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

Paul Belanger, Ph.D.

Geologist/Paleoclimatologist

week 1: March 30th, 2017

INTRODUCTIONS – Part 1

- Ed Struzeski: classroom assistant, liaison to me/OLLI
  - Logistics: bathrooms, breaks, no open containers, no peanuts/peanuts snacks
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  - 720-842-5073

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INTRODUCTIONS – part 2

- **Intro**:
  - Yourselves – what brought you here
  - Paul
  - http://denverclimatestudygroup.com/ (OLLI tab)
  - Web page - 10 year history; Resume in “About” tab
  - Facebook - https://www.facebook.com/denverclimatestudygroup/

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

week 1: March 30th, 2017

- 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"

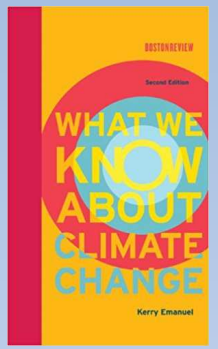
Richard Feynman, 1974

My comment:

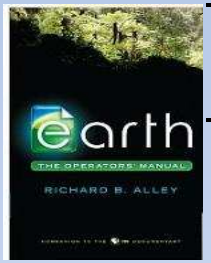
We've become a country of self-proclaimed experts on everything.

Three books to consider:

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

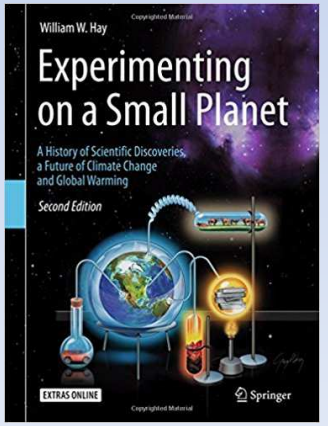


- **Intermediate Level Book:**
  - **Earth: The Operators' Manual** by Richard B. Alley (Apr 18, 2011)
  - http://earththeoperatorsmanual.com/



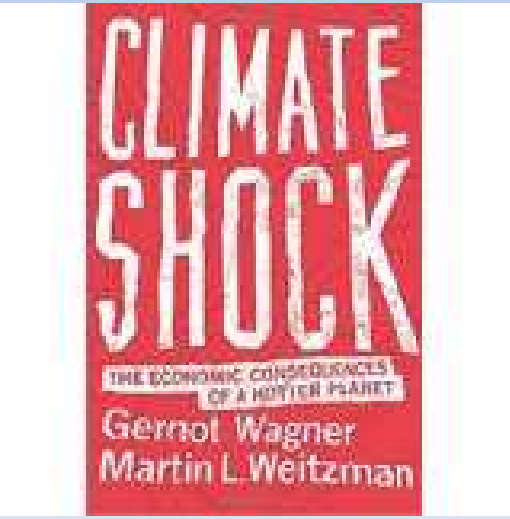
- **More comprehensive book:**

  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

can change within
a few minutes or hours!

Climate

takes very long time
to change!

VIDEO - what is climate

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

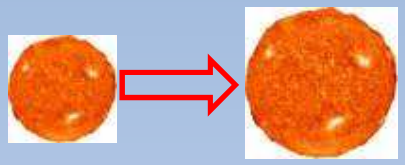
TAKE AWAY: This is Weather

This is NOT Climate Change

Chair of the Senate Environment Committee

What determines Earth's climate

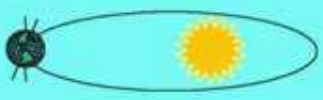
- **Primary Influences (3):**
  1. **SOLAR input:**



0.9% less
100 My ago

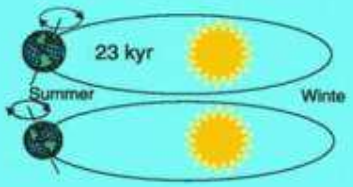
& sunspots

Obliquity



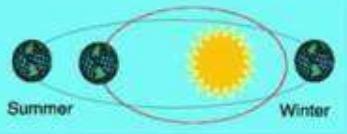
Tilt; 40,000 years:
21.5 – 24.5 degrees

Precession



20,000 years:
summer season

Eccentricity



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

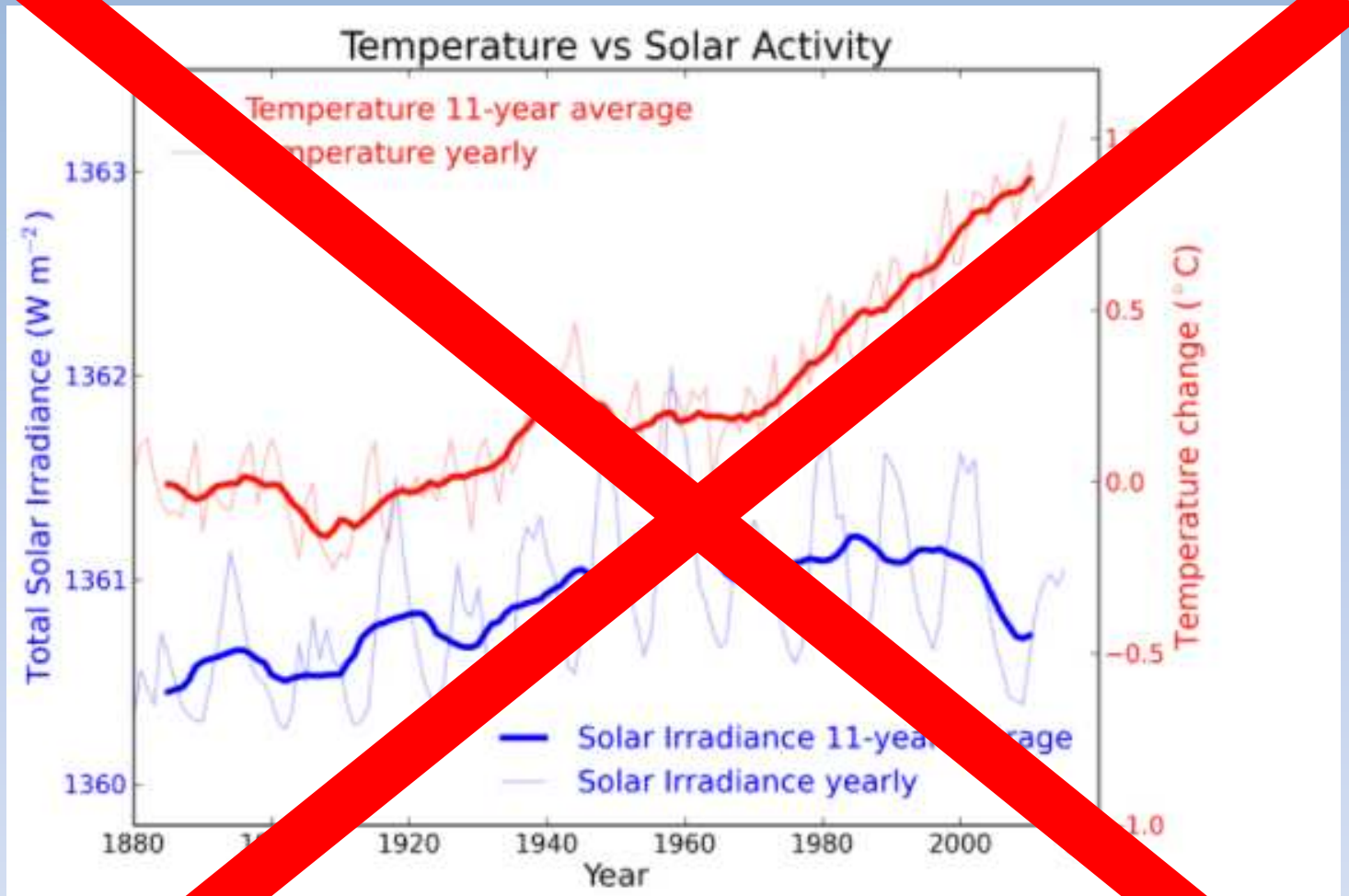
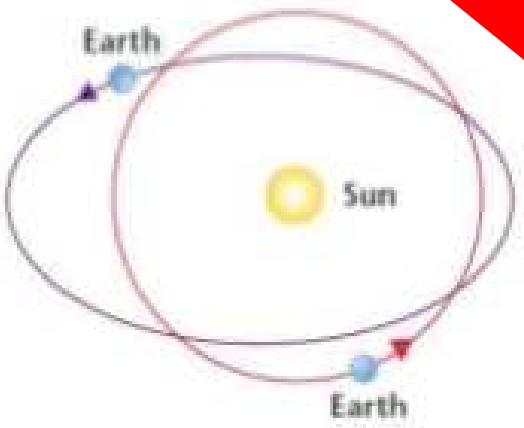


Figure 1: Annual global temperature change (thin light red) with 11 year moving average of temperature change (thick dark red). Temperature from NASA GISS. Annual Total Solar Irradiance (thin light blue) with 11 year moving average of TSI (thick dark blue). TSI from 1880 to 1978 Krivova et al 2007. TSI 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 rece from the sun when Earth's orbit elongated than it does when 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 he relationship betw th's tilt and eccentric

19 – 24,0 ars

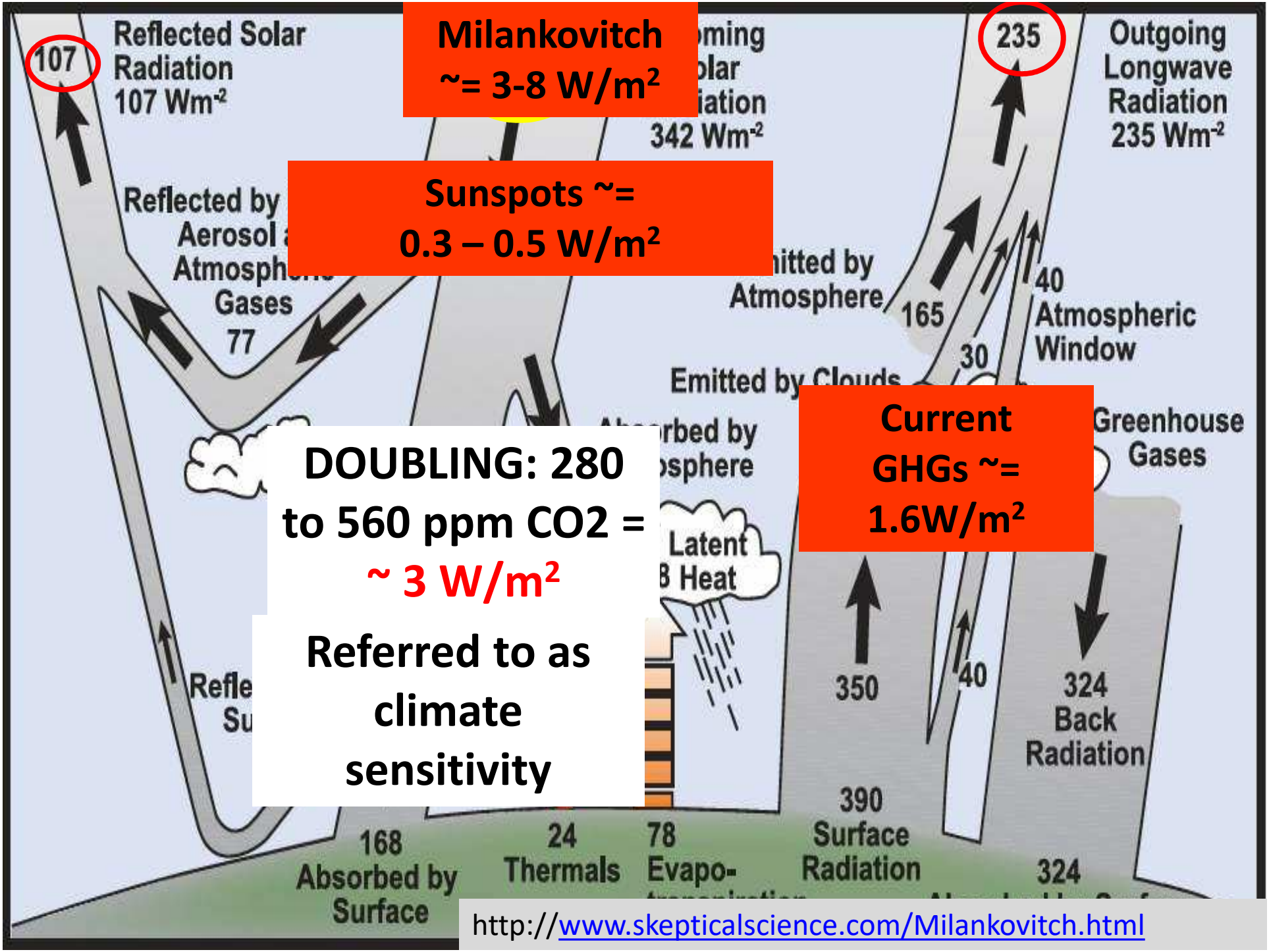
https://www.slideshare.net/syadur/milankovitch-theory

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)

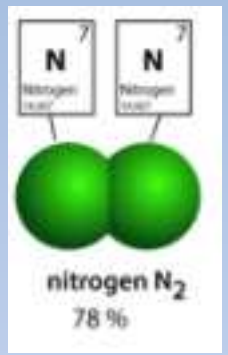
=

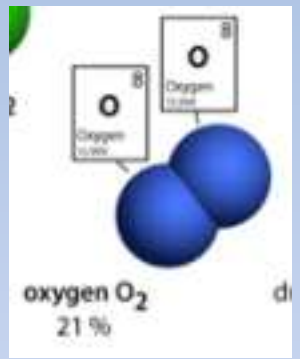
Energy out (infrared)

- 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

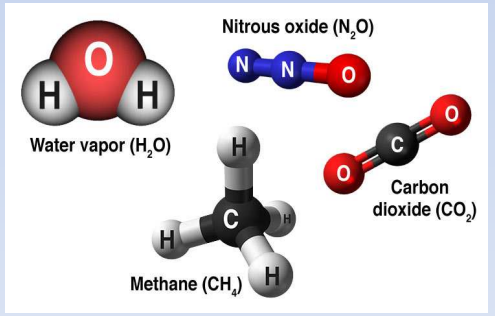
Let's look at our atmosphere

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



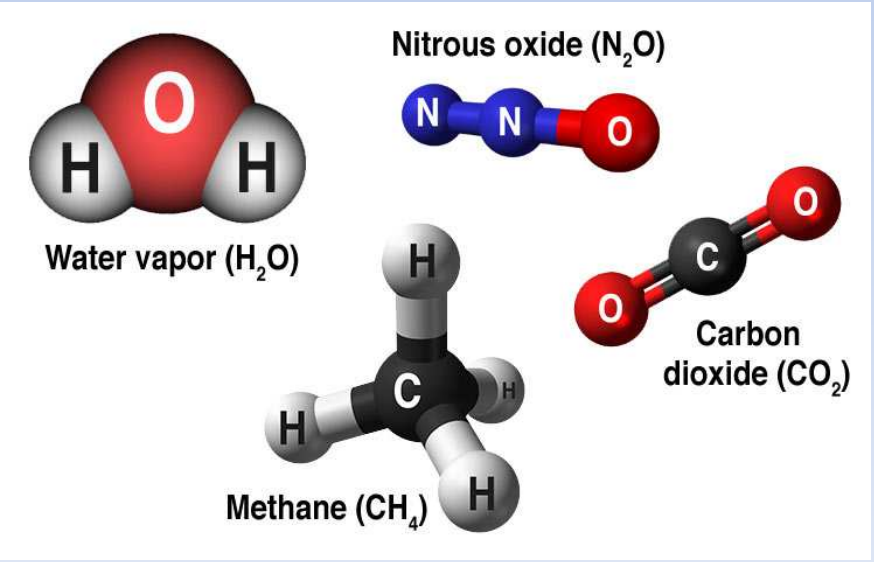


- CO_2 = -.408%
- H_20 = variable
- Other: CH_4, CFCs, O_3, etc.



GREENHOUSE GASES (GHGs)

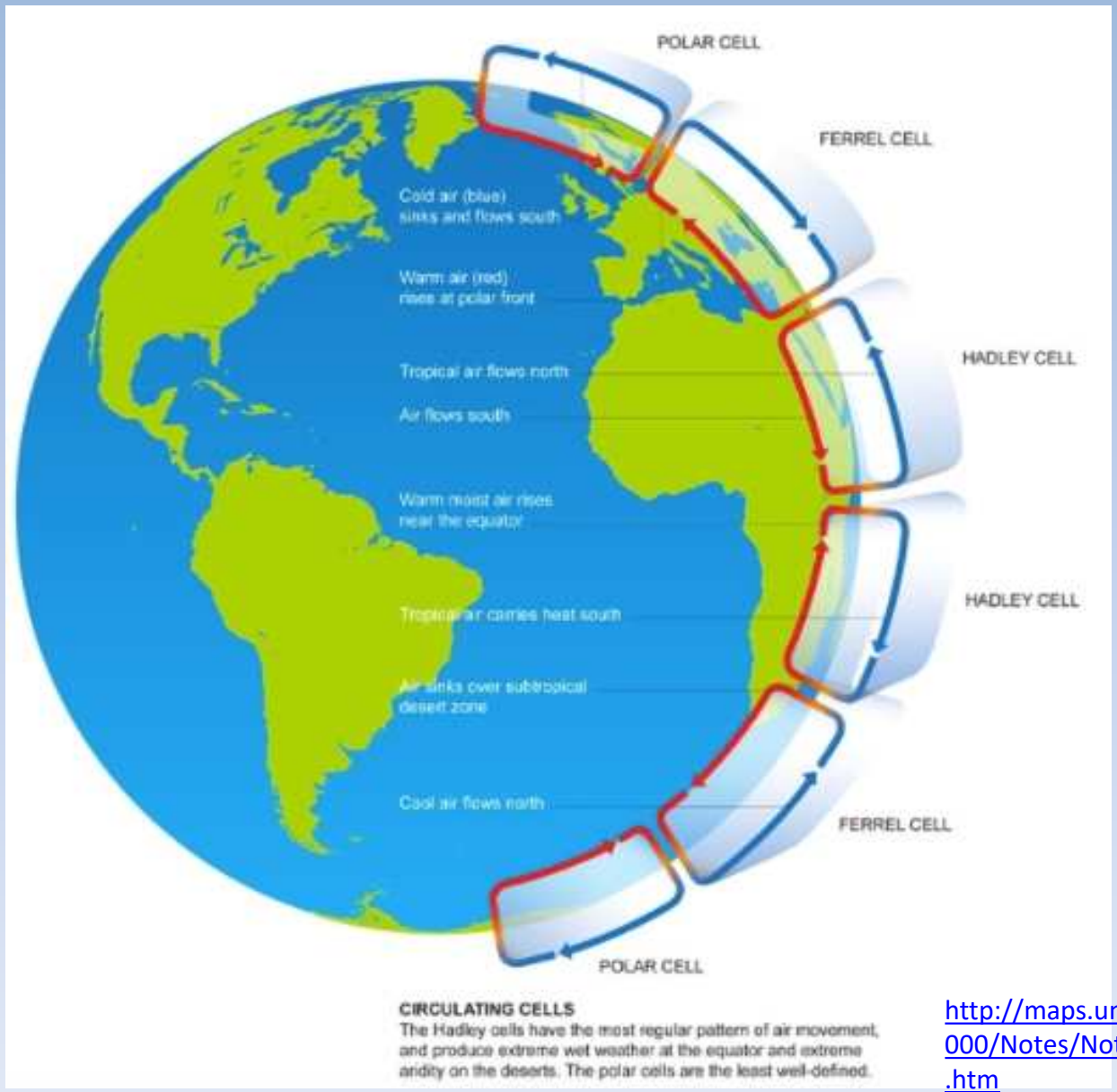
- Water – H_2O – the amount is a feedback of temperature held in by the "blanket" of other GHGs
- Carbon dioxide - CO_2
- Methane - CH_4
- Ozone - O_3
- Nitrous oxide- N_2O
- others



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

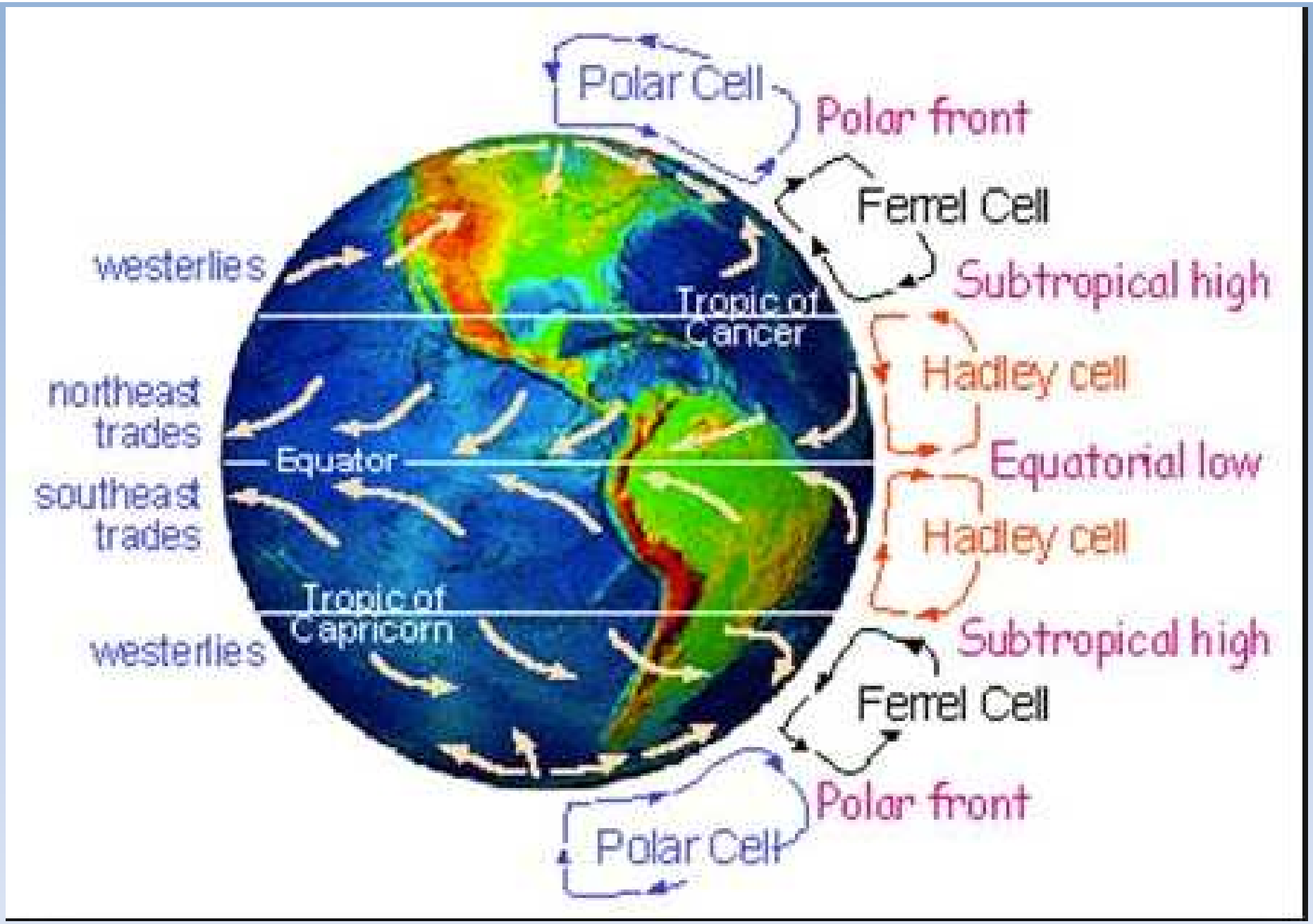


CIRCULATING CELLS
The Hadley cells have the most regular pattern of air movement, and produce extreme wet weather at the equator and extreme aridity on the deserts. The polar cells are the least well-defined.

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



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

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

T, P and V relationships with density

$$PV = nRT$$

- Temperature: INCREASES
  - V increases and thus
  - **Density decreases**
- Pressure: INCREASES
  - V decreases and thus
  - **Density increase**
- Volume: INCREASES
  - T decreases and thus
  - **Density Decreases**

HOWEVER:

- Changes in the composition of medium can also cause **density** to change

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 Negligible
- CO_2 = .408% C=12; 12 +32 = 44
- H_20 = var Not to be ignored so much 18
- Other: CH_4, CFCs, O_3, etc.

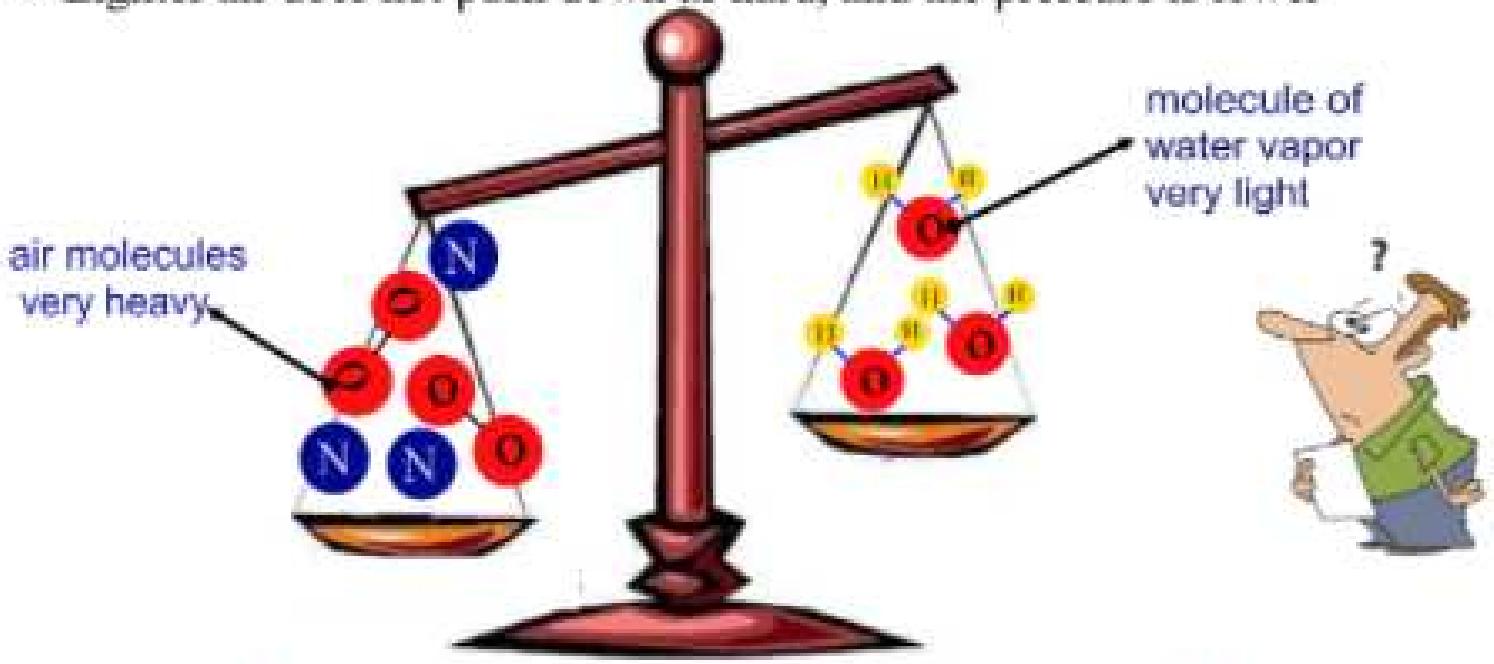
ANSWER as to which weighs more:

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

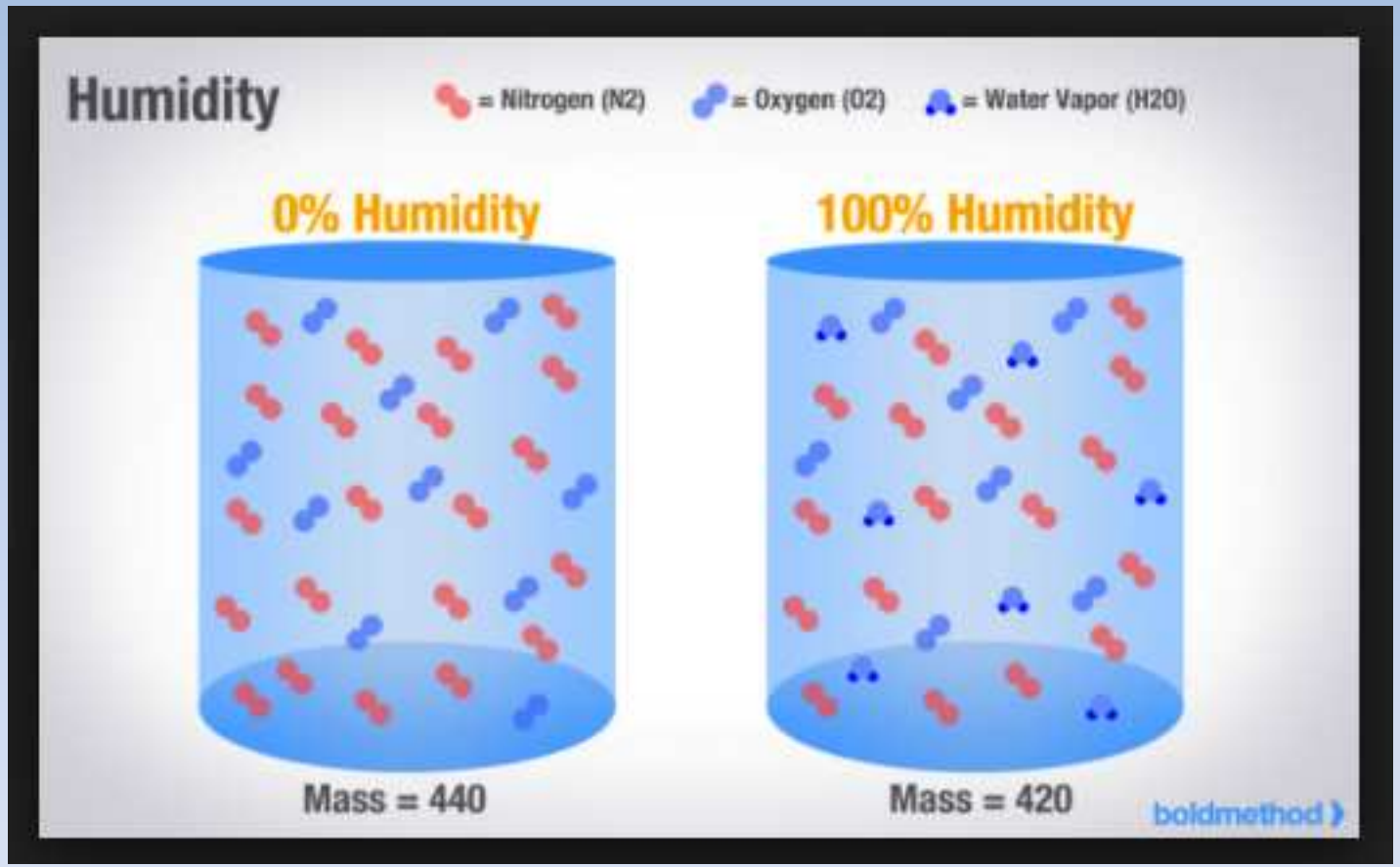
- WEATHER:
  - WHAT'S A STORM ASSOCIATED WITH
    - LOW PRESSURE? **MOISTURE: STORMS, HURRICANES**
    - WHY? **WATER VAPOR WEIGHS LESS THAN N_2 & O_2**

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 (02)
= Water Vapor (H20)
0% Humidity
100% Humidity
Mass = 440
Mass = 420
boldmethod

TAKE AWAY:

adding **H_2O VAPOR** decreases density

TAKE AWAY:

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

Water vapor

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

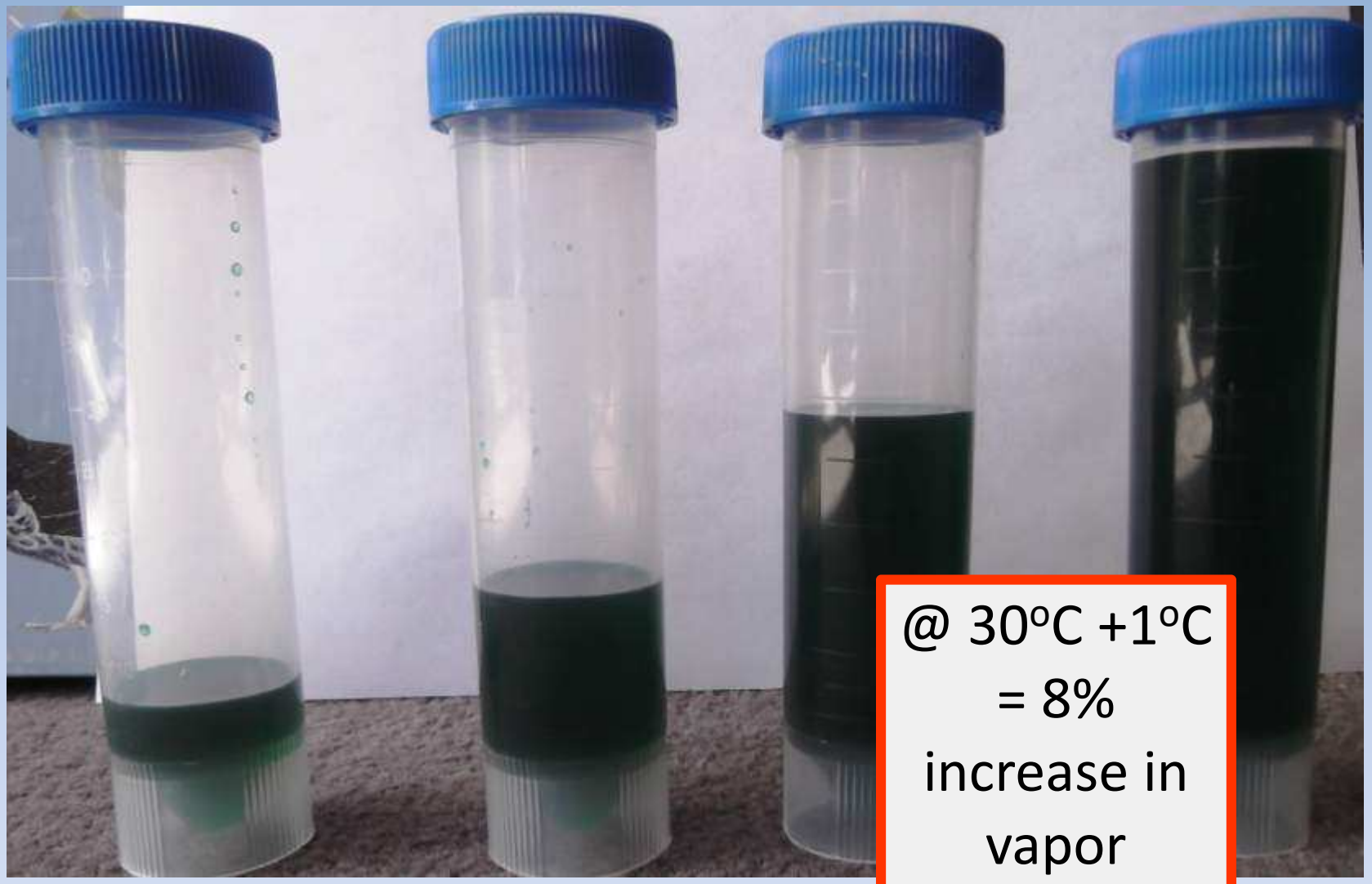
Table 1 Specific humidity of a kilogram of air (at average sea level pressure)

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

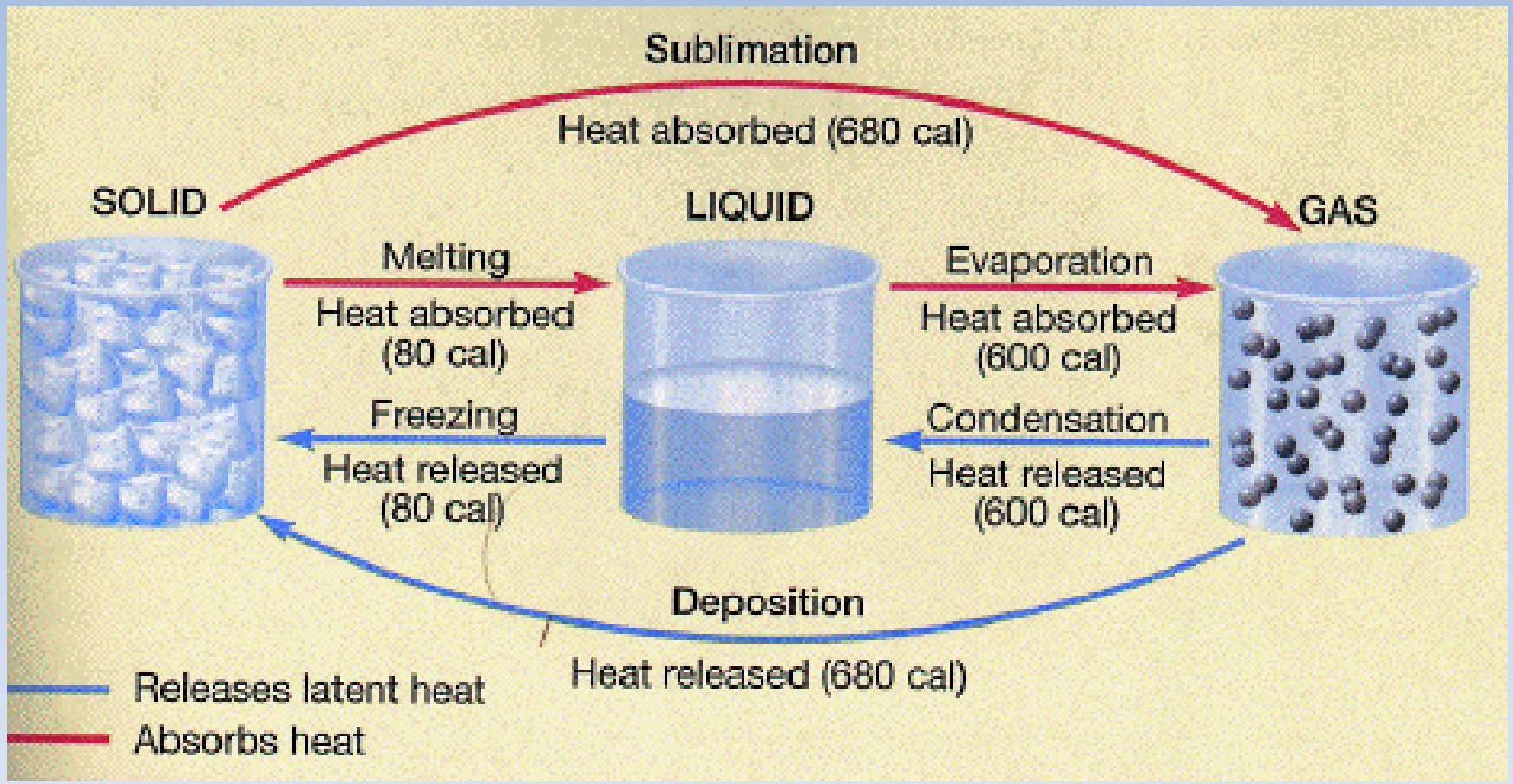
TAKE AWAY:

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

The Energy involved with WATER VAPOR

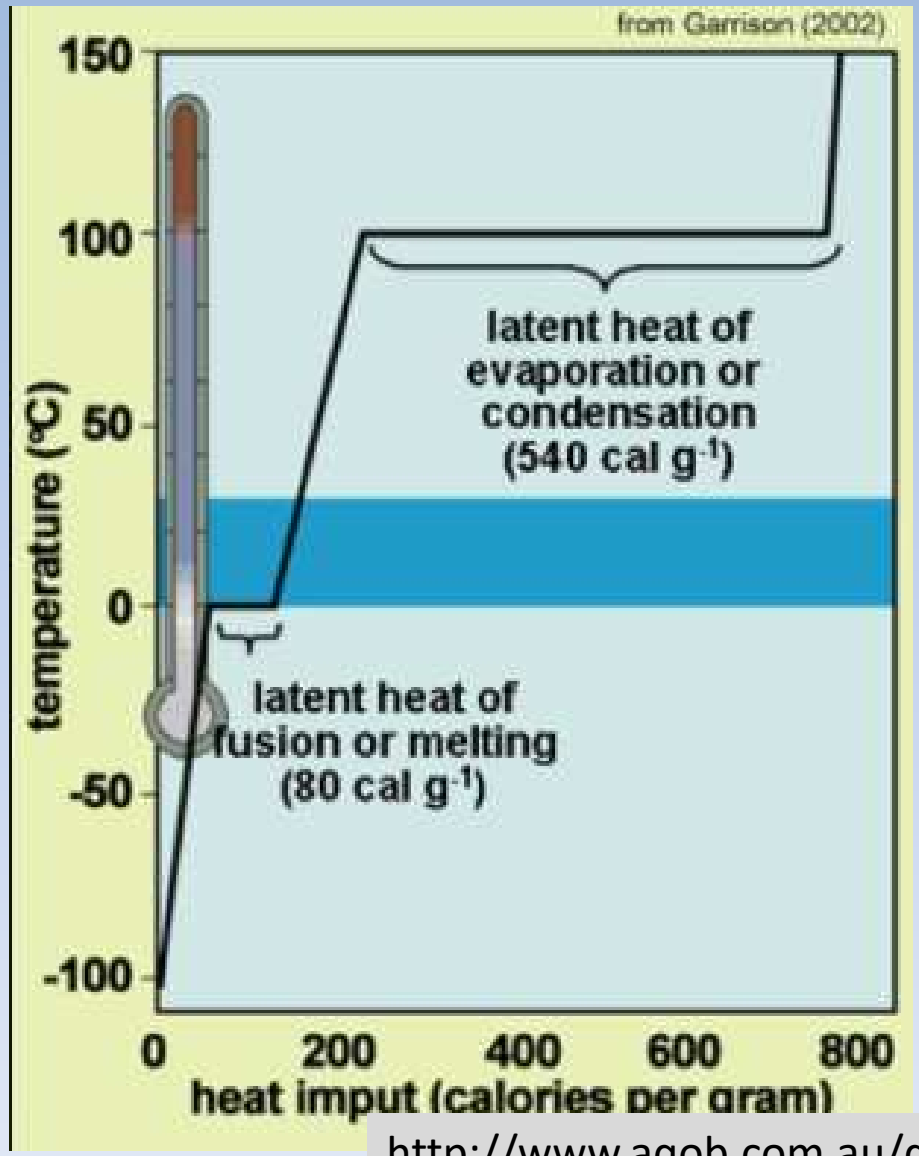
- To melt ice (solid to liquid) = 80 calories / gram
- To heat water 1^{o} C = 1 calorie / gram
- To go from 100^{o} C liquid to 100^{o} C steam/vapor – 540 calories / gram

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:

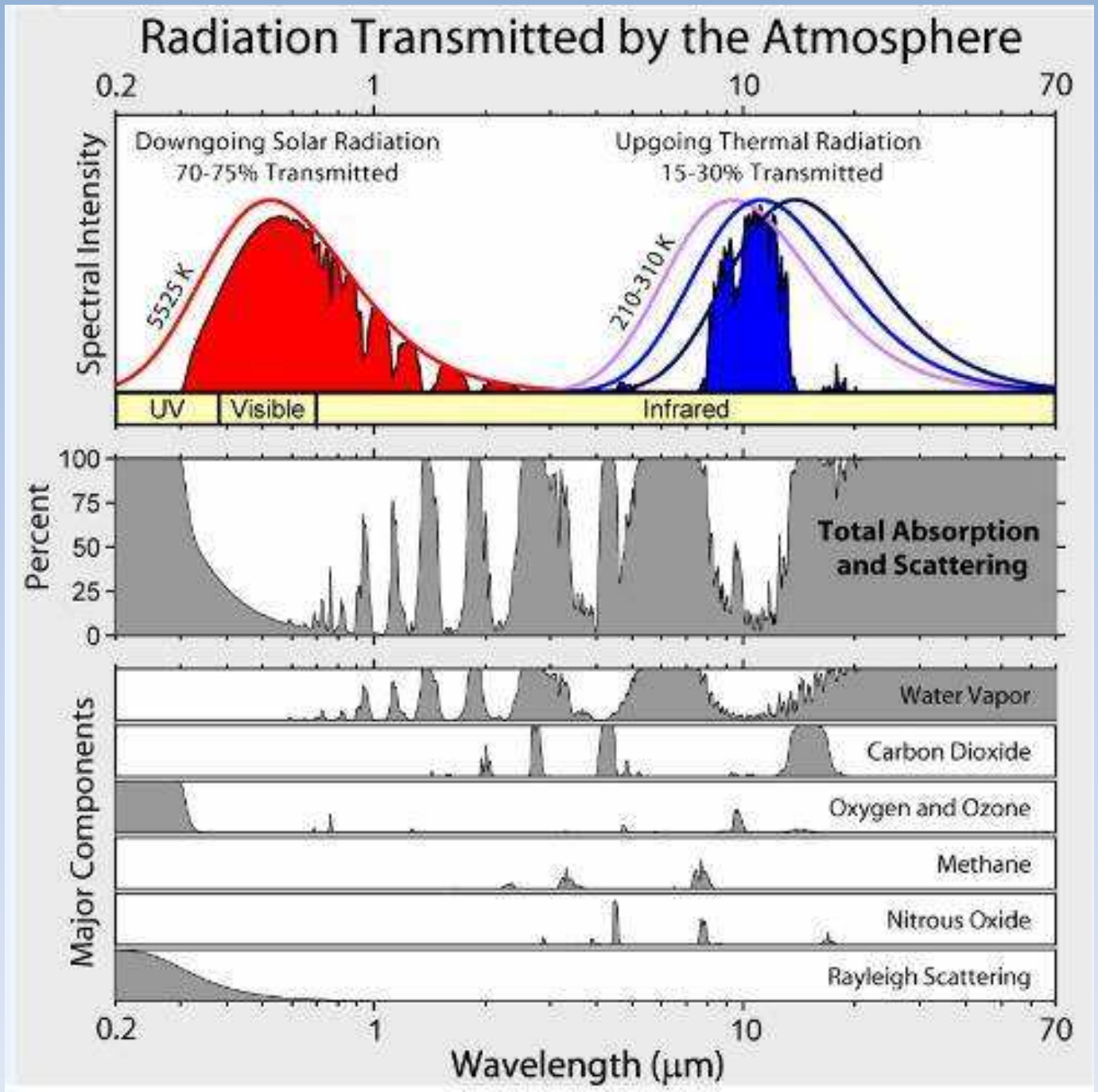
- IF YOU INCREASE THE AVERAGE ATMOSPHERIC TEMPERATURE YOU INCREASE THE AMOUNT OF WATER VAPOR IT HOLDS
- IF YOU DO THAT YOU INCREASE THE AMOUNT OF ENERGY IN THE ATMOSPHERE

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 WE HAVE EITHER:

- COOLING or
- WARMING

How GHGs Blanket the Earth

- **Blanket Earth:**
- http://climate.nasa.gov/causes/
- https://www.youtube.com/watch?v=aqkGoCglp_U&feature=youtu.be
- https://www.youtube.com/watch?v=we8VXwa83FQ

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

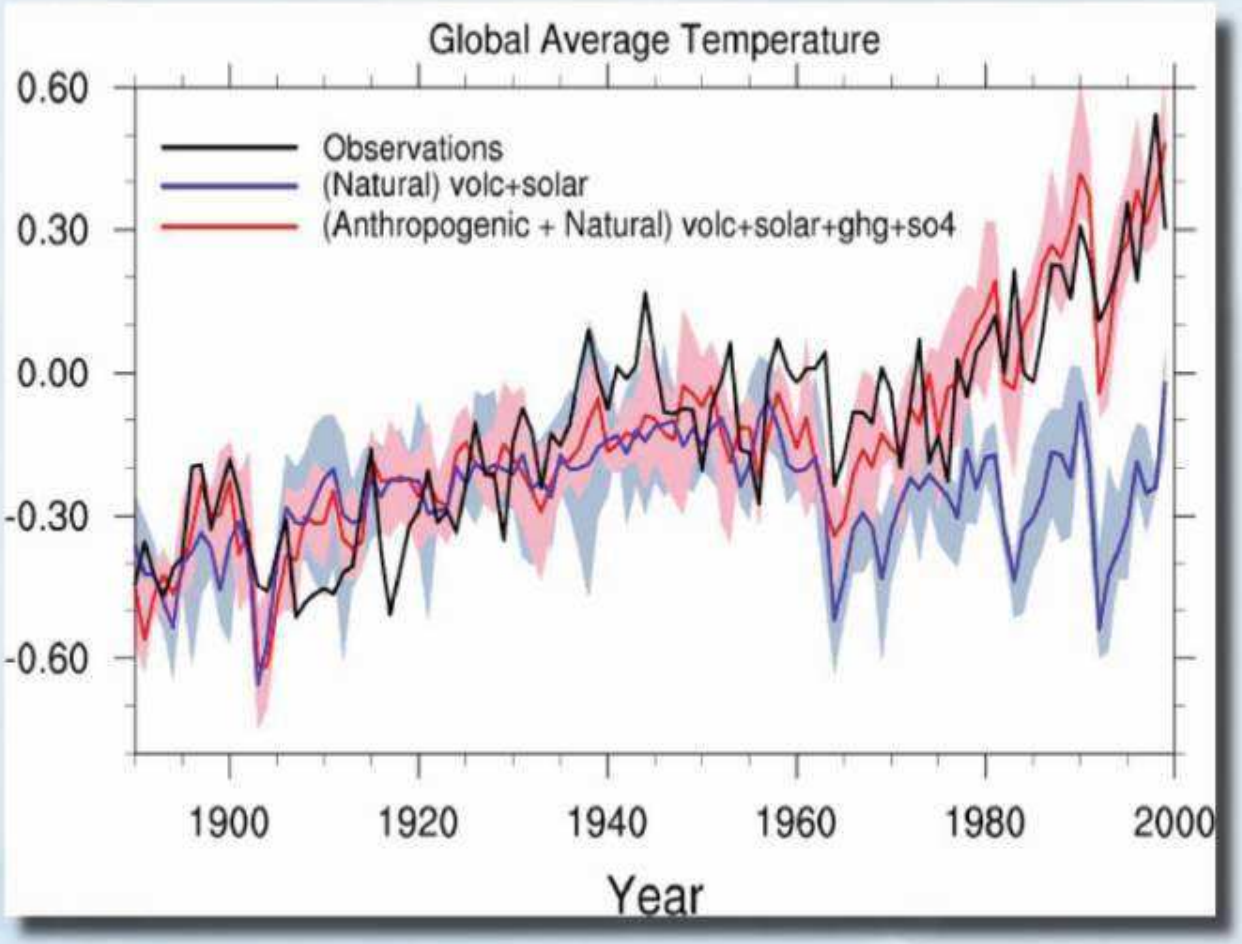
As a result it is concentrated in the lower atmosphere of the tropics

RESULTS:

- Greater warming at High Latitudes
- Reduction Arctic sea ice
- Melting glaciers
- Rising sea levels
- Average temperature increases
- Earlier springs / earlier snow melt
- Ocean acidification

Simulations of the 20th century: Time

NCAR

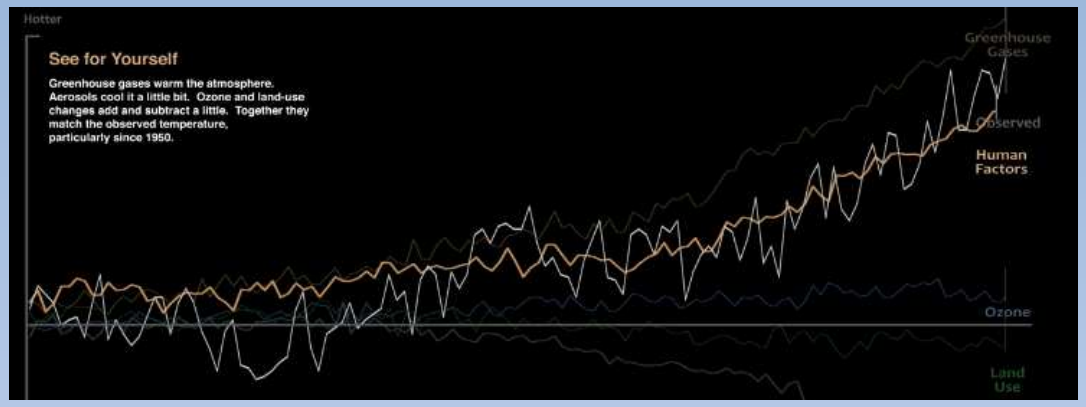


All forcings

Natural only

Meehl et al. 2004

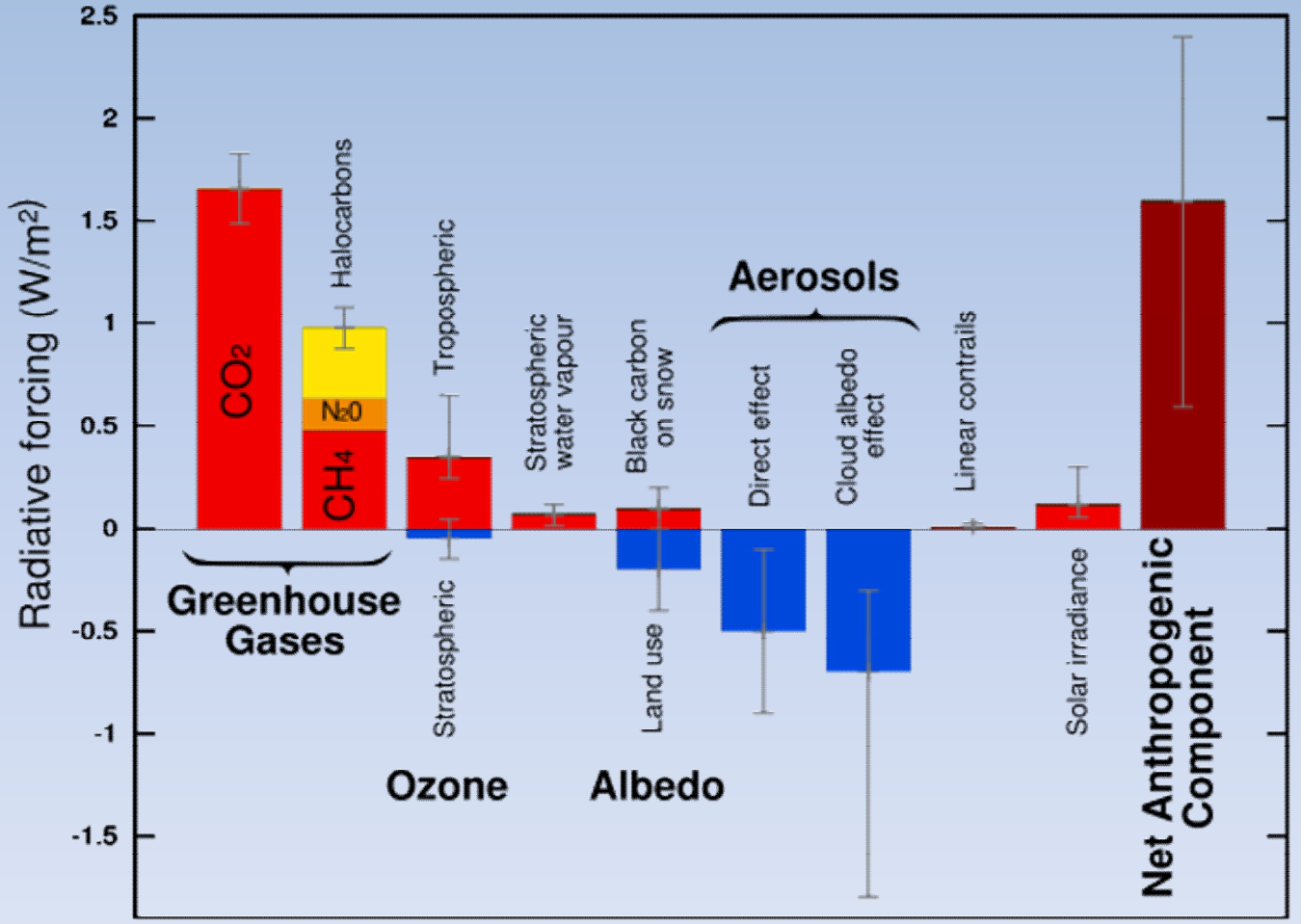
How global warming stacks up



- 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

Radiative Forcing Components

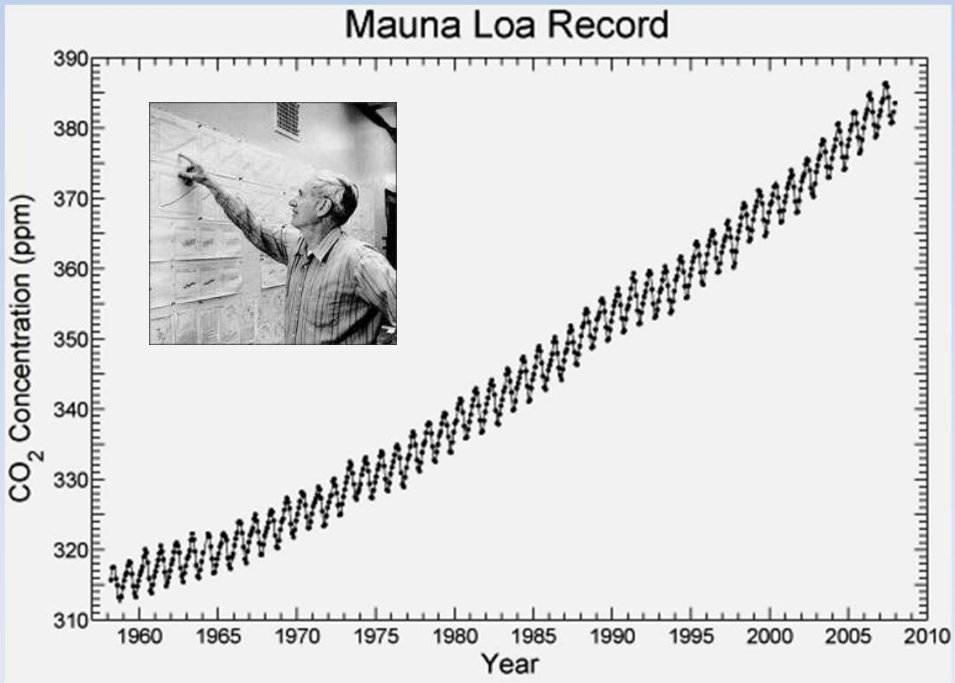


Incoming Solar irradiance: 342 W/m^2

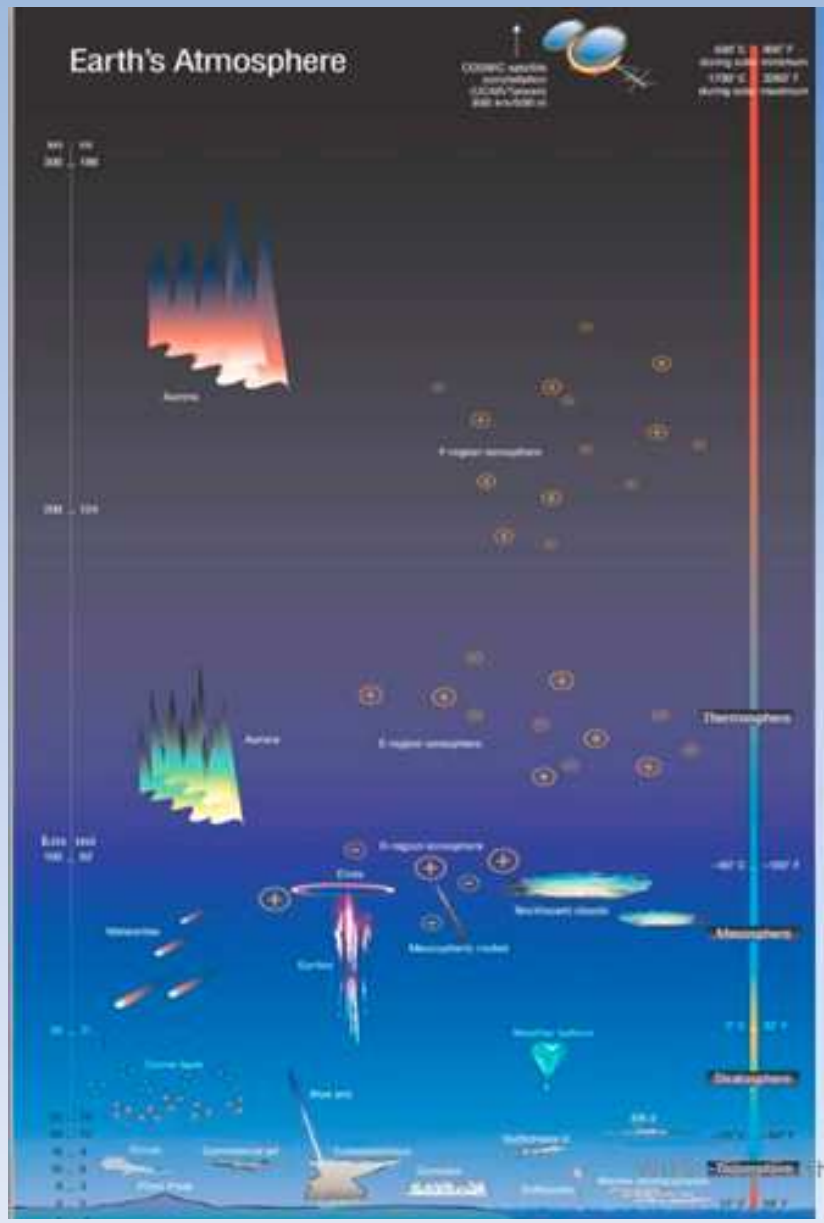
IPCC, 2007

3: EMISSIONS FROM HUMAN ACTIVITIES LARGELY TO BLAME

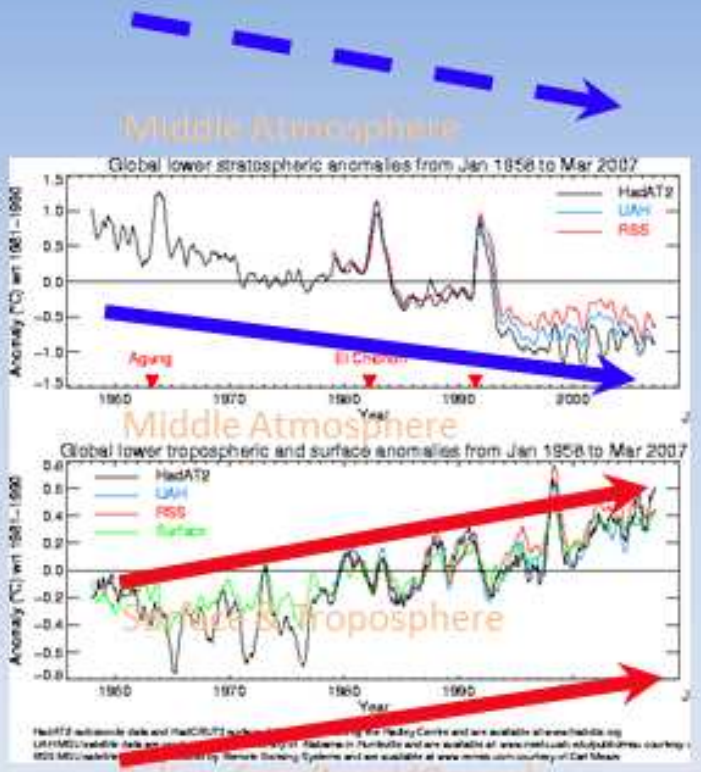
- 40% increase in CO_2
- Dead carbon altering atmospheric C^{14}
- That Carbon is more negative/enriched in C^{12}

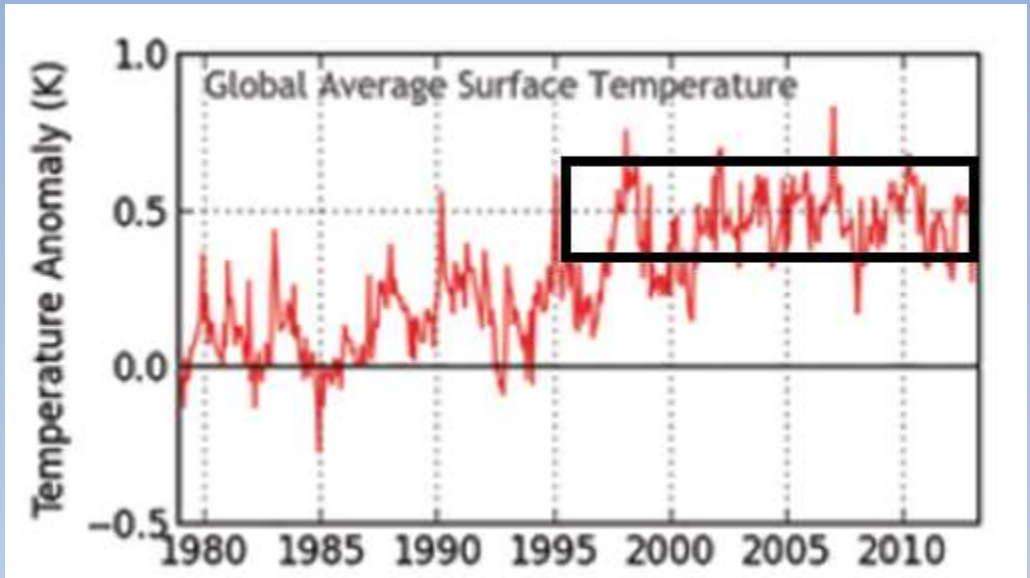


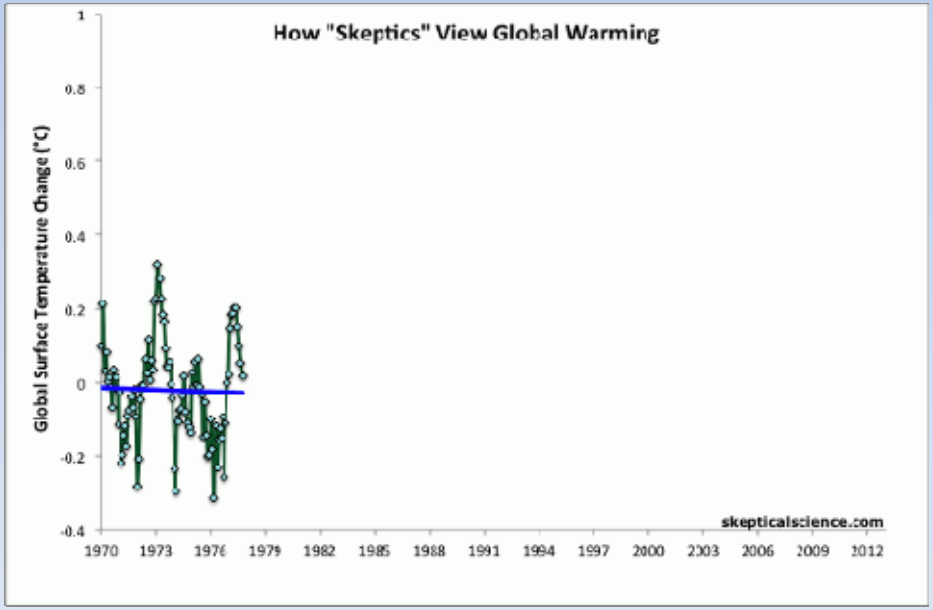
5: SURFACE TO STRATOSPHERE CHANGES

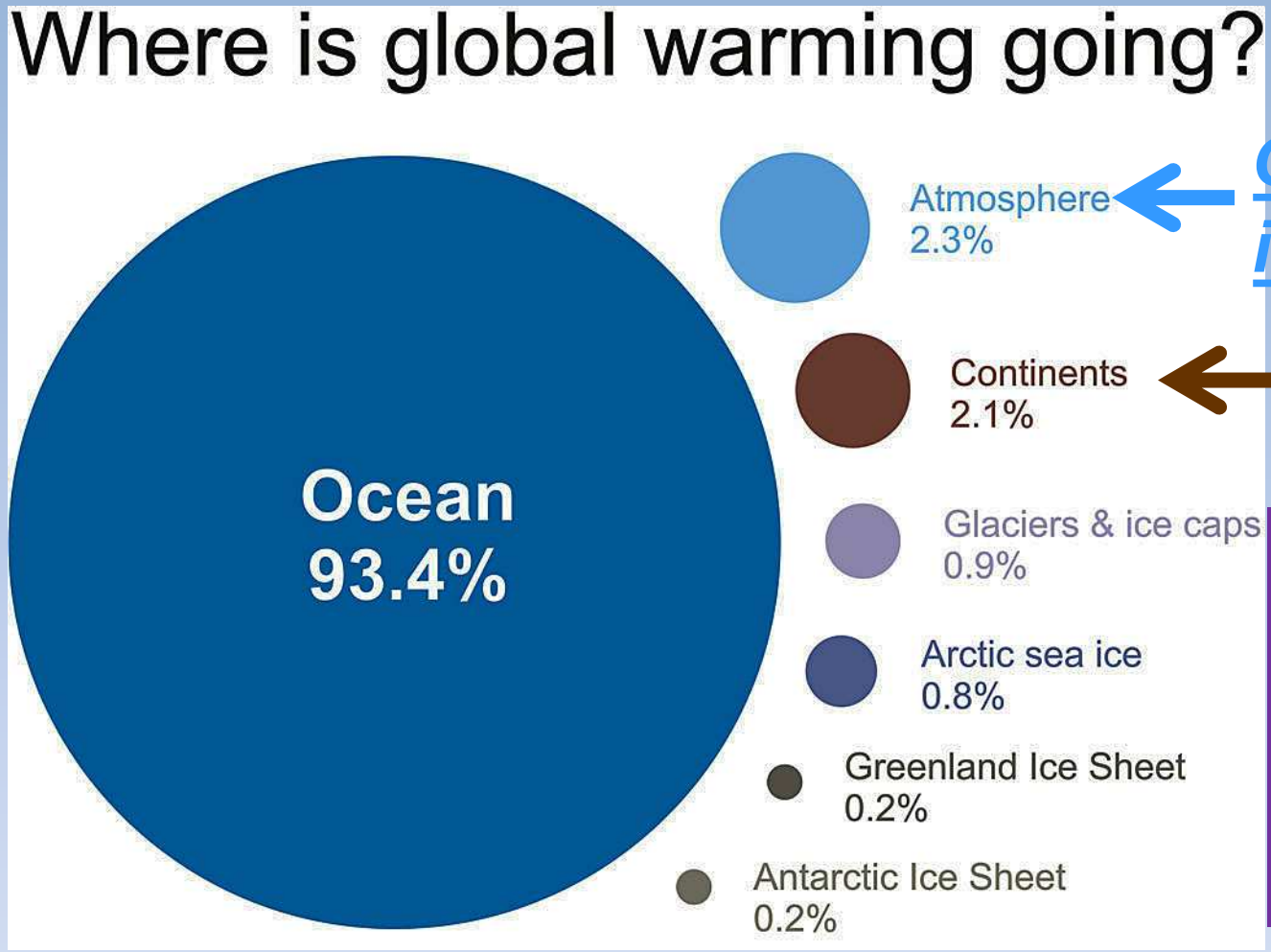


Greenhouse Fingerprint




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



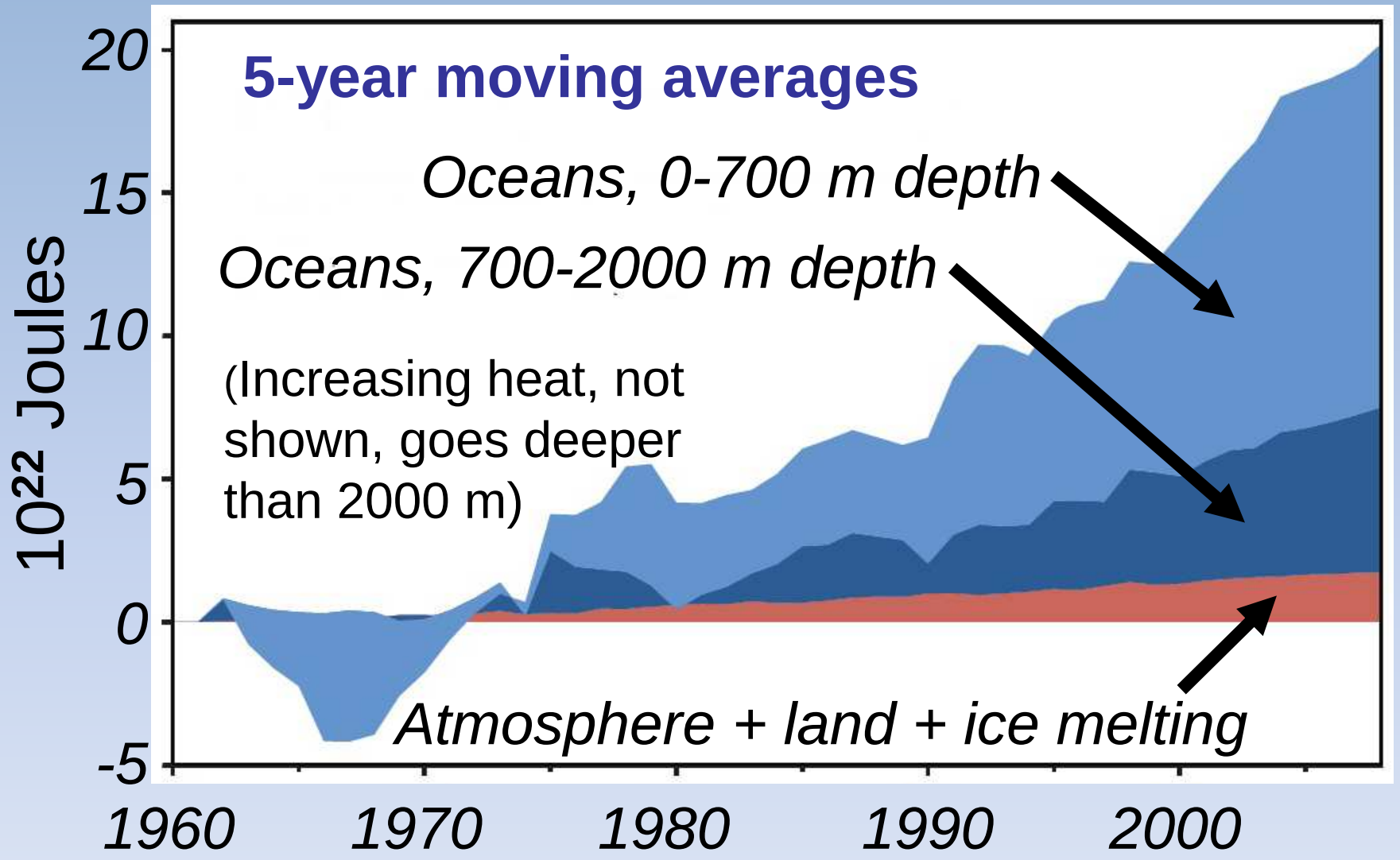
Only ~2% stays in atmosphere

~2% warms the land

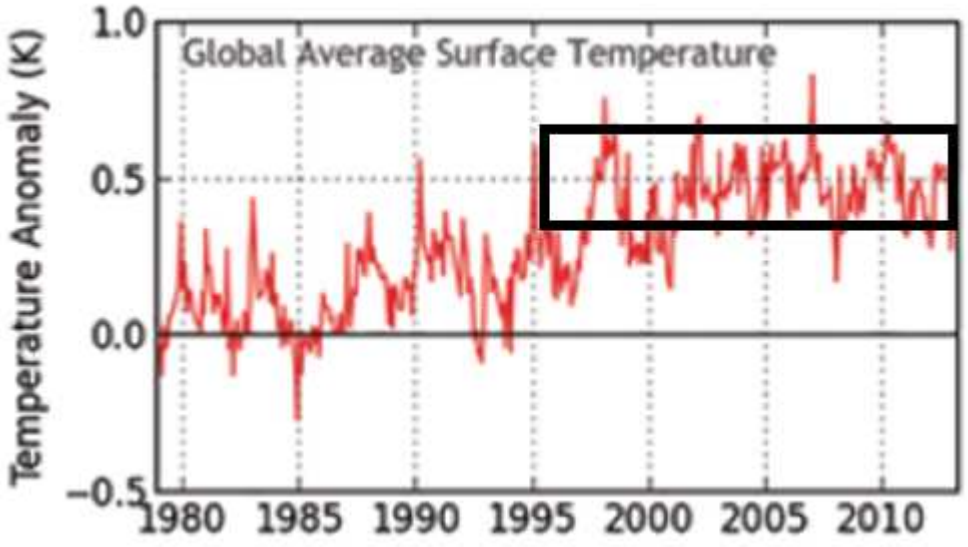
Melting ice absorbs ~2%

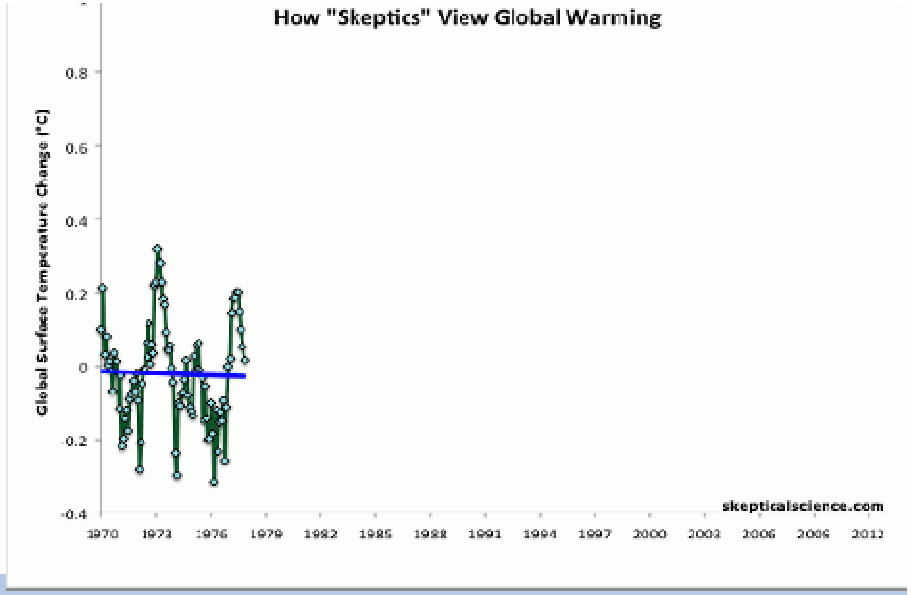
John Cook, from IGPP 2007 data; ~93% to oceans continues (NOAA/NODC, 2012)

Change in heat content, 1958-2011

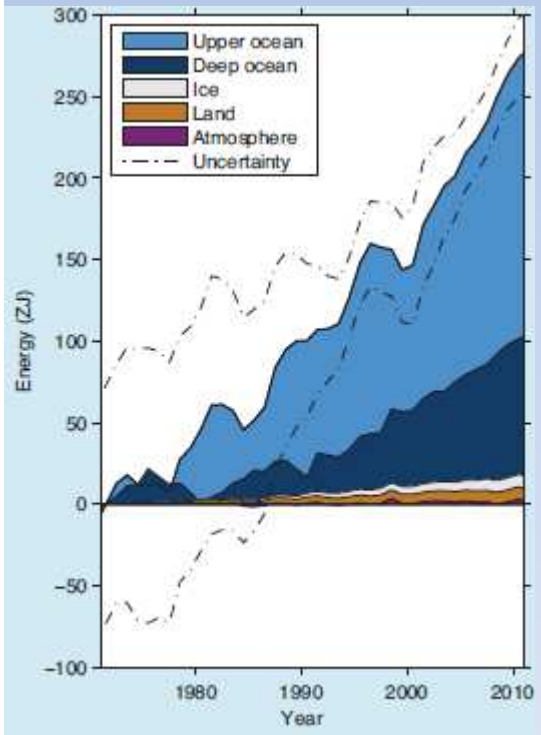


(NOAA 2012 data, Nuccitelli et al. 2012 plot)

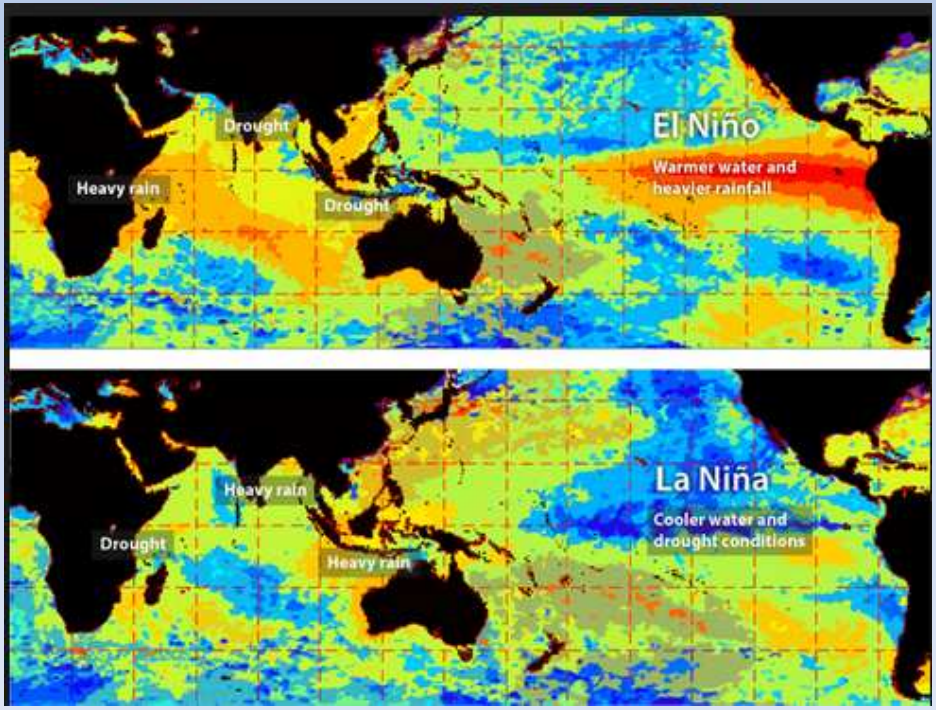




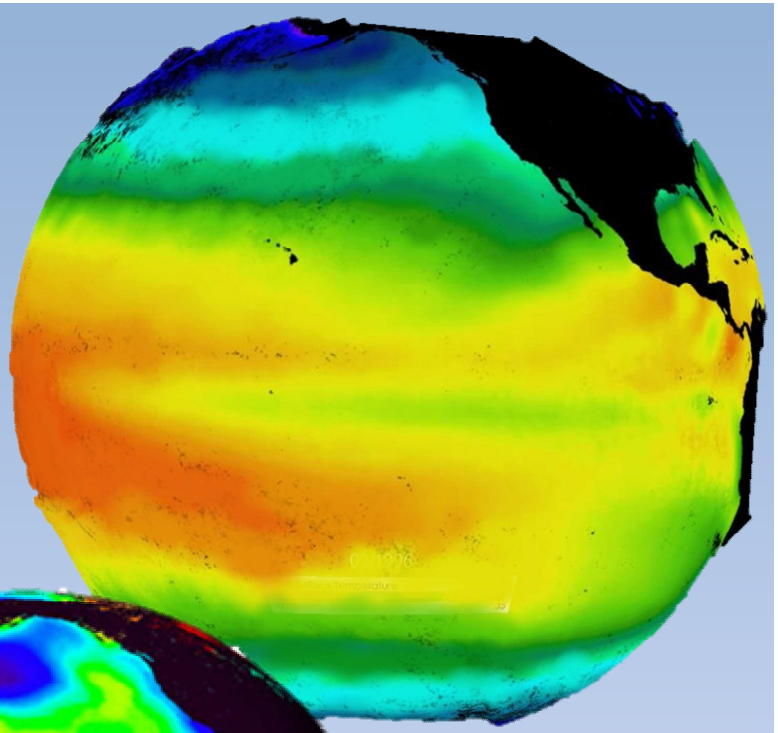
http://www.skepticalscience.com/graphics.php?g=47



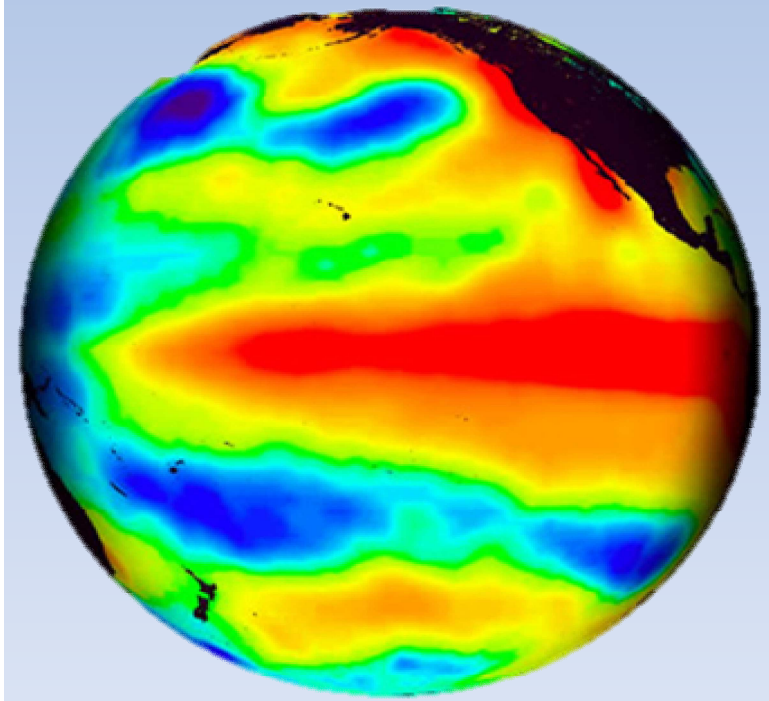
Box 3.1, Figure 1 | Plot of energy accumulation in ZJ (1 ZJ = 10^{21} J) withi



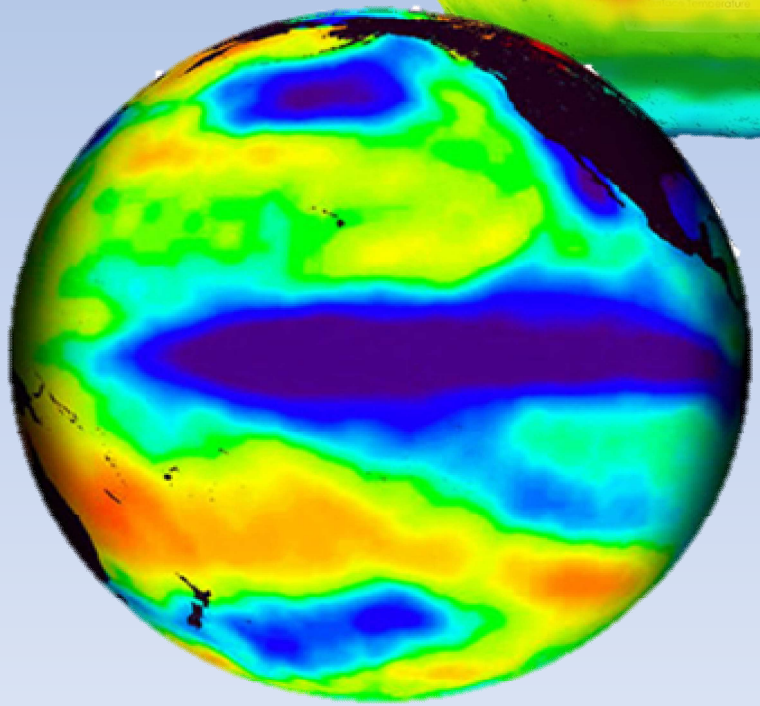
The Pacific –
‘normal condition’



El Niño



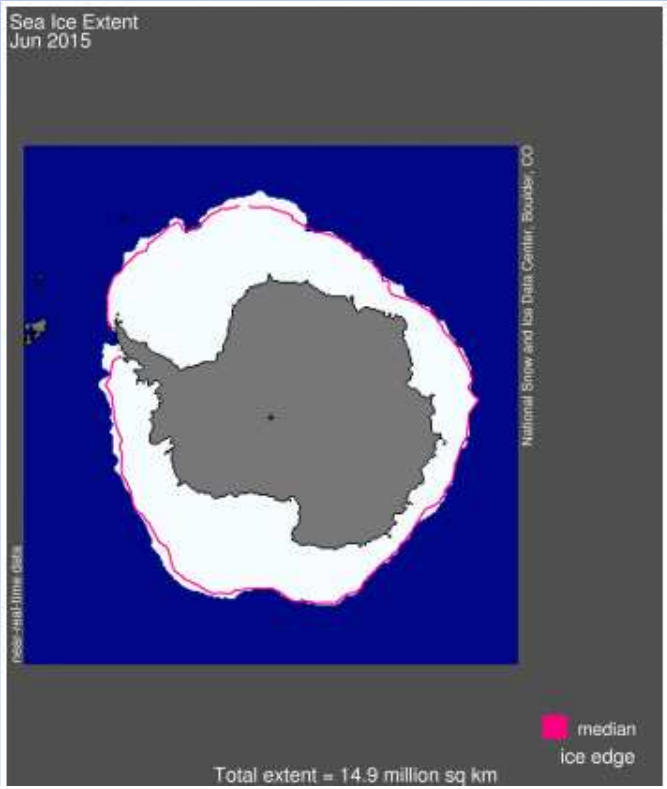
La Niña

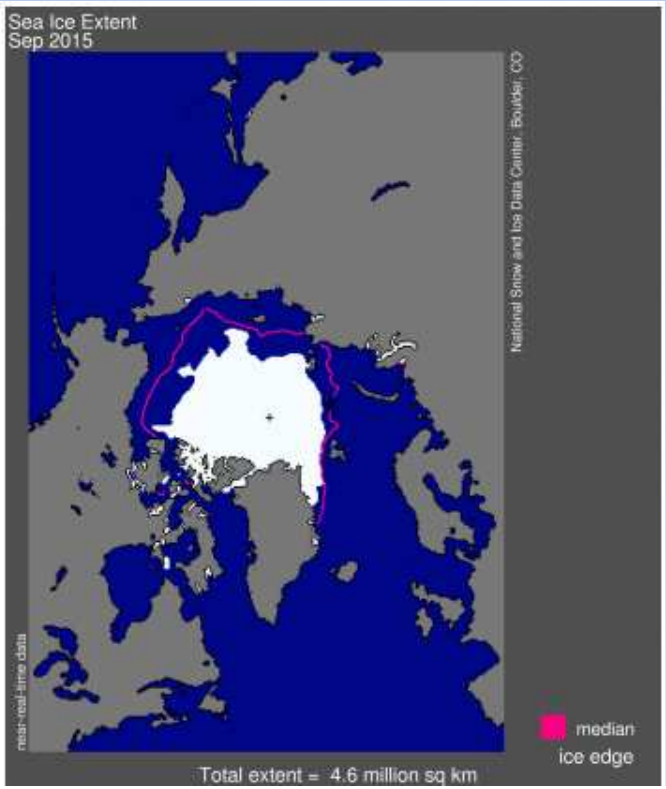


Temperature
Anomaly °C

12. ARCTIC ICE vs. ANTARCTIC SEA ICE

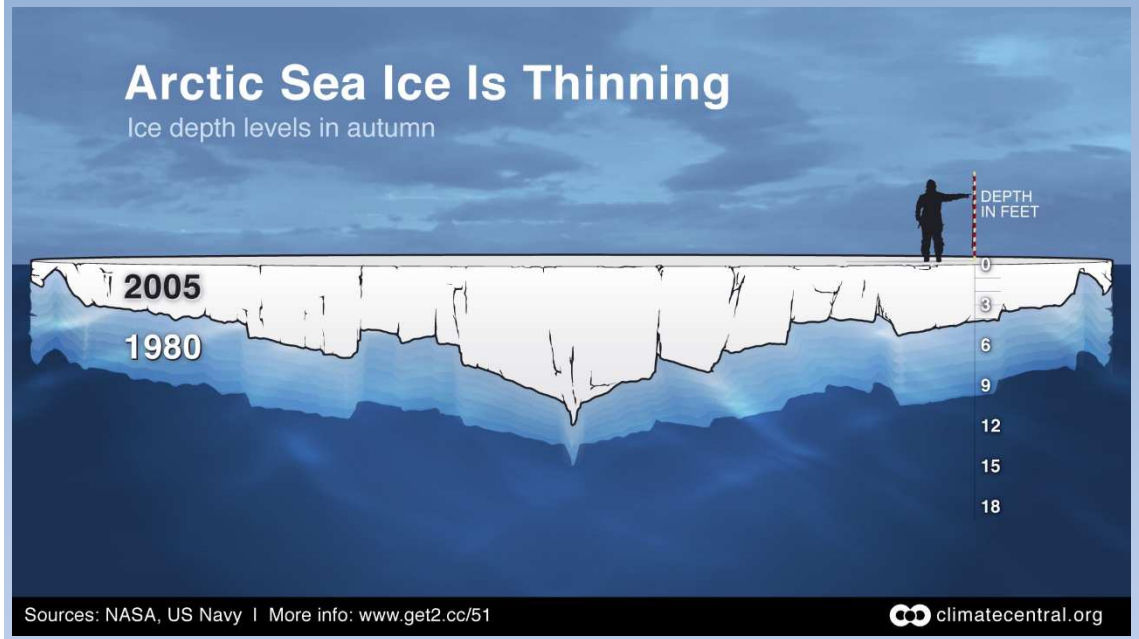
- Ans. More moisture in air around Antarctica (AA) to nucleate sea ice
- Despite > AA is does not compensate for Arctic loss

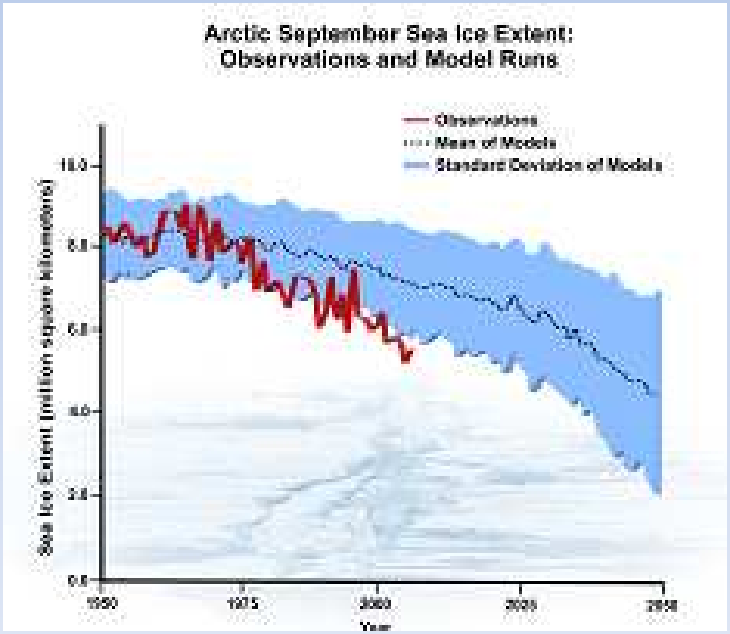


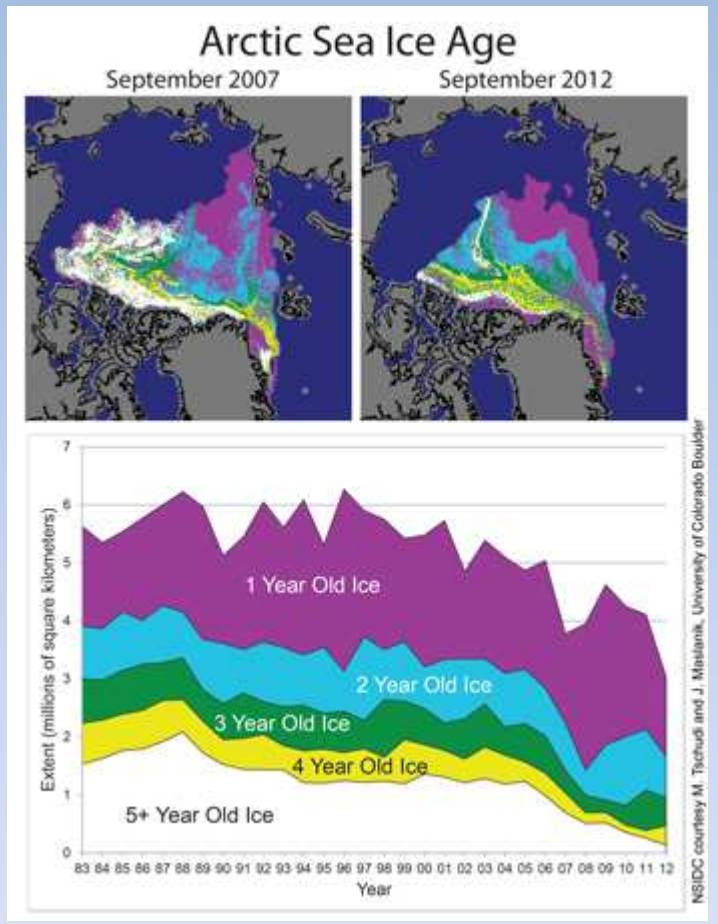


2015

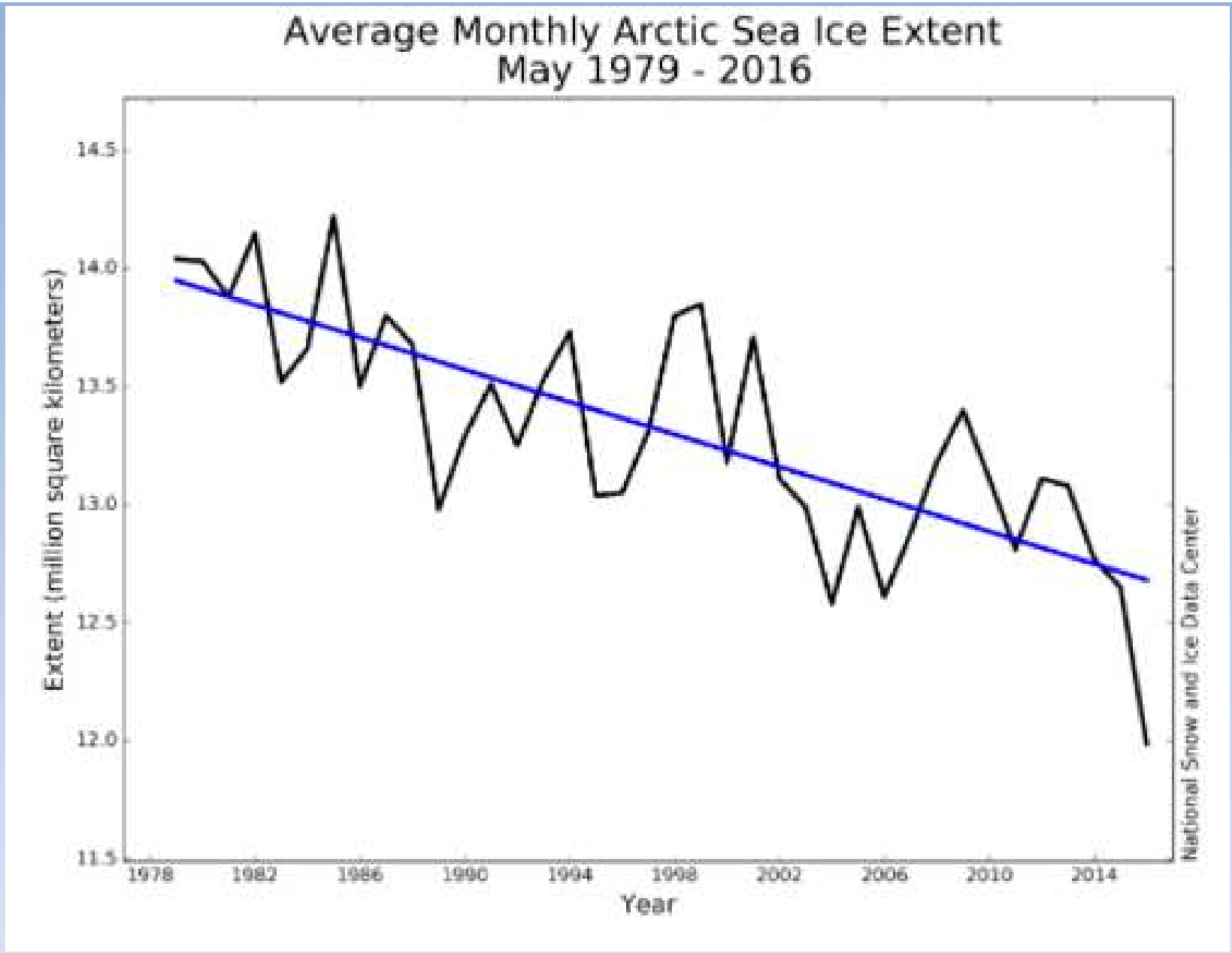
http://nsidc.org/arcticseaicenews/2015/





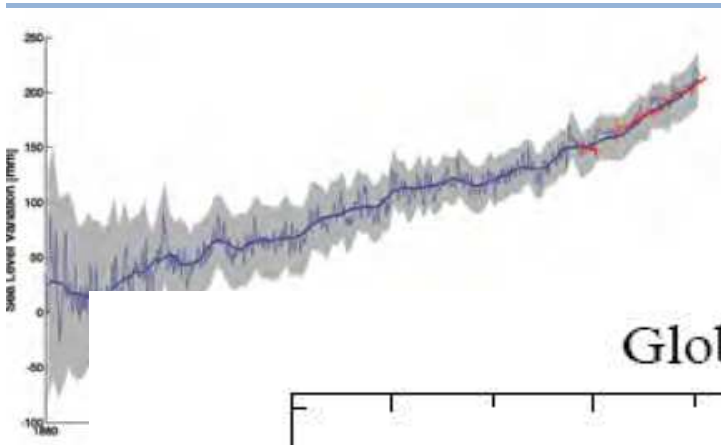


http://nsidc.org/arcticseaicenews/2015/

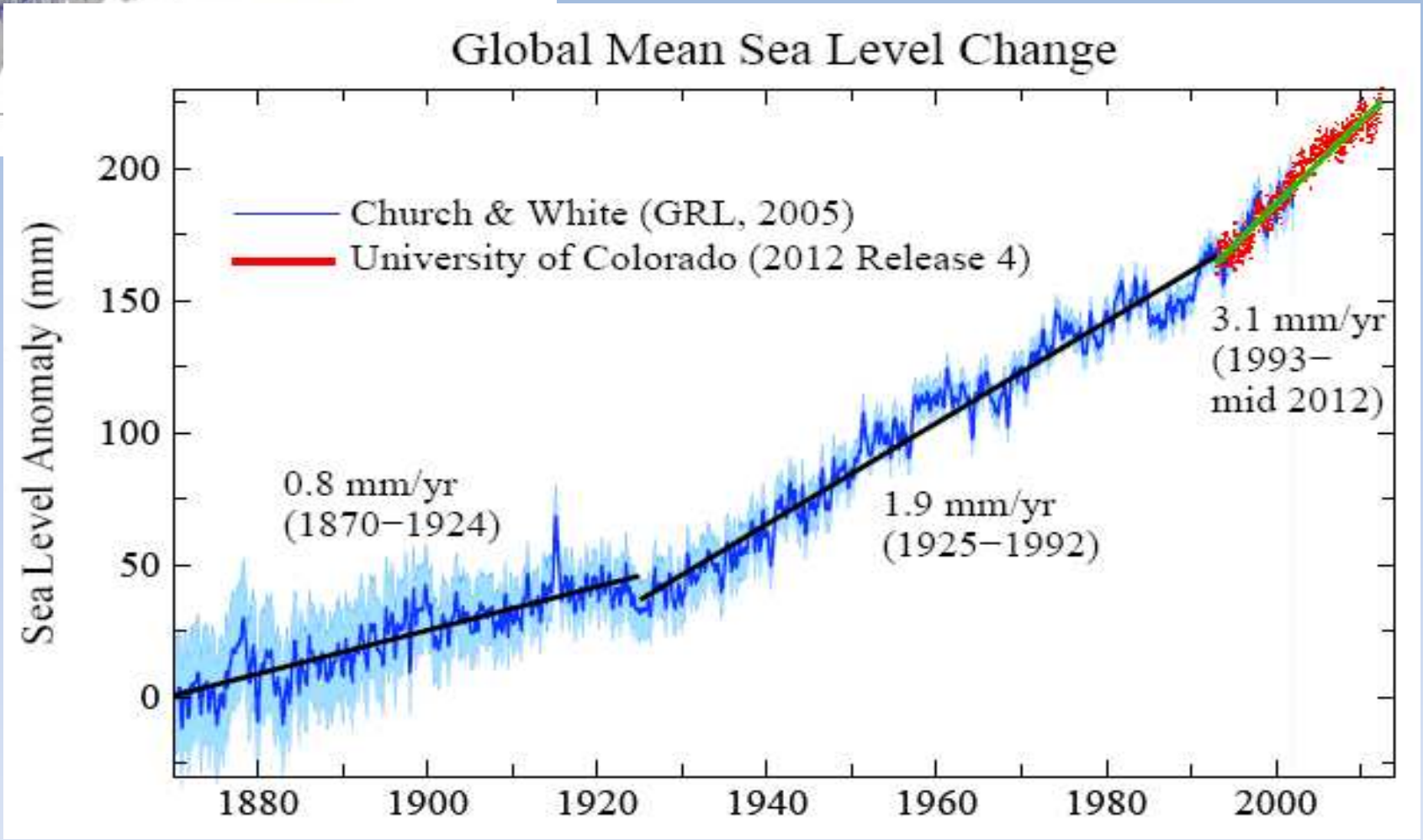


For more see: http://www.skepticalscience.com/melting-ice-global-warming.htm

http://nsidc.org/arcticseaicenews/2016/06/



14: HOW FAST IS SEA LEVEL RISING?

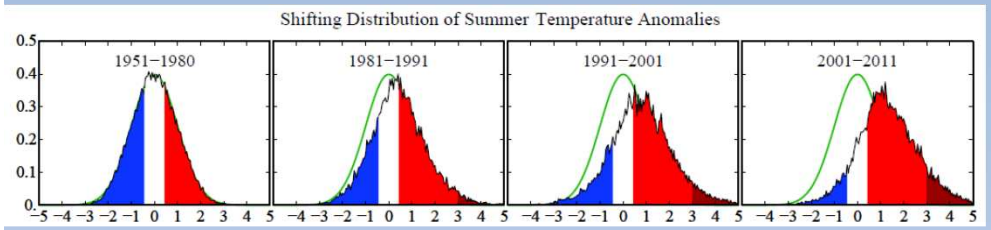


Blue: Sea level change from tide-gauge data *(Church J.A. and White N.J., Geophys. Res. Lett. 2006; 33: L01602)*
Red: Univ. Colorado sea level analyses in satellite era *(http://www.columbia.edu/~mhs119/SeaLevel/)*.

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