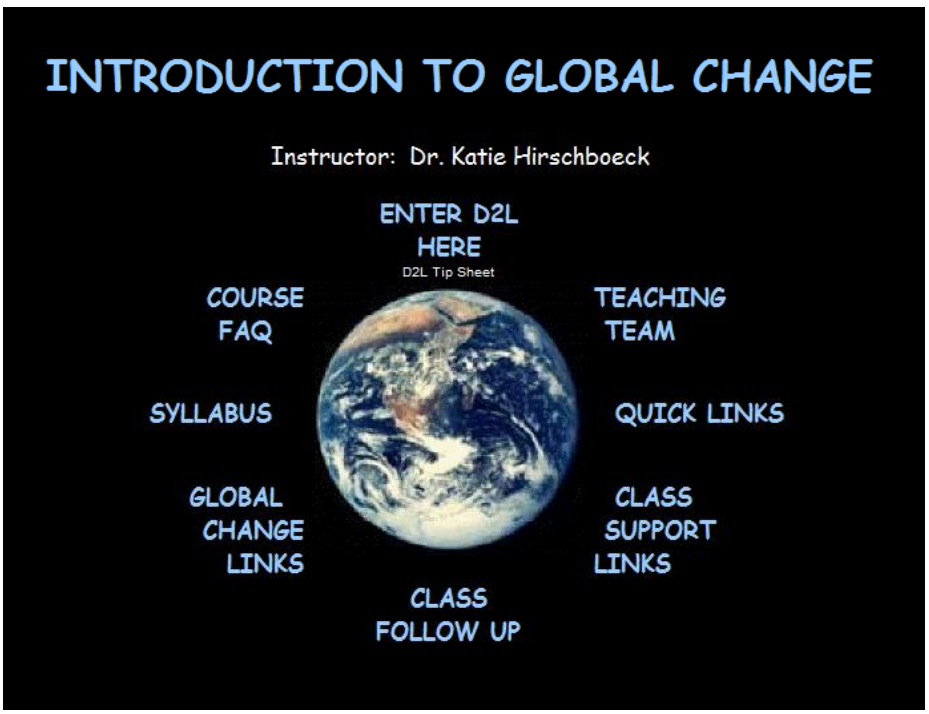
NATS 101 The Earth & Its Environment
Lecture 51+52 & 53+54 FALL 2010

INTRODUCTION TO GLOBAL CHANGE

INSTRUCTOR: Dr. Katie Hirschboeck

CLASS NOTES PACKET



Fall 2010

UA GENERAL EDUCATION
FOUNDATION FOR SUCCESS
THE UNIVERSITY OF ARIZONA

HOW TO USE THIS
CLASS NOTES PACKET

Welcome to NATS 101! This CLASS NOTES packet is designed to be a companion to the classroom portion of **NATS 101-GC Introduction to Global Change**, taught by Dr. Katie Hirschboeck. **<u>You should bring this packet with you to every class.</u>** (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:

- **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.

  [NOTE: <u>during</u> class you will probably want to write down your main lecture notes in a separate notebook instead of in the CLASS NOTES packet. Use the course topic pages of the packet in class to write down short explanatory notes, annotation of figures, filling in blanks, etc. -- but not as a substitute for taking lecture notes.]

- 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 Laboratory of Tree-Ring Research **(last page).**

See the NATS 101-GC 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:

NATS 101-GC WEBPAGE: http://fp.arizona.edu/kkh/nats101gc/

INTRODUCTION TO GLOBAL CHANGE
CLASS NOTES PACKET
FALL 2010

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NATS 101-GC Introduction to Global Change – Fall 2010
TEXTBOOK READING ASSIGNMENTS & SELF-TEST / READINESS QUIZ SCHEDULE

Class Topic		SGC Text [1] SGC-I Kump et al. (1st half)	SGC Text [1] SGC-II Hobson (2nd half)	DP Text *Dire Predictions*	Other, e.g. Quick Links, Class Notes	Self Test (ST) + Readiness Quiz (RQ)	ST/RQ Cutoff Date
1	Course Overview					*Syllabus & FAQ*	--
2	On Science & Being a Scientist	Ch 1 (1-17)			Pirsig Essay Class Notes Topic # 2	*Global Change*	--
3	Global Change & Quantifying It				The Ecological Footprint		
4	Energy & Matter Overview		Ch 2 (29-47) & Ch 6 (116-130)		Appendix II (Periodic Table)	1– Energy & Matter	Sep 2
5	Observations: Past & Present			Pt 1 (36-59)	Class Notes Topic #5		
6	Electromagnetic Radiation & Spectrum	Ch 3 (34-38)	Ch 9 (190-200)			2 –Electro-magnetic Radiation & Spectrum	Sep 9
	Introduction to Tree Rings				Appendix II (Tree Rings)		
7	The Radiation Laws	Ch 3 (39-44)		Pt 1 (22-23)			
8	Atmos Structure & Composition	Ch 3 (44-48)		Pt 1 (26-29) (32-33)		3- Atmospheric Structure & Composition	Sep 23
9	Thermodynamics & Energy Transfer		Ch 7 (131 -143)			4- Thermo-dynamics	Sep 30
10	The Global Energy Balance	Ch 3 (42-43) Ch 3 (48-51)		Pt 1 (64-65)	Appendix II (Energy Balance)		
11	Systems and Feedbacks, Models	Ch 2 (18-33) Ch 3 (51-54)		Pt 1 (24-25)		5 – Systems & Feedbacks	Oct 21
12	How Climate Works	Ch 4 (55-82)		Pt 1 (10-15)			
13	Natural Climatic Forcing	Ch 15 (289-316)		Pt 1 (18 + 40) (60-63)		6-Climate & Natural Forcing	Oct 28
14	Global Warming & Anthropogenic Forcing		Ch 9 (206-215)	Pt 1 (66 – 75) (94-97)		7 – Global Warming	Nov 4
15	Ozone Depletion in the Stratosphere		Ch 9 (201-205)	Pt 1 (30-31)		8 – Ozone Depletion	Nov 16 (Tue)
16	The IPCC Findings Projections & Impacts			Intro (6-9) Pt 1 (20-21) Pt 2 (77-105) Pt 3 (107-139)	IPCC –AR4 SPM [2]		
17	Adaptations, Solutions & Choices		Ch 7 (143-147)	Pt 4 (141-153) Pt 5 (155-197)	Class Notes Topic #17 Appendix II		
	Global Change & Climate Sci Literacy	Re-read Ch 1 (1-17)			Appendix I	9-GC & Climate Sci Literacy	Dec 7 (Tue)
FINAL EXAM (Thu Dec 16)							

[1] ***SGC = The Science of Global Change: An Introduction*** *(each half has its own chapters and page #s)*

[2] ***IPCC-AR4*** *The Intergovernmental Panel on Climate Change 2007 Fourth Assessment Report Summaries for Policymaker (SPM): Synthesis, Working Groups I, II, & III*

NATS 101-GC SEMESTER-ON-A-PAGE -- FALL 2010

Get calendar updates online and tape or staple here as needed

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
AUGUST	AUG 22	23 *First day of classes*	**24** #1 – Course Overview	25	**26** #2 – On Science & Being a Scientist	27	28
	29	30	**31** #3 – Global Change & the Challenge of Quantifying It	SEP 1	**2** #4 – Energy & Matter Overview **RQ-1 CUTOFF**	3	4
SEPTEMBER	5	6 *Labor Day - no classes*	**7** #5 – Observations: Climate Change & Variability in the Past & Present	8	**9** #6 – Electromagnetic Radiation & Spectrum **RQ-2 CUTOFF**	10	11
	12	13	**14** Special Topic: Introduction to Tree Rings	15	**16** **TEST #1**	17 *Last day to drop via w/o a grade*	18
	19	20	**21** #7 – The Radiation Laws	22	**23** #8 – Atmo Structure & Chemical Composition **RQ-3 CUTOFF**	24	25
	26	27	**28** #8 – Atmo Structure & Chemical Composition (cont.)	29	**30** #9 – Thermodynamics Energy Transfer / Conservation **RQ-4 CUTOFF**	OCT 1	2
OCTOBER	3	4	**5** **TEST #2**	6	**7** Class Bristlecone Pine Activity	8	9
	10	11	**12** Class Bristlecone Pine Activity	13	**14** **MIDTERM EXAM**	15 *Last day to drop a class with grade of W*	16
	17	18	**19** #10 – The Global Energy Balance	20	**21** #11 – Systems & Feedbacks **RQ-5 CUTOFF**	22	23
	24	25	**26** #12 – How Climate Works	27	**28** #13 – Natural Climatic Forcing **RQ-6 CUTOFF**	29	30
NOVEMBER	31	NOV 1	**2** **TEST #3**	3	**4** #14 – Global Warming & Anthropogenic Forcing **RQ-7 CUTOFF**	5	6
	7	8	**9** #14 – Global Warming & Anthropogenic Forcing (cont.)	10	**11** *Veteran's Day -- no classes*	12	13
	14	15	**16** #15 – Ozone Depletion in the Stratosphere **RQ-8 CUTOFF**	17	**18** **TEST #4**	19	20
	21	22	**23** #16 The IPCC Findings: Projections & Impacts	24	25 *Thanksgiving*	26 *Break*	27
DECEMBER	28	29	**30** #17 Adaptations, Solutions & Choices	DEC 1	**2** #17 Adaptations, Solutions & Choices (cont.)	3	4
	5	6	**7** Global Change Wrap-Up & Climate Science Literacy **RQ-9 CUTOFF**	8 *Last day of classes*	9	10	11
	12	13	14	15	**16 FINAL EXAM** *(Sorry, no early final exams given)*	17 *Finals End*	18 *Semester Ends*

Online Self Test & Readiness Quiz (RQ) Topics

*** NOTE: these are practice quizzes & will not go into your gradebook*

- ❑ *RQ-Practice – Syllabus, FAQ & Policies ***
- ❑ *RQ-Practice – Global Change Overview ***
- ❑ RQ 1 – Energy & Matter
- ❑ RQ 2 – Electromagnetic Spectrum
- ❑ RQ 3 – Atmo Structure & Composition
- ❑ RQ 4 – Thermodynamics
- ❑ RQ 5 – Systems & Feedbacks
- ❑ RQ 6 – Climate & Natural Forcing
- ❑ RQ 7 – Global Warming
- ❑ RQ 8 – Ozone Depletion
- ❑ RQ 9 – Global Change & Climate Science Literacy

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

ADDITIONAL NOTES:

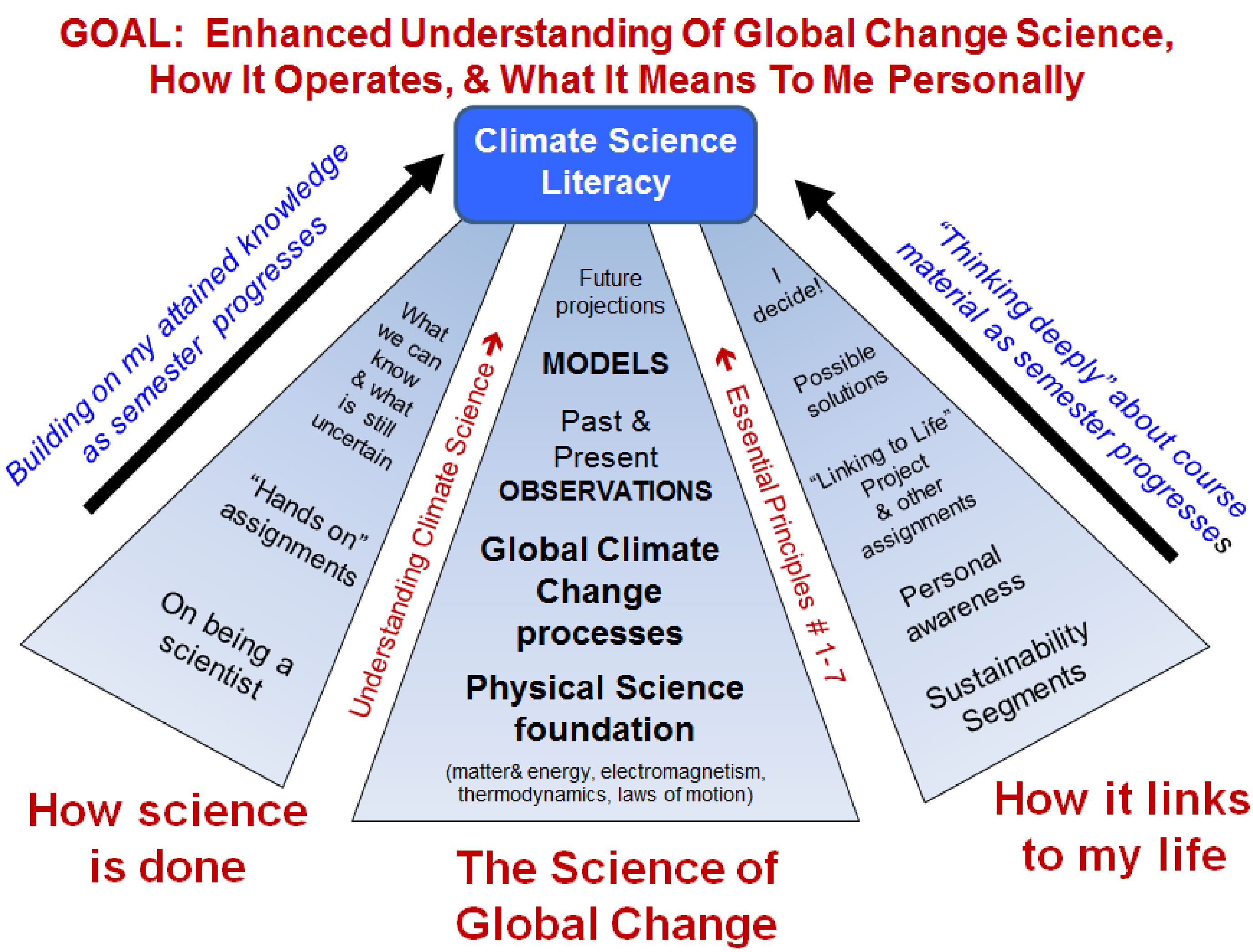
TOPIC #1 COURSE OVERVIEW & INTRODUCTION TO SCIENCE

Science is simply common sense at its best. ~Thomas Huxley

1. What is this course all about?
    - Science (how it operates, what it can and can't do, how YOU approach things scientifically)
    - Physical science concepts (the building blocks for understanding global change processes)
    - The Earth's processes: ➔ emphasis on global *climate* change and its consequences
    - How & why these global changes occur
    - What impacts are expected to occur from these changes and how likely they are
    - What to do about them: possible solutions, adaptations, mitigations
    - Your role as a citizen of our planet with respect to global change ("Linking to Life")

Questions GLOBAL CHANGE SCIENTISTS are asking and studying:

- How and why are these changes occurring? (physical & biological sciences)
- Are these changes good or bad for people? (social sciences: vulnerability, adaptation)
- Can human beings do anything to stop or reverse those changes?
  . . . or are they part of natural variability that will happen no matter what we do?



WHAT IS CLIMATE SCIENCE LITERACY?
http://climateliteracynow.org/

Climate Science Literacy is an understanding of your influence on climate and climate's influence on you and society.

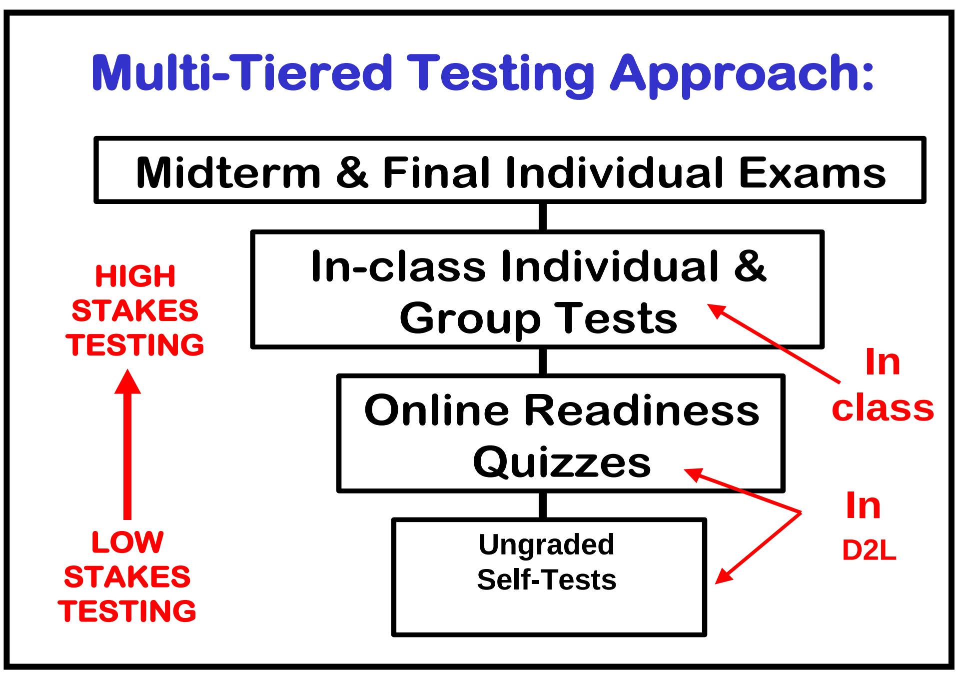
A climate-literate person:

- understands the essential principles of Earth's climate system,
- knows how to assess scientifically credible information about climate,
- communicates about climate and climate change in a meaningful way, and
- is able to make informed and responsible decisions with regard to actions that may affect climate.

People who are climate science literate know that climate science can inform our decisions that improve quality of life. They have a basic understanding of the climate system, including the natural and human-caused factors that affect it. Climate science literate individuals understand how climate observations and records as well as computer modeling contribute to scientific knowledge about climate. They are aware of the fundamental relationship between climate and human life and the many ways in which climate has always played a role in human health. They have the ability to assess the validity of scientific arguments about climate and to use that information to support their decisions.

NATS 101 GC COURSE LOGISTICS

1) How we'll operate (Teaching Team w/ Preceptors, lectures & hands-on, learning teams)
2) "Desire To Learn" D2L Learning Web
3) Multi-Tiered Testing Approach
4) Grading Criteria
5) Course & Classroom Policies (see also FAQ)
6) Respectful learning environment vs. disruptive classroom behavior
7) In case of fire or emergency . . .
8) Other??



TOPIC #2 -- ON SCIENCE AND 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*

I) **Science Overview**

II) **Methods Used:**

Experiments, Observations
Standard "tools of science" -- hypotheses, prediction, testing, theories

III) **Personal side of being a scientist**

IV) **Scientific Methods & The Nature of Scientific Research**

1. Traditional: **observation ==> hypothesis ==> prediction ==> testing**
2. Delving deeper:
   observations vs. experiments
   hypothesis vs. theory vs. law
   prediction and testing

3. One view of "formal" scientific method: **1. state problem, 2. develop hypotheses, 3. experiments to test each hypothesis, 4. predicted results, 5. observed results, 6.conclusions based on results**

4 Types of reasoning: **inductive** (induction) & **deductive** (deduction)
IN-duction: individual obs ==> general conclusion
DE-duction: the big picture (theory) ==> conclusion/prediction about individual obs

How it's "really" done: weaving back & forth between induction & deduction, interconnectivity (see Pirsig essay *"On Scientific Method"* (under Quick Links)

5. **Critiques of Science**
   Facts and observations can be "theory laden"

6. Important aspect of science: (Karl Popper) **Theories can never be positively proven to be true, but some can be disproved by "falsifying" them.**

7. **Science in action:**
   curiosity
   persistence
   rare joys of discovery
   importance of reproducibility of results
   importance of communal review
   cumulative enterprise "standing on the shoulders of giants"
   keep an open -- but skeptical -- mind
   be ready to change any preconceived ideas if the evidence shows otherwise
   human error / fraud gets weeded out over time
   conflicts of interest may occur / ethics require that they be recognized and reported
   collaborative efforts important
   wonder-awe-joy-mystery!

DICTIONARY DEFINITIONS ASSOCIATED WITH SCIENCE

[from Webster's Collegiate Dictionary, 10th edition]

SCIENCE -knowledge covering general truths or the operation of general laws, especially as obtained and tested through the scientific method; **NATURAL SCIENCES** are any of the sciences that deal with *matter*, *energy*, and their *interrelations* and *transformations*

SCIENTIFIC METHOD -systematic pursuit of knowledge involving:

- the recognition & formulation of a problem
- the collection of data through observations and experiments
- the formulation and testing of hypotheses

HYPOTHESIS -a tentative assumption made in order to draw out and test its logical or empirical consequences

ASSUMPTION -a fact or statement taken for granted; an assuming that something is true

The synonyms **HYPOTHESIS, THEORY, & LAW** mean a formula derived by inference from scientific data that explains a principle operating in nature. **HYPOTHESIS** implies insufficient evidence to provide more than a tentative explanation <a *hypothesis* explaining the extinction of the dinosaurs>. **THEORY** implies a greater range of evidence and greater likelihood of truth <the *theory* of evolution>. **LAW** implies a statement of order and relation in nature that has been found to be invariable under the same conditions <the *law* of gravitation>.

OBSERVE -to come to realize or know esp. through consideration of noted facts; to take notice; to watch carefully esp. with attention to details or behavior for the purpose of arriving at a judgment; to make a scientific observation or note of

OBSERVATION - an act of recognizing and noting a fact or occurrence often involving measurement with instruments; a record or description so obtained; a judgment on or inference from what one has observed

DESCRIBE -to represent or give an account of in words

DISCOVER -to obtain sight or knowledge of for the first time

The synonyms **DISCOVER, ASCERTAIN, DETERMINE, UNEARTH, LEARN** mean to find out what one did not previously know. **DISCOVER** may apply to something requiring exploration or investigation or to a chance encounter <*discovered* the source of the river>. **ASCERTAIN** implies effort to find the facts or the truth proceeding from awareness of ignorance or uncertainty <attempts to *ascertain* the population of a region>. **DETERMINE** emphasizes the intent to establish the facts definitely or precisely <unable to *determine* the origin of the word>. **UNEARTH** implies bringing to light something forgotten or hidden <*unearth* old records>. **LEARN** may imply acquiring knowledge with little effort or conscious intention (as simply being told) or it may imply study and practice.

WONDER -a cause of astonishment or admiration, marvel; the quality of exciting amazed admiration; rapt attention or astonishment at something awesomely mysterious or new to one's experience; to be in a state of wonder; to feel surprise; to be curious or in doubt about

A Definition of a Scientifically Literate Person:

One who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes. *American Association for the Advancement of Science, AAAS*

*Compare this with the definition of **Climate Science Literacy** covered earlier under Topic #1.*

QUOTES FROM SCIENTISTS ABOUT DOING SCIENCE

See also: *The Poetry of Reality (An Anthem for Science)* at: http://www.symphonyofscience.com/

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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: <u>The Atmosphere -- A challenge, The Science of Jule Gregory Charney</u> 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)*
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PERSEVERENCE

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*

BACKGROUND READING: A DESCRIPTION OF SCIENTIFIC METHOD

From: Trefil J.and Hazen, R.M., 1995, *The Sciences, An Integrated Approach*. John Wiley & Sons, New York, pp 6-7.

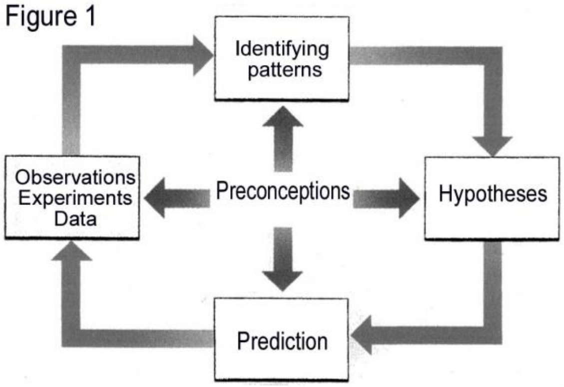
We will encounter many . . . laws in this book, all backed by millions of observations and measurements. It is important, however, to remember where these laws come from. They are not written on tablets of stone, nor are they simply good ideas that someone once had. They arise from repeated and rigorous observation and testing. They represent our best understanding of how nature works. Remember -- we never stop questioning the validity of our hypotheses, theories, or laws of nature. Scientists constantly think up new, more rigorous experiments to test the limits of our theories. In fact, one of the central tenets of science is:

Every law of nature is subject to change, based on new observations.

Scientific Method in Operation

The elements of observation, hypothesis formation, prediction, and testing together comprise scientific method. In practice, you can think of the method as working as shown in the Figure 1. It is a never-ending cycle in which observations lead to hypotheses, which lead to more observations.

Figure 1



If observations confirm a hypothesis, then more tests may be devised. If the hypothesis fails, then the new observations are used to revise it, after which the revised hypothesis is tested again. Scientists continue this process until the limits of existing equipment are reached, in which case researchers often try to develop better instruments to do even more tests.

If and when it appears that there's just no point to going further, the hypothesis may be elevated to a theory , or even a law of nature.

Several important points should be made about the scientific method:

1. Scientists are not required to observe nature with an "open mind," with no preconceptions about what they are going to find. Although some scientists do try to operate this way, most experiments and observations are designed and undertaken with a specific hypothesis in mind, and most researchers have a preconception about whether that hypothesis is right or wrong. **Perhaps the most important point about the scientific method is that scientists have to believe the results of their experiments and observations, whether they fit preconceived notions or not.** Science does not demand that we have no ideas when we enter the cycle in Figure 1 only that we be ready to change those ideas if the evidence forces us.

2. There is no "right" place to enter the cycle. Scientists can (and have) started their work by making extensive observations, but they can also start with a theory and test it. It makes no difference where you enter the cycle-eventually the scientific process takes you all the way around.

3. Observations and experiments must be reported in such a way that anyone with the proper equipment can verify the results. Scientific results, in other words, must be reproducible.

4. The cycle is continuous; it has no end. Science does not provide final answers, nor is it a search for ultimate truth. Instead, it is a way of producing successively more detailed and exact descriptions of wider and wider areas of the physical world-descriptions that allow us to predict more of the behavior of that world with higher and higher levels of confidence.

5. Finally, we should stress that while the orderly cycle shown in Figure 1 provides a useful framework to help us think about science, it shouldn't be thought of as a kind of rigid cookbook-style set of steps to follow. Because science is done by human beings, it involves occasional bursts of intuition, sudden leaps, a joyful breaking of the rules, and all the other characteristics we associate with other human activities.

ADDITIONAL NOTES:

TOPIC #3 –GLOBAL CHANGE
& THE CHALLENGE OF QUANTIFYING IT

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

GLOBAL CHANGE (GC) OVERVIEW

Your Textbooks:
SGC-1 = *The Science of Global Change* (first half): *The Earth System*, by Kump et. al.
SGC-2 = *The Science of Global Change* (second half*)* *Physics Concepts and Connections* by Hobson
DP = *Dire Predictions, Understanding Global Warming* by Mann & Kump

4 key themes in your textbooks: (a) **Basics: Physical Science Background** (b) **Basics: Energy Balance & Climate, and How They Change** (c) **Observations of Climate Variability and Change** (d) **Future Projections, Impacts, Vulnerability, Adaptation, Mitigation and Solutions**

GC processes based on underlying physical science principles:
-- **Matter, Thermodynamics, Electromagnetism, Laws of Motion**

Overview of GC Science (see SGC-1, Ch 1, pp1-17)
-- U of A: many departments, schools, IE (Institute for the Environment)
-- US Global Change Research Program (USGCRP)
-- Intergovernmental Panel on Climate Change (IPCC) + its Working Groups (WG)
Working Groups: I (The Science), II (Impacts, Adaptation & Vulnerability), III (Mitigation)

Methods Used: Experiments, Observations, Modeling . . . .
Standard "tools of science" -- hypotheses, prediction, testing, theories
Methods unique to GC?:

Issues to consider / debate (as the semester progresses) re: YOU and Global Change:

Sustainability (ecological) = the ability to utilize natural resources without depleting their stocks or irrevocably damaging ecosystems. Maintaining resources in a way that they will be available for the benefit of future generations

Sustainability (economic) = growth in economic activity at such a rate that the economy keeps up with (or surpasses) the needs of a growing population.

Global Footprint Network
Advancing the Science of Sustainability

We can estimate ecological sustainability via
THE ECOLOGICAL FOOTPRINT

The **Ecological Footprint** has emerged as the world's premier measure of humanity's demand on nature. **It measures how much land and water area a human population requires to produce the resource it consumes and to absorb its wastes, using prevailing technology.**

SOURCE: Global Footprint Network http://www.footprintnetwork.org/

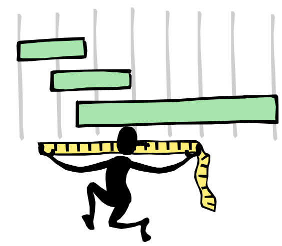
Epilogue: For the future of the planet three possible approaches are:

- **SUSTAINABILITY --** use of resources now won't preclude their use in future or damage/change things irreparably
- **TECHNOLOGICAL INNOVATIONS --** "we can fix the problem"
- **NATURE / HANDS OFF --** "let Nature take its course"

HOW TO QUANTIFY GLOBAL CHANGE:
RELATIVE SCALES OF THINGS IN NATURE & RATES OF CHANGE

> 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*

ON QUANTIFYING NATURE



quantify (def) = to make explicit the logical quantity of; to determine, express, or measure the quantity of

PROBLEM: 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 in different ways and at different rates.

THE RELATIVE SCALES OF THINGS

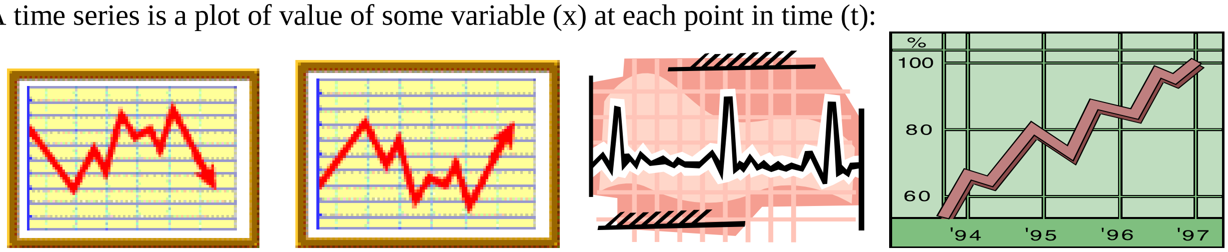
"POWERS OF 10 VIDEO" – illustrates the above problem. It is important to develop a sense of the RELATIVE SCALES in physical phenomena How do we deal with such vast ranges???

Through the TOOL of SCIENTIFIC NOTATION!!

To quantify global CHANGE we examine TIME SERIES CHANGE:

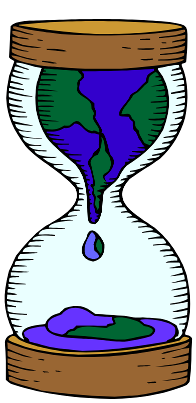
A time series is a plot of value of some variable (x) at each point in time (t):

x



t t t t

We also need to quantify 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

example: "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**

And we need to understand LINEAR & NONLINEAR CHANGES

HUGE RANGE IN SCALES – NEED "POWERS OF TEN" TO DESCRIBE

A journey dealing with the relative size of things in the universe and the effect of adding another zero

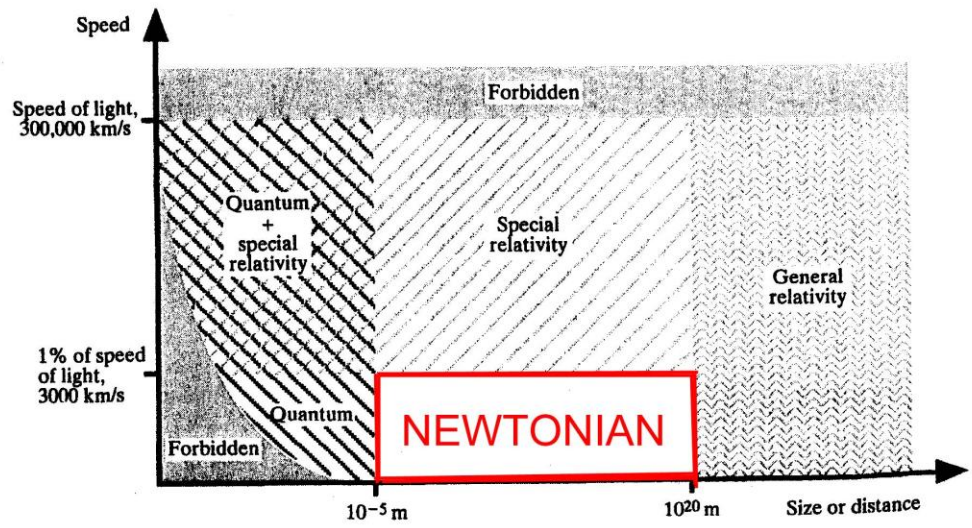
We'll start by looking at a scene 1 meter wide and viewing it from 1 meter above the area. Every 10 seconds the "camera" will move out to view the scene from 10 times farther away and our field of view will be 10 times wider.

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)	
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 – mostly space
1×10^{-12}	0.01 Ångstrom (= 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}

Now a look at the scale of objects (size and speed) we'll study in this class on Global Change:



Newtonian physics breaks down for very small objects, very large objects, and very fast objects. *(The diagram is only schematic and approximate.)*

> 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*

REVIEW

Scientific Notation: (Brief review of the rules for those who need a "brush up")

- Any large (or small) number can be expressed as the product of two terms.
- A number with a value between 1 and 10 (the *prefactor*) that gives the precision or accuracy of the original number.
- A power of 10 (i.e. an exponent, the exponent is the "power"
- To multiply numbers in scientific notation, multiply the prefactors and add the exponents (e.g. the powers of 10)
- 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

Examples: $10^4 = 10 \times 10 \times 10 \times 10$

$2,578,000 = 2.578 \times 10^6$

$0.000002578 = 2.578 \times 10^{-6}$

$(2.5 \times 10^6) \times (3 \times 10^{-4}) = 7.5 \times 10^2$

$(7.5 \times 10^5) / (2.5 \times 10^2) = 3.0 \times 10$ <=== *what is the exponent?*

Practice: The wavelength of ultraviolet radiation is 10^{-7} meters = _____________ m

The population of the world is ~ 6,000,000,000 people = _____________people

The ratio of the diameter of the Earth (use "whole globe" on the Powers of Ten chart) to the diameter of a carbon atom (use "outer electron shell of C atom" in chart) is: ______________________

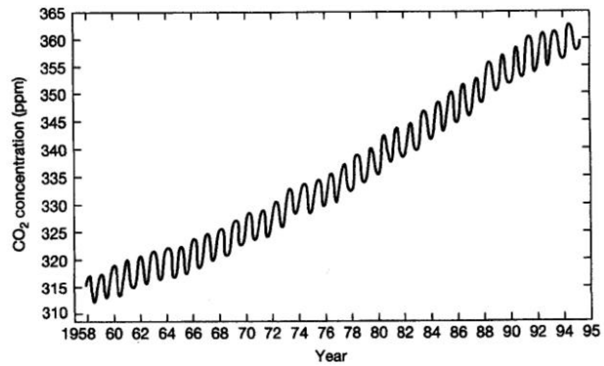
PLOTTING CHANGE OVER TIME:
Recognizing & Describing Different Types of Change As Depicted in Time Series Plots

☐ 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

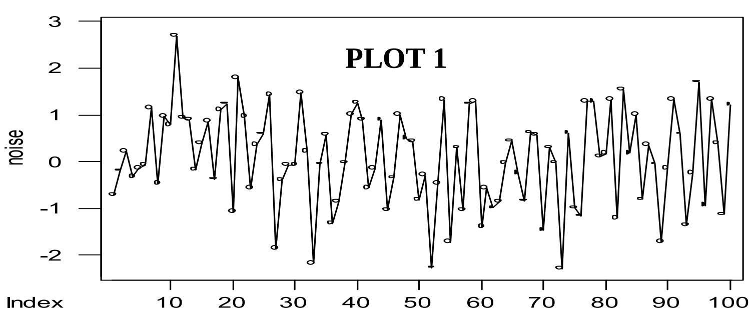


HINTS: Here are some terms that will help you describe time series changes more precisely in fewer words:

- **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)

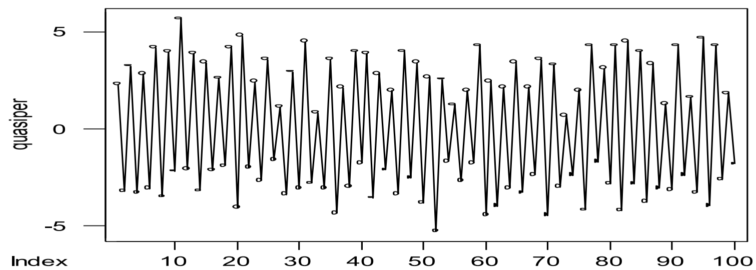
PLOTS: Different Types Of Change As Depicted In Time Series Plots

[NOTE: The description for PLOT 1 is done for you, to give you an example.]

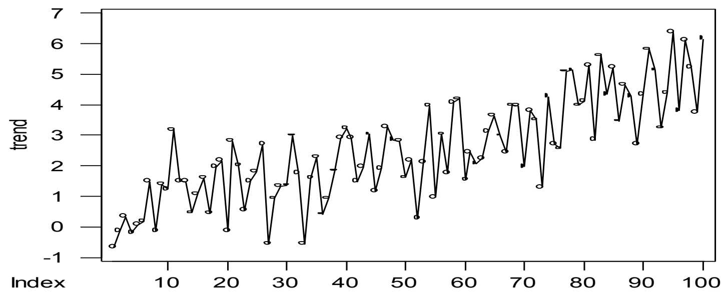


Description:

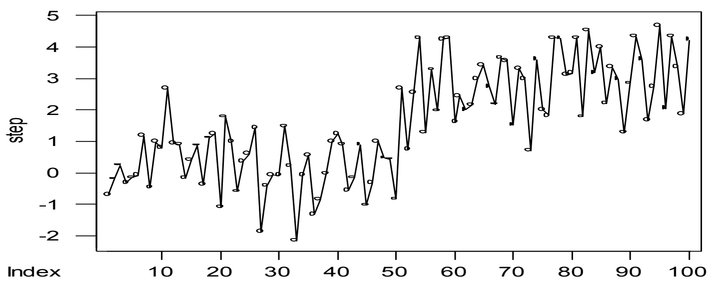
This plot appears to go up and down without any regular pattern (e.g., randomly); there are about as many points above the time series mean (average) as below; and the range of wiggles above and below the mean seems to be about the same over time.



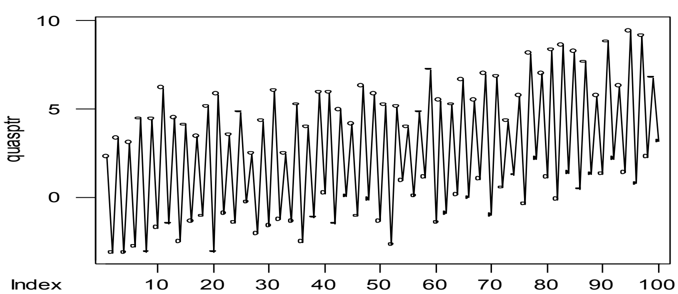
PLOT 2



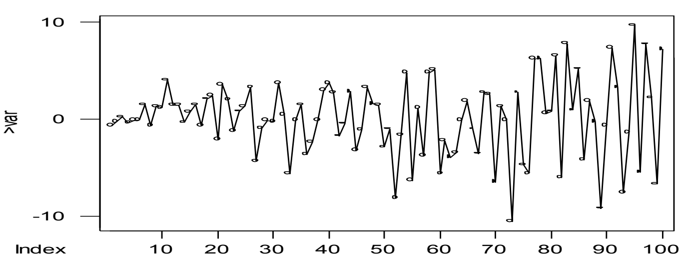
PLOT 3



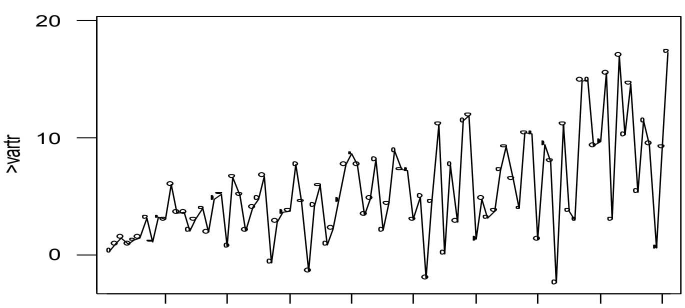
PLOT 4



PLOT 5



PLOT 6



PLOT 7

TOPIC # 4 ENERGY & MATTER 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

🌎 **LINK TO GLOBAL CHANGE:** The basic physical concepts of **matter,** 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.

<u>ENERGY OVERVIEW: TERMS & UNITS</u>

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)

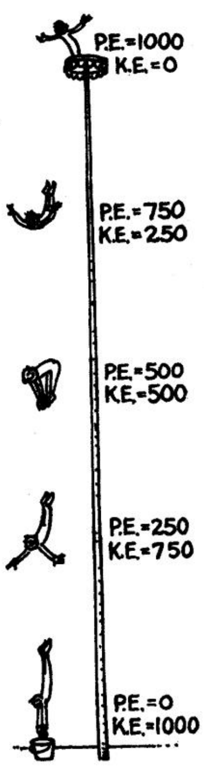
Force - A push or pull that, acting alone, causes a change in acceleration of the object on which it acts.

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*

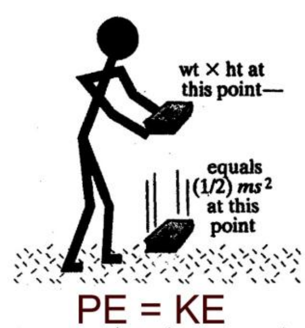


Power can be expressed in joules/sec = **watts** (or calories/sec)
1 watt of power = (1 joule of energy) ÷ (1 second of time)

***Energy* can therefore also be expressed in terms of power and time:**
energy (in joules) = power (in watts) x time (in seconds)

A *calorie* is a common unit of energy defined as the amount of heat required to raise 1 gram of room-temperature water 1 degree Celsius in temperature. **1 calorie = 4.186 joules**
1 calorie per second = 4.186 joules per sec = 4.186 watts 1 calorie per minute = 0.07 watts

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



An amazing thing: The gravitational energy at the beginning precisely equals the kinetic energy at the end.

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.

FORMS OF POTENTIAL ENERGY

Gravitational potential energy - Energy associated with the position of a mass in a gravitational field; *energy stored by virtue of its position*. The gravitational potential energy of an object on the surface of the earth equals its weight (the force of gravity exerted by the object) times its height above the ground. (Example: a boulder balanced on top of a hill, ready to roll down) In the example at left, the diver starts with zero KE and 1000 units PE, when he reaches the ground, he no longer has any PE and all the energy has been converted into KE).

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

Chemical potential energy - 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 potential energy - 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. Electricity is a force, more powerful than gravity, that moves objects both toward and away from each other, depending upon the charge. *Electrical fields and electric currents can be produced by changing magnetic fields.*

Magnetic potential energy - Energy stored in a magnetic field. A magnetic force is the force exerted by magnets on each other; a magnetic field is a collection of lines that map out the direction that compass needles would point in the vicinity of a magnet. *Magnetic fields can be created by the motion of electrical charges*

➔ **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. 🌎 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 receive from the Sun. *(more on this later!)*

➔ **Thermal Energy (Heat Energy) -** 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.

KEY CONCEPT: **ENERGY TRANSFORMATIONS & CONSERVATION OF ENERGY**

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

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.

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

First Law Of Thermodynamics (is another way of stating this law) *In an isolated system the total amount of energy, including heat energy, is conserved, although energy may change from one form to another over and over again.*

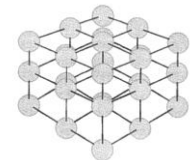
NOTE: Although energy may not be destroyed, it can become ***inefficient*** -- i.e., is not easily used or available to do work!

Efficiency = work done / energy used

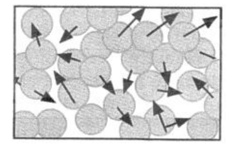
MATTER OVERVIEW

States of Matter -- Atoms -- Particles -- Electronic Structure -- Quantum Behavior

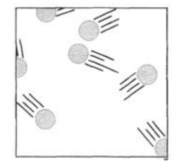
Matter: Whatever occupies space & is perceptible to the senses; made up of atoms; matter can be in form of solids, liquids, or gases ("states of matter")



Solid: a substance that resists changes of shape and volume; characterized by *structure* in the particular order and bonding of atoms that make up the material. Example = a crystal in which the molecules are locked into a strict geometrical order.



Liquid: a substance that flows freely in response to unbalanced forces; molecules more or less move freely past one another as individuals or small groups and are not confined to fixed positions, as in solids. LIQUIDS CAN EXHIBIT PRESSURE (pressure = a force per unit area) and will take the shape of the container they are in.



Gas: a substance that expands (and contracts) easily, rapidly, and indefinitely, filling all space available to it and taking the shape of its container; the distance between molecules is such that no cohesive forces exist; atoms or molecules are in high speed motion, with many collisions and rebounds. GASES CAN ALSO EXHIBIT PRESSURE; atmospheric pressure = the weight of air pressing upon you.

> ***KEY CONCEPT: ENERGY & MATTER INTERACT***
>
> *The change in the state of a substance from a solid to a liquid form, or from a liquid to a gaseous form, (or vice versa) is called a **change of state** or **change of phase.** Energy in the form of heat, i.e., **thermal energy** is involved in phase changes.*

Terms & Definitions: Quick Review

Atom: Fundamental building blocks for all matter; the smallest representative sample of an element; consists of a positively charged nucleus and negatively charged electron(s) in orbit. It's the smallest particle that retains its chemical identity, i.e., the smallest particle of an element that has all of the element's chemical properties, e.g. oxygen (O) or hydrogen (H).

Element: A chemical substance (material) made from a single type of atom that cannot be broken down any further (e.g. carbon, C) as in *Periodic Table of the Elements*

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

Molecule: Any collection of two or more atoms bound together; a cluster of atoms bound together; the basic constituent of many different kinds of materials. It's the smallest part of any substance that has all the chemical properties of the substance, e.g. water molecule = H_2O

Electron: Tiny negatively charged particles that circle in orbits around a positively charged nucleus of an atom. The electron is an atomic particle with a negative charge and very low mass. *(- charge)*

Nucleus: The small, massive central part of an atom; it is made up of elementary particles that are even smaller *(* see NOTE on next page discussing **hadrons**)*

Proton: Positively charged nuclear particle. *(+ charge)*

Neutron: Electrically neutral nuclear particle, approximately equal in mass to a proton. Both protons and neutrons have much greater relative mass than electrons. *(neutral charge)*

Strong Force: The force responsible for holding the nucleus together; operates over extremely short distances to hold the elementary particles together

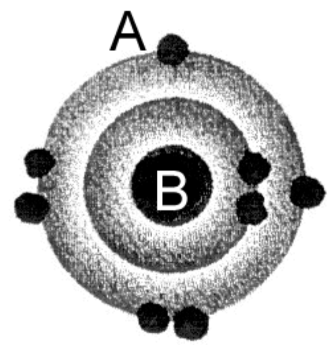
DESCRIBING ATOMS WITH "CONCEPTUAL MODELS"

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

The ***atomic number*** of an atom is the number of protons, or units of positive charge, in the nucleus. If the atom is neutral (i.e. not a positively or negatively charged atom *see **ion***) . **The atomic number is also equivalent to the number of electrons,** e.g., a hydrogen atom has a single proton and an atomic number of 1. A carbon atom has 6 protons and 6 electrons (when neutral) and has an atomic number of 6.

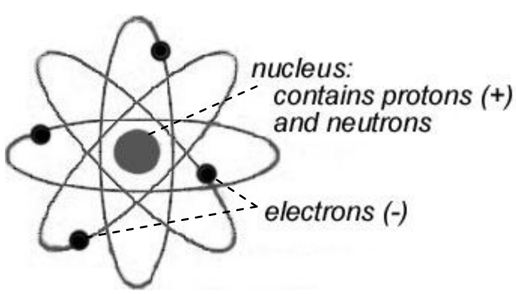
The ***mass number*** of an atom is the total number of protons and neutrons in the nucleus of the atom. **

"DOT DIAGRAM MODEL" of an atom of OXYGEN (O) = a *schematic model that can be used to distinguish one element from another based on the number and placement of electrons around the nucleus*



What is the small circular black feature at A called? _____________
What is the large circular black feature in the center at B called? _____________
How many electrons does the atom have? ______
How many protons does the atom have (if the atom has <u>no charge</u>)? _____
How many neutrons does the atom have? ____
What is the atomic number of oxygen? ____

THE PLANETARY MODEL OF THE ATOM – A nucleus with orbiting is a useful theory that explains a lot of observed behavior of matter at microscopic and smaller scales.



- Familiar representation / compares an atom to solar system
- Neutrons & protons occupy dense central region = nucleus
- Electrons orbit the nucleus like planets orbiting the Sun (but orbits are not confined to a plane as in Solar System).
- In an actual atom the radius of the nucleus is about 100,000 times smaller than the radius of the entire atom
- In an actual atom, electrons have little mass; are really more like "point" particles without a physical extent

THE BOHR MODEL OF THE ATOM – More recent experiments require the planetary model to be replaced by **the quantum atom model** of the atom proposed by Niels Bohr in 1915.

[We'll focus on the Bohr Model in this class, but note that current scientific models of atomic behavior are more sophisticated!]

- The term "quantum" means "a small, discrete quantity" and the **theory of quantum mechanics** describes the behavior of matter on a microscopic scale – molecules and smaller.).
- The quantum model of the atom states that **electrons can exist only in discrete allowed places within shells (or energy levels) and not in between.**
- The **electrons move --** not according to Newtonian laws of motion -- but according to **quantum mechanics.** *(see schematic diagrams next page).*

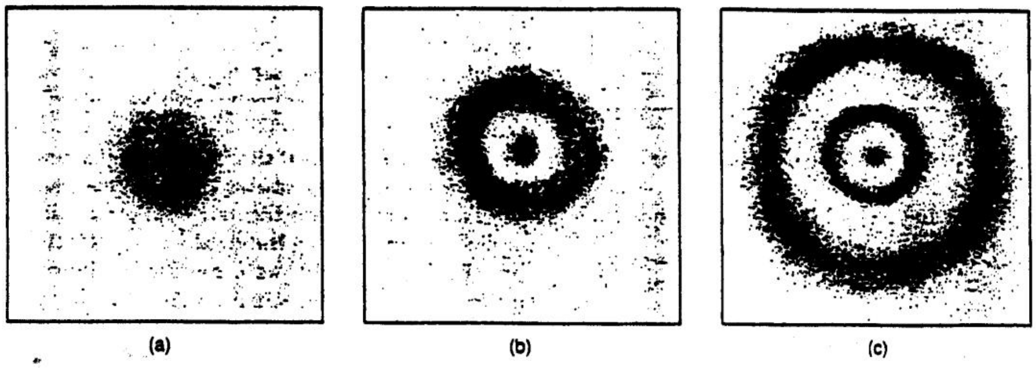
----

* The number of "elementary particles" that reside in a nucleus is very large – all the different kinds of particles that exist inside the nucleus are collectively referred to as "**hadrons**" or 'strongly interacting ones.' Some carry an electric charge, some are neutral (**protons** and **neutrons** are each examples of hadrons). BUT even the elementary hadrons are made up of things more elementary still – things that are given the name **quark** *(pronounced quork)* and they are considered to be the truly fundamental building blocks of hadrons.
However, at present we have no way to isolate or study a quark – scientists infer that they exist because elementary particles behave *as if* they were made up of quarks.

** For example, 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. 12 (mass number) minus 6 (atomic number) = 6 neutrons. Atoms that have the same atomic number but different mass numbers are called ***isotopes***. So in the example just given we were referring to an isotope of carbon called "carbon-12" or ^{12}C.

Schematic Diagrams Representing Electron Shells In The Bohr Model:

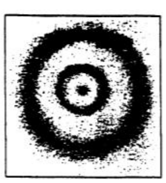
(These are not photographs of electrons, but rather models based on a mathematical theory of the atom.)



Electron "cloud" in ground state   Electron cloud in 1st excited state   Electron cloud in 2nd excited state

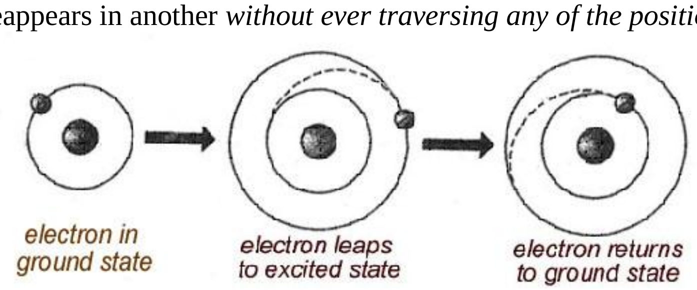
The diagrams are for a hydrogen atom (H) -- which has only one electron. The probability of the position of that electron being in a particular place is represented by a "cloud" of points. The densely shaded regions indicate **places where an electron is likely to be found.** The less densely shaded zones indicate **regions where the probability of finding an electron is low**.

- Electrons circling the nucleus cannot maintain their orbits at just *any* distance from the center of the atom; there are only certain "allowed orbits" (shells) located at specified distances from the center in which an electron can exist for long periods of time without giving off radiation.
- As long as the electron remains at one of these distances, its energy is fixed. These fixed states are designated by numbers (quantum numbers) (n = 1, 2, 3, etc.)
- The electron in the lowest energy level (n = 1) is called the *ground state*, while all the energy levels above the ground state are called *excited states (first excited state, second excited state*, etc.)
- Each electron energy level can accommodate only a limited number of electrons, then it is "full"
- The electrons at a given energy level make up an **"electron shell"**
- The higher the shell number (n) the more distant are its electrons from the nucleus and the greater the energy of the electrons. The electrons that can be separated most easily from its atom is therefore an electron in the highest shell.



-- 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
. . . but how do they get from one level to another???

- An electron moves between shells or energy levels by "quantum leaps," i.e., it disappears from one energy level and reappears in another *without ever traversing any of the positions in between!*



But what "causes" the leap? And what does it have to do with Global Change? (more on this in Topic # 6!)

ADDITIONAL NOTES:

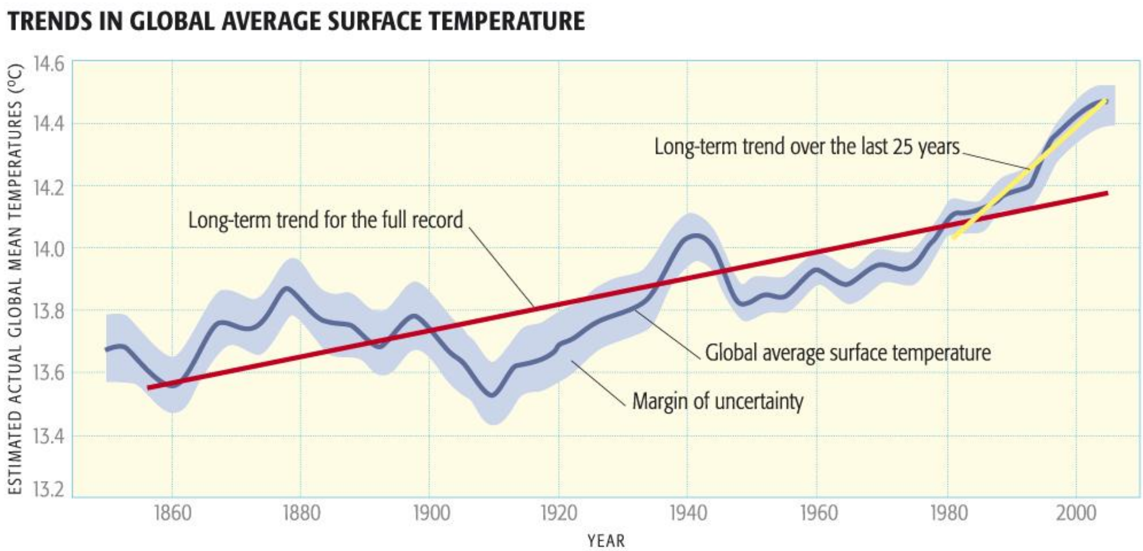
TOPIC # 5 – THE OBSERVATIONS: CLIMATE CHANGE & VARIABILITY IN THE PAST & PRESENT

> "All things are connected. Whatever befalls the earth, befalls the children of the earth." ~Chief Seattle

IMPORTANT DEFINITIONS (from IPCC AR4 WG-1 Glossary http://www.ipcc.ch/pdf/glossary/ar4-wg1.pdf)

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

Climate variability: Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).



Climate shift: An abrupt shift or jump in mean values signaling a change in climate regime . Most widely used in conjunction with the 1976/1977 climate shift that seems to correspond to a change in El Niño-Southern Oscillation behavior.

Patterns of climate variability: Natural variability of the climate system, in particular on seasonal and longer time scales, predominantly occurs with preferred spatial patterns and time scales, through the dynamical characteristics of the atmospheric circulation and through interactions with the land and ocean surfaces. Such patterns are often called *regimes*, *modes* or *teleconnections*. Examples are the North Atlantic Oscillation (NAO), the Pacific-North American pattern (PNA), the El Niño- Southern Oscillation (ENSO), the Northern Annular Mode (NAM), and the Southern Annular Mode (SAM) (see 3.6 of the Working Group I Report.

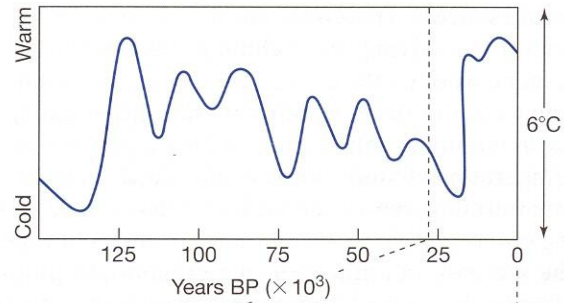
Abrupt climate change: (sometimes called rapid climate change, abrupt events or even surprises.) The term abrupt often refers to time scales faster than the typical time scale of the responsible forcing. However, not all abrupt climate changes need be externally forced. Some possible abrupt events that have been proposed include a dramatic reorganisation of the thermohaline circulation, rapid deglaciation and massive melting of permafrost or increases in soil respiration leading to fast changes in the carbon cycle. Others may be truly unexpected, resulting from a strong, rapidly changing forcing of a *nonlinear* system. (A process is called *nonlinear* when there is no simple proportional relation between cause and effect.)

NOTE: United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

CLIMATIC CHANGES & VARIABILITY HAVE OCCURRED IN THE PAST

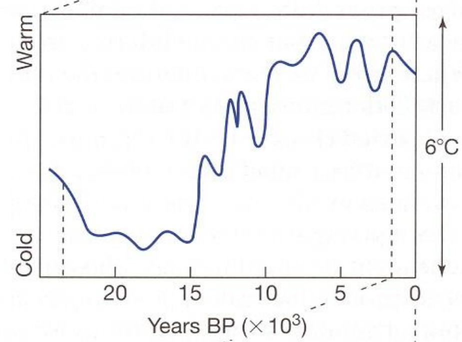
Graphs depicting MEAN GLOBAL TEMPERATURE CHANGE
Since the Last Glacial Maximum over "telescoping" time scales

(a) Generalized oxygen isotope curve from deep-sea sediments



Years BP "years before present"

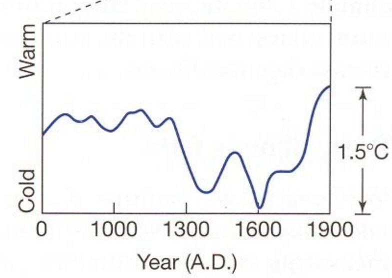
(b) Generalized estimates from pollen data & alpine glaciers (mid-latitudes of eastern N. America & Europe)



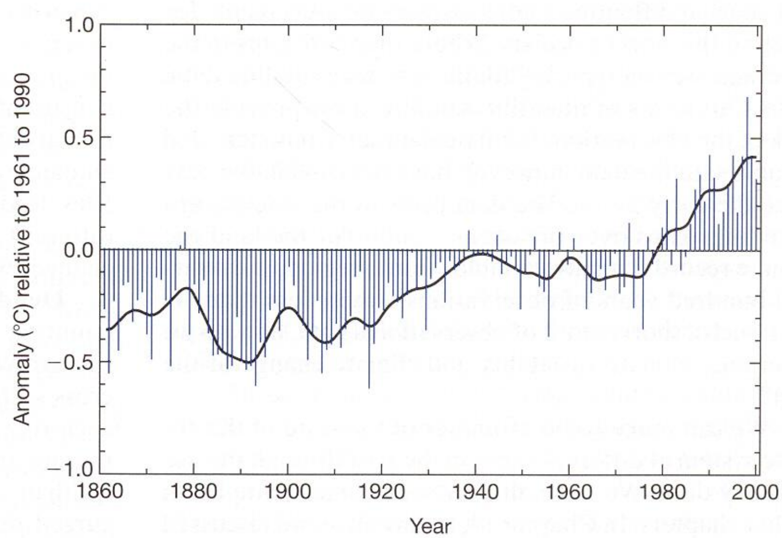
Medieval Warm Period (MWP)
9th-14th centuries
(800-1300)

Little Ice Age (LIA)
15th – 19th centuries
(1400-1800)
esp. 1600 -1800

(c) General estimates from historical documents (emphasis on the North Atlantic region)



(d) Annual anomalies of global land-surface air temperature (°C), 1861 to 2000, relative to 1961-1990 values.



🌎 Time Series Graphs Showing Change since 1850

Time-Series of Observations Showing Temperature-Related Changes

Observed changes in:

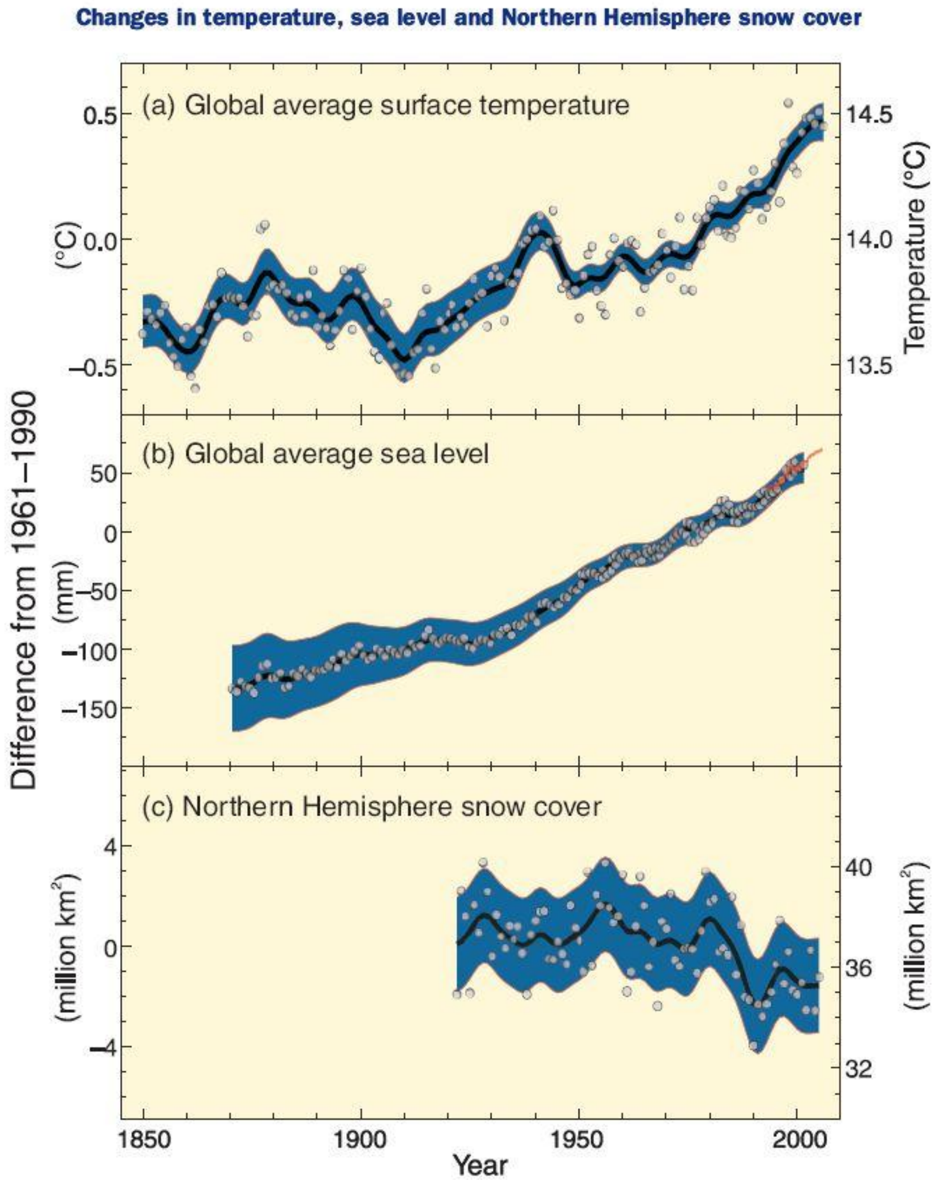
(a) Global average surface temperature

(b) Global average sea level from tide gauge and satellite data

(c) Northern Hemisphere snow cover for March-April.

All differences are relative to corresponding averages for the period 1961- 1990. Smoothed curves represent decadal averaged values while circles show yearly values.

The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c).



To make an <u>incontrovertible</u> case about the role that humans play in global warming, 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

Most Recent Findings of the Intergovernmental Panel on Climate Change (IPCC)

See: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-direct-observations.html

- Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level .

- Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases.

- There is *medium confidence* that other effects of regional climate change on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic driver

Checklist of Direct Observations of Recent Climate Change

TEMPERATURE: [daytime _____ nighttime _____ heat waves _____ # cold days/ frosts _____]

PRECIPITATION: [water vapor _____ drought _____ heavy rains _____]

HYDROLOGY: [streamflow ______ snowmelt ____ floods _____ reservoirs /dams____ water supply ____]

CRYOSPHERE: [snowpack _____ mt glaciers _____ sea ice____ ice caps ____ frozen ground _____]

OCEAN: [sea level _____ sea surface temps _____ salinity ______ corals _____ fisheries _____]

BIOSPHERE: [plant / animal ranges _____ phenology_____ crop dates _____ disease ______]

OTHER: [atmospheric circulation ____ wind belts / storm tracks _____ hurricanes _____]

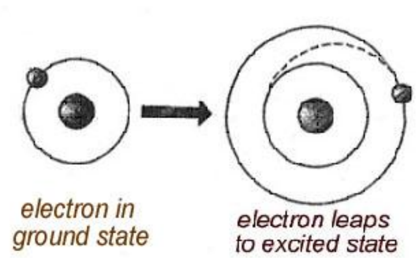
Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend[b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely*[c]	*Likely*[d]	*Virtually certain*[d]
Warmer and more frequent hot days and nights over most land areas	*Very likely*[e]	*Likely (nights)*[d]	*Virtually certain*[d]
Warm spells/heat waves.Frequency increases over most land areas	*Likely*	*More likely than not*[f]	*Very likely*
Heavy precipitation events.Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*[f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not*[f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)[g]	*Likely*	*More likely than not*[f,h]	*Likely*[i]

http://www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-direct-observations.html#table-spm-2

TOPIC # 6 – ELECTROMAGNETIC RADIATION & THE ELECTROMAGNETIC SPECTRUM

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

But what "causes" the leap??



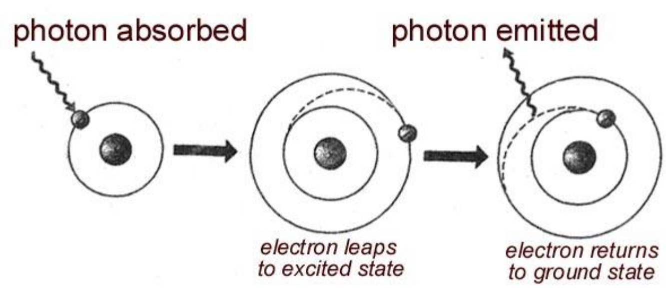
> Electrons can be promoted to higher energy levels or even knocked free from their atoms in a variety of ways – **one way that is critical to global change processes involves a packet of energy called a PHOTON.**

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.**

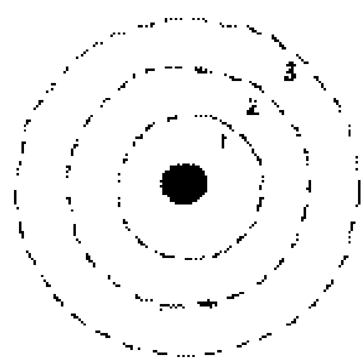
THE QUANTUM BEHAVIOR OF ELECTRONS IN ATOMS



*SKETCH IT YOURSELF: O*n 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 circle 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.)



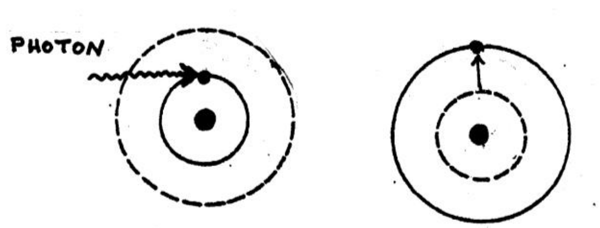
QUANTUM BEHAVIOR RECAP

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

WHAT HAPPENS WHEN ELECTRONS CHANGE LEVELS *(another view)*

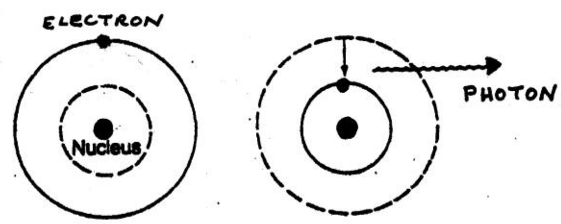
As an electron receives & absorbs electromagnetic energy (in form of a photon), it jumps from a Lower → Higher energy state (level).

As an electron emits or "gives off" electromagnetic energy (in form of a photon), it jumps from a Higher → Lower energy state (level)



An electron in its ground state, about to absorb a photon

The electron leaps to a higher level as the photon is absorbed

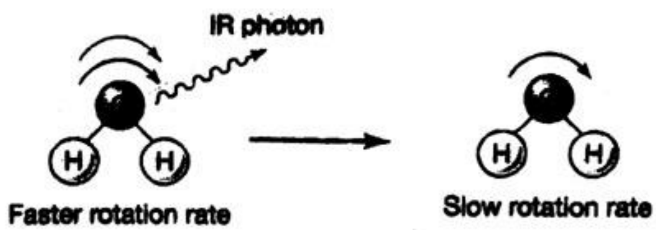


An electron in an excited state.

When the electron drops to a lower level, a photon is emitted.

QUANTUM BEHAVIOR AT THE <u>MOLECULAR</u> LEVEL

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



MOLECULAR QUANTUM & KINETIC MOTION BEHAVIOR

LINK TO GLOBAL CHANGE:

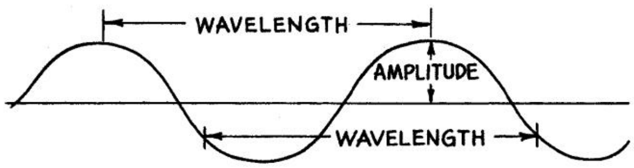
Molecular motions in the gases WATER VAPOR and CARBON DIOXIDE (H_2O and CO_2) explain why some gases (e.g., H_2O, CO_2) contribute to the greenhouse effect and others (e.g., O_2, N_2) do not!!

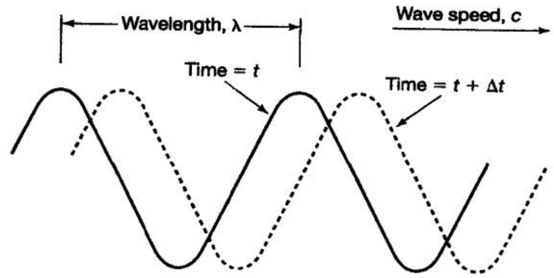
(more on this later . . .)

***Recap of Key Concept*: ENERGY & MATTER INTERACT !!!**

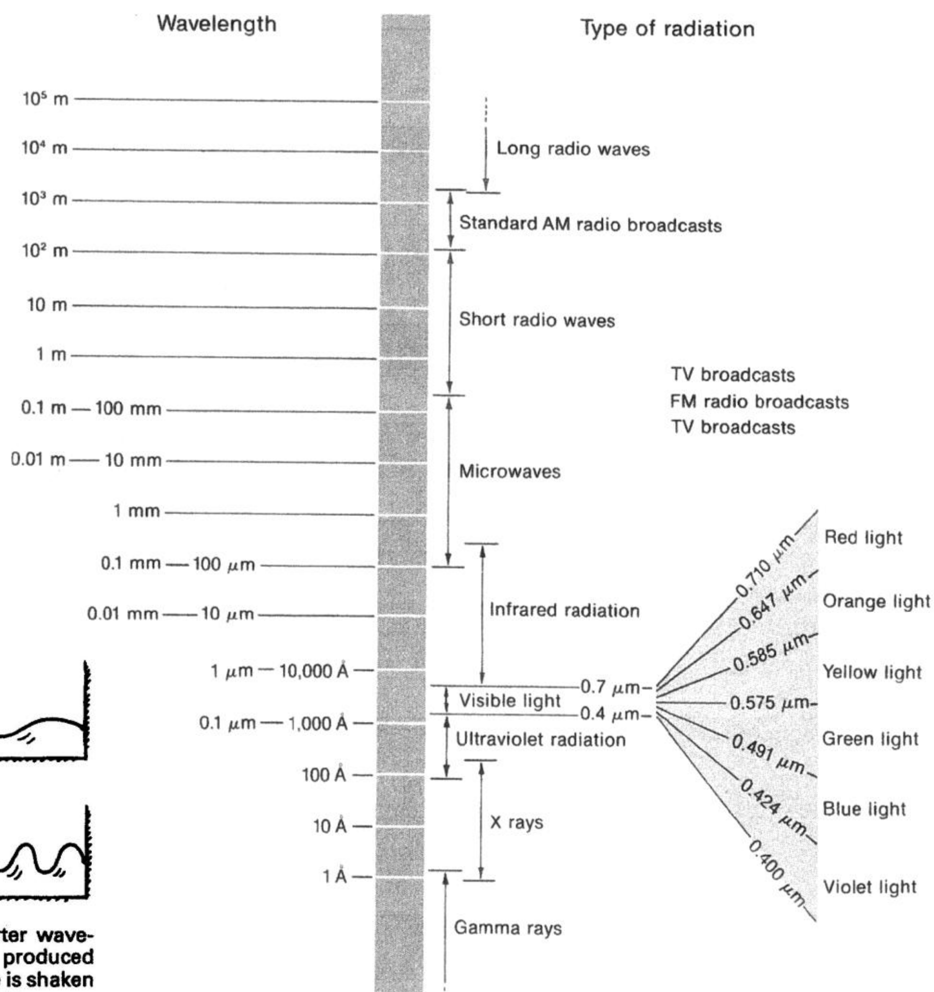
The Electromagnetic Spectrum

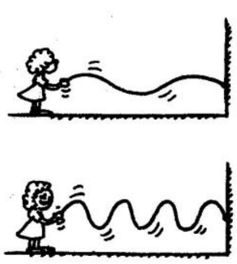
> Come forth into the light of things. Let nature be your teacher. ~ *William Wordsworth*





THE ELECTROMAGNETIC SPECTRUM



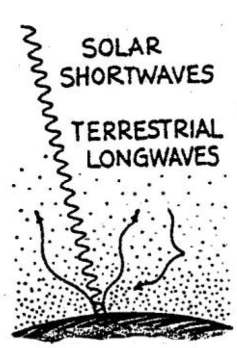


NOTE: **Shorter wavelengths are produced when the rope is shaken more vigorously.**

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

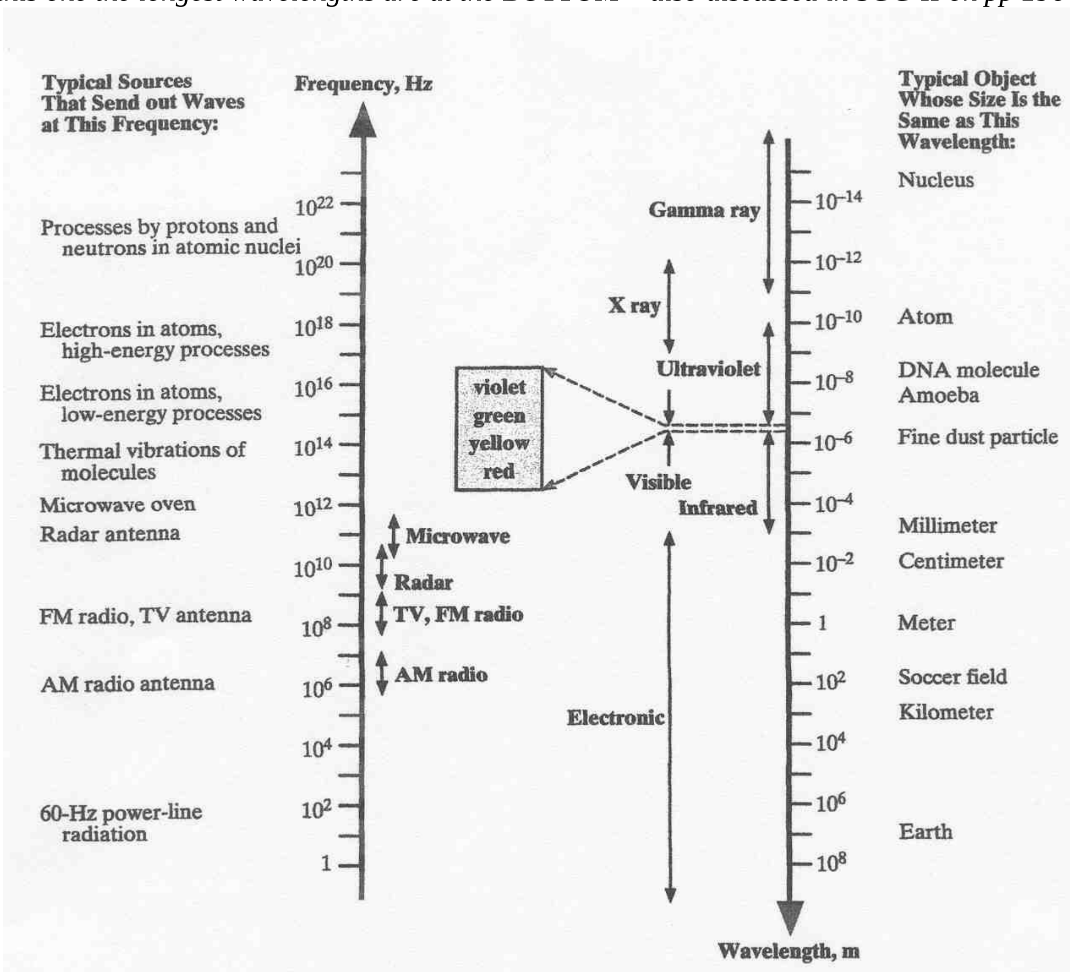
LINK TO GLOBAL CHANGE:

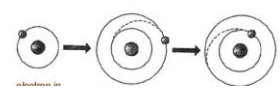
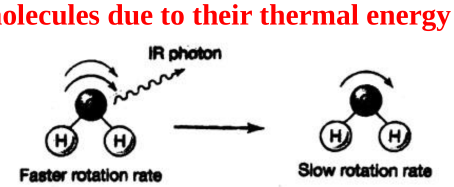
The differences in solar and terrestrial wavelengths of energy are the underlying basis for the **GREENHOUSE EFFECT** and our concerns about GLOBAL WARMING



ANOTHER VIEW OF THE ELECTROMAGNETIC SPECTRUM

(in this one the longest wavelengths are at the BOTTOM – also discussed in SGC-II on pp 196-199)



Type of Electromagnetic Radiation	Range of Wavelengths (in units indicated)	Typical Source
Gamma rays	**10^{-16} to 10^{-11}** in meters (m) using scientific notation	**high-energy processes within nucleus caused by the strong force**
UV Ultraviolet radiation UVC .20 - .29 UVB .29 - .32 UVA .32 - .40	**.0001 to 0.4** in micrometers (µm)	**electrons moving (quantum leaps) within individual atoms** 
VIS Visible light	**0.4 to 0.7** in micrometers (µm)	
IR Infrared radiation	**0.7 to ~30 (up to 1000)** in micrometers (µm)	**chaotic thermal kinetic motion of molecules 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	**electronically produced by microwave oven**
AM Radio waves	**10 to 10^{2}** in meters (m) using scientific notation	**electronically produced -- waves vibrate in human-made electrical circuits**

TOPIC # 7 - THE RADIATION "LAWS"

🌎 Keys to Understanding the Greenhouse Effect

> 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*

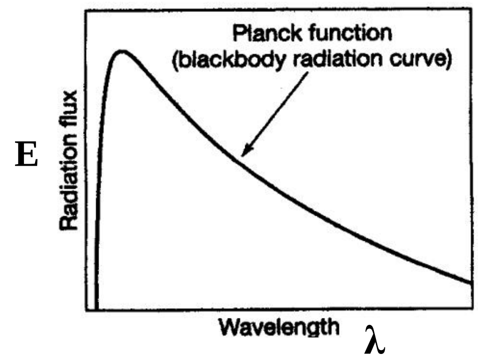
First, a definition: **Irradiance** (def): Radiation incident per unit area upon a surface. It is usually expressed in watts per square meter (W/m^2), but may also be expressed in joules per square meter (J/ m^2)

LAW # 1. Emission of radiation:

LAW #1➔ All substances emit radiation as long as their temperature is above absolute zero (-273.15°C or 0 K).

*(NOTE: Laws # 2 & # 3 are both related to the concept of "**ideal emitters**" and "**temperature**")*

LAW # 2: The Plank function & the concept of "blackbodies"



black body (def): a hypothetical object that is an "ideal emitter" i.e., it absorbs all of the radiation that strikes it. It also emits radiation ("Energy flux") at a maximum rate for its given *temperature*.

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

LAW # 2**:** ➔ 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 (h):

E = h * speed of light / wavelength

$\mathbf{E = h\, c / \lambda}$

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

LAW # 3 : The Stefan-Boltzmann Law

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* and can be represented as: $\mathbf{E = \sigma T^4}$

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

LAW #3➔ Stefan-Boltzmann Law (easy way) "the hotter the body, the (much) greater the amount of energy flux"

Why is it important? means that amount of radiation emitted is very sensitive to temperature of object

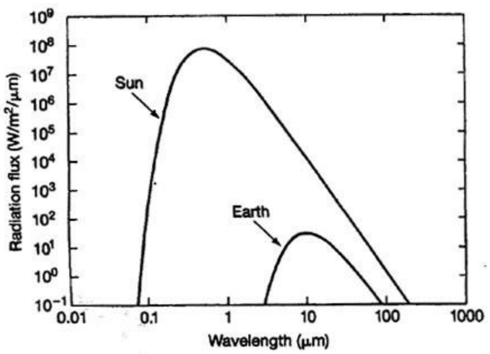
LAW # 4: Temperature and wavelength -- Wien's law (also called *Wien's displacement law*)

LAW #4 ➔ As substances get hotter, the wavelength at which radiation is emitted will become shorter.

This is called Wien's law. It can be represented as**:** $\lambda_m = a/T$

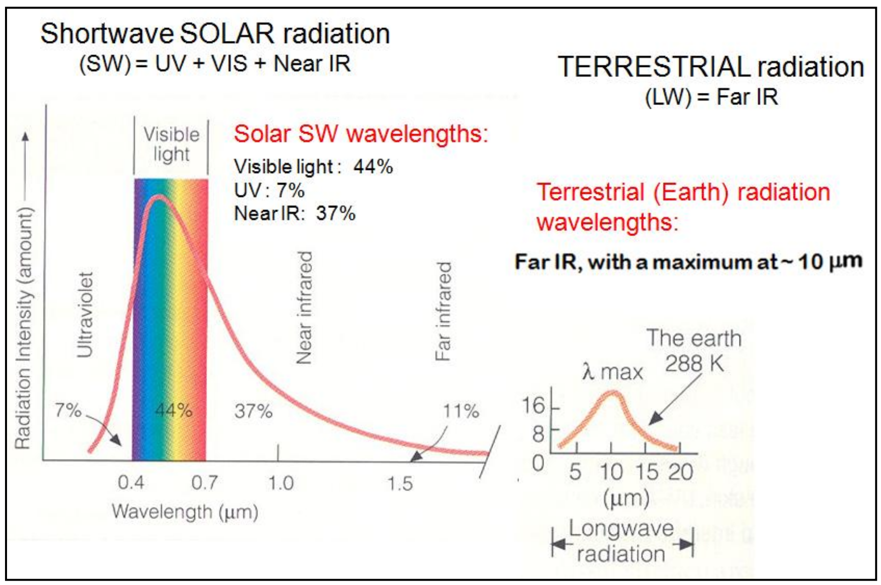
where λ_m ***is the wavelength** at which the peak occurs in the spectrum,*
***T is the absolute temperature** of the body (in Kelvin)*
a is a constant** with a value of 2898 if* λ_m *(in micrometer)s. [Note: in ES p 45,* ***k *is used instead of* ***a*** *]*

Wien's Law (easy way): λ max = constant / T (Inverse relationship between wavelength and temperature)
"The hotter the body, the shorter the wavelength"
"The cooler the body, the longer the wavelength"



Wien's Law -- Why is this concept important?

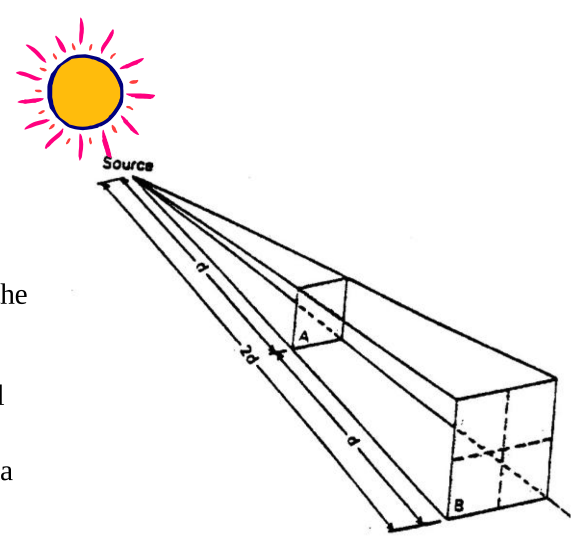
Because it means that very hot objects (like the sun) that radiate like blackbodies will radiate the maximum amount of energy at short wavelengths, while cooler bodies will radiate most of their energy at longer wavelengths.



The **Sun** ☼ radiates most of its energy at **~0.5 µm** (right in the middle of the **visible light** part of the spectrum) but also radiates a fair amount in the **UV** and **Near IR** parts of the spectrum – and also at other wavelengths

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

LAW # 5: Radiation and distance: the inverse-square law



The inverse square law describes **how solar flux decreases with increasing distance from the source** of the flux (radiation), the Sun.

LAW # 5➔ **Inverse Square Law** = 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 ($1/d^2$).

Why is this concept important? Because it means that relatively small changes in distance from the source of energy (e.g., the ☼ Sun) can result in relatively large changes in the amount of energy received by a planet's surface. 🌎 (think of the "Goldilocks Effect")

<u>LAW # 6:</u> Selective emission and absorption *(There are two parts to this law)*

LAW #6 (a) ➔ **Some substances emit and absorb radiation at certain wavelengths only.**
(This is mainly true of gases.)
LAW #6 (b) ➔ **These substance absorb <u>only</u> radiation of wavelengths they can emit:**

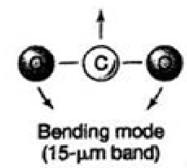
Implications of LAW #6:

- 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.**

- **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**.)
Or the IR can be emitted upward to outer space and be lost from the system altogether.

- 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.

- **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 micrometers (µm), at ~ 4 µm and especially at a wavelength **of about 15 µm.** We often call this last wavelength band the "15 µm CO_2 band."
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.

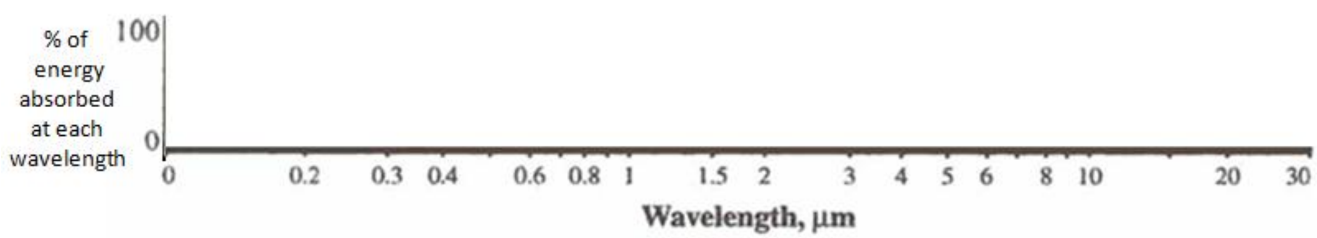


- **O_3 (ozone)** selectively **absorbs ultraviolet (UV) radiation** at wavelengths < ~ 0.3 µm
This is how the ozone layer in the stratosphere protects us from harmful, high energy radiation.

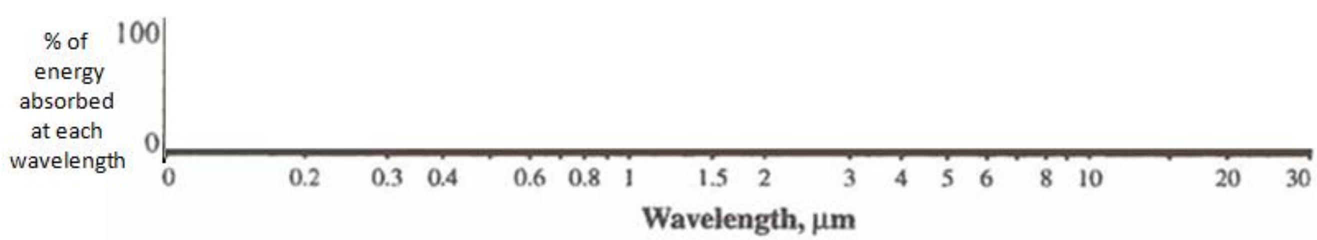
ABSORPTION CURVES (diagrams that show *which* wavelengths of energy different gases selectively absorb)

We use an absorption curve to show the relationship between wavelength (along the horizontal axis) and % of energy at a given wavelength that is absorbed (vertical axis):

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



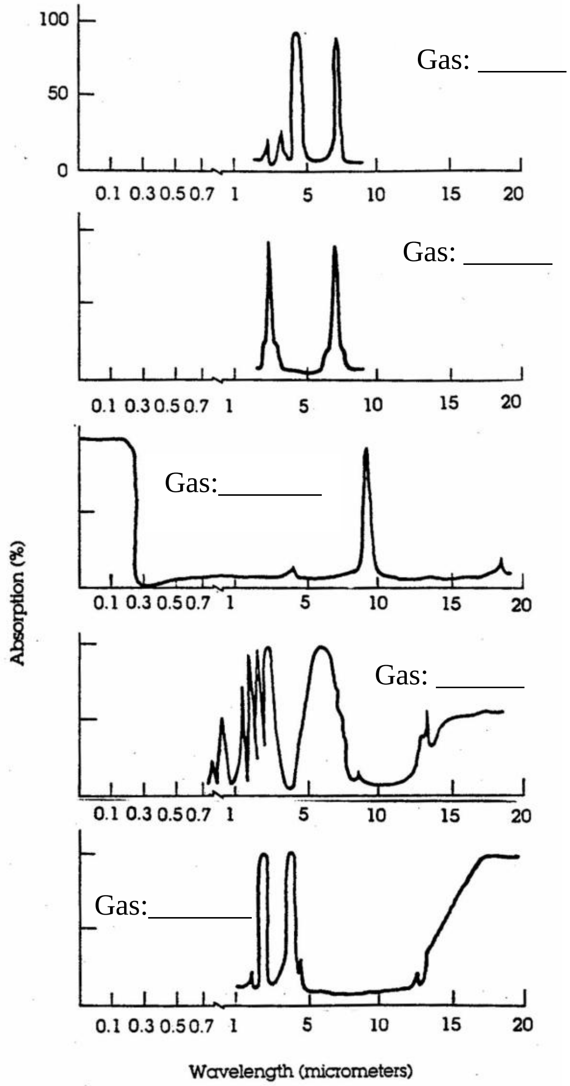
Draw an absorption curve for a "perfect" greenhouse gas that absorbs ALL IR radiation, but no visible or UV:



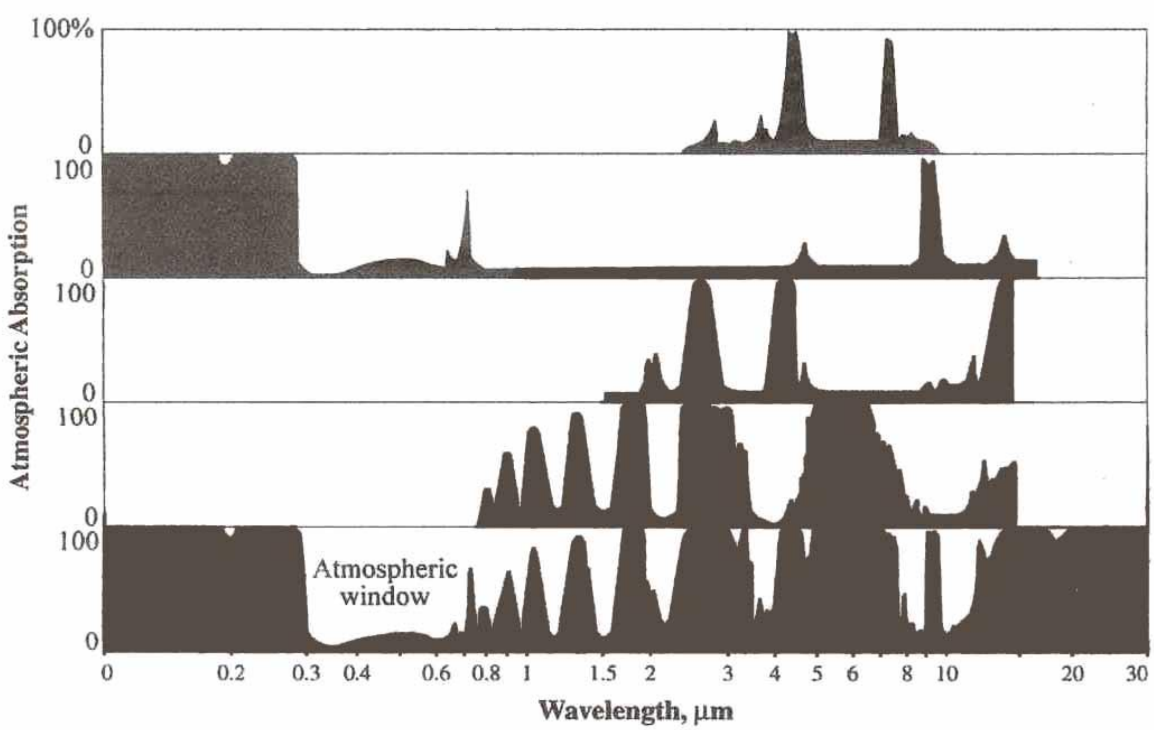
MATCH THE ABSORPTION CURVE WITH ITS GAS

The table below shows **the primary wavelengths of electromagnetic energy that different atmospheric gases readily absorb**. Based on this information, figure out which absorption curve (shown at right) MATCHES which atmospheric gas in the table below **and LABEL the absorption curve with the proper gas molecule's chemical symbol** (e.g. H_2O)

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	
Methane (CH_4)	2 and 6.5	
Carbon dioxide (CO_2)	2 to 2.5 3 to 4 13 to 20	



Here is another representation of absorption curves. Which curve goes with which gas?



The bottom curve is the absorption curve for ALL the gases in the atmosphere together, i.e. what you would get if you superimposed all the individual absorption curves for each gas on top of each other!

TOPIC # 8 ATMOSPHERIC STRUCTURE & CHEMICAL COMPOSITION

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

🌎 *KEY CONCEPT:*

The atmosphere's **vertical structure** is defined by "pauses," (changes or reversals) in the trend of atmospheric temperature with height.

These changes in temperature are the result of differential absorption of shortwave (SW) and longwave (LW) radiation by atmospheric gases at various altitudes:

THERMOSPHERE - 80 to ?, temp increases with increasing elevation; (however, gases are so sparse at this level that air doesn't "feel" warm, individual fast-moving gas molecules are too far apart)

- - - - Mesopause - - - -

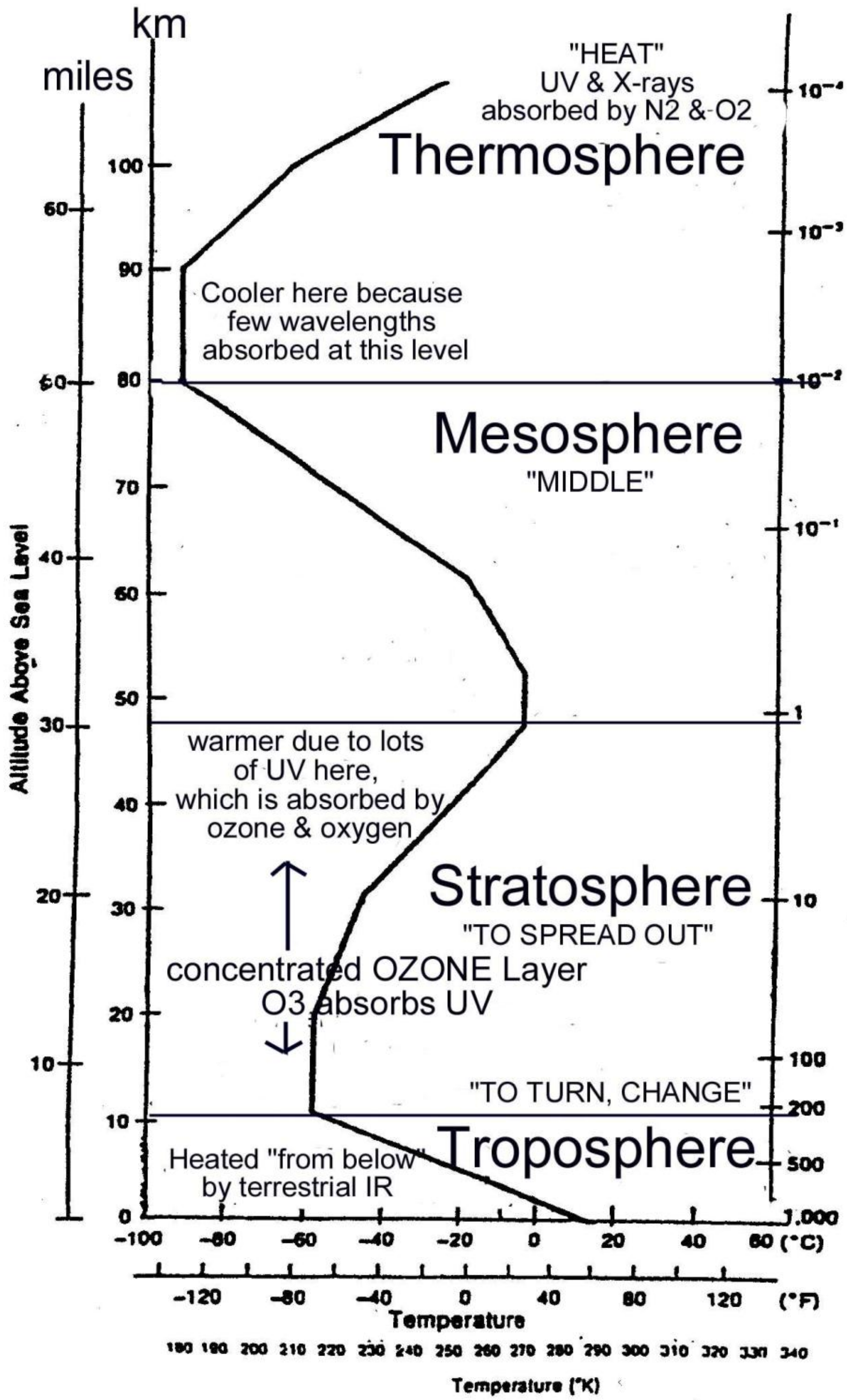
MESOSPHERE - ~50 to about 80 km, temp decreases with increasing elevation; (gases at this level do not absorb much SW radiation, hence no heating up)

- - - - Stratopause - - - -

STRATOSPHERE - 12 to about 50 km, temp increases with increasing elevation; (absorption of incoming SW by O_3 and O_2 heats air at this level)

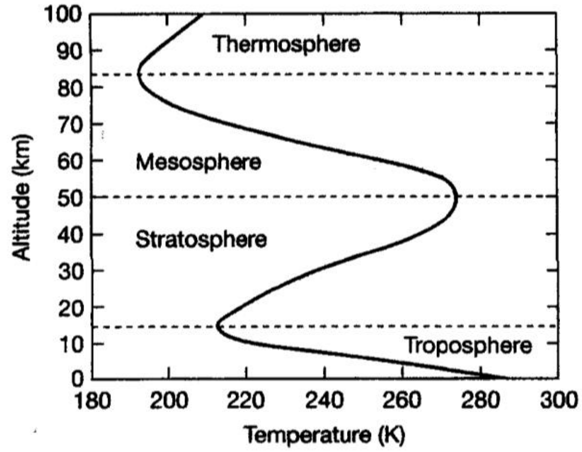
- - - - Tropopause - - - -

TROPOSPHERE - 0 to about 12 km, temp decreases with increasing elevation; (troposphere "heated from below" by LW radiation, 🌎 greenhouse gases absorb & reradiate LW to surface ==> temps highest at surface)



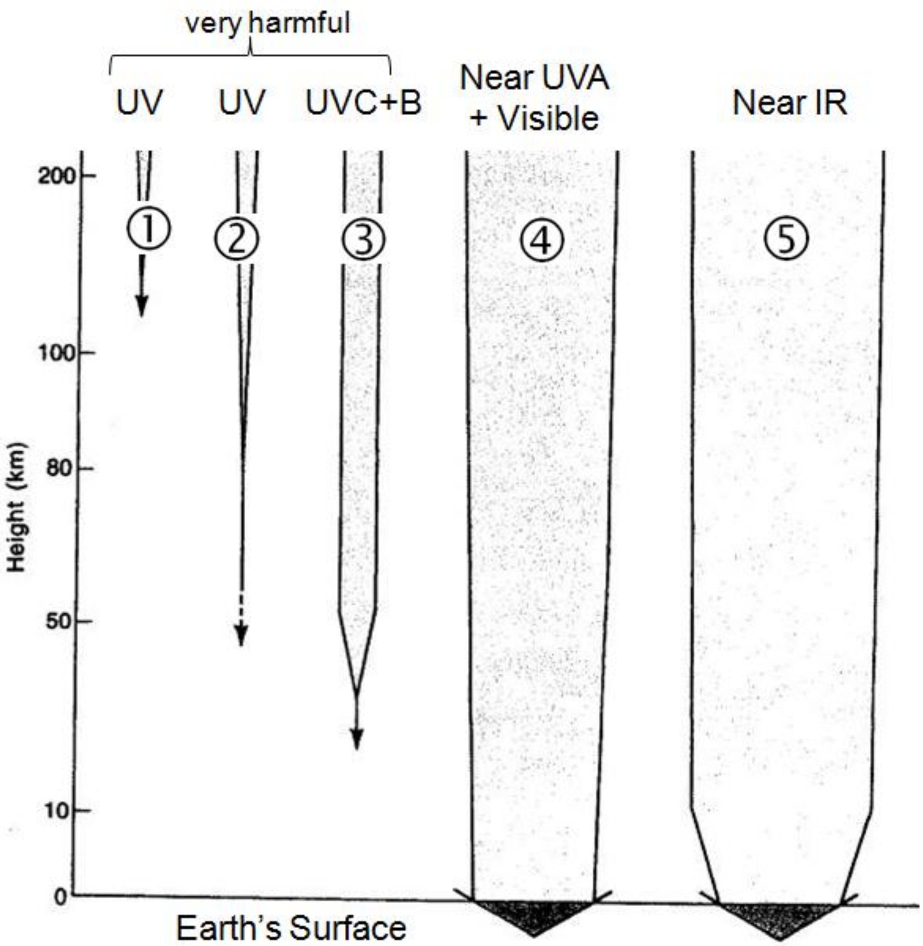
Vertical Structure of the Atmosphere
(another view)

from Chapter 3 in SGC-I p 45



Transfer & Absorption of Solar Radiation

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



On the diagram at left, draw in the Tropopause, Stratopause & Mesopause.

Then answer the following questions:

(a) 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?

(b) Why does ARROW #5's radiation get attenuated below 10 km??

(c) How about ARROW #3 below 50 km?

1. **UV, λ < 0.12 μm, absorbed by N_2 and O_2 in upper atmosphere**
2. **UV, 0.12 μm ≤ λ < 0.18 μm absorbed by O_2**
3. **UV, 0.18 μm ≤ λ < 0.34, μm absorbed by O_3 in ozone layer**
4. **Near UV and visible, 0.34 μm ≤ λ < 0.7 μm transmitted nearly undiminished except for scattering**
5. **Near IR, 0.7 μm ≤ λ < 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**

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
Most Abundant:				
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+ (*2009*) http://co2now.org/	390+ (*2010*) http://co2now.org/	1.66
* **Methane**	CH_4	0.0001774 *(in 2005)*	1.774	0.48
* **Nitrous Oxide**	N_2O	0.0000319	0.319	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	

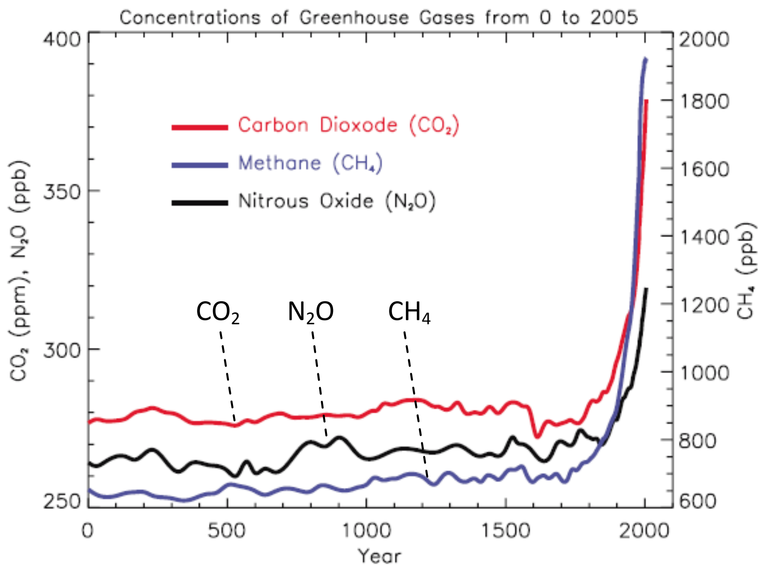
For more on GHG concentrations see: http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf Table 2.1

GREENHOUSE GASES OVERVIEW

The main greenhouse gases (GHG) in order of their concentration in the atmosphere (ppm by volume)

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) 387+ ppm (2009)	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

Two Important Global Change Terms Related to Atmospheric Composition

(They are being introduced now, but we'll discuss them in more detail later)

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.

In the IPCC report, radiative forcing is further defined as the change relative to the year 1750 and, unless otherwise noted, refers to a global and annual average value. (IPCC 2007)

Global warming potential (GWP) - An index, based upon radiative properties of well-mixed greenhouse gases, measuring the **radiative forcing** of a unit mass of a given greenhouse gas in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide.

GWP represents the combined effect of the differing times GHG's remain in the atmosphere and their relative effectiveness in absorbing outgoing thermal infrared radiation." (IPCC 2007)

More insights on (GWP)

- GWP is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming.
- It is a relative scale which compares the gas in question to that of the same mass of carbon dioxide (whose GWP = 1 by definition).
- A GWP is calculated over a specific time interval and the value of this must be stated whenever a GWP is quoted or else the value is meaningless. (The substances subject to restrictions in the Kyoto protocol either are rapidly increasing their concentrations in Earth's atmosphere or have a large GWP.)
- The GWP of a gas depends on: (1) the absorption of infrared radiation by a given gas, (2) the location of its absorbing wavelengths on the electromagnetic spectrum, and (3) the atmospheric lifetime of the gas
- A high GWP correlates with a large infrared absorption and a long atmospheric lifetime.
- A gas has the most effect if it absorbs in a "window" of wavelengths where the atmosphere is fairly transparent.

Based on: http://en.wikipedia.org/wiki/Global_warming_potential

SUMMARY: ATMOSPHERIC STRUCTURE & CHEMICAL COMPOSITION

Key Climate Science Literacy & 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, $\mathbf{O_3}$ 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 longwave 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."**

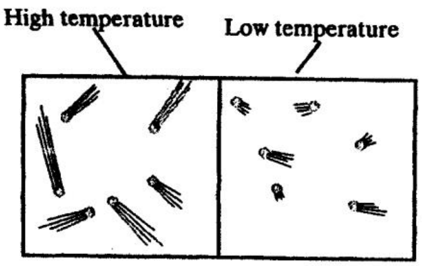
4. **The differential absorption of wavelengths of radiation by atmospheric gases at various elevations leads to the "vertical structure" of the atmosphere:** troposphere, stratosphere, mesosphere, thermosphere. The boundaries separating these layers of the atmosphere are defined by temperature changes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

ADDITIONAL NOTES:

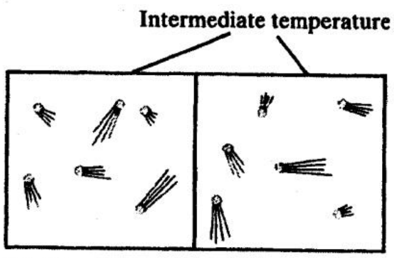
TOPIC # 9 – LAWS OF THERMODYNAMICS
KEYS TO ENERGY TRANSFER & CONSERVATION

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

THERMAL ENERGY (INTERNAL ENERGY) - A measure of the quantity of atomic **kinetic & potential 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.



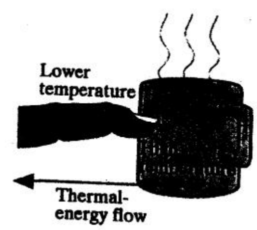
(a) A hot box of gas and a cold box of gas, at the instant they are put into contact: Most of the molecules in the hot box move rapidly, while most of the molecules in the cold box move slowly.

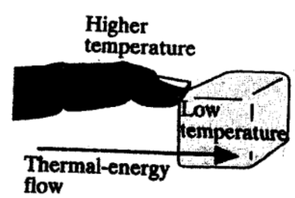


(b) After there has been time for the hot box to warm up the cold box, the molecules in the left-hand box have slowed down while those in the right-hand box have sped up.

Temperature = tells how warm or cold a body is with respect to some standard (e.g., Fahrenheit, Celsius, or Kelvin standard scales). Temperature is a measure of the average kinetic energy of each molecule in a body. 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 molecule on the average has 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.**





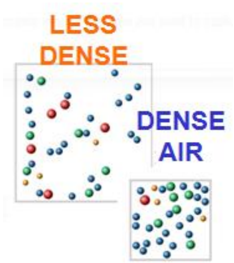
Unit of Measure of Thermal Energy - the *joule* or *calorie*. A calorie is the amount of thermal energy required to change the temperature of 1 gram of water by 1°C (specifically from 14.5°C to 15.5°C) (one gram of water is roughly equivalent to the weight of one cubic centimeter of water)

Specific Heat = the amount of thermal energy (in calories) required to raise the temperature of 1 gram of *any substance* by 1°C.

Why will he burn his tongue??

Heat Capacity = specific heat x mass (density) of a substance for a given volume. (Density measured in grams per cubic centimeter.) Heat capacity represents the capacity of a substance to absorb heat in relation to its *volume* and *density*.

Substance	Specific Heat		Heat Capacity *(calories per cubic cm)*
	calories	*joules*	
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

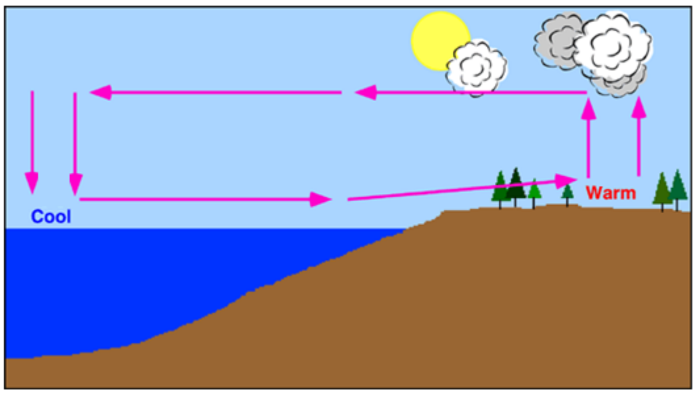


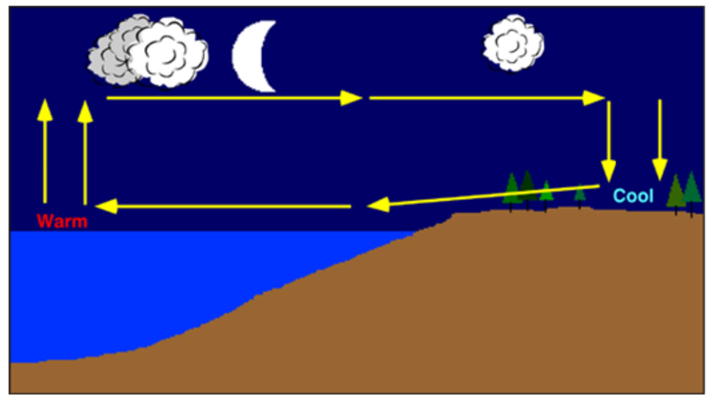
MORE THERMAL PROPERTIES OF SUBSTANCES

Heat generally causes *expansion* of a substance, because when the temperature of the substance is increased, the molecules jiggle faster and the more energetic collisions between the molecules force them to move farther apart, thus expanding the substance (and making it less dense).

🌎 **Hot air is less dense than cold air and tends to rise; cold air is more dense than hot air and tends to sink <== key factor in global weather & climate**

Thermally driven density differences of air
+ differences in the specific heat / heat capacity of LAND vs. WATER ➔ atmospheric circulation

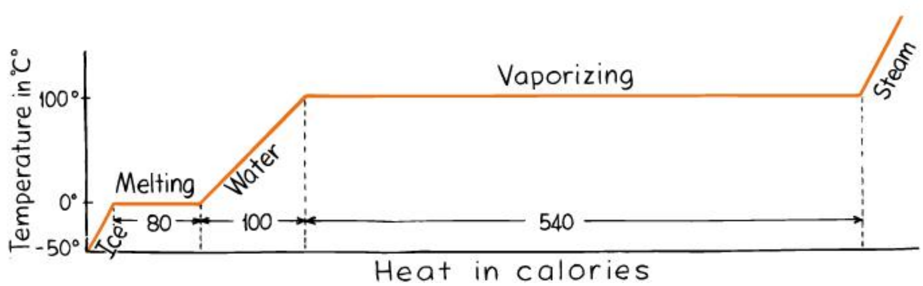




THERMAL ENERGY & PHASE CHANGES IN MATTER

Phase Changes in Matter: solid => liquid => gas, solid <= liquid <= gas, etc.

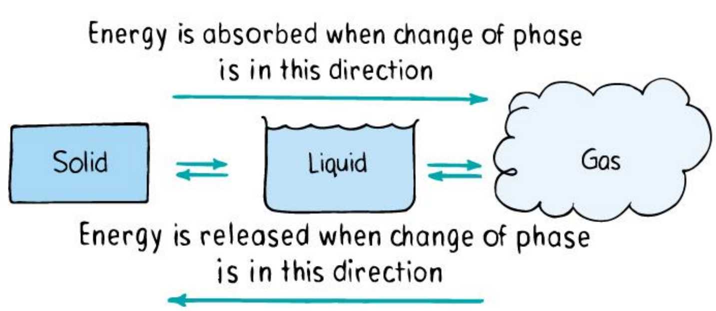
Water example: What's happening to the energy at the points when the graph is horizontal??



LATENT ENERGY (LE) & SENSIBLE HEAT (H)

Energy in the form of **sensible heat (H)** is absorbed from the surrounding environment and stored in the form of **latent energy (LE)** (hidden energy) during the melting and evaporation (or boiling) processes. This cools the environment.

Energy is released into the surrounding environment from its latent (hidden) form into sensible heat (H) during the condensation and freezing processes. This warms up the surrounding environment.



During these times of when the state of the H_2O is changing, the H_2O does not change its temperature because the energy involved is LE, not H.

THERMAL ENERGY TRANSFER

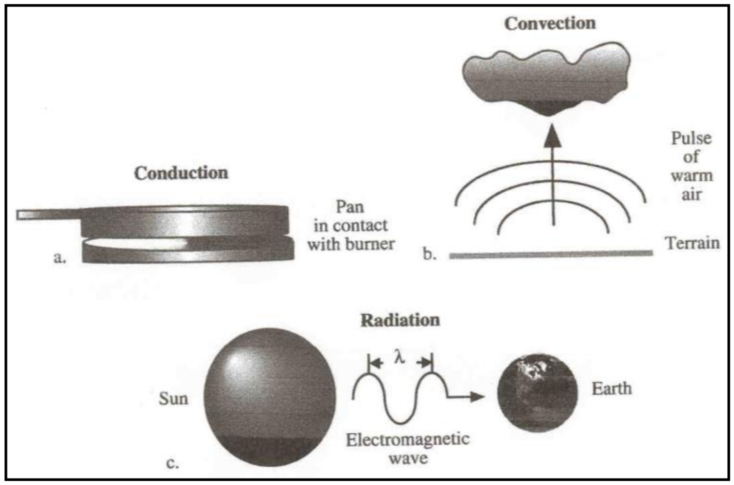
(aka " Heat Transfer")

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*****.**

<u>**CONDUCTION**</u> = 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.

<u>**CONVECTION**</u> = 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***.

In a convection cell, a liquid or gas is heated from below and the areas of the liquid or gas closest to the heat source expand. By expanding, the density of the warmer areas of liquid or gas is reduced, and they rise through the rest of the liquid or gas. Near the top, they cool because they are away from the heat source; hence they stop expanding, start to become more dense, and begin to sink. This process continues until heat is uniformly distributed throughout the liquid or gas.



<u>**RADIATION**</u> = 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 <u>*not*</u> require atoms or molecules (matter)** to facilitate the transfer process.

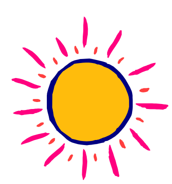
More about Electromagnetic Radiation:

Radiant energy, includes LIGHT - Energy originating from vibrating electrons in matter, due to oscillating electrical charges (not from molecular motion), and transported through space by means of *electromagnetic waves* or high-speed particles (*photons*).

- All matter emits (gives off) radiant energy.
- **Light** is composed of ***photons***, the basic packet of electromagnetic radiation where electrons not only vibrate but leap from higher to lower energy states within an atom.
- Electromagnetic energy does not NEED matter to be transferred, but when it DOES **react with matter,** it can be TRANSMITTED, ABSORBED, SCATTERED, or REFLECTED through -- or by -- the matter.

IMPORTANT POINT TO KEEP IN MIND: **Electromagnetic energy (radiation) is energy that <u>does not</u> involve <u>*molecular*</u> 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

KEY CONCEPT: **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, etc.)**



All of the energy transformations related to THERMAL ENERGY, described above are governed by LAWS (see next page)

ENERGY TRANSFORMATIONS & THE LAWS OF THERMODYNAMICS

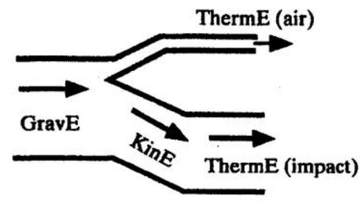
"Everything that happens can be described as energy transformation."

THE FIRST LAW OF THERMODYNAMICS *(stated as the "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.

Other ways of stating the FIRST LAW OF THERMODYNAMICS:

- Energy can be transformed (changed from one form to another), but the total amount always remains the same.
- In an isolated system the total amount of energy, including heat energy, is conserved, although energy may change from one form to another over and over again.
- When heat flows to or from a system, the system gains or loses an amount of thermal energy equal to the amount of heat transferred.
- Heat added to a system = increase in thermal energy of the system + external work done by the system.



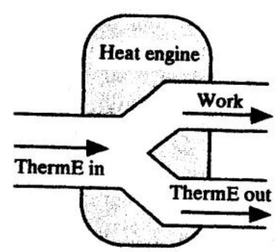
Energy flow diagram for a falling book, with air resistance. The widths of the pipes correspond to the amounts of energy involved in different parts of the process. Since energy is conserved in each stage of the process, the pipe widths match up at each intersection.

SECOND LAW OF THERMODYNAMICS *(stated as the "Law of Heating")*

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.

Other ways of stating the SECOND LAW OF THERMODYNAMICS:

- *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.**



IMPICATIONS FOR GLOBAL CLIMATE CHANGE SOLUTIONS VIA ENERGY CONSERVATION:

Irreversibility: Once a system creates thermal energy, that system will never by itself (spontaneously) be able to return to its previous condition. 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/

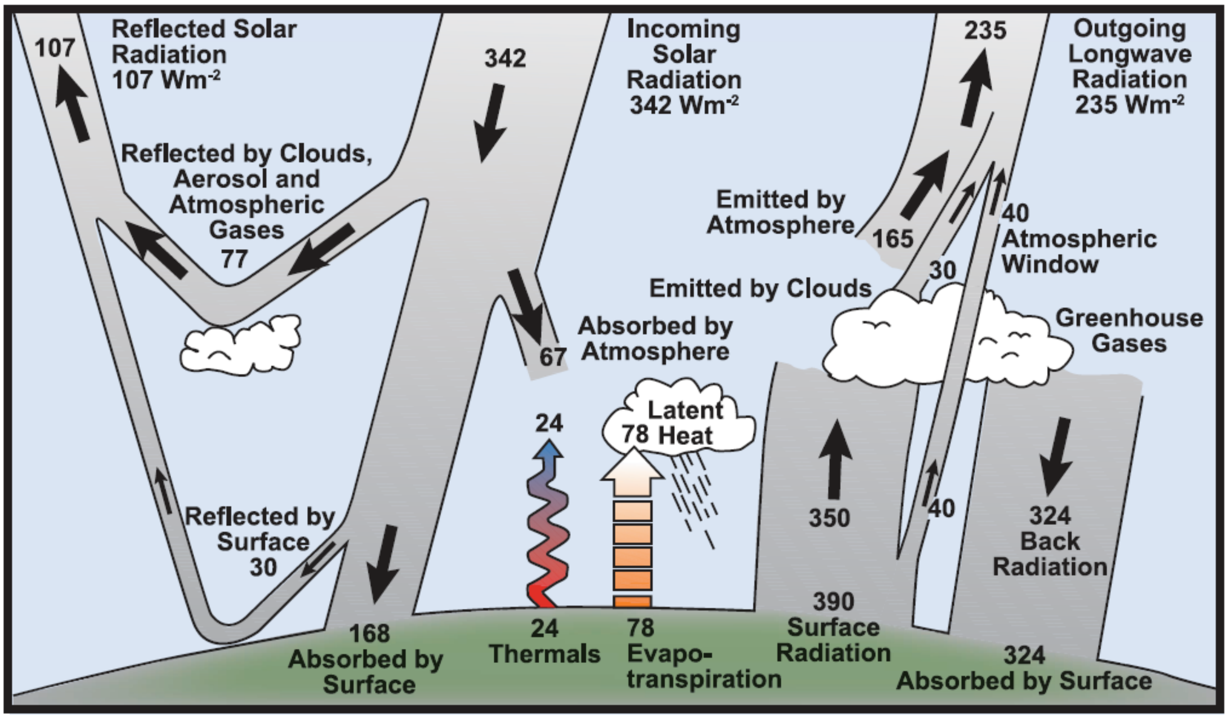
TOPIC # 10 – THE GLOBAL ENERGY BALANCE

> 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.



IPCC AR4 WG I: FAQ 1.1, Figure 1. Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997). http://www.ipcc.ch/ipccreports/ar4-wg1.htm

ALBEDO = reflectivity of a surface

Represented as:
a decimal from 0 to 1.0 or %

100 % = perfect reflectivity.

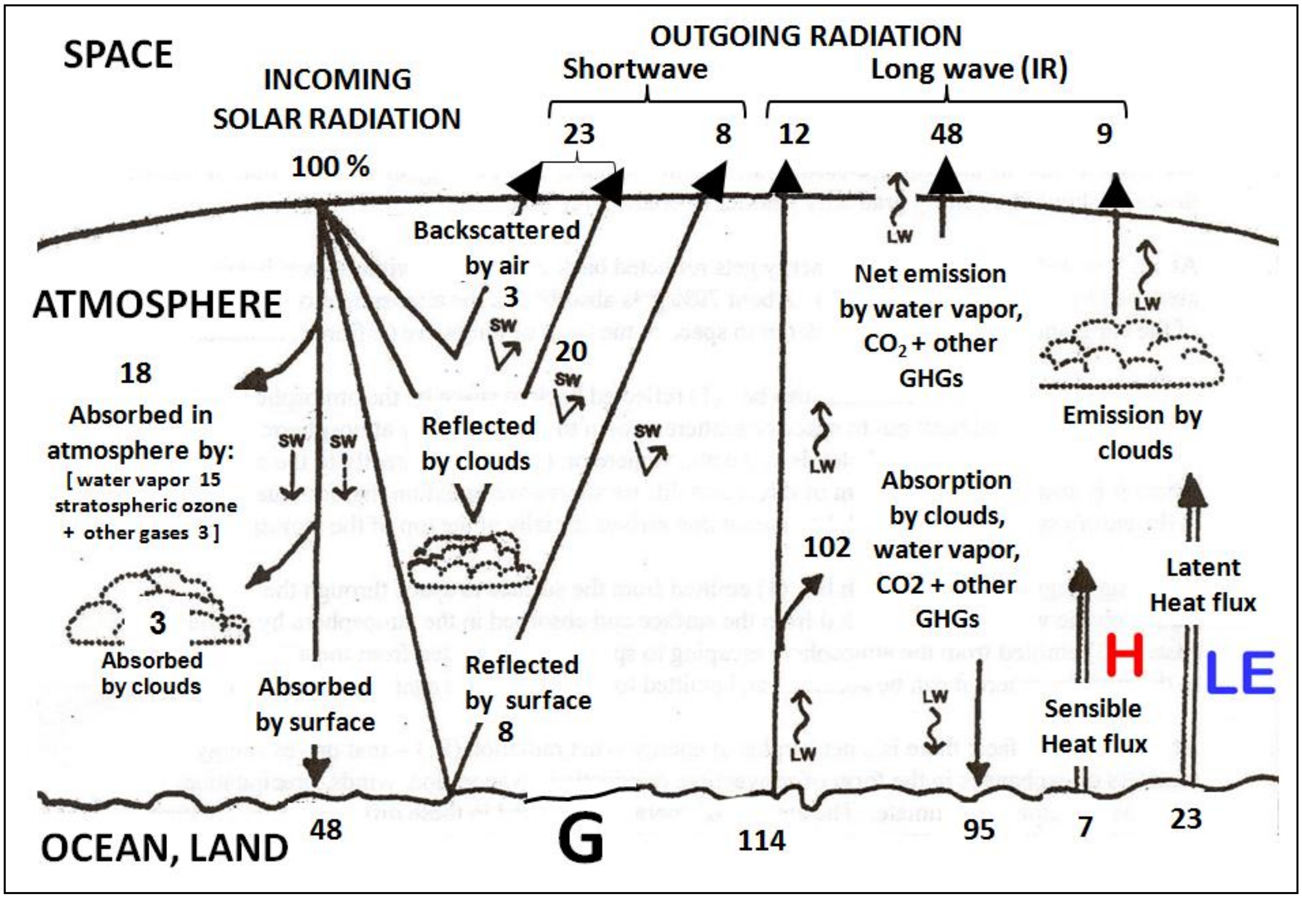
The amount *absorbed* = (1.0 – albedo)

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

Representation of the Energy Balance & Energy Pathways

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



(Figure updated from M.C. MacCracken and F.M. Luther, eds. *Detecting The Climatic Effects of Increasing Carbon Dioxide*. Report DOE/ER-0325. 1985, U.S. Department of Energy, Washington D.C.) Compare with SGC Fig 3-19 (p 51). Update based on IPCC 2007

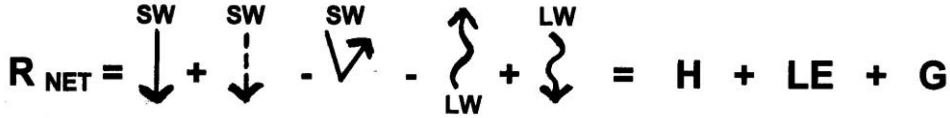
DOES IT REALLY BALANCE? The distribution of 100 units of incoming solar radiation and outgoing infrared radiation on a global scale indicates excess heating ("Net Radiation") at the Earth's surface. This excess heat energy is transferred to the atmosphere via sensible heat flux (H) and latent heat flux (LE).

	INCOMING		OUTGOING		R_{NET}
	SW	LW	SW	LW	IN - OUT
Balance at top of atmosphere	**100 %**	0	23 + 8 = **31**	12 + 48 + 9 = **69**	**0**
Balance within atmosphere	**21**	**102**	0	95 + 48 + 9 = **152**	**- 29**
Balance at Earth's surface	**48**	**95**	0	**114**	**+ 29**

R_{NET} = 0 at the top of the atmosphere
R_{NET} = + 29 at the Earth's surface, but these surplus units go into H + LE fluxes to atmosphere (G = 0)
R_{NET} = - 29 within the atmosphere, but this deficit is balanced by H + LE fluxes from Earth's surface

SELF TEST: See <u>Dire Predictions</u> text (bottom of p 64) "Budgeting the Incoming Radiation" Can you find the matching portions on the diagram above??

THE ENERGY BALANCE



Key **<u>Climate Science Literacy & Global Change Concepts</u>**

1. We 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.

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.

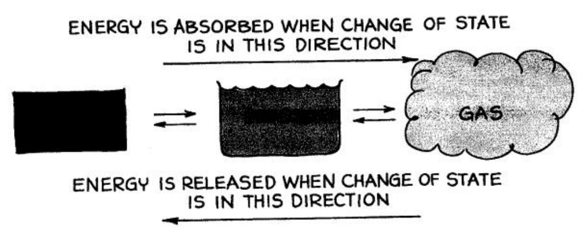
3. Incoming shortwave solar radiation can be: (1) reflected back to space by the atmosphere or by the surface, (2) scattered back out to space or scattered down to the surface by atmospheric gases, dust, etc., (3) absorbed by gases and clouds in the atmosphere or, (4) beamed directly to the surface where 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. Outgoing longwave radiation can be: (1) emitted from the surface to space through the "atmospheric window," (2) emitted from the 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 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 -- **net radiation (R_{net})** -- that drives energy transfers or exchanges in the form of convection, conduction, evaporation, winds, precipitation, etc.....our weather and climate. The amount of energy transferred in these different forms -- **latent heat (LE), sensible heat (H),** and **ground (soil) heat flux (G)** -- varies from place to place on the earth.

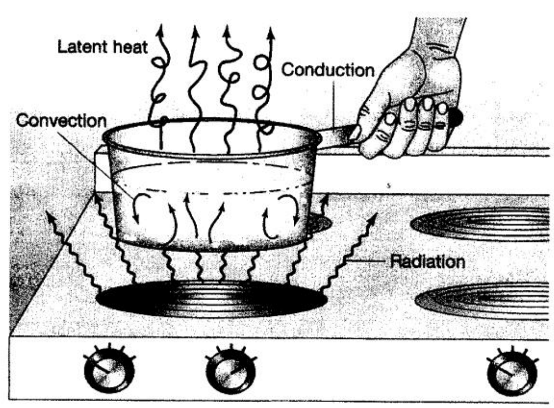
Review for Understanding the RIGHT side of the equation: H + LE + G (see also Topic #9)

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.

H = sensible heat transfer



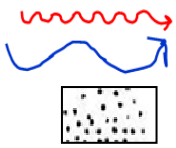
Sensible heat is the energy or heat of molecular motion. It can be "sensed" with a thermometer, and we "feel" it as heat, unlike LE. It is transferred by ***conduction*** from warmer to cooler objects (most common in solids); and by ***convection*** (large scale, mostly vertical, motion of gases or liquids)

G = "ground storage," i.e. transfer of heat into the ground or soil; ground / soil heat flux

Heat ***conducted*** into soil (or water) and temporarily stored there to be released later. 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.

CLASS CONCEPTS SELF TEST

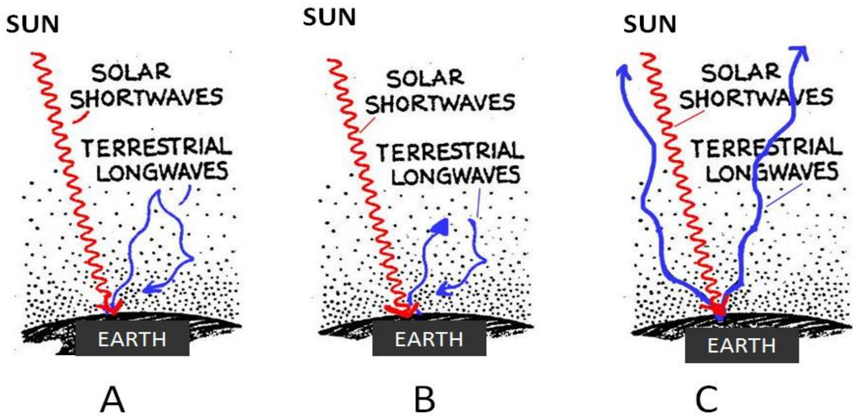
KEY:



= **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)



Q1. Which diagram above shows SW radiation being reflected back to space?
Diagram A Diagram B Diagram C None of them

Q2. 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 the Greenhouse Effect works? Yes No Partly

Q3. Diagram B shows LW radiation being absorbed and them emitted by the gases in the atmosphere. Is this an accurate depiction of how the Greenhouse Effect works? Yes No Partly

Q4. Diagram C shows LW radiation going right through the atmosphere out to space. Is this an accurate depiction of how the Greenhouse Effect works? Yes No Partly

Q5. 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 the Greenhouse Effect.

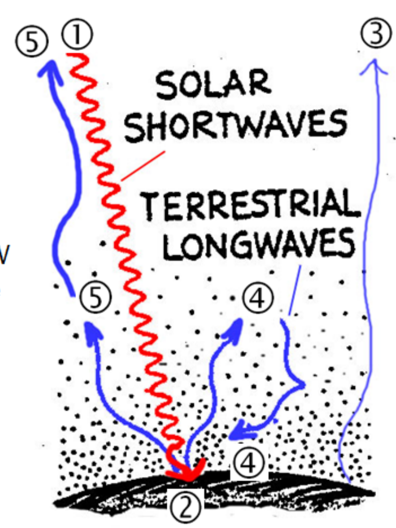
Q6. Below is a modified version of the cartoon. It is more complete and more accurate, but there are still some important processes not being represented. Can you think of what they might be?

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"



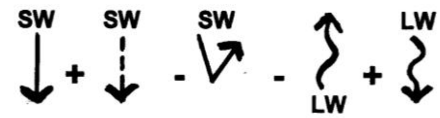
④ Some IR radiation is absorbed by GH gases in the atmosphere and emitted <u>back</u> to Earth

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

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 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 your next test or the midterm exam.

Phenomena related primarily to the LEFT side of the equation:



1) You see the sky as blue.

2) People wear sunglasses on the ski slope.

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

4) 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)*

5) The Greenhouse effect.

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

7) 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.

8) Traditionally, players wear white on the tennis court.

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

10) You see the colors of a rainbow.

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

12) 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

13) a hot air balloon

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

15) 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.

ADDITIONAL NOTES:

TOPIC #11 SYSTEMS & FEEDBACKS
INTRODUCTION TO MODELING

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

SYMBOLIC NOTATION

- use of a picture or diagram instead of words
- abbreviation, symbol, or acronym instead of spelling out the whole word or concept:

NATS 101-GC $ % & + - = x or * IPCC

NUMBERS!!

1, 2, 8 3.8×10^{-4}

Elements and molecules:

H, He, H_2O CO_2

Formulas & Equations

$y = a + bx$ (equation for a straight line)

WHAT IS A MODEL?

- a representation of something (usually miniature or not to scale)
- an example for imitation or emulation
- a person or thing that serves as a pattern
- an analogy or analogue of something
- "a description or analogy to help visualize something that cannot be directly observed"
- or "a <u>system</u> of postulates, data, and inferences presented as a mathematical description of an entity or state of affairs"

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

<u>Component</u> *(def)* =

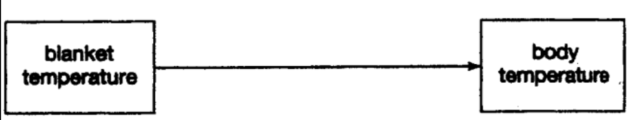
An individual part of a system. A component may be a reservoir of matter or energy, a system attribute, or a subsystem.

<u>Coupling</u> *(def):*

The links between any two components of a system.

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

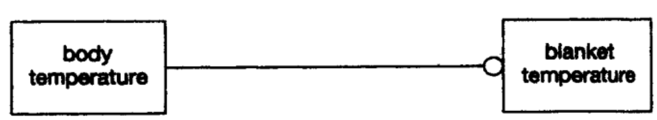
A coupling between an electric blanket temperature component and a body temperature component:



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)* =

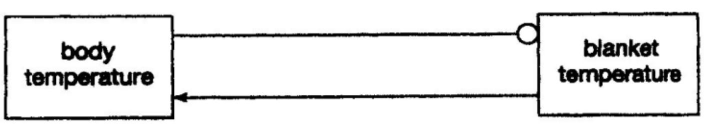
A linkage of two or more system components that forms a ROUND-TRIP flow of information.

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

FEEDBACK LOOP

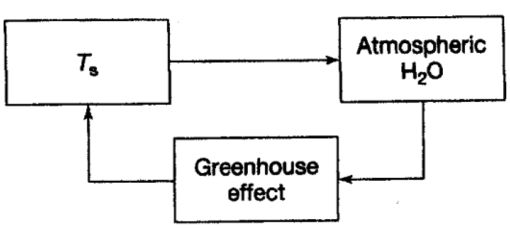
What kind of FEEDBACK LOOP IS IT?

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



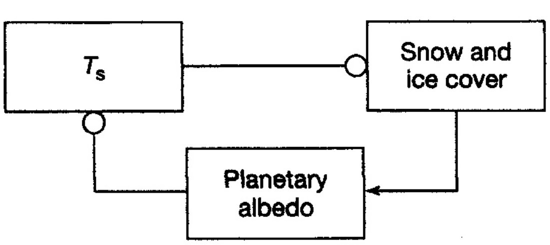
WATER VAPOR Feedback in the Earth-Atmosphere

What kind of FEEDBACK LOOP IS IT?



SNOW AND ICE ALBEDO Feedback

What kind of FEEDBACK LOOP IS IT?



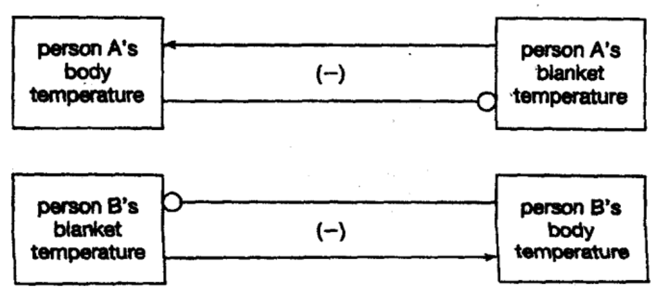
A ***positive feedback*** is an interaction that amplifies the response of the system in which it is incorporated

(self-enhancing; amplifying)

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

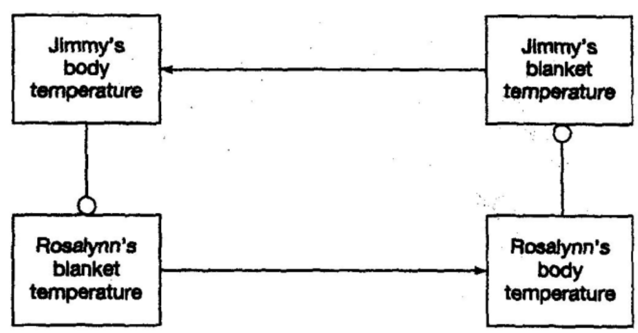
(self-regulating; diminishes the effect of perturbations)

Proper alignment of dual control electric blanket:



Improper alignment:

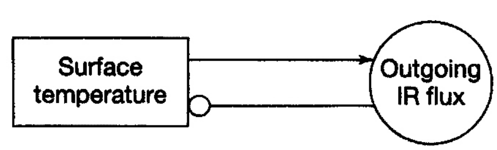
What kind of FEEDBACK LOOP IS IT?



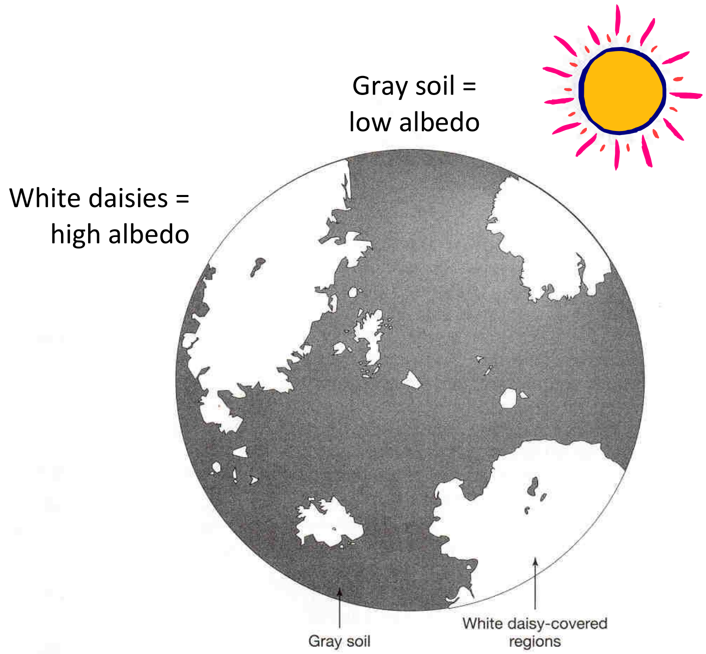
A __________ FEEDBACK LOOP that ____________ the effect!

OUTGOING INFRARED ENERGY FLUX / TEMPERATURE Feedback

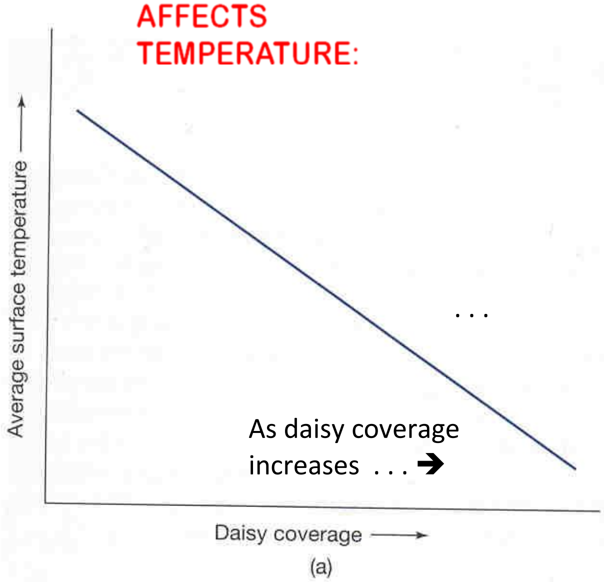
What kind of FEEDBACK LOOP IS IT?

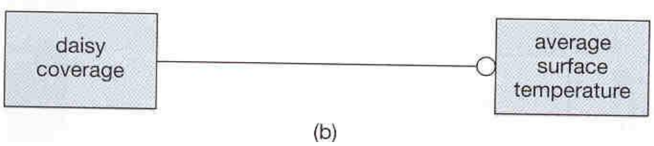


DAISYWORLD MODELING:

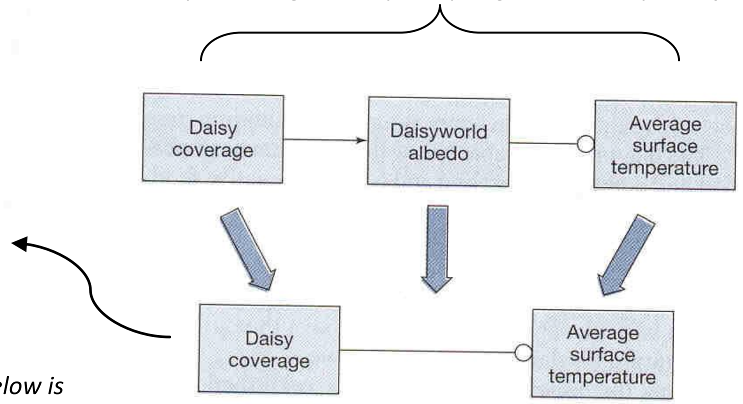


HOW DAISY COVERAGE AFFECTS TEMPERATURE:



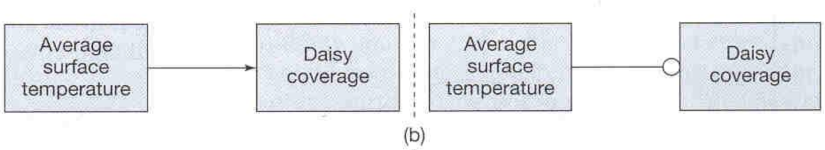


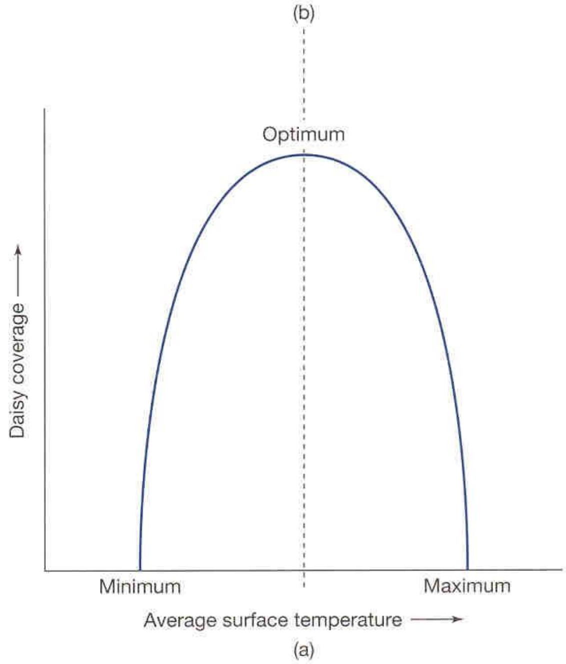
These are the "in between" processes that explain the Daisy Coverage/ Temp coupling relationship at left



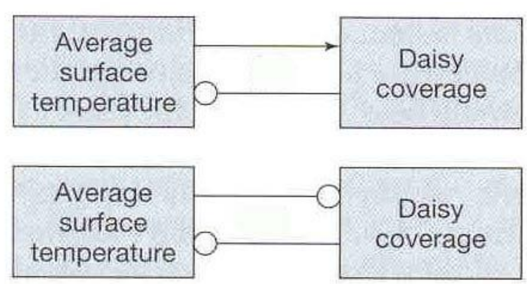
HOW TEMPERATURE AFFECTS DAISY COVERAGE:

Note how the order of the couplings below is reversed from that in the coupling above



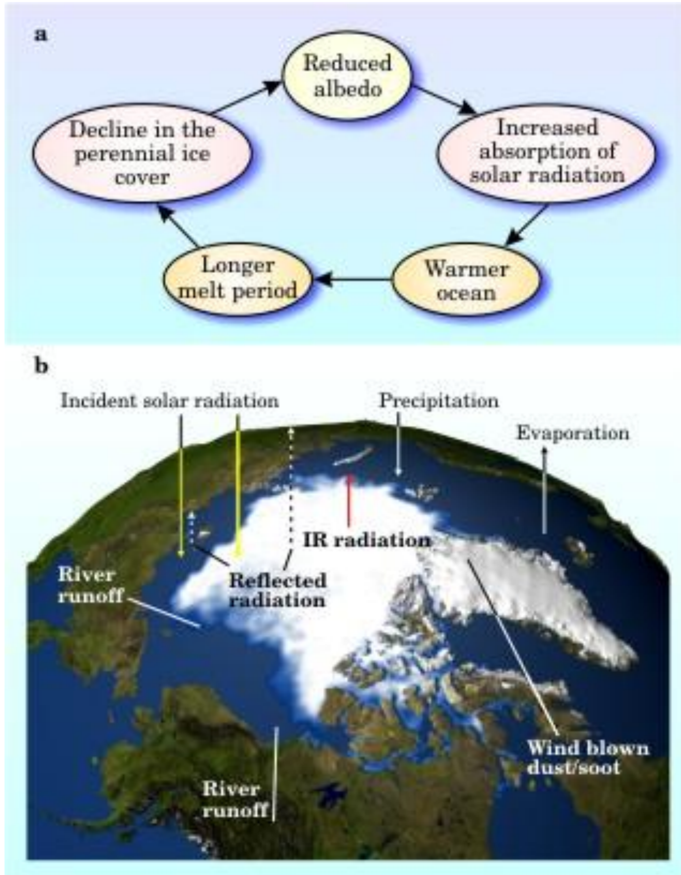


One loop is + and one is –
Which is which?



Which loop is in a STABLE equilibrium state?

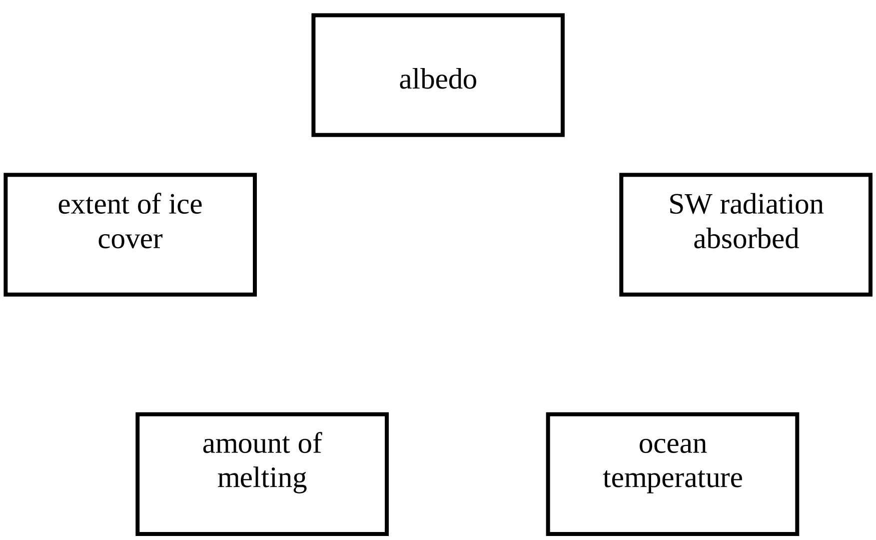
SELF-TEST: IS THIS FEEDBACK LOOPS POSITIVE OR NEGATIVE?



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 SGC textbook. 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 SGC arrow symbols to indicate positive or negative couplings between each of the components set up for you in the boxes below.

When your sketch is completed, state whether the entire loop is a POSITIVE (self-enhancing) or NEGATIVE (self-regulating) feedback loop.

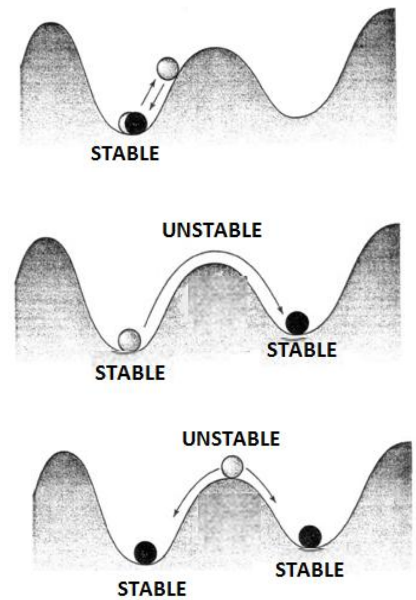


EQUILIBRIUM STATES

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)

PERTURBATIONS & FORCINGS
can upset equilibrium states

Perturbation = temporary disturbance of a system (shorter-term than a forcing)
Forcing = more persistent disturbance of a system (longer-term than a perturbation)

A **forcing** can be quantified as an *index* of the importance of some <u>factor</u> (e.g. GHG concentration) as a potential climate change mechanism (e.g., "anthropogenic CO_2 contributes n-degrees to global temperature warming")

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

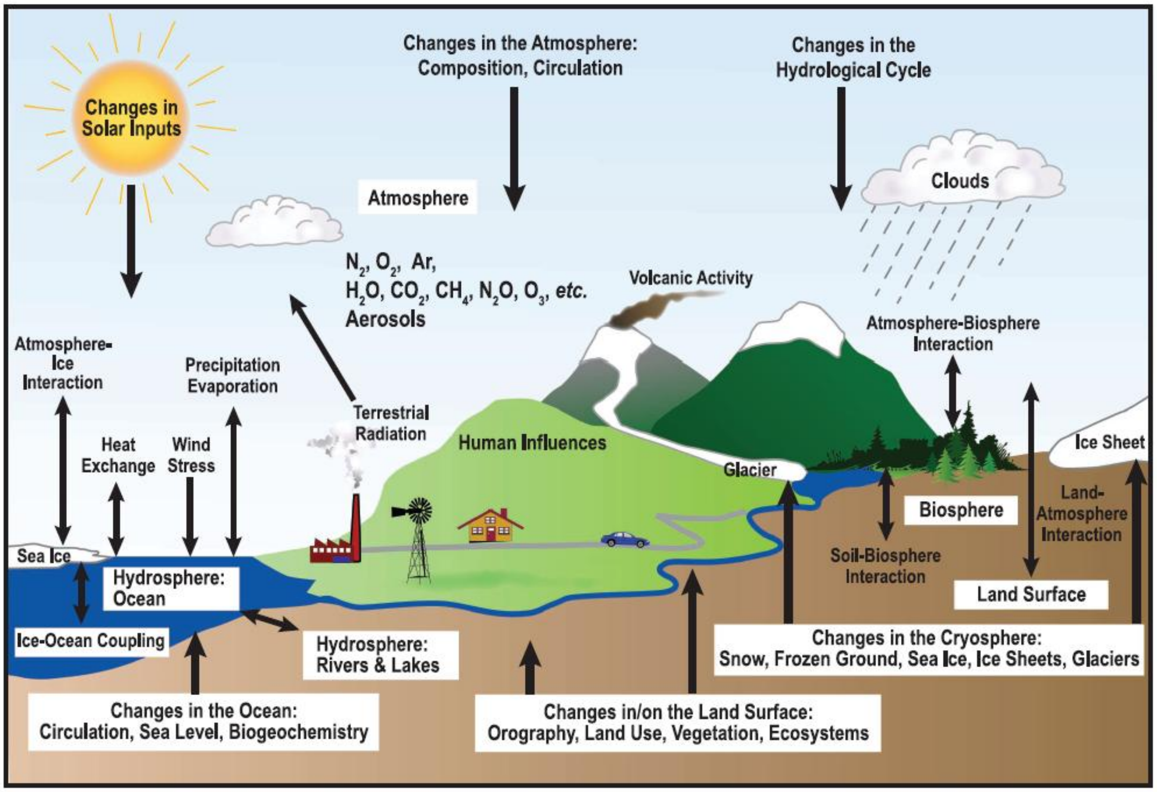
VS.

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?

MODELING THE CLIMATE SYSTEM: A BRIEF LOOK

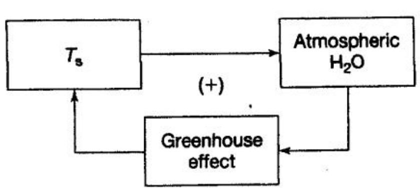


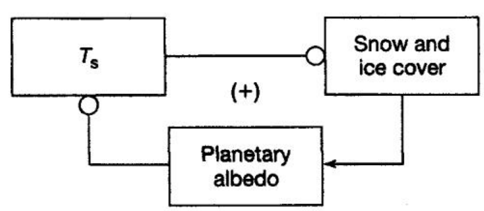
Schematic view of the components of the climate system, their processes and interactions.
[Source: IPCC AR4-WG-I FAQ Figure 1 http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-faqs.pdf]

Incorporating Feedbacks into Models:

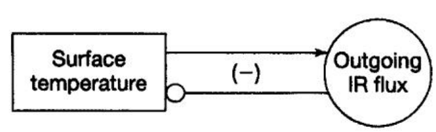
Recap on Feedback mechanism (def): a sequence of interactions in which the final interaction influences the original one. A ***positive feedback*** is an interaction that amplifies the response of the system in which it is incorporated (self-enhancing; amplifying). A ***negative feedback*** is an interaction that reduces or dampens the response of the system in which it is incorporated (self-regulating; diminishes the effect of perturbations)

Feedbacks in the Earth-Atmosphere system can come from **water vapor** in the atmosphere (*positive* feedback loop) and the effects of **snow and ice albedo** (*positive* feedback loop).





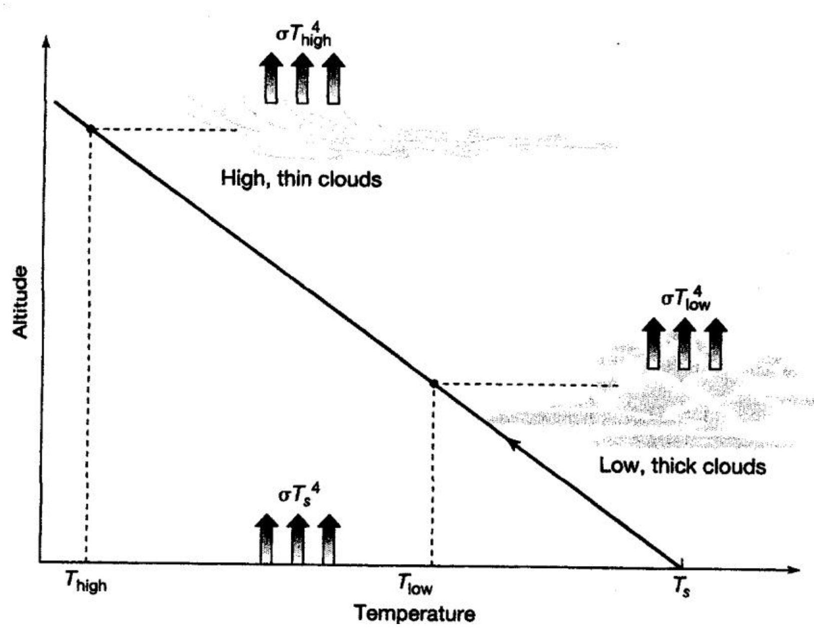
The IR Flux/Temperature feedback is a *negative* feedback loop which helps to stabilize the climate – it ends up in a **steady state** between outgoing IR and the Earth's surface temperature



__**Radiative Convective Models**__ (RCM) – these can model **several different layers of the atmosphere** and take into account **H (convection) and LE (evaporation) fluxes**. RCM's can incorporate things like H, LE, and albedo in their **calculation of the radiation balance and temperature** in different atmospheric layers, **but cannot model horizontal variations** or address ***feedback mechanisms.***

They *can* **estimate global average surface temperature change** due to **a doubling of CO_2** (2 x CO_2) with no feedbacks incorporated into model.

CLOUDS (can contribute to BOTH *positive* or *negative*, feedback mechanisms, depending on the type and height of the clouds!)



High, thin clouds (cirrus) are made of ice crystals and are somewhat transparent; they allow incoming solar radiation to pass through, however, they absorb outgoing IR radiation;. Also, because they are high in the atmosphere they are very cold clouds, hence according to the Stefan-Boltzmann law, they radiate less of the IR they absorb out to space.
(Positive feedback => amplifies the effect of global warming)

Low, thick clouds (stratus) reflect much of the incoming solar radiation. They also absorb IR terrestrial radiation, but because they are lower in the atmosphere, they are warmer clouds and according to the Stefan-Boltzmann law they radiate more of the IR they absorb out to space.
(Negative feedback => diminishes the effect of global warming)

<u>General Circulation Models</u> (GCMs)

These are highly **complex three-dimensional models** of the atmosphere on a grid. The models compute atmospheric pressure, velocity, density, and water vapor as functions of time **for each grid box in a latitude-longitude grid covering the entire Earth** in the horizontal dimension, and as many as **20 layers of the atmosphere** in the vertical dimension.

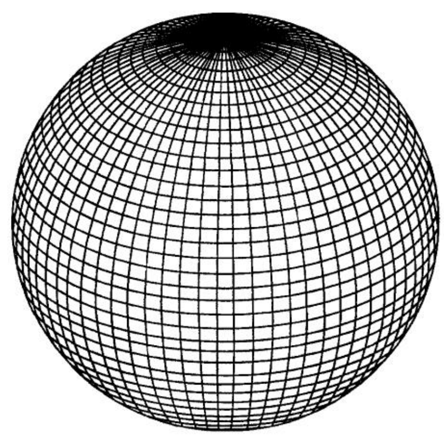


FIGURE 13-8
Latitude-longitude grid for a typical atmospheric general circulation model (GCM).

- These models can predict not only how much change in temperature might occur due to an enhanced greenhouse effect **but also *where* the changes are likely to manifest themselves**.
- All of the calculations are based on physical principles such as the **1st law of thermodynamics and Newton's 2nd law of motion**. Some models "couple" the ocean and atmosphere for better results.
- **The models are so complex that they require hundreds of hours of computing time on a supercomputer!**
- **They <u>can</u> incorporate some feedback mechanisms, but even such sophisticated models cannot predict processes, such as cloud feedback mechanisms, that occur at scales smaller than a grid box.** Hence the inability to model processes like cloud radiational effects in detail, leads to uncertainties and differences in the estimates produced by different GCMs.
- Even with their uncertainties, **GCMs can give good results and fairly reliable estimates of the range of expected change** in the atmosphere (e.g. global temperature increase) due to GHG forcing.

ADDITIONAL NOTES:

TOPIC # 12 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**, Topic #7).

> **The latitudinal variation of INSOLATION drives the general circulation of the atmosphere and the resulting weather and climate throughout the globe!**

The total daily insolation received at a given latitude is a factor of **Intensity + Duration**

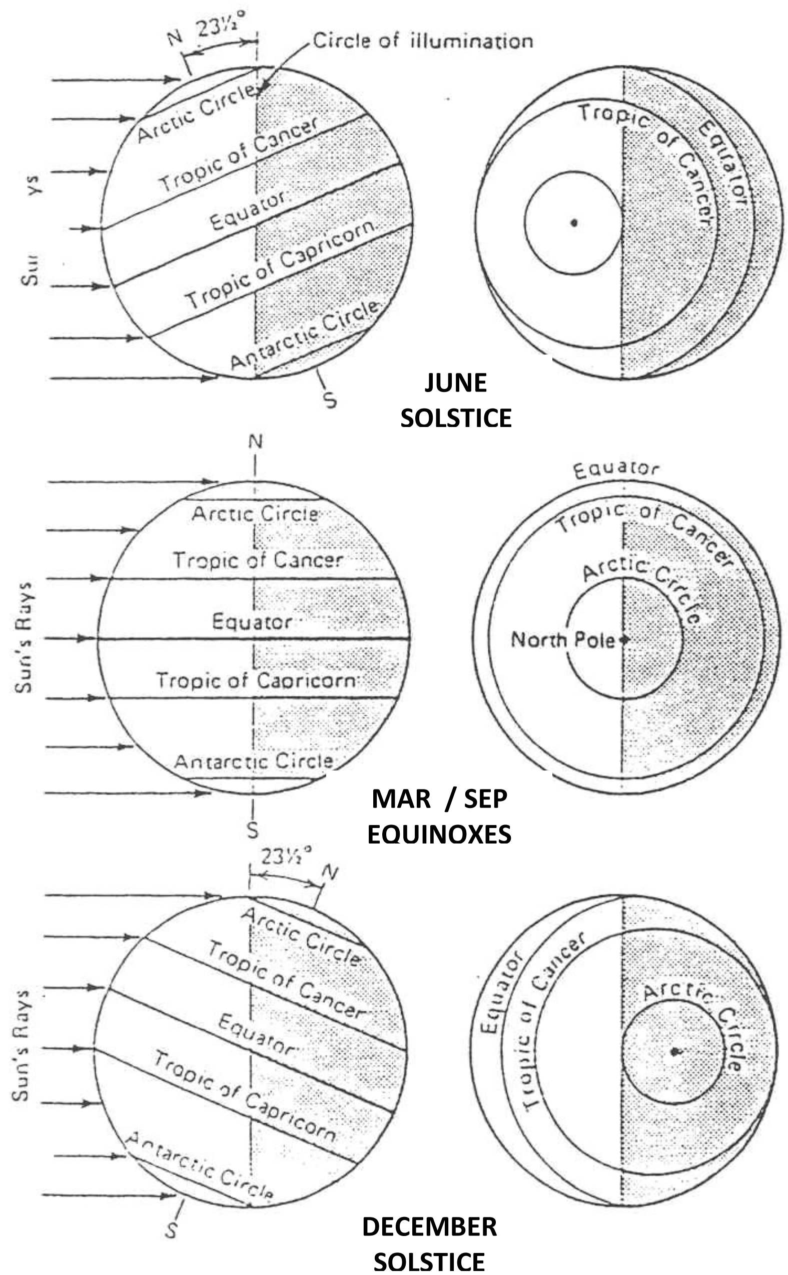
- **INTENSITY** of sun's rays
  [depends on axis tilt and how earth intercepts sun's rays]
  Intensity varies with latitude and with the time of year

- **DURATION** of daily insolation (the "Day length"
  [depends on where circle of illumination intersects latitude band]
  Day length varies with latitude and with the time of year

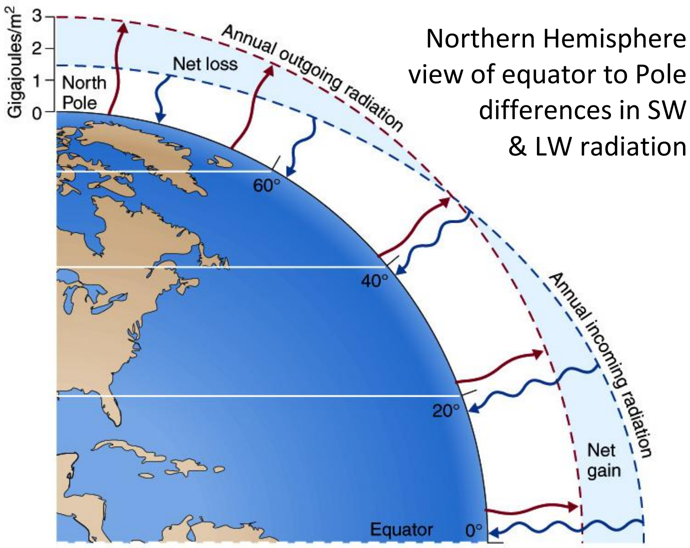
  Solstices and Equinoxes are Key Dates:

  Jun and Dec Solstices: Earth's axis tilt is at a maximum either away from, or toward the Sun – day lengths vary, depending on latitude ; uneven receipt of insolation between N & S Hemispheres

  Mar and Sept Equinoxes: Earth's axis tilt is not pointed toward or away from the Sun – day lengths are the same at all latitudes; fairly even receipt of insolation in both hemispheres



THE RADIATION BALANCE &
THE GENERAL CIRCULATION OF THE ATMOSPHERE



HOW IT ALL FITS TOEGETHER:

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

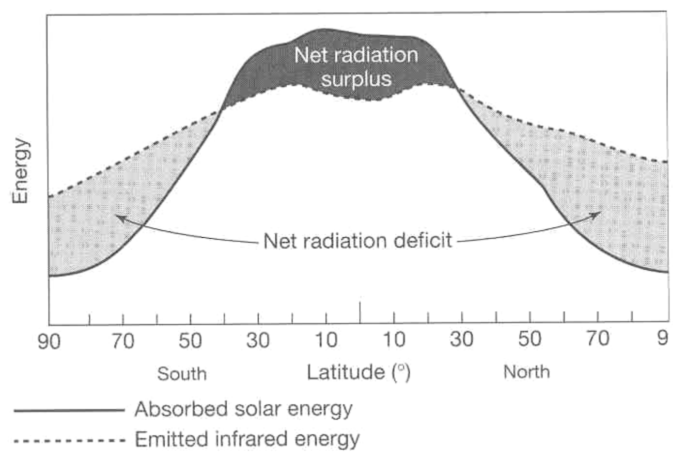
• OUTGOING **TERRESTRIAL LW** radiation varies by latitude too (more LW emitted at warmer tropical latitudes, less in the cooler high latitudes)

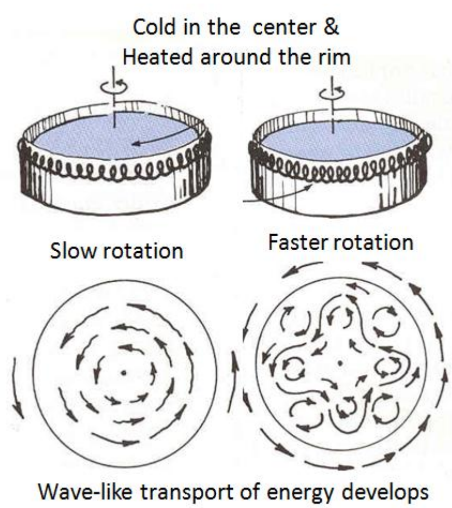
• The **EQUATOR–POLE DIFFERENCES** in how much LW radiates out are not as great as the equator-pole differences in how much SW comes in. Hence more comes <u>in</u> than goes out at the <u>low latitudes</u> and more goes <u>out</u> than comes in at the <u>high latitudes.</u>

• 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.

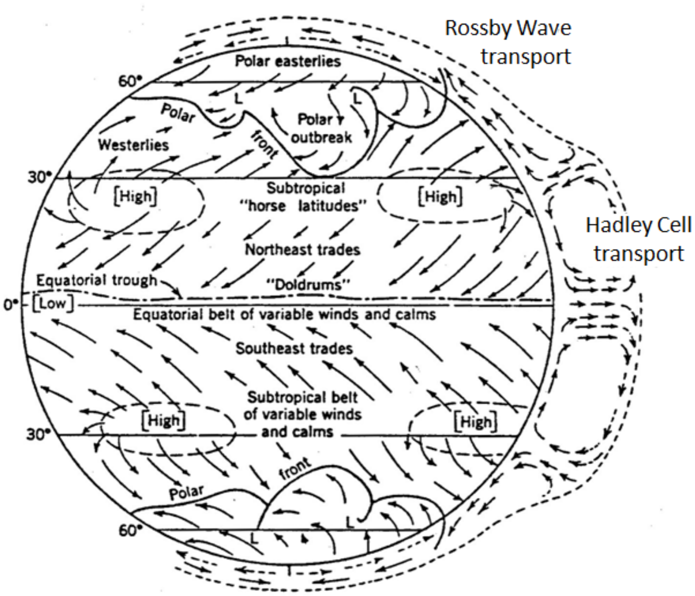
Pole-to-Pole view of differences in SW & LW radiation





The "dishpan experiment" (depicted above) demonstrates how – in a rotating system – **convections cells**, and eventually a "wave-like" circulation (called **Rossby waves**) are needed to balance out the thermal differences in the pan.

The resulting circulation system in this "analog model" balances out the deficit of energy in the cold center of the pan (the modeled "North Pole") with the surplus of energy at the heated outer rim of the pan (the modeled "Equator").

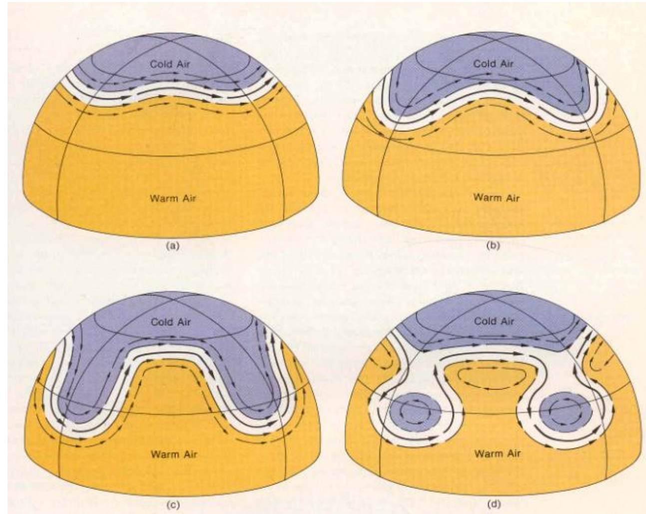


The General Circulation of The Atmosphere

MORE ON ATMOSPHERIC CIRCULATION & THE ENERGY BALANCE

About Upper Level Winds

Far above the Earth's surface and away from the influence of surface friction, winds can move with great velocity. They are fastest where the thermal and pressure differences are the greatest at the surface. In the upper troposphere, a narrow band of high velocity winds, called the **jet stream**, flows along the boundary between cold polar air and warm tropical/subtropical air in a meandering or wavy pattern sometimes referred to as **ROSSBY WAVES** or the **CIRCUMPOLAR VORTEX**. The polar front is the surface expression of the upper air Rossby waves.



The wavy pattern of the jet stream and circumpolar vortex changes from day-to-day and season-to-season.

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

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.

Why does the Rossby wave circulation develop?

The "dishpan experiment" demonstrates that to balance out the deficit of net radiation near the poles with the surplus of net radiation near the equator, convective cell transport of energy (as in the Hadley Cells) is not sufficient.

To achieve the balance most efficiently, Rossby wave transport of energy is needed. In the real world, this is achieved through the expansion and contraction of the circumpolar vortex and the periodic development of meridional (north-south) circulations during times of great energy imbalance between low and high latitudes (i.e. winter).

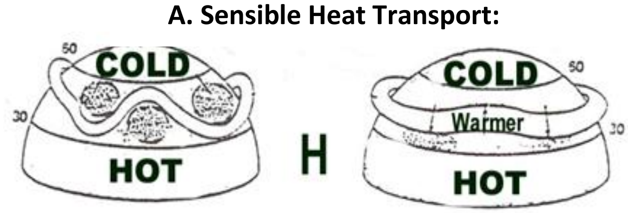
HOW HIGH LATITUDE ENERGY DEFICITS & LOW LATITUDE ENERGY SURPLUS ARE BALANCED OUT

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

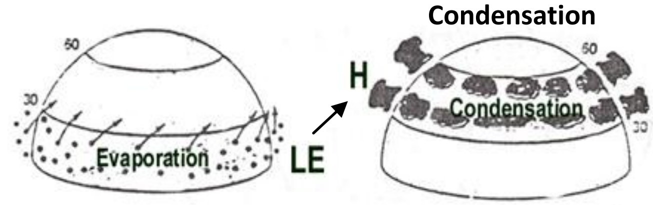
B. Large amounts of **energy also can be transferred** across latitudes in the **form of <u>latent heat</u> (LE).**

- **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:

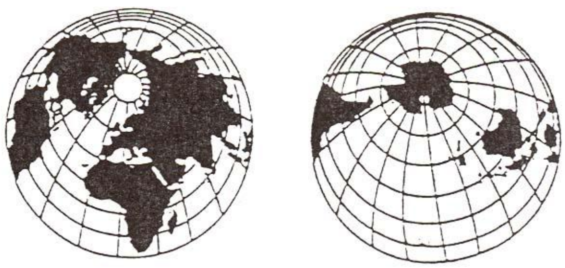


B. Latent Heat Transport:

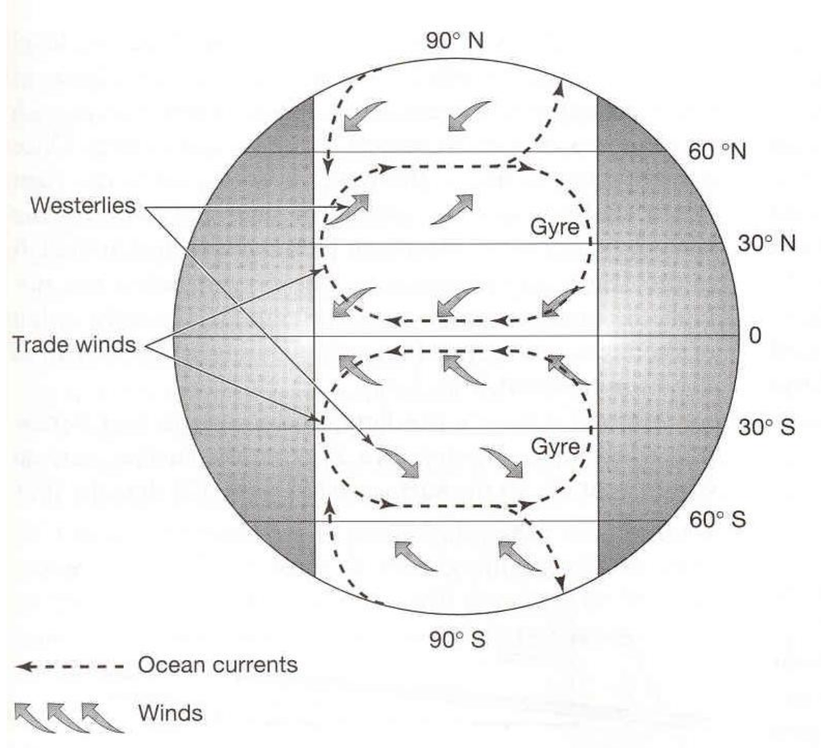


Oceanic Circulation Patterns

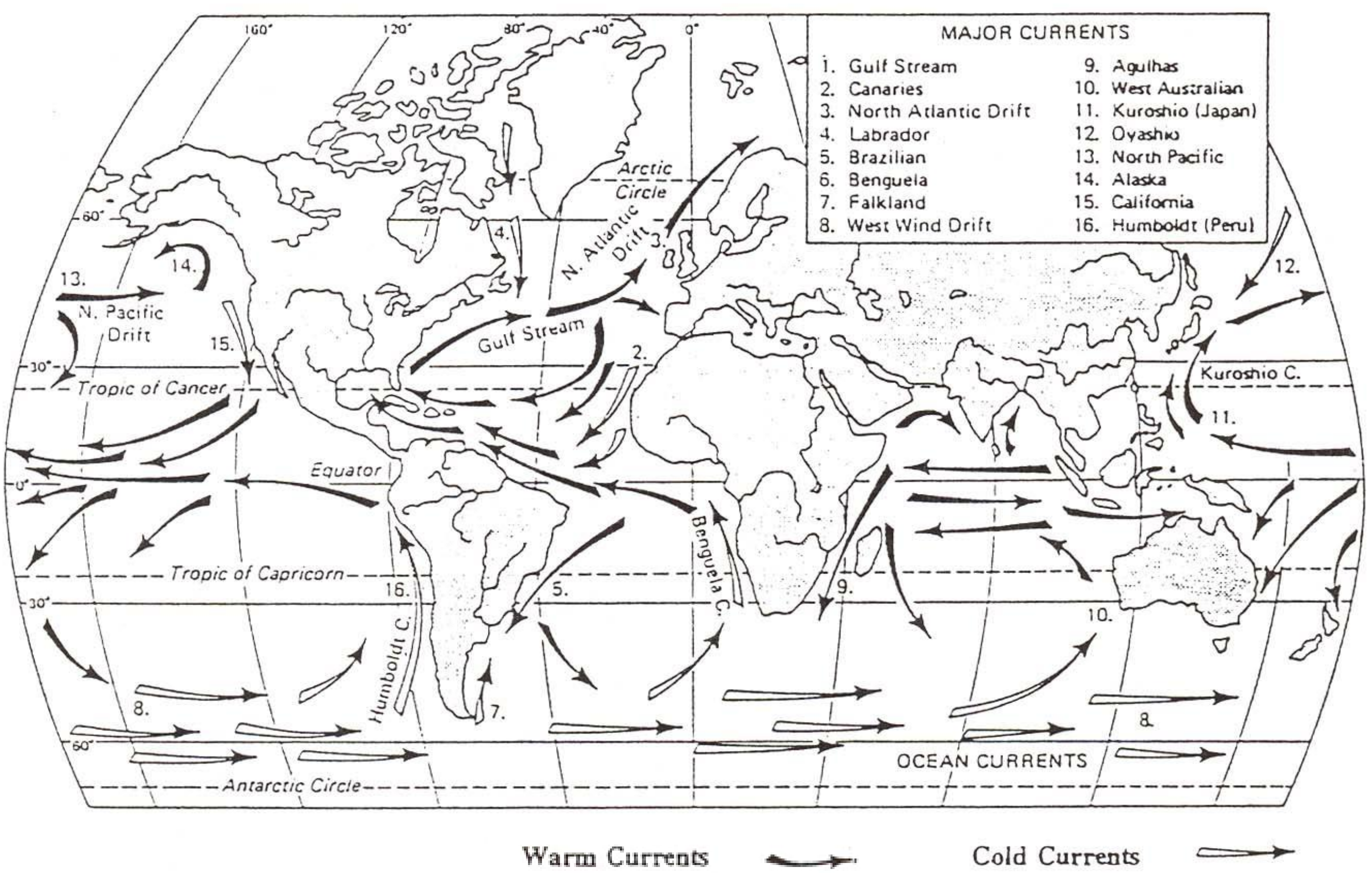
Land vs. Ocean
in Northern vs. Southern Hemispheres



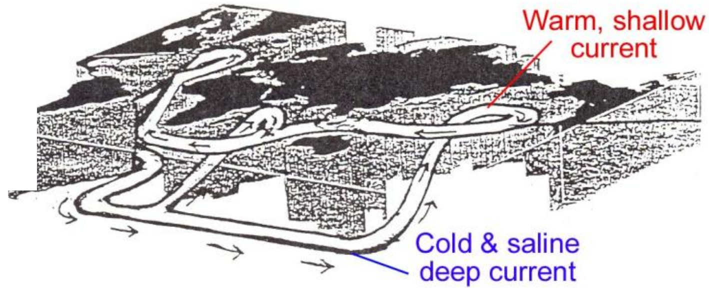
How the Atmospheric Circulation Drives the Surface Ocean Current Circulation ➔



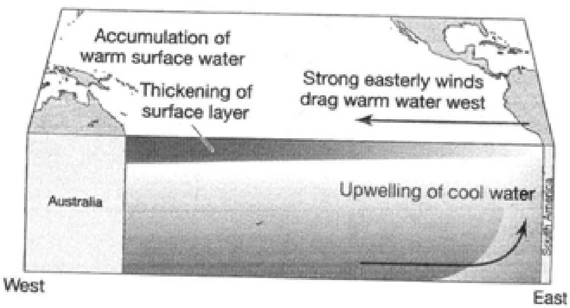
Major Warm & Cold Surface Ocean Currents



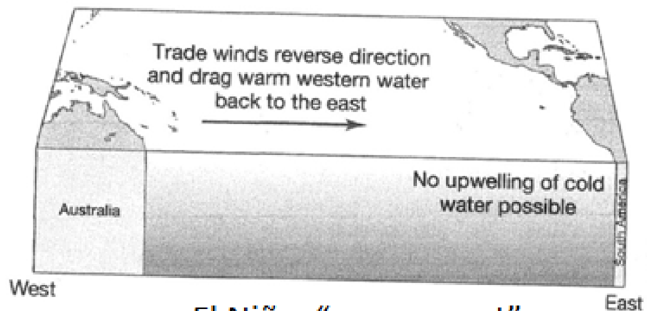
Deep Ocean Circulation
The Thermohaline
“Conveyor Belt” Circulation



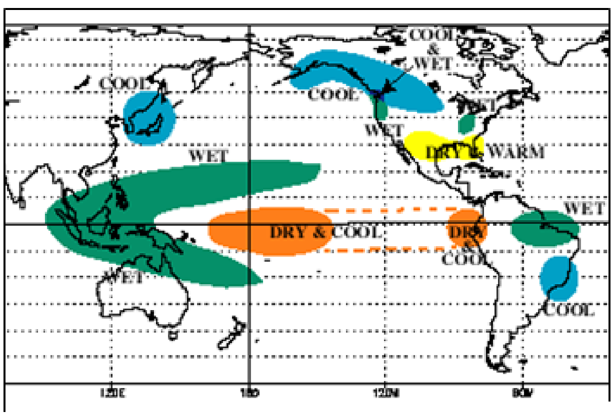
El Niño & La Niña Ocean Circulations & Associated Global Climate Patterns



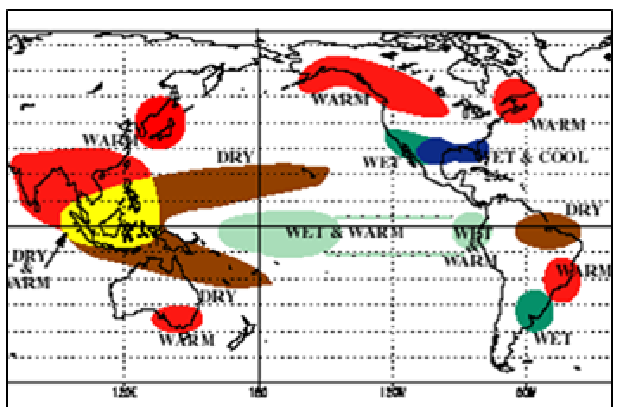
La Niña “cool event”



El Niño “warm event”



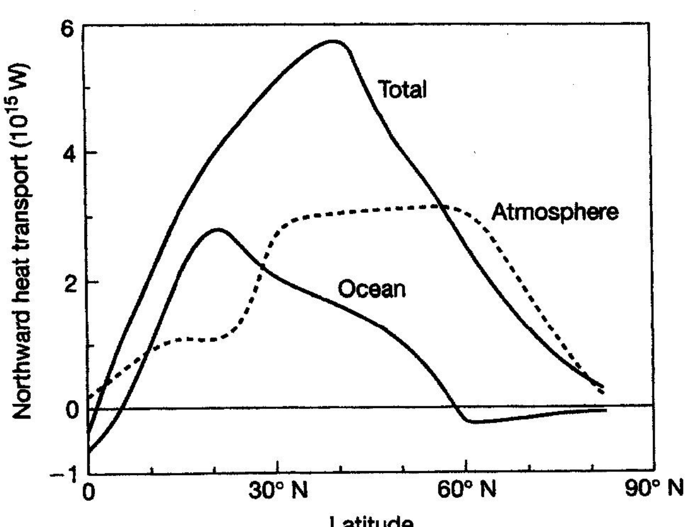
La Niña (Dec – Feb)
Global Temperature & Precipitation Patterns



El Niño (Dec – Feb)
Global Temperature & Precipitation Patterns

Poleward heat transport in the Northern Hemisphere by:

- Atmospheric circulation
- Ocean circulation
- Total of both



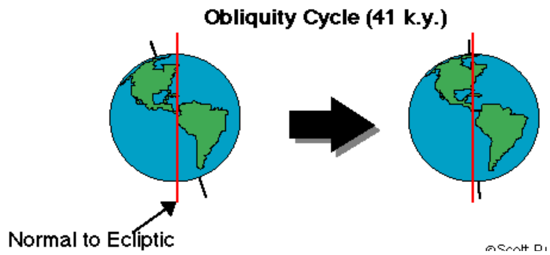
ADDITIONAL NOTES:

TOPIC # 13 NATURAL CLIMATIC FORCING

SOLAR "ASTRONOMICAL" FORCING OF CLIMATE CHANGE

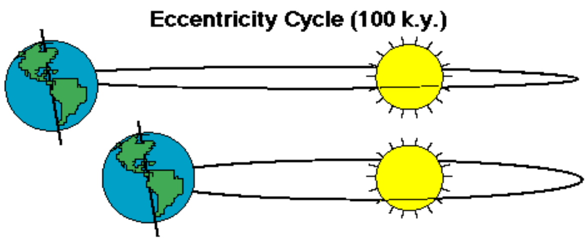
due to "Earth-Sun Orbital Relationships"

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



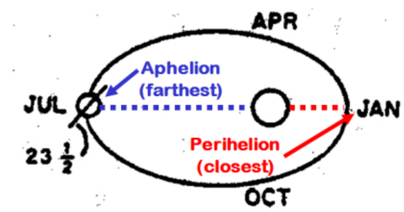
1. OBLIQUITY OF EARTH'S AXIS

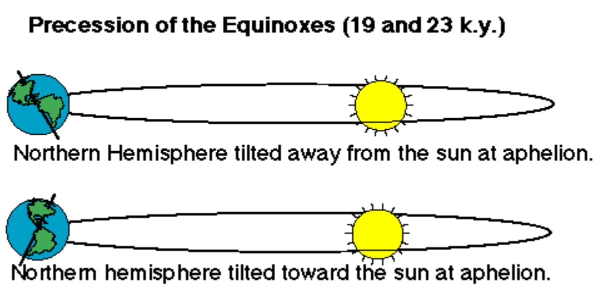
axis "tilts" 23.5 degrees from plane of ecliptic; causes the seasons; has varied in the past



2. ECCENTRICITY OF ORBIT

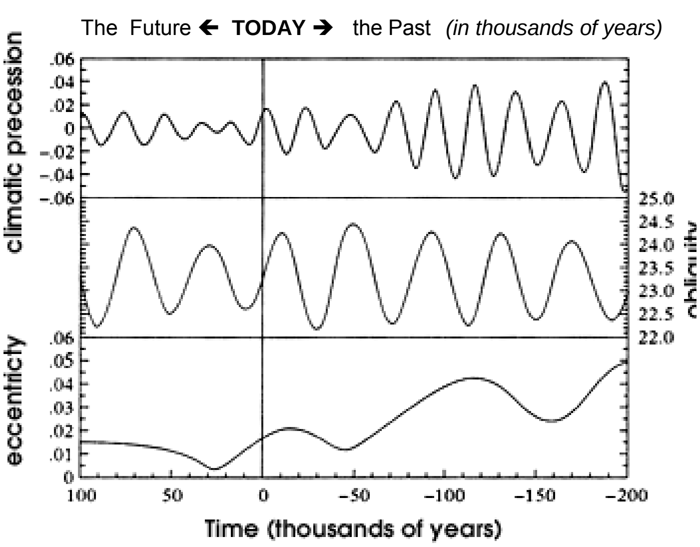
Earth's orbit around sun is not symmetrical; more; circular => elliptical shape has varied in the past



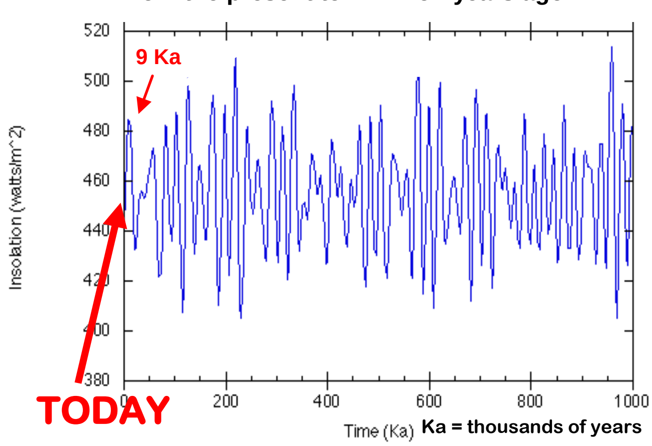


3. Timing of Seasons in Relation to Orbit: PRECESSION OF THE EQUINOXES

*Earth is currently is closest **(perihelion)** to the Sun in January (just after the Dec Solstice) and farthest (**aphelion**) in July. This has varied in the past.*



SOLAR INSOLATION calculated for 65° N latitude from the present to 1 million years ago:



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.

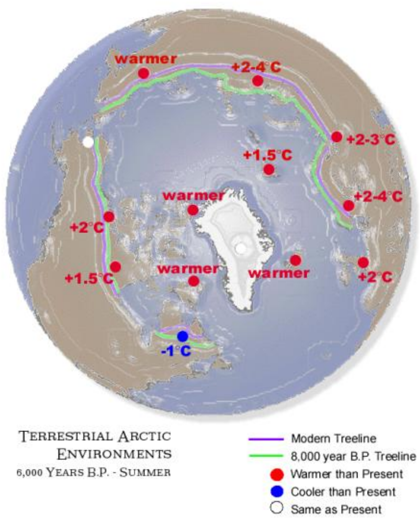
SOLAR VARIABILITY FORCING

over the Last 10,000 Years

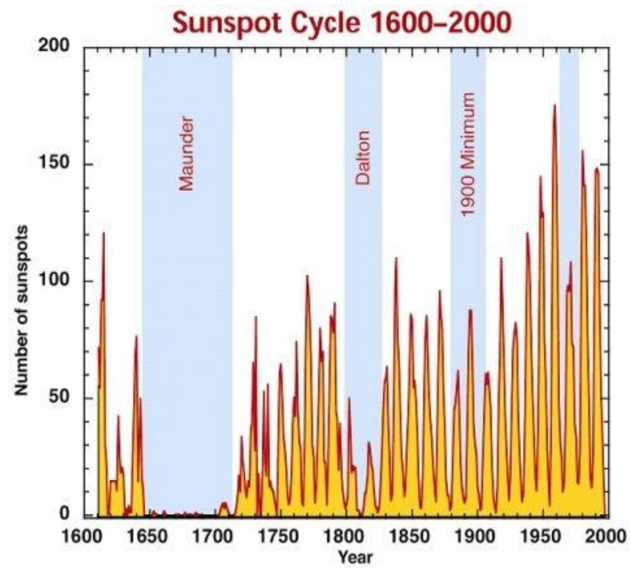
Mid-Holocene warm period
(~ 6,000 years ago)

Generally warmer than today, but only in summer and only in the northern hemisphere.

Cause = "astronomical" climate forcing



SUNSPOT VARIATIONS & SOLAR VARIABILITY
sunspot minima = LESS solar brightness
Sunspot cycles (quasi-periodic)



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.

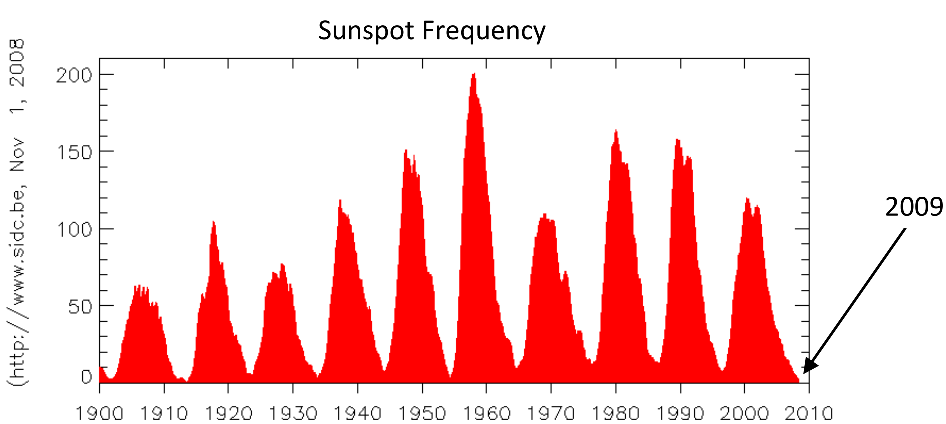
Since the Dalton Minimum, the Sun gradually brightened: the "Modern Maximum" (max in 2001)
But increase in solar brightness accounted for only:

- 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.

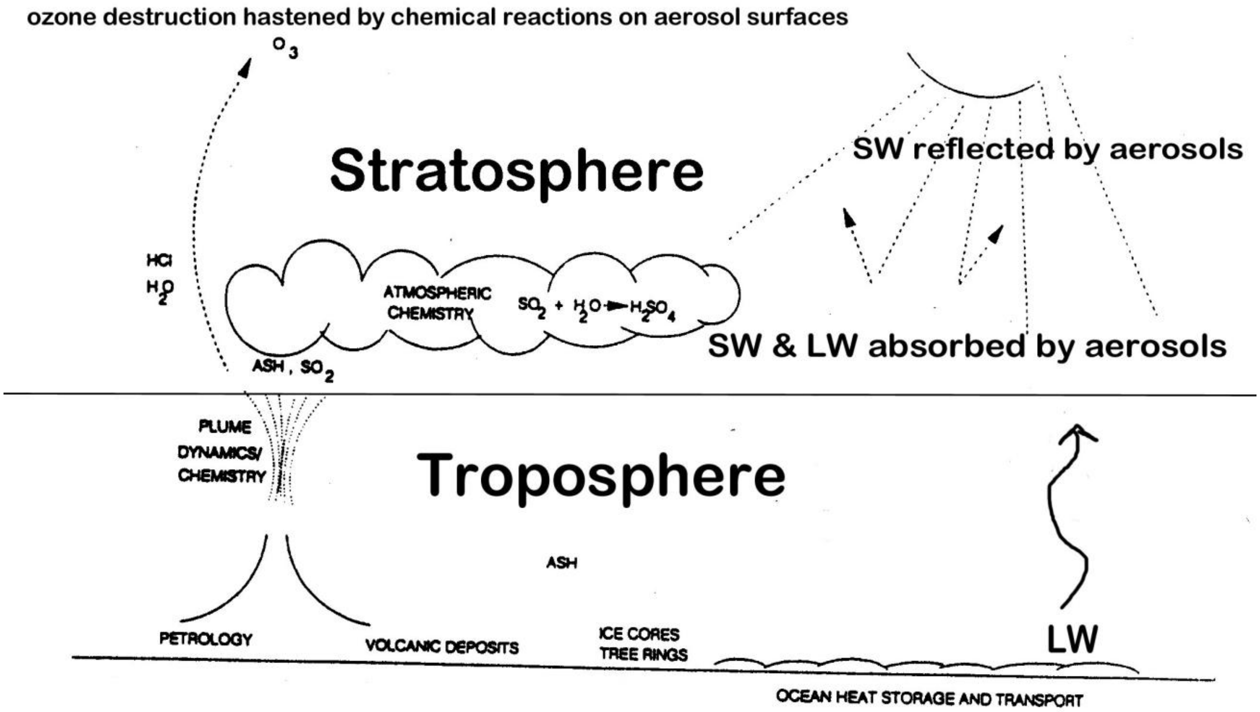
We are now (2009) in a Solar Minimum – but something is unusual about the current sunspot cycle!
- minimum has been unusually long
- number of "spotless" days has not been equaled since 1933
- the vigor of sunspots (in terms of magnetic strength and area) has greatly diminished
- another Maunder-like period? Return of activity within the year? Time will tell . . .

(see EOS v 30 28 Jul 2009)



VOLCANIC FORCING

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



KEY CONCEPTS

How the Climatic Effect Occurs .... 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 aggregates and quickly falls out of the atmosphere within 10s to 100s of km from eruption (albedo of ash is *not* the reason for cooling after an eruption!)
  - SO_2 remains gaseous and is eventually converted to sulfuric acid (H_2SO_4) which condenses in a mist of fine particles (sulfate aerosols).

- **The radiative effects of the sulfate aerosol cloud produce responses in the climate system through the Radiation Balance**
  - the sulfate aerosols *reflect* some of the incoming solar SW radiation back to space, **cooling the troposphere**;
  - the aerosols also *absorb* some wavelengths of the incoming SW radiation and some of the Earth's outgoing LW radiation, **warming the stratosphere**
  - as the aerosols settle down into the upper troposphere, they may also serve as nuclei for cirrus (high) clouds, further affecting the Earth's radiation balance. (remember how?)

- **The chemical effects of the sulfate aerosol cloud can also produce responses in the climate system through ozone destruction & the Radiation Balance**
  - the volcanic aerosols serve as surfaces for chemical reactions **that destroy stratospheric ozone**
  - this lowers ultraviolet (UV) absorption of the incoming solar SW and hence reduces the radiative heating in the lower stratosphere, BUT the net effect is still heating.

    (NOTE: this ozone-destroying effect of volcanism has only become important in recent decades because it depends on anthropogenic chlorine, e.g. from CFCs.)

Which Eruptions are Climatically Effective?

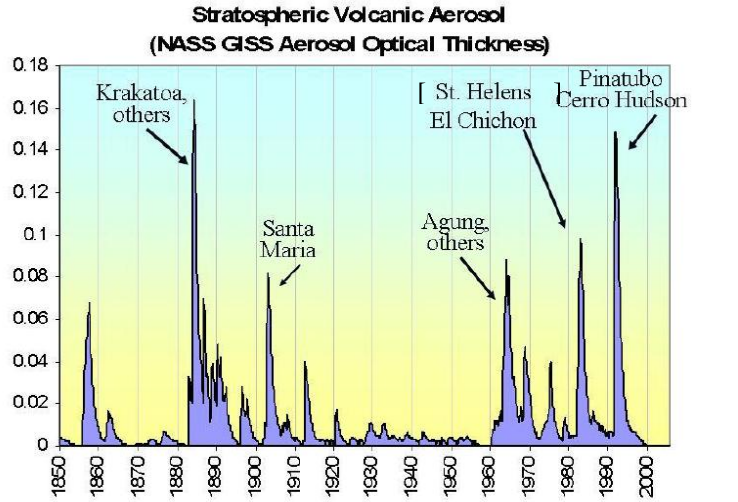
Eruptions that:

- 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



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

How Do Regional Climates Respond to an Explosive Eruption?

- Explosive eruptions **warm the stratosphere** and **cool the troposphere**, especially during the summer season.
- Tropical eruptions, especially, can have a global effect on climate and result in observable tropospheric cooling in the lower latitudes
-

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.

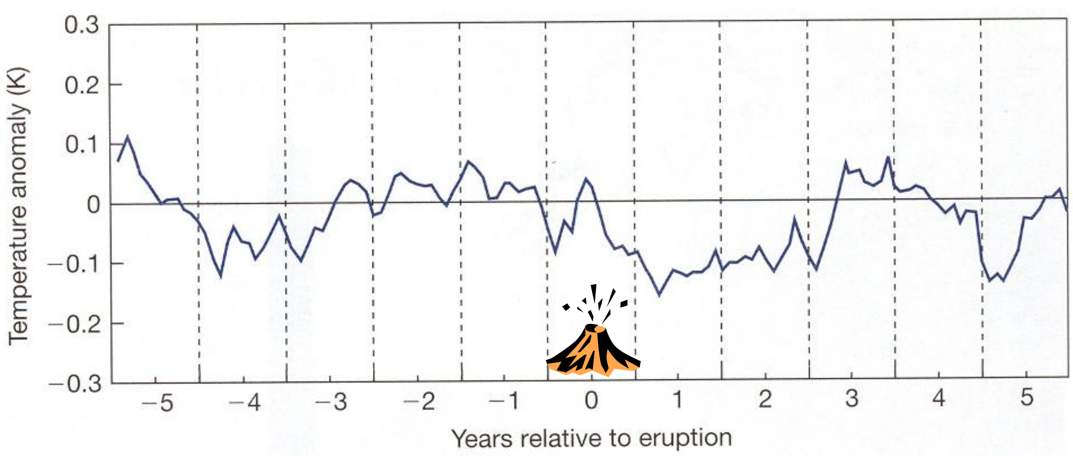
How Important is Explosive Volcanism as a Forcing Mechanism for Past and Future Climate Changes?

- 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.

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).

(Fig 15-6 in SGC- I, p 302)



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 586°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:

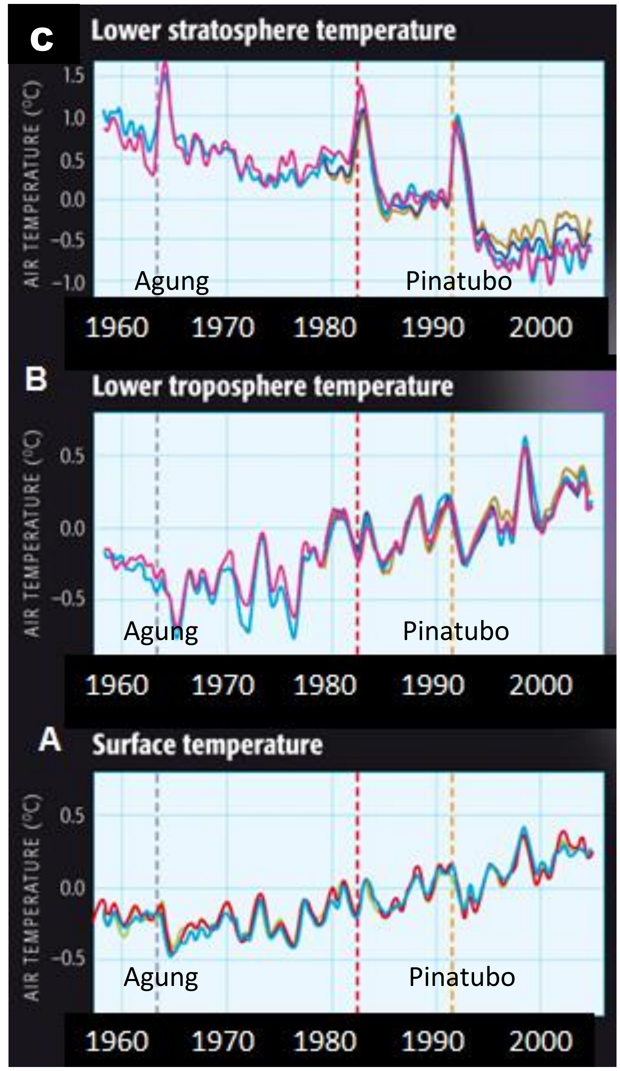
#1 ____

____

#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 El Niño, we'll focus on the other two eruptions.)*



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 ____

____

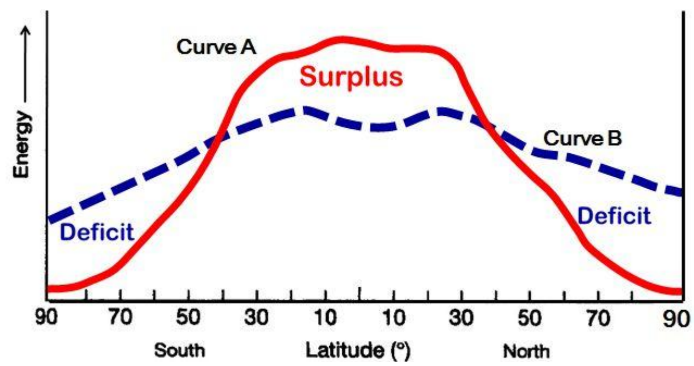
B-Lower Troposphere______________________________

____

C- Lower Stratosphere______________________________

____

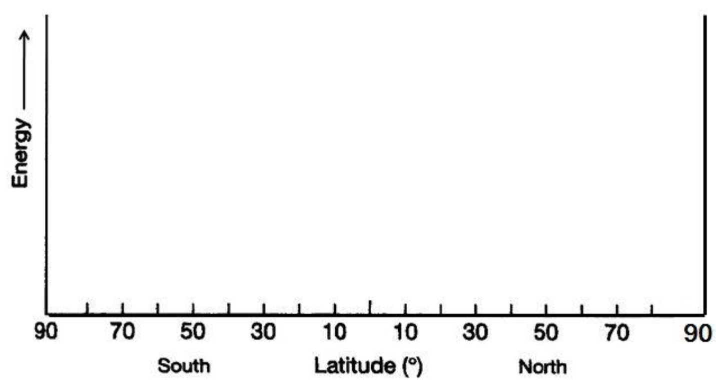
5. At right is the graph showing annual incoming SW solar radiation absorbed in the **troposphere's** earth-atmosphere system and outgoing LW terrestrial radiation **leaving the tropospheric** earth-atmosphere system at various latitudes.



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

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

SKETCH A NEW **CURVE A** OR NEW **CURVE B** to show how the energy balance would change if **a major volcanic eruption** (like Krakatau or Tambora) occurred . Assume that the **eruption produces a long-lived aerosol veil in the stratosphere** over both hemispheres and that this veil reflects large amounts of incoming solar radiation back to space *before* it enters the troposphere's earth-atmosphere system shown in the graph.
[Hint: you do not need to worry about stratospheric warming for this question.]

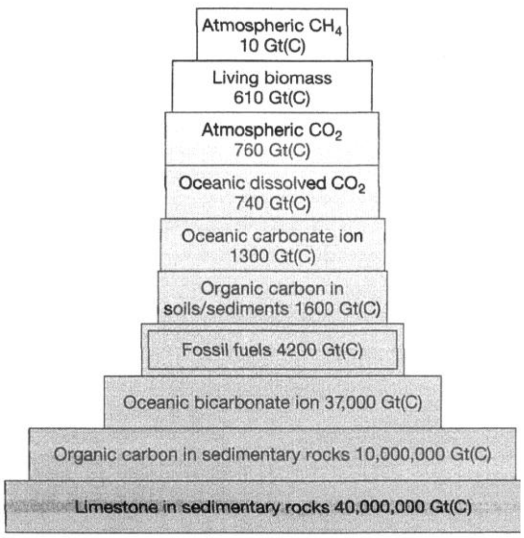


TOPIC # 14 GLOBAL WARMING & ANTHROPOGENIC FORCING

> I'm extremely concerned that the Earth has a chronic disease, and that chronic disease is CO2 syndrome, it's something that's creeping on us. We have plenty of fossil fuel so it's going to continue to get worse, and it's going to affect every aspect of life on the planet, from food production to drinking water to cight of the poor in the tropics, and so forth. *~Wally Broecker , Paleoclimatologist*

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

CARBON RESERVOIRS



Useful Info:

The amount of carbon in reservoirs and fluxes is usually expressed in units of Gtons (gigatons) of carbon. The amounts represent the mass of carbon atoms only, not the other atoms to which they are attached (e.g. CO2)

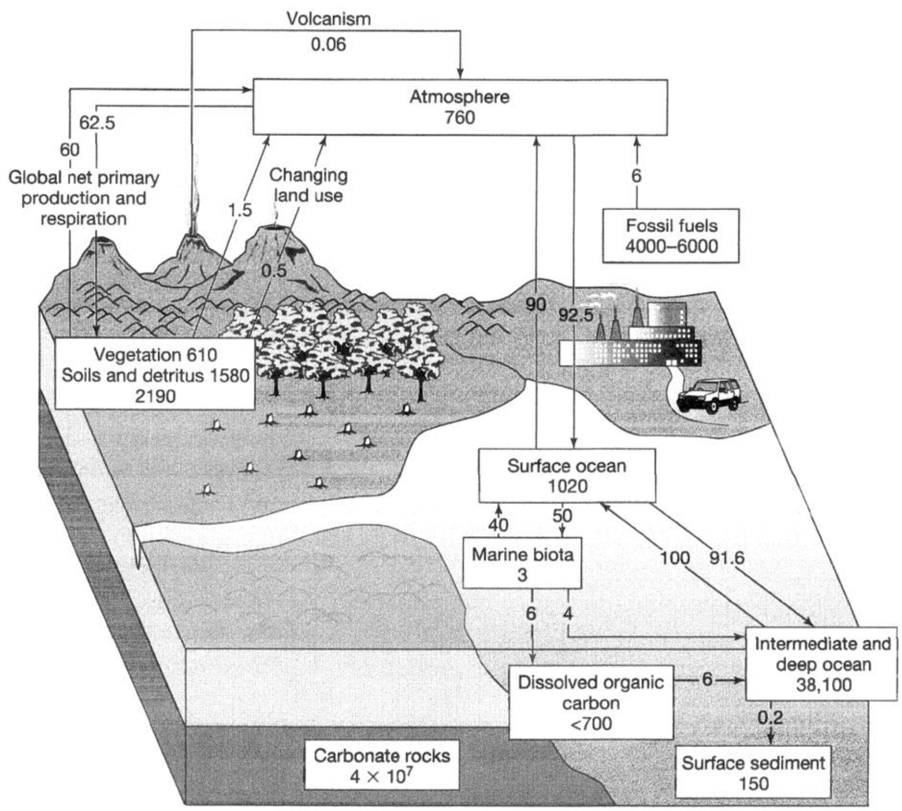
1 Gton = 10^9 metric tons
1 metric ton = 1000 kg = 10^3 kg
1 kilogram (kg) = 10^3 g
1 gram (g) = ~ the mass of 1 cubic cm of water

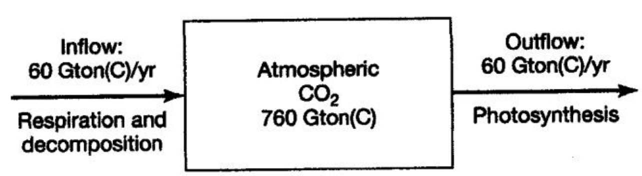
hence 1 Gton = $10^9 \times 10^3 \times 10^3$ g = 10^{15} g
60 Gtons = 6×10^{16} g   760 Gtons = 7.6×10^{17} g

Alternative way of expressing scientific notation:

60 Gtons = 6e+16 g   760 Gtons = 7.6e+17 g

CARBON RESERVOIRS & FLUXES





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

NATURAL FLUXES INTO & OUT OF THE ATMOSPHERIC CARBON RESERVOIR:

LARGE FLUX IN:

Respiration: $CH_2O + O_2 \longrightarrow CO_2 + H_2O.$

(carbohydrate + oxygen gas → carbon dioxide + water)

LARGE FLUX OUT:

Photosynthesis (Primary Production): $CO_2 + H_2O \longrightarrow CH_2O + O_2.$

(carbon dioxide + water → carbohydrate + oxygen gas)

SOME DEFINITIONS:

Respiration = a biochemical process by which living organisms take up oxygen from the environment and consume organic matter, releasing carbon dioxide, heat, and water.

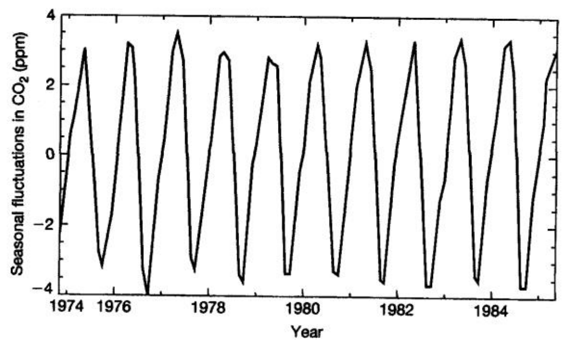
Decomposition = the breakdown of organic matter by bacteria and fungi, releasing carbon dioxide to the atmosphere

Photosynthesis = the manufacture of carbohydrates (organic matter) and oxygen from carbon dioxide and water in the presence of chlorophyll with sunlight as the energy source. Oxygen is released in the process. The solar energy is converted to chemical energy, part of which is stored in living tissues and then utilized by other organisms (consumers) that cannot use solar energy directly.

Primary productivity is the amount of organic matter produced by photosynthesis in a unit time over a unit area of the Earth's surface. Photosynthesis occurs in plants, algae, and bacteria.

Biomass = the total mass of organic matter in living organisms in a particular reservoir. In terms of carbon, the total living biomass (the combined biomasses of all primary producers and consumers) is about equal to the atmospheric carbon reservoir.

<u>The Keeling Curve</u>



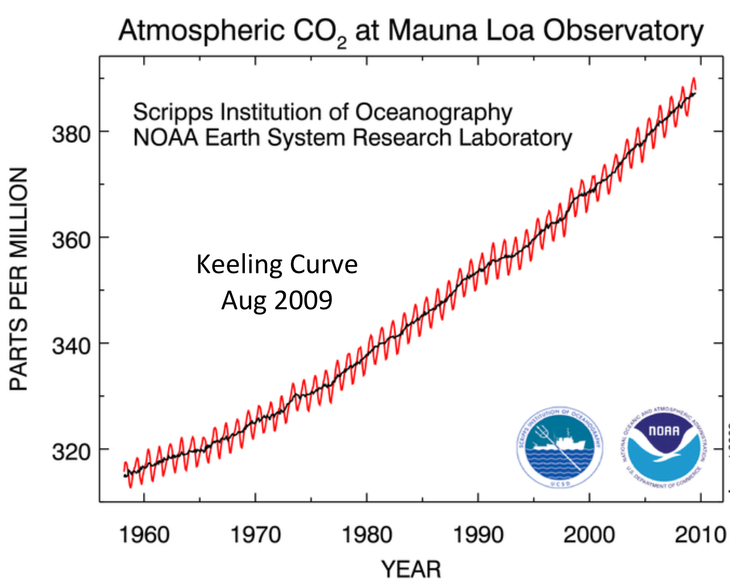
WHAT ABOUT THOSE ZIG-ZAGS?
(See close up at right. NOTE: trend due to anthropogenic increases has been removed in the close up version.)

They represent seasonal fluctuations driven by the balance between respiration and photosynthesis in Northern Hemisphere forests. *[Tick marks are at Jan of each year.]*

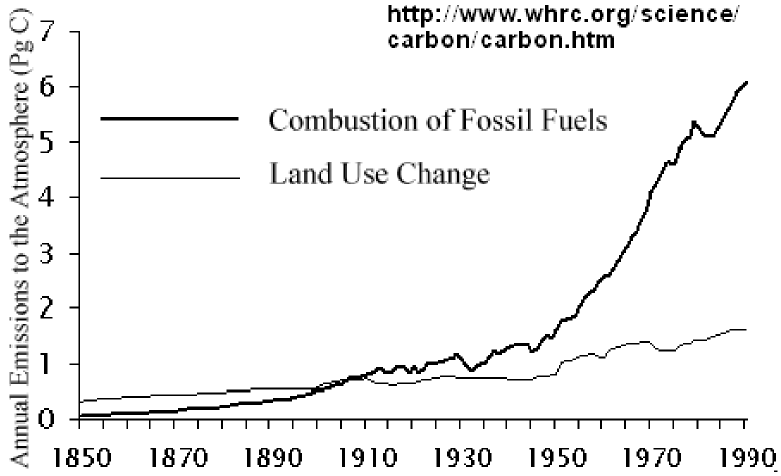
Photosynthesis > Respiration (CO_2 goes down in summer)
Respiration > Photosynthesis (CO_2 levels rise in fall/winter)

OTHER NATURAL FLUXES:

- **Volcanic outgassing** of CO_2 (very small flux from large carbonate rock reservoir into atmosphere)
- **Ocean-Atmosphere exchanges** (dissolution of carbon dioxide in the oceans) NOTE: carbon dioxide also diffuses through ocean surface and once in surface ocean, CO_2 is taken up by marine photosynthesizers. However, the total marine biomass is much smaller than terrestrial biomass.
- *On longer time scales:* **dissolution of sea-floor carbonates** & **weathering of continental rocks**



ANTROPOGENIC INFLUENCES ON CARBON IN THE AMTOSPHERE

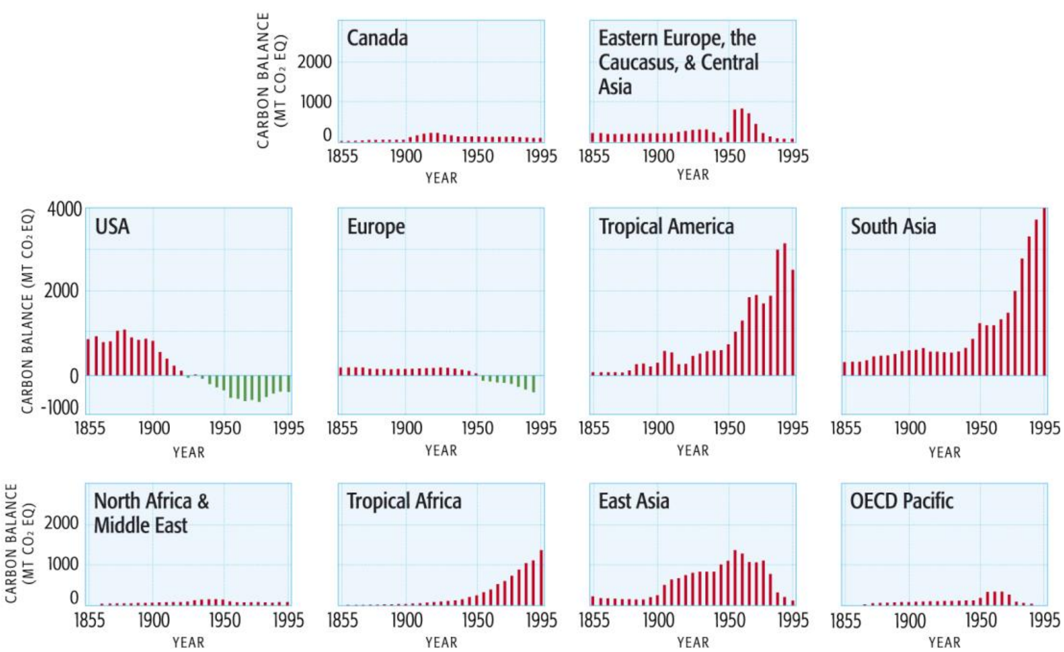


Anthropogenic-Driven Change

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.).

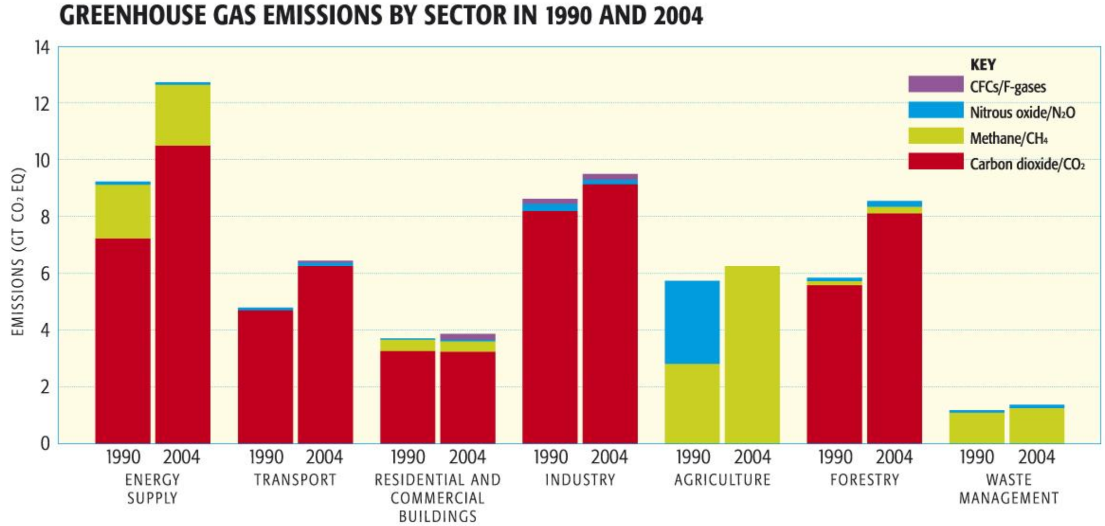
Which process emits more carbon into the atmosphere and how do the trends compare over time?

HISTORICAL TRENDS IN FOREST CARBON EMISSIONS AND UPTAKE



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

GREENHOUSE GAS EMISSIONS BY SECTOR IN 1990 AND 2004

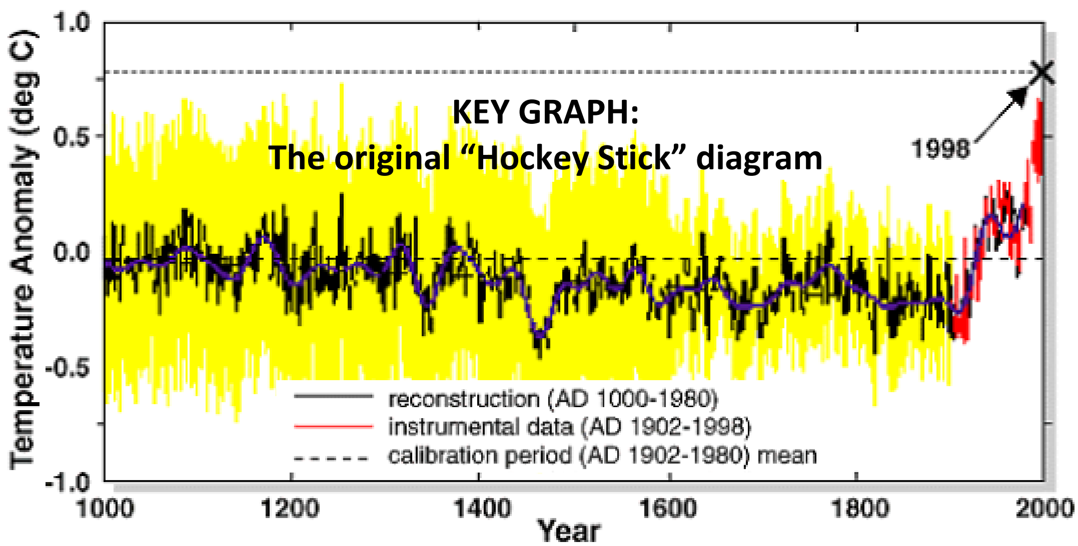


B. Evidence From Natural Archives

> *"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.

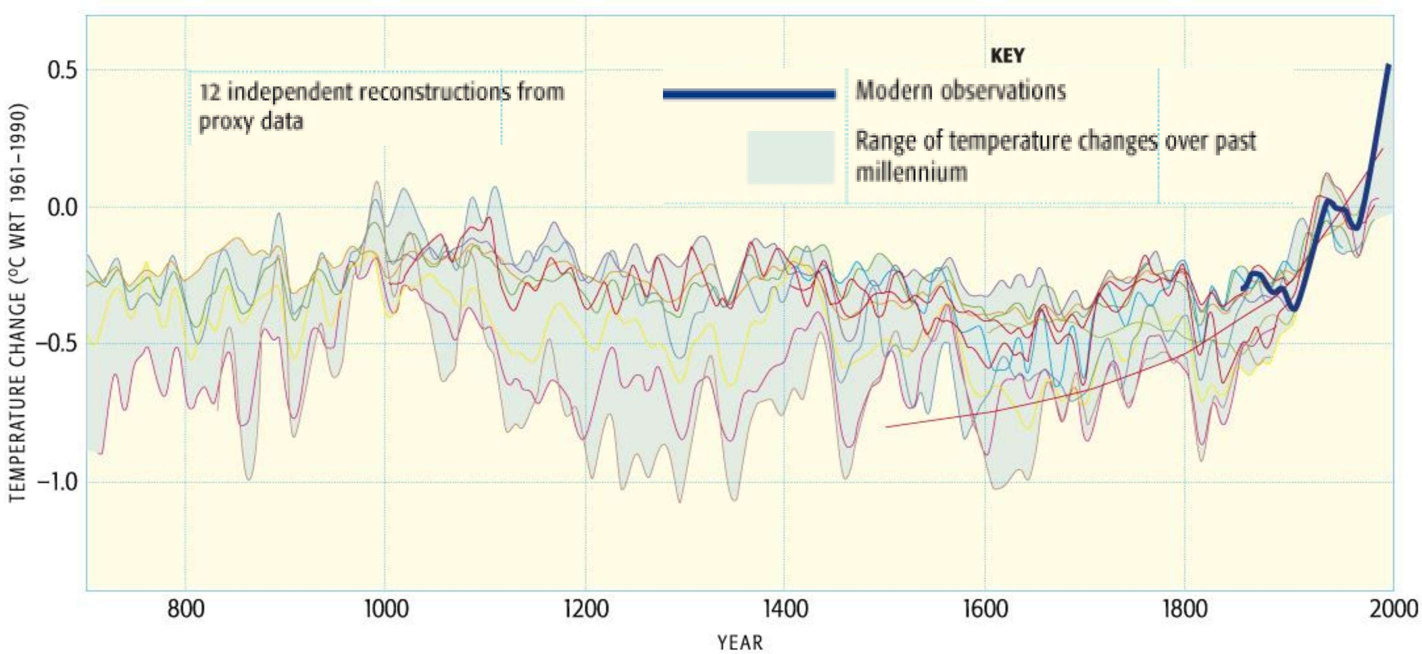
Over much longer geologic time, the 20th & 21st centuries may not necessarily be the warmest time in Earth's history . . . **but what is unique is that the recent warmth is global and cannot be explained by natural forcing mechanisms.**



From the latest IPCC report:

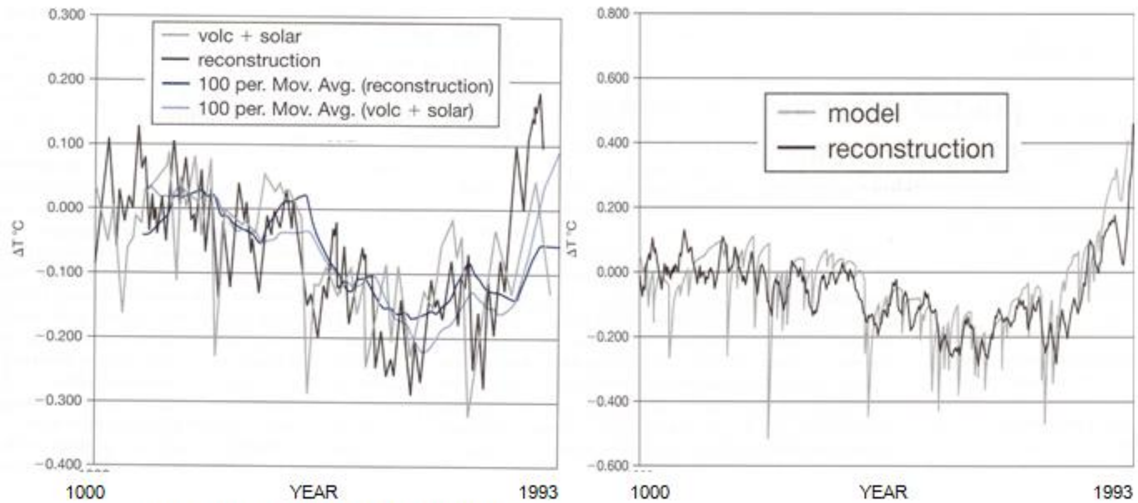
NORTHERN HEMISPHERE TEMPERATURE CHANGES OVER THE PAST MILLENNIUM

(see color version in DP p47)



C. Evidence from Natural vs. Anthropogenic Model Comparisons

1000-YEAR RECONSTRUCTION OF NORTHERN HEMISPHERE TEMPERATURES
w/ MODELING RESULTS OF AN ENERGY BALANCE MODEL FORCED IN DIFFERENT WAYS

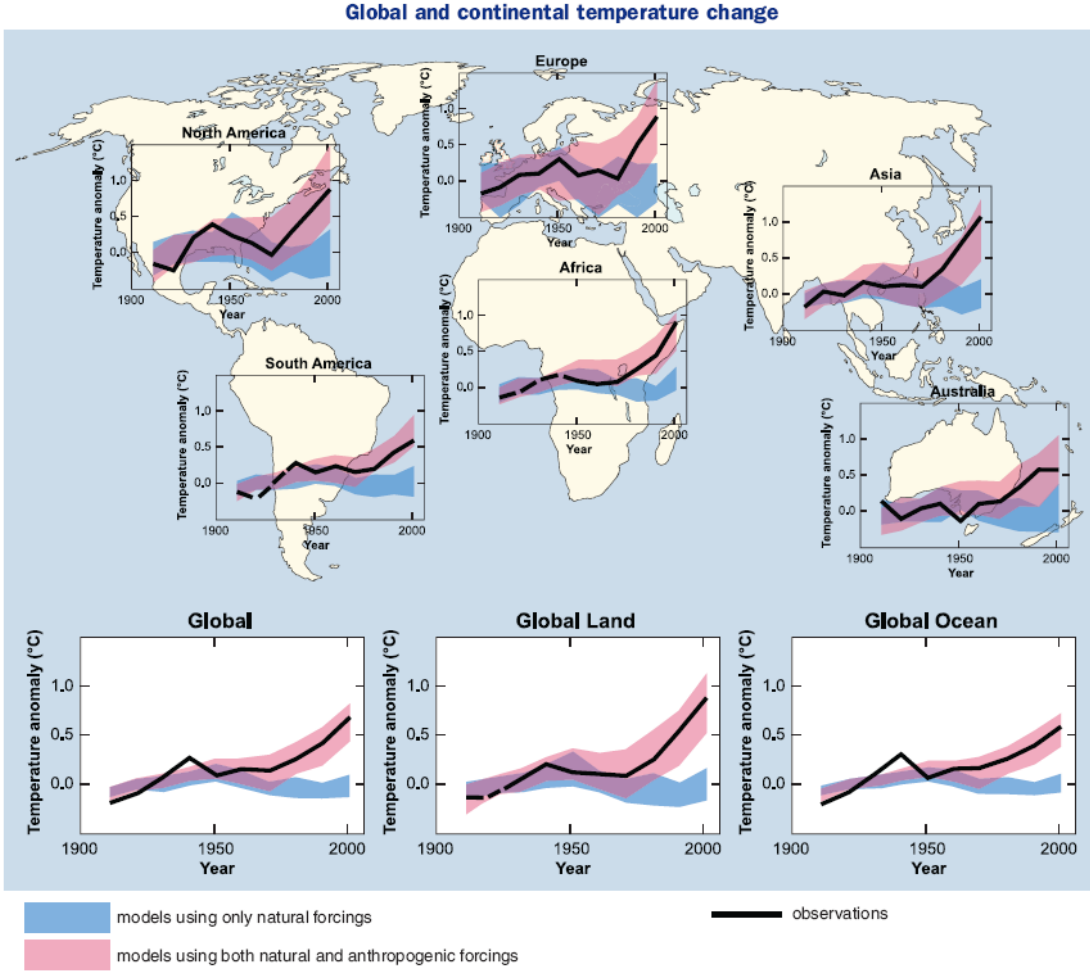


Forced with solar orbital variations & volcanic eruptions only
anthropogenic GHGs not included
(model does not capture recent warming)

Forced with solar orbital variations, volcanic eruptions, & greenhouse gas concentrations
(a much better fit ➔ evidence for anthropogenic GHG forcing)

Evidence of Anthropogenic –Induced Temperature Change on All Continents:
(see Synthesis Report Summary for Policymakers -SPM)

Global and continental temperature change



D. Global Warming Early Warning Signs

www.climatehotmap.org/

Global Warming Fingerprints = Events that are direct manifestations of a widespread and long-term trend toward warmer global temperatures as projected by models of a changing climate.

The following events are identified as global warming fingerprints:

- Heat waves and periods of unusually warm weather
- Ocean warming, sea-level rise and coastal flooding
- Glaciers melting
- Arctic and Antarctic warming

Harbingers of climate change = Events that foreshadow the types of IMPACTS likely to become more frequent and widespread with continued warming.

- Spreading disease
- Earlier spring arrival
- Plant & animal range shifts & population changes
- Coral reef bleaching
- Downpours, heavy snowfalls, and flooding
- Droughts and fires

E. Anthropogenic Influence on Global Change

Summary based on IPCC AR4 2007

Human influences have:

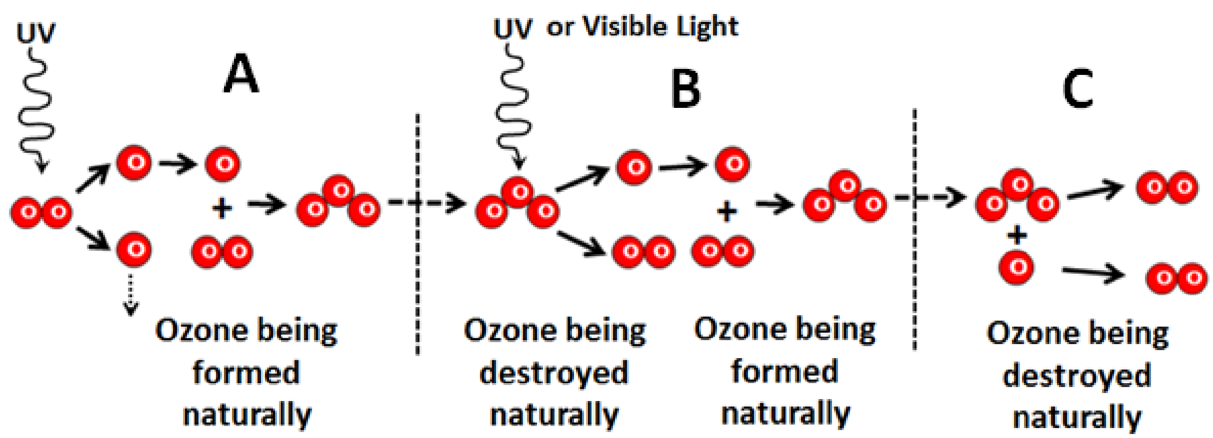
- *Very likely* contributed to sea level rise during the latter half of the20th century
- *Likely* contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns
- *Likely* increased temperatures of extreme hot nights, cold nights and cold days
- *More likely than not* increased risk of heat waves, area affected by drought since the 1970s and frequency of heavy precipitation events

TOPIC # 15 - OZONE DEPLETION IN THE STRATOSPHERE
A Story of Anthropogenic Disruption of a Natural Steady State

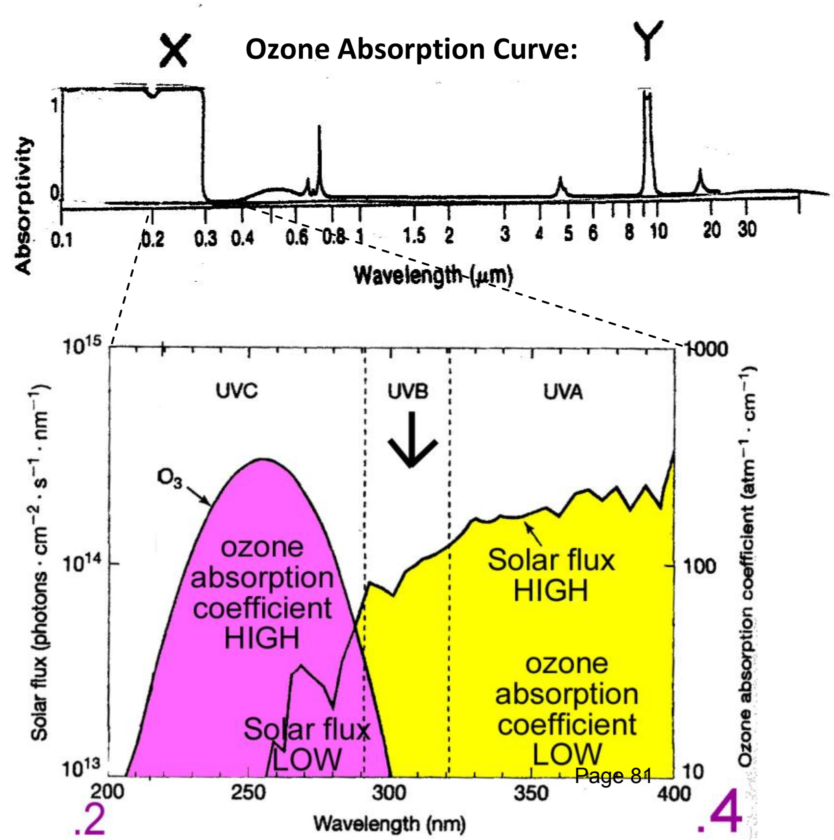
> [The Ozone Treaty is] the first truly global treaty that offers protection to every single human being
> . ~*Mostofa K. Tolba, Director of the UN Environment Programme*

THE CHAPMAN MECHANISM: produces ozone layer 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)



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



IN-CLASS ACTIVITY TO CONNECT CONCEPTS TOGETHER:

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

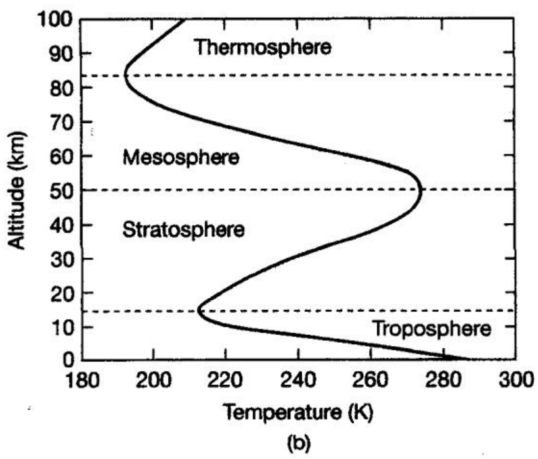
(a) D*raw in horizontal lines* to indicate the **boundary between**:

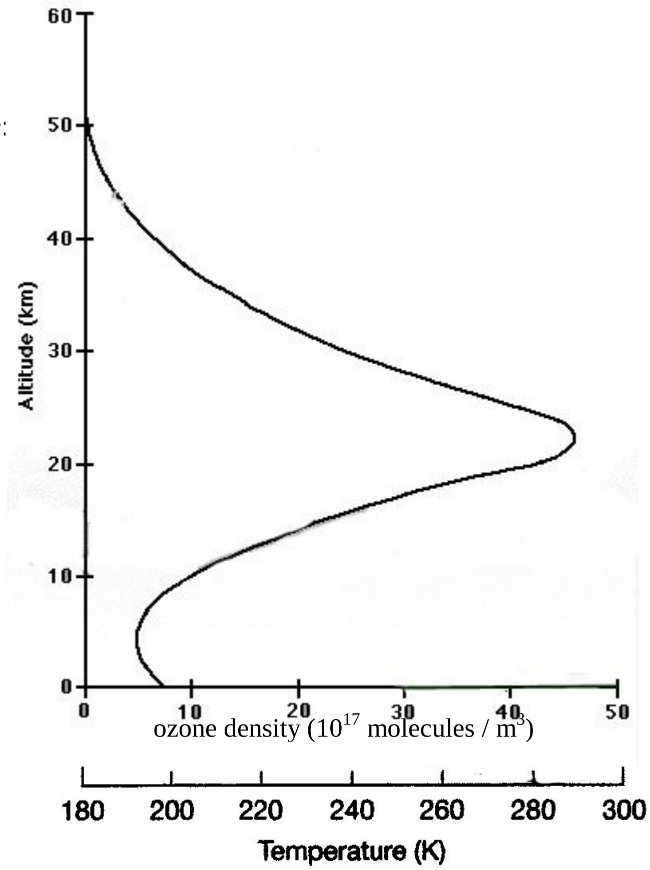
- **the troposphere and the stratosphere**
- **the stratosphere and the mesosphere**

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

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

(c) Using the figure below to guide you, roughly sketch in the vertical temperature profile on the ozone figure at right to indicate how temperature varies with altitude.





2. CIRCLE the correct word in the brackets to properly describe the temperature trend you have sketched in part (c) above and then complete the statement in the blanks below.

==> The temperature of the atmosphere **[increases / decreases]** with increasing altitude in the stratosphere.

==> The reason for this is because:

____

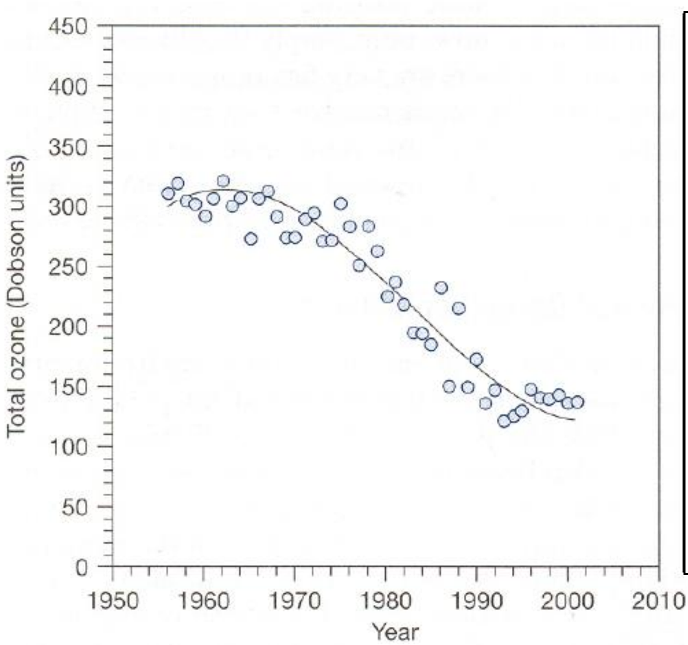
____

____

3. Which of the following is a **catalyst** in the chemical reactions that lead to ozone depletion?
(circle all that apply)

CO_2 **NO** **O_3** **Cl** **HNO_3**

The OZONE "HOLE" – Seasonal Depletion over Polar Areas



Mean total ozone over Antarctica during the month of October (SGC Fig 1-5, p 8)

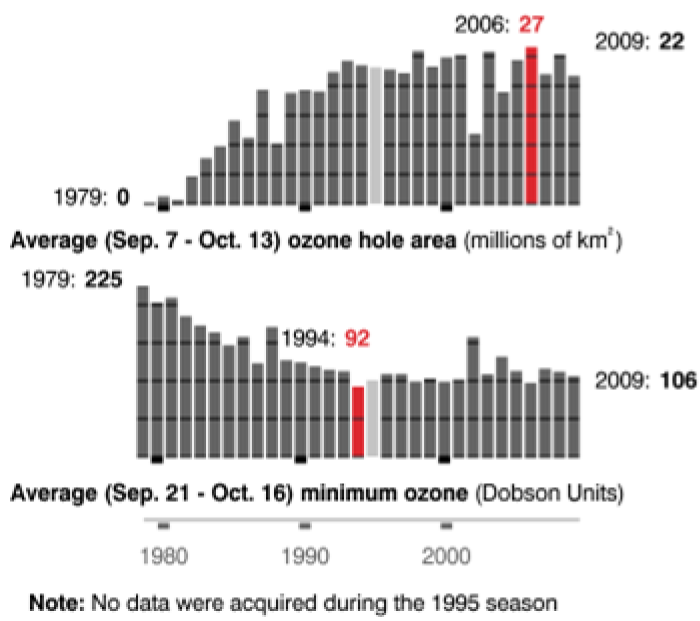
The units, called Dobson units, measure the gas per unit area between Earth's surface and the top of the atmosphere (a measurement known as column depth). One Dobson unit (DU) is equivalent to a 0.001 cm-thick layer of pure ozone at the surface.

The "Ozone Hole" is defined as the area with ozone concentrations less than 290 DU.

Sketch the 290 DU threshold on the figure to determine when the "hole" (as defined here) began forming.

Annual record since 1979

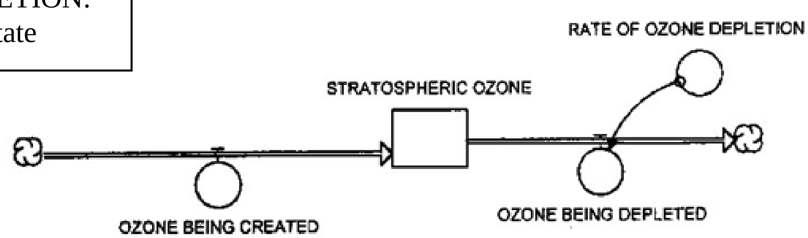
The severity of the ozone hole varies somewhat from year to year. These fluctuations are superimposed on a trend extending over the last three decades. The graphs below show these variations. The red bars indicate the largest area and the lowest minimum value.



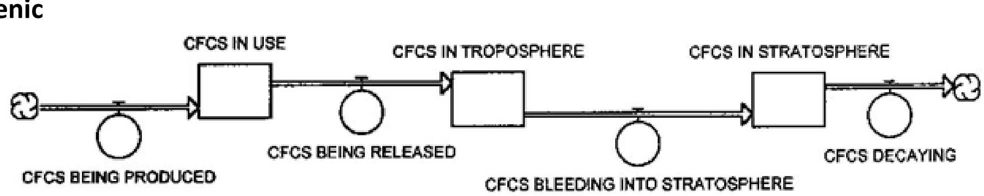
Check out the changes in the hole as the semester progresses at: http://ozonewatch.gsfc.nasa.gov/

MODELING OZONE DEPLETION:
Disruption of a Steady State

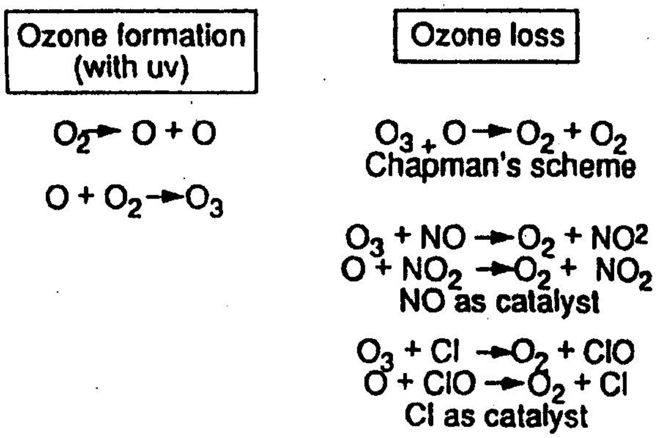
Natural Steady State



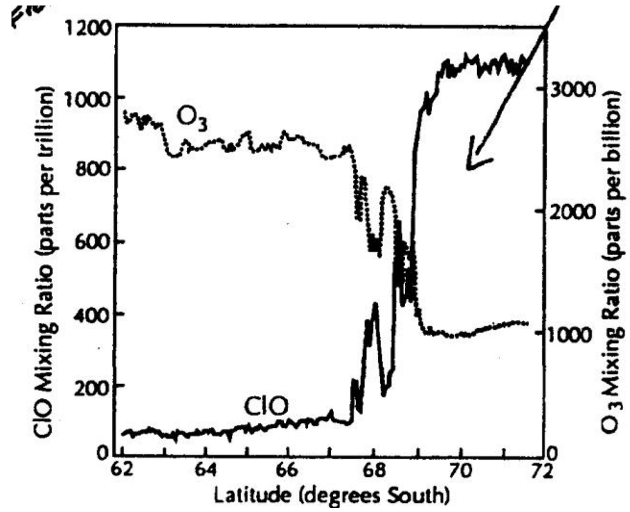
Anthropogenic Impact



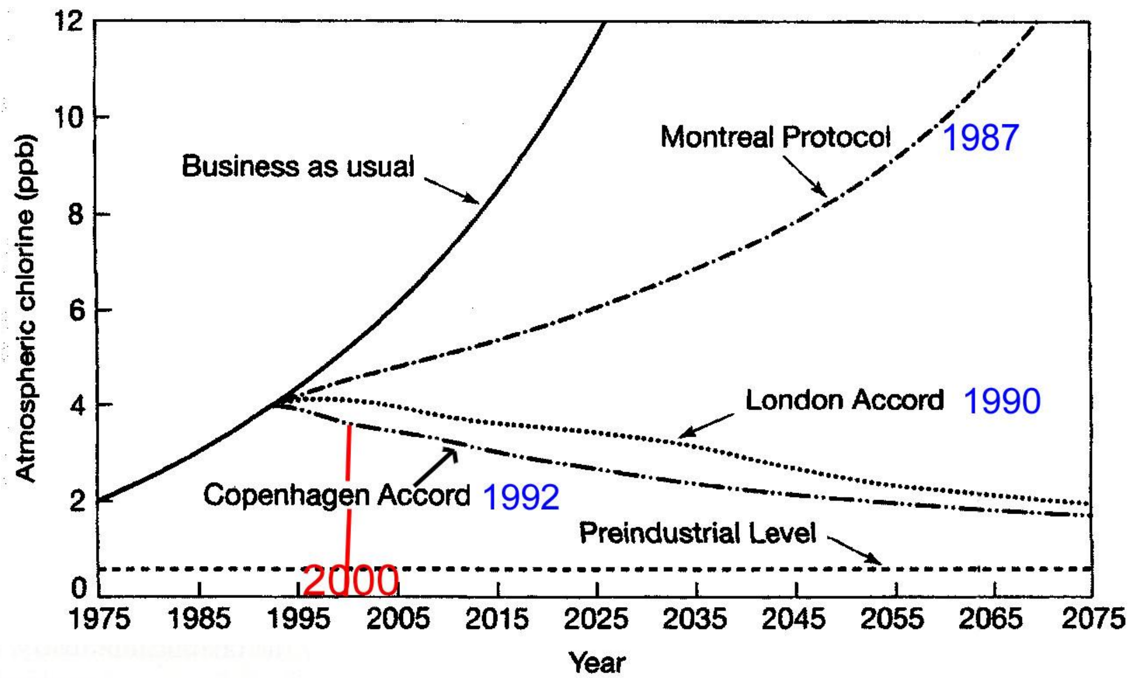
Ozone loss occurs naturally *and* from photochemical reactions with catalysts (Cl & NO)

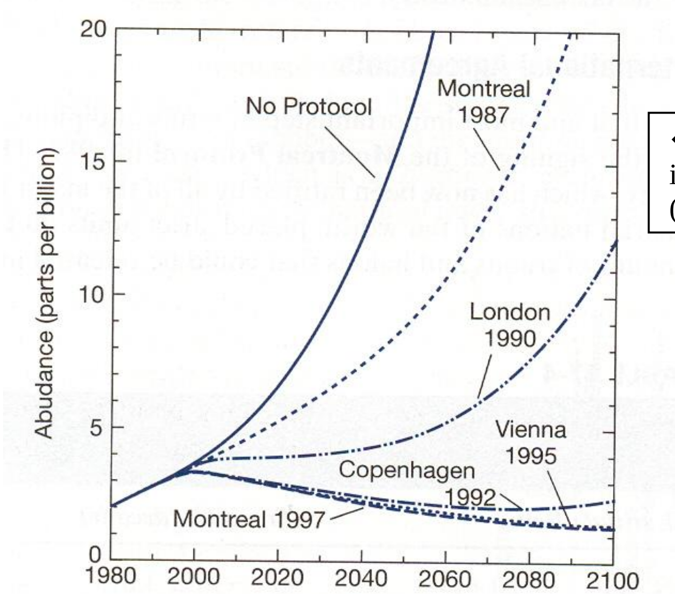


Where ClO is high, O_3 is low, suggesting that chemical mechanism is main cause of O_3 loss (see SGC Fig 106)



Graph showing changing concentration of **Atmospheric Chlorine** over time & dates of international agreements





🡐 Projected chlorine concentrations under the various international agreements (*another view*)

Where are we now in mitigating ozone depletion?

KEY OZONE DEPLETION CONCEPTS

- The ozone "hole" is a depletion of ozone in the lower stratosphere (12-25 km) that has occurred with increasing severity each spring since systematic measurements began in the mid-1970s.

- The theory that the ozone layer in the stratosphere might be damaged or depleted by human intervention (supersonic jets, CFC's, etc) preceded the actual observation of the ozone hole.

- The Chapman mechanism (proposed in 1930s) explains how ozone is continuously produced and destroyed through chemical reactions in the stratosphere involving oxygen, molecular oxygen, UV radiation, and ozone. In theory, a balance of ozone is established over time that prevents much of the harmful UV radiation from reaching the earth's surface.

- This balance is being disrupted by the introduction of CFC's which are dissociated into free chlorine atoms and other molecular fragments by UV rays. Through chemical reactions the chlorine removes ozone from the stratosphere and also frees more chlorine atoms to begin the process all over again: A single chlorine atom may destroy hundreds of thousands of ozone molecules during its residence in the stratosphere.

- The "hole" has unique regionality and seasonality : it 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)

- Theories to explain the hole have included: 1) solar variability (sunspot cycle), 2) dynamical air motion, and 3) chemical mechanisms (both natural due to volcanic eruptions and anthropogenic due to CFCs). The chemical reaction theory due to anthropogenic influence is almost universally accepted as conclusive at present. The prominent scientists involved in developing the chemical reaction theory were awarded the Nobel Prize for Physics in 1995.

- The special conditions that make the ozone hole most severe over polar regions (esp. Antarctica) are: (1) the unique circumpolar circulation pattern over Antarctica in winter which isolates the stratosphere inside the vortex and acts like a "containment vessel" in which chemical reactions may occur in near isolation; and (2) the presence of polar stratospheric ice clouds -- on the surfaces of these extremely cold cloud particles certain chemical reactions are more efficient and faster.

- A variety of measurements (ground-based and satellite) have shown that global levels of stratospheric ozone have fallen several percent between 1969 and the present. Decreases in all latitude zones have occurred (1.1 - 9% in S.H. and (1.1 - 3.7% in N.H.)

- Ozone is *increasing* in the troposphere due to car exhaust, etc., but only at the rate of about 1% per year, hence stratospheric levels are going down at a rate faster than ozone is being added in the troposphere.

THINGS TO KNOW & PONDER ABOUT THE OZONE ISSUE

- Understand the difference between stratospheric and tropospheric ozone concentrations and effects.

- Tie the ozone hole discussion to earlier material on the electromagnetic spectrum, atmospheric structure and composition, and the time-latitude curve of solar radiation to answer: Why is the loss of ozone a concern? and, What's so special about spring in the polar regions that influences the onset of the chemical reactions that destroy ozone?

- Think about the connections between the ozone hole problem and the greenhouse effect problem. Are they the same thing? Do they occur in the same part of the atmosphere? Do they involve radiation in the same part of the electromagnetic spectrum? Are they related to each other? Does the media sometimes err in confusing the two? Are the "solutions" to both problems the same? etc.

ADDITIONAL NOTES:

TOPIC #16 – THE IPCC FINDINGS: PROJECTED CHANGES & IMPACTS

"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

The most comprehensive source of information on Global Climate Change -- the IPCC

WMO INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE UNEP

http://www.ipcc.ch/

ABOUT THE IPCC:

- Recognizing the problem of potential global climate change the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) in 1988.
- The IPCC was established to provide the decision-makers and others interested in climate change with an objective source of information about climate change.
- The IPCC does not conduct any research nor does it monitor climate related data or parameters.
- Its role is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation.
- IPCC reports should be neutral with respect to policy, although they need to deal objectively with policy relevant scientific, technical and socio economic factors.
- They should be of high scientific and technical standards, and aim to reflect a range of views, expertise and wide geographical coverage.

The IPCC has three working groups and a Task Force:

- **Working Group I** assesses the scientific aspects of the climate system and climate change.
- **Working Group II** addresses the vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change, and options for adapting to it.
- **Working Group III** assesses options for limiting greenhouse gas emissions and otherwise mitigating climate change.
- The **Task Force on National Greenhouse Gas Inventories** oversees the National Greenhouse Gas Inventories Programme

The **Fourth Assessment Report (AR4) "Climate Change 2007"** provides a comprehensive and up-to-date assessment of the policy-relevant scientific, technical, and socio-economic dimensions of climate change.

➔ Read *Climate Change 2007 AR4 Synthesis Report: Summary for Policymakers* online at: www.ipcc.ch/

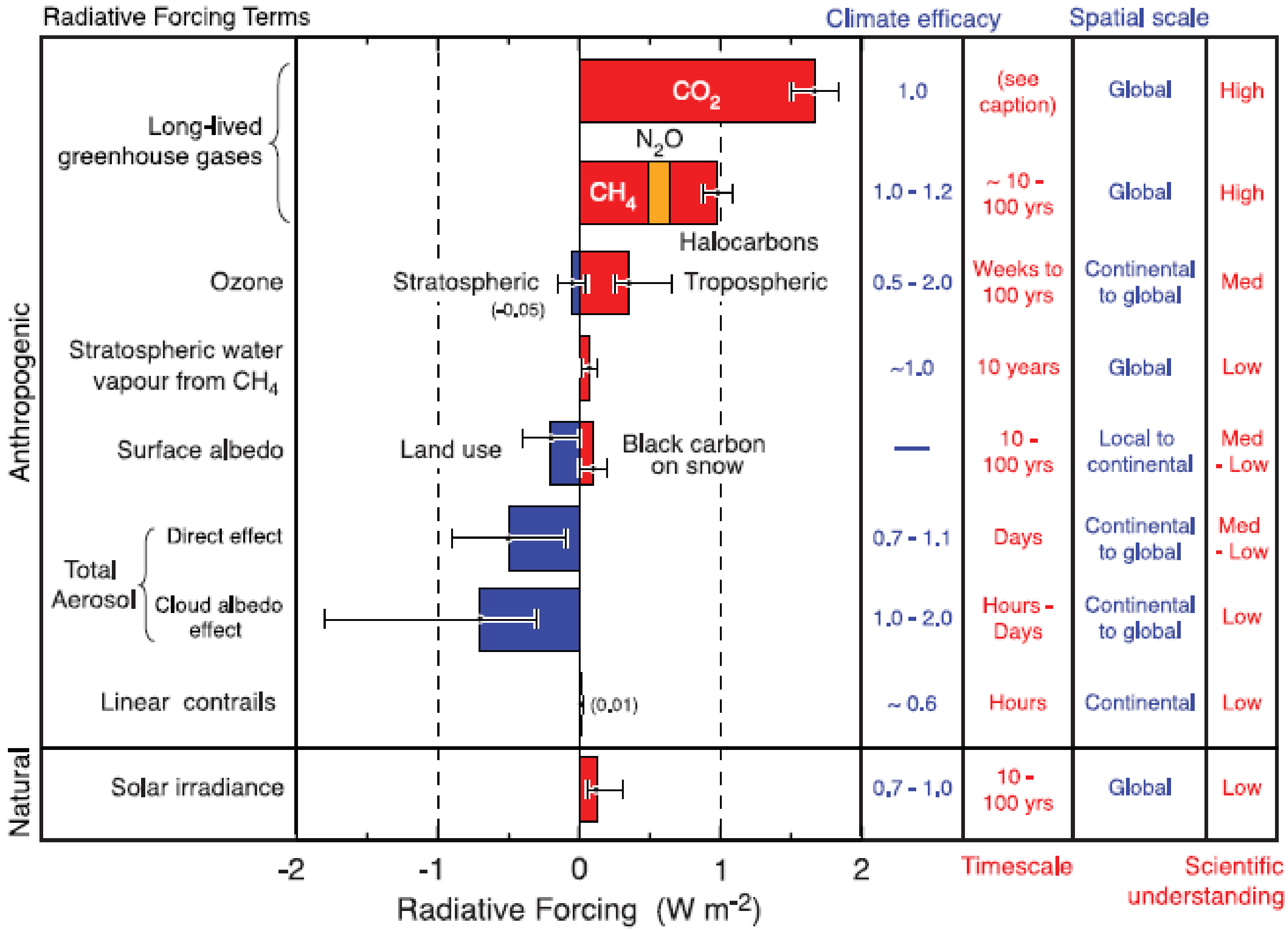
We've been covering the highlights of the IPCC AR4 Reports all semester in the *Dire Predictions* text !

The Key To It All: RADIATIVE FORCING OF CLIMATE

RADIATIVE FORCING is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system, and is an index of the importance of the factor as a potential climate change mechanism. It is expressed in Watts per square meter (Wm^{-2}).

More specifically, it is 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 change, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun. In the IPCC report, radiative forcing is further defined as the change relative to the year 1750 and, unless otherwise noted, refers to a global and annual average value.

Radiative forcing of climate between 1750 and 2005



Global mean radiative forcing (RFs) from anthropogenic carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific.

Anthropogenic RFs and **the natural direct solar RF** are shown.(*Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature*).

Climate efficacy is a measure of how effective a radiative forcing from a given anthropogenic or natural mechanism is at changing the equilibrium global surface temperature compared to an equivalent radiative forcing from carbon dioxide. (A carbon dioxide increase by definition has an efficacy of 1.0.)

Time scales represent the length of time that a given RF term would persist in the atmosphere after the associated emissions and changes ceased. No CO2 time scale is given, as its removal from the atmosphere involves a range of processes that can span long time scales, and thus cannot be expressed accurately

The level of scientific understanding is shown for each term. [Source IPCC-AR4 WG-I: Ch 2.9, Figure 2.20]

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

IPCC 2007:
Projected Climate Change for Different Scenarios of GHG Emissions

Scenarios for GHG emissions from 2000 to 2100 (in the absence of additional climate policies) and projections of surface temperatures

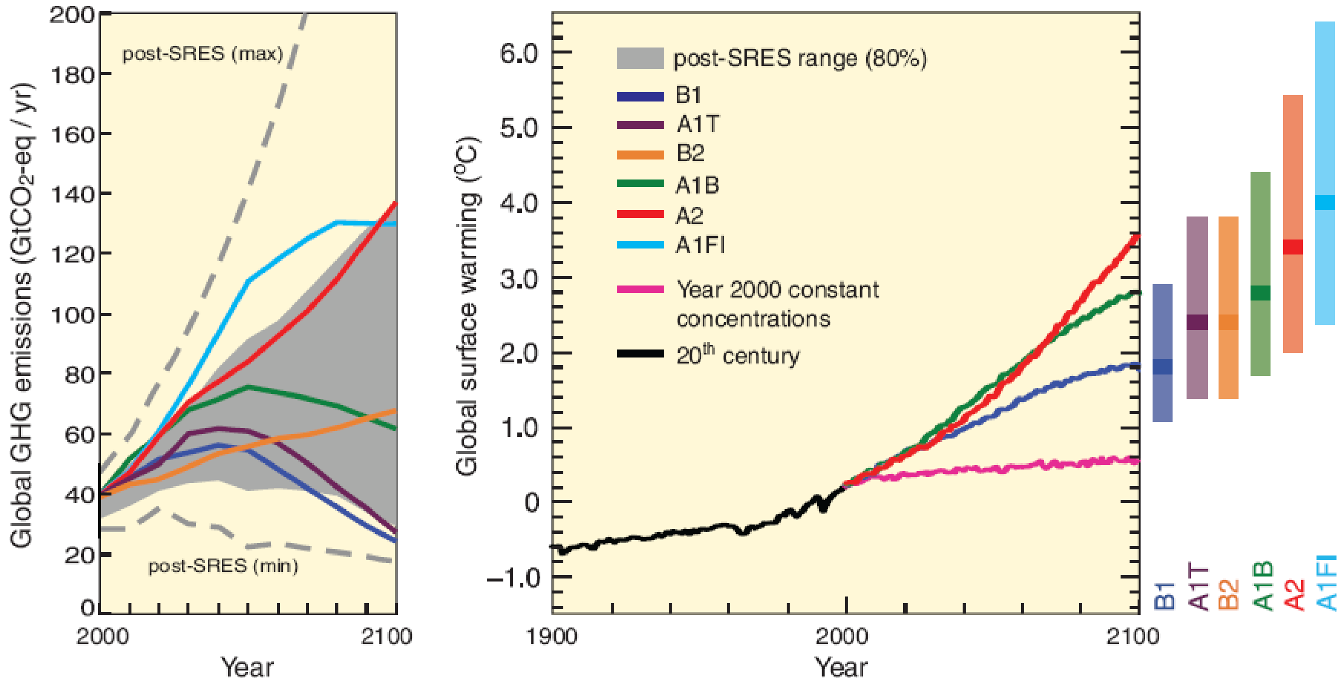


Figure SPM.5. ***Left Panel:*** *Global GHG emissions (in $GtCO_2$-eq) in the absence of climate policies: six illustrative SRES marker scenarios (coloured lines) and the 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions include CO_2, CH_4, N_2O and F-gases.* ***Right Panel:*** *Solid lines are multi-model global averages of surface warming for scenarios A2, A1B and B1, shown as continuations of the 20th-century simulations. These projections also take into account emissions of short-lived GHGs and aerosols. The pink line is not a scenario, but is for Atmosphere-Ocean General Circulation Model (AOGCM) simulations where atmospheric concentrations are held constant at year 2000 values. The bars at the right of the figure indicate the best estimate (solid line within each bar) and the* likely *range assessed for the six SRES marker scenarios at 2090-2099. All temperatures are relative to the period 1980-1999. {Figures 3.1 and 3.2}*

Table SPM.1. *Projected global average surface warming and sea level rise at the end of the 21st century. {Table 3.1}*

Case	Temperature change (°C at 2090-2099 relative to 1980-1999) [a, d]		Sea level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant year 2000 concentrations[b]	0.6	0.3 – 0.9	Not available
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Notes:

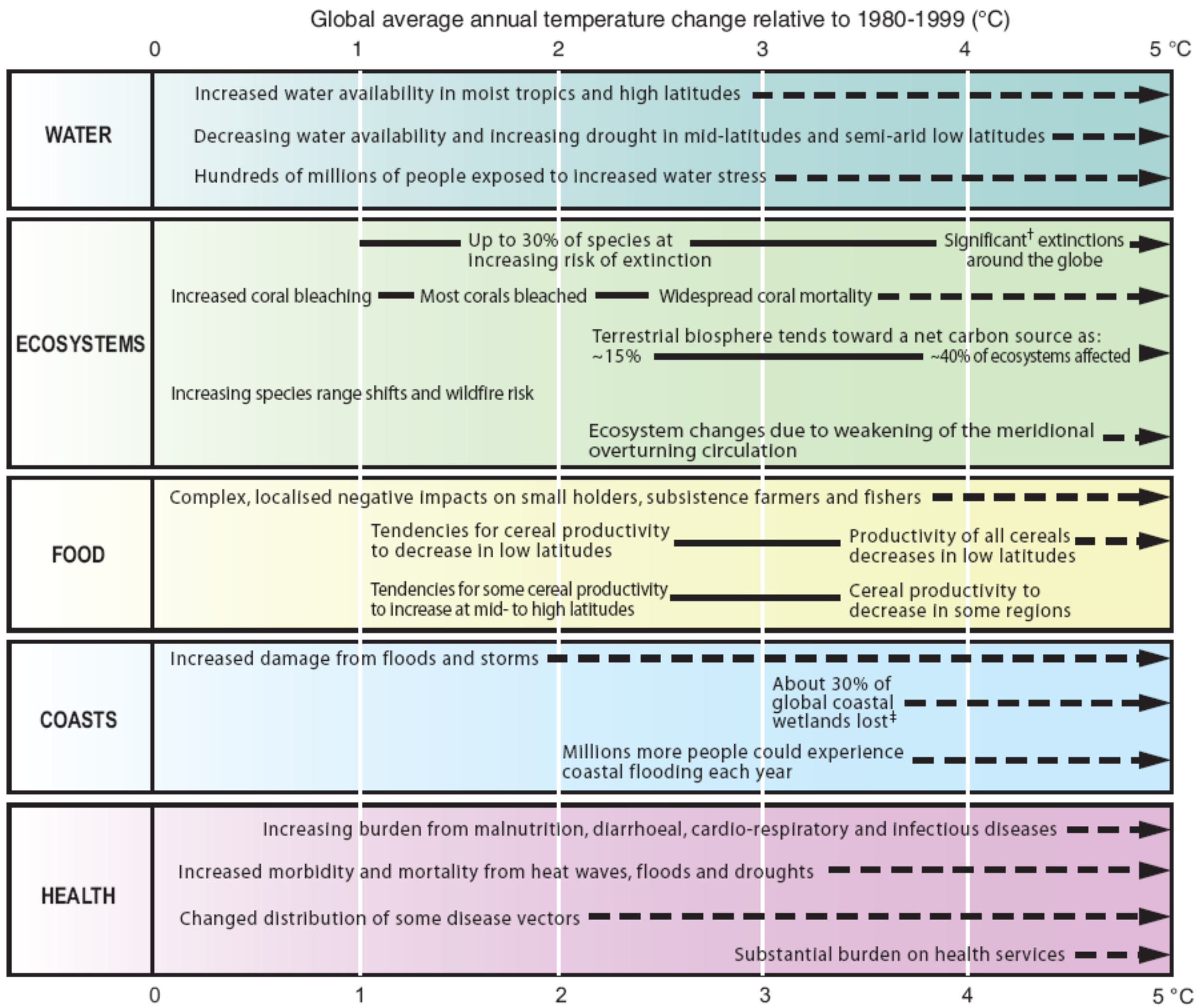
a) Temperatures are assessed best estimates and *likely* uncertainty ranges from a hierarchy of models of varying complexity as well as observational constraints.

b) Year 2000 constant composition is derived from Atmosphere-Ocean General Circulation Models (AOGCMs) only.

c) All scenarios above are six SRES marker scenarios. Approximate CO_2-eq concentrations corresponding to the computed radiative forcing due to anthropogenic GHGs and aerosols in 2100 (see p. 823 of the Working Group I TAR) for the SRES B1, AIT, B2, A1B, A2 and A1FI illustrative marker scenarios are about 600, 700, 800, 850, 1250 and 1550ppm, respectively.

d) Temperature changes are expressed as the difference from the period 1980-1999. To express the change relative to the period 1850-1899 add 0.5°C.

Examples of impacts associated with global average temperature change
(Impacts will vary by extent of adaptation, rate of temperature change and socio-economic pathway)



† Significant is defined here as more than 40%. ‡ Based on average rate of sea level rise of 4.2mm/year from 2000 to 2080.

Projected Regional-Scale Changes:

- warming greatest over land and at most high northern latitudes and least over Southern Ocean and parts of the North Atlantic Ocean, continuing recent observed trends
- contraction of snow cover area, increases in thaw depth over most permafrost regions and decrease in sea ice extent; in some projections using SRES scenarios, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century
- *very likely increase* in frequency of hot extremes, heat waves and heavy precipitation
- *likely increase* in tropical cyclone intensity; less confidence in global decrease of tropical cyclone numbers
- poleward shift of extra-tropical storm tracks with consequent changes in wind, precipitation and temperature patterns
- *very likely precipitation increases* in high latitudes and likely decreases in most subtropical land regions, continuing observed recent trends.
- There is high confidence that by mid-century, annual river runoff and water availability are projected to increase at high latitudes (and in some tropical wet areas) and decrease in some dry regions in the mid-latitudes and tropics.
- There is also high confidence that many semi-arid areas (e.g. Mediterranean Basin, western United States, southern Africa and north-eastern Brazil) will suffer a decrease in water resources due to climate change.

MORE IMPACTS: BIODIVERSITY, ECOSYSTEMS & THE ENERGY BALANCE

BIODIVERSITY = the variety of life forms found in the natural world. The concept usually refers to the different *species* but also includes *ecosystems* and the genetic diversity within a given species.

DEFORESTATION = any forestry practice that results in a long-term land use change away from the forest

Types of change: Forest → agriculture Forest → human settlements Forest → non-forest uses e.g., urban, industrial, livestock, etc.

Perturbations to one part of the system can have impacts THROUGHOUT the system. Hence systems are connected together, the removal of one species will affect the presence of other species.

TROPICAL DEFORESTATION

Causes of Tropical Deforestation: (1) Agricultural expansion, (2) Harvesting of fuel-wood for domestic energy purposes, (3) Conversion to farms and ranches *(all aided by road construction)*

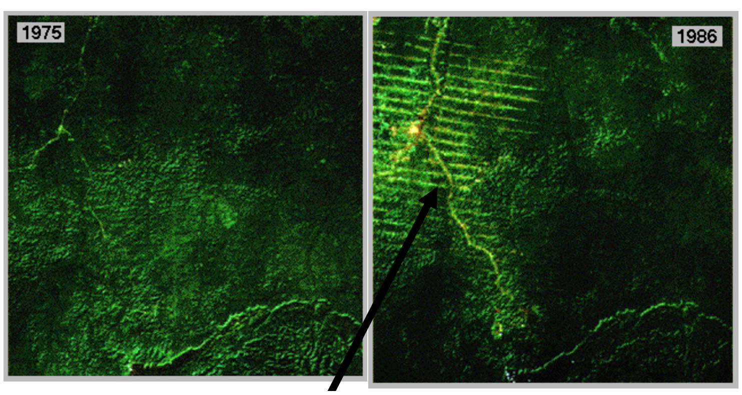
KEY CONCEPT #1: Loss of Biodiversity The Tropics contain 3/4 of all the living things on Earth (or 2/3 of all plant and animal species) although they cover only 6% of the land surface. Therefore they play a major role in shaping ecosystems on earth. With such diversity, deforestation of the tropics could lead to 27,000 species lost every year!!

KEY CONCEPT #2: Loss of Natural Carbon Sink

Forests are a major SINK for atmospheric CO_2,
hence DEFORESTATION → an INCREASE of CO_2
in the atmosphere . . .. . . and an INCREASE in Greenhouse Gases!

Q. Would this lead to global **COOLING or WARMING** ?

TROPICAL DEFORESTATION
(satellite imagery)



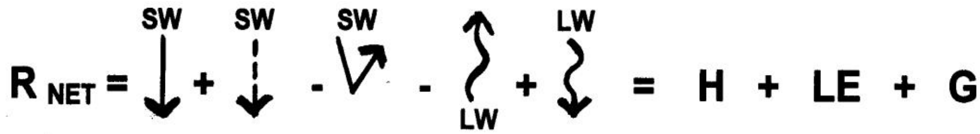
Striped pattern of deforestation due to construction of logging and access roads

BIODIVERSITY VULNERABILITY & ECOLOGICAL HOTSPOTS

- The TROPICAL RAINFORESTS have the largest extinction rates, but they are not the only places where species are at risk.
- 25 HOT SPOTS OF HABITAT LOSS = areas with many species that live nowhere else and that are in greatest danger of extinctions as a result of human activity

CORAL REEFS also at risk: coral bleaching due to increased temperatures / ENSO events; also reduced carbonate ion concentrations → one study – almost 60% of world's coral reefs maybe threatened by human activity

Key Concepts #3 & #4 relate to the ENERGY BALANCE:

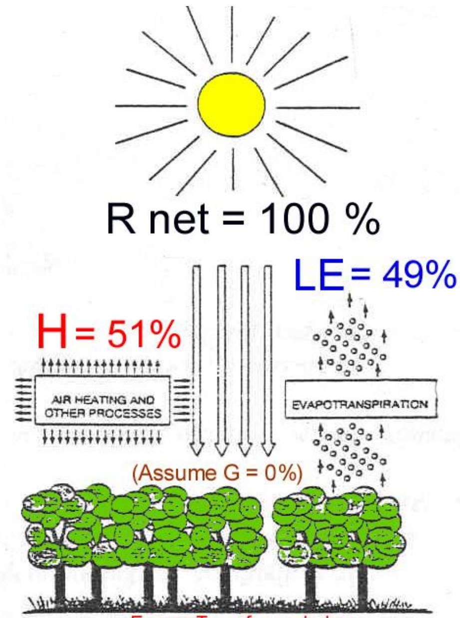


<u>KEY CONCEPT #3</u>: Change in Local Hydrology, The Water Cycle & The Energy Balance

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.

> Deforestation leads to a DECREASE in the amount of energy stored in **H / LE** *[circle one]* and an INCREASE in the amount of energy stored in **H / LE** *[circle one]*
>
> Would this lead to local **COOLING or WARMING** ? *[circle one]*

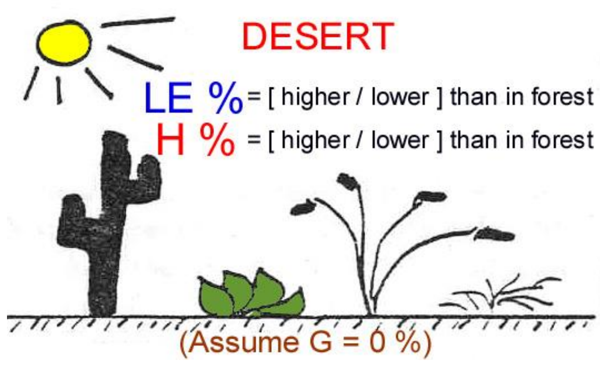


Energy Transfer each day above forest in Amazon Basin

<u>KEY CONCEPT #4</u>: Change in the Albedo of the Earth's Surface & the Energy Balance

Will albedo **INCREASE / DECREASE** *[circle one]* with deforestation?

Would this lead to local **COOLING or WARMING** ? *[circle one]*



How does the ENERGY BALANCE differ in an arid environment?

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

TOPIC # 17 SOLUTIONS & CHOICES: MITIGATION, ADAPTATION, SUSTAINABLE SYSTEMS, TECHNOLOGY & OTHER CHOICES

IMPORTANT DEFINITIONS (from IPCC AR4 WG-2 Glossary http://www.ipcc.ch/pdf/glossary/ar4-wg2.pdf

Question: To Adapt or Mitigate? 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*.

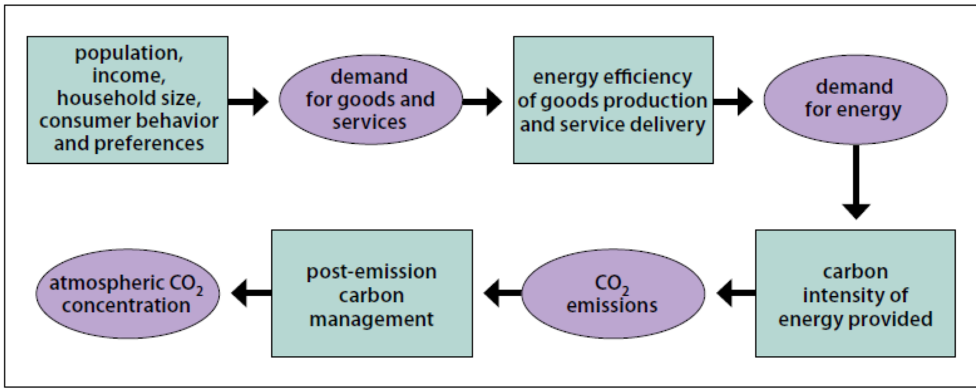


Figure 2. The chain of factors that determine how much CO_2 accumulates in the atmosphere. The green boxes represent factors that can potentially be influenced to affect the outcomes in the purple circles.

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.

- *Anticipatory adaptation* – takes place before impacts of *climate change* are observed.
- *Autonomous adaptation* – does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or *welfare* changes in *human systems*.
- *Planned adaptation* – is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

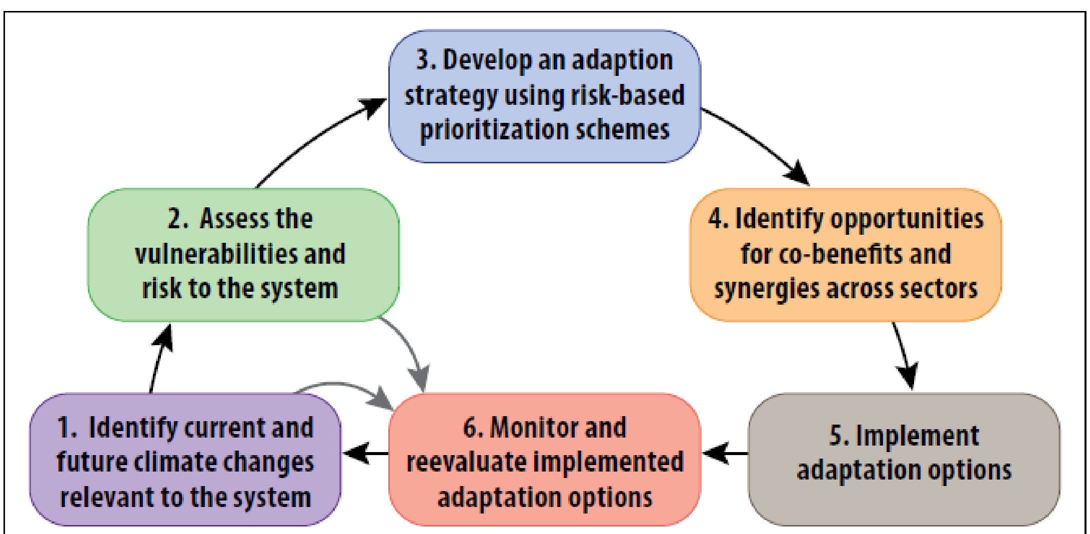


Figure 1. Adaptation planning is envisioned as a cyclical, iterative process incorporating these six steps.

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.

Some limited adaptation is occurring now, to both observed and projected future climate change, e.g.:

- partial drainage of the Tsho Rolpa glacial lake (Nepal)
- changes in livelihood strategies in response to permafrost melt by the Inuit in Nunavut (Canada)
- increased use of artificial snow-making by the Alpine ski industry
- coastal defenses in the Maldives and the Netherlands
- water management in Australia (and, to some extent, Arizona!)
- government responses to heatwaves in, for example, some European countries

Adaptation measures are seldom undertaken in response to climate change alone.

Adaptation will be necessary to address impacts resulting from the warming which is already unavoidable due to past emissions.

Many adaptations can be implemented at low cost, but comprehensive estimates of adaptation costs and benefits are currently lacking.

Adaptive capacity is uneven across and within societies.

- A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to future climate change.
- If climate change is faster than is anticipated, many developing countries simply cannot cope with more frequent/intense occurrence of extreme weather events, as this will drain resources budgeted for other purposes.
- Climate change will occur in the life cycle of many infrastructure projects (coastal dikes, bridges, sea ports, etc.). Strengthening infrastructures based on new criteria may take decades to implement.

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 (rainwater harvesting in Tucson) -

sustainable lifestyles . . . and more!

Examples of current and potential options for adapting to climate change for vulnerable sectors.
IPCC Ar4 wg2 Table TS.6, see: http://www.ipcc.ch/publications_and_data/ar4/wg2/en/tssts-5.html#ts-5-1

	Food, fibre and forestry	Water resources	Human health	Industry, settlement and society
Drying/ Drought	*Crops*: development of new drought-resistant varieties; intercropping; crop residue retention; weed management; irrigation and hydroponic farming; water harvesting *Livestock*: supplementary feeding; change in stocking rate; altered grazing and rotation of pasture *Social*: Improved extension services; debt relief; diversification of income	Leak reduction Water demand management through metering and pricing Soil moisture conservation e.g., through mulching Desalination of sea water Conservation of groundwater through artificial recharge Education for sustainable water use	Grain storage and provision of emergency feeding stations Provision of safe drinking water and sanitation Strengthening of public institutions and health systems Access to international food markets	Improve adaptation capacities, especially for livelihoods Incorporate climate change in development programmes Improved water supply systems and co-ordination between jurisdictions
Increased rainfall/ Flooding	*Crops*: Polders and improved drainage; development and promotion of alternative crops; adjustment of plantation and harvesting schedule; floating agricultural systems *Social*: Improved extension services	Enhanced implementation of protection measures including flood forecasting and warning, regulation through planning legislation and zoning; promotion of insurance; and relocation of vulnerable assets	Structural and non-structural measures. Early-warning systems; disaster preparedness planning; effective post-event emergency relief	Improved flood protection infrastructure "Flood-proof" buildings Change land use in high-risk areas Managed realignment and "Making Space for Water" Flood hazard mapping; flood warnings Empower community institutions
Warming/ Heatwaves	*Crops*: Development of new heat-resistant varieties; altered timing of cropping activities; pest control and surveillance of crops *Livestock*: Housing and shade provision; change to heat-tolerant breeds *Forestry*: Fire management through altered stand layout, landscape planning, dead timber salvaging, clearing undergrowth. Insect control through prescribed burning, non-chemical pest control *Social*: Diversification of income	Water demand management through metering and pricing Education for sustainable water use	International surveillance systems for disease emergence Strengthening of public institutions and health systems National and regional heat warning systems Measures to reduce urban heat island effects through creating green spaces Adjusting clothing and activity levels; increasing fluid intake	Assistance programmes for especially vulnerable groups Improve adaptive capacities Technological change
Wind speed/ Storminess	*Crops*: Development of wind-resistant crops (e.g., vanilla)	Coastal defence design and implementation to protect water supply against contamination	Early-warning systems; disaster preparedness planning; effective post-event emergency relief	Emergency preparedness, including early-warning systems More resilient infrastructure Financial risk management options for both developed and developing regions

An example of choice we all make: MODES OF TRANSPORTATION
(Solutions & Choices are Linked to the Laws of Motion & Momentum)

> Mathematical and mechanical principles are the alphabet in which God wrote the world.
> *~ Robert Boyle*

FIRST SOME DEFINITIONS WE NEED:

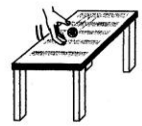
- **Force** (F) = any influence that can cause a body to be *accelerated*. The common force unit is the *newton.* A force is an *action*, not a thing. Every force is similar to a push or a pull.

- **Acceleration (a) =** change in velocity (Δv) / t (time interval) **Velocity** = distance (d) / time (t)
NOTE: *In each of these cases a hand push is accelerating the ball:*

Push ball at rest

Push moving ball to speed it up

Pat it in opposite direction to slow it



Push it from the side to change direction

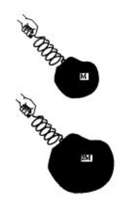
- **Net force** = the total, overall force on an object. The net force due to two forces acting in the same direction is the sum of the two. The net force due to two forces acting in opposite directions is the difference between the two and acts in the direction of the stronger force.

- **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.**

Q*:* *If the anvil is more massive than the astronaut, which shakes more – the anvil or the astronaut?*

- **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.

The larger stone has twice the mass of the smaller stone, hence its inertia is twice that of the smaller stone =>



- **Weight** = The force due to gravity upon a body. The net gravitational force exerted on it by all other bodies.

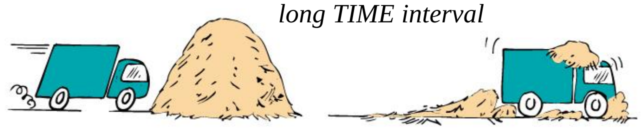
- **Momentum** (*p*) = inertia in motion; the product of mass of an object and its velocity.
Momentum = mass x velocity or **Momentum =** $m\,v$ or $p = m\,v$

An *external* force applied over time is required to **change the momentum** of a body:
Impulse = Force x time interval = change in (mass x velocity) $F\,t = \Delta(mv)$

Wall is opposite FORCE slowing down the truck over short TIME interval

MASS x VELOCITY = TIME x **FORCE**

Haystack is opposite FORCE slowing down the truck over long TIME interval



MASS x VELOCITY = **TIME** x FORCE

MOMENTUM IS CONSERVED "before" and "after" in each case

NEWTON'S 1ST LAW OF MOTION (also called "<u>The Law of Inertia</u>")
(Note different ways to state it)

- ***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
- ***Every body continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it.***

  or
- ***All bodies have inertia***.

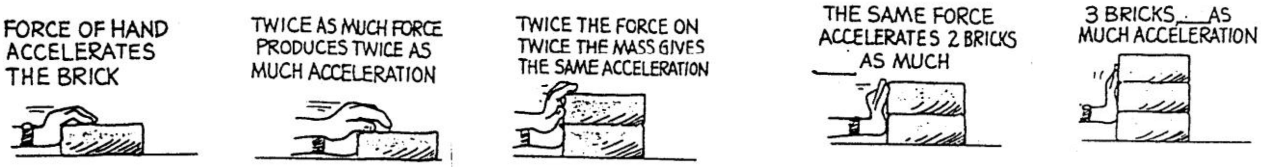
1st Law the easy way: The key word is " ___________" If a body is at rest, it continues to stay at rest; if moving, it continues to move in a straight line. It can't start or stop moving on its own without some external force, i.e. "a body does not accelerate itself."

NEWTON'S 2ND LAW OF MOTION:

- ***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
- ***Acceleration $\propto$ net force / mass*** $\propto$ = "is proportional to"

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



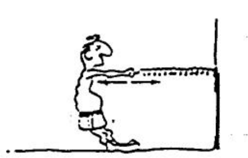
fill in the two blanks above

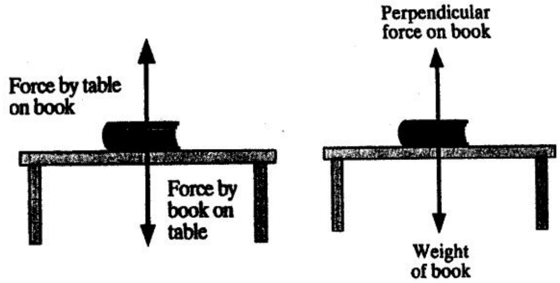
NEWTON'S 3RD LAW OF MOTION (Also sometimes called "<u>The Law Of Force Pairs</u>")

- ***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***

ACTION: Man pulls on spring
REACTION : ________ pulls on __________





Some GC-Savvy Info on the Pros & Cons of SUV's vs. Econo Cars

Video on *"Understanding Car Crashes It's Basis Physics"*

DIRECTIONS: Fill in the blanks or circle the correct answers below as you watch the video.
If you missed some answers, watch it again online in D2L

NEWTON'S LAWS – *Video shows test track, dummy on back of truck*

1. Why did the dummy get left behind? It's called _________________, the property of matter that causes it to____.

2. Isaac Newton's *(circle one)* [**1st 2nd 3rd**] **Law of Motion** states: "A body at rest remains at __________ unless acted upon by an external ______________ and a body in ______________ continues to move at a constant _____________ in a straight line, unless it is acted upon by an external force."

Video shows more test track action & crashing dummies

3. Now watch what happens when the car crashes into a barrier. The front end of the car is crushing and absorbing __________________ which slows down the rest of the car.

4. In this case, it is the steering wheel and windshield that applies the _________________ that overcomes the dummy's _____________.

Video shows Equations of the Laws of Motion *(see class notes as well)*

5. Newton explained the relationship between crash forces and inertia in his *(circle one)*
[**1st 2nd 3rd**] **Law of Motion.**

6. Fill in the blanks to explain what each letter in the formula represents:

F = ___________ ➔ $F = ma$

$m =$ __________________________

$a =$ __________________________

$F = \frac{m \Delta v}{t}$

$\Delta v =$ __________________________

$t =$ __________________________

Ft = ____________ ➔ $Ft = m \Delta v$

$m \Delta v =$ __________________________

MOMENTUM: *Video shows surfers, cheetah, & elephant*

7. Momentum is ___________________ in motion. It is the product of an object's _____________ and its ____________________.

8. Which has more momentum? An 80,000 pound big rig truck traveling 2 mph or a 4,000 pound SUV traveling 40 mph? *(circle one)* **[big rig truck SUV neither, their momentum is the same]**

Video shows soccer kicks, slap shots, & egg toss

9. What is it that changes an object's momentum? _________________. This is the product of ____________ and the ___________________ for which it acts.

10. If the eggs are of equal mass and are thrown at the same velocity they will have the same _____________________. The wall and the sheet both apply equal ________________.

11. The wall applies a _______________ force over a _________________ time, while the sheet applies a _________________ force over a ___________________ time.

12. With panic braking the driver stops in less time or distance and experiences more ________________.

Video shows more crashing and smashing

13. The second animated vehicle's front end is less stiff so it crushes two feet instead of one, causing the deceleration to ____.

14. Extending the time of impact is the basis for many of the ideas about keeping people safe in crashes. List three applications in vehicle or highway safety:

(1) _____________________ (2) ________________________ (3) _____________________

CONSERVING MOMENTUM & ENERGY – *Video shows more collision examples*

15. In a collision of two cars of unequal mass, the occupants of the lighter car would experience much higher _____________________, hence much higher ________________ than the occupants of the heavier car.

16. Motion related energy is called _____________________. Energy due to an object's position or conditions is called ______________________________.

17. *Circle* the correct formula for kinetic energy (KE):

KE = 1/2 m2v **KE = 1/2 2 mv^2** **KE = 1/2 mv^2** **KE = 1/2 mv2**

PART 2: ADDITIONAL SELF TEST QUESTIONS TO APPLY THE VIDEO'S CONCEPTS
(answers will be posted online)

18. Show mathematically why an 80,000 pound (36,000 kg) big rig traveling 2 mph (0.89 m/s) has the **SAME momentum** as a 4,000 pound (1800 kg) sport utility vehicle (SUV) traveling 40 mpg (18 m/s):

HINT: Momentum is the product of an object's mass and velocity. The formula is ***p* = m v**
(Use SI units. The SI unit for momentum is kilogram x meter/second (kg m/s)

19. Show mathematically why a small increase in your vehicle's speed results in a tremendous increase in your vehicle's **kinetic energy (KE)**, (e.g. doubling your speed from 30 mph to 60 mph results in a quadrupling of your kinetic energy.)

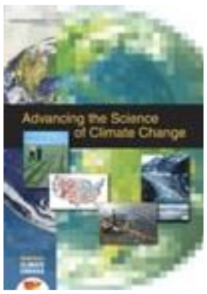
20. The **Law of Conservation of Energy** states: *"energy cannot be created or destroyed; it can be transformed from one form to another but the total amount of energy never changes."* Car crashes involve huge amounts of energy. How does the **crashworthiness** of the car affect the transfer and transformations of the energy and, ultimately, protect the occupants?

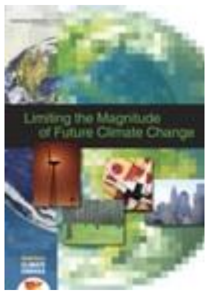
NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

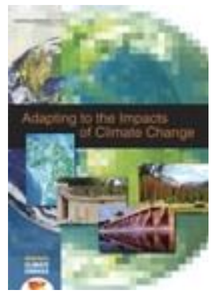
America's CLIMATE CHOICES

http://americasclimatechoices.org

Strong Evidence on Climate Change Underscores Need For Actions to Reduce Emissions and Begin Adapting to Impacts


Advancing the Science of Climate Change


Limiting the Magnitude of Climate Change


Adapting to the Impacts of Climate Change

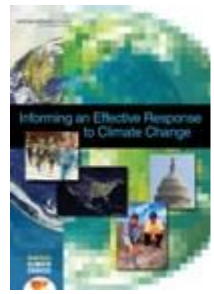

Informing an Effective Response to Climate Change

Table 1. Sea Level Rise and Lake Level Changes: Examples of some adaptation options for one expected outcome*

Impact	Possible adaptation action	Federal	State	Local govt.	Private sector	NGO / Indiv.
Gradual inundation of low-lying land; loss of coastal habitats, especially coastal wetlands; saltwater intrusion into coastal aquifers and rivers; increased shoreline erosion and loss of barrier islands; changes in navigational conditions	Site and design all future public works projects to take sea level rise into account	■	■	■		
	Eliminate public subsidies for development in high hazard areas along the coast	■	■			
	Develop strong, well-planned, shoreline retreat or relocation plans/programs (public infrastructure and private properties), and post-storm redevelopment plans		■	■		
	Retrofit/protect public infrastructure (stormwater/wastewater systems, energy facilities, roads, causeways, ports, bridges, etc.)	■	■	■		
	Use natural shorelines, setbacks, and buffer zones to allow inland migration of shore habitats and barrier islands over time (e.g., dunes and forested buffers)	■	■	■		■
	Encourage alternatives to shoreline "armoring" through "living shorelines"	■	■	■	■	

* Excerpted from Table 3.8 in the full report

NOTES

ADDITIONAL NOTES:

APPENDIX I

CLIMATE LITERACY:

THE ESSENTIAL PRINCIPLES OF CLIMATE SCIENCES

A Guide for Individuals and Communities
Second Version: March 2009

For full version see:
http://climateliteracynow.org/

U.S. Global Change Research Program /Climate Change Science Program
1717 Pennsylvania Avenue, NW Suire 250 Washington DC 20006 USA
+1.202.223.6262 (Voice) + 1.202.223.3065 (Fax)

http://www.climatescience.gov
climate.literacy@climatescience.gov

For an up to date list of partners please refer to U.S Climate Change Science Program at:
http://www.climatescience.gov

ADDITIONAL NOTES:

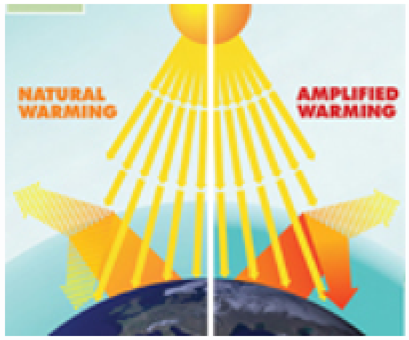
CLIMATE LITERACY: The Essential Principles of Climate Science

http://climateliteracynow.org/

Essential Principle 1 CLIMATE & LIFE ON EARTH

The Sun is the primary source of energy for Earth's climate system

Concepts



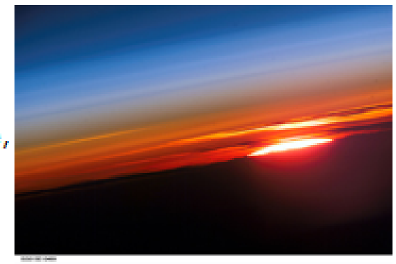
The greenhouse effect is a natural phenomenon whereby heat-trapping gases in the atmosphere, primarily water vapor, keep the Earth's surface warm. Human activities, primarily burning fossil fuels and changing land cover patterns, are increasing the concentrations of some of these gases, amplifying the natural greenhouse effect.

Source: Modified from the Marian Koshland Science Museum of the National Academy of Sciences' "Global Warming: Facts & Our Future" 2004

- 1a. Sunlight reaching the Earth can heat the land, ocean, and atmosphere. Some of that sunlight is reflected back to space by the surface, clouds, or ice. Much of the sunlight that reaches Earth is absorbed and warms the planet.
- 1b. When Earth emits the same amount of energy as it absorbs, its energy budget is in balance, and its average temperature remains stable.
- 1c. The tilt of Earth's axis relative to its orbit around the Sun results in predictable changes in the duration of daylight and the amount of sunlight received at any latitude throughout a year. These changes cause the annual cycle of seasons and associated temperature changes.
- 1d. Gradual changes in Earth's rotation and orbit around the Sun change the intensity of sunlight received in our planet's polar and equatorial regions. For at least the last 1 million years, these changes occurred in 100,000-year cycles that produced ice ages and the shorter warm periods between them.
- 1e. A significant increase or decrease in the Sun's energy output would cause Earth to warm or cool. Satellite measurements taken over the past 30 years show that the Sun's energy output has changed only slightly and in both directions. These changes in the Sun's energy are thought to be too small to be the cause of the recent warming observed on Earth.

Climate is regulated by complex interactions among components of the Earth system

Concepts



Caption: Solar power drives Earth's climate. Energy from the Sun heats the surface, warms the atmosphere, and powers the ocean currents.
Source: Astronaut photograph ISS015-E-10469, courtesy NASA/JSC Gateway to Astronaut Photography of Earth.

- 2a. Earth's climate is influenced by interactions involving the Sun, ocean, atmosphere, clouds, ice, land, and life. Climate varies by region as a result of local differences in these interactions.

- 2b. Covering 70% of Earth's surface, the ocean exerts a major control on climate by dominating Earth's energy and water cycles. It has the capacity to absorb large amounts of solar energy. Heat and water vapor are redistributed globally through density-driven ocean currents and atmospheric circulation. Changes in ocean circulation caused by tectonic movements or large influxes of fresh water from melting polar ice can lead to significant and even abrupt changes in climate, both locally and on global scales.

- 2c. The amount of solar energy absorbed or radiated by Earth is modulated by the atmosphere and depends on its composition. Greenhouse gases—such as water vapor, carbon dioxide, and methane—occur naturally in small amounts and absorb and release heat energy more efficiently than abundant atmospheric gases like nitrogen and oxygen. Small increases in carbon dioxide concentration have a large effect on the climate system.

- 2d. The abundance of greenhouse gases in the atmosphere is controlled by biogeochemical cycles that continually move these components between their ocean, land, life, and atmosphere reservoirs. The abundance of carbon in the atmosphere is reduced through seafloor accumulation of marine sediments and accumulation of plant biomass and is increased through deforestation and the burning of fossil fuels as well as through other processes.

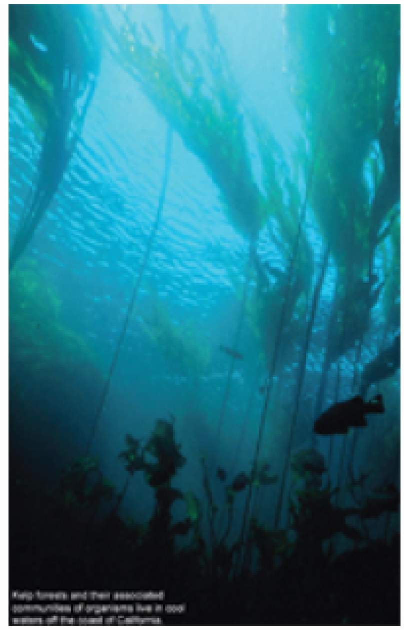
- 2e. Airborne particulates, called "aerosols," have a complex effect on Earth's energy balance: they can cause both cooling, by reflecting incoming sunlight back out to space, and warming, by absorbing and releasing heat energy in the atmosphere. Small solid and liquid particles can be lofted into the atmosphere through a variety of natural and man-made processes, including volcanic eruptions, sea spray, forest fires, and emissions generated through human activities.

- 2f. The interconnectedness of Earth's systems means that a significant change in any one component of the climate system can influence the equilibrium of the entire Earth system. Positive feedback loops can amplify these effects and trigger abrupt changes in the climate system. These complex interactions may result in climate change that is more rapid and on a larger scale than projected by current climate models

Essential Principle 3 SUN, ENERGY, & CLIMATE

. Life on Earth depends on, is shaped by, and affects climate.

Concepts



Kelp forests and their associated communities of organisms live in cool waters off the coast of California.

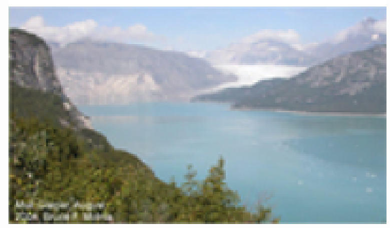
- A. Individual organisms survive within specific ranges of temperature, precipitation, humidity, and sunlight. Organisms exposed to climate conditions outside their normal range must adapt or migrate, or they will perish.
- B. The presence of small amounts of heat-trapping greenhouse gases in the atmosphere warms Earth's surface, resulting in a planet that sustains liquid water and life.
- C. Changes in climate conditions can affect the health and function of ecosystems and the survival of entire species. The distribution patterns of fossils show evidence of gradual as well as abrupt extinctions related to climate change in the past.
- D. A range of natural records shows that the last 10,000 years have been an unusually stable period in Earth's climate history. Modern human societies developed during this time. The agricultural, economic, and transportation systems we rely upon are vulnerable if the climate changes significantly.
- E. Life—including microbes, plants, and animals and humans—is a major driver of the global carbon cycle and can influence global climate by modifying the chemical makeup of the atmosphere. The geologic record shows that life has significantly altered the atmosphere during Earth's history.

Essential Principle 4 WEATHER SYSTEMS & CLIMATE

Climate varies over space and time through both natural and man-made processes

Concepts

Muir Glacier, August 1941, William O. Field



Muir Glacier, August 2004, Bruce F. Molnia

- 4a. Climate is determined by the long-term pattern of temperature and precipitation averages and extremes at a location. Climate descriptions can refer to areas that are local, regional, or global in extent. Climate can be described for different time intervals, such as decades, years, seasons, months, or specific dates of the year.

- 4b. Climate is not the same thing as weather. Weather is the minute-by-minute variable condition of the atmosphere on a local scale. Climate is a conceptual description of an area's average weather conditions and the extent to which those conditions vary over long time intervals.

- 4c. Climate change is a significant and persistent change in an area's average climate conditions or their extremes. Seasonal variations and multi-year cycles (for example, the El Niño Southern Oscillation) that produce warm, cool, wet, or dry periods across different regions are a natural part of climate variability. They do not represent climate change.

- 4d. Scientific observations indicate that global climate has changed in the past, is changing now, and will change in the future. The magnitude and direction of this change is not the same at all locations on Earth.

- 4e. Based on evidence from tree rings, other natural records, and scientific observations made around the world, Earth's average temperature is now warmer than it has been for at least the past 1,300 years. Average temperatures have increased markedly in the past 50 years, especially in the North Polar Region.

- 4f. Natural processes driving Earth's long-term climate variability do not explain the rapid climate change observed in recent decades. The only explanation that is consistent with all available evidence is that human impacts are playing an increasing role in climate change. Future changes in climate may be rapid compared to historical changes.

- 4g. Natural processes that remove carbon dioxide from the atmosphere operate slowly when compared to the processes that are now adding it to the atmosphere. Thus, carbon dioxide introduced into the atmosphere today may remain there for a century or more. Other greenhouse gases, including some created by humans, may remain in the atmosphere for thousands of years.

Essential Principle 5 — CLIMATE VARIATION

Our understanding of the climate system is improved through observations, theoretical studies, and modeling..

Concepts

A rosette device containing 36 seawater samples is retrieved in the Southern Ocean. Seawater samples from various depths are analyzed to measure the ocean's carbon balance.
Source: B. Longworth © 2008

- 5a. The components and processes of Earth's climate system are subject to the same physical laws as the rest of the Universe. Therefore, the behavior of the climate system can be understood and predicted through careful, systematic study.

- 5b. Environmental observations are the foundation for understanding the climate system. From the bottom of the ocean to the surface of the Sun, instruments on weather stations, buoys, satellites, and other platforms collect climate data. To learn about past climates, scientists use natural records, such as tree rings, ice cores, and sedimentary layers. Historical observations, such as native knowledge and personal journals, also document past climate change.

- 5c. Observations, experiments, and theory are used to construct and refine computer models that represent the climate system and make predictions about its future behavior. Results from these models lead to better understanding of the linkages between the atmosphere-ocean system and climate conditions and inspire more observations and experiments. Over time, this iterative process will result in more reliable projections of future climate conditions.

- 5d. Our understanding of climate differs in important ways from our understanding of weather. Climate scientists' ability to predict climate patterns months, years, or decades into the future is constrained by different limitations than those faced by meteorologists in forecasting weather days to weeks into the future.1

- 5e. Scientists have conducted extensive research on the fundamental characteristics of the climate system and their understanding will continue to improve. Current climate change projections are reliable enough to help humans evaluate potential decisions and actions in response to climate change.

1 Based on "Climate Change: An Information Statement of the American Meteorological Society," 2007

Essential Principle 6 CLIMATE & HUMAN ACTIVITIES

Human activities are impacting the climate system

Concepts

Society relies heavily on energy that is generated by burning fossil fuels—coal, oil, and natural gas.
Source: A. Palmer, 2008

- 6a. The overwhelming consensus of scientific studies on climate indicates that most of the observed increase in global average temperatures since the latter part of the 20th century is very likely due to human activities, primarily from increases in greenhouse gas concentrations resulting from the burning of fossil fuels.2

- 6b. Emissions from the widespread burning of fossil fuels since the start of the Industrial Revolution have increased the concentration of greenhouse gases in the atmosphere. Because these gases can remain in the atmosphere for hundreds of years before being removed by natural processes, their warming influence is projected to persist into the next century.

- 6c. Human activities have affected the land, oceans, and atmosphere, and these changes have altered global climate patterns. Burning fossil fuels, releasing chemicals into the atmosphere, reducing the amount of forest cover, and rapid expansion of farming, development, and industrial activities are releasing carbon dioxide into the atmosphere and changing the balance of the climate system.

- 6d. Growing evidence shows that changes in many physical and biological systems are linked to human-caused global warming.3 Some changes resulting from human activities have decreased the capacity of the environment to support various species and have substantially reduced ecosystem biodiversity and ecological resilience.

- 6e. Scientists and economists predict that there will be both positive and negative impacts from global climate change. If warming exceeds 2 to 3°C (3.6 to 5.4°F) over the next century, the consequences of the negative impacts are likely to be much greater than the consequences of the positive impacts.

2 Based on IPCC, 2007: The Physical Science Basis: Contribution of Working Group I
3 Based on IPCC, 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II

Essential Principle 7 CLIMATE & DECISIONS

Climate change will have consequences for the Earth system and human lives

Concepts

Iowa National Guard preparing to put sandbags in place on a levee in Kingston, Iowa, to protect rough ly 50,000 acres of farmland threatened by flood waters.
Source: Iowa National Guard photo by Sgt. Chad D. Nelson

- 7a. Melting of ice sheets and glaciers, combined with the thermal expansion of seawater as the oceans warm, is causing sea level to rise. Seawater is beginning to move onto low-lying land and to contaminate coastal fresh water sources and beginning to submerge coastal facilities and barrier islands. Sea-level rise increases the risk of damage to homes and buildings from storm surges such as those that accompany hurricanes.

- 7b. Climate plays an important role in the global distribution of freshwater resources. Changing precipitation patterns and temperature conditions will alter the distribution and availability of freshwater resources, reducing reliable access to water for many people and their crops. Winter snowpack and mountain glaciers that provide water for human use are declining as a result of global warming.

- 7c.. Incidents of extreme weather are projected to increase as a result of climate change. Many locations will see a substantial increase in the number of heat waves they experience per year and a likely decrease in episodes of severe cold. Precipitation events are expected to become less frequent but more intense in many areas, and droughts will be more frequent and severe in areas where average precipitation is projected to decrease.2

- 7d. The chemistry of ocean water is changed by absorption of carbon dioxide from the atmosphere. Increasing carbon dioxide levels in the atmosphere is causing ocean water to become more acidic, threatening the survival of shell-building marine species and the entire food web of which they are a part.

- 7e. Ecosystems on land and in the ocean have been and will continue to be disturbed by climate change. Animals, plants, bacteria, and viruses will migrate to new areas with favorable climate conditions. Infectious diseases and certain species will be able to invade areas that they did not previously inhabit.

- 7f. Human health and mortality rates will be affected to different degrees in specific regions of the world as a result of climate change. Although cold-related deaths are predicted to decrease, other risks are predicted to rise. The incidence and geographical range of climate-sensitive infectious diseases—such as malaria, dengue fever, and tick-borne diseases—will increase. Drought-reduced crop yields, degraded air and water quality, and increased hazards in coastal and low-lying areas will contribute to unhealthy conditions, particularly for the most vulnerable populations.

CLIMATE CHANGES

Throughout its history, Earth's climate has varied, reflecting the complex interactions and dependencies of the solar, oceanic, terrestrial, atmospheric, and living components that make up planet Earth's systems. For at least the last million years, our world has experienced cycles of warming and cooling that take approximately 100,000 years to complete. Over the course of each cycle, global average temperatures have fallen and then risen again by about 9°F(5°C), each time taking Earth into an ice age and then warming it again. This cycle is believed associated with regular changes in Earth's orbit that alter the intensity of solar energy the planet receives. Earth's climate has also been influenced on very long timescales by changes in ocean circulation that result from plate tectonic movements. Earth's climate has changed abruptly at times, sometimes as a result of slower natural processes such as shifts in ocean circulation, sometimes due to sudden events such as massive volcanic eruptions. Species and ecosystems have either adapted to these past climate variations or perished.

While global climate has been relatively stable over the last 10,000 years—the span of human civilization—regional variations in climate patterns have influenced human history in profound ways, playing an integral role in whether societies thrived or failed. We now know that the opposite is also true: human activities—burning fossil fuels and deforesting large areas of land, for instance—have had a profound influence on Earth's climate. In its 2007 Fourth Assessment, the Intergovernmental Panel on Climate Change (IPCC) stated that it had "very high confidence that the global average net effect of human activities since 1750 has been one of warming." The IPCC attributes humanity's global warming influence primarily to the increase in three key heat-trapping gases in the atmosphere: carbon dioxide, methane, and nitrous oxide. The U.S. Climate Change Science Program published findings in agreement with the IPCC report, stating that "studies to detect climate change and attribute its causes using patterns of observed temperature change in space and time show clear evidence of human influences on the climate system (due to changes in greenhouse gases, aerosols, and stratospheric ozone)."1

To protect fragile ecosystems and to build sustainable communities that are resilient to climate change—including extreme weather and climate events—a climate-literate citizenry is essential. This *climate science literacy* guide identifies the essential principles and fundamental concepts that individuals and communities should understand about Earth's climate system. Such understanding improves our ability to make decisions about activities that increase vulnerability to the impacts of climate change and to take precautionary steps in our lives and livelihoods that would reduce those vulnerabilities.

HOW DO WE KNOW WHAT IS SCIENTIFICALLY CORRECT?

The Peer Review Process

Science is an on-going process of making observations and using evidence to test hypotheses. As new ideas are developed and new data are obtained, oftentimes enabled by new technologies, our understanding evolves. The scientific community uses a highly formalized version of peer review to validate research results and our understanding of their significance. Researchers describe their experiments, results, and interpretations in scientific manuscripts and submit them to a scientific journal that specializes in their field of science. Scientists who are experts in that field serve as "referees" for the journal: they read the manuscript carefully to judge the reliability of the research design and check that the interpretations are supported by the data. Based on the reviews, journal editors may accept or reject manuscripts or ask the authors to make revisions if the study has insufficient data or unsound interpretations. Through this process, only those concepts that have been described through well-documented research and subjected to the scrutiny of other experts in the field become published papers in science journals and accepted as current science knowledge. Although peer review does not guarantee that any particular published result is valid, it does provide a high assurance that the work has been carefully vetted for accuracy by informed experts prior to publication. The overwhelming majority of peer-reviewed papers about global climate change acknowledge that human activities are substantially contributing factors.

KEY DEFINITIONS

Weather The specific conditions of the atmosphere at a particular place and time, measured in terms of variables that include temperature, precipitation, cloudiness, humidity, air pressure, and wind.

Weather Forecast A prediction about the specific atmospheric conditions expected for a location in the short-term future (hours to days).

Climate The long-term average of conditions in the atmosphere, ocean, and ice sheets and sea ice described by statistics, such as means and extremes.

Climate Forecast Aprediction about average or extreme climate conditions for a region in the long-term future (seasons to decades).

Climate Variability Natural changes in climate that fall within the normal range of extremes for a particular region, as measured by temperature, precipitation, and frequency of events. Drivers of climate variability include the El Niño Southern Oscillation and other phenomena.

Climate Change A significant and persistent change in the mean state of the climate or its variability. Climate change occurs in response to changes in some aspect of Earth's environment: these include regular changes in Earth's orbit about the sun, re-arrangement of continents through plate tectonic motions, or anthropogenic modification of the atmosphere.

Global Warming The observed increase in average temperature near the Earth's surface and in the lowest layer of the atmosphere. In common usage, "global warming" often refers to the warming that has occurred as a result of increased emissions of greenhouse gases from human activities. Global warming is a type of climate change; it can also lead to other changes in climate conditions, such as changes in precipitation patterns.

Climate System The matter, energy, and processes involved in interactions among Earth's atmosphere, hydrosphere, cryosphere, lithosphere, biosphere, and Earth-Sun interactions.

Likely, Very Likely, Extremely Likely, Virtually Certain These terms are used by the Intergovernmental Panel on Climate Change (IPCC) to indicate how probable it is that a predicted outcome will occur in the climate system, according to expert judgment. Aresult that is deemed "likely" to occur has a greater than 66% probability of occurring. A"very likely" result has a greater than 90% probability. "Extremely likely" means greater than 95% probability, and "virtually certain" means greater than 99% probability.

Mitigation Human interventions to reduce the sources of greenhouse gases or enhance the sinks that remove them from the atmosphere.

Vulnerability The degree to which physical, biological, and socio-economic systems are susceptible to and unable to cope with adverse impacts of climate change.**2**

Adaptation Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects.**3**

Fossil fuels Energy sources such as petroleum, coal, or natural gas, which are derived from living matter that existed during a previous geologic time period.

Feedback The process through which a system is controlled, changed, or modulated in response to its own output. Positive feedback results in amplification of the system output; negative feedback reduces the output of a system.

Carbon Cycle Circulation of carbon atoms through the Earth systems as a result of photosynthetic conversion of carbon dioxide into complex organic compounds by plants, which are consumed by other organisms, and return of the carbon to the atmosphere as carbon dioxide as a result of respiration, decay of organisms, and combustion of fossil fuels.

1. *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*. Thomas R. Karl, Susan J. Hassol, Christopher D. Miller, and William L. Murray, editors, 2006. AReport by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.
2. Based on IPCC, 2007: *Impacts, Adaptation and Vulnerability. Contribution of Working Group II*
3. Based on IPCC, 2007: *Mitigation of Climate Change. Contribution of Working Group III*

INFORMED CLIMATE DECISIONS REQUIRE AN INTEGRATED APPROACH.

In the coming decades, scientists expect climate change to have an increasing impact on human and natural systems. In a warmer world, accessibility to food, water, raw materials, and energy are likely to change. Human health, biodiversity, economic stability, and national security are also expected to be affected by climate change. Climate model projections suggest that negative effects of climate change will significantly outweigh positive ones. The nation's ability to prepare for and adapt to new conditions may be exceeded as the rate of climate change increases.

Reducing our vulnerability to these impacts depends not only upon our ability to understand climate science and the implications of climate change, but also upon our ability to integrate and use that knowledge effectively. Changes in our economy and infrastructure as well as individual attitudes, societal values, and government policies will be required to alter the current trajectory of climate's impact on human lives. The resolve of individuals, communities, and countries to identify and implement effective management strategies for critical institutional and natural resources will be necessary to ensure the stability of both human and natural systems as temperatures rise.

This *climate science literacy* document focuses primarily on the physical and biological science aspects of climate and climate change. Yet as nations and the international community seek solutions to global climate change over the coming decades, a more comprehensive, interdisciplinary approach to climate literacy—one that includes economic and social considerations— will play a vital role in knowledgeable planning, decision making, and governance. Anew effort is in development within the social sciences community to produce a companion document that will address these aspects of climate literacy. Together, these documents will promote informed decision-making and effective systems-level responses to climate change that reflect a fundamental understanding of climate science. It is imperative that these responses to climate change embrace the following guiding principle

GUIDING PRINCIPLE FOR INFORMED CLIMATE DECISION: Humans can take actions to reduce climate change and its impacts.

a. Climate information can be used to reduce vulnerabilities or enhance the resilience of communities and ecosystems affected by climate change. Continuing to improve scientific understanding of the climate system and the quality of reports to policy and decision-makers is crucial.

b. Reducing human vulnerability to the impacts of climate change depends not only upon our ability to understand climate science, but also upon our ability to integrate that knowledge into human society. Decisions that involve Earth's climate must be made with an understanding of the complex inter-connections among the physical and biological components of the Earth system as well as the consequences of such decisions on social, economic, and cultural systems.

c. The impacts of climate change may affect the security of nations. Reduced availability of water, food, and land can lead to competition and conflict among humans, potentially resulting in large groups of climate refugees.

d. Humans may be able to mitigate climate change or lessen its severity by reducing greenhouse gas concentrations through processes that move carbon out of the atmosphere or reduce greenhouse gas emissions.

e. Acombination of strategies is needed to reduce greenhouse gas emissions. The most immediate strategy is conservation of oil, gas, and coal, which we rely on as fuels for most of our transportation, heating, cooling, agriculture, and electricity. Short-term strategies involve switching from carbon-intensive to renewable energy sources, which also requires building new infrastructure for alternative energy sources. Long-term strategies involve innovative research and a fundamental change in the way humans use energy.

f. Humans can adapt to climate change by reducing their vulnerability to its impacts. Actions such as moving to higher ground to avoid rising sea levels, planting new crops that will thrive under new climate conditions, or using new building technologies represent adaptation strategies. Adaptation often requires financial investment in new or enhanced research, technology, and infrastructure.

g. Actions taken by individuals, communities, states, and countries all influence climate. Practices and policies followed in homes, schools, businesses, and governments can affect climate. Climate-related decisions made by one generation can provide opportunities as well as limit the range of possibilities open to the next generation. Steps toward reducing the impact of climate change may influence the present generation by providing other benefits such as improved public health infrastructure and sustainable built environments.

APPENDIX II

Supplementary Materials for Background & Use in Class Activities

a) Periodic Table Activity

b) Modeling the Energy Balance

c) Introduction to Tree Rings & Dendrochronology

d) Classifying Wood Samples

e) Making Skeleton Plots

f) The Bristlecone Pine Research Project

g) Understanding Cap & Trade: A Simple Analogy

PERIODIC TABLE ACTIVITY

==> *TO BEGIN, OPEN THE ENVELOPE & TAKE OUT THE 11 ATOM "DOT DIAGRAMS"*

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. **These similarities are the key to describing the underlying basis for the structure of the Periodic Table.**

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 ==>

To earn your participation points, students who worked on this answer sheet, SIGN HERE:

Name: ____ Team #_________

Name: ____ Team #_________

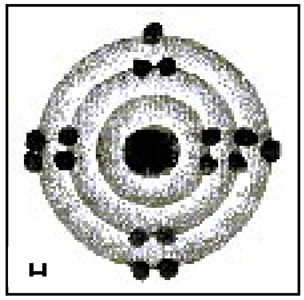
Name: ____ Team #_________

==> ***PLEASE RETURN THE DIAGRAMS TO THE ENVELOPE & RETURN IT TO DR. H*** ☺

PERIODIC TABLE ACTIVITY BACKGROUND

In the envelope you will find schematic "dot" diagrams of 11 different atoms (elements) in a random order.

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 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*

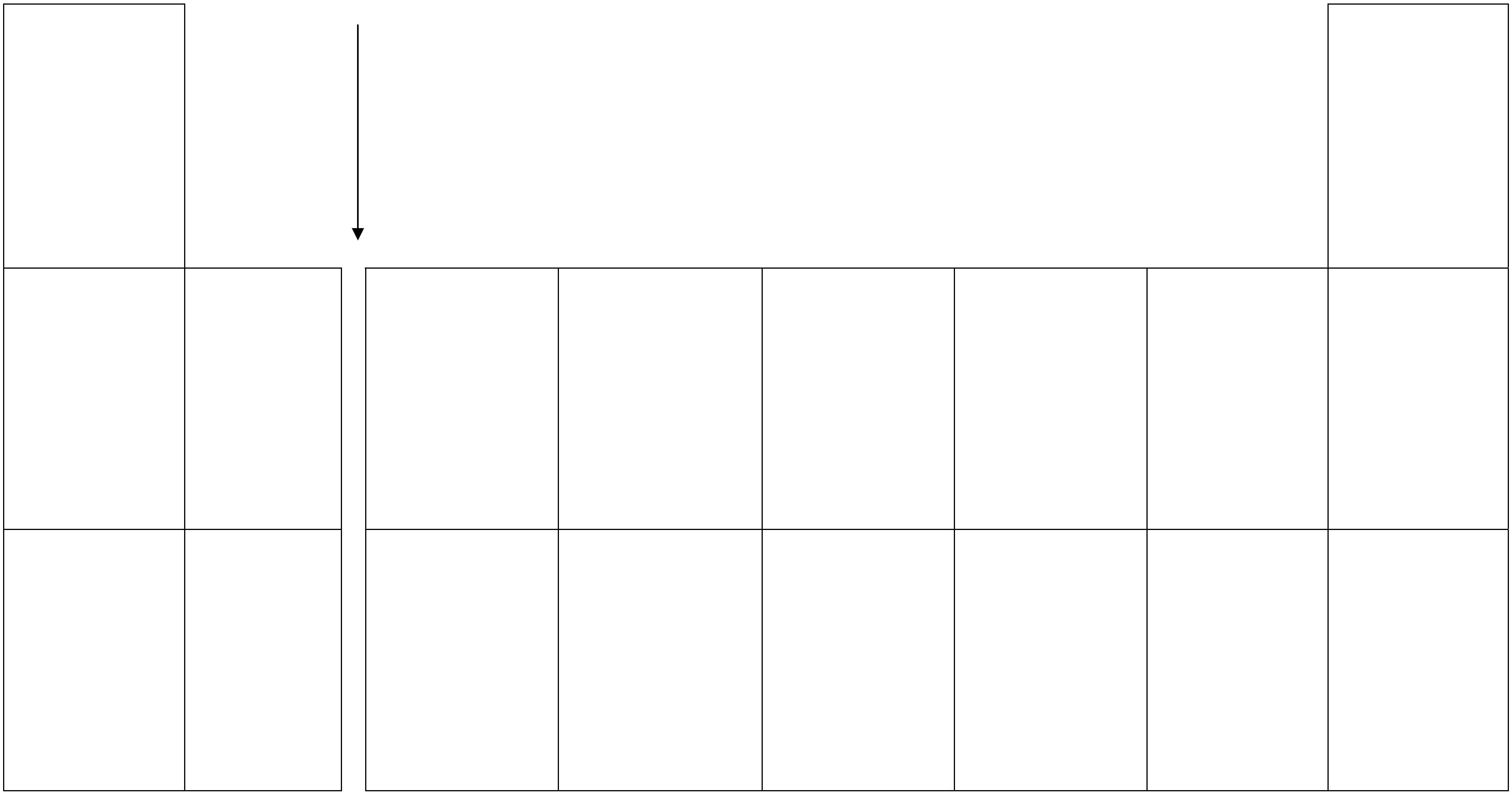
SQUARE LAYOUT FOR ARRANGING THE ATOM "DOT DIAGRAMS"

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

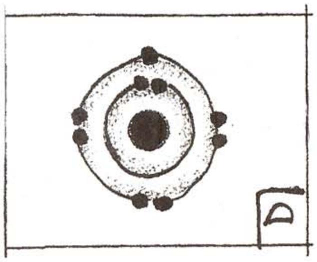


THE PERIODIC TABLE OF THE ELEMENTS

8 — Atomic Number **O** — Atomic Symbol 15.9994 — Atomic Mass

1 **H** 1.00797																	2 **He** 4.0026
3 **Li** 6.939	4 **Be** 9.0122											5 **B** 10.811	6 **C** 12.011	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.998	10 **Ne** 20.183
11 **Na** 22.990	12 **Mg** 24.312											13 **Al** 26.982	14 **Si** 28.086	15 **P** 30.974	16 **S** 32.064	17 **Cl** 35.453	18 **Ar** 39.948
19 **K** 39.02	20 **Ca** 40.08	21 **Sc** 44.956	22 **Ti** 47.90	23 **V** 50.942	24 **Cr** 51.995	25 **Mn** 54.938	26 **Fe** 55.847	27 **Co** 58.933	28 **Ni** 58.71	29 **Cu** 63.54	30 **Zn** 65.37	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.922	34 **Se** 78.96	35 **Br** 79.909	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.63	39 **Y** 88.905	40 **Zr** 91.22	41 **Nb** 92.906	42 **Mo** 95.94	43 **Tc** (99)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.4	47 **Ag** 107.870	48 **Cd** 112.40	49 **In** 114.82	50 **Sn** 118.69	51 **Sb** 121.75	52 **Te** 201.59	53 **L** 200.59	54 **Xe** 200.59
55 **Cs** 132.91	56 **Ba** 137.34	*	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.85	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.09	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.37	82 **Pb** 207.19	83 **Bi** 208.98	84 **Po** (210)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (233)	88 **Ra** (226)	**															

*Lanthanide Series (Rare Earths)	57 **La** 138.91	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (147)	62 **Sm** 150.35	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.92	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97
**Actinide Series	89 **Ac** (227)	90 **Th** 232.04	91 **Pa** (231)	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (254)	100 **Fm** (253)	101 **Md** (256)	102 **No** (254)	103 **Lw** (257)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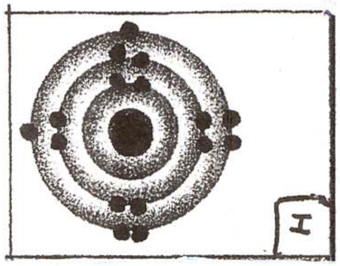
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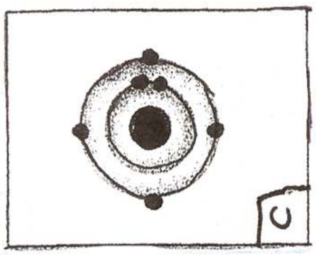
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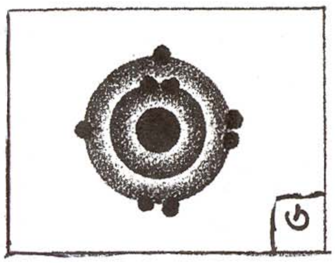
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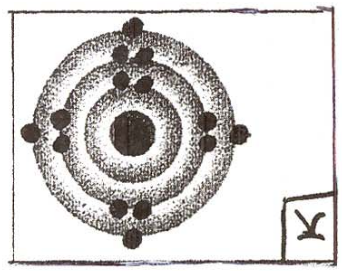
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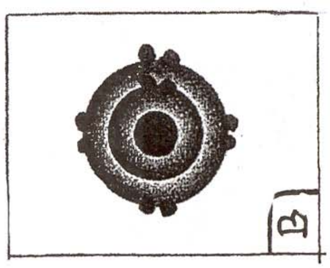
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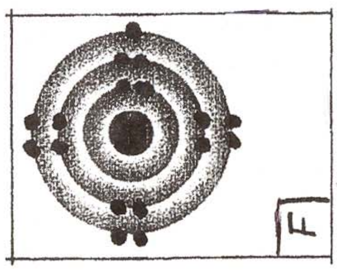
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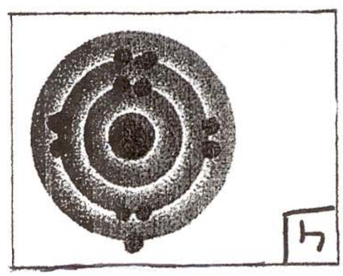
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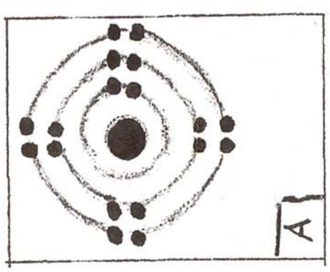
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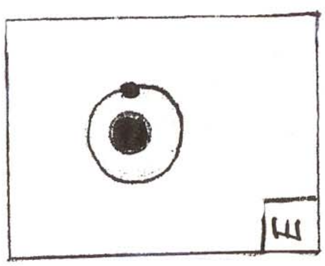
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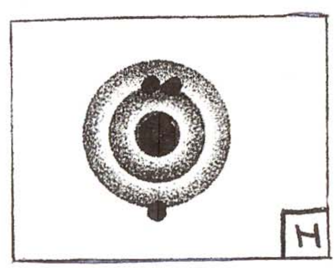
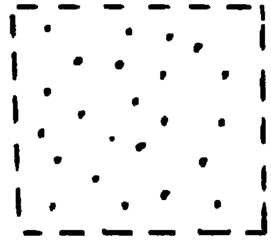

I

ADDITIONAL NOTES:

“CARTOON” SYMBOLS:

To represent the Earth’s surface:

“CARTOON” SYMBOLS:

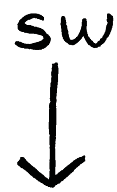


To represent the atmosphere – composed of both invisible gases, aerosols, dust and other particulate matter:

“CARTOON” SYMBOLS:

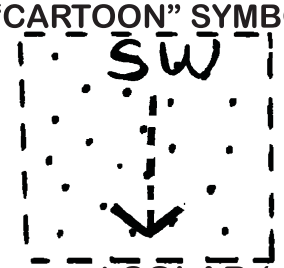
To represent CLOUDS

“CARTOON” SYMBOLS:



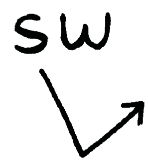
To represent SOLAR (shortwave) radiation coming in DIRECTLY. (aka Direct shortwave radiation)

“CARTOON” SYMBOLS:



To represent SOLAR (shortwave) radiation coming in as DIFFUSE shortwave radiation, i.e. scattered by gases, clouds, and particles in the atmosphere.

“CARTOON” SYMBOLS:



To represent SOLAR (shortwave) radiation that is REFLECTED (or scattered) BACK TO SPACE by: atmosphere, clouds, Earth’s surface, etc.

“CARTOON” SYMBOLS:

To represent TERRESTRIAL (longwave IR) radiation emitted upward by the Earth’s surface or the atmosphere

“CARTOON” SYMBOLS:

To represent TERRESTRIAL (longwave IR) re-radiation emitted downward by the Earth’s ATMOSPHERE

MODELING THE ENERGY BALANCE

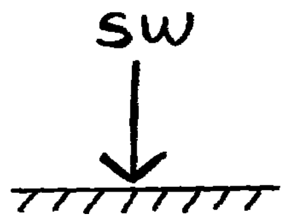
THE EARTH'S ENERGY BALANCE
Making a Model of It!

PUTTING IT TOGETHER:

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

R =

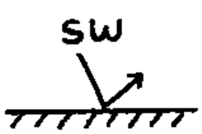
SW BEAMED DIRECTLY TO EARTH'S SURFACE WHERE IT IS ABSORBED:



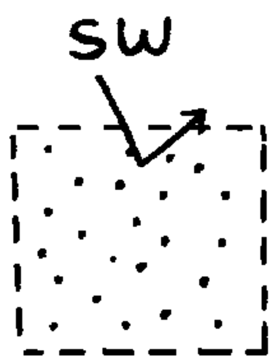
SW REFLECTED BACK TO SPACE:

By clouds

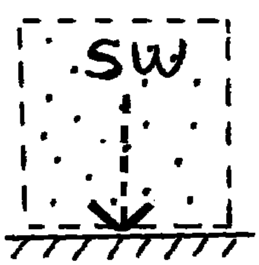
By Earth's surface



SW SCATTERED BACK TO SPACE BY ATMOSPHERE:

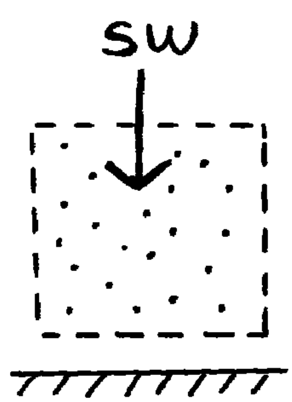


SW SCATTERED DOWN TO EARTH's SURFACE where it is absorbed



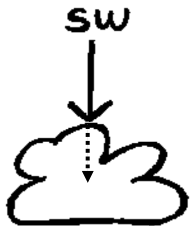
SW ABSORBED IN ATMOSPHERE BY GASES, DUST, etc.

(including Ozone absorbing shortwave UV)



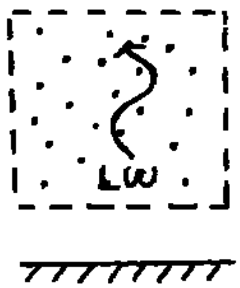
SW ABSORBED In ATMOSPHERE BY CLOUDS & H2O vapor:

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

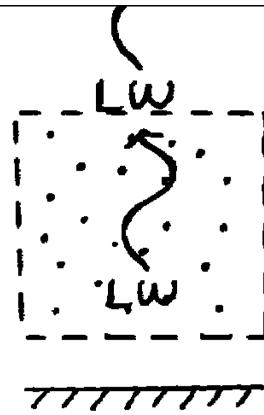


LW (IR) EMITTED FROM EARTH'S SURFACE ESCAPING TO SPACE THROUGH THE "OUTGOING IR ATMOSPHERIC WINDOW"

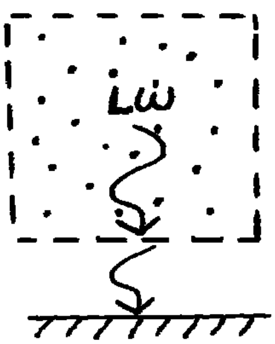
IR EMITTED FROM EARTH'S SURFACE BUT ABSORBED IN THE ATMOSPHERE BY GREENHOUSE GASES (H_2O,CO_2, CH_4, ETC.)



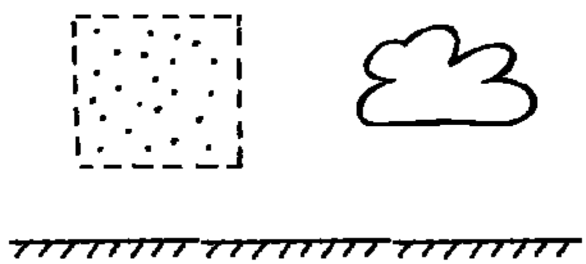
IR EMITTED FROM <u>ATMOSPHERE</u> ESCAPING TO SPACE



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



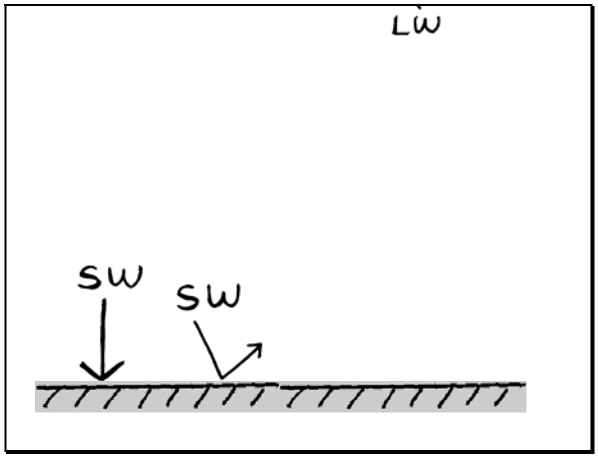
All together now:



What if? . . .

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

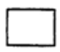
What would the energy pathways in the Earth-Sun system look like?

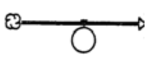


Finally, we'll create a model to represent the "Earth's Energy Balance with No Atmosphere"

The model is designed based on the STELLA MODELING software . . .

Model Components:

 Earth Energy (reservoir)

 Solar–to-Earth (flow & valve)
Earth IR-to-Space (flow & valve)

 converters

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

 plus connectors (as needed)

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 =

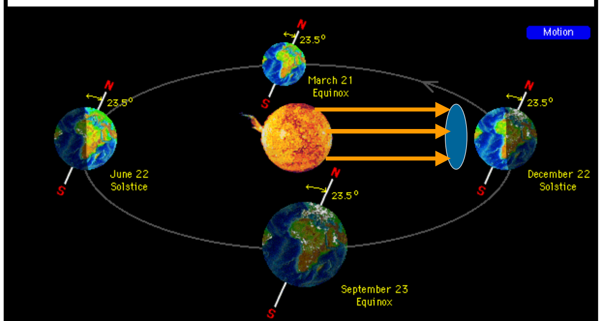
The amount of radiation given off by a substance is proportional to the fourth power of its absolute temperature

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

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

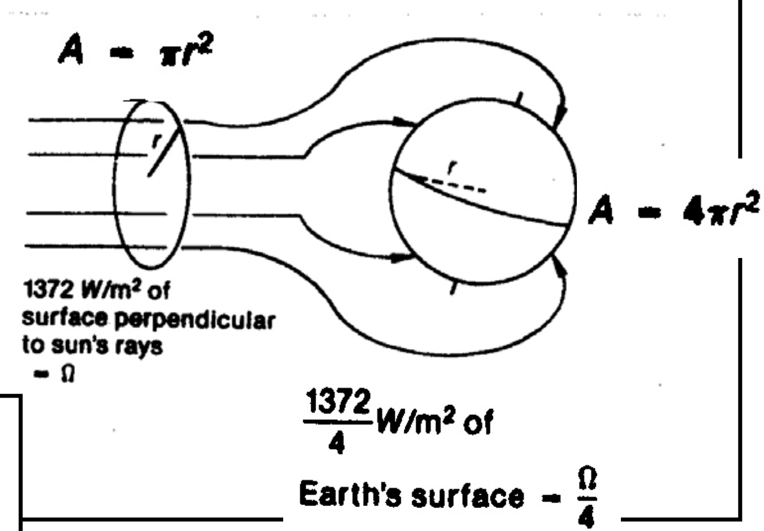
Earth's Cross Sectional Area:

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

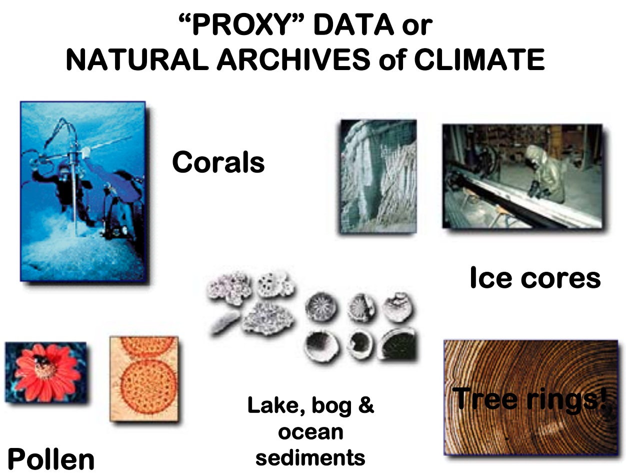
Influenced directly by how much energy is in the Earth Energy stock & the Earth's Heat Capacity

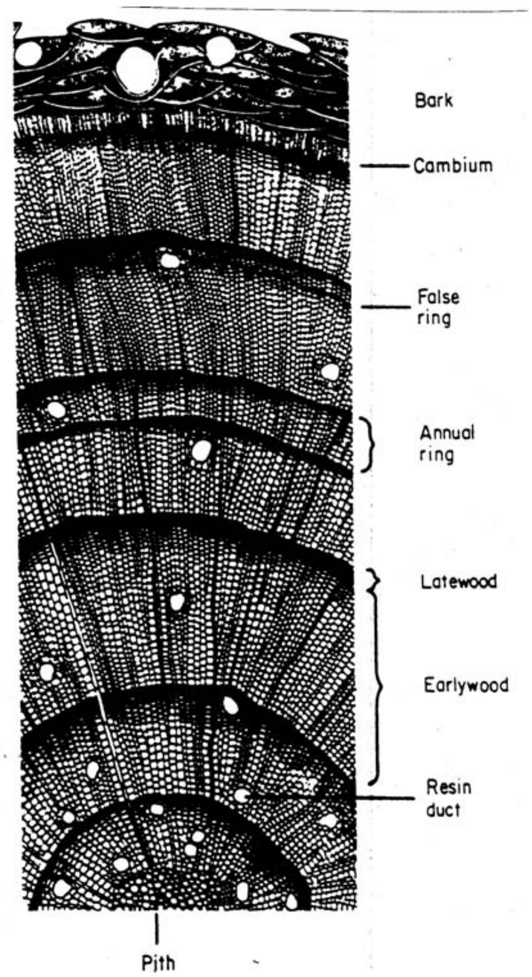
Now let's put it all together in a Stella model!

Stella Model of Earth Energy Balance with No Atmosphere

INTRODUCTION TO TREE RINGS & DENDROCHRONOLOGY

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





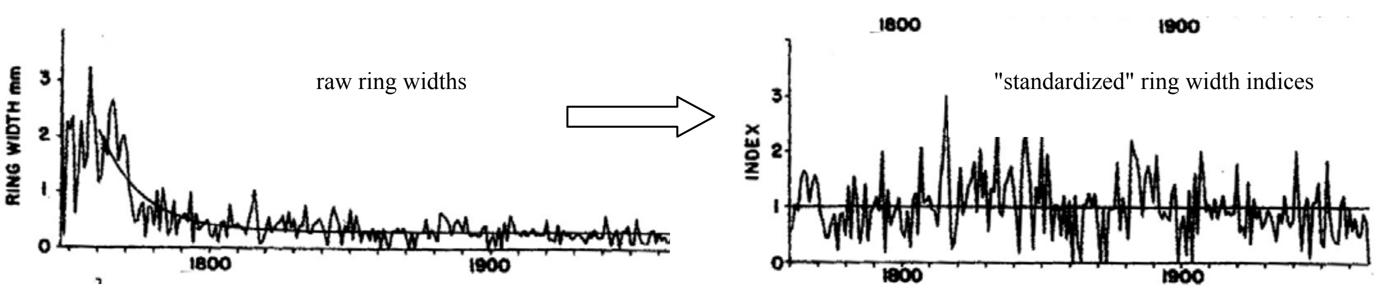
How old is the tree shown above? _____ years

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

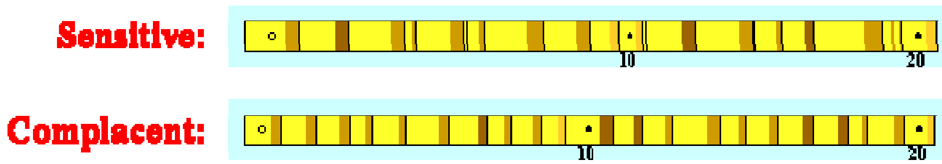
- *Uniformitarianism* --“the present is the key to the past;” can reconstruct past based on present linkages
- *Limiting Factors* --growth can occur only as fast as allowed by factor that is most limiting (e.g. rainfall)
- *Site Selection* -- sites are selected based on criteria of tree-ring sensitivity 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:

- Missing rings & false rings (need for “master chronology”)
- 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 > 4,000 years old: 4,780+)
- Value of precise dating (long chronologies, climate reconstructions, archaeology, radiocarbon dating)

Sensitive vs. Complacent Tree-Ring Growth

Source: Dr. Paul Sheppard's LTRR



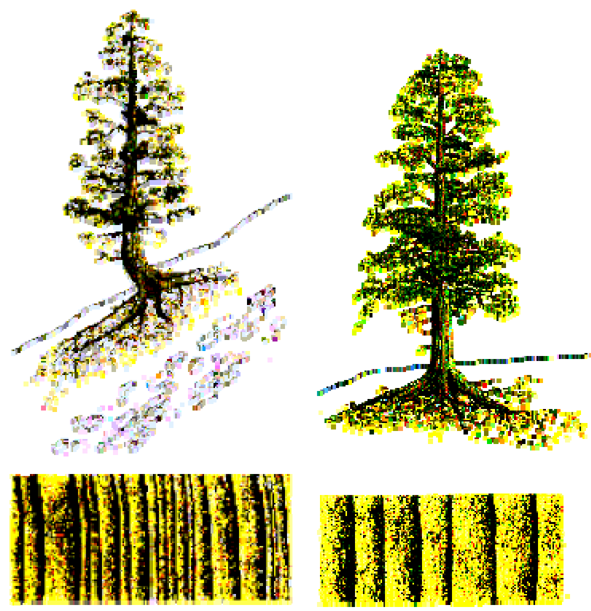
: *http://tree.ltrr.arizona.edu/skeletonplot/sensitivitycomplacency.htm*

"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 moisture complacency)
- Complacent ring growth can be difficult to crossdate: matching patterns of relatively wide and narrows rings across trees is harder when not much variation exists

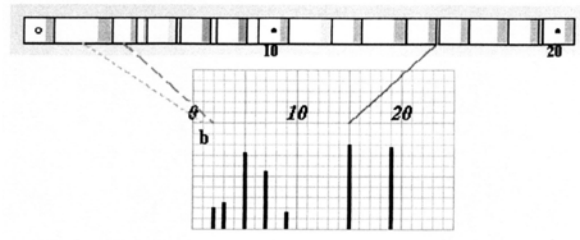
"Sensitive" tree growth:

- 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 blanks with the proper label for each tree and ring-growth pattern: **"Complacent" or "Sensitive"**   ____________   ____________

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

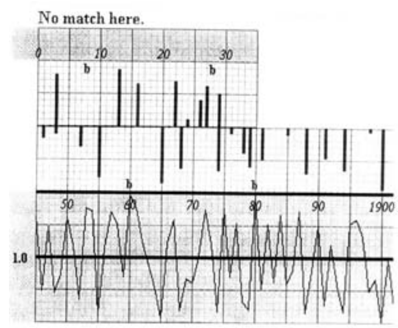
The objective: To find the mirror image of the patterns
. . . of the marks pointing <u>up</u> on the skeleton plot
. . . .with the marks hanging <u>down</u> on the <u>master chronology</u>

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

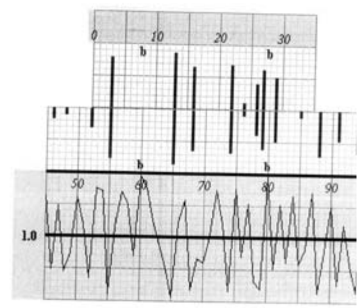
How to know when you have a match:

- 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**
- the tree rings are **annual**, i.e., one ring is formed each calendar year
- 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.
- 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)

CLASSIFYING WOOD SAMPLES FROM DIFFERENT TYPES OF TREES

BACKGROUND: *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**
- the tree rings are **annual**, i.e., one ring is formed each calendar year
- 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.
- 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)

Goal: To classify the wood samples in your wood kit into three categories -- those trees that are **(1) Suitable, (2) Unsuitable, or (3) Possibly Suitable** for crossdating and subsequent dendrochronological analysis.

Here's the key to the codes on the wood specimens, so you know what kind of wood you are looking at:

ABCO = White Fir
Agave = Agave
BLF = Aspen
Fan Palm = Fan Palm
Little Leaf Palo = Little Leaf Palo Verde
Mes = Mesquite
Mul = Mulberry
NMLocust = New Mexico Locust

PIPO = Ponderosa Pine
PIST = White Pine
PP or not labeled = Prickly Pear
PSME = Douglas Fir
SAG = Saguaro
SEGI = Sequoia
SHP2000 = Bristlecone Pine (longaeva=Great Basin)
SiLeafOak = Silver Leaf Oak

Tree-ring Cores = Lodgepole Pine

QUESTIONS

1. From the wood samples in your kit, select one that represents a **complacent tree** and one that represents a **sensitive tree**.

   Complacent tree sample: _____________________________

   Sensitive tree example:______________________________

   Describe what you observe in the wood to make this designation:

2. Classify the wood samples into to the following three categories: those trees that are **(1) Suitable, (2) Unsuitable, or (3) Possibly Suitable** for crossdating and subsequent dendrochronological analysis. Then list the common name of the tree (see code table) in the corresponding column in the table below:

1. Suitable	2. Unsuitable	3. Possibly suitable

3. Now, **justify your choices** of suitable, unsuitable, or possibly suitable by explaining the **criteria** you used to classify each sample:

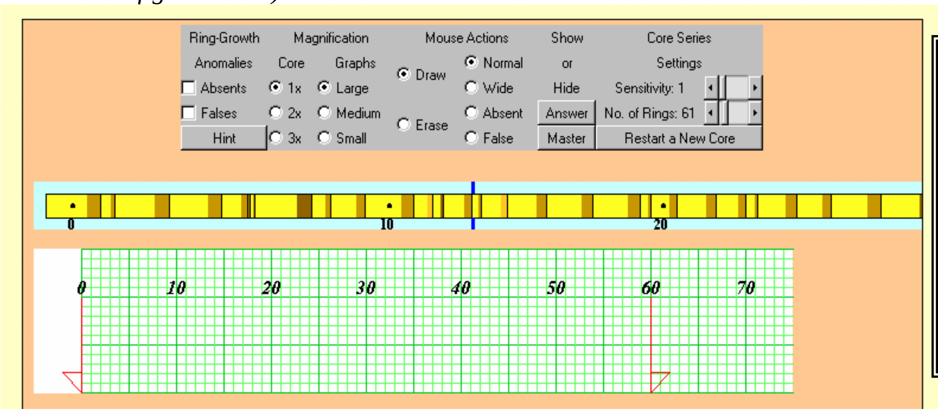
ADDITIONAL NOTES:

ASSIGNMENT: Making Skeleton Plots of Tree-Ring Core Samples

Go to the following website (enlarge the window to full screen if necessary). You can also go to the website directly without going through WebCT by entering: http://www.ltrr.arizona.edu/skeletonplot/introcrossdate.htm

1. Click on and READ through the Crossdating Tutorial's **Explanatory Pages** (Items #1 through #11, esp. #6-11). Be sure **to try out the examples** at each step to learn what to do.

2. Then click on #12, **'Try skeleton plotting for yourself'** to begin your skeleton plot. *(The screen image should look like the figure below).*



You can complete this on your own by following the step-by-step directions.

Want some extra help?

Come to office hours held by the TAs and Dr H, or email a preceptor to set up a meeting for help. We may also hold additional "Help Sessions" at set times. These will be announced in class

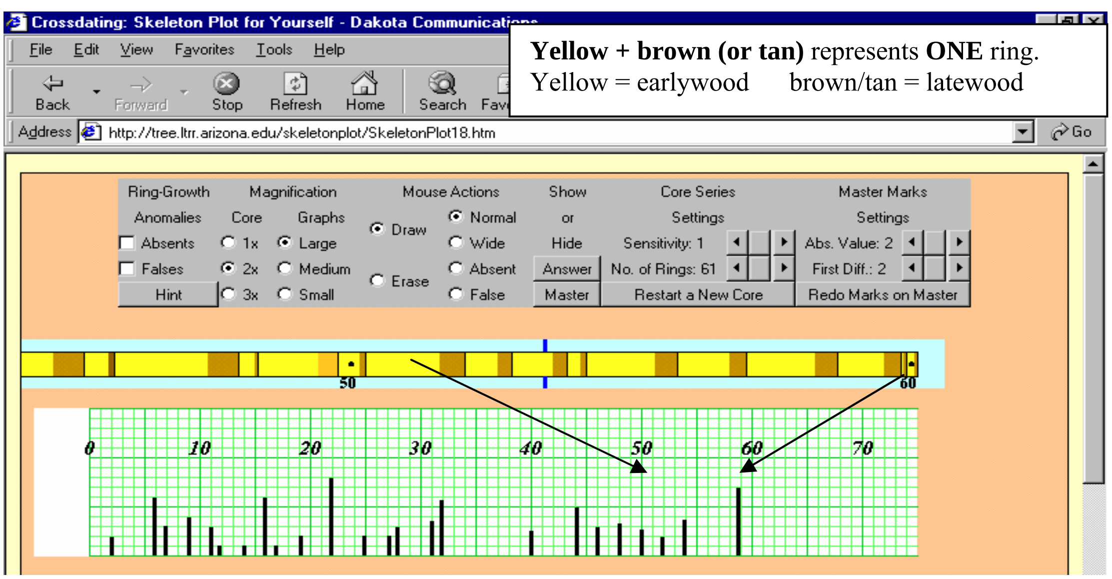
3. ***Begin skeleton plotting!*** **BIG HINT: CONCENTRATE only on the narrow rings!!**

4. To see the really **tiny rings better,** you can change the **zoom** on the core and the graph by clicking on 1x, 2x, or 3x for the core and large, medium, small for the graph paper.

5. If you **make a mistake** and put a mark on the wrong graph line or want to change the height of the mark, select **'ERASE'** and click on that mark to erase it. Then re-select **'DRAW'** to continue.

6. **Plot vertical marks for the narrowest rings -- the narrower the ring, the longer your mark** (see tutorial #6 on "Making Skeleton Plots"). To make your mark, on the graph paper, click on the vertical green line that corresponds to the proper ring number at the height you want to assign to your mark (e.g., 8-10 grid lines up for REALLY narrow; 5-7 for quite narrow; 2-4 for narrow.)

7. **Move the core** by clicking on it and **dragging.** You can use the blue marker line to keep track of the rings as you count and plot them. *(See figure below for example of completed skeleton plot.)*

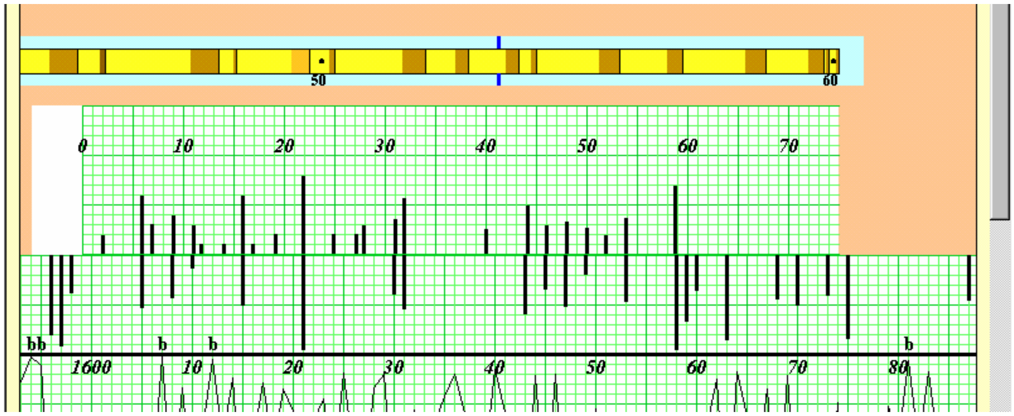


Yellow + brown (or tan) represents **ONE** ring.
Yellow = earlywood brown/tan = latewood

8. **When you have finished your __skeleton plot__** of the core's 61 rings (rings 0 through 60, defined by the two red arrows on the graph paper), click on the **MASTER** button to reveal the master chronology's skeleton plot and ring width indices.

9. To **pattern match** your skeleton plot with the master, **click and drag the master** until you find the match.

Here's an example of a correct pattern match ==>

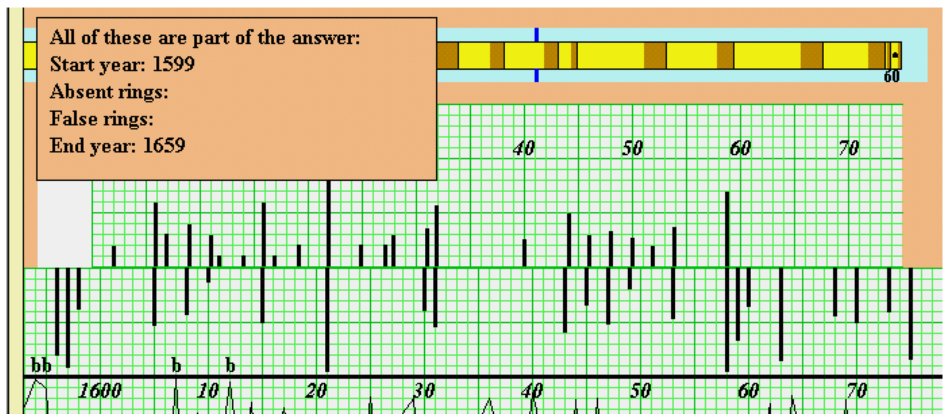


10. To **crossdate** your core after you find the match, find the **Start Year** (the year that corresponds with ring 0 on your plot) and **End Year** (the year for ring 60 on your plot).

11. When you think you have correctly matched *and* figured out the Start & End years, **click on 'ANSWER' to confirm that you have correctly pattern matched and crossdated your core & plot.** *(See the answer box on the figure below and note how the graph years match the answer box years.)*

12. If your plot's **Start & End years** agree with the **ANSWER**, you have successfully skeleton plotted, pattern matched, and crossdated your core!!!

Now, **keep your crossdated image on the screen** and follow these directions:



Create your document to submit for grading. It should contain:

- Your **NAME, Team # & Date**
  A "screen image" copy of your successfully **crossdated plot**. *(see Directions below)*
- **A written summary of what you did (~half page, double spaced, 10-12 font, 1 inch margins) which includes:** (a) a definition and description of the three main steps in your analysis: **skeleton plotting**, **pattern matching**, & **crossdating,** (b) a description of what a **master chronology** is and how it is used in crossdating, (c) an explanation of the difference between **complacency and sensitivity** and why it's important for crossdating, and (d) something interesting that *you* learned by doing this activity.

DOCUMENT DIRECTIONS:

With your crossdated image still on the screen, hold down the **Alt** and **Print Screen keys** (at the same time) and a copy of the computer screen image will be saved to the computer's temporary "clipboard."

Now start up MS Word (or other word processing software) and open a new document. **Type your NAME, GROUP #** and the **date** at the top of the page. Then click on **Paste** (or hold down the **Ctrl** and **V keys**) and what you copied from the screen will be pasted into the document. Below your plot, **Type** your half-page **written summary** (either right now or you can wait and write this part up later.) Save the document and **print it out** so you can turn it in at the start of class on the due date**.** *(If you are in a computer lab with no printer access, you can EMAIL your saved document to yourself as an attachment and finish it and print it out later.)*

BONUS POINT OPPORTUNITY (2 pts): After you've saved your work (see above), change the SENSITIVITY from 1 (very sensitive) to 4, 5 or 6 (more complacent). Then click "Restart a New Core" and try to plot, match, and crossdate the more complacent core. If you are successful, save the image as above and write a Bonus Point paragraph describing the challenges of crossdating a complacent core.

NAME: ___________________________________ **GROUP:**_________

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

(NOTE: Take careful notes during the class activity on this worksheet.
*You will **turn this worksheet in** as part of your BCP Activity Write-Up.)*

Objectives:
- to learn more about bristlecone pine sites and how to collect and analyze tree-ring data from cores
- to understand the concept of pattern-matching & crossdating between trees and between sites
- to become aware of the influences of climate and elevation on trees
- to understand the methods of making a master chronology
- to discover evidence of how climate varies through time

Logistics for the class project:

Five tree-ring sites are being studied (see attached site map). There are 4 groups working on each site; two groups working on the early period of the record at a site (1750-1900) and two groups working on the later period of the record at a site (1850- present -- *note overlap in record*).

At each site, there are records from for 4 different trees (for groups with more than 4 members, some students will have duplicate cores) (2 cores per tree -- early part and later part of record is represented in different groups)

1 master chronology for the site *(to be provided by instructor)*

What you should have completed in advance:
- A skeleton plot on graph paper for your own core, marked with frost rings if applicable, & starting & ending dates
- A "site composite" with all the plots for your site properly pattern-matched, dated, & taped together

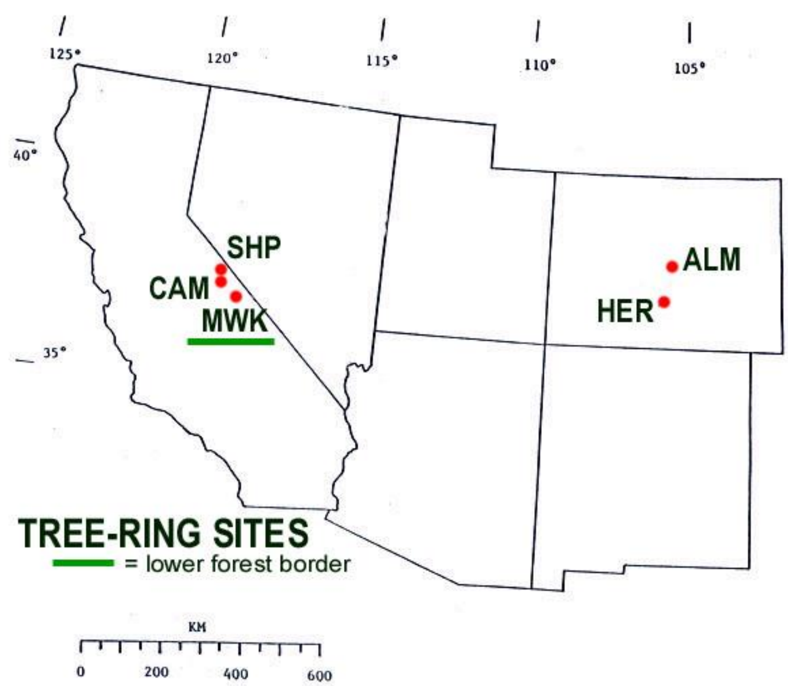
****

PART A -- DESCRIPTIONS OF THE FIVE BRISTLECONE PINE SITES (class presentation)

❑ 1. 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 and for your BCP Research Reports.

BRISTLECONE PINE SITES

	Core ID
Sheep Mt (SHP)	**C**
Campito Mt (CAM)	**D**
Methuselah Walk (MWK)	**B**
Almagre Mt (ALM)	**E**
Hermit Lake (HER)	**A**



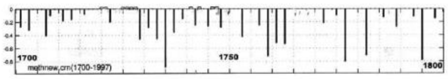
VARIABLES *(NOTE: A variable is something that varies from site to site or from time to time at one or more sites*)	**OBSERVATION TABLE: SITE-to-SITE COMPARISONS**				
	Sheep Mt Core ID = C	**Campito Mt Core ID = D**	**Methuselah Walk Core ID = B**	**Almagre Mt Core ID = E**	**Hermit Lake Core ID = A**
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?					
Moisture- or Temperature- sensitive?					
Rock / soil type	dolomite	sandstone	dolomite	granite	sandstone
# 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:					

PART B -- ANALYZING YOUR SITE

❑ Your Preceptor will gather together the 2 teams that analyzed the same site (the early part of the record & the later part of the record) into a **SITE GROUP**. Your Preceptor will present and explain the full chronology of the measured **ring-width indices** for your site and point out key things to notice. **Discuss** what you discovered about your site (e.g., variations, frost rings, and trends -- Are there differences between pre-1900 ring widths and post-1900 ring widths and frost ring frequency?)

Enter the name of your site: [ ]

Data collection & Observations from your site's **SKELETON PLOT MASTER:**



Enter the **years** during which **frost rings** formed at your site:

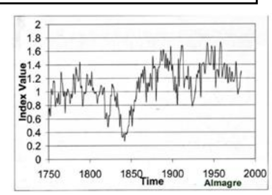
[ ]

Describe the relationship between **frost ring years** and **narrow ring years** (if any):

[ ]

Describe differences (if any) between pre-1900 & post-1900 frequency of frost rings:

[ ]



Data collection & Observations from your site's **RING WIDTH INDICES PLOT :**

Describe the variation in the time series of the **ring width indices** at your site (e.g., *increasing trend, no trend, step change beginning at 1900, etc. etc.)*

[ ]

Describe any other interesting things about your site that you observed:

[ ]

PART C: ANALYZING SITE-TO-SITE COMPARISONS

❑ Your Preceptor will then provide you with **the skeleton plot masters** and **ring-width indices for the 4 other sites** so you can compare the data from site to site. Spend some time looking at all the site chronologies and reviewing the notes you took during Dr H's presentation. Which sites appear to be similar in terms of tree growth? Which are different? What explanations can you come up with for the similarities and differences?

✍Now continue to fill in the **observation table** so that you can make site-to-site comparisons

PART D: DEVELOPING & TESTING HYPOTHESES

As a SITE GROUP, **discuss and develop various hypotheses** about site-to-site comparisons in tree-ring variability and what 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)

IMPORTANT: 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:

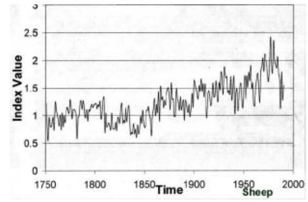
❑ **Hypothesis #1: Trees in sites that are closer together will pattern-match and crossdate better than sites that are far apart.**
(Discuss and figure out how to test this hypothesis. HINT: use the master skeleton plots!)

❑ 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:

	Results of comparison between the **California** sites only:	Results of comparison between the **Colorado** sites only:	Results of comparison between the **California & Colorado** sites:
Describe whether sites pattern match and/or crossdate			
Is Hypothesis #1 supported?			

❑ 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 data you have collected 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.

❑ STATE SEVERAL EXPLANATIONS for why this hypothesis might be true or not true:

Additional notes:

ADDITIONAL NOTES:

UNDERSTANDING CAP & TRADE: A SIMPLE ANALOGY

Source: Holmes Hummel, PhD hummrlhh@mindspring.com See a complete & updated version at: http://www.grist.org/article/cap-and-trade-through-musical-chairs/

Goals of Cap & Trade

Overall goal of an emission cap is to lower emissions over time

Cap is lowered over time

- Provides economic incentives for achieving reductions in the emissions of pollutants

Credits are retired

- Companies may voluntarily retire credits
- Individuals may purchase carbon credits and retire them to further reduce the overall level of emissions

Musical Chairs: A Helpful Analogy

This game of managed scarcity can help illustrate the following important concepts and issues:

- Trading
- Allocation
- Banking

Using Musical Chairs: An Illustration of Managed Scarcity

Each chair represents the "right to pollute":
one ton of carbon dioxide

If you have a permit, you can have a chair.

Musical chairs

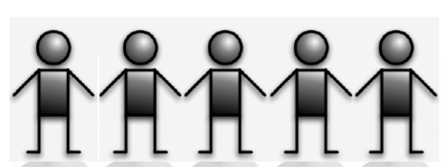
At the start of the game, everyone has a seat – because there are no limits on carbon emissions.

Musical chairs

After the first year, a cap is imposed by limiting the amount of permits and making players compete for the permits available.

In our analogy, one player doesn't have a chair...

So, the market price for the "right to pollute" in the first year is $30 for one ton of carbon dioxide...



2009

Using Market Incentives

At that price, some players may realize it would be more profitable to reduce their emissions and sell their permits.

Profit opportunities are a main driver for innovation and investment in the global economy today, and the climate challenge needs both.

2009

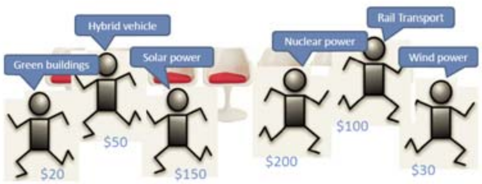
Using Market Incentives

2010

Achieving Reduction Targets

In a market, players leave when they find better options as costs rise.

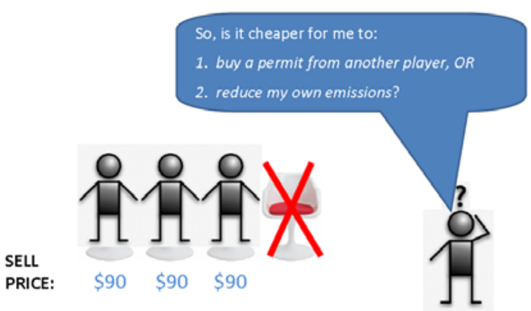
Cap-and-trade lets players choose at what price they leave the game – *and how they want to make that change.*



2020

Achieving Reduction Targets

The Carbon Market at Work



2020

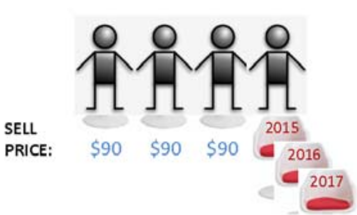
Banking

2020

Banking

Players who receive more permits than they need would like to "bank" them.

By saving a spare permit, the player can pollute that amount in a future year or sell that permit to someone else in the future.



Achieving Reduction Targets

The last ones remaining in the game are those who:

A) can afford to pay the most, or

B) have the least flexibility to change games.

The underlying assumption is that uses of fossil fuels for which people are willing to pay the most must be the most valuable.

To stabilize global warming, *most* uses of coal, oil, and gas will have to move to a different game: the clean energy economy.

Dr. Katie Hirschboeck
(How to find my office in the Tree-Ring Lab)

Laboratory of Tree-Ring Research
Office: 208 West Stadium
Phone: 621-6466
Email: **katie@LTRR.arizona.edu**

To find my office in the Tree-Ring Lab,
go to the WEST side of the Football Stadium.

Walk in under the stands
and look for a sign that says <u>GATE 15.</u>

Go <u>up the stairs</u> at **Gate 15**. At the top of the stairs, turn left (south)

My office is just down the hall, a blue door with my name on it: **<u>Room 208</u>**

The Tree-Ring Laboratory is located under the stands of the WEST side of the Football Stadium.