Earth's Climate: Past, Present and Future – concerns and solutions

Paul Belanger, Ph.D.

Geologist/Paleoclimatologist

Week 1: January 23, 2019

INTRODUCTIONS – Part 1

- Shelly McHugh; classroom assistant, liaison to me/you and OLLI
  - Logistics: bathrooms, breaks, no open containers, Shelly McHugh, mchugh3693@centurylink.net ; home (303) 337-0885
- Paul Belanger:
  - PEBelanger@glassdesignresources.com
  - c. 303-249-7966; h. 303-526-7996

INTRODUCTIONS – part 2

- **Intro**:
  - Yourselves – what brought you here
  - Paul
  - http://denverclimatestudygroup.com/ (OLLI tab)
  - Web page - 11 year history; Resume in “About” tab
  - Facebook - https://www.facebook.com/denverclimatestudygroup/

Earth's Climate: Past, Present and Future – concerns and solutions

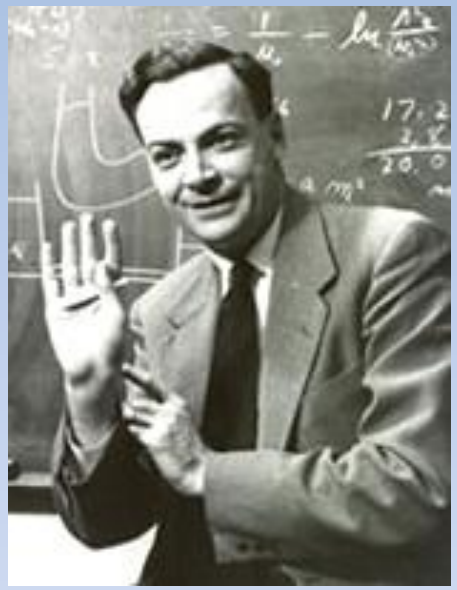
Week 1: January 23rd, 2019

- Introductions
- Key principles of climate change
- The difference between weather and climate
- Climate system: feedbacks, cycles and self-regulation (climate, not government)
- What determines Earth's climate

A thought – passed on from Warren Hamilton

"In this age of specialization, men who thoroughly know one field are often incompetent to discuss another. . . . You must not fool yourself--and you are the easiest person to fool"

Richard Feynman, 1974

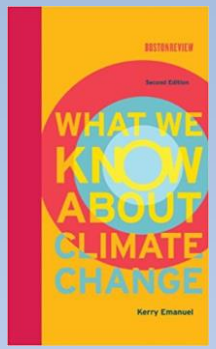


My comment:

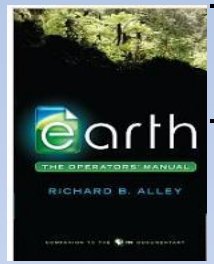
We've become a country of self-proclaimed experts on everything.

Three books to consider:

- **Simple succinct Summary:**
  - **What We Know About Climate Change (Boston Review Books)** by Kerry Emanuel (Nov 30, 2012)

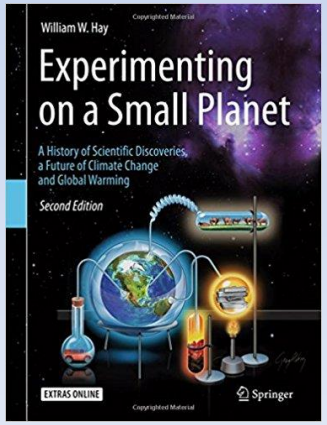


- **Intermediate Level Book:**
  - **Earth: The Operators' Manual** by Richard B. Alley (Apr 18, 2011)
  - http://earththeoperatorsmanual.com/



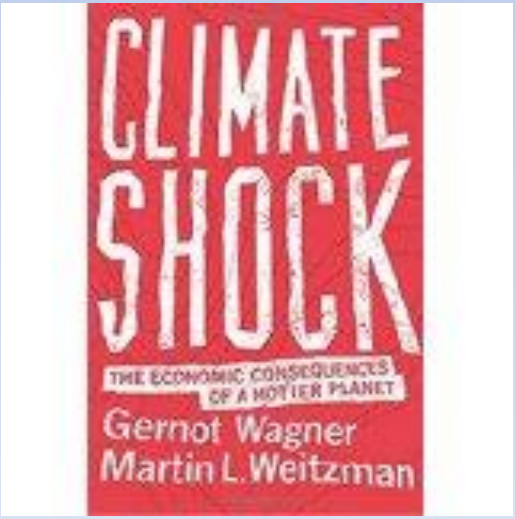
- **More comprehensive book:**

Experimenting on a Small Planet: A History of Scientific Discoveries, a Future of Climate Change and Global Warming 2nd ed. 2016 Edition



Another book to consider:

- **Economics:**
  - Climate Shock; the economic consequence of a hotter planet
  - by Gernot Wagner & Martin Weitzman



We need a Paradigm shift

- Which led to my email quote from Kerry Emanuel and the need for a social paradigm shift:
- "…there are few, if any, historical examples of civilizations consciously making sacrifices on behalf of descendants two or more generations removed"
- Recent discussions for a new Presidential candidate: **Secretary of the future**

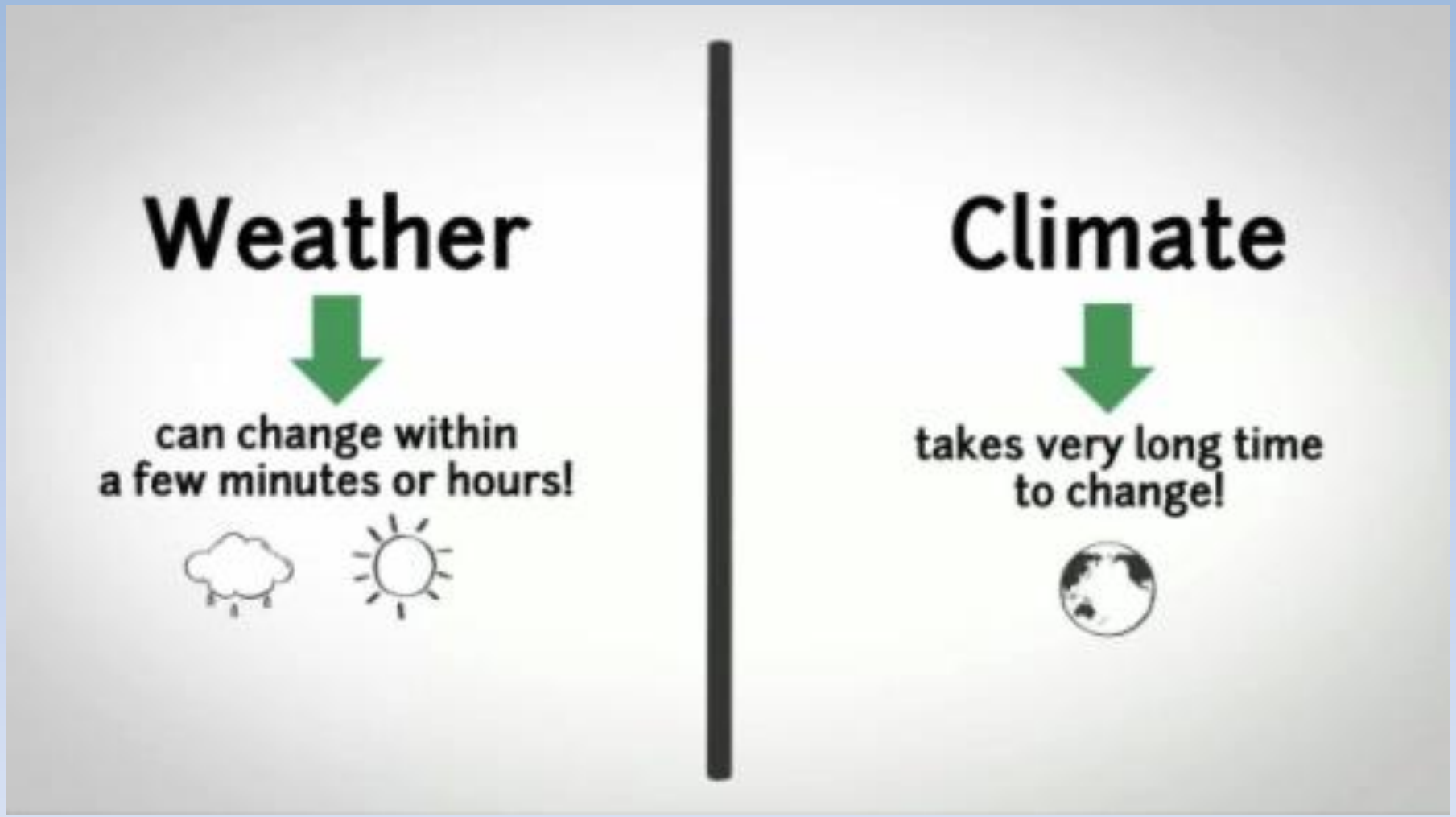
So What is Climate Change

Weather vs. Climate

- **Weather:** consists of the short-term (minutes to months) changes in the atmosphere.
  - temperature, humidity, precipitation, cloudiness, brightness, visibility, wind, and atmospheric pressure, as in high and low pressure.
- **Climate:** long-term averages of daily weather.
  - The statistics of weather

https://www.nasa.gov/mission_pages/noaa-n/climate/climate_weather.html

Weather vs. Climate



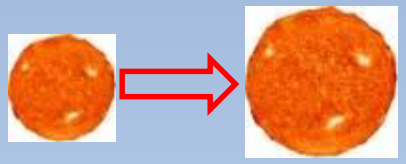
VIDEO - what is climate

IF we have time:

- https://www.futurelearn.com/courses/climate-change-challenges-and-solutions/todo/123
  - Requires my loging: and go to 1.4; 2 minutes, 50 seconds
- http://www.metoffice.gov.uk/climate-guide

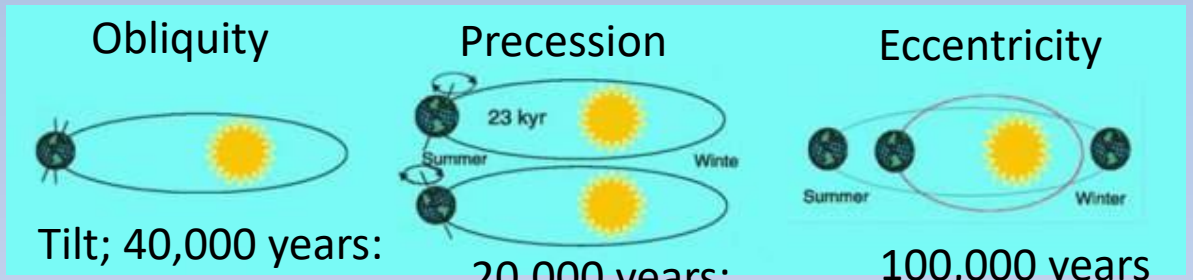
What determines Earth's climate

- **Primary Influences (3):**
  1. **SOLAR input:**



0.9% less
100 My ago

& sunspots



Tilt; 40,000 years:
21.5 – 24.5 degrees

20,000 years:
summer season

100,000 years
400,000 years

  2. **Greenhouse Gases (GHGs)**
     (gases that absorb radiation in or out)



  3. **Albedo**
     (reflectivity:30-85%)

- **Feedbacks:** INTERNAL dynamics and responses
  - e.g. higher water vapor in atm. due to heating of atm

What determines Earth's climate TODAY:

- The Sun
- Orbital parameters aka Milankovitch
- Greenhouse Gases (GHGs)

The Sun

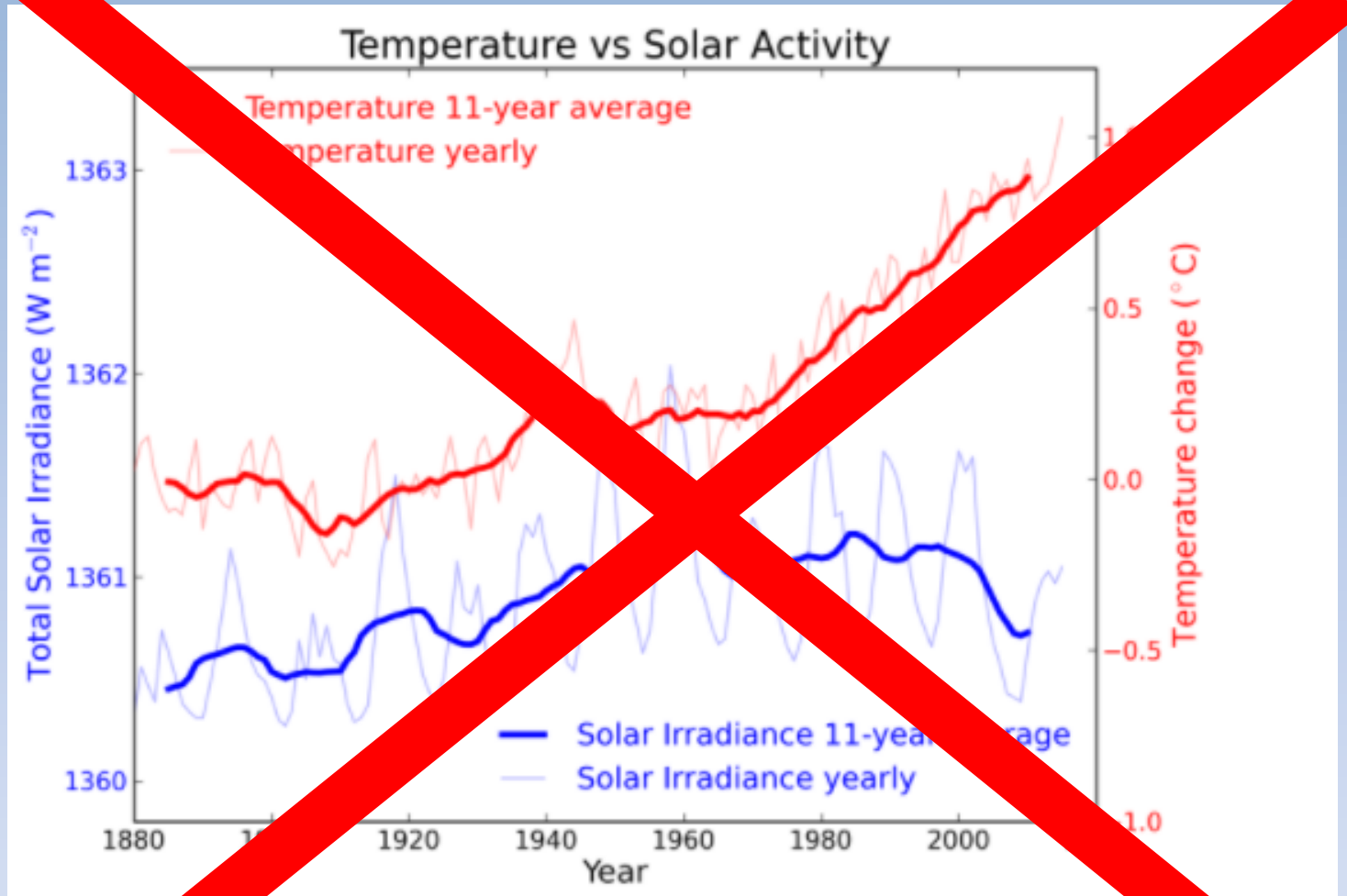
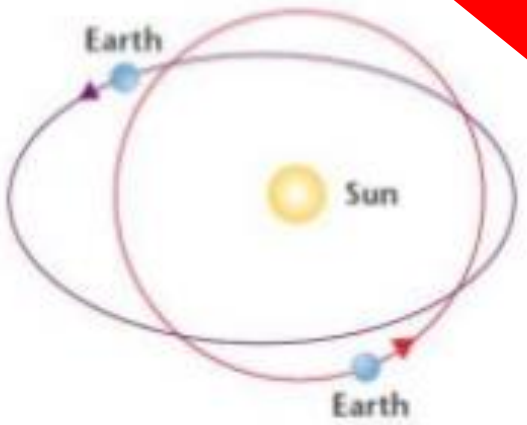


Figure 1: Annual global temperature change (thin light red) with 11 year moving average of temperature (thick dark red). Temperature from NASA GISS. Annual Total Solar Irradiance (thin light blue) with 11 year moving average of TSI (thick dark blue). TSI from 1880 to 1978 Krivova et al 2007. TSI from 1979 to 2015 from PMOD (see the PMOD index page for data updates).

https://skepticalscience.com/solar-activity-sunspots-global-warming.htm

Milankovitch Cycle



Eccentricity Earth encounters more variation in the energy that it recei from the sun when Earth's orbit elongated than it does whe n's orbit is more circular.

100,0 ears
40 0 years

Tilt The tilt of Earth's axis vari between 22.2° and 24.5°. The greater the tilt angle is, the more solar energy the poles receive.

41,000 years

Precession A gradual hange, or "wobble," in the tation of Earth's axis a he relationship betwe th's tilt and eccentric

19 – 24,00 ars

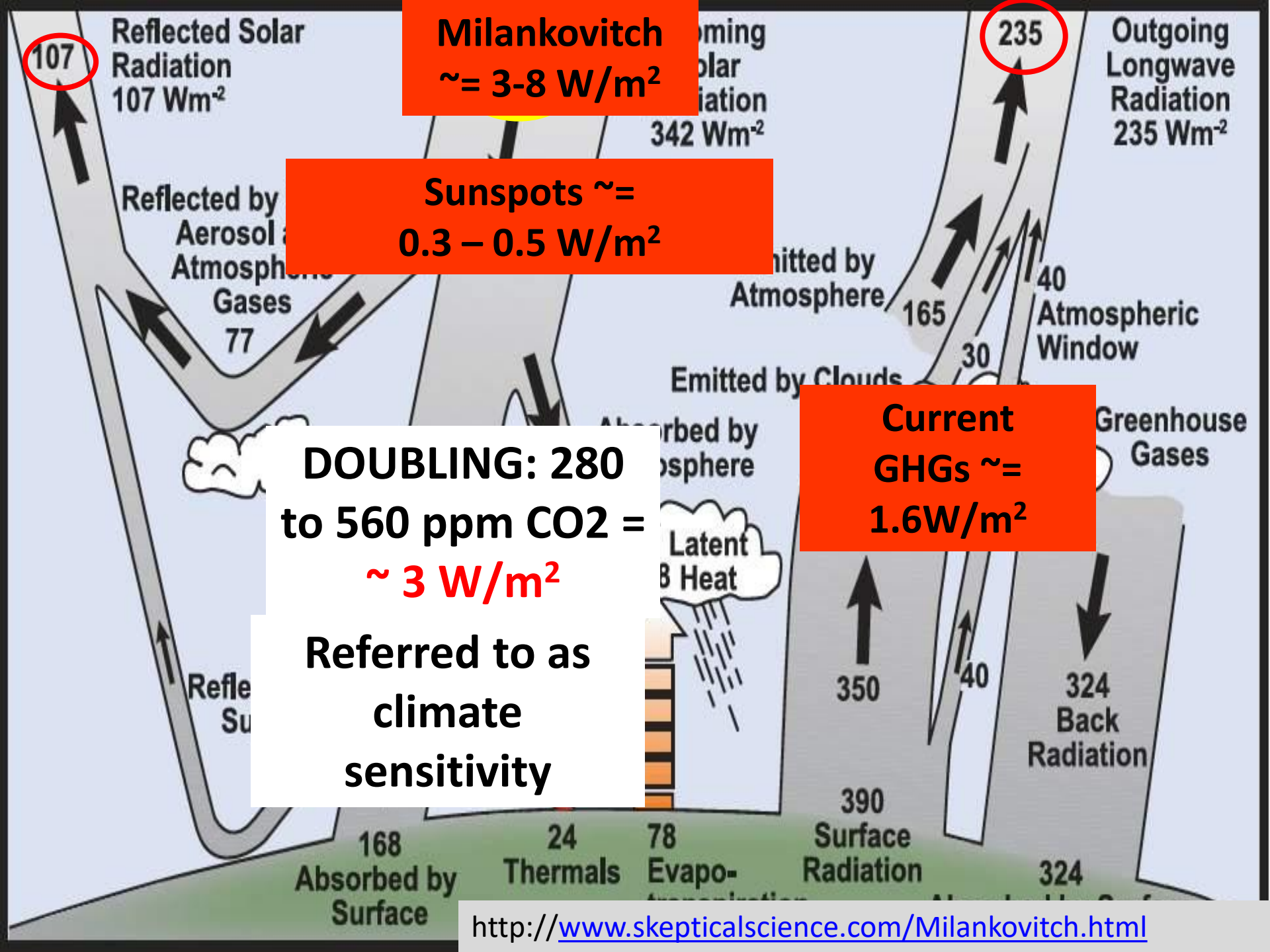
https://www.slideshare.net/syadur/milankovitch-theory

Thus it leaves it to Greenhouse Gases

And so we will explore this a little further

Thus it leaves it to Greenhouse Gases

And so we will explore this a little further



http://www.skepticalscience.com/Milankovitch.html

FOR THERE TO HAVE NO CLIMATE CHANGE

Energy in (Visible)

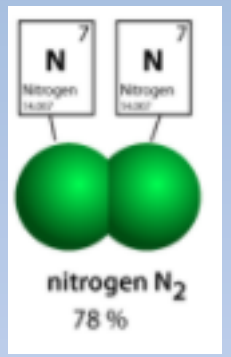
=

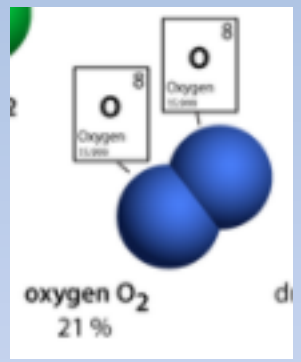
Energy out (infrared)

- Relatively stable last 10,000 years
- GHGs Now Changing our climate – but at an unprecedented rate
  - Threatens our sustainability as DO other factors:
    - Population
    - Sea level rise
    - Extreme weather
    - Resources (Energy, food)
    - Ocean acidification

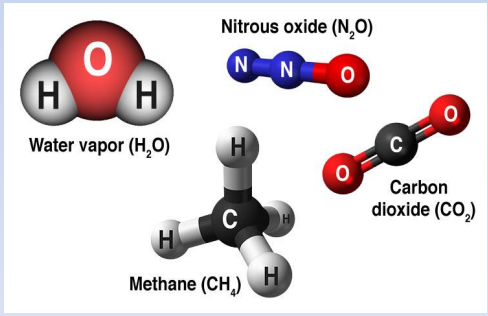
Let's look at our atmosphere

- N_2 = 78%
- O_2 = 21%
- Ar = 0.93%



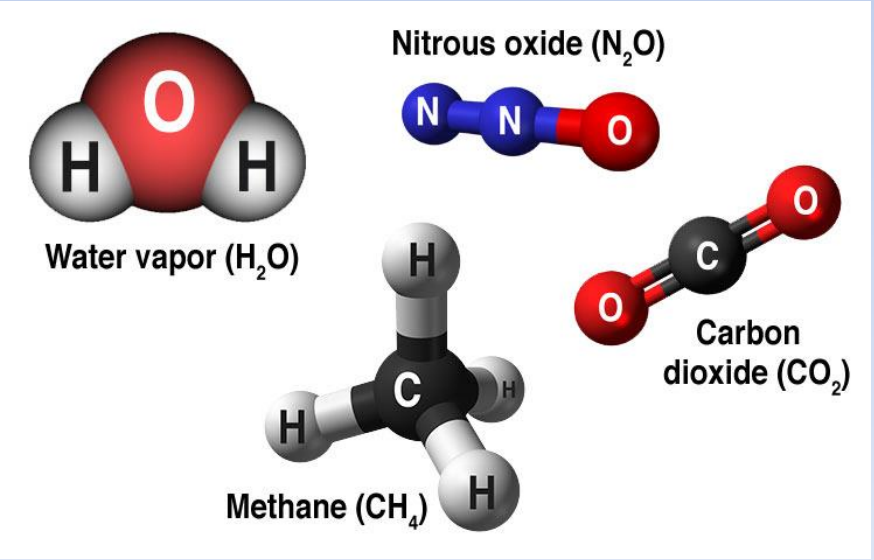


- CO_2 = -.408%
- H_20 = variable
- Other: CH_4, CFCs, O_3, etc.



GREENHOUSE GASES (GHGs)

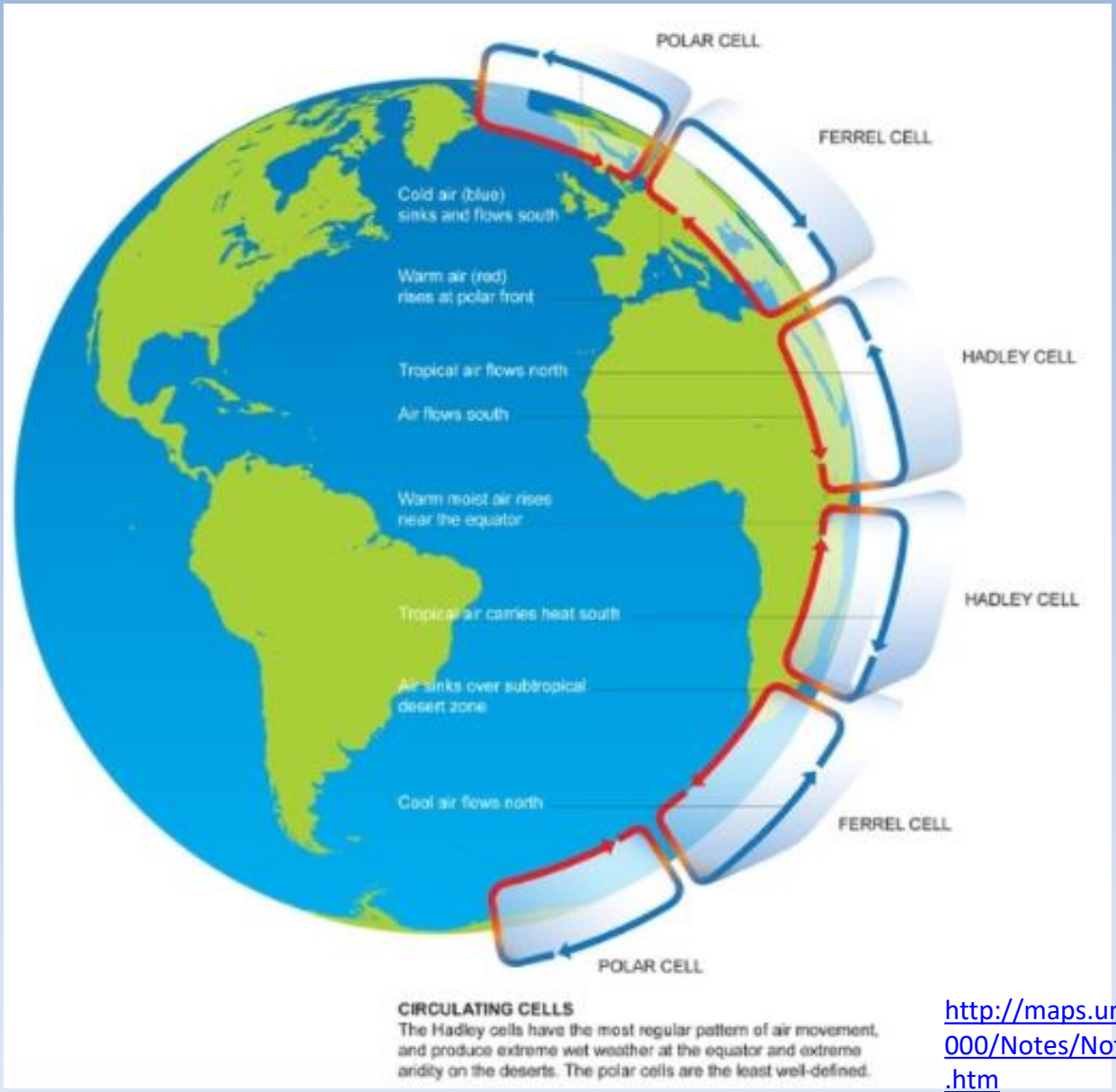
- Water – H_2O – the amount is a feedback of temperature held in by the "blanket" of other GHGs
- Carbon dioxide - CO_2
- Methane - CH_4
- Ozone - O_3
- Nitrous oxide- N_2O
- others



Some basic Meteorology

- First some facts:
  - Atmospheric circulation
  - Coriolis forces
- Then Background for some Explanations:
  - Gas laws
  - Weather: Highs and Lows –
    - Causes
    - Coriolis effect
  - Latent heat

Atmospheric circulation



CIRCULATING CELLS
The Hadley cells have the most regular pattern of air movement, and produce extreme wet weather at the equator and extreme aridity on the deserts. The polar cells are the least well-defined.

http://maps.unomaha.edu/Peterson/geog1000/Notes/Notes_Exam1/Seasons&Climate.htm

Coriolis forces affecting movement

- As fluids on a rotating sphere change latitude they have different momentum
  - Northern hemisphere – to the RIGHT
  - Southern hemisphere – to the LEFT

Gas laws

- Boyles Law, Charles Law, Gay-Lussac Law

BUT THIS IS THE RELATIONSHIP YOU NEED TO KNOW:

- IDEAL GAS LAW (COMBINED):

$$PV = nRT$$

http://chemistry.bd.psu.edu/jircitano/gases.html

For more info: https://en.wikipedia.org/wiki/Gas_laws

TAKE AWAY:

air cools 10^{o}C for every km elevation gain due to decrease pressure

A TRICK QUIZ

- 2 ROOMS – EQUAL IN SIZE, ELEVATION and TEMPERATURE
  1. ROOM 1 – 10% HUMIDITY
  2. ROOM 2 – 95% HUMIDITY

- WHICH ONE WEIGHS MORE (I.E. IS DENSER: DENSITY = MASS/VOLUME)
  1. ROOM 1?
  2. ROOM 2?

A TRICK QUIZ

- 2 ROOMS – EQUAL IN SIZE, ELEVATION and TEMPERATURE
  1. ROOM 1 – 10% HUMIDITY
  2. ROOM 2 – 95% HUMIDITY
- YOU PROBABLY DON'T REALIZE YOU KNOW THE ANSWER
- HINT:
  - WEATHER:
    - WHAT'S A STORM ASSOCIATED WITH
      - HIGH PRESSURE
      - Or LOW PRESSURE?
      - WHY?

Our Atmosphere

- N_2 = 78% Mass 14 x 2 = 28
- O_2 = 21% Mass 16 x 2 = 32
- A
- CO_2 = -.408% C=12; 12 +32 = 44
- H_20 = var 18
  - Other: CH_4, CFCs, O_3, etc.

Negligible

Not to be ignored so much

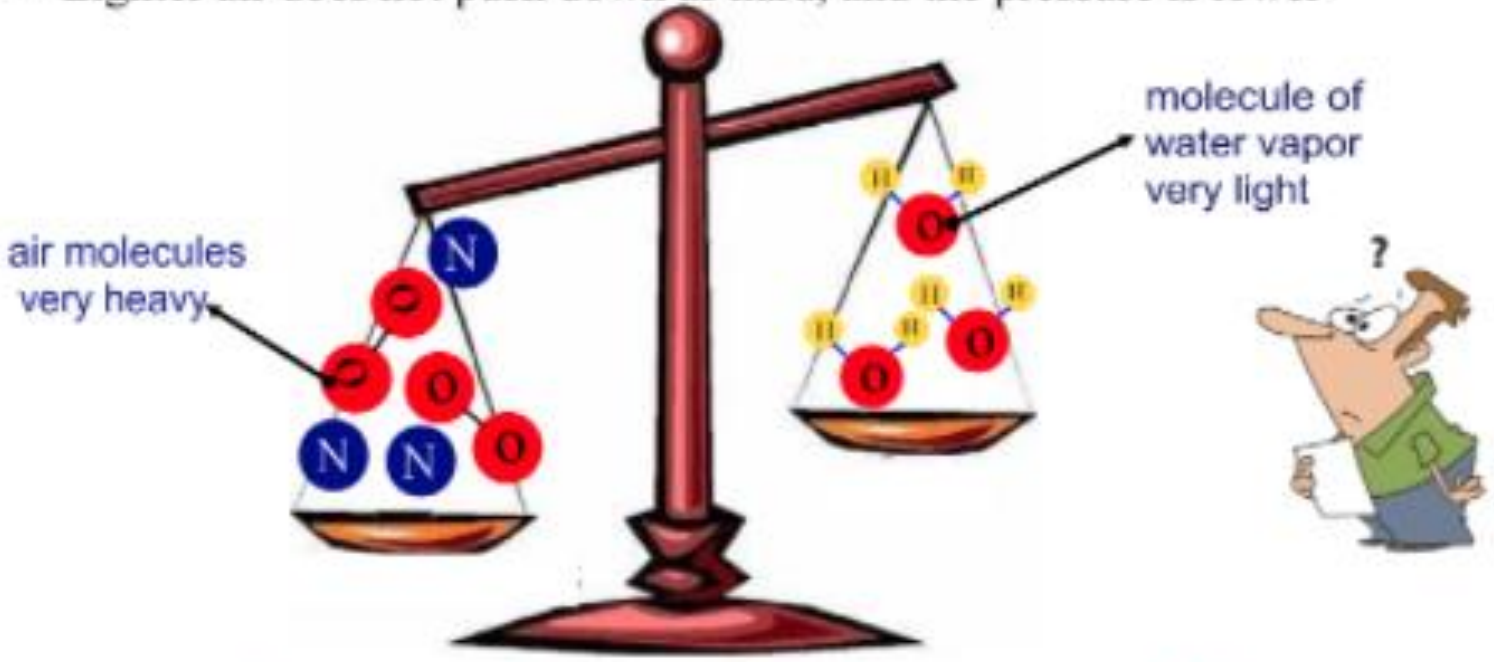
ANSWER as to which weighs more:

- 2 ROOMS – EQUAL IN SIZE, ELEVATION and TEMPERATURE
  1. ROOM 1 – 10% HUMIDITY **WEIGHS MORE**
  2. ROOM 2 – [illegible] HUMIDITY

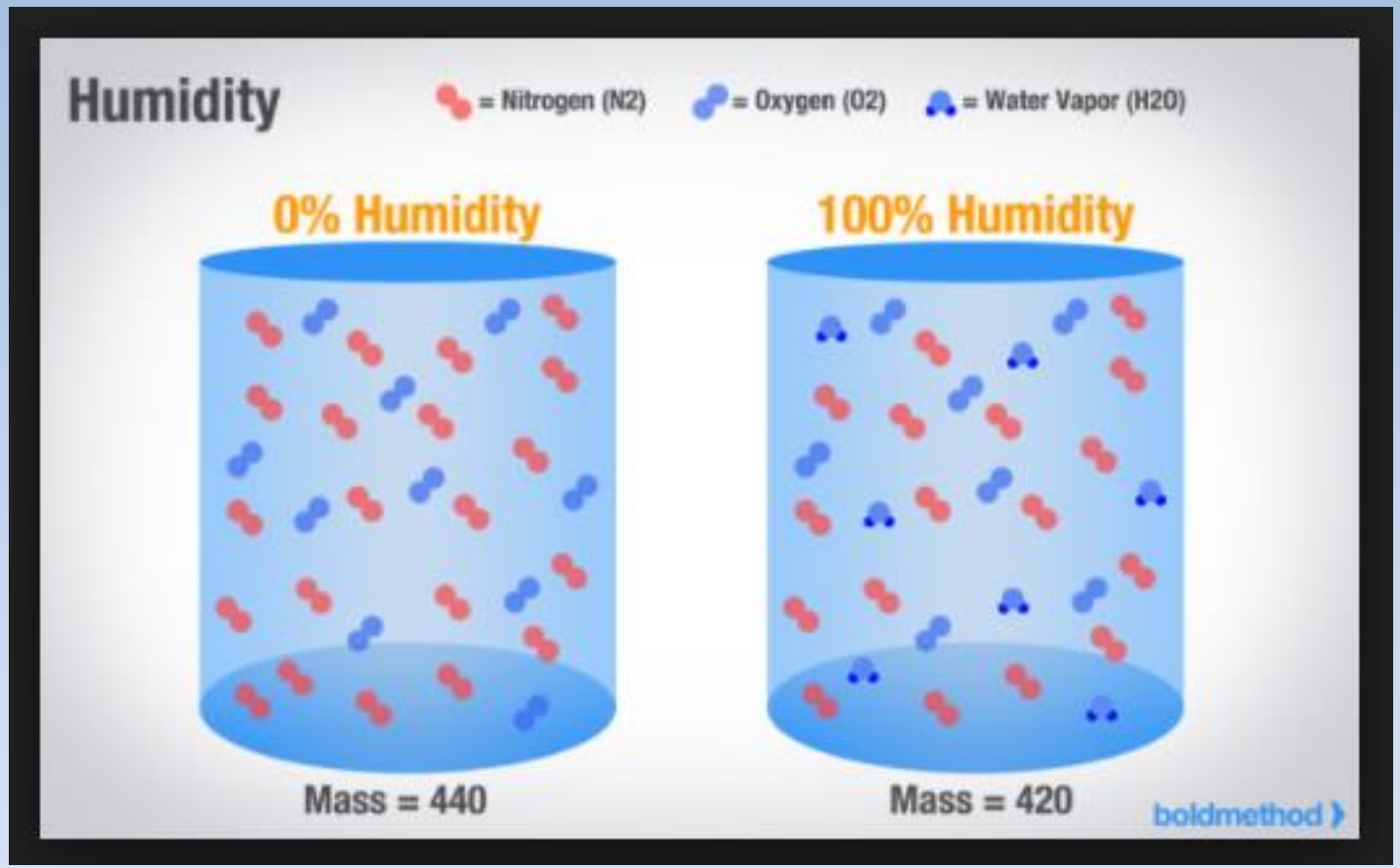
- WEATHER:
  - WHAT'S A STORM ASSOCIATED WITH
    - LOW PRESSURE? **MOISTURE: STORMS, HURRICANES**
    - WHY? **WATER VAPOR WEIGHS LESS THAN N_2 & O_2**

Air Pressure - Water Vapor (Humidity)

- Water vapor is lighter than the oxygen, nitrogen, and hydrogen molecules that make up our air.
- So as you add water vapor to the air, the air becomes lighter
- Lighter air does not push down as hard, and the pressure is lower



- as water vapor increases, air pressure decreases


Humidity
= Nitrogen (N2)
= Oxygen (O2)
= Water Vapor (H2O)
0% Humidity
100% Humidity
Mass = 440
Mass = 420
boldmethod

TAKE AWAY:

adding **H_2O VAPOR** decreases density

Water vapor

The amount of water vapor that the atmosphere can hold DOUBLES FOR EVERY 10^{o}C

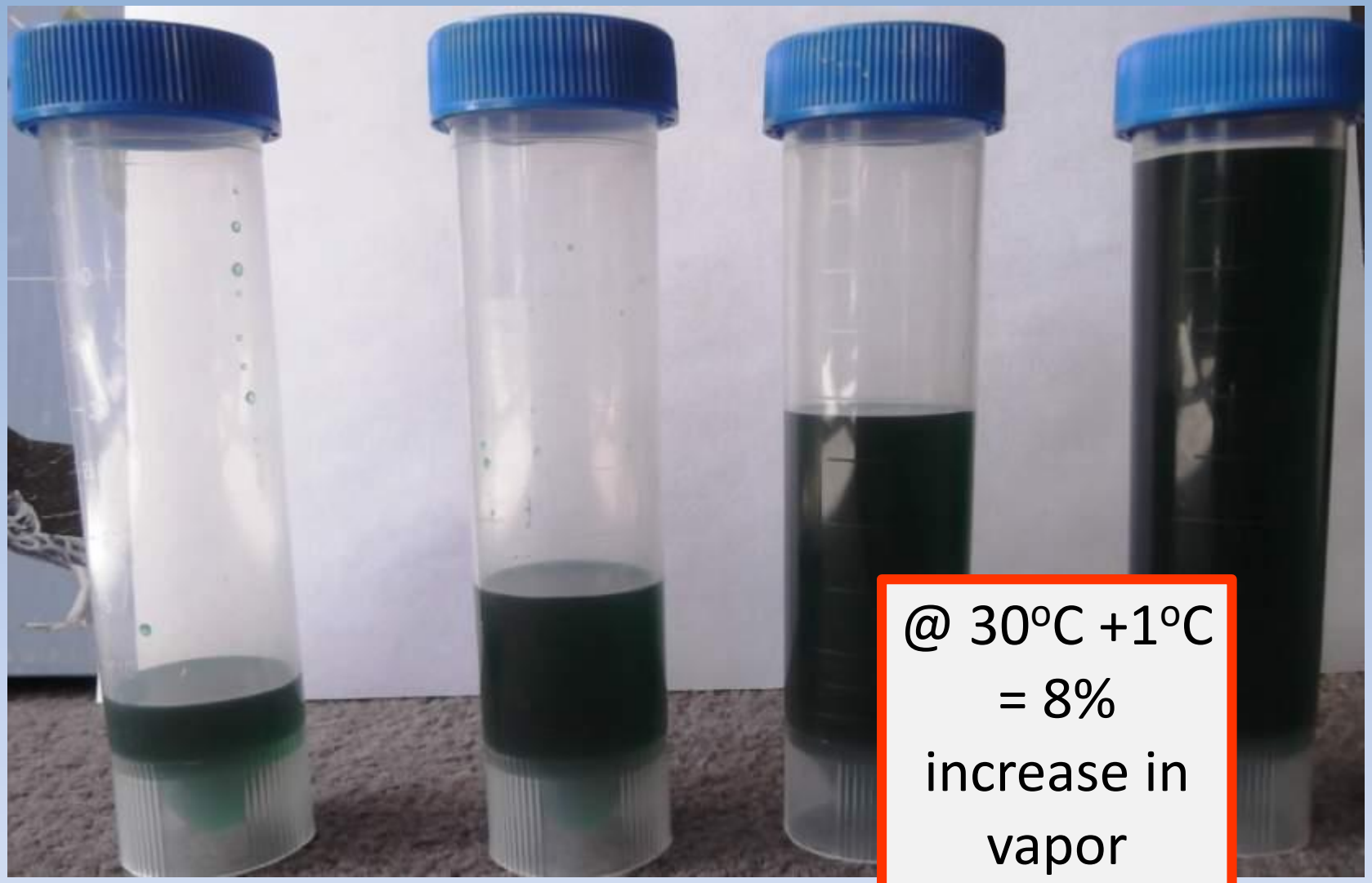
Table 1 Specific humidity of a kilogram of air (at average sea level pressure)

Temp. (°C)	Temp. (°F)	Grams of water vapor per kg of air (g/kg)
-40	-40	0.1
-35	-31	0.2
-30	-22	0.3
-25	-13	0.51
-20	-4	0.75
-10	14	1.8
0	32	3.8
5	41	5
10	50	7.8
15	59	10
20	68	15
25	77	20
30	86	27.7
35	95	35
40	104	49.8

What is the volume of 1 kg of air?

Answer: 0.8562 m^3

(95 cm x 95 cm x 95 cm)



10°C = (50°F)	20°C = (68°F)	30°C = (86°F)	40°C = (104°F)
7.8 cc	15 cc	27.7 cc	49.8 cc

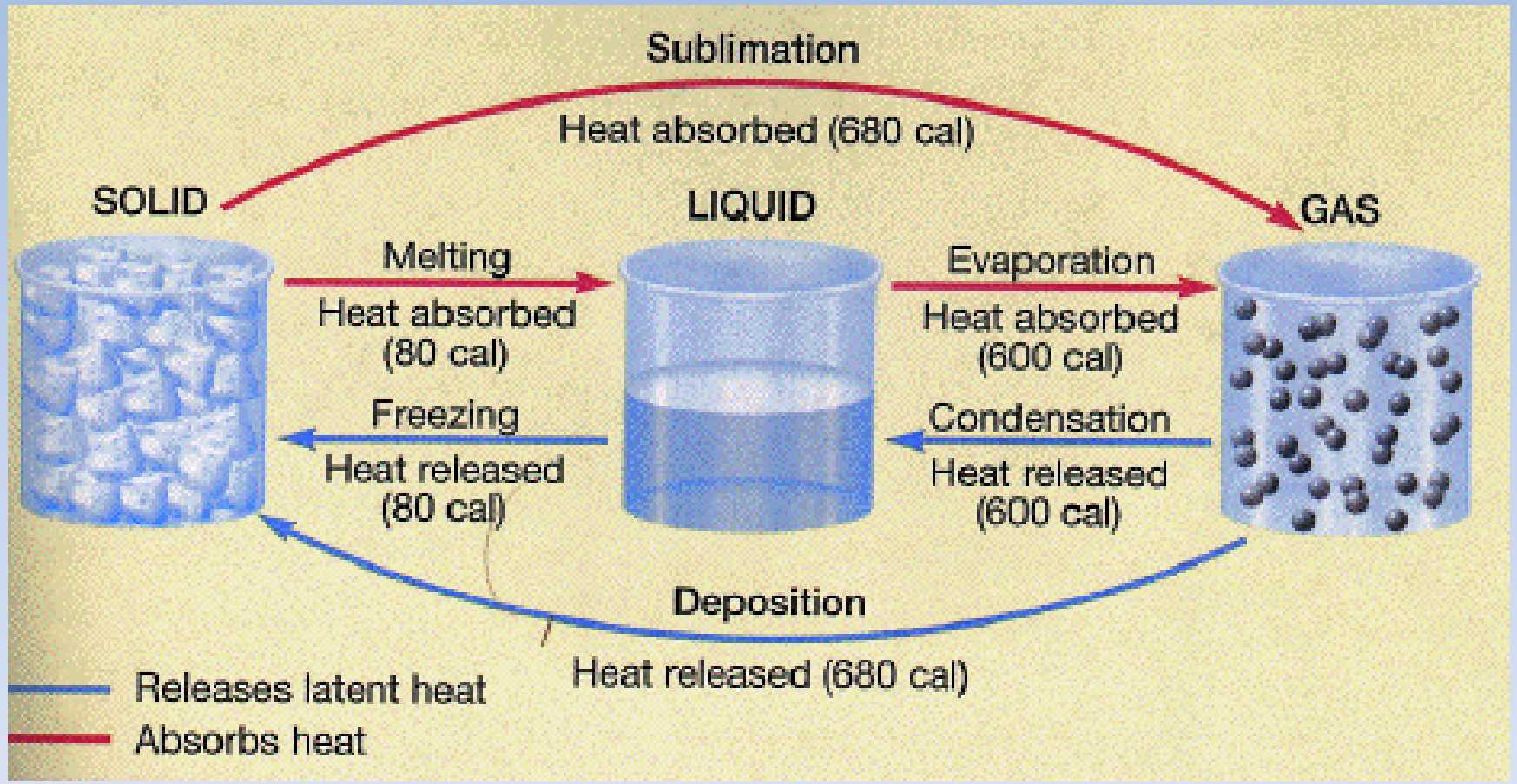
TAKE AWAY:

Water vapor in the atmosphere
~ DOUBLES WITH EVERY +10^{o}C

The Energy involved with WATER VAPOR

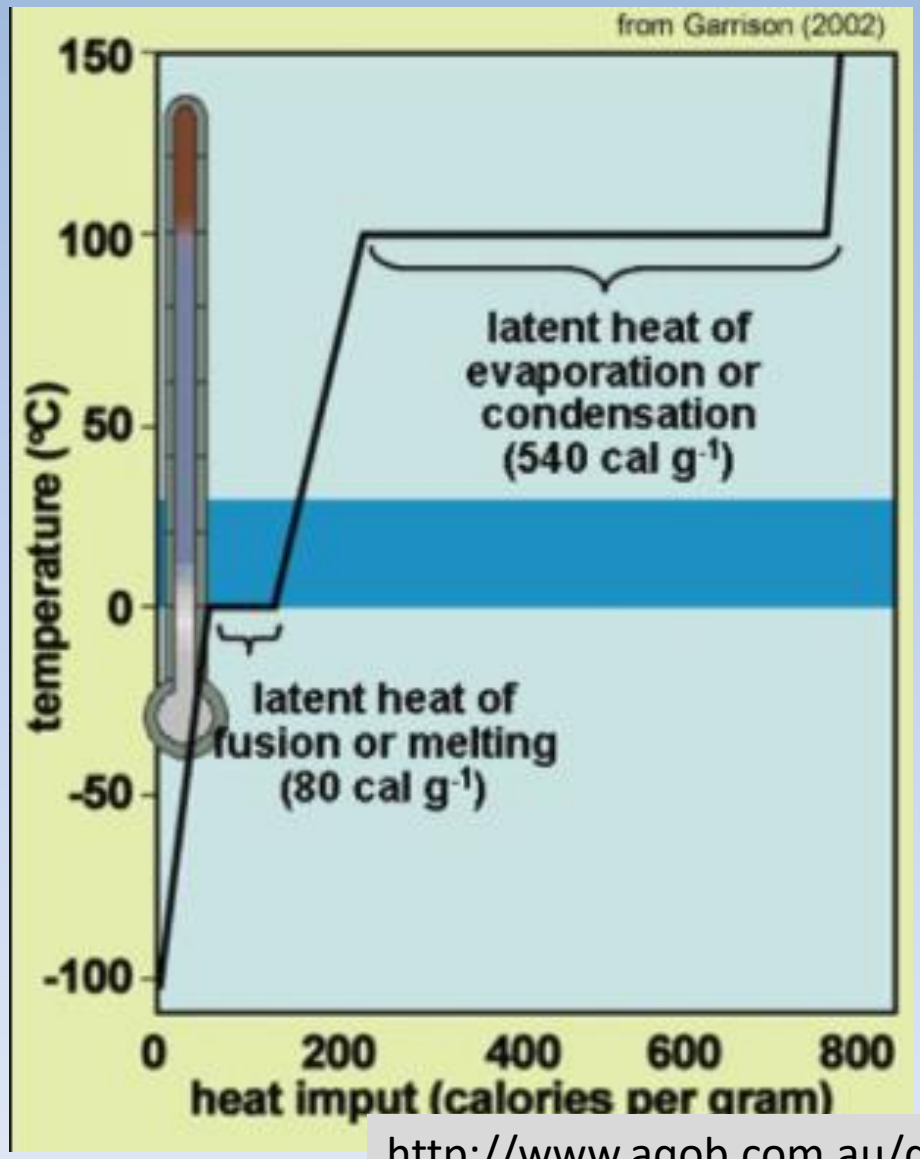
- To melt ice (solid to liquid) = 80 calories / gram
- To heat water 1^{o} C = 1 calorie / gram
- To go from 100^{o} C liquid to 100^{o} C steam/vapor – 540 calories / gram

The Energy in phase changes



http://www.uh.edu/~jbutler/physical/chapter6notes.html

The Energy in phase changes



http://www.aqob.com.au/details.php?p_id=371

TAKE AWAY:

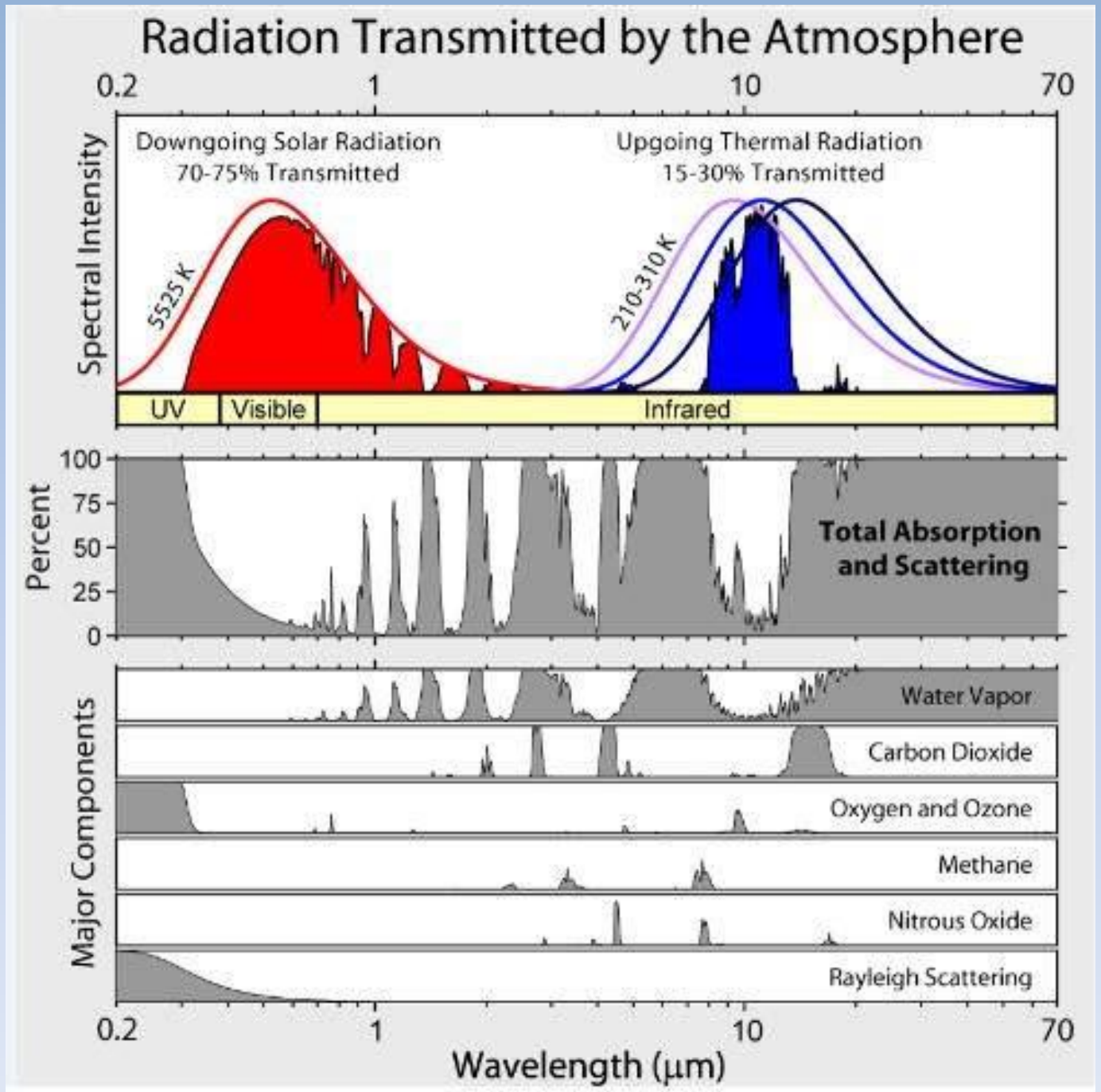
- IF YOU INCREASE THE AVERAGE ATMOSPHERIC TEMPERATURE YOU INCREASE THE AMOUNT OF WATER VAPOR IT HOLDS
- IF YOU DO THAT YOU INCREASE THE AMOUNT OF ENERGY IN THE ATMOSPHERE

EARTH’S HEAT BUDGET

RADIATION RECEIVED

vs.

RADIATION EMITTED BACK TO SPACE


Radiation Transmitted by the Atmosphere
0.2
1
10
70
Spectral Intensity
Downgoing Solar Radiation
70-75% Transmitted
Upgoing Thermal Radiation
15-30% Transmitted
5525 K
210-310 K
UV
Visible
Infrared
Percent
100
75
50
25
0
Total Absorption and Scattering
Major Components
Water Vapor
Carbon Dioxide
Oxygen and Ozone
Methane
Nitrous Oxide
Rayleigh Scattering
0.2
1
10
70
Wavelength (μm)

IF EARTH'S HEAT BUDGET CHANGES OVER TIME WE HAVE EITHER:

- COOLING or
- WARMING

How GHGs Blanket the Earth

Blanket Earth:

- **NASA –Global Climate Change Cause:** http://climate.nasa.gov/causes/

Denial 101x - Video includes First handout Global warming:

- https://www.youtube.com/watch?v=aqkGoCglp_U&feature=youtu.be

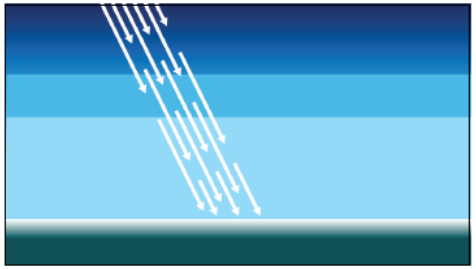
Denial 101x - Second handout – Increasing Greenhouse Effect:

- https://www.youtube.com/watch?v=we8VXwa83FQ

Increasing GHGs 1 of 3

DENIAL101x - 3.3.2.1 - Animation 1 v3

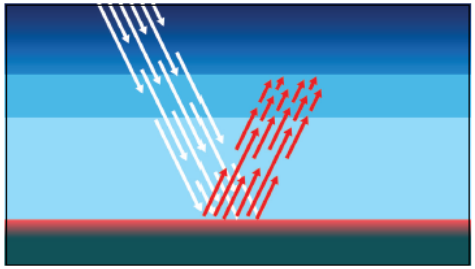
1 — 5 sec



Voice Over:
Greenhouse gases let sunlight through to warm the surface.

Visual: White arrows continually move into the Earth's surface. Earths surface glows white.

2 — 3 sec



Voice Over:
The surface then glows with infrared light.

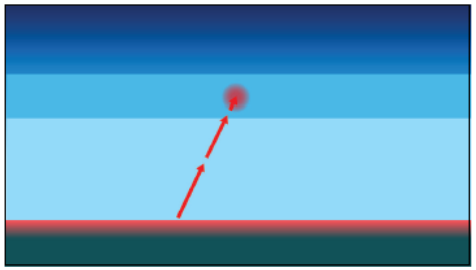
Visual:
Earths surface glows red. Red arrows move away from the ground reducing in speed as they move through the greenhouse gas.

3 — 4 sec

Voice Over:
Our eyes aren't tuned to its frequency so it's invisible to us.

Visual:
All arrows and glows disappear.

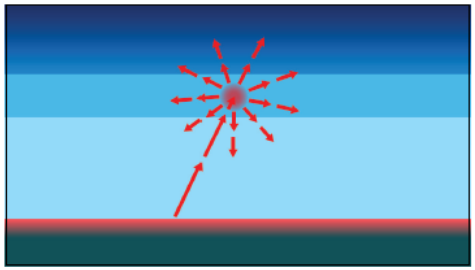
4 — 7 sec



Voice Over:
But greenhouse gases absorb some of this infrared. At the same time, they glow with their own infrared.

Visual:
Glow reappears and a single arrow continually moves up from the ground in the greenhouse gas. The a small section of the greenhouse gas glows where the arrow collides.

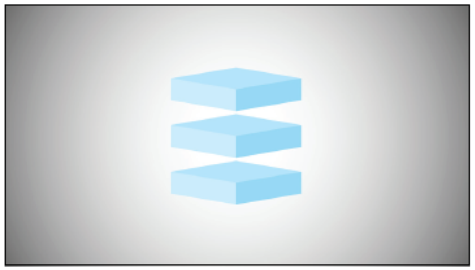
5 — 8 sec



Voice Over:
They glow in all directions, and the part of the glow that goes up can be absorbed by greenhouse gases further up in the atmosphere.

Visual:
Arrows are emitted from the glow in the greenhouse gas.

6 — 3 sec



Voice Over:
It's useful to think of the atmosphere as layers.

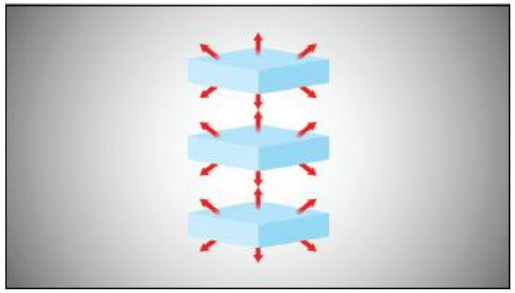
Visual:
Cut to new scene showing layers of atmosphere.

animation by Daniel Greenup, University of Queensland for Denial101x

Increasing GHGs 2 of 3

DENIAL101x - 3.3.2.1 - Animation 1 v3

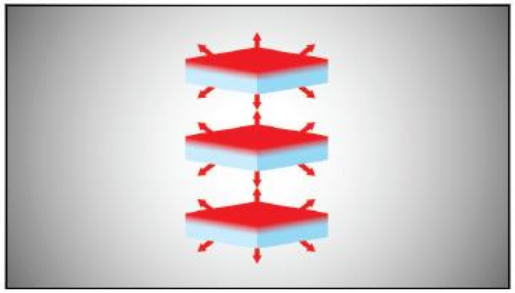
7 — 4 sec



Voice Over:
Each layer of the atmosphere has a greenhouse glow in every direction.

Visual:
Layers separate more and arrows are emitted.

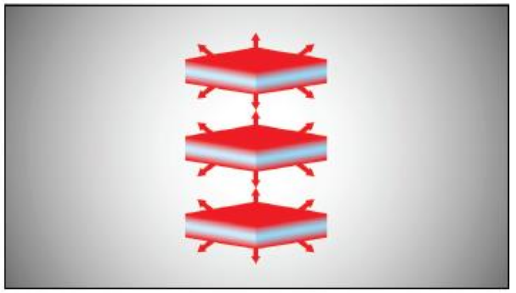
8 — 5 sec



Voice Over:
Meanwhile, each layer absorbs some of the infrared glow that comes from the layer above,

Visual:
Top of layers glow.

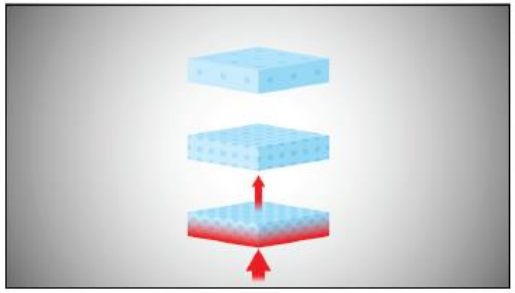
9 — 3 sec



Voice Over:
and some from the layer below.

Visual:
Bottoms of layers start glowing.

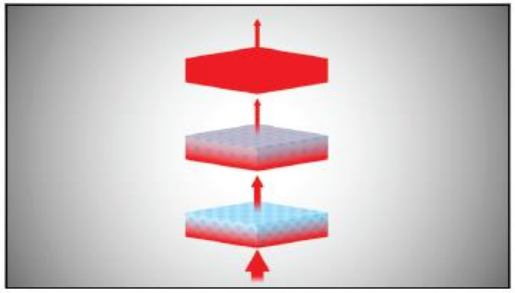
10 — 9 sec



Voice Over:
Low down in the atmosphere, the air is thicker than higher up. Each layer has enough greenhouse gas to absorb much of the infrared going through it.

Visual:
Glow and arrows are removed. Dots appear in layers to indicate air thickness. A new arrows moves through the bottom layer and reduce in size. The bottom of the layer glows.

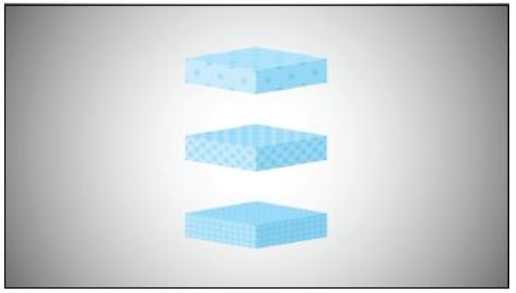
11 — 11 sec



Voice Over:
Higher up in the atmosphere, the air gets thinner. That's why it's harder to breathe at the top of a mountain. Each layer doesn't have enough greenhouse gas to fully trap passing infrared.

Visual:
Arrows move through all of the layers reducing in size.

12 — 9 sec



Voice Over:
Burning coal, oil and gas releases carbon dioxide, a greenhouse gas. Stirred by the winds, it mixes through the atmosphere.

Visual:
Arrows and glows are removed and extra dots appear in each layer.

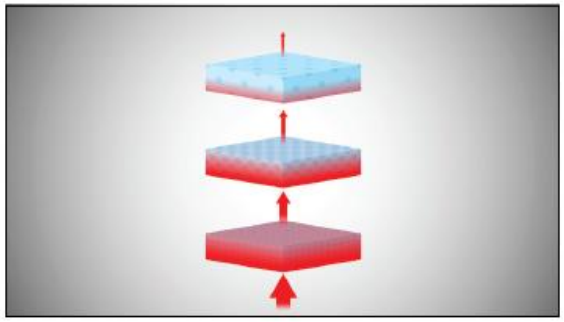
animation by Daniel Greenup, University of Queensland for Denial101x

Increasing GHGs 3 of 3

DENIAL101x - 3.3.2.1 - Animation 1 v3

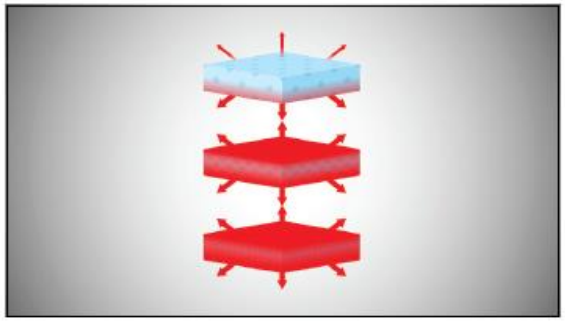
3 of 3

13 10 sec



Voice Over:
The biggest effect is high up where the air is thinner. This is where infrared previously escaped to space. Adding more greenhouse gases captures this infrared.

14 9 sec

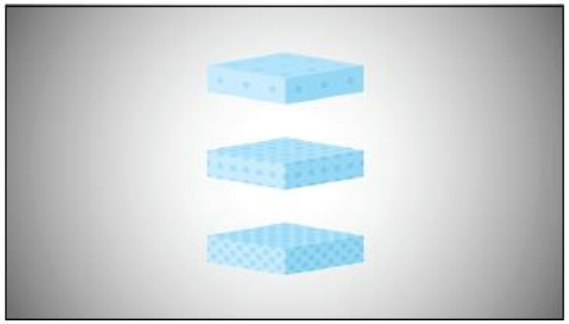


Voice Over:
This upper layer now glows a little more brightly. A little more heat is recycled back into the atmosphere. This is how adding more greenhouse gases makes us warmer.

DENIAL101x - 3.3.2.1 - Animation 2 v2

1 of 1

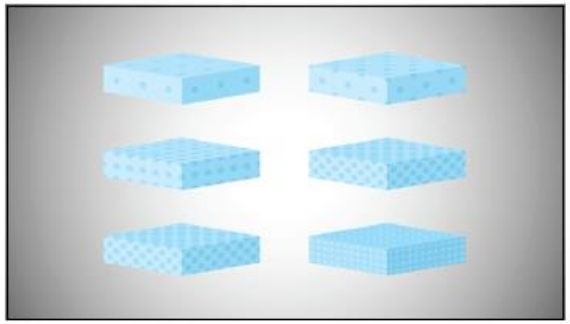
1 9 sec



Voice Over:
In the upper layers of the atmosphere, the greenhouse effect isn't saturated. The concentration of greenhouse gases is a lot less than in Angstrom's tube.

Visual:
Layers of atmosphere appear.

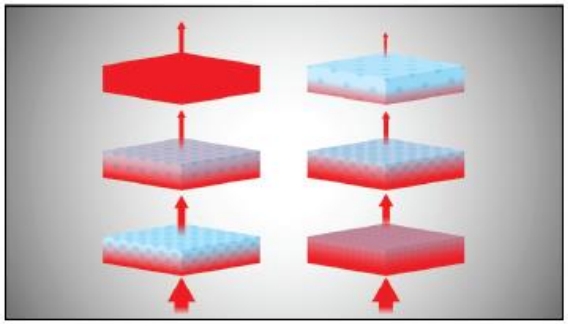
2 6 sec



Voice Over:
Adding greenhouse gases blocks the infrared's escape path to space.

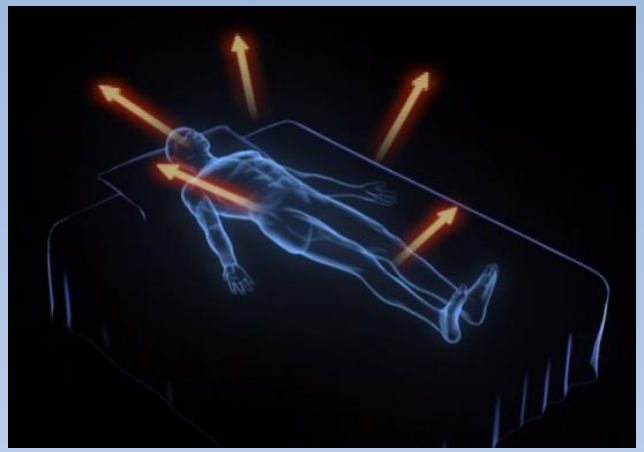
Visual:
Layers of atmosphere and greenhouse gases appear.

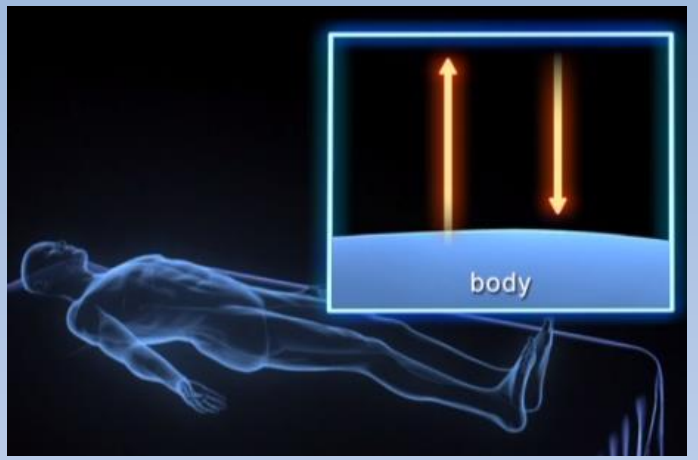
3 8 sec

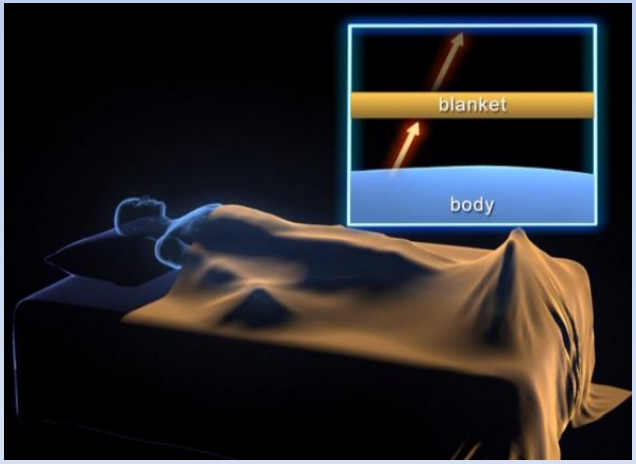


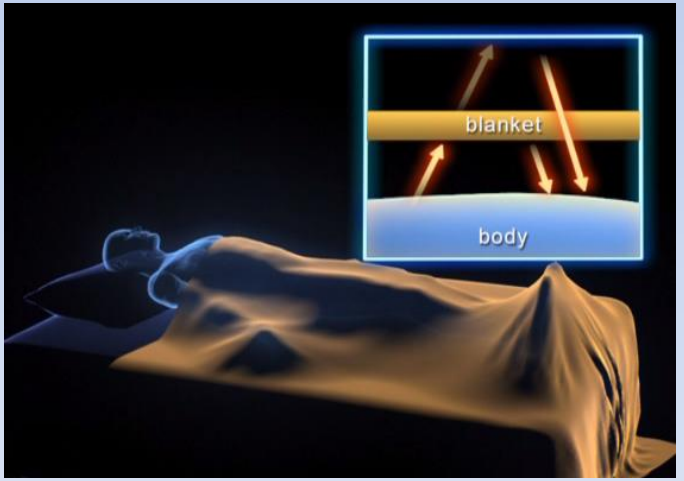
Voice Over:
Some of the infrared that used to escape to space has now been trapped. The layer's greenhouse glow sends some of it back down to warm us up.

Visual:
Arrows move through layers.




body


blanket
body


blanket
body

The CO_2 greenhouse gas effect is concentrated in the polar regions ! ! !

Particularly in the Arctic !

CO_2 and other Greenhouse gases are evenly distributed throughout the atmosphere

The large H_2O greenhouse effect is controlled by temperature – H_2O saturation doubles with every 10°C increase

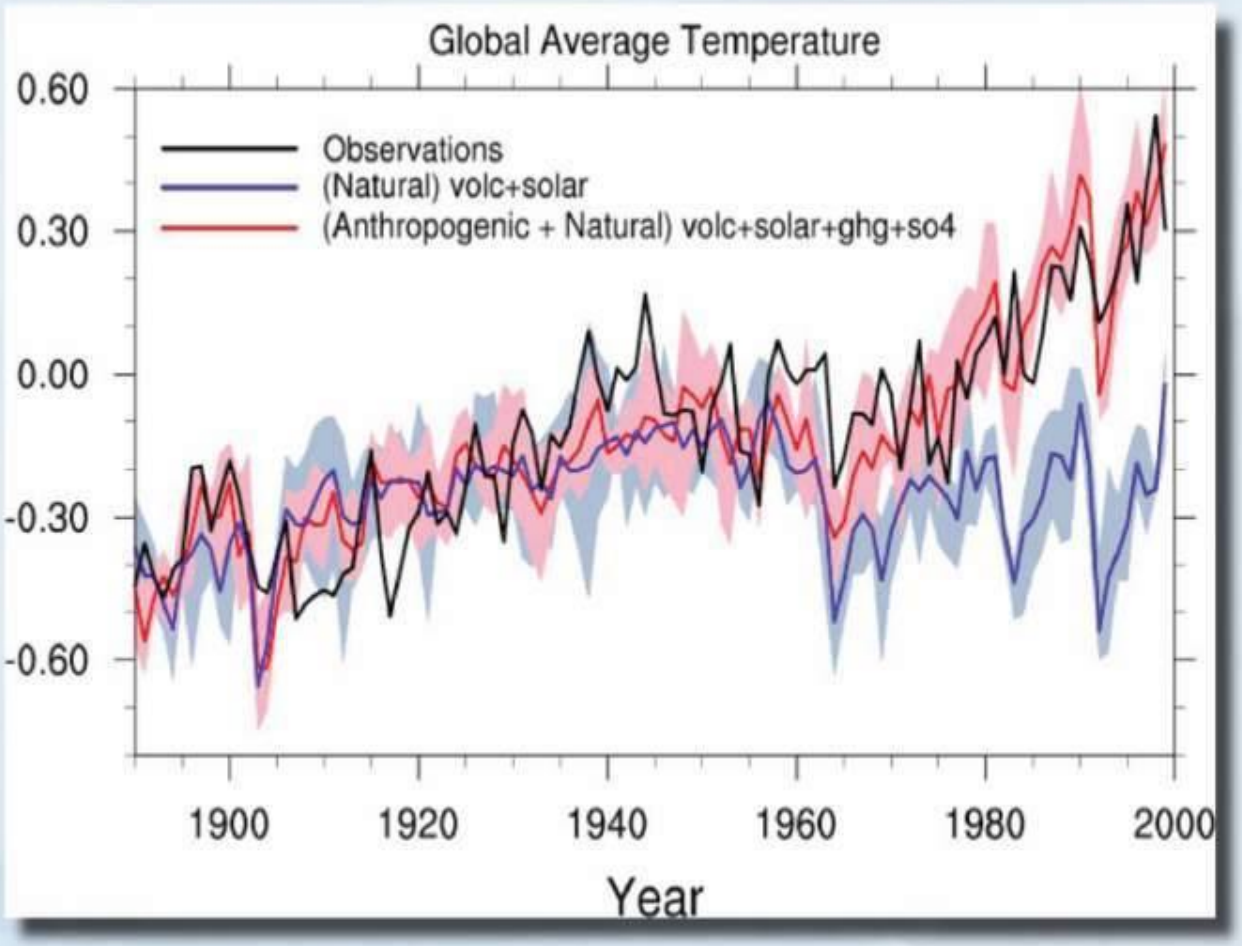
As a result it is concentrated in the lower atmosphere of the tropics

Global Warmng Results:

- Greater warming at High Latitudes:
  - Due to CO_2 being more important as a GHG
  - Increase in H_2O over time as average temperature increases
- Reduction Arctic sea ice changing albedo (reflectivity)
- Melting glaciers changing albedo
- Rising sea levels
- Average temperature increases also changes amount of moisture in atmosphere
- Earlier springs / earlier snow melt
- Ocean acidification

Simulations of the 20th century: Time

NCAR

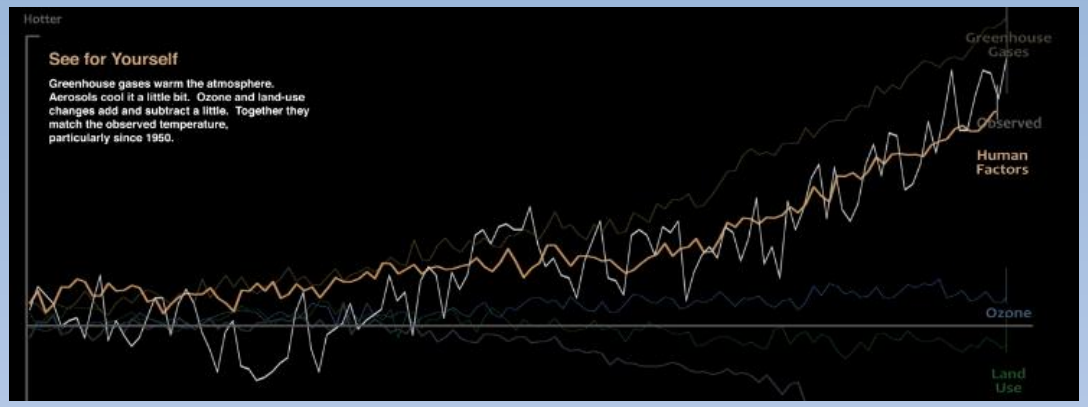


All forcings

Natural only

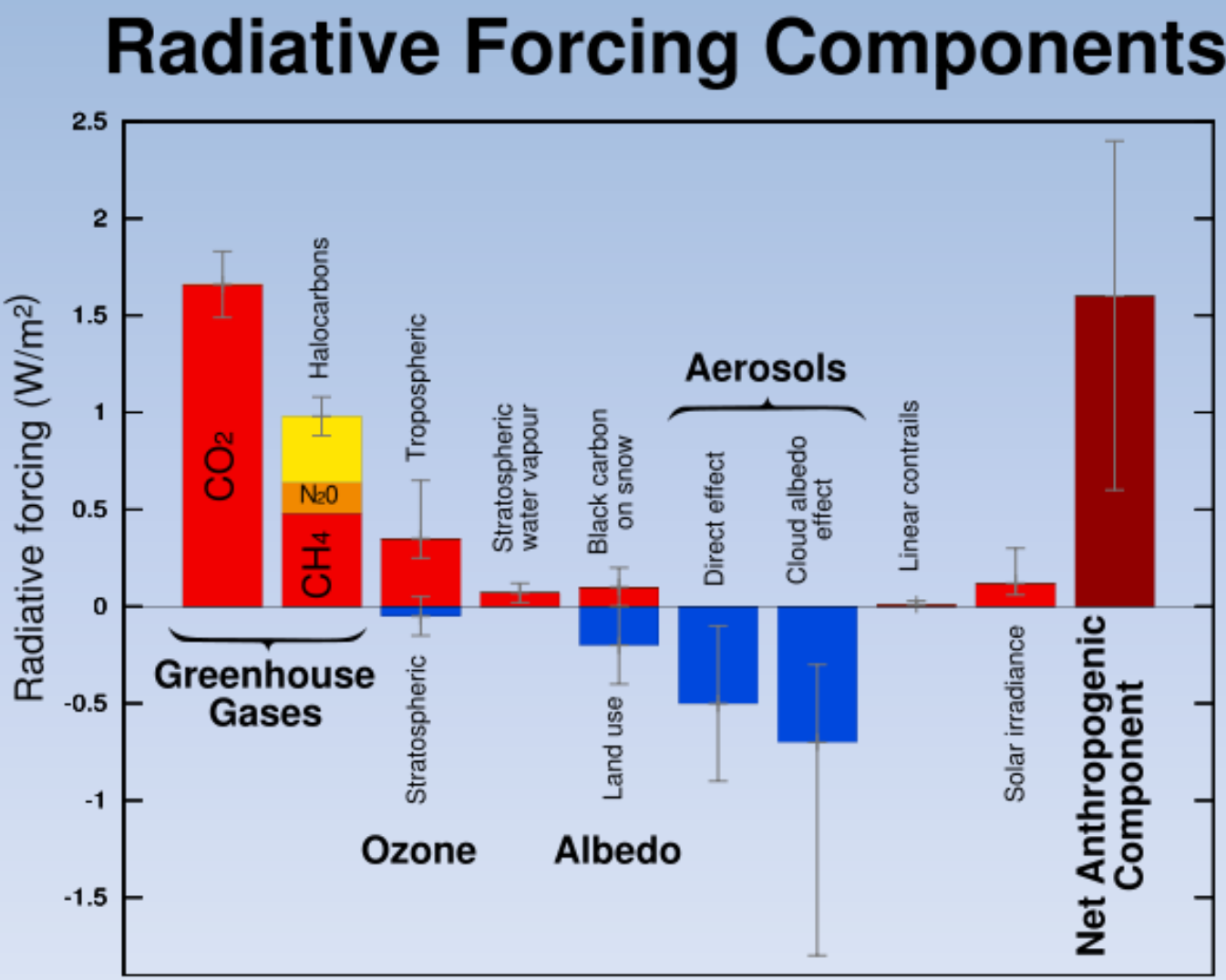
Meehl et al. 2004

How global warming stacks up



- https://www.youtube.com/watch?v=-gHUHoqBn-Y
- Published on Sep 15, 2016
- Skeptics of manmade climate change offer various natural causes to explain why the Earth has warmed 1.4 degrees Fahrenheit since 1880. But can these account for the planet's rising temperature? Watch to see how much different factors, both natural and industrial, contribute to global warming, based on findings from NASA's Goddard Institute for Space Studies.

GLOBAL WARMING CONCERNS

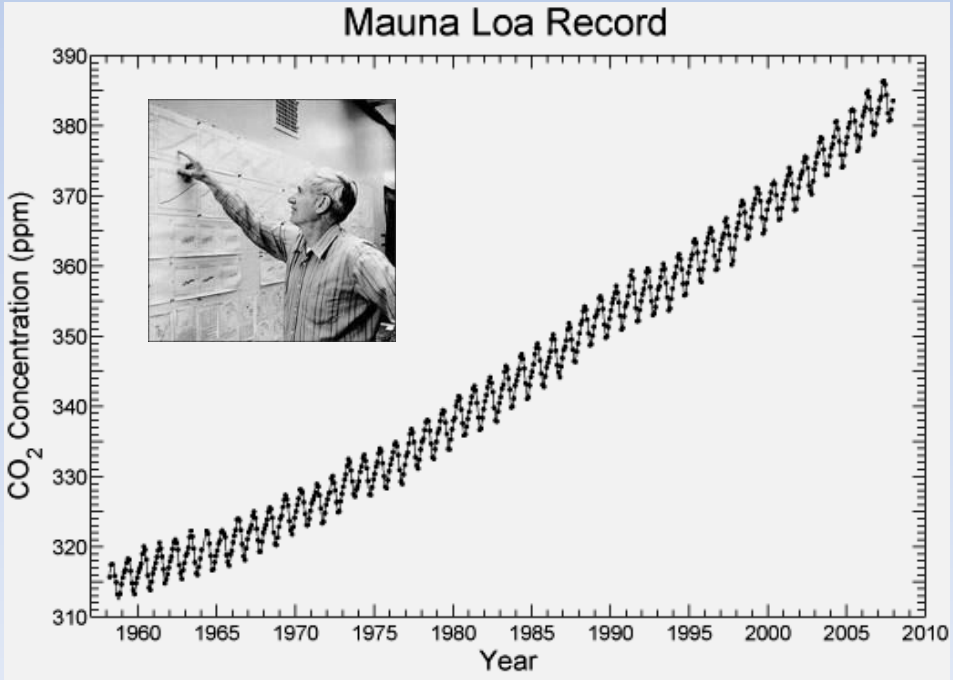


Incoming Solar irradiance: 342 W/m^2

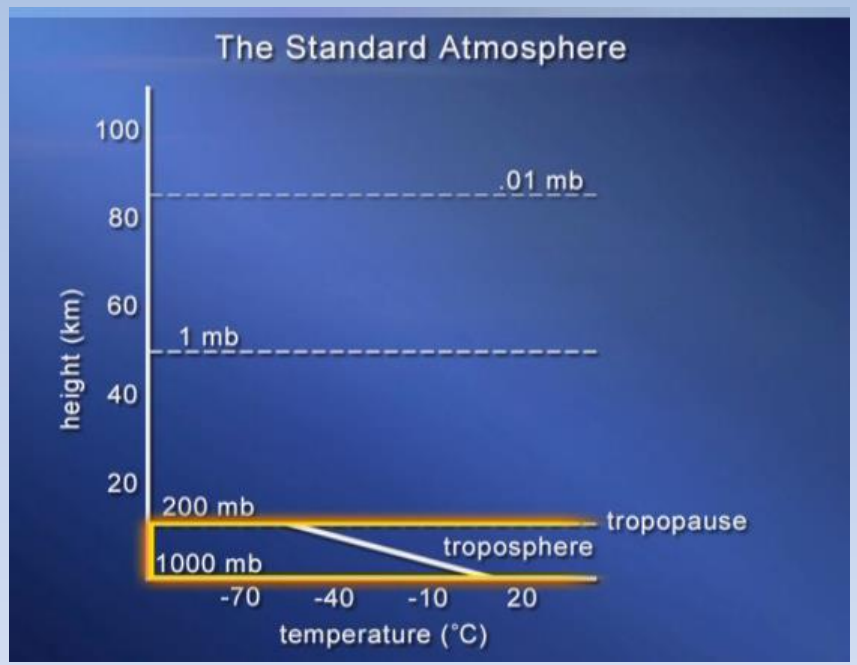
IPCC, 2007

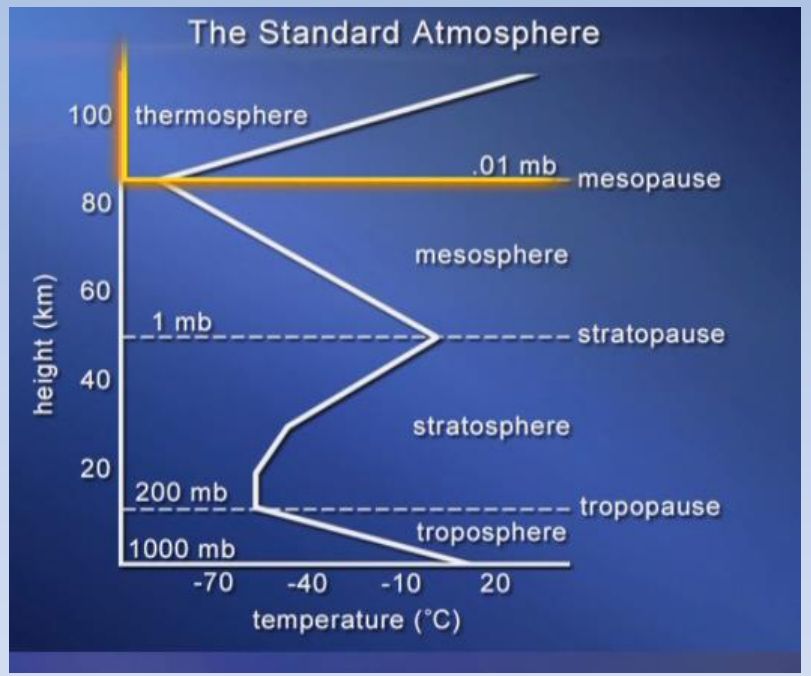
3: EMISSIONS FROM HUMAN ACTIVITIES LARGELY TO BLAME

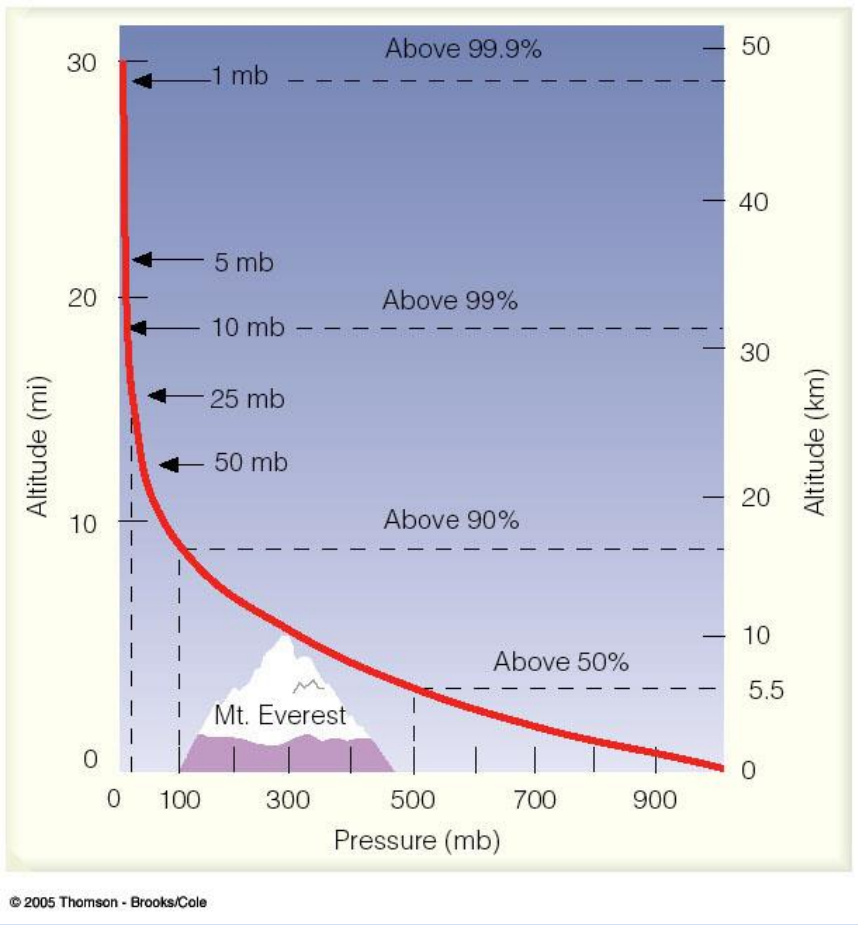
- 40% increase in CO_2
- Dead carbon altering atmospheric C^{14}
- That Carbon is more negative/enriched in C^{12}

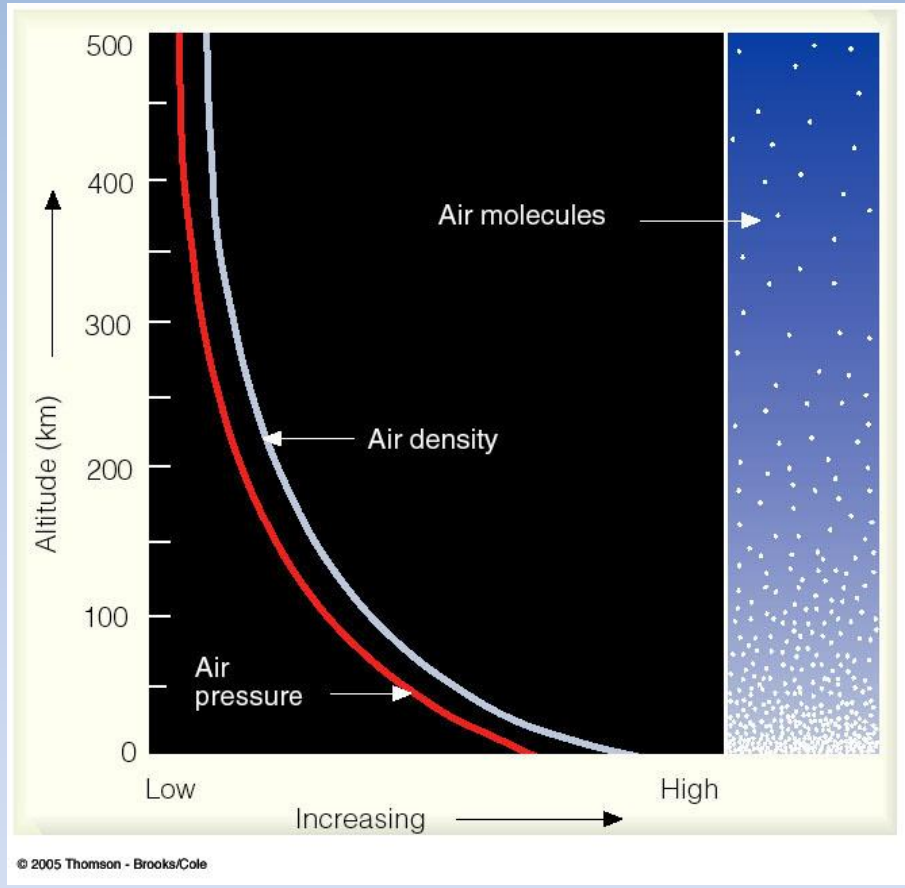


Air – The Standard Atmosphere

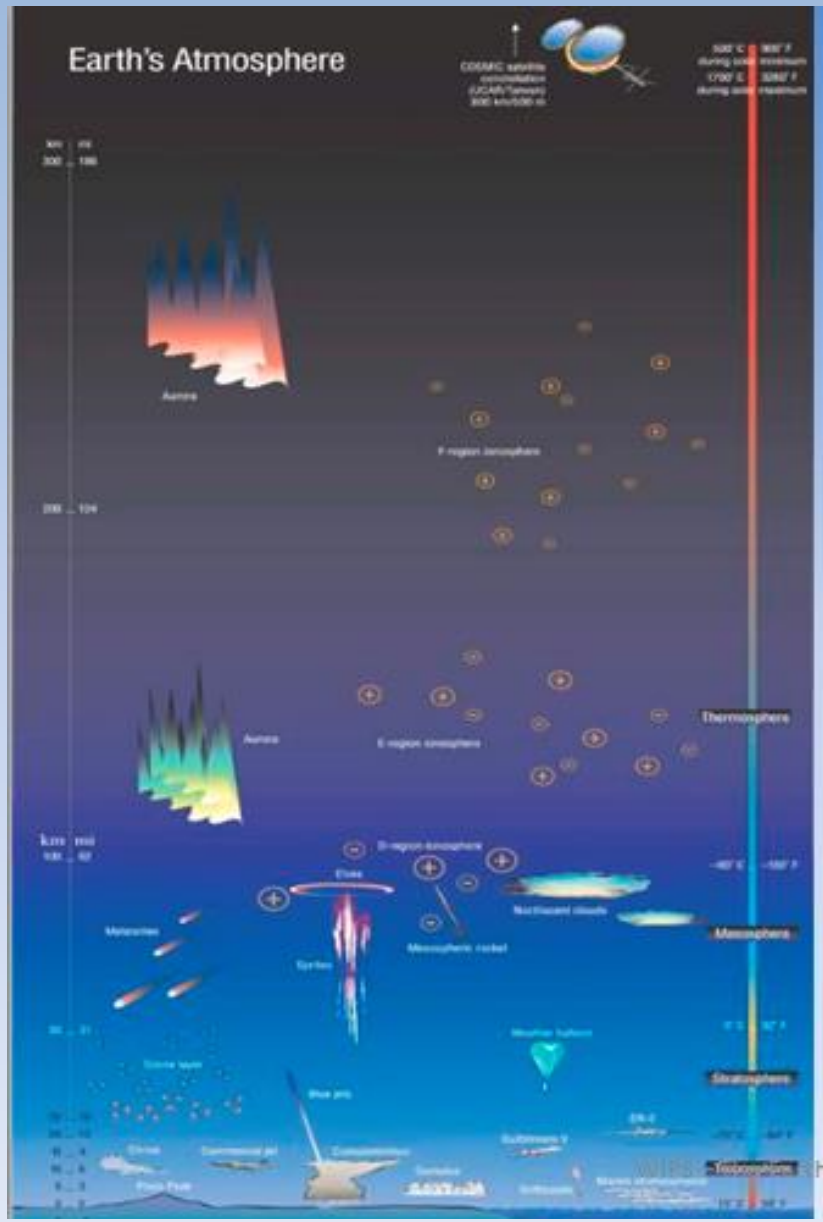






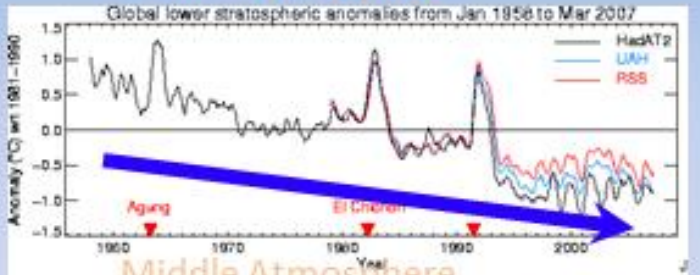


5: SURFACE TO STRATOSPHERE CHANGES

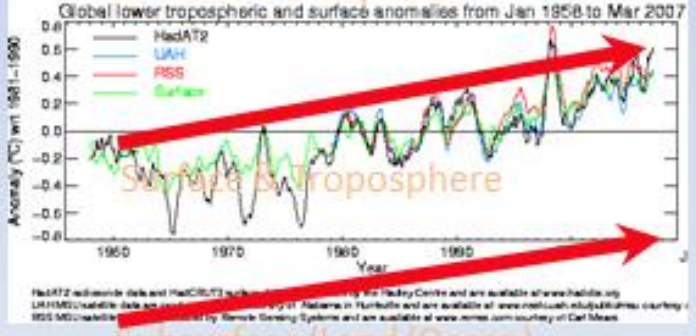


Greenhouse Fingerprint

Middle Atmosphere

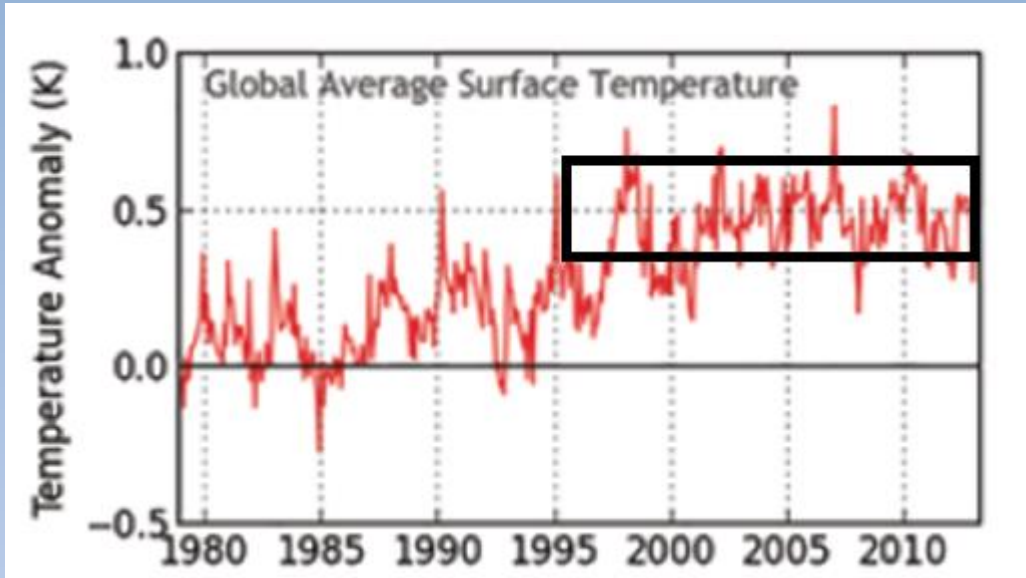


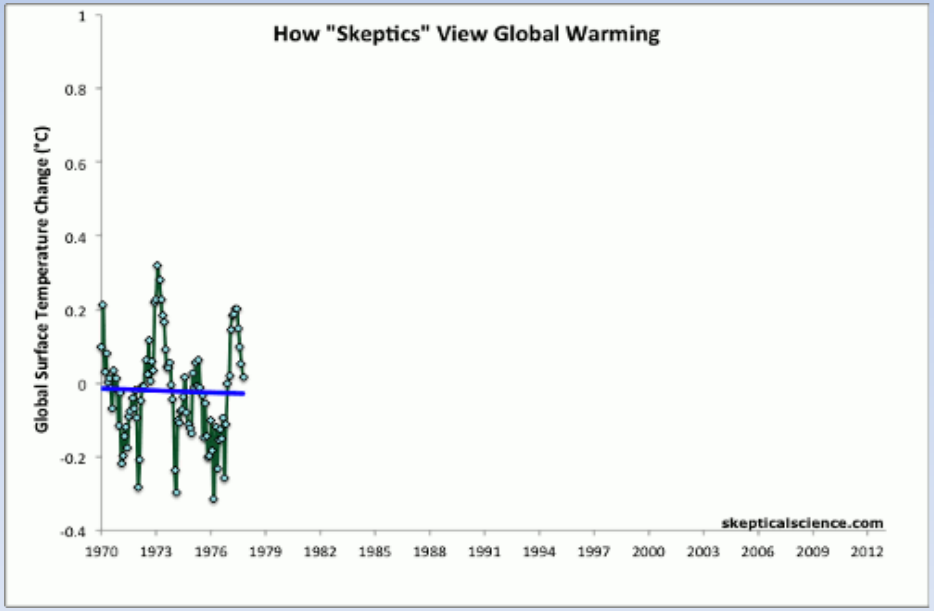
Middle Atmosphere

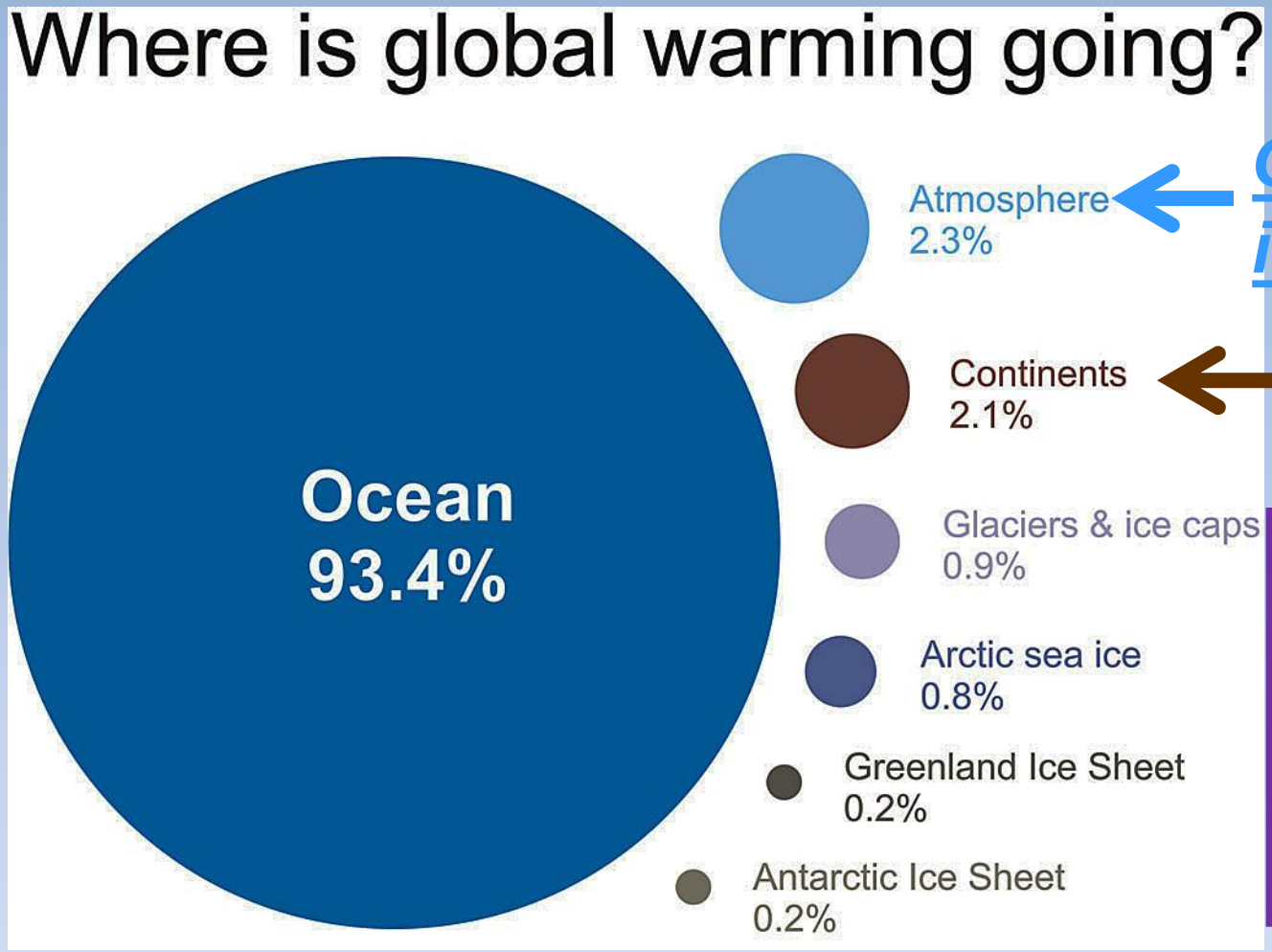


Surface & Troposphere

Subsurface (Land/Ocean)


Global Average Surface Temperature
Temperature Anomaly (K)
1.0
0.5
0.0
−0.5
1980
1985
1990
1995
2000
2005
2010


How "Skeptics" View Global Warming
Global Surface Temperature Change (°C)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
skepticalscience.com



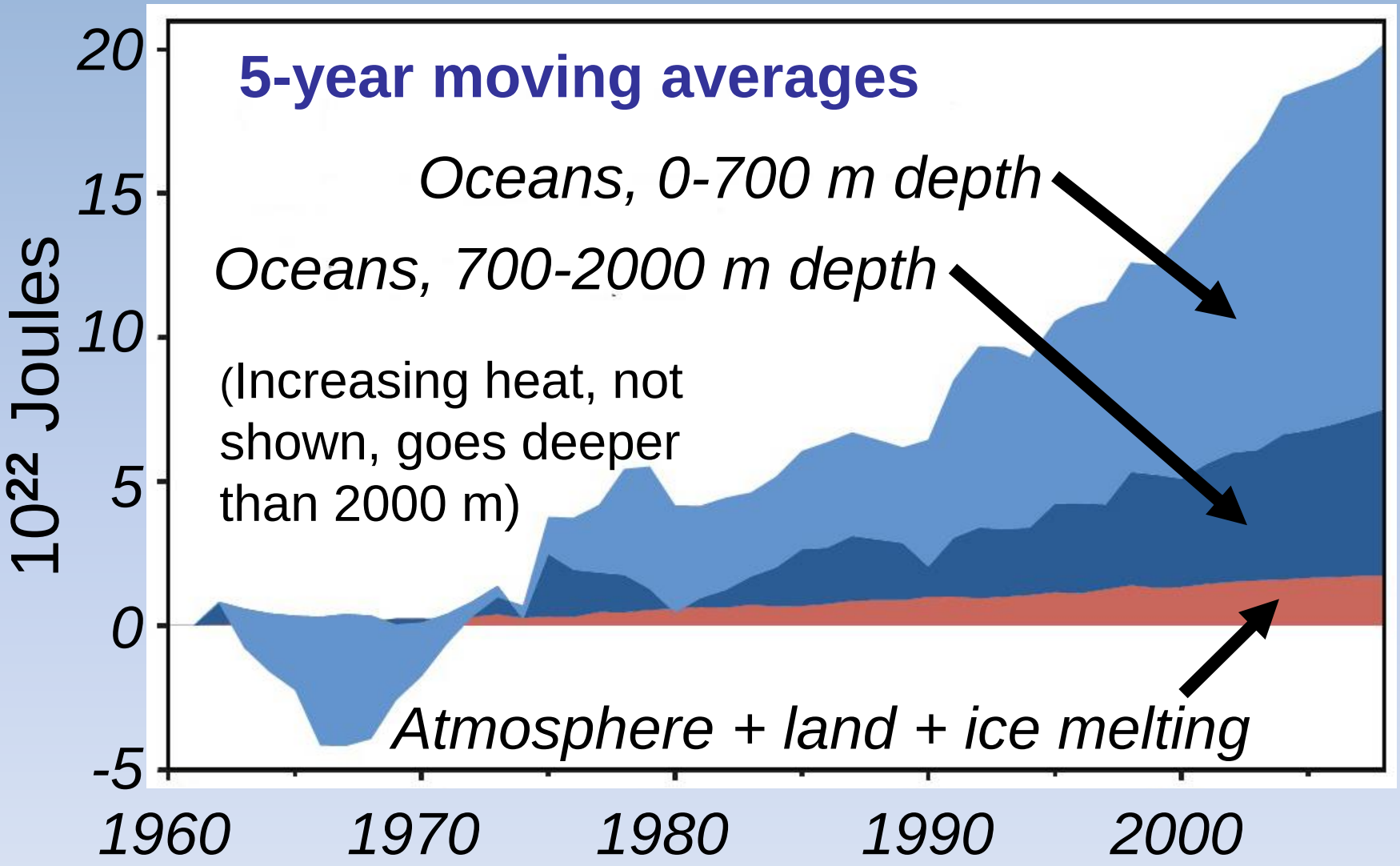
Only ~2% stays in atmosphere

~2% warms the land

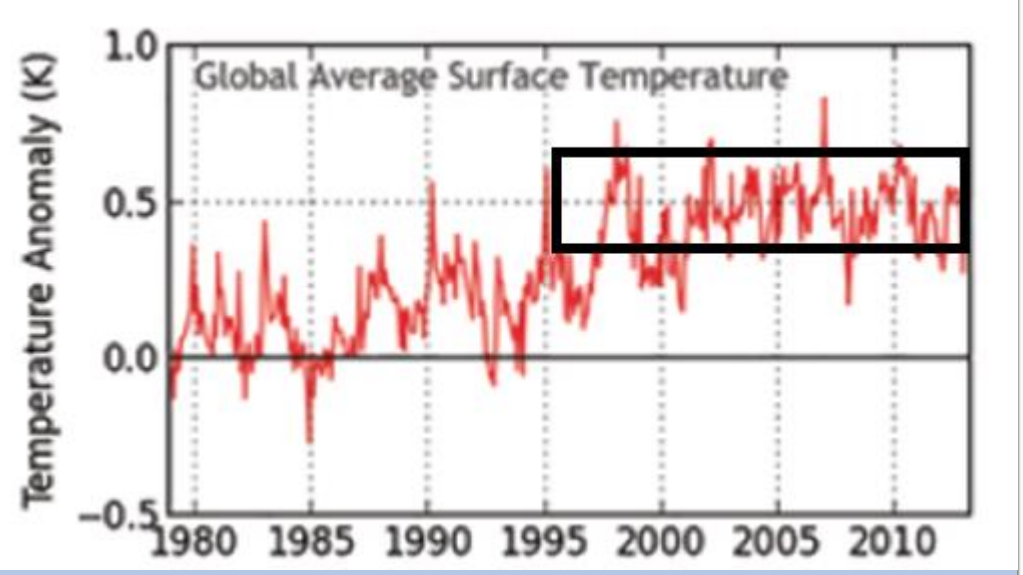
Melting ice absorbs ~2%

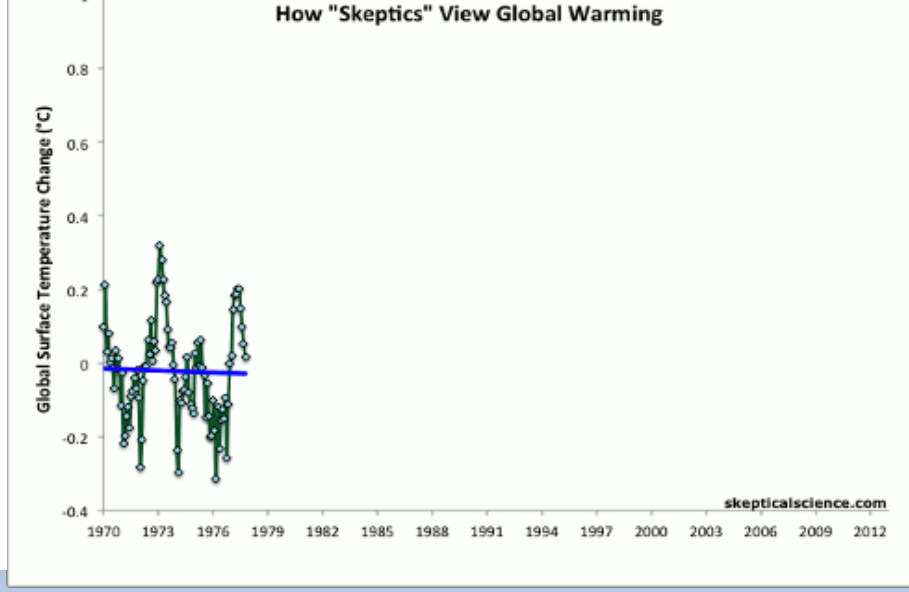
John Cook, from IGPP 2007 data; ~93% to oceans continues (NOAA/NODC, 2012)

Change in heat content, 1958-2011

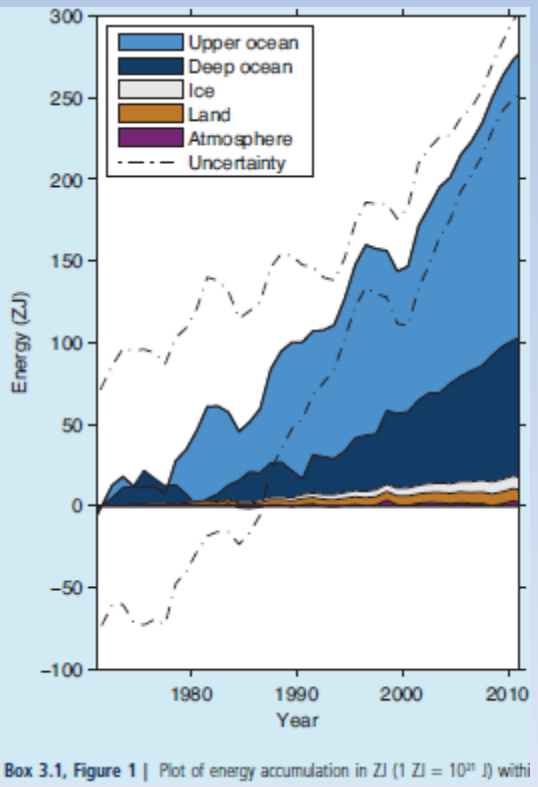


(NOAA 2012 data, Nuccitelli et al. 2012 plot)

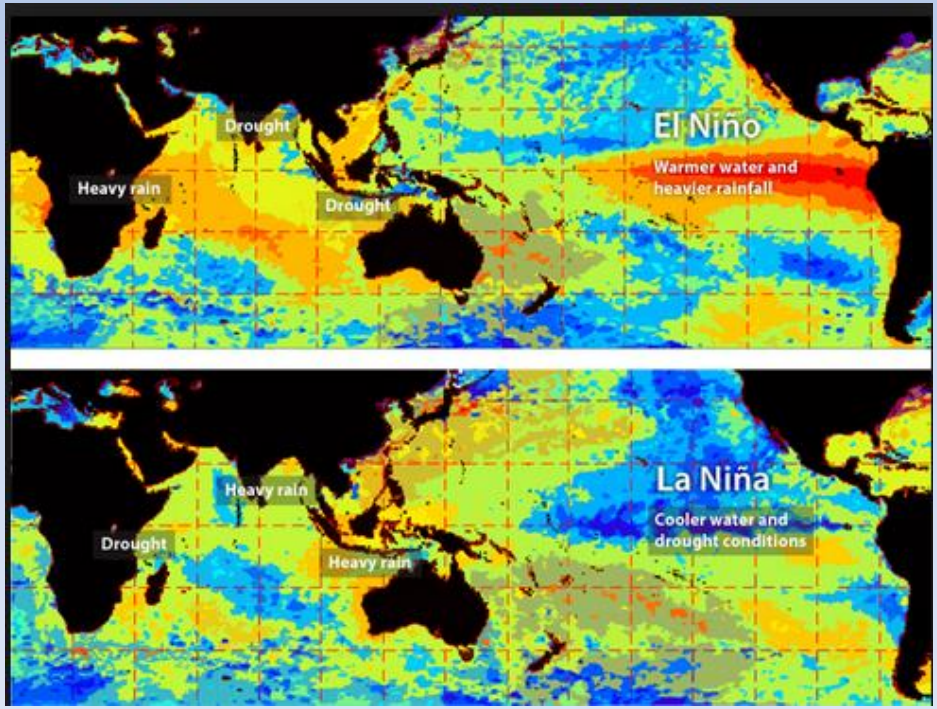




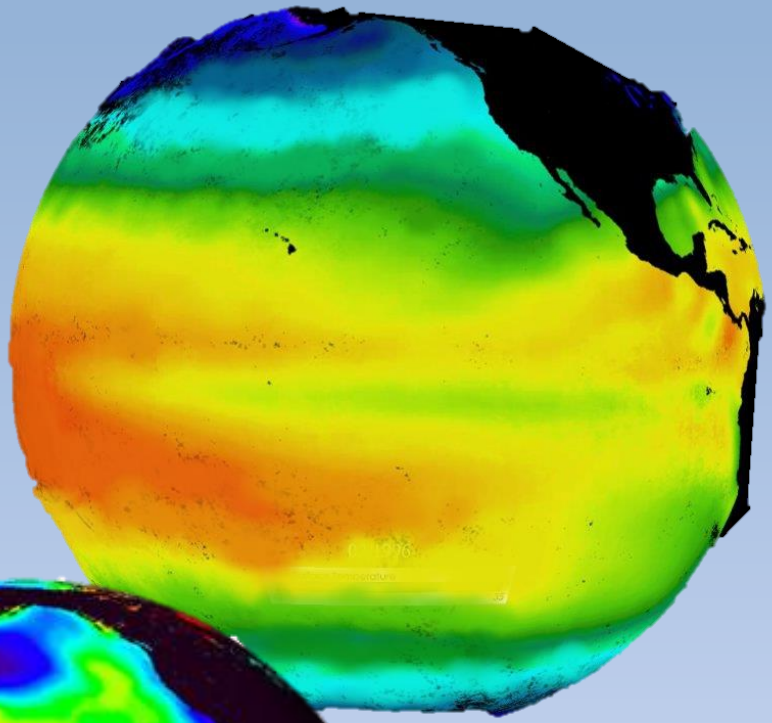
http://www.skepticalscience.com/graphics.php?g=47



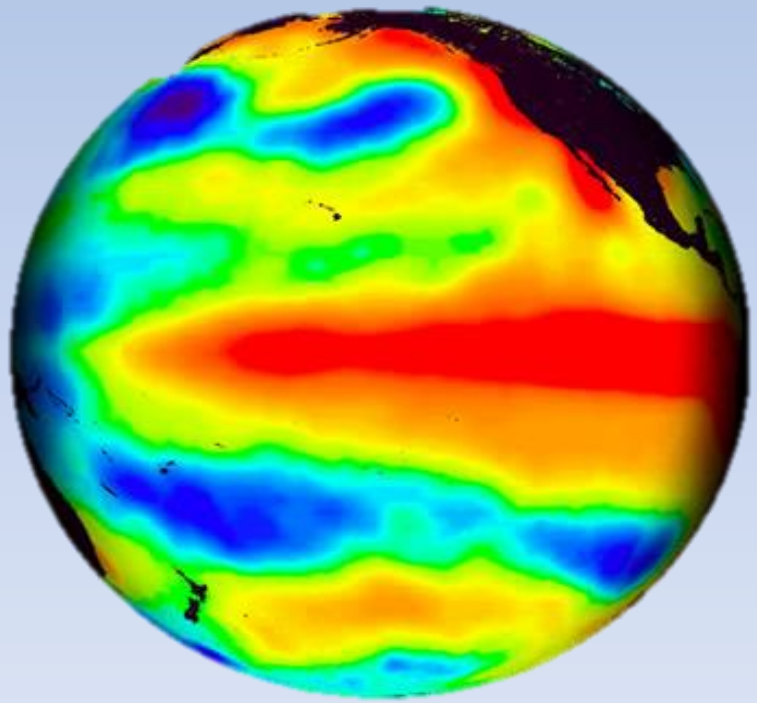
Box 3.1, Figure 1 | Plot of energy accumulation in ZJ (1 ZJ = 10^{21} J) withi



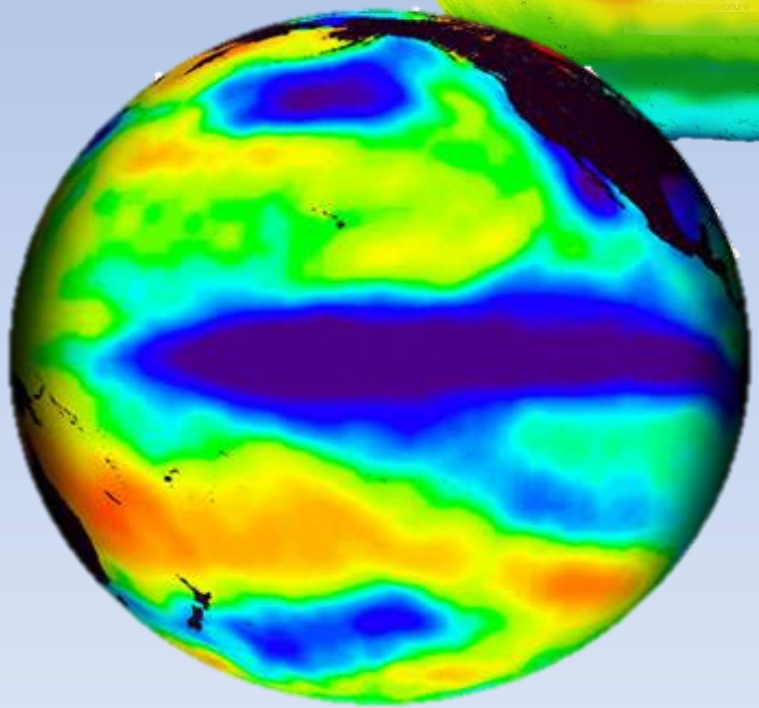
The Pacific – ‘normal condition’



El Niño



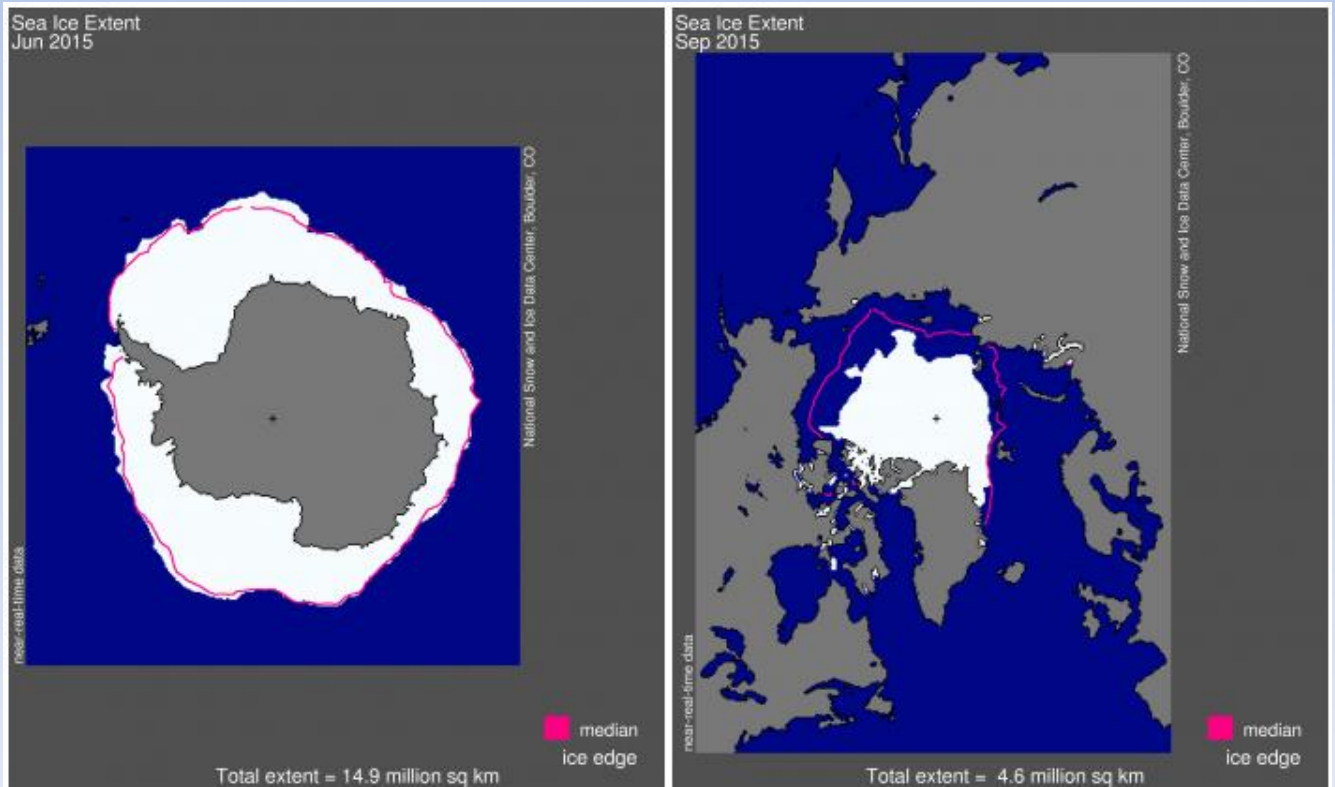
La Niña



Temperature Anomaly °C

12. ARCTIC ICE vs. ANTARCTIC SEA ICE

- Ans. More moisture in air around Antarctica (AA) to nucleate sea ice
- Despite > AA is does not compensate for Arctic loss



2015

http://nsidc.org/arcticseaicenews/2015/

12. ARCTIC ICE vs. ANTARCTIC SEA ICE

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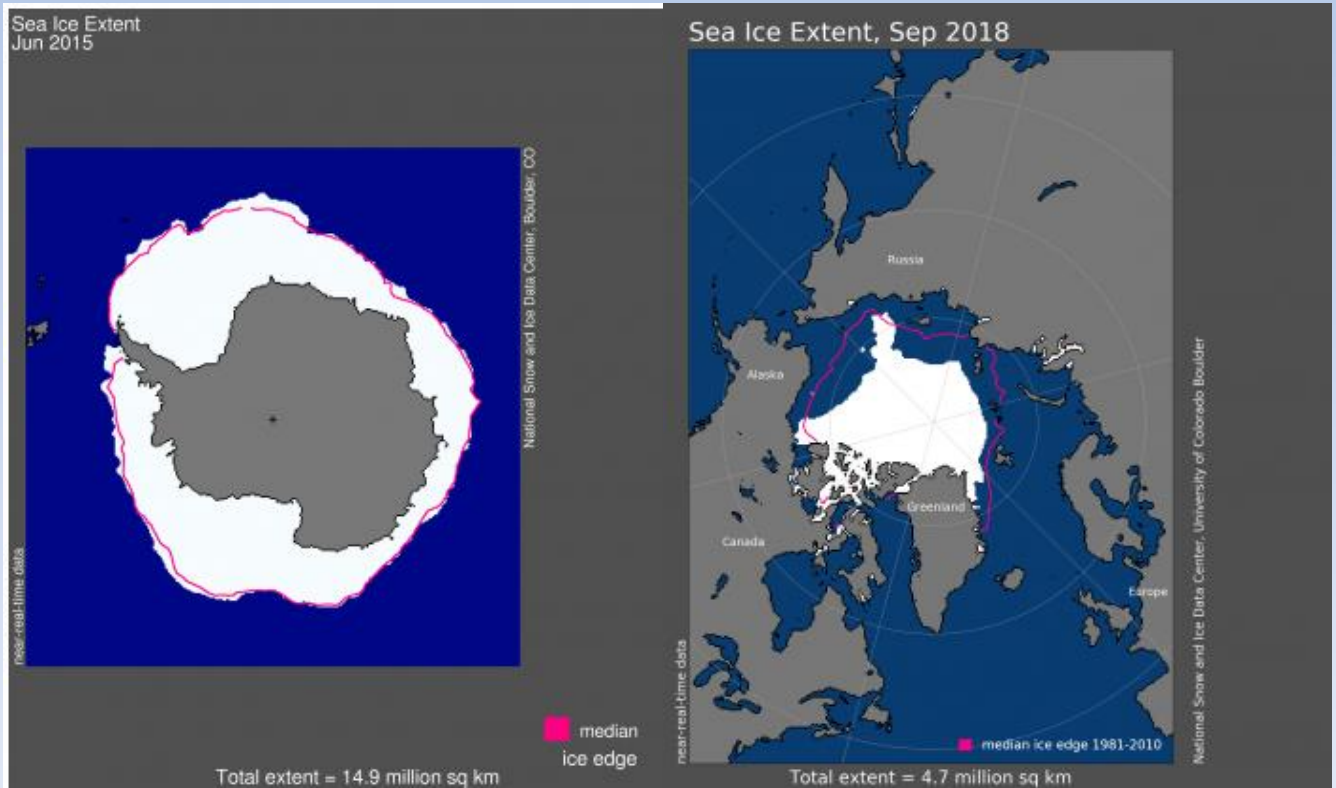


2018

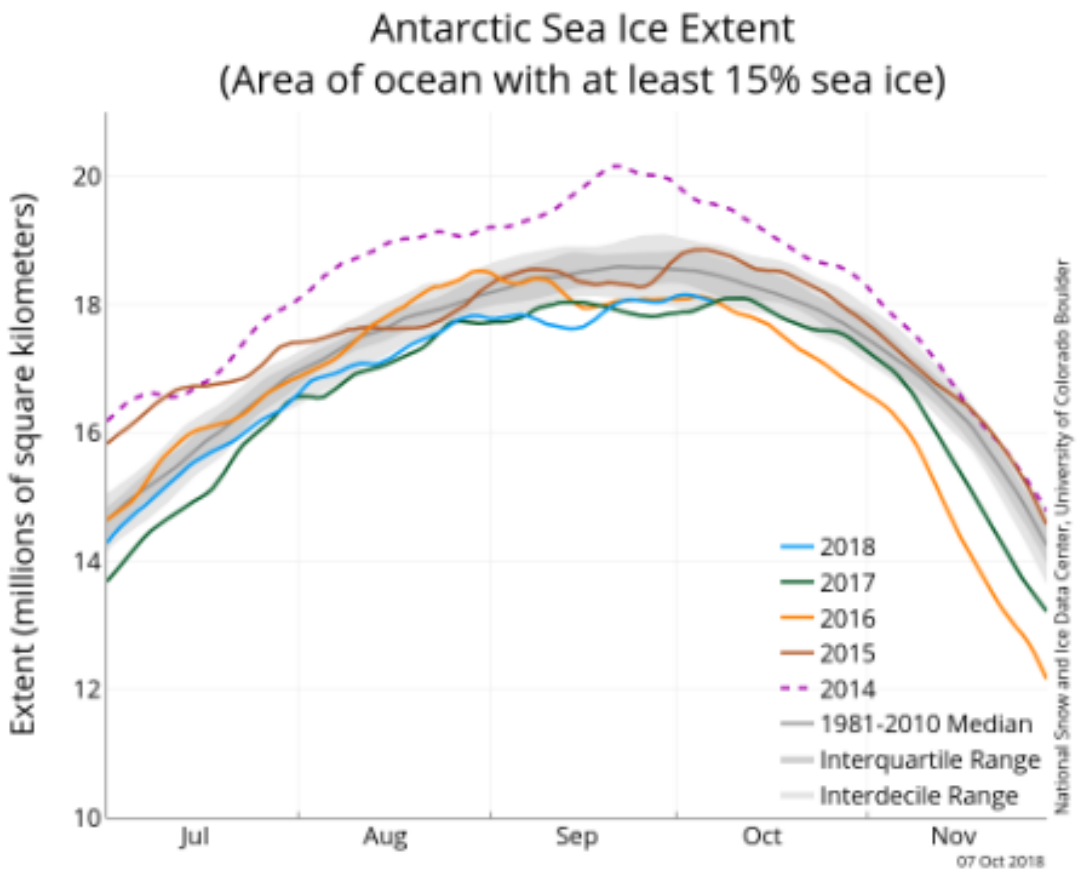
http://nsidc.org/arcticseaicenews/2018/

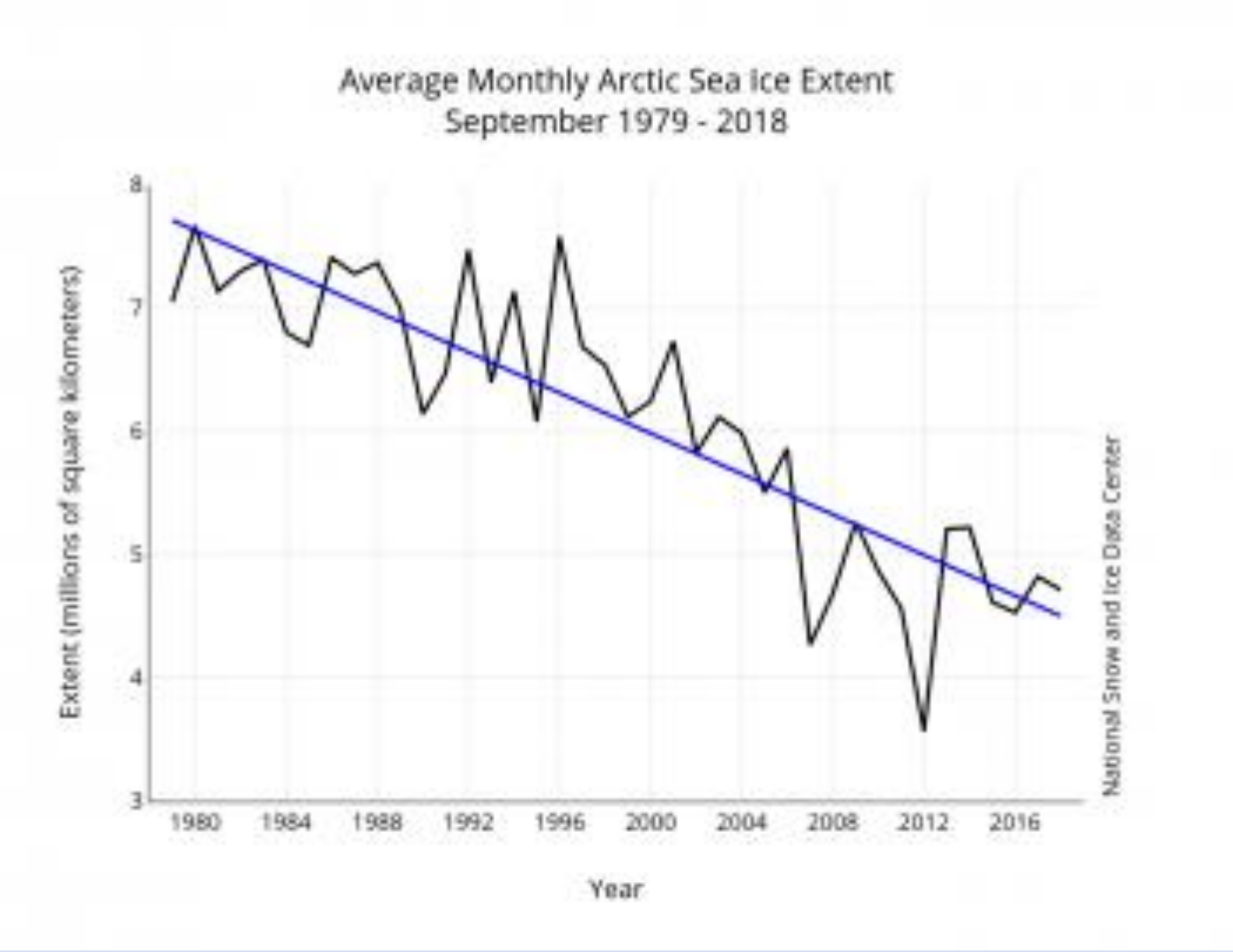
Antarctic changes

Figure 6. The graph above shows Antarctic sea ice extent as of October 7, 2018, along with daily ice extent data for four previous years. 2018 is shown in blue, 2017 in green, 2016 in orange, 2015 in brown, and 2014 in dotted purple. The 1981 to 2010 median is in dark gray. The gray areas around the median line show the interquartile and interdecile ranges of the data. Sea Ice Index data.

Credit: National Snow and Ice Data Center
High-resolution image
Image 9 of 9 (play slideshow) Download

CLOSE ✕

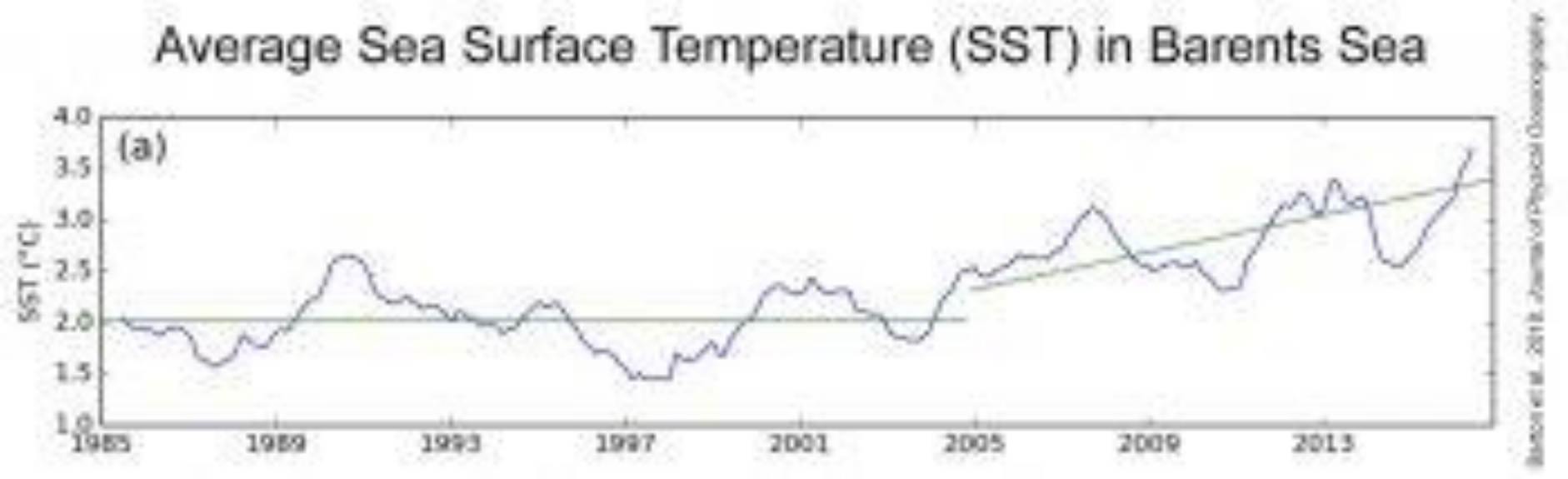


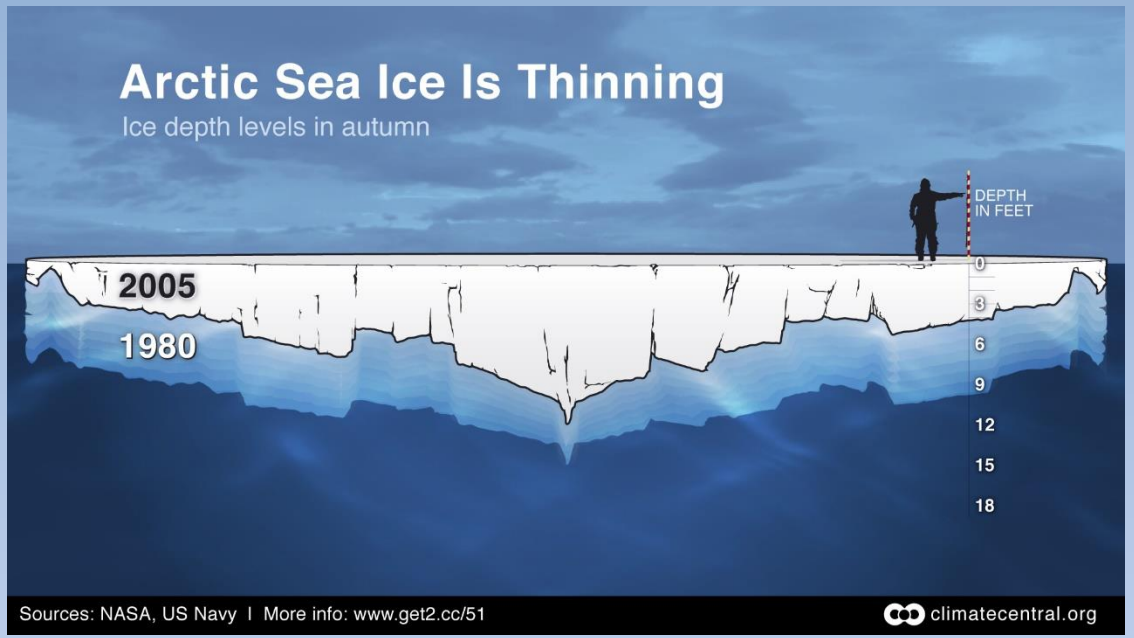


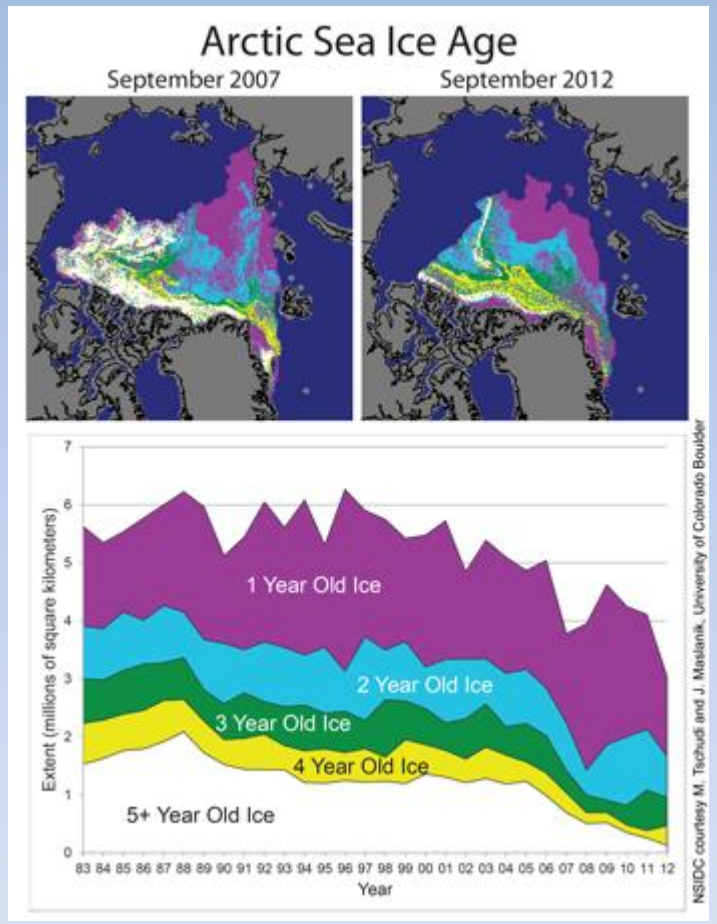
http://nsidc.org/arcticseaicenews/2018/10/

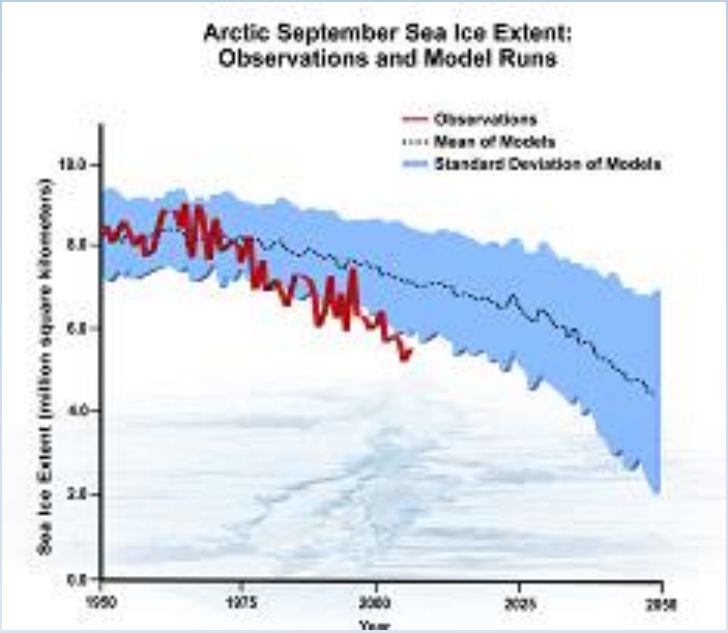
For more see: http://www.skepticalscience.com/melting-ice-global-warming.htm

Other Data

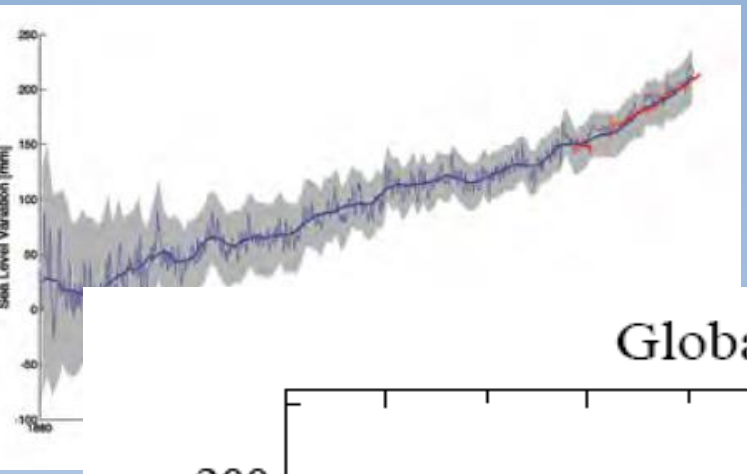

Average Sea Surface Temperature (SST) in Barents Sea
(a)
SST (°C)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
1985
1989
1993
1997
2001
2005
2009
2013



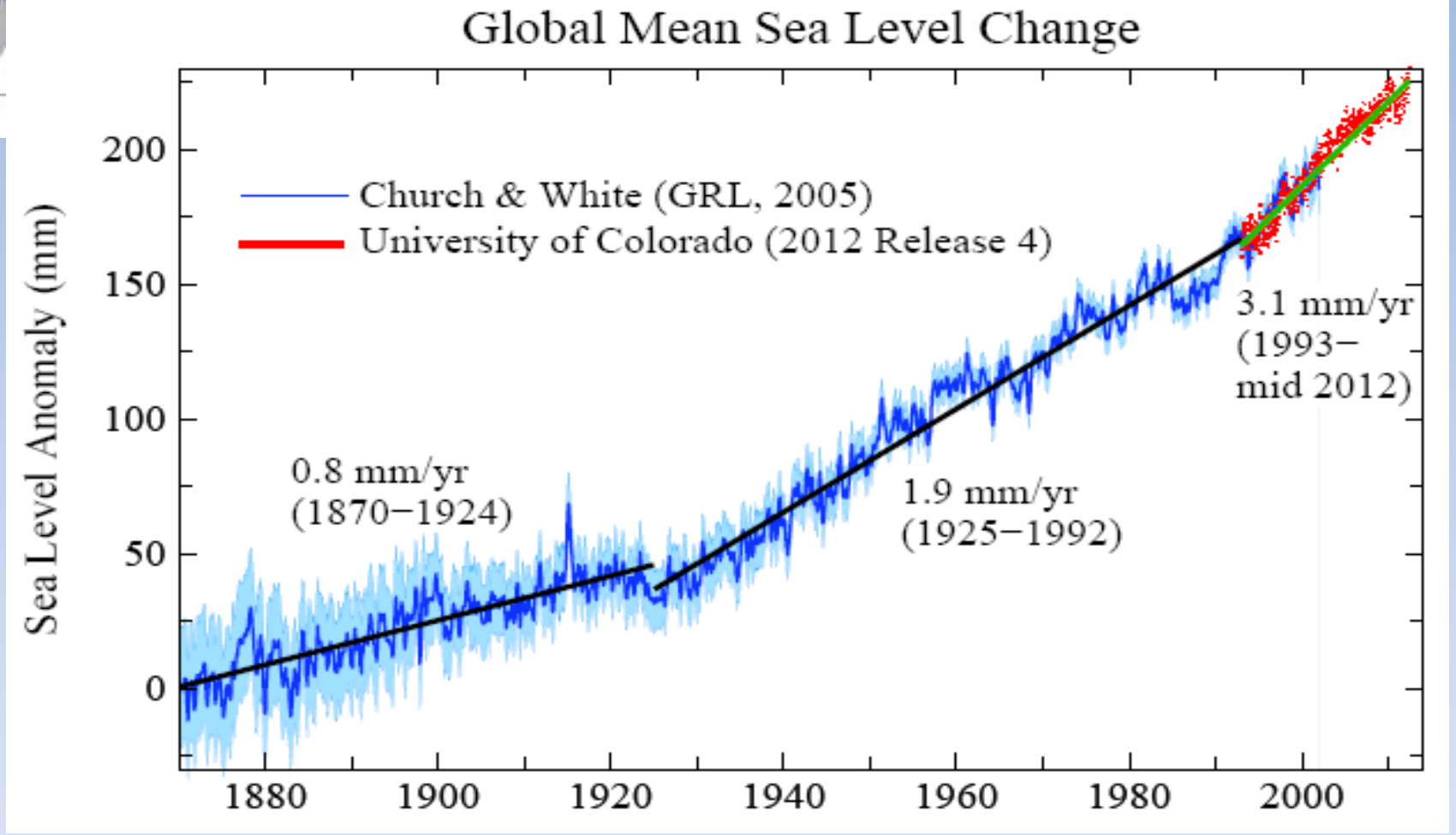




http://nsidc.org/arcticseaicenews/2015/



14: HOW FAST IS SEA LEVEL RISING?

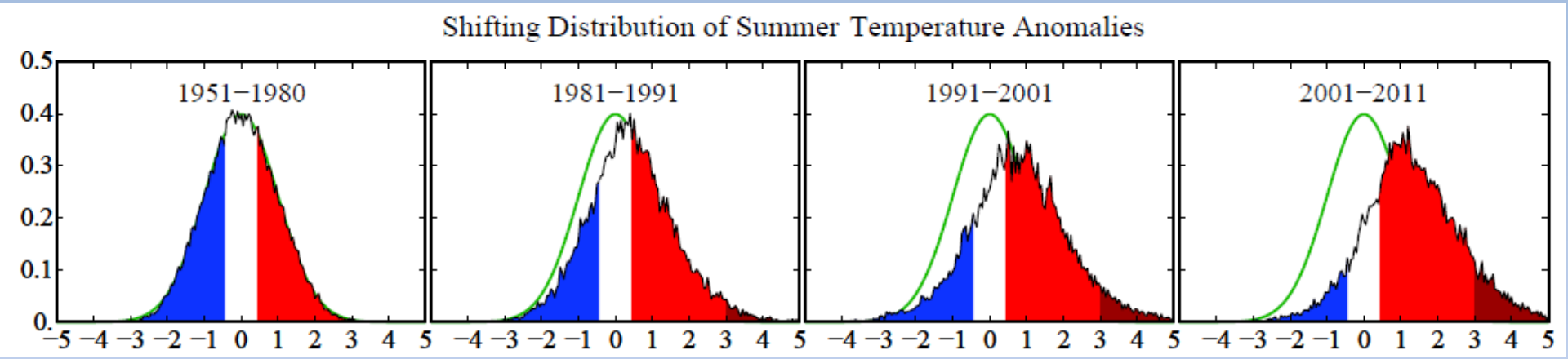


Blue: Sea level change from tide-gauge data *(Church J.A. and White N.J., Geophys. Res. Lett. 2006; 33: L01602)*
Red: Univ. Colorado sea level analyses in satellite era *(http://www.columbia.edu/~mhs119/SeaLevel/)*.

Loaded Climate Dice: global warming is increasing extreme weather events.

Extreme summer heat anomalies now cover about 10% of land area, up from 0.2%.

This is based on observations, not models.



Frequency of occurrence (vertical axis) of local June-July-August temperature anomalies (relative to 1951-1980 mean) for Northern Hemisphere land in units of local standard deviation (horizontal axis). Temperature anomalies in the period 1951-1980 match closely the normal distribution ("bell curve", shown in green), which is used to define cold (blue), typical (white) and hot (red) seasons, each with probability 33.3%. The distribution of anomalies has shifted to the right as a consequence of the global warming of the past three decades such that cool summers now cover only half of one side of a six-sided die, white covers one side, red covers four sides, and an extremely hot (red-brown) anomaly covers half of one side.
Source: Hansen, J., Sato, M., and Ruedy, R., Proc. Natl. Acad. Sci., 2012.

End of week 1

https://i.kinja-img.com/gawker-media/image/upload/t_original/ihsllhptnnm4vb7wuvgq.jpg