,000 years old!
- Value of precise dating (long chronologies, climate reconstructions, archaeology, radiocarbon dating)

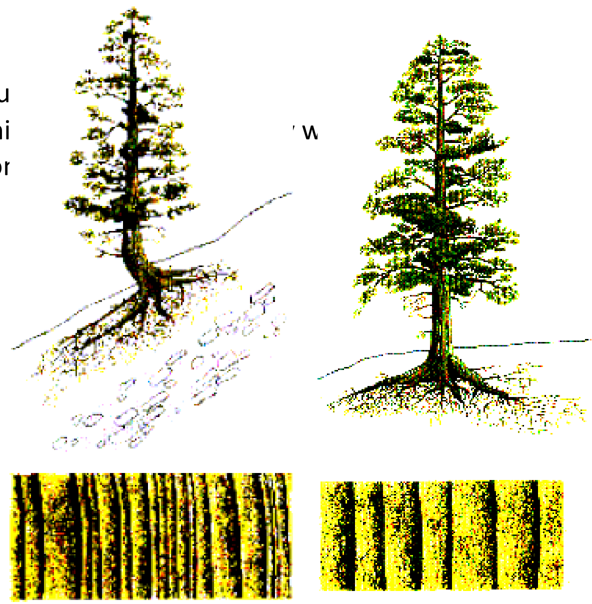
Sensitive vs. Complacent Tree-Ring Growth
Source: Dr. Paul Sheppard, LTRR



http://www.ltrr.arizona.edu/skeletonplot/introcrossdate.htm

"Complacent" tree growth:
- Low degree of annual variation
- Rings are roughly the same for many years consecutively
- Limiting growth factor is not variable from year to year
- Especially true for benign sites (flat with deep soil for moistu
- Complacent ring growth can be difficult to crossdate: matchi narrows rings across trees is harder when not much variatior

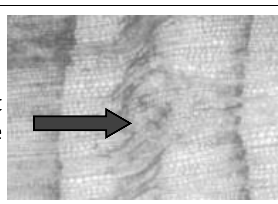
"Sensitive" tree growth:
- High degree of annual variation
- Wide and narrow rings intermixed through time
- Limiting growth factor (e.g., rainfall) is highly variable year to year
- Especially true for harsh sites (steep/rocky for moisture sensitivity)
- Reasonably sensitive ring growth is good: Matching patterns of relatively wide and narrows rings across trees is easier when ample variation exists



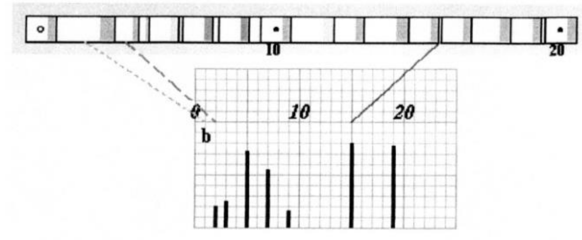
Fill in the blank with the proper label for each tree and ring-growth pattern: **"Complacent" or "Sensitive"**

------------------------------ ----------------------------

Some individual trees rings have unique markers! *(often these help with crossdating)*

	**FIRE SCARS:** Can be used to date the occurrence of past fires. The scar represents a healing or healed-over injury caused or aggravated by fire on a tree or woody plant
Frost damage 	**FROST RINGS:** Produced by a severe freeze occurring DURING the tree’s growing season. Can occur during 2 nights < - 5 °C with an intervening day that doesn't go above freezing (0 °C)

Making Skeleton Plots



When skeleton plotting ring-width variation of a core, note that:

- Narrow rings merit marks on the skeleton plot
- The narrower the ring, the longer the mark
- Very wide rings occasionally merit a little "b" mark (for big)
- Normal or average rings DO NOT merit marks on the skeleton plot
- For example, compare the core and skeleton plot below:
  - The narrowest ring is connected (blue line) with the longest skeleton mark
  - The widest ring is connected (green line) with a "b" mark (for big)
  - Note the dashed line: it points to a ring of average width, but it seems narrow compared to the preceding "b" ring. It merits a small mark because of the large year-to-year difference based on the previous extremely wide ring.

Pattern Matching: Skeleton Plot and Master Chronology

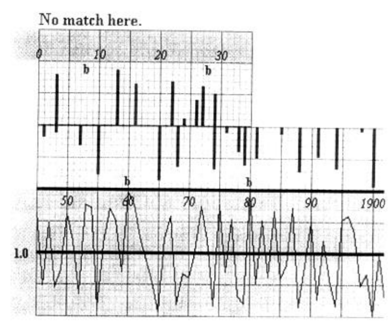
The objective: To find the mirror image of the patterns
. . . of the marks pointing up on the skeleton plot
. . . .with the marks hanging down
on the master chronology

Move the skeleton plot back and forth on top of the master chronology until the plot marks line up.

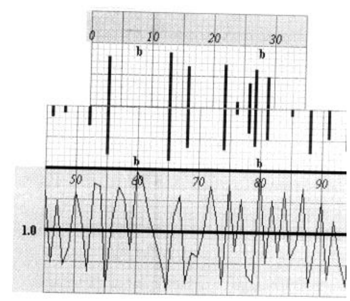
How to know when you have a match:

- All of the skeleton plot marks -- and even the "b" marks should line up with those on the dated master chronology
- The mirror imaging should be visually obvious

NO MATCH



YES! A MATCH



WHICH TYPES OF TREES CAN BE USED IN DENDROCHRONOLOGY?

The characteristics that make a tree suitable for crossdating are:

- The tree has a **ring growth structure** *(not all trees have rings!)*
- The tree-ring **boundaries are distinct** *(some species have more distinct boundaries than others)*
- The tree rings are **annual**, i.e., one ring is formed each calendar year *(can't tell by looking!)*
- The tree growth **pattern is sensitive** (not complacent) so that variations from year-to-year ("interannual variations") show enough variations with distinct patterns that can be matched from core to core and tree to tree.
- The tree growth pattern has "**circuit uniformity**," i.e. the rings are continuous around the entire circumference of the tree so that the same ring pattern will appear if you core different sides of the tree. *(can best be evaluated with a cross-section sample from a tree)*
- the length of tree-ring **record is long enough** so that a valid pattern match can be made *(in general, a tree-ring record of 50 continuous rings or more is needed)*

Working with Wood: Do all trees have rings??

Mini-Introduction to Tree Anatomy & Some Principles of Dendrochronology

Background: *Many trees and other woody plants produce growth rings in their central trunk. These rings may or may not be annual, record climatic and environmental variables, or have enough variability to be used in dendrochronology. Before being included in a dendrochronological study, scientists evaluate the potential of a species using criteria based on growth form, age, and response of the plant to climate and the environment*

Objectives: *When you conclude this assignment, you should be able to look at the structure of a cross-section of wood and, by understanding and applying terms and principles of dendrochronology, generally determine if the piece might be suitable for use in a dendrochronological study.*

Instructions:

• Remove all wood samples and white envelope from your wood kit box.

• Place a label (from the white envelope) on the corresponding correct wood sample from the kit.

• Using terminology from lecture (see class notes) and from the illustrations below, describe (in the table on the second page) how each of the species is suitable to use for dendrochronology.

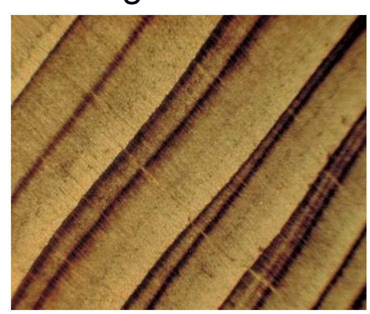
• Write down at least three descriptive features for each species; there can and will be reasons for and against using each individual piece of wood for dendrochronology.

• Finally, write yes or no in the right hand column to indicate if you would use this piece of wood in your own laboratory for a dendrochronological study.

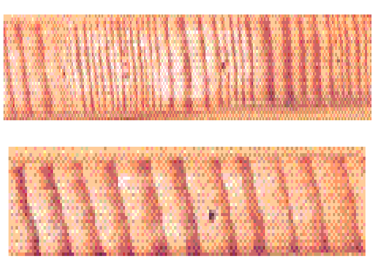
1. Has Rings:

2. Distinct Ring Boundaries:

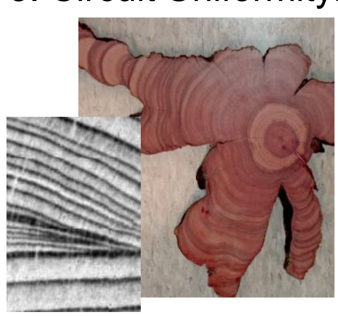
3. Rings are Annual:



4. Sensitive Growth:



5. Circuit Uniformity:



6. Long Ring Record:

Tree species	Dendrochronological Criteria		Y/N
	Reasons FOR using	Reasons for NOT using	
Bristlecone pine (*Pinus longaeva*)			
Fan palm (*Washingtonia spp.*)			
Lodgepole pine (*Pinus contorta*)			
Mesquite (*Prosopis spp.*)			
Mulberry (*Morus spp.*)			
Saguaro (*Carnegiea gigantea*)			
Giant redwood (*Sequoiadendron giganteum*)			
White pine (*Pinus strobus*)			

ADDITIONAL NOTES:

DATA COLLECTION & ANALYSIS WORKSHEET
The Bristlecone Pine (BCP) Class Activity)

DESCRIPTIONS OF THE FIVE BRISTLECONE PINE SITES *(class presentation)*

❑ As you listen to the presentation on the 5 bristlecone pine sites, fill in the TABLE on the next page with information and comments about the 5 sites being analyzed by the class. You will need this information to answer questions later.

<u>THE FIVE SITES:</u>

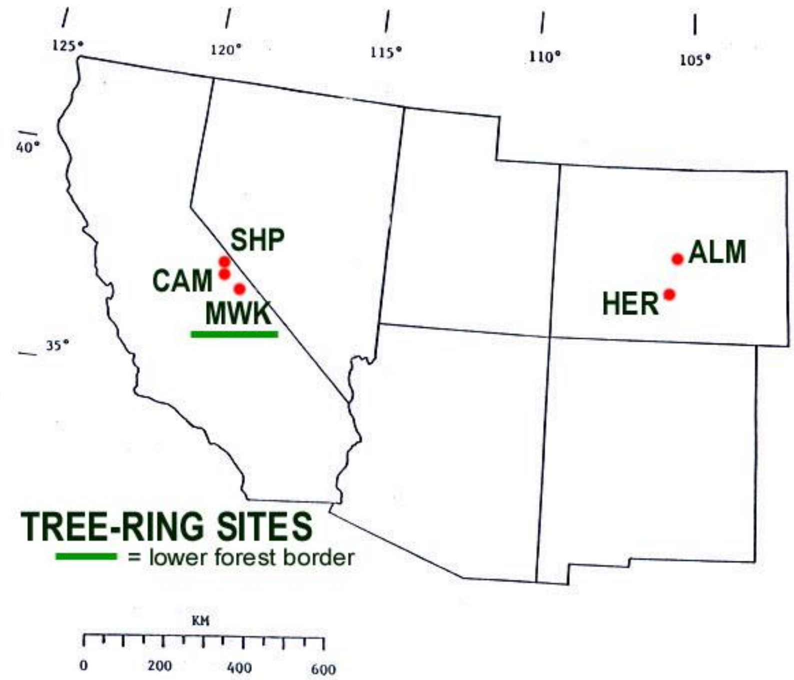
Sheep Mt (SHP)

Campito Mt (CAM)

Methuselah Walk (MWK)

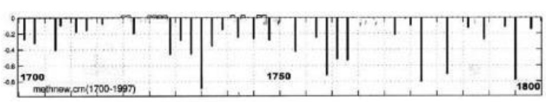
Almagre Mt (ALM)

Hermit Lake (HER)



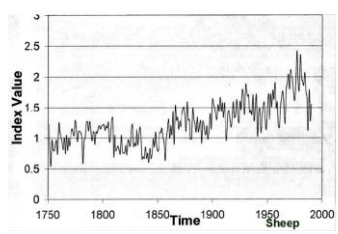
<u>TREE-RING DATA YOU WILL BE ANALYZING:</u>

Skeleton Plot Masters:



(Some of the Skeleton Plots have **FR** for FROST RING marked in certain years.)

Ring Width Indices Plots:



EXAMINING THE TREE-RING DATA

❑ To begin, examine the **SKELETON PLOTS** and **RING WIDTH INDICES** for the sites and look for similarities and differences.

Are some of the **frost ring dates** on the SKELETON PLOTS common to more than one site?

Do you see **any trends** in the RING WIDTH INDICES? (i.e, *increasing trend, no trend, step change beginning at 1900, etc.)*

Also note any other interesting things you observe. . . .

VARIABLES *(NOTE: A variable is something that varies from site to site or from time to time at one or more sites* **)**	**SITE-to-SITE COMPARISON TABLE**				
	Sheep Mt Core ID = C	**Campito Mt Core ID = D**	**Methuselah Walk Core ID = B**	**Almagre Mt Core ID = E**	**Hermit Lake Core ID = A**
Geographic Location	White Mountains near Bishop, California	White Mountains near Bishop, California	White Mountains near Bishop, California	Front Range of the Colorado Rockies	Front Range of the Colorado Rockies
Elevation	3475 m (~11,500 ft)	3400 m (~11,000 ft)	2805 m (~ 9200 ft)	3536 m (~11,600 ft)	3657 m (~ 12,000 ft)
Upper or Lower Forest Border?	upper	upper	lower	upper	upper
Moisture- or Temperature- sensitive?	temperature	temperature	moisture	temperature	temperature
Rock / soil type	dolomite	sandstone	dolomite	granite	sandstone
	Complete the rest of the site-to-site observations (below) based on our in-class discussion				
# of frost rings in entire record:					
Any differences in # of frost rings over time?					
Describe any trends in the time series of the ring width indices:					
Describe any pre- & post 1900 differences:					
Describe any other interesting things you noticed about any of the sites:					

ANALYZING SITE-TO-SITE COMPARISONS *(see Table)*

❑ Now by viewing the **skeleton plot masters** (which show frost rings) and the **ring width index plots** for all 5 site**s, complete the SITE-TO-SITE COMPARISON TABLE** so that you can make site-to-site comparisons.

As we fill in the table together in class, we'll DISCUSS the patterns from site to site. Which sites appear to be similar in terms of tree growth? Which are different? What explanations can we come up with for the similarities and differences based on location, moisture or temperature sensitivity, rock or soil type, or other factors?

TEST HYPOTHESES

❑ **Discuss and develop various hypotheses** about site-to-site comparisons in tree-ring variability and the evidence of global change the trees at the study sites might contain.

(NOTE: to review what a hypothesis is, see Topic #2 in Class Notes)

A hypothesis must be stated in a way that can be tested by the available data.

Hypotheses #1 & # 2 are stated for you to get you started:

❑ **Hypothesis #1: Trees in sites that are closer together will pattern-match and crossdate better than sites that are far apart.**

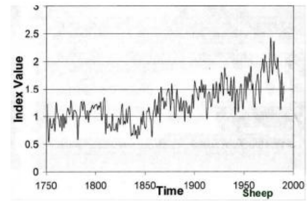
(Discuss and figure out how to test this hypothesis. HINT: use the master skeleton plots!)

❑ Determine which sites are **near each other** and which are far apart (e.g. CA sites vs. CO sites), TEST **Hypothesis #1** and RECORD YOUR FINDINGS HERE:

Do the **California** sites pattern-match and crossdate with each other?	Do the **Colorado** sites pattern-match and crossdate with each other?	Do the **California** sites pattern-match and crossdate with the **Colorado** sites?
Is Hypothesis #1 supported? *(State YES or NO and explain why or why not)*		

❑ SPECULATE on what factors (similar local climate, similar species, similar elevation, etc.) might influence whether sites **pattern-match & crossdate** or not.

❑ Scientists have proposed different hypotheses for why the tree growth at some of the study sites exhibits a prominent increasing trend in the 1900s , as seen in one or more of the **Ring Width Indices** plots ➔



One of these hypotheses is:

Hypothesis #2: The increasing growth trend in the 1900s is evidence of a local or regional temperature response to the Northern Hemisphere / Global warming trend.

This hypothesis can **NOT** be tested with the tree-ring data alone -- additional data would have to be collected to test it.

❑ DISCUSS & DESCRIBE WHAT ADDITIONAL DATA would be useful to test **Hypothesis #2** to determine if it is correct:

❑ **CONSTRUCT A TESTABLE HYPOTHESIS about Frost Rings in the trees at the study sites.**

(Hints: Might the frost ring frequency be expected to change under warmer conditions? Might frost rings be expected to occur more often in some locations rather than others? Do frost rings always occur in otherwise stressful years, or stress the tree's growth in a future year? etc. etc.)

Your Hypothesis #3:

❑ Now examine the frequency and characteristics of frost rings over time at the various sites, TEST your **Hypothesis #3**, and DESCRIBE YOUR FINDINGS & EXPLAIN THEM:.

APPENDIX B: PERIODIC TABLE REVIEW ACTIVITY

==> TO BEGIN, USING THE 11 ATOM "DOT DIAGRAMS" do the following:

Diagram	A	B	C	D	E	F	G	H	I	J	K
Atomic #											
Element Symbol											

1. Figure out the **ATOMIC NUMBER** of the atom shown in each diagram (A, B, C, etc.) and write it in the table above under the diagram's letter. *[Please do not write on the diagrams themselves!]*

2. Now look at the **PERIODIC TABLE** and identify each element. Write the symbol (e.g. He, F) for each diagram's element in the table above.

3. **What reasoning did you use to figure out the atomic number of each element and to identify the element?**

4. Now **place the atom diagrams on the square layout to represent the proper arrangement of elements** (in ROWS AND COLUMNS) **for the first 3 rows of the Periodic Table**. After you get your elements lined up properly, raise your hand to check you answer with the answer key. (The teaching team has ANSWER KEYS). Make adjustments as needed in your arrangement after checking the key.

Now look at your arrangement of the atom diagrams and identify what is common (similar) for all the diagrams that are in the same ROW, and what is similar for all the diagrams that are in the same COLUMN. **<u>These similarities are the key to describing the underlying basis for the structure of the Periodic Table.</u>**

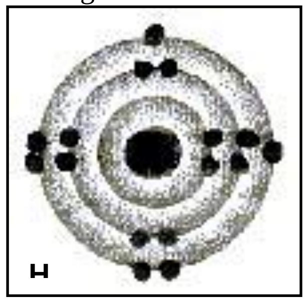
5. **Briefly explain the basis for the arrangement of elements in the Periodic Table (in both rows and columns).**

6. Finally, based on your answers and other information you've learned in this activity, **SKETCH A DOT DIAGRAM FOR HELIUM (He)** in the blank square at right ==>

PERIODIC TABLE REVIEW ACTIVITY BACKGROUND

Here's an example of one of the schematic "dot" diagrams of the 11 different atoms (elements).

Each atom has a letter **A through K**.



The large black dot in the center represents the **NUCLEUS**, the smaller black dots outside the nucleus represent **ELECTRONS** and the shaded circles orbiting the nucleus represent electron **SHELLS.**

The atoms are all **<u>neutral,</u>** (i.e. non-charged) and as ATOMS, they represent the smallest particle of an element that has all of the element's chemical properties.

(You can disregard the fact that some symbols are darker than others **--** *this was caused by the photocopier!)*

==> Your task is *to group atoms with similar properties* in a logical pattern of rows and columns (corresponding with the Periodic Table) by following the directions in #'s 1 through #6 on the previous page.

The following table (also shown under Topic #4) will help you understand the relationship between the first 18 elements and the number of electrons that can reside in the first 3 shells around the nucleus:

ELECTRON CONFIGURATION OF ELEMENTS 1 to 18*

Atomic #	Element & Symbol	Number of Electrons in Each Shell			Total # of Elec-trons
		1st	2nd	3rd	
1	Hydrogen, H	1			1
2	Helium, He	2 (Full)			2
3	Lithium, Li	2	1		3
4	Beryllium, Be	2	2		4
5	Boron, B	2	3		5
6	Carbon, C	2	4		6
7	Nitrogen, N	2	5		7
8	Oxygen, O	2	6		8
9	Fluorine, F	2	7		9
10	Neon, Ne	2	8 (Full)		10
11	Sodium, Na	2	8	1	11
12	Magnesium Mg	2	8	2	12
13	Aluminum, Al	2	8	3	13
14	Silicon, Si	2	8	4	14
15	Phosphorus, P	2	8	5	15
16	Sulfur, S	2	8	6	16
17	Chlorine, Cl	2	8	7	17
18	Argon, Ar	2	8	8 (Full)	18

** Among the heavier elements, the distribution of electrons becomes more complicated because of the division of shells into sub-shells*

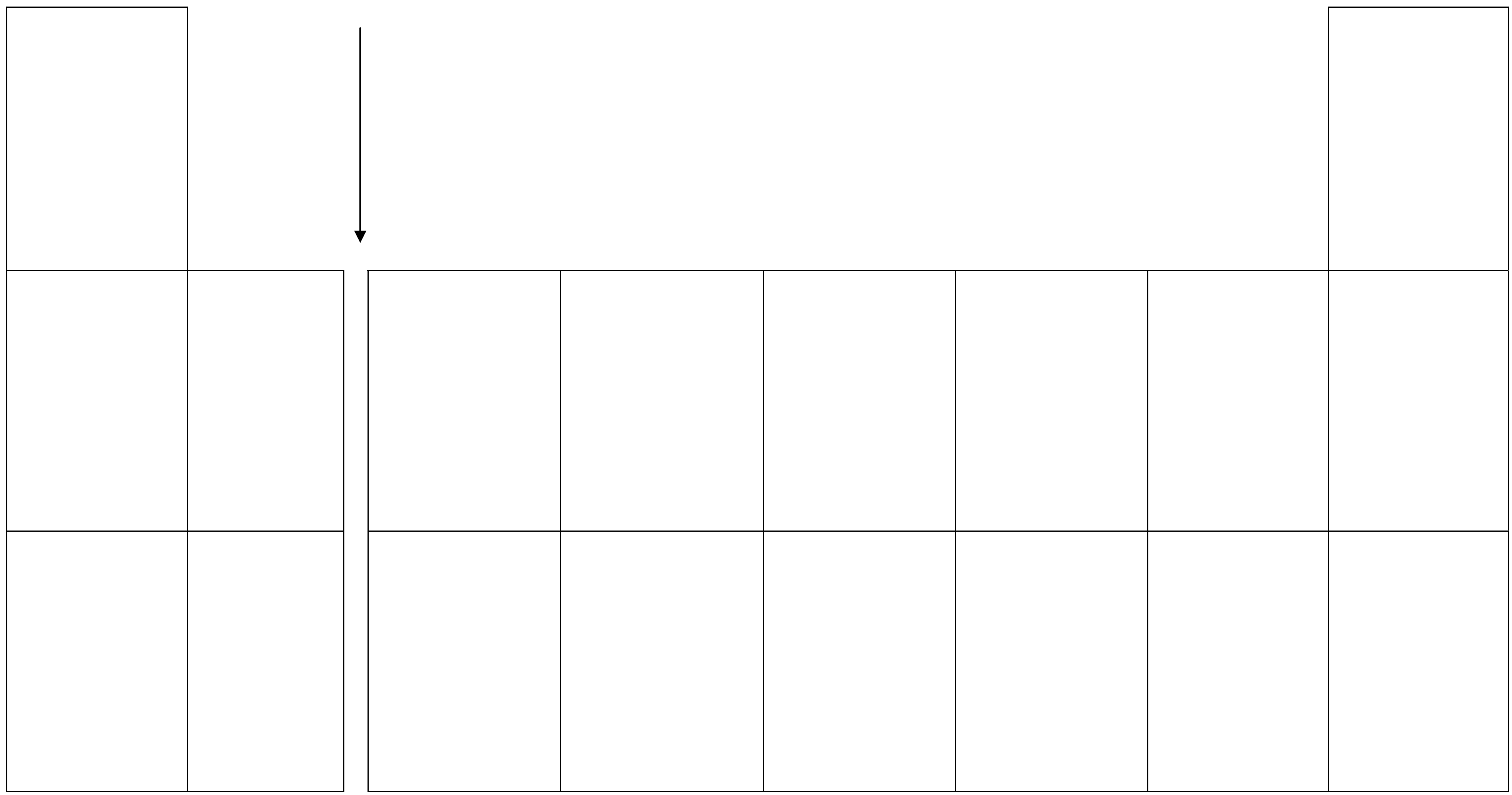
SQUARE LAYOUT FOR ARRANGING THE ATOM "DOT DIAGRAMS"

Place the atom diagrams on the square layout below to represent the proper arrangement of elements (in ROWS AND COLUMNS) for **the first 3 rows of the Periodic Table.**

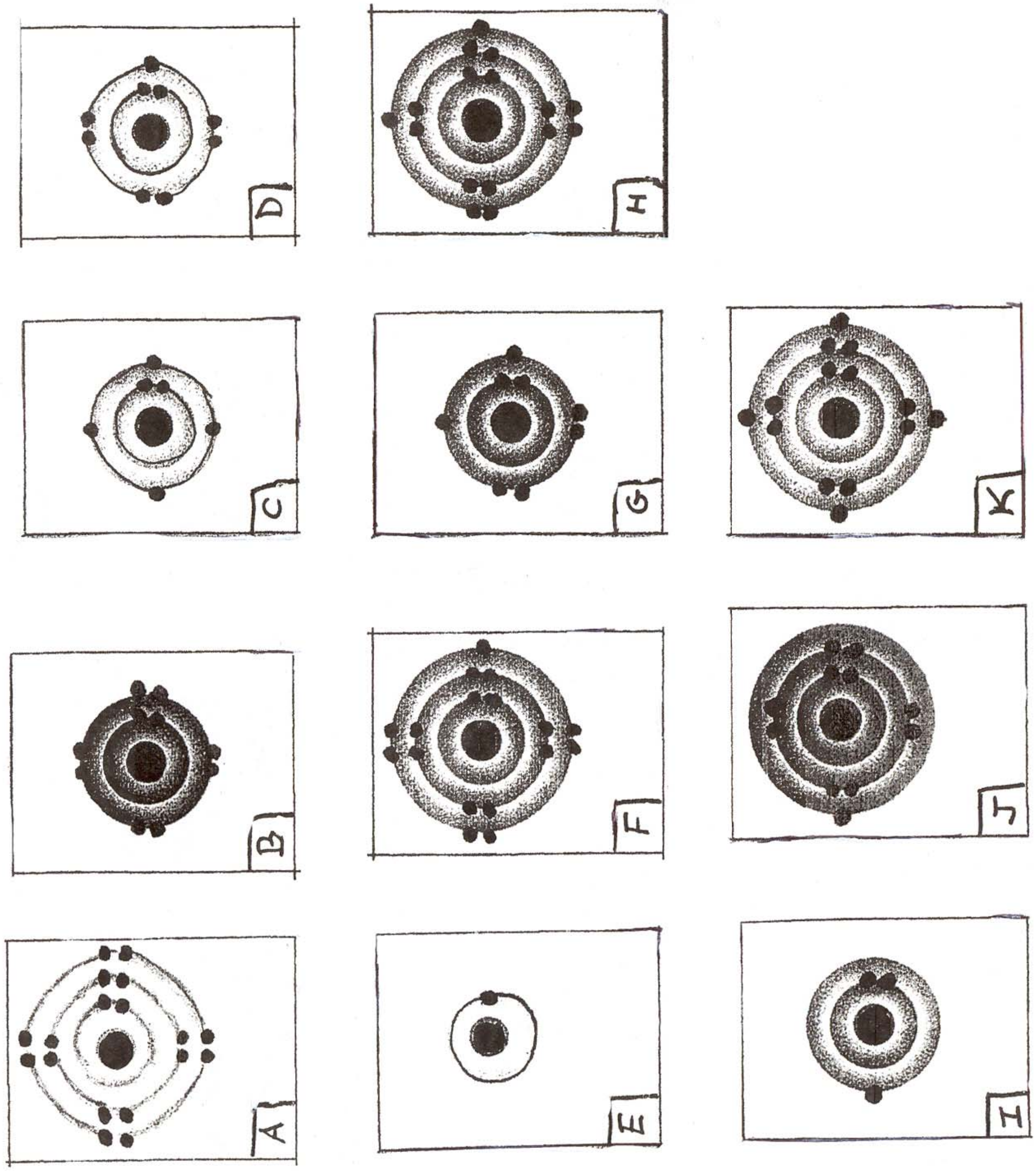
Diagrams A - K represent only 11 of the 18 elements in the first 3 rows, so some squares in the table will NOT have a corresponding element diagram and you will have some empty squares in the layout.

Note also that in the first 3 rows of the *actual* Periodic Table there is a gap between the first two columns, and the last six columns in these rows. (See the Periodic Table handout to confirm this.)

GAP



ADDITIONAL NOTES:


D
H
C
G
K
B
F
J
A
E
I

ADDITIONAL NOTES:

APPENDIX C: ENERGY EFFICIENCY

(1) ENERGY EFFICIENCY OF LIGHT BULBS -- New light bulbs have reached the marketplace with increased energy efficiency over a standard incandescent bulb. While only 10% of the energy used in a normal light bulb is converted to light (the rest being lost as heat into the surrounding environment), some LED lights achieve up to 80% efficiency. Review the information in the table below about each type of bulb.

Information from U.S. EPA Energy Star website: www.energystar.gov/index.cfm?c=lighting.pr_what_are#what_are

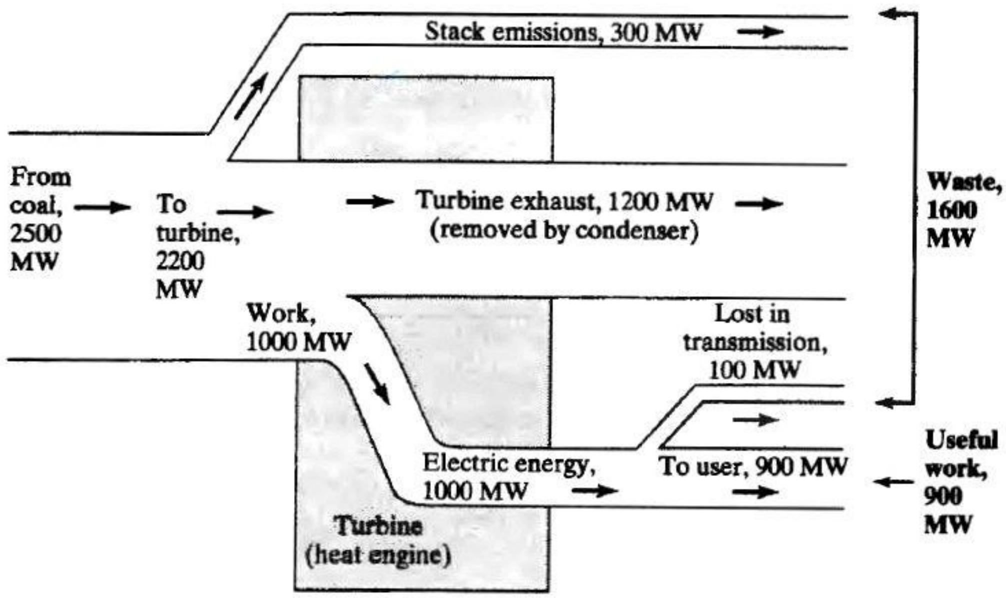
	**Incandescent bulbs** create light by passing electricity through a metal filament until it becomes so hot that it glows. **Incandescent bulbs release 90% of their energy as heat.**
	**In a CFL** (compact fluorescent light)**,** an electric current is driven through a tube containing gases. This reaction produces ultraviolet light that gets transformed into visible light by the fluorescent coating (called phosphor) on the inside of the tube. **A CFL releases about 80% of its energy as heat.**
	**LED lighting** products use light emitting diodes to produce light very efficiently. The movement of electrons through a semiconductor material illuminates the tiny light sources we call LEDs. A small amount of heat is released backwards, into a heat sink. When designed properly, an LED circuit **will approach 80% efficiency, which means 80% of the electrical energy is converted to light energy.**

(2) In the boxes below **draw AN ENERGY FLOW DIAGRAM** (See Topic # 8) for each type of light bulb representing **electricity** (*electromagnetic energy*) converted into **light** (***electromagnetic energy***) and **heat** (*thermal energy*). *Be sure to draw the flow arrows with widths that show the relative proportions of energy in each type of flow.*

		RANK
	Diagram for Incandescent bulb:	
	Diagram for CFL bulb:	
	Diagram for LED w/ 80% efficiency:	

(3) Based on your Energy Flow Diagrams, **RANK** the amount of thermal energy being emitted by each bulb type based on the bulb's expected temperature -- from coolest (#1) to hottest (#3) -- and explain the basis for your hypothesized ranking. Using an IR thermometer, in class we'll measure the bulb temperatures to see if your hypothesis about the bulb types and the thermal energy they are emitting is correct!

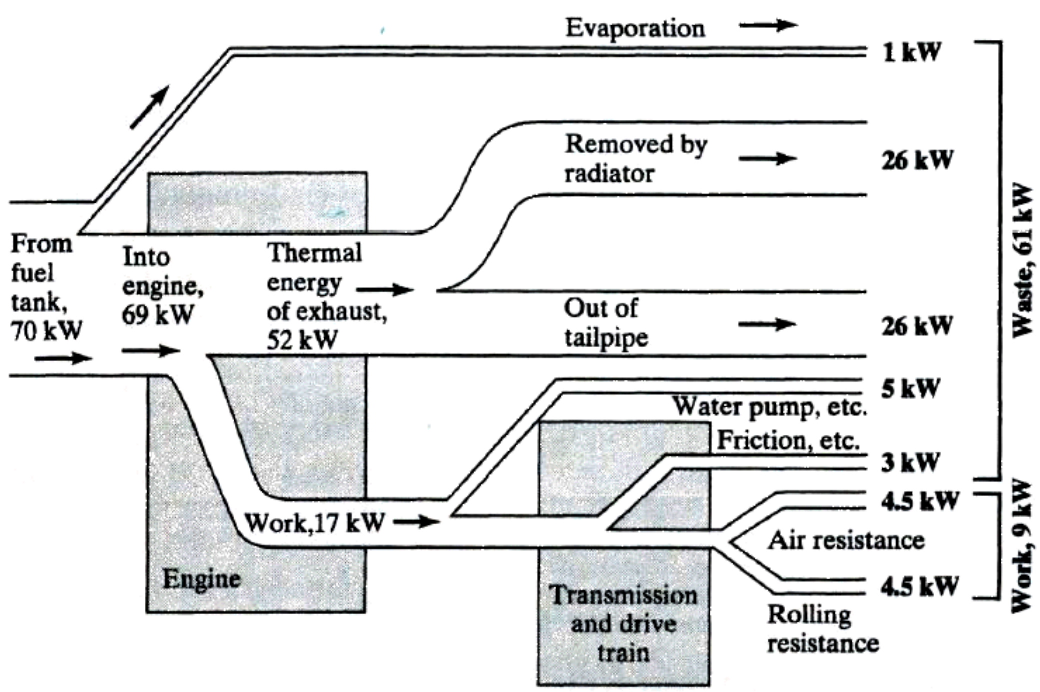
ENERGY TRANSFORMATIONS & THE COAL POWER PLANT



Energy flow diagram for a typical 1000 megawatt (MW) coal-fueled electric generating plant

Energy Efficiency of the power plant = 40%:
(1000 MW electrical energy produced ÷ 2500 MW in coal fuel = 0.40 = 40%)

ENERGY TRANSFORMATIONS & THE AUTOMOBILE



Energy flow diagram for an unaccelerated gasoline-fueled car at a moderate highway speed

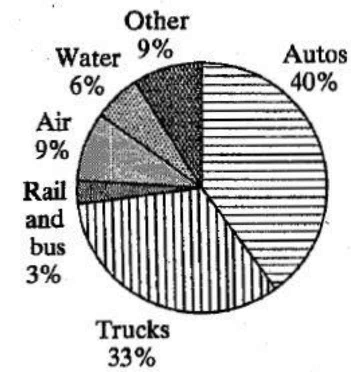
Q1. What % of the energy in the fuel does work running the engine? ________ **= Engine's Energy Efficiency**

Q2. What % of the energy in the fuel eventually does "work" that moves the car (by overcoming air resistance and rolling resistance)? ________ **= Overall Energy Efficiency of the Automobile**

ENERGY EFFICIENCY & THE TRANSPORTATION SECTOR

Freight-moving efficiencies of three transportation modes

	kg-km per MJ	tonne-km per liter
Rail (freight train)	2900	100
Truck (heavy)	720	25
Air (freight)	145	5



The fraction of total U.S. "Direct Transportation" energy consumed by each transportation mode

Q3. Why do you think trains are so much more efficient for moving freight?

Q4. Why do you think air freight is the least energy efficient mode?

Passenger-moving efficiencies of several human transportation modes.

	passenger-mi per gal	passenger-km per liter	passenger-km per MJ
Human on bicycle	1530*	642*	18.0
Human walking	425*	178*	5.0
Intercity rail	144	60	1.7
Urban bus	76	32	0.9
Carpool auto (occupancy = 4)	60	25	0.7
Commercial airline	34	14	0.4
Commuting auto (occupancy = 1.15)	17	7	0.2

*per gallon or liter of gasoline's energy equivalent in food calories.

Q5. Why do you think bicycling is almost 4 times more efficient than simply walking?

ADDITIONAL NOTES:

APPENDIX D: Ecological Footprints

"The Footprint" Concept

Examples: Ecological Footprint, Carbon Footprint, Water Footprint

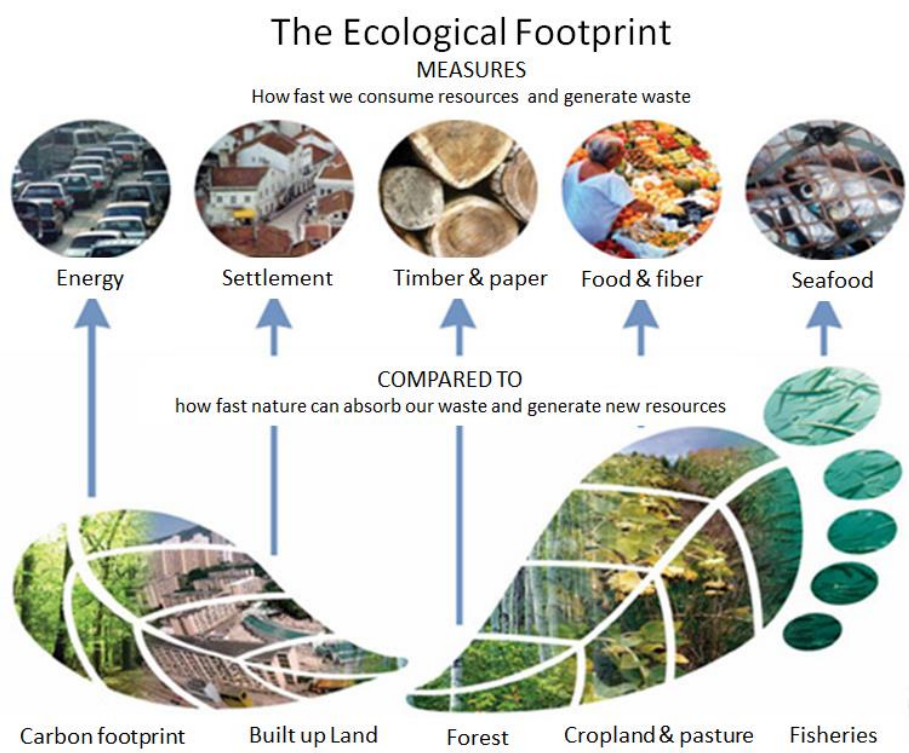
Your Ecological Footprint = A measure of how much area of **Earth's biologically productive land and water** you require
(a) to produce all the resources you consume , and
(b) to absorb the waste you generate
. . . . using prevailing technology and resource management practices.

- The Ecological Footprint includes the **areas** for producing the resources consumed, the **space** for accommodating buildings and roads needed, and the **ecosystems for absorbing the waste** emissions, such as carbon dioxide.

- The Ecological Footprint is usually measured in global hectares (or sometimes, number of "Earth's needed"). This is because trade is global and therefore an individual or country's Ecological Footprint includes land or sea from all over the world.

- 1 hectare = 1/100th of a square kilometer, 10,000 square meters, 2.471 acres.
A hectare is approximately the size of a soccer field)

- The Footprint can be computed for an individual, a particular activity, a group of people, or an entire nation



Source: http://www.footprintnetwork.org/

The term "**carbon footprint**" is often used as shorthand for the amount of carbon being emitted by an activity or organization (see pp 182 -183 in *Dire Predictions*.). However, the **carbon component of the Ecological Footprint** translates the amount of carbon dioxide emitted into the amount of productive land and sea area required to sequester carbon dioxide emissions. This tells us the demand on the planet that results from burning fossil fuels.

Take the **ECOLOGICAL FOOTPRINT QUIZ** at:
www.footprintnetwork.org/en/index.php/GFN/page/calculators/

Global Footprint Network
Advancing the Science of Sustainability

Are there ways to reduce a big footprint? This semester we'll explore some: a HANDPRINT!

ADDITIONAL NOTES:

MODELING THE ENERGY BALANCE

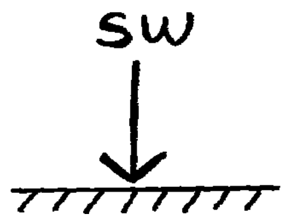
THE EARTH'S ENERGY BALANCE
Making a Model of It!

PUTTING IT TOGETHER:

Can you place + and – signs where they ought to go in the equation?

R = 

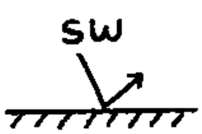
SW BEAMED DIRECTLY TO EARTH'S SURFACE WHERE IT IS ABSORBED:



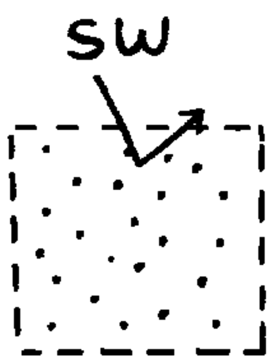
SW REFLECTED BACK TO SPACE:

By clouds

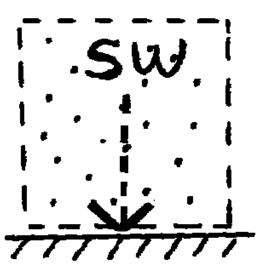
By Earth's surface



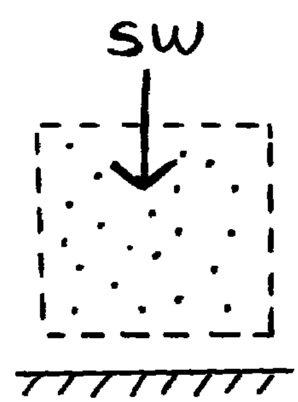
SW SCATTERED BACK TO SPACE BY ATMOSPHERE:



SW SCATTERED DOWN TO EARTH's SURFACE where it is absorbed

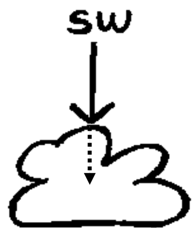


SW ABSORBED IN ATMOSPHERE BY GASES, DUST, etc.
(including Ozone absorbing shortwave UV)



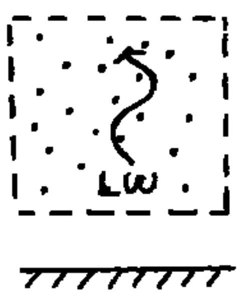
SW ABSORBED In ATMOSPHERE BY CLOUDS & H2O vapor:

(NOTE: clouds are made up of tiny droplets of water surrounded by lots of water vapor)

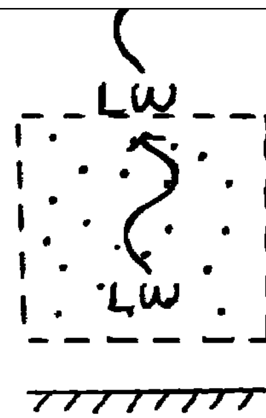


LW (IR) EMITTED FROM EARTH'S SURFACE ESCAPING TO SPACE THROUGH THE "OUTGOING IR ATMOSPHERIC WINDOW"

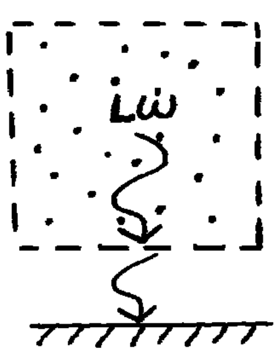
IR EMITTED FROM EARTH'S SURFACE BUT ABSORBED IN THE ATMOSPHERE BY GREENHOUSE GASES (H_2O,CO_2, CH_4, ETC.)



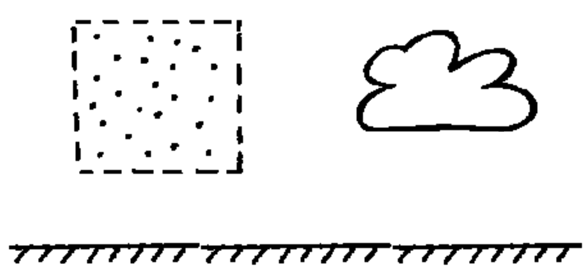
IR EMITTED FROM <u>ATMOSPHERE</u> ESCAPING TO SPACE



IR EMITTED FROM <u>ATMOSPHERE</u> AND RADIATED BACK TO SURFACE WHERE IT IS ABSORBED



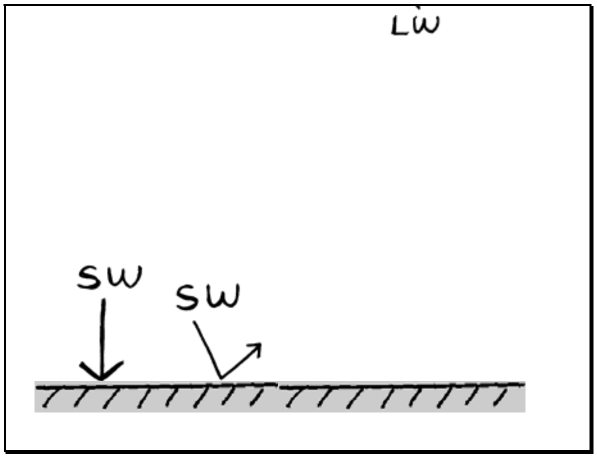
All together now:



What if? . . .

. . . The Earth didn't have an atmosphere, and therefore didn't have a greenhouse effect??

What would the energy pathways in the Earth-Sun system look like?



THINKING DEEPER

Finally, think about how you could create a model to represent "Earth's Energy Balance with No Atmosphere" . . . . .

Components needed to MODEL the EARTH'S ENERGY BALANCE:

Earth Energy

Solar–to-Earth

Earth IR-to-Space

Earth Albedo
Solar Constant
Earth's Heat Capacity
Earth's Surface Temperature
Stefan Boltzmann Constant
Earth Cross Sectional Area
Earth's Surface Area

SOLAR CONSTANT = the rate at which energy is received just outside the earth's atmosphere on a surface that is perpendicular to the incident radiation, and at the mean distance of the Earth from the sun.

The solar constant is not constant! Also, different values can be found in the scientific literature . . .

Solar constant = 1400 Joules/ m^2
1372 J/ m^2
in *The Earth System* text => 1368 J/ m^2

Earth's Heat Capacity = *specific heat* of Earth x mass. (represents the capacity of a substance to absorb heat in relation to its volume and density.)

Specific Heat = the amount of thermal energy required to raise the temperature of 1 gram of any substance by 1° C

Stefan Boltzmann Law =

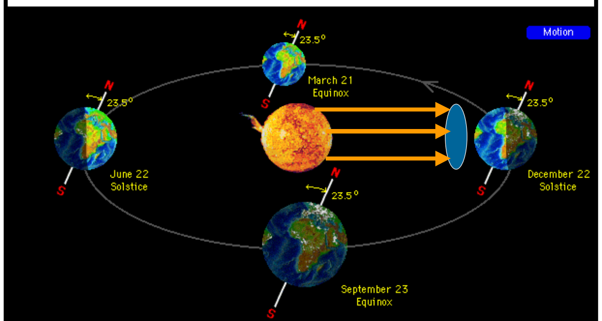
The amount of radiation given off by a substance is proportional to the fourth power of its absolute temperature

$$\text{Energy} = \sigma T^4$$

σ = Stefan Boltzmann constant = 5.67×10^{-8} J / m^2

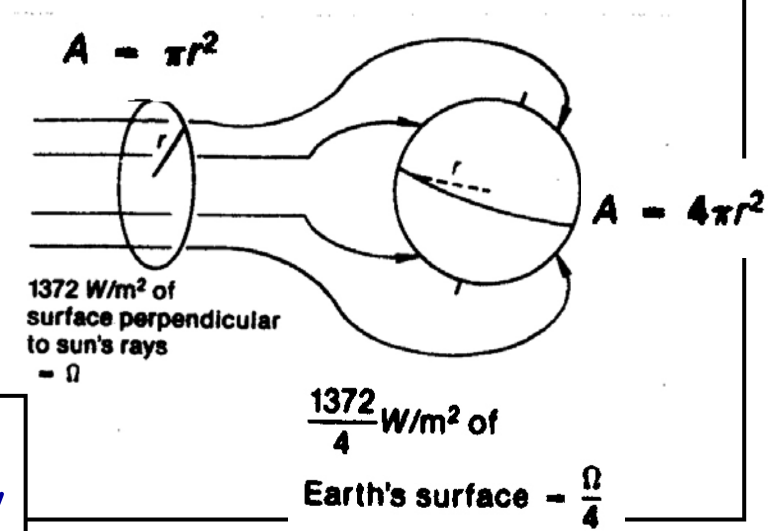
Earth's Cross Sectional Area:

Needed for calculating Solar-to-Earth flux



Earth's Cross Sectional Area:

Needed for calculating Solar-to-Earth flux



Earth's Surface Area

Needed to calculate amount of energy Earth's surface radiates

$$F_{out} = \frac{a\Omega}{4} + \sigma T^4$$

Earth's Surface Temperature

Influenced directly by how much energy is in "Earth Energy" & the Earth's Heat Capacity

Model of Earth Energy Balance with No Atmosphere

ADDITIONAL NOTES:

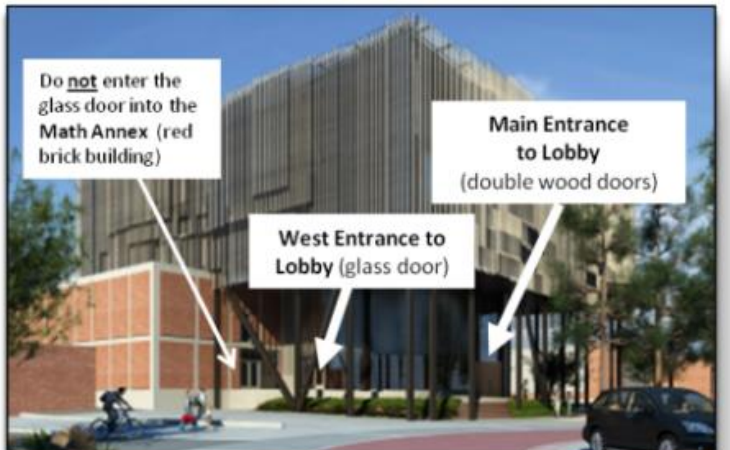
How to find Dr. Katie Hirschboeck's Office

Bannister Tree-Ring Building, Room 319

621-6466 katie@LTRR.arizona.edu

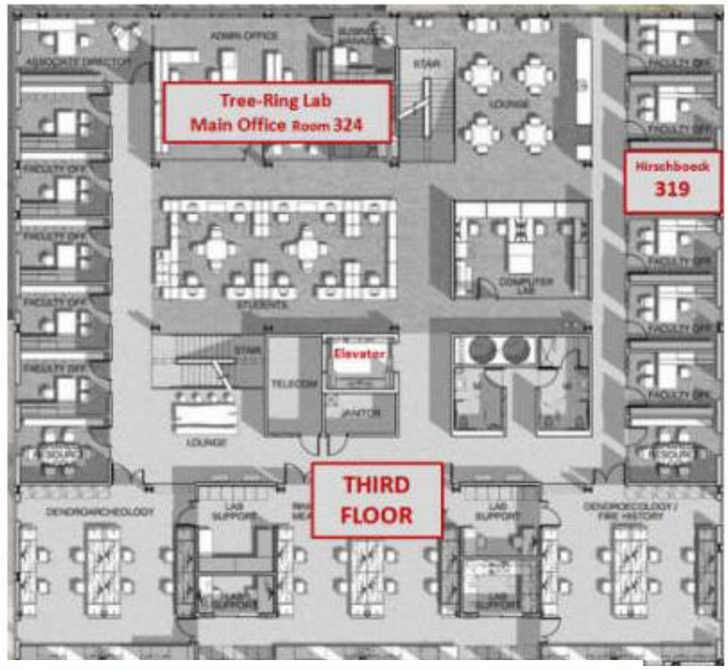
Bryant Bannister Tree-Ring Building

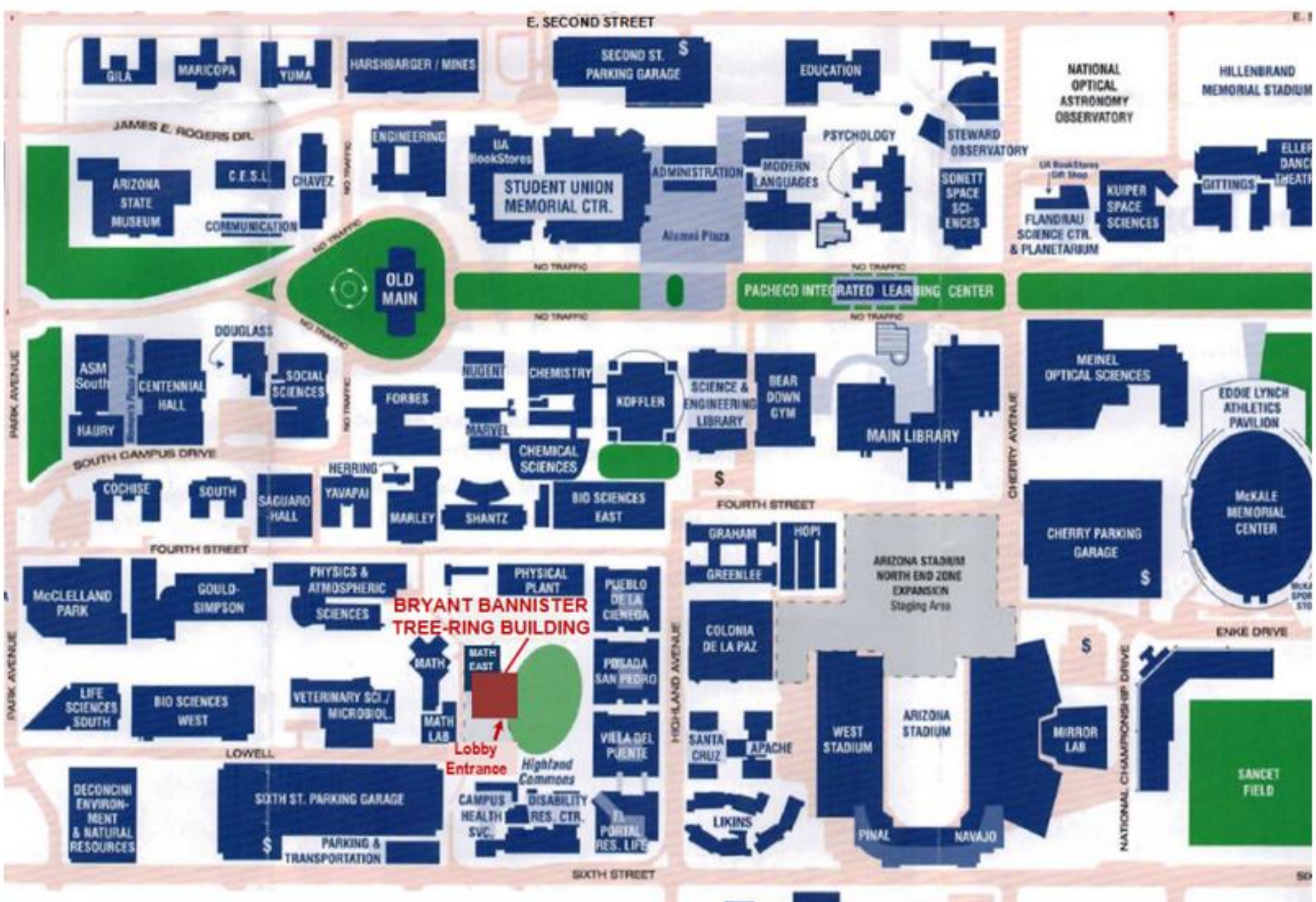
1215 E. Lowell St. Tucson AZ 85721



Enter the building through the Lobby on the south side

[View of Bannister Tree-Ring Building from southeast corner]





BRYANT BANNISTER TREE-RING BUILDING LOCATION MAP