BetterBuiltNW

A Sea Change

By Sandy (George) Lawrence

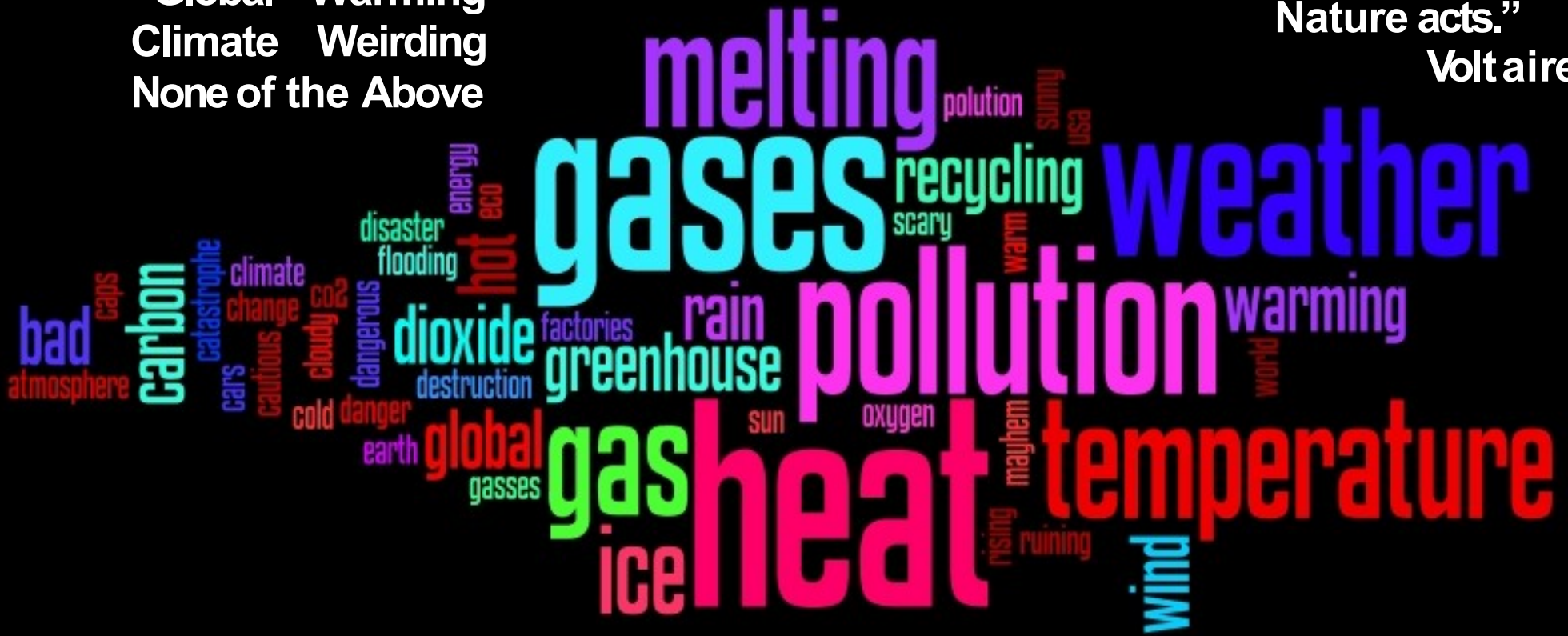
Home Efficiency Forum

October 11, 2018

Climate Change

Global Warming
Climate Weirding
None of the Above

"Men argue.
Nature acts."
Voltaire



Acidification
Albedo
Arctic Death Spiral
Blackbody
Bombardment
CO_2
Cyanobacteria
Decarbonization
Deforestation
Deluge
Desertification
Drought
★ Eemian Epoch
Electrification
Extinctions
★ Holocene Epoch
Hothouse World
Icehouse World
Interglacial
Orbital forcing
Overpopulation
Oxidation Event
Melting ice
Methane ice
★ Milankovitch
Mitigation
Nitrous Oxide
Plankton
Radiative forcing
Sea level rise
Stratosphere

Gobsmacked by Climate Change

Ferryland, Newfoundland, population 465

Iceberg Alley season bumper crop 2017

- **> 600** bergs drifted North Atlantic shipping lanes
- usual April accumulation only 80

Iceberg death throes 15,000 yrs in making

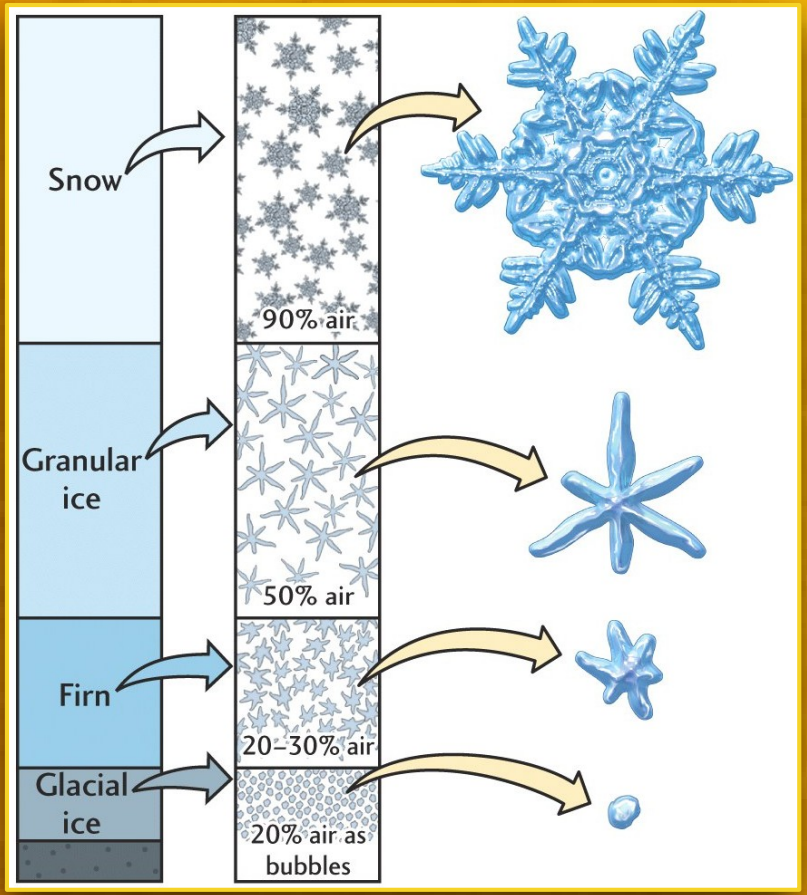
- began Greenland snow last glacial period
- glacial calving last 3 yrs into Baffin Bay
- eventually caught southbound Labrador Current

International Ice Patrol US Coast Guard operated

Nuisance local fishing industry

Brash Ice

Not like Refrigerator Ice



Snow to granular ice to **firn** to glacial ice:

- incorporated ancient air
- *older* than 11,700 y/o geologic Holocene Epoch
- ancient air with pollen, ash, dust
- Antarctic CO_2 ± a few *ppm* to 800ka
- comparable CH_4 accuracy to ~ 10 *ppb*

Energy Systems Analytically

Reversing Fossil Fuel Climate Forcing

Energy **efficiency** + demand response faster, easier, cheaper: 'negawatts' + 'negabarrels' plus smoothing peaking [lighting 7%]

Current solar energy [almost] all sustainable energy types: biofuel, hydropower, wave power, OTEC, **photovoltaic**, concentrating solar, **wind**

Ancient solar energy consists of all fossil fuels: coal, natural gas, conventional oil, bitumen oil, kerogen oil

Nuclear fission possible from ancient type II supernovas producing 90-Th + 92-U + 94-Pu [basis of fuel cycles]

Geothermal energy originates from compressive accretional formation of planet, coupled with extensive suite of radioactive substances decaying over eons

Tidal energy derives at root solely from gravitational interactions of Earth + Moon + Sun

Piezoelectric + thermoelectric generation from materials science

Hydrogen [fuel cells] + electricity secondary forms of energy

Current exclusions:

- fusion power
- captured lightning
- other exotic energy sources

Perpetual motion machines

Efficiency

Solar PV

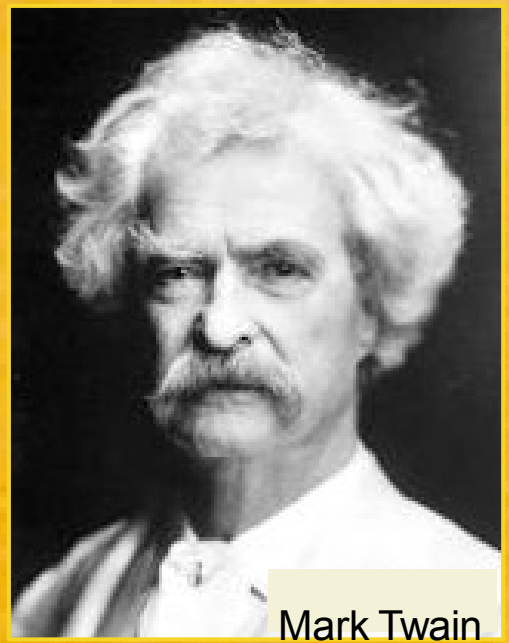
Wind

"There are three kinds of lies: lies, damned lies, and statistics"

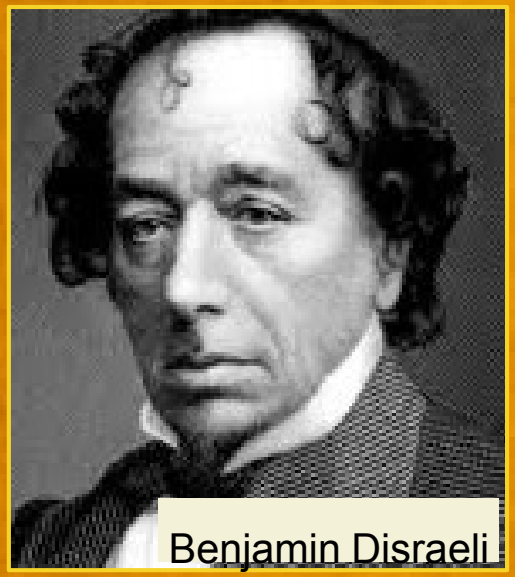
Popularized in America by Mark Twain (among others), who in turn attributed it to 19th Century British Prime Minister Benjamin Disraeli

However phrase not found in any of Disraeli's works + earliest known appearances years after his death

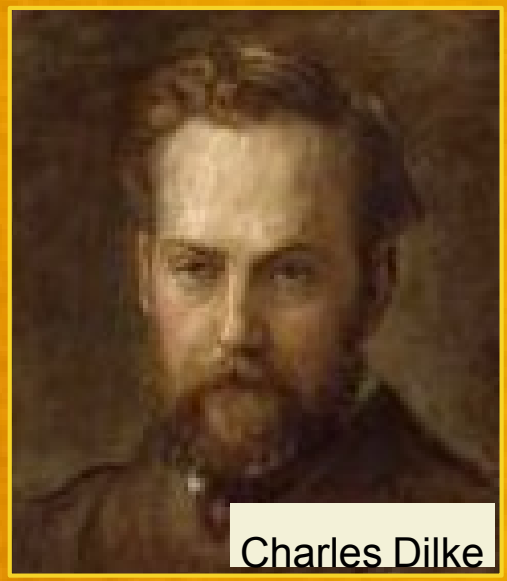
Other coiners proposed - most plausible with current evidence, Englishman Charles Wentworth Dilke (1843–1911)



Mark Twain



Benjamin Disraeli



Charles Dilke

"Just because something isn't a lie does not mean that it isn't deceptive A liar knows that he is a liar, but one who speaks mere portions of truth in order to deceive is a craftsman of destruction"

Criss Jami

"There are three kinds of lies: lies, damned lies, and statistics" and graphs

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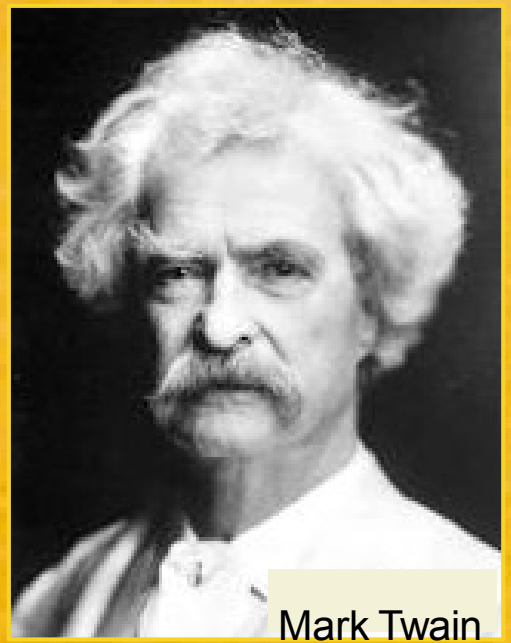

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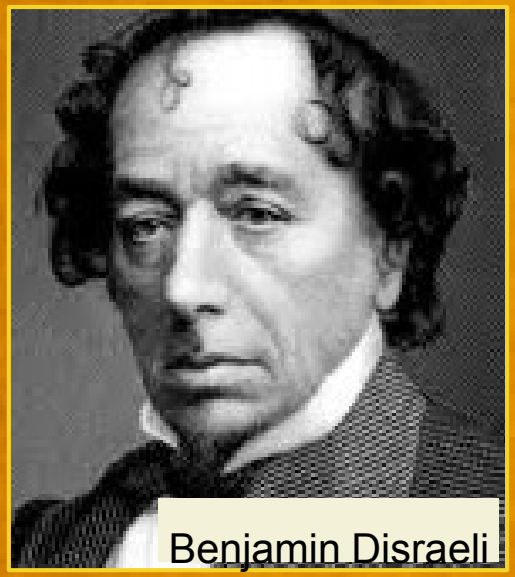

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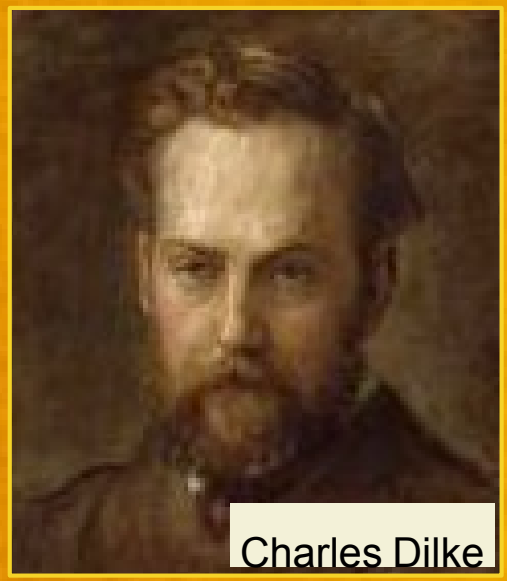


Charles Dilke

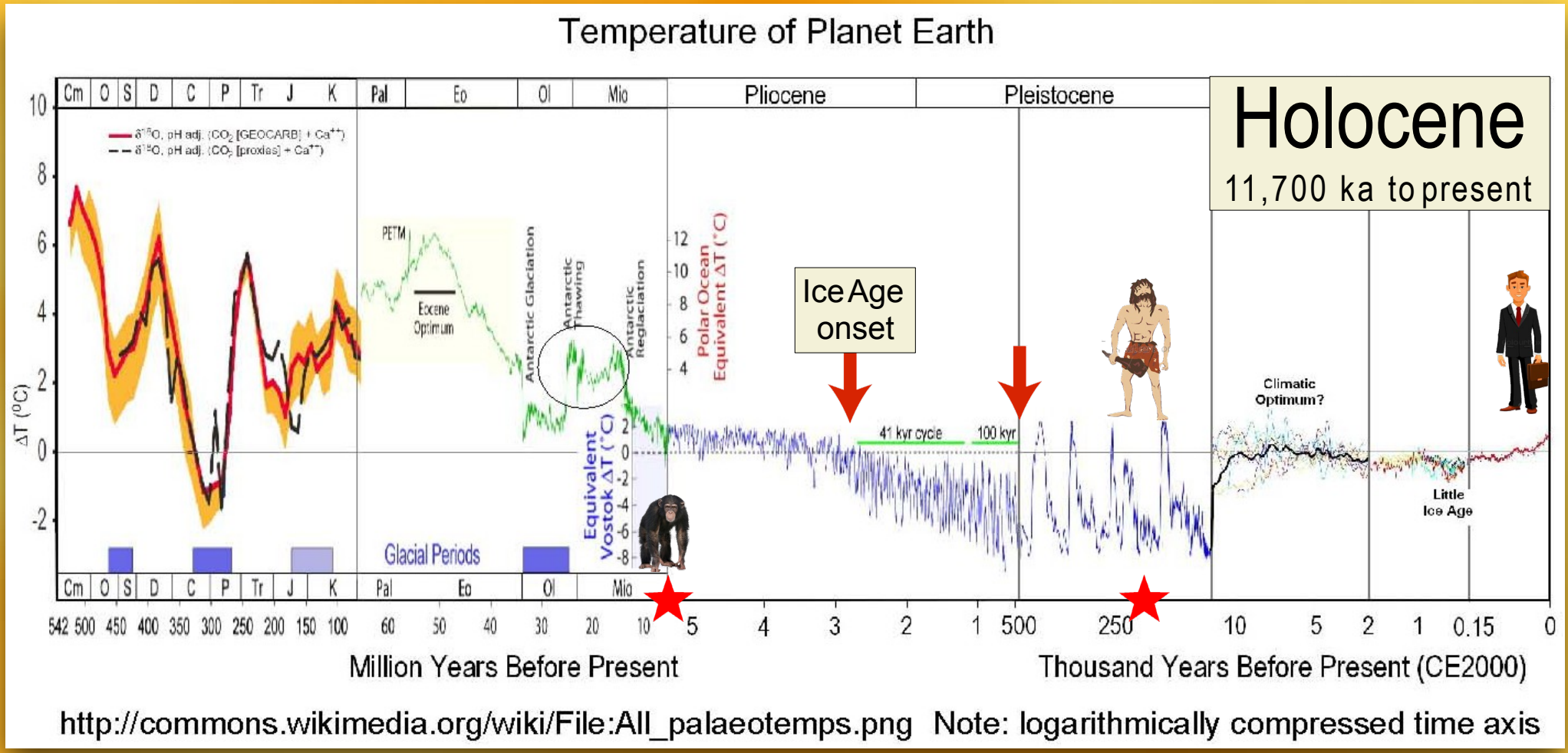
But these are not lies:

- Earth colder now than majority prehistory
- Earth mostly ice-free since 4.6 Ga
- Earth now only one modern history knows

Oceans warming, expansion, rising inflows, acidification, deoxygenation, plastification, overfishing, bleaching coral

Variations in Earth Climate

Control Knobs of GHG+ Orbital Variations



http://commons.wikimedia.org/wiki/File:All_palaeotemps.png Note: logarithmically compressed time axis

James Hansen + GHGs

Well Established Science since 1800s

1981 Hansen + NASA scientists seminal article in *Science*, "Climate Impact of Increasing Atmospheric Carbon Dioxide"

- **1988** first brought to broad public attention
- testimony before congressional committee

Hansen + 11 prominent climate scientists now warn:

- global mean temperature 2016 ~1.1ºC = 1.7ºF warmer
- baseline pre-industrial times defined **1880-1920**
- heat-trapping **carbon dioxide**, **methane**, **nitrous oxide**

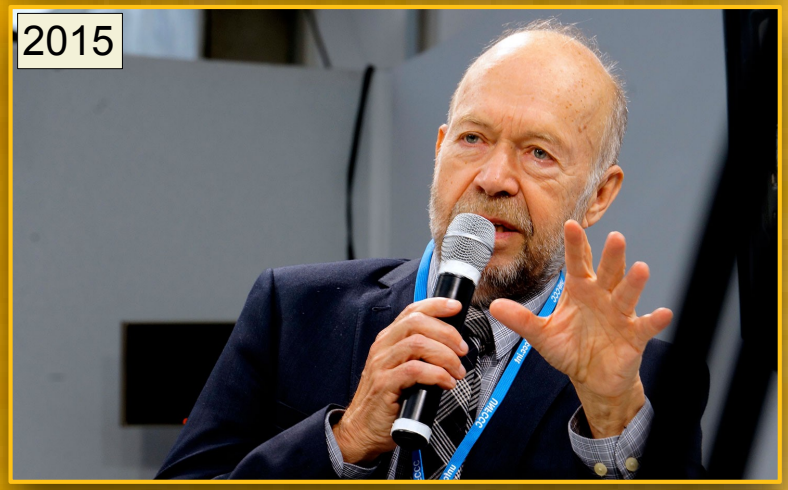
Planet's 3 most dangerous GHG rising:

- fossil fuels must be taxed
- "dubious" proposition carbon capture + sequestration or CCS
- price tag hundreds trillions

Already FF burning unnaturally propelled Earth to temperature range last seen 130,000-115,000 yrs ago, when "sea level was six to nine meters (20-30 ft) higher than today"

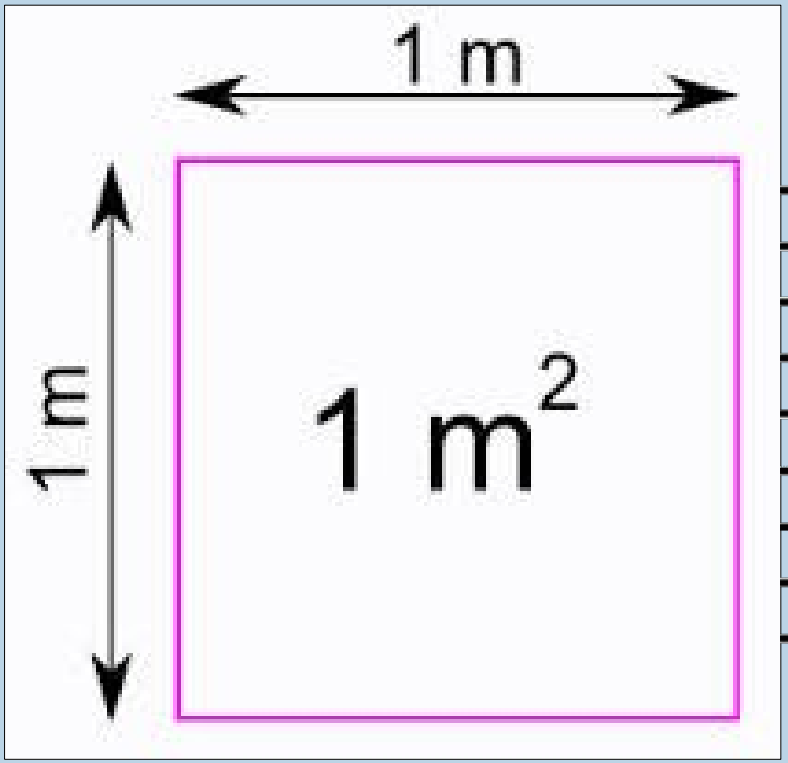
1826 Fourier temperature discrepancy
1859 Tyndall proposed trace atmospheric gases

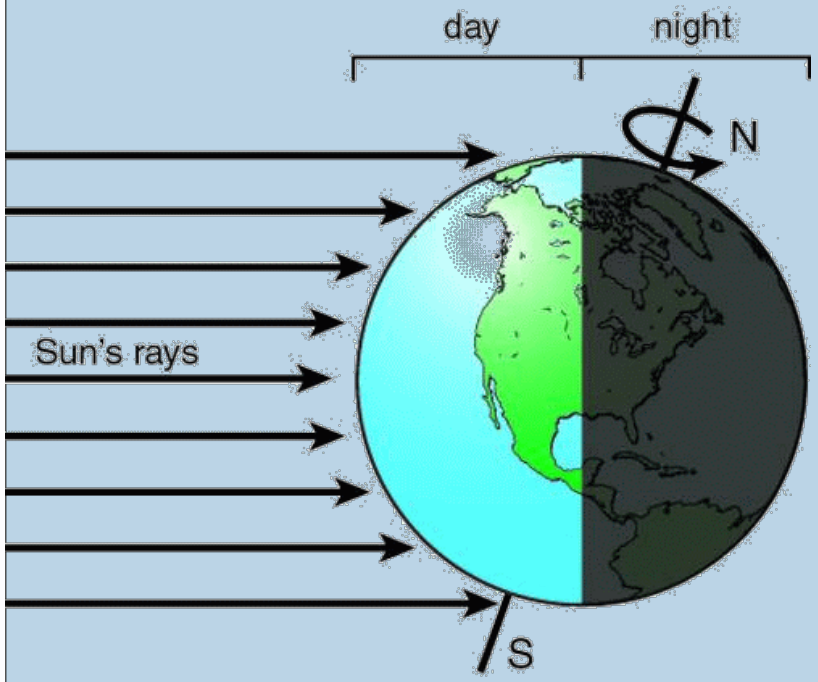
*Svante Arrhenius proved in laboratory experiment that CO_2 trapped heat on Earth…in **1896***



How Big is a Square Meter?

And how big is the Top of Atmosphere or TOA?





1 meter = 39.37”
1 m² = 1.55 square yards

---

526 T m² at TOA sphere
510 T m² for Earth’s surface
128 T m² facing sun *constantly*

---

1 trillion = 12 zeroes

TOA considered 100 km above surface

Big number = 526 T m² [apple skin]

- but consider *area* facing sun
- conceptually slice an orange
- calculates to **~ 128 T m²**

Trap average additional **2.29 W** solar energy by each m² of *apple skin*

Really, first slice the orange

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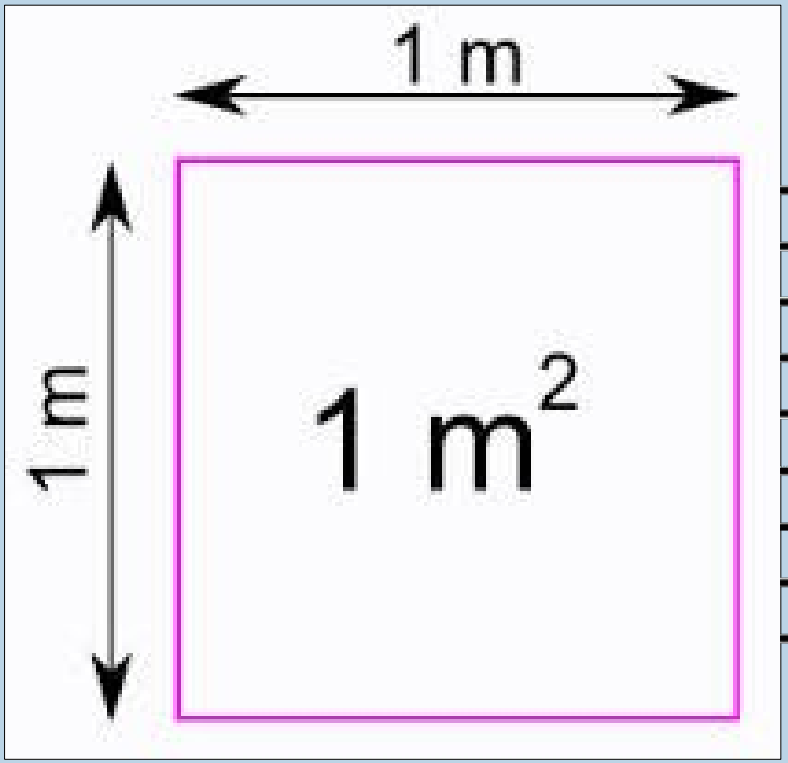

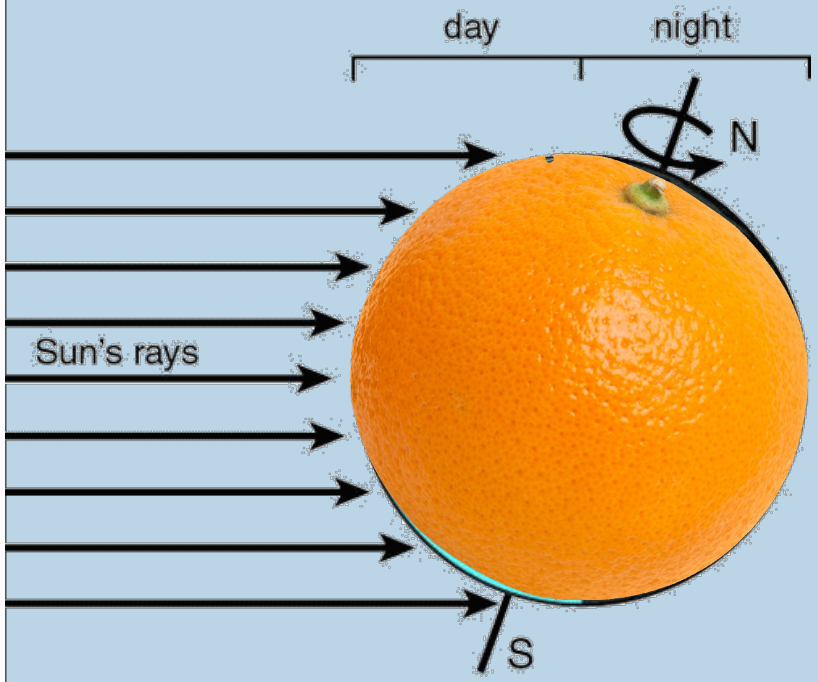

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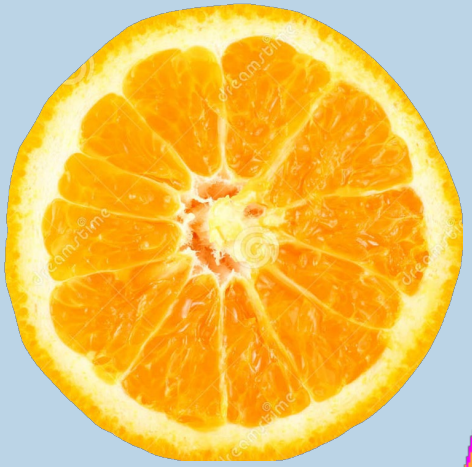
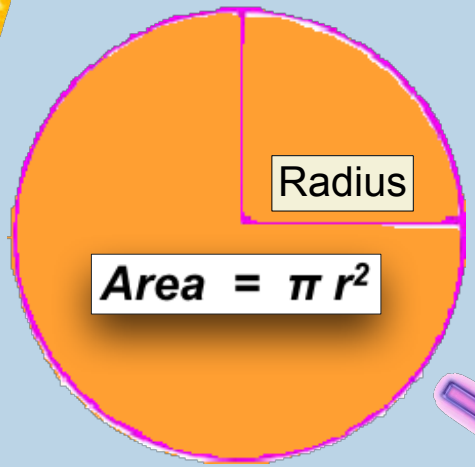
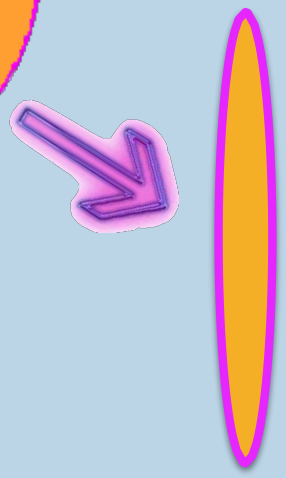




Area still = π r^2
- just rotated
- radius = 6,371 km
- crunches ~128 T m^2



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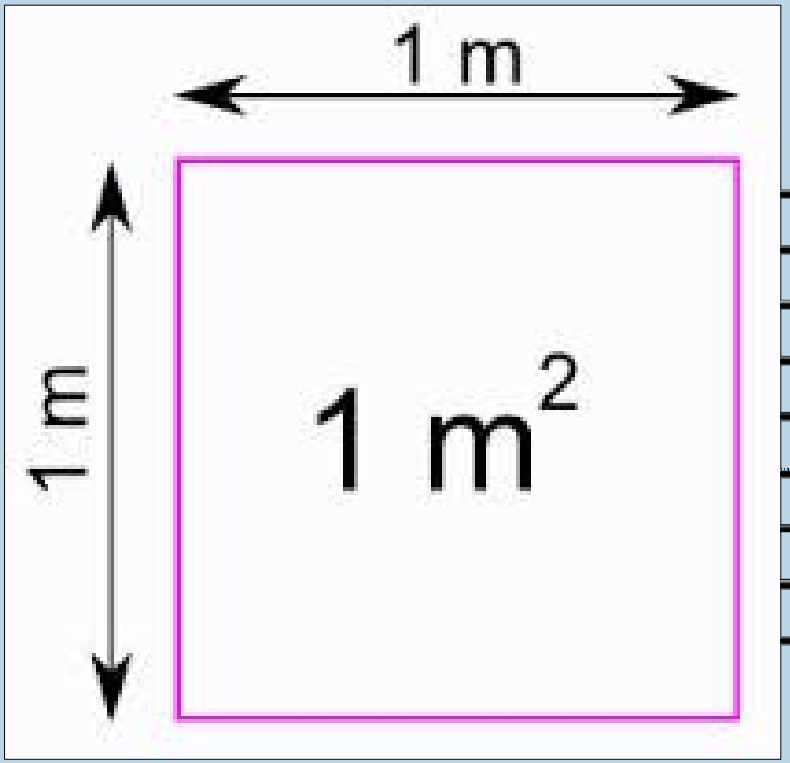

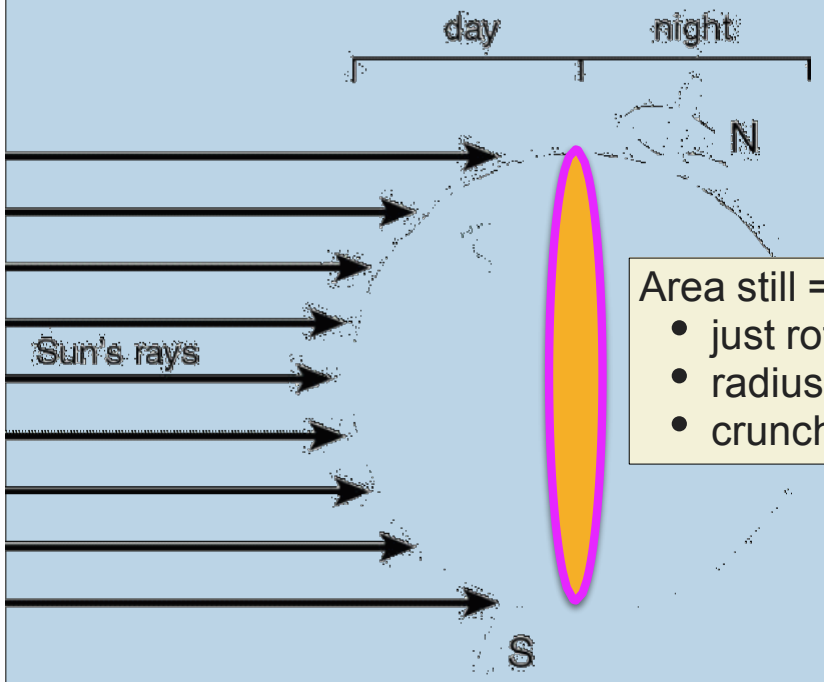

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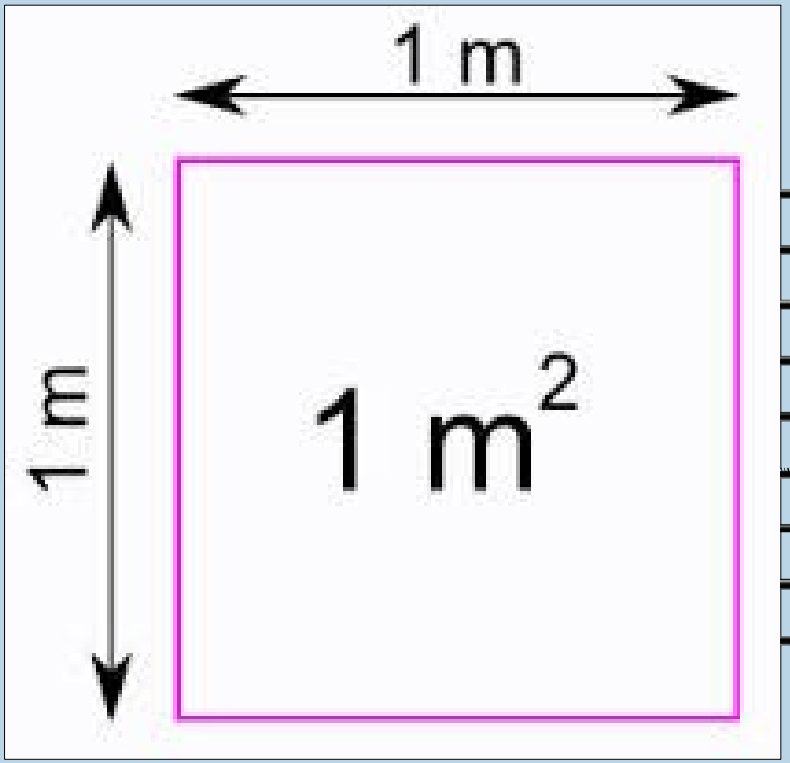

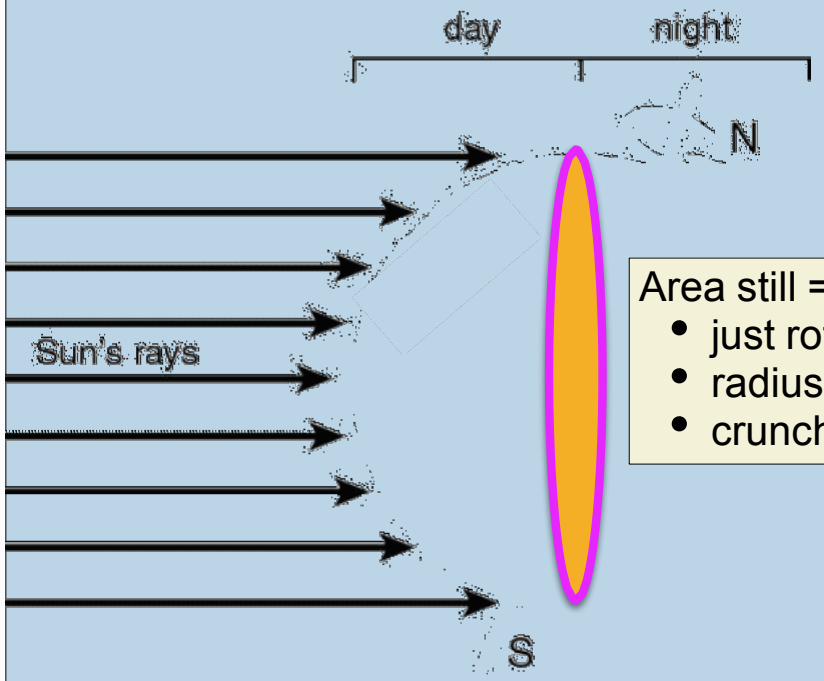

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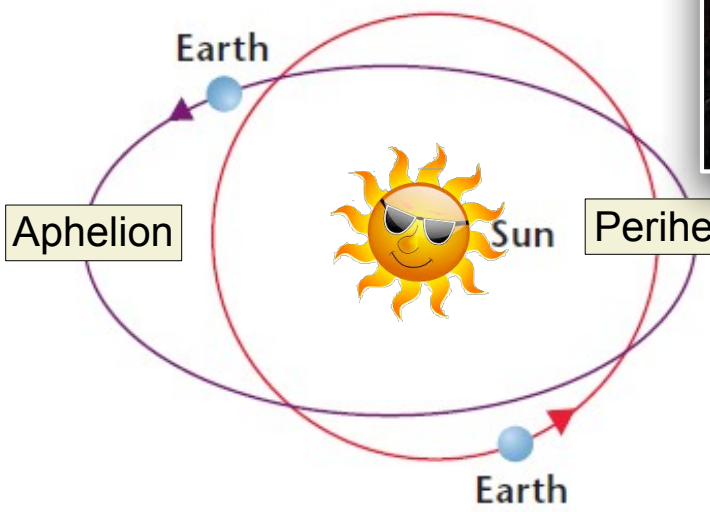
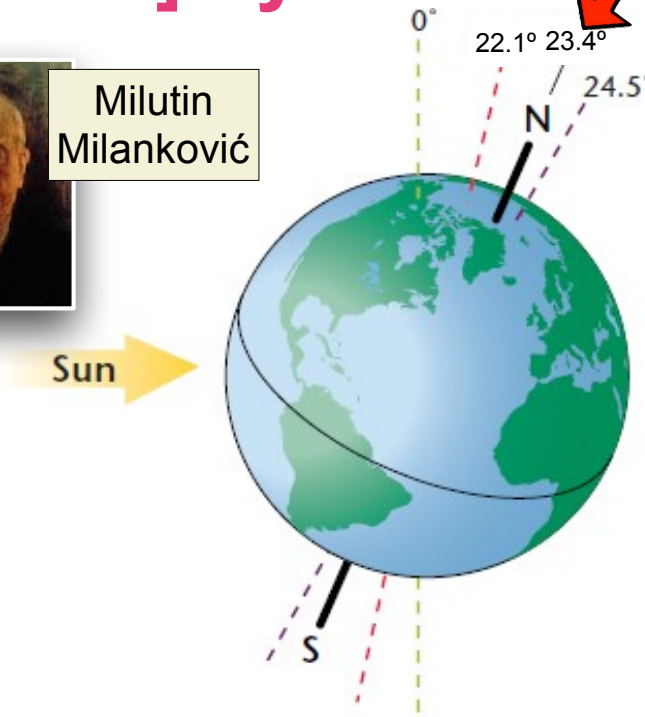
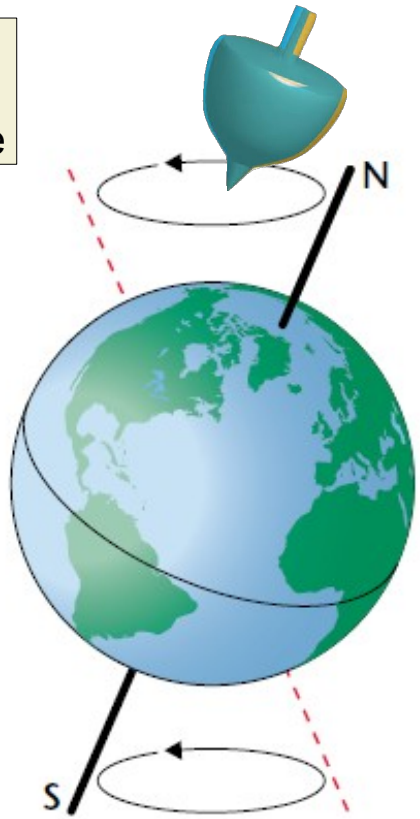
292 trillion watts or terawatts or TW trapped = **4 Hiroshima explosions/sec**, or ~400,000 explosions per day

Celestial [Newtonian] Mechanics or Milankovitch [Milanković] Cycles



Milutin Milanković





Eccentricity or 'ellipticity'

~100ka cycle [400ka]

Jupiter + Saturn gravity fields

Insolation varies perihelion to aphelion:

- *6% when more circular*
- *30% when less circular*
- *now getting more circular*

Small effect < 0.2% or radiative forcing ~0.45 Wm^{-2}

Obliquity or 'tilt'

~41ka cycle

Axis varies between 22.2° + 24.5°

Greater tilt warms both poles + favors deglaciation

Which way we headed?

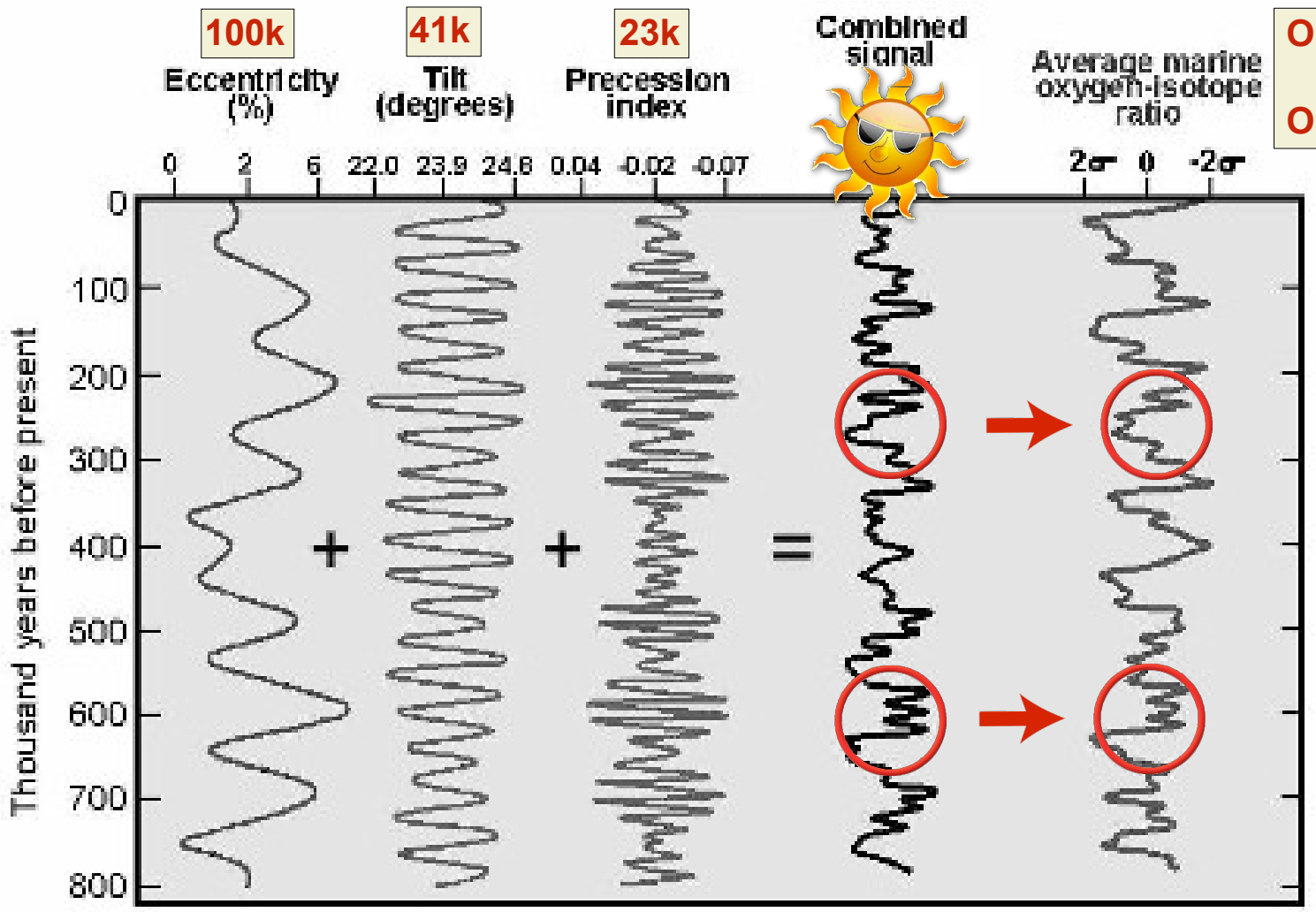
Precession or 'wobble'

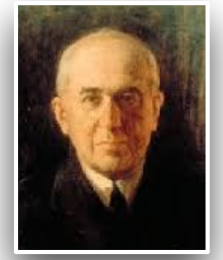
23ka cycle [19ka]

Sun + Moon tidal forces acting on oblate spheroid

Axis Polaris now, Vega ~13ka

How much variation based on orbital forcings?





Milutin Milanković

Paleoclimate from O_2 isotopes + pollen/plankton in sediment cores + other markers

Energy transfer thru TOA [apple skin]:

- **~1366 Wm^{-2}** arrives directly from sun [30% reflected right back out]
- **1.4 Wm^{-2}** = 0.1% variation with sun spot cycles
- [**0.45 Wm^{-2}** from *seasonal* variation of eccentricity cycle]

Extra **2.29 Wm^{-2}** trapped by deforestation, cement, combustion fossil fuels, other GHG

Milankovich cycles all about redistribution solar energy around planet

Holocene Epoch ~last 11,700 yrs

Now Departing Holocene for Anthropocene

Last surviving hominin thriving with predictable agriculture + hydrologic cycle:

- **~10,000 yrs ago** onset warming in interglacial MIS-1 with *deforestation* + CO_2
- **~5,000 yrs ago** further warming *outforcing* orbital cycles with *rice farming* + CH_4
- **~200 yrs ago** start Industrial Revolution temperature resulting **1.1ºC** rise

★ Most if not whole planetary history entire range only **15ºC or 27ºF** ★

- Icehouse Earth sea level 1700 ft lower
- Hothouse Earth sea level 240 ft higher

2008 Northwest + Northeast Passages opened up first time [Amundsen 1906]
2009 lightning up 20-fold in Arctic, with some of first *tundra* + *taiga fires*

Holocene most stable climate interval last 650,000 yrs

Permafrost

Underground Planetary Icebox

~24% Northern Hemispheric terrestrial surface [deep ~600m]

Two times more *organic* carbon than in atmospheric CO_2

Thaw converts long-term *sinks* into active *sources* $CO_2 + CH_4$

Permafrost degradation

- intensifies thermokarst development
- coastline erosion
- liquefaction of ground

*"Observed warming was up to **3°C** in parts of Northern Alaska… up to **2°C** in parts of the Russian European North….IPCC 2013*

"Permafrost becoming, well, less permanent" Brian Kahn

Stabilization @ 2ºC:

- current 15 M km²
- eventual > 40% loss
- 4 M km² per each ºC

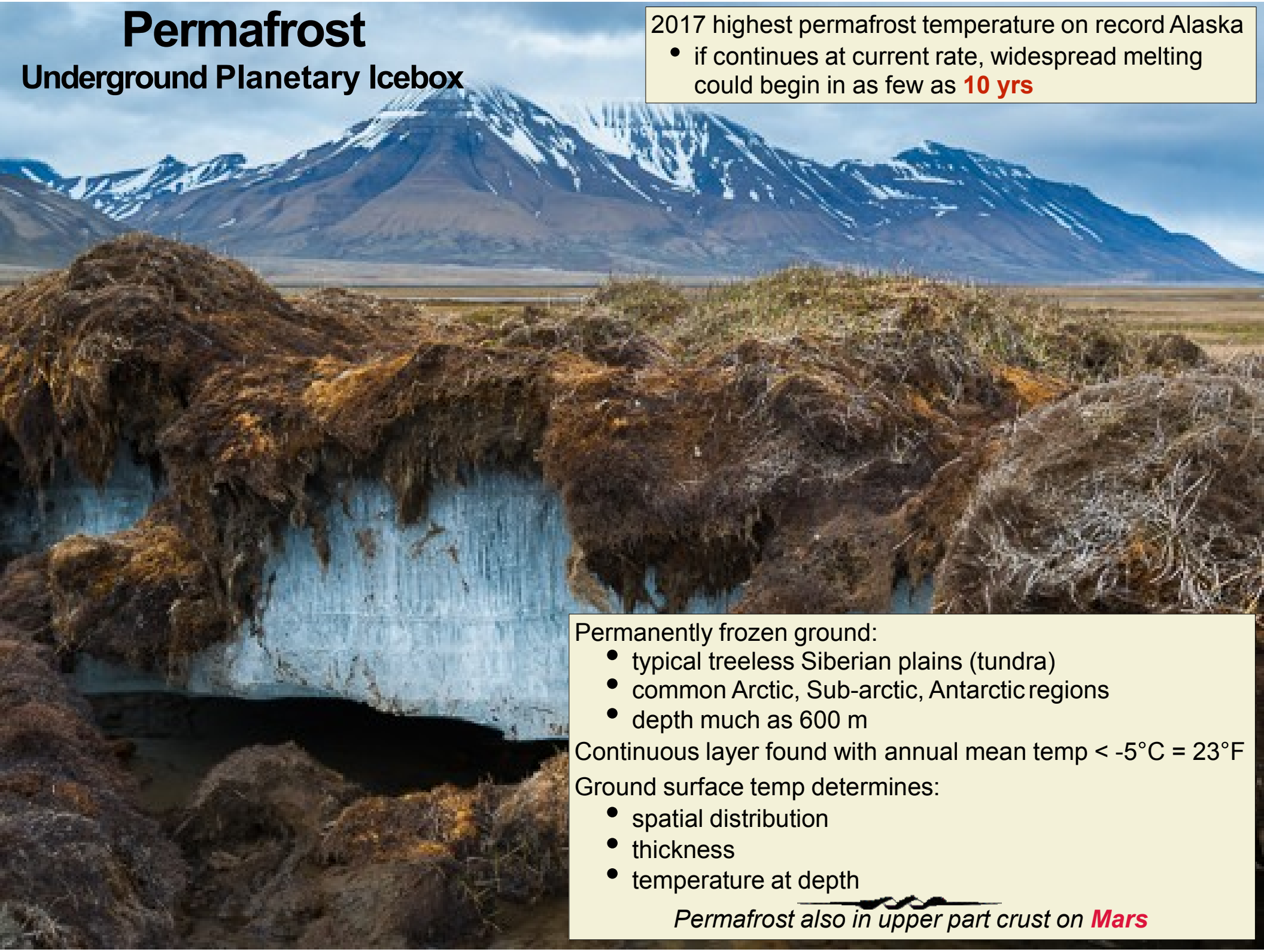
Drunken forest

Thermokarst

Structural failure

Permafrost

Underground Planetary Icebox



2017 highest permafrost temperature on record Alaska

- if continues at current rate, widespread melting could begin in as few as **10 yrs**

Permanently frozen ground:

- typical treeless Siberian plains (tundra)
- common Arctic, Sub-arctic, Antarctic regions
- depth much as 600 m

Continuous layer found with annual mean temp < -5°C = 23°F

Ground surface temp determines:

- spatial distribution
- thickness
- temperature at depth

*Permafrost also in upper part crust on **Mars***

Marine Methane Clathrates

Underwater Planetary Icebox

'The Ice That Burns' or Methane Hydrates

4. % methane by weight trapped *lattice* structure [water ice]
Marine methane clathrates least *match* current atmospheric carbon
NG migrates up subsea geological faults + contacts cold seawater
800,000 yr Antarctic ice core record of atmospheric methane

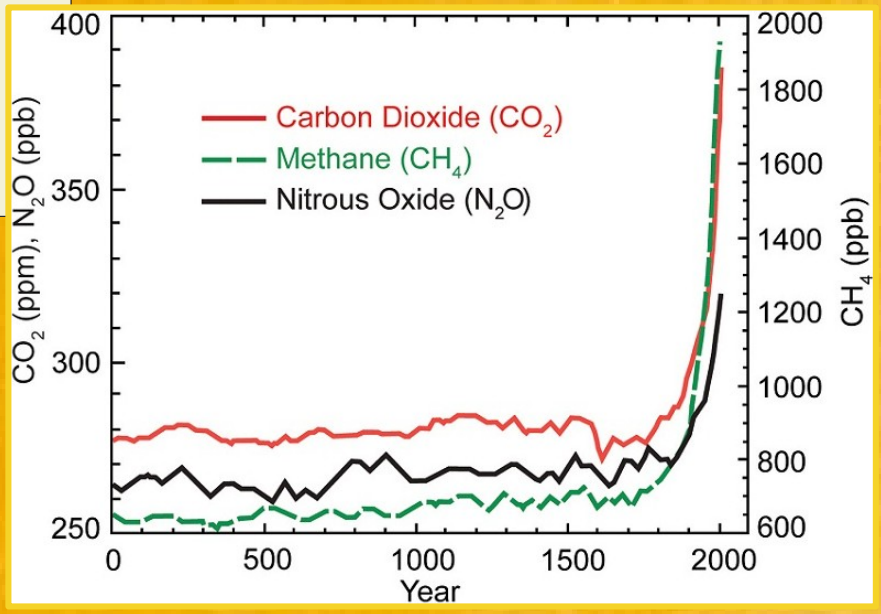
Necessary conditions:

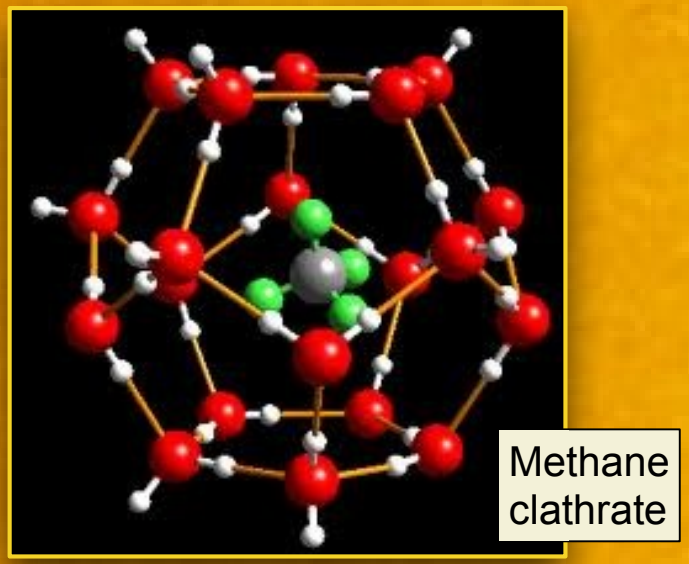
- continental sedimentary rocks mean surface T < 0°C
- oceanic sediment depths > 300 m bottom water T ~2°C
- deep fresh water lakes like Lake Baikal in Siberia

Methane responsible **~20% warming** since pre-industrial times:

- 86 times GHG effect > CO_2 over first 20 yrs
- 36 times GHG effect > CO_2 over first century
- 20 times GHG effect > CO_2 until conversion to CO_2

Hydrates with other substances, including H_2 or CO_2 or Ne

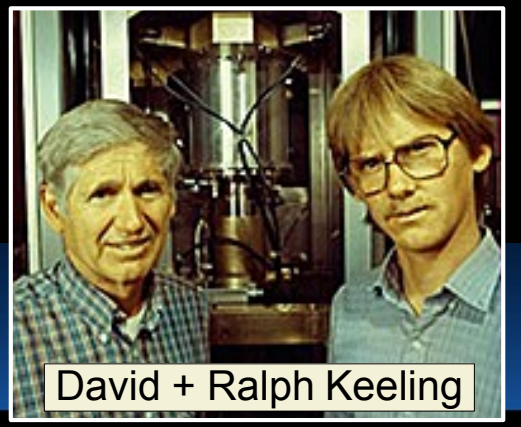




Keeling Curve

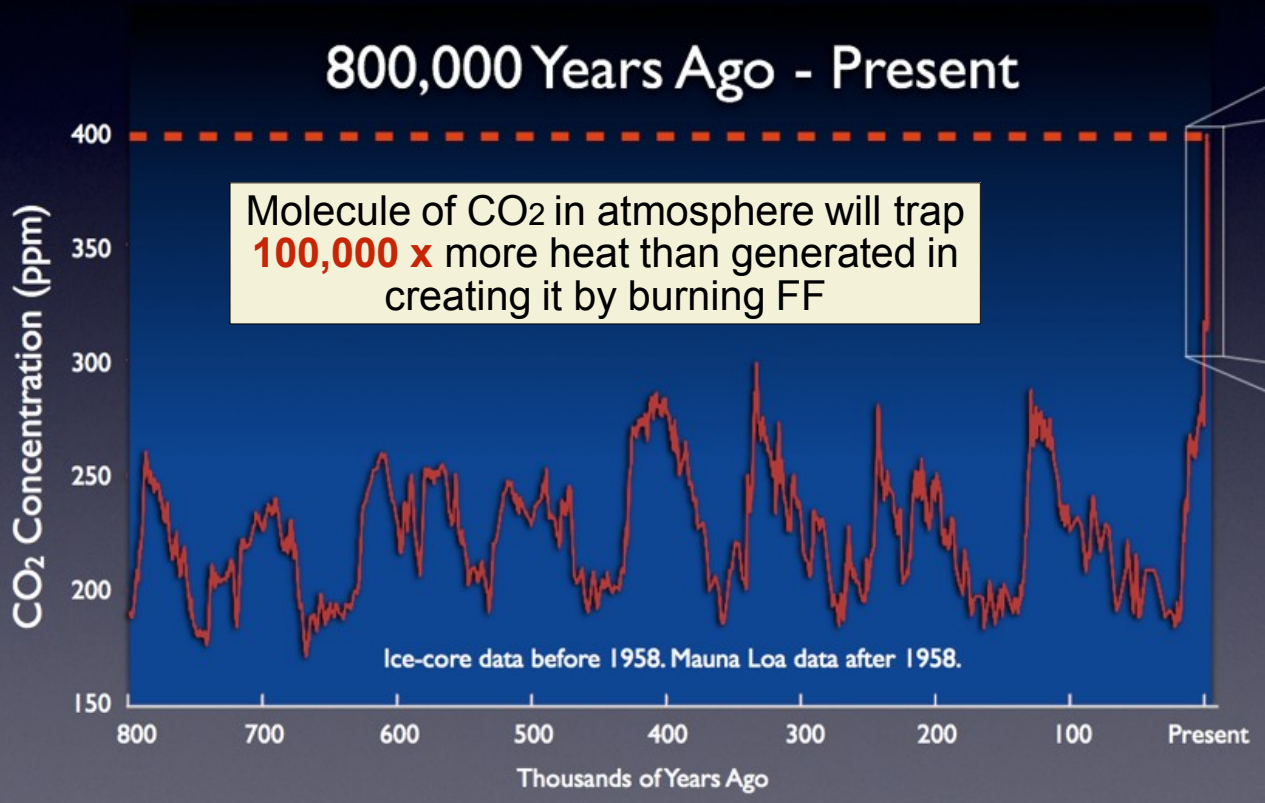
CO_2 Inarguably Positive Forcing

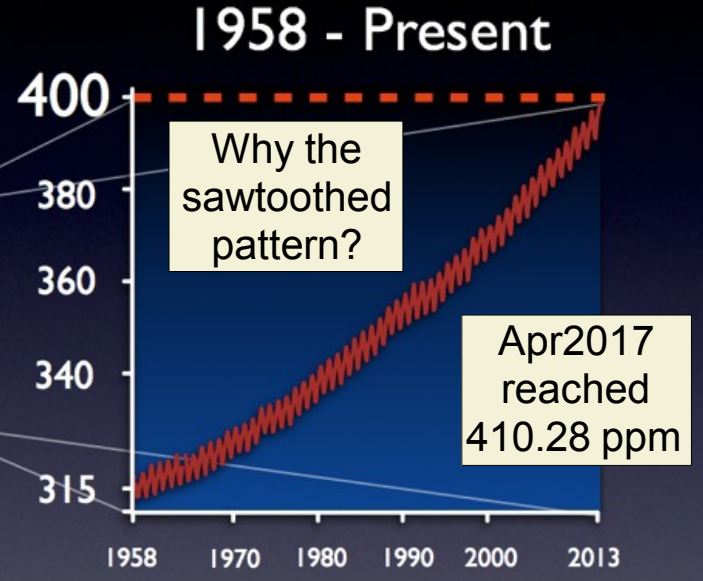
Climate Sensitivity Estimated 3ºC per Doubling CO_2


David + Ralph Keeling

CO_2 400 PPM MILESTONE

- Long-lived, heat-trapping gas
- Hit 400 ppm 2013 during annual May peak
- Last time we were at this level, human life did not exist





If we increase 3ºC changes:

- **permafrost**
- **methane clathrates**

Positive feedbacks

Quarter of CO_2 still in atmosphere thousand yrs later

OCEAN ACIDIFICATION

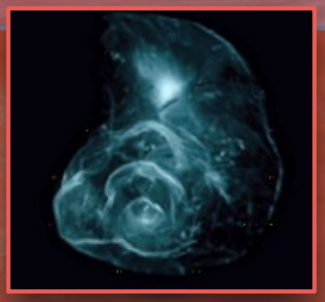
"Equally evil twin" to global warming

HOW WILL CHANGES IN OCEAN CHEMISTRY AFFECT MARINE LIFE?

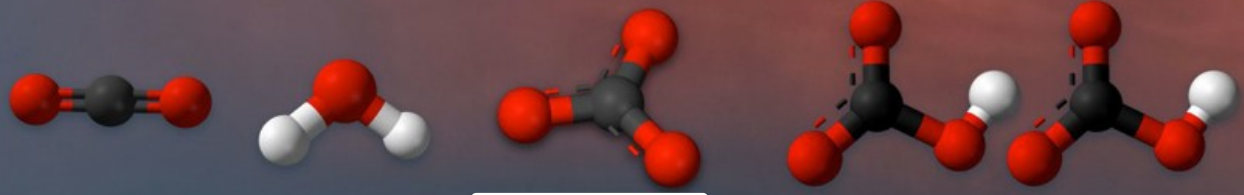
CO_2 absorbed from the atmosphere

Pteropod

Pteropod



$$CO_2 + H_2O + CO_3^{2-} \rightarrow 2\,HCO_3^-$$



carbon dioxide | water | carbonate ion | 2 bicarbonate ions

Ocean at equilibrium holds **50 times** more carbon than atmosphere

consumption of carbonate ions impedes calcification

Corals + clams + coccolithophores build shells with $CaCO_3$

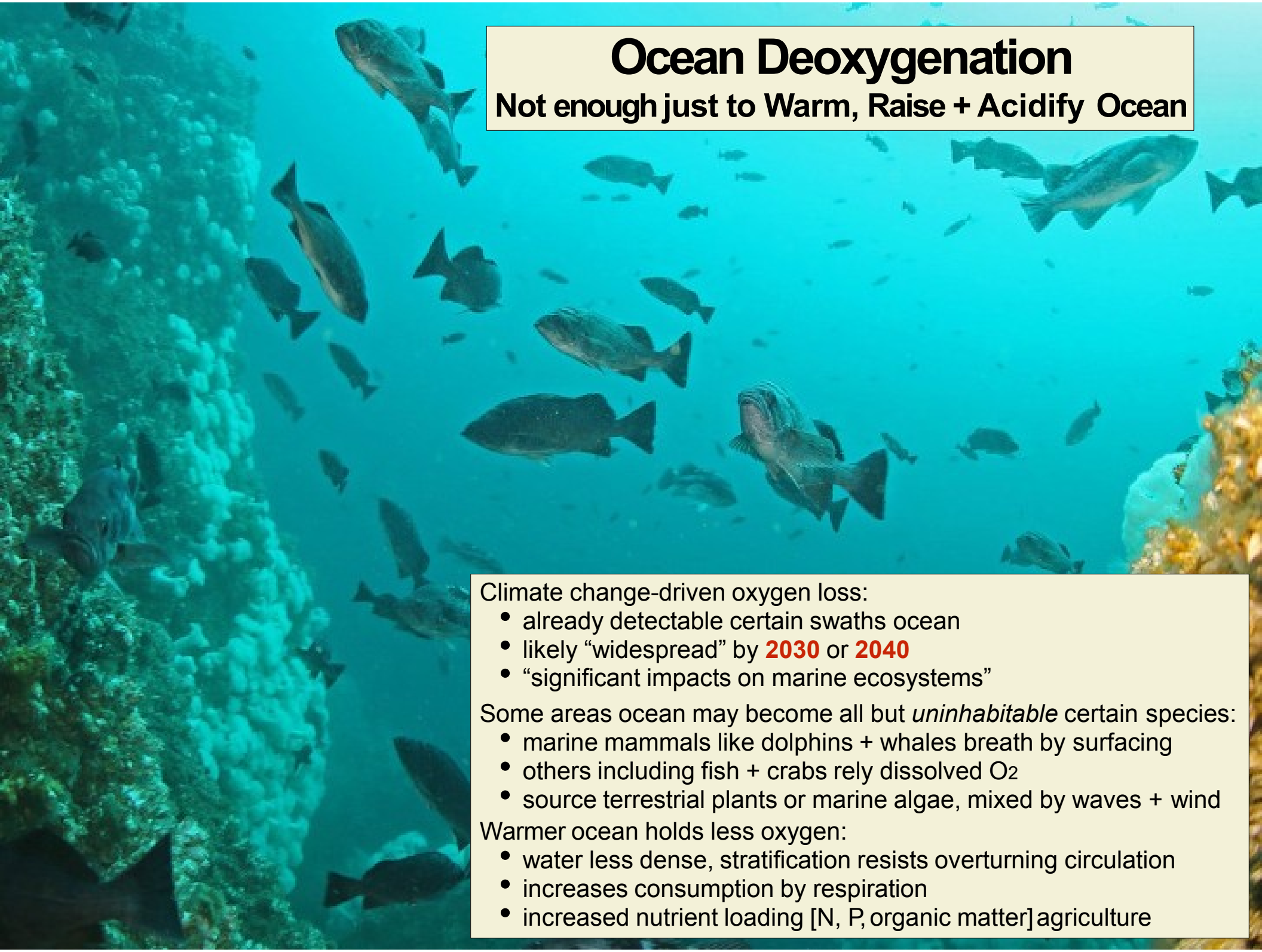
Sponges + diatoms + radiolaria build shells with SiO_2

Oceans absorb ~ **26%** atmospheric CO2 from:

- fossil fuel burning
- cement production ~5%
- land clearance ~11%

Intervals between bleaching:

- 25-30 yrs early 1980s
- 5.9 yrs in 2016



Ocean Deoxygenation

Not enough just to Warm, Raise + Acidify Ocean

Climate change-driven oxygen loss:

- already detectable certain swaths ocean
- likely “widespread” by **2030** or **2040**
- “significant impacts on marine ecosystems”

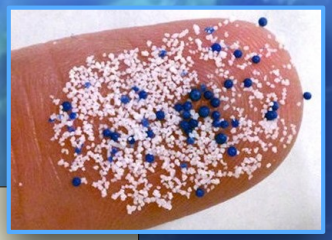
Some areas ocean may become all but *uninhabitable* certain species:

- marine mammals like dolphins + whales breath by surfacing
- others including fish + crabs rely dissolved O_2
- source terrestrial plants or marine algae, mixed by waves + wind

Warmer ocean holds less oxygen:

- water less dense, stratification resists overturning circulation
- increases consumption by respiration
- increased nutrient loading [N, P, organic matter] agriculture

Plastic Ocean
Plastic Fantastic



Microbeads latest addition marine plastics problem
- multicolored, spherical balls fraction millimeter diameter
- many popular exfoliating facial scrubs
- cosmetics, soaps, sunscreens, even toothpaste

Problematic:
- small enough pass through filters wastewater-treatment
- troublesome tendency absorb + concentrate pollutants
- look like fish eggs + thus food variety aquatic organisms

Scientists estimate 110 Mt plastic floating oceans
- serious risk for marine animals
- entrap, starve, suffocate
- famous Great Pacific Garbage Patch

Guilt-free drinks:
- plastic 6-pack **soda rings** tangled or eaten
- new *edible 6 pack ring* potential replacement
- *biodegradable* from barley + such

Plastic accumulates mostly big subtropical **gyres**:
- ~ 1% plastic pollution gyres + other surface waters
- concentrating Arctic Ocean, especially Barents Sea
- critical component thermohaline circulation

Plastic could outweigh all fish by 2050, UN Jun2017

China's Pressure on World Fisheries

Predominant Culprit

Overfishing depleting oceans:

- **90%** fisheries fully exploited or facing collapse
- UN Food + Agriculture Organization or FAO
- millions depend on sea for income + food

China's outsize impact:

- fishermen exploiting waters other countries
- subsidies for employment + food security
- corruption + weak enforcement West Africa

2/3 fishing contravenes national or international laws

- distant-water fishing fleet nearly 2,600 vessels
- 10-fold > US fleet
- cost West African economies $2 B per year

China indisputable king of the sea,
biggest seafood exporter, plus consumes
third *all oceanic fish [figure growing 6% a yr]*

Part China's enormous fishing fleet in harbor in Zhejiang, China

China's Zero Sum Game

Concomitant $60 B Aid + Exploitation

Senegal impoverished nation 14 M:

- fishing stocks plummeting
- local fishermen use hand-hewn canoes
- competing megatrawlers + huge nets/lines

Sea's diminishing returns mean:

- plummeting fishing incomes
- higher food prices Senegalese

"If things keep going the way they are, people will have to eat jellyfish to survive"

Changing Climate Damaging Fisheries

Fishery Failure Fuels Climate Change

Fishing vessels help assert territorial ambitions South China Sea:

- Spratlys archipelago claimed by Philippines
- Paracel Islands considered territory Vietnam
- maritime ‘militia’ gets subsidized fuel, ice, navigation devices

Backed by Chinese naval frigates:

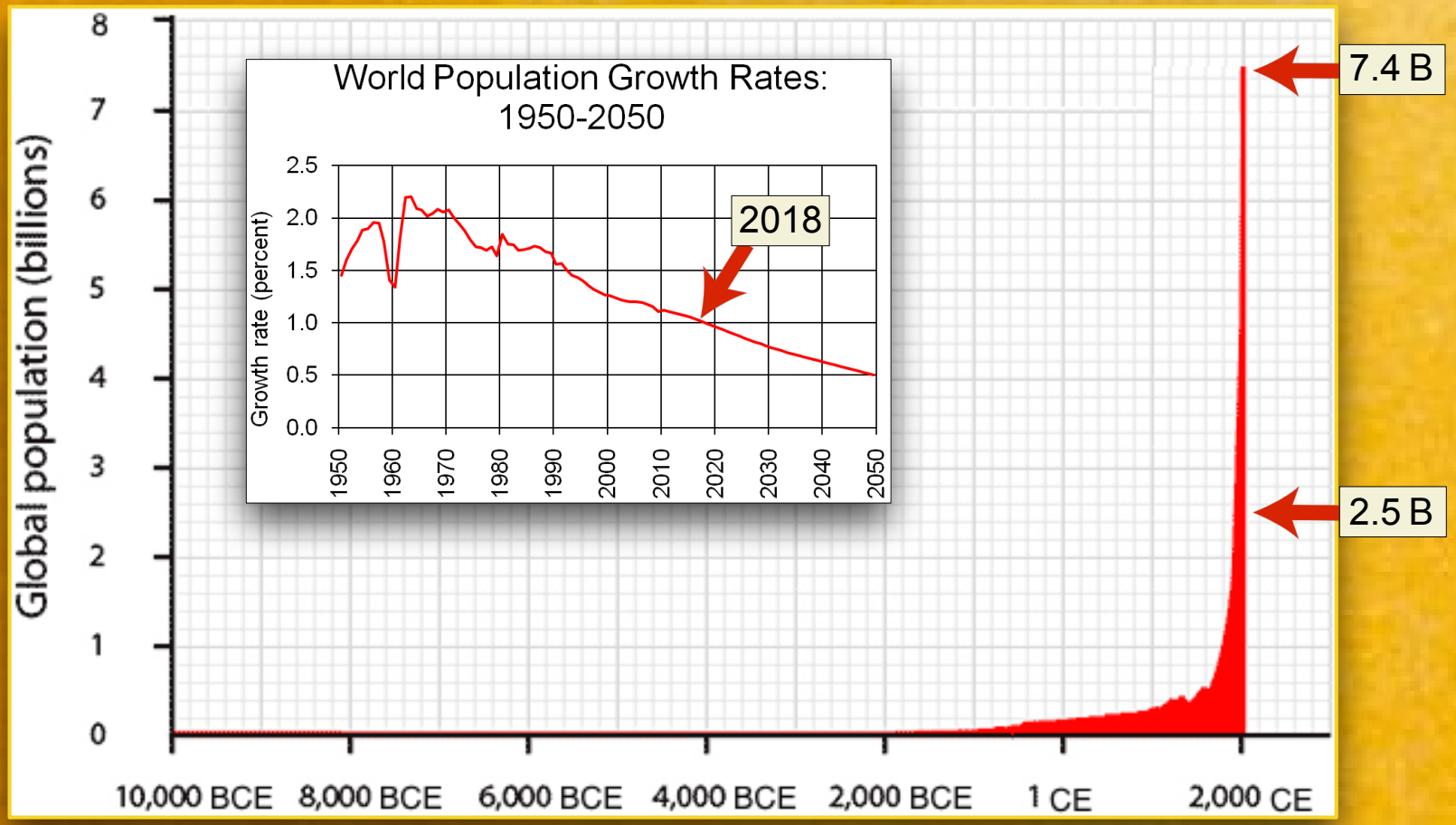
- driven away thousands Filipino fishermen
- impact reflected in rows idled outriggers
- clouds smoke drifting across freshly denuded hillsides

Outrigger fishermen in front slash-and-burn agriculture Philippine Darocotan Island

Unable to live off sea:

- desperate fishermen burning protected coastal jungle
- attempting rice fields
- steep land useless after rain-induced erosion

Human Population Growth in Holocene



World 7,442,857,700
United States 326,486,555
Dec2017 ~4.4% of world population
http://www.census.gov/popclock/
Global birthrate now peaking ~ 134 M per yr

80 nations at or below replacement rate fertility:

- increase half-child per couple → 11 B
- decrease half-child per couple → 6 B

Solutions straight-forward:

- women's education in literacy + numeracy
- whole spectrum reproductive health care
- personal call to action

Climate Change Blamed for Half Increased Forest Fire Danger

Forest fires burning longer + stronger across western US

- residents become refugees
- homes incinerated
- wildlife habitats destroyed

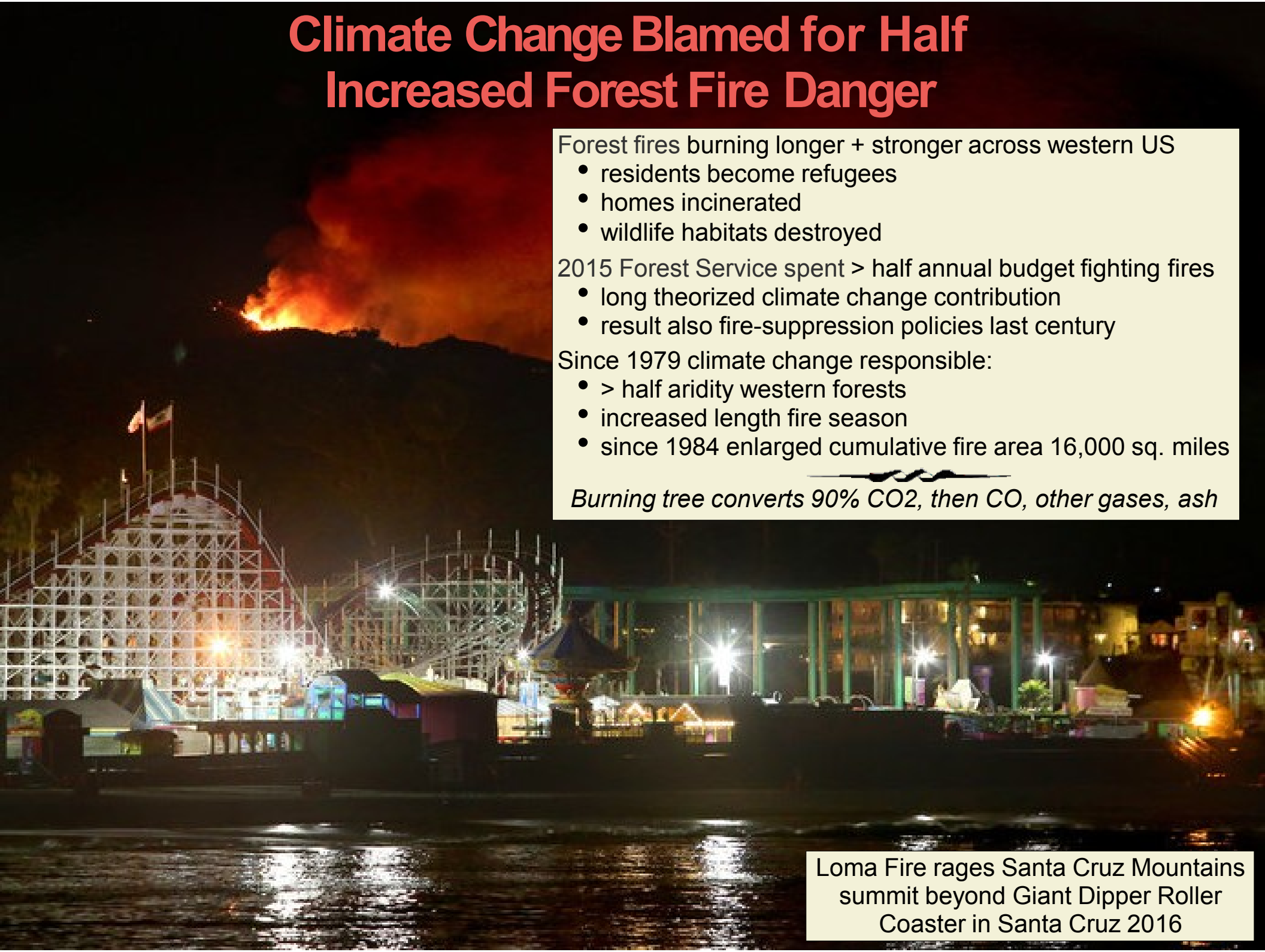
2015 Forest Service spent > half annual budget fighting fires

- long theorized climate change contribution
- result also fire-suppression policies last century

Since 1979 climate change responsible:

- > half aridity western forests
- increased length fire season
- since 1984 enlarged cumulative fire area 16,000 sq. miles

Burning tree converts 90% CO2, then CO, other gases, ash



Loma Fire rages Santa Cruz Mountains summit beyond Giant Dipper Roller Coaster in Santa Cruz 2016

Climate Change Blamed for Half Increased Forest Fire Danger

Cyclical climate variations:

- changes in Pacific
- historic fire suppression
- land development
- fire ignitions
- more lightning
- bark beetles
- less mountain snowpack

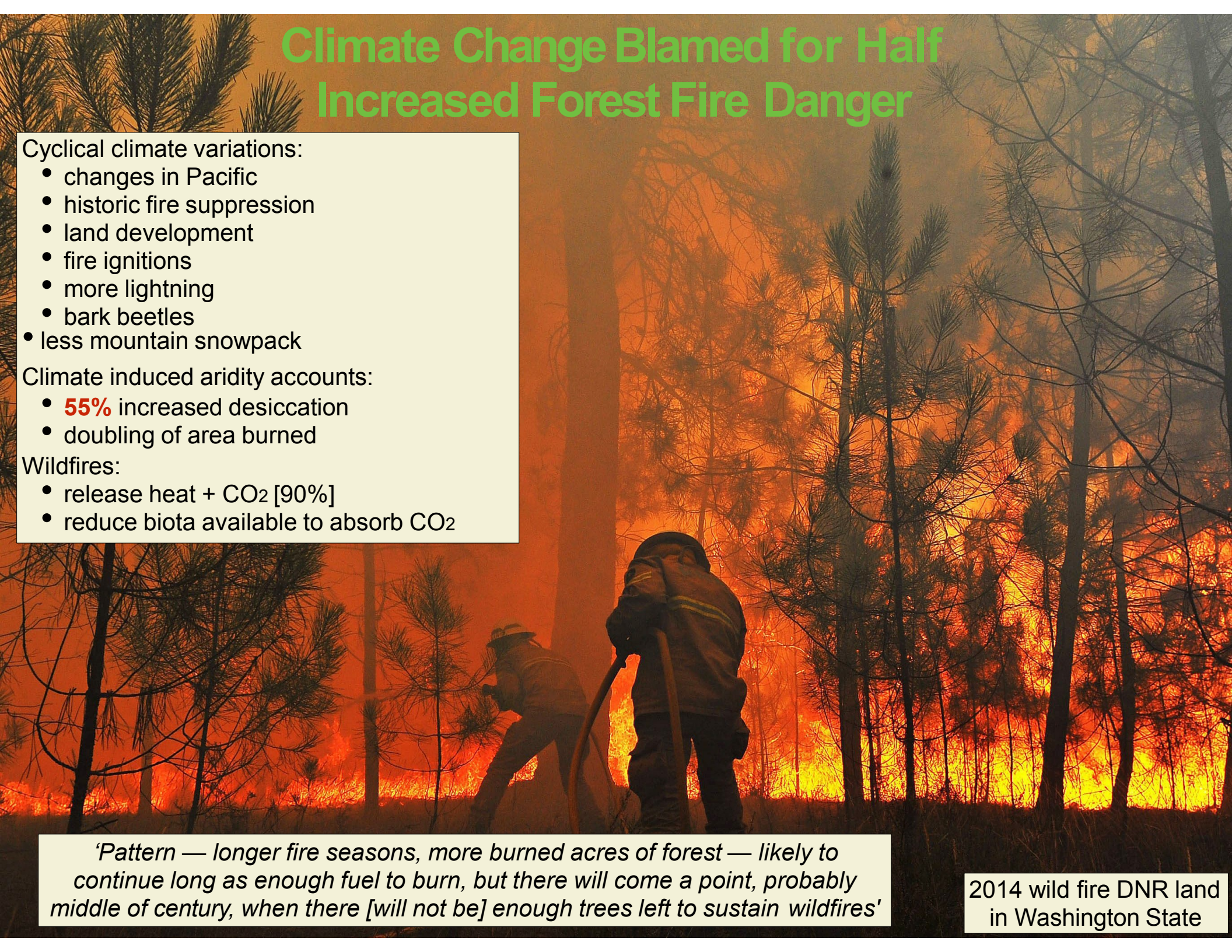
Climate induced aridity accounts:

- **55%** increased desiccation
- doubling of area burned

Wildfires:

- release heat + CO_2 [90%]
- reduce biota available to absorb CO_2

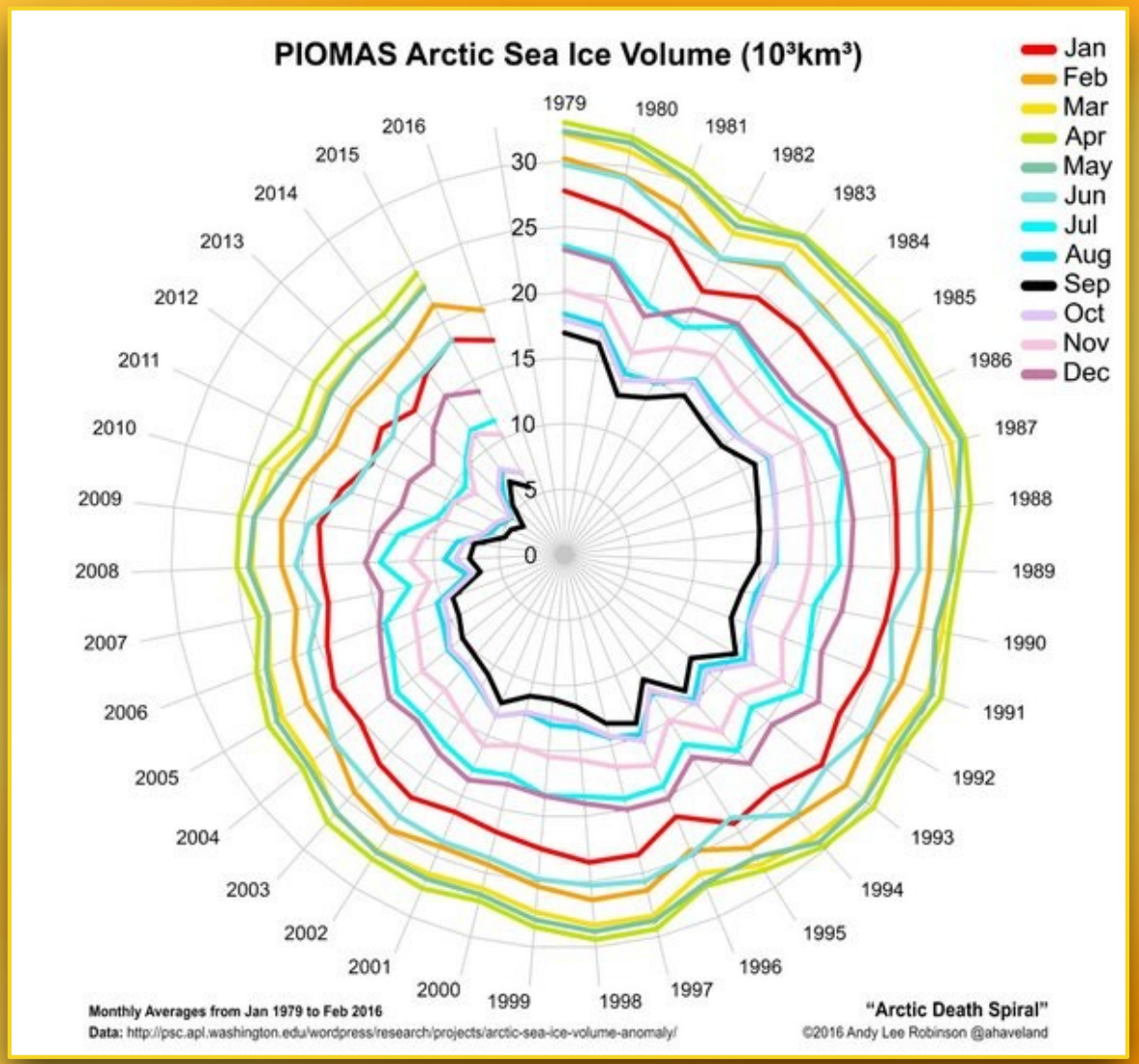
'Pattern — longer fire seasons, more burned acres of forest — likely to continue long as enough fuel to burn, but there will come a point, probably middle of century, when there [will not be] enough trees left to sustain wildfires'



2014 wild fire DNR land in Washington State

Infamous Arctic Sea Ice Death Spiral

Geopolitical Implications more by Area



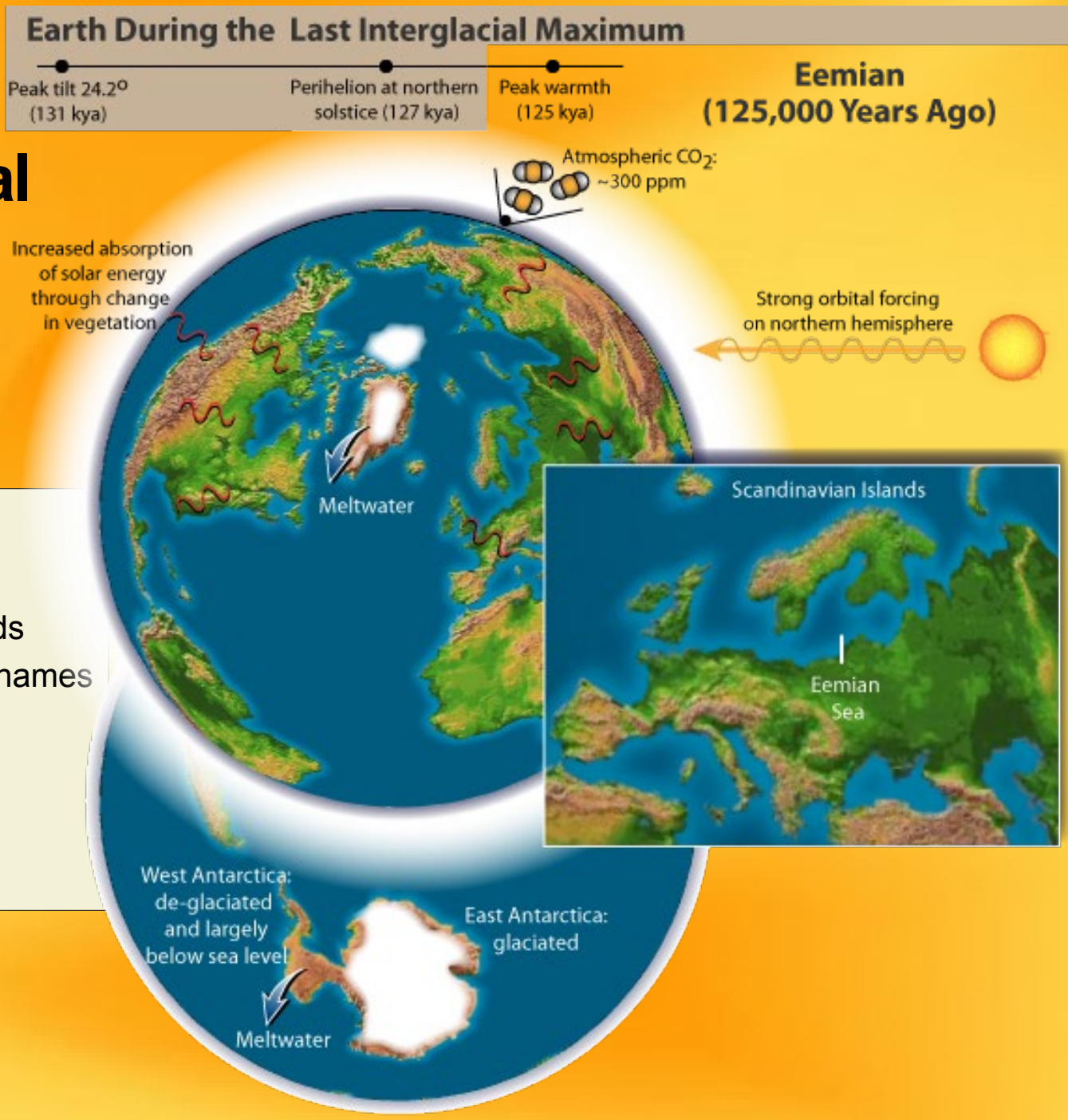
Area of melt now > 48 contiguous states:

- areal extent critical in navigation + drilling + fishing
- mass depletion another metric of climate change

Potentially seasonally ice-free by 2030s

Eemian Interglacial

Comparison to Present



Eemian [Last] Interglacial:

- followed Saale Glacial Stage
- preceded Weichsel Glacial Stage
- named for stream eastern Netherlands
- hippopotamus far north as Rhine + Thames
- hazel + oak grew far north as Finland

Robust geologic field data:

- persuasive case rapid sea level rise
- height +6–9 m relative today
- strong storms **Bahamas** + **Bermuda**

Late-Eemian Comparison to Present

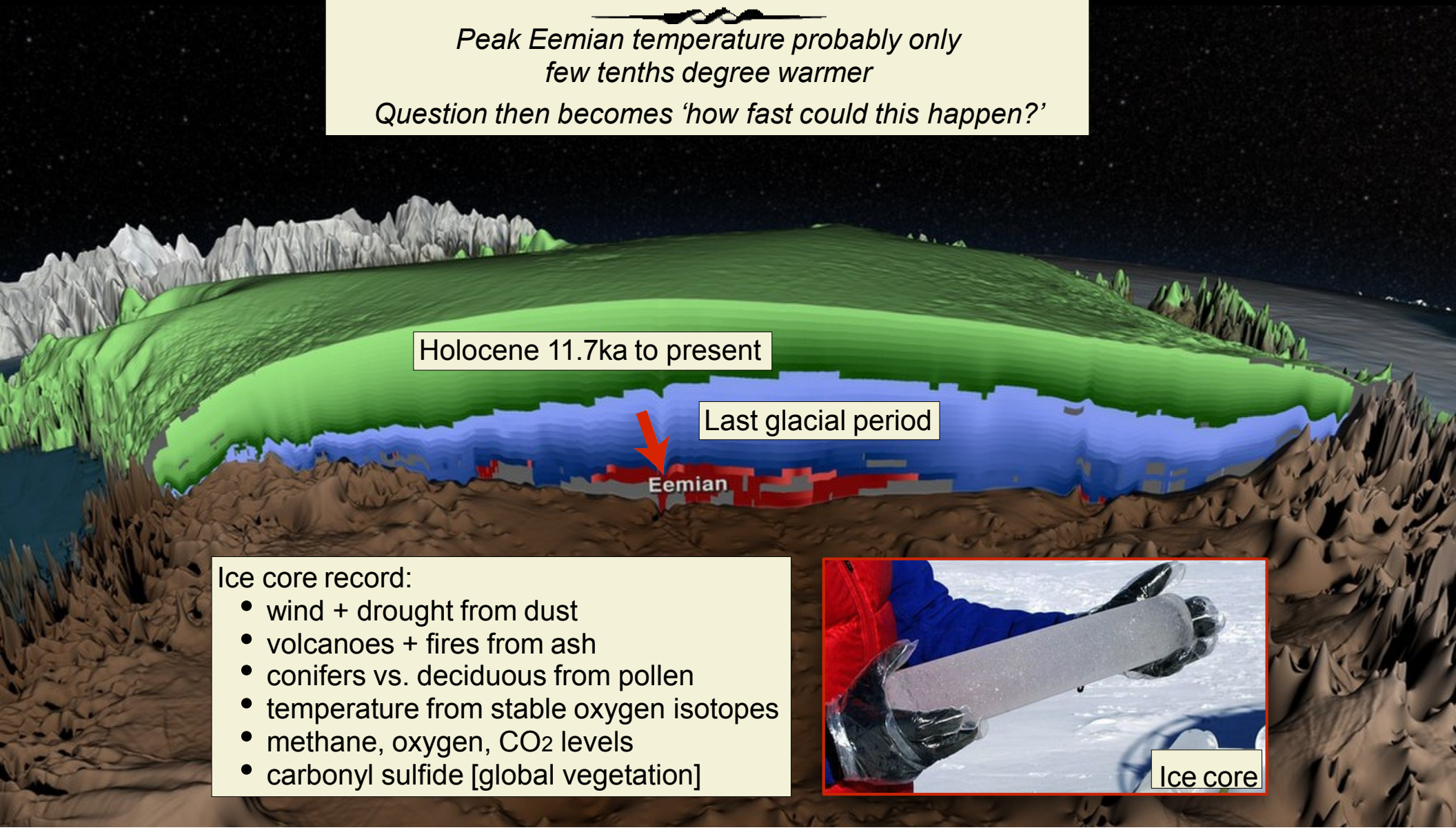
Greenland Ice Core Record

Eemian or Last Interglaciation or LIG ~130 ka to ~115 ka

- *last time* Earth warm as today
- sea level most Eemian relatively stable at **+3–4 m**
- following rapid late-Eemian sea level rise to about **+9 m**

Peak Eemian temperature probably only few tenths degree warmer

Question then becomes 'how fast could this happen?'

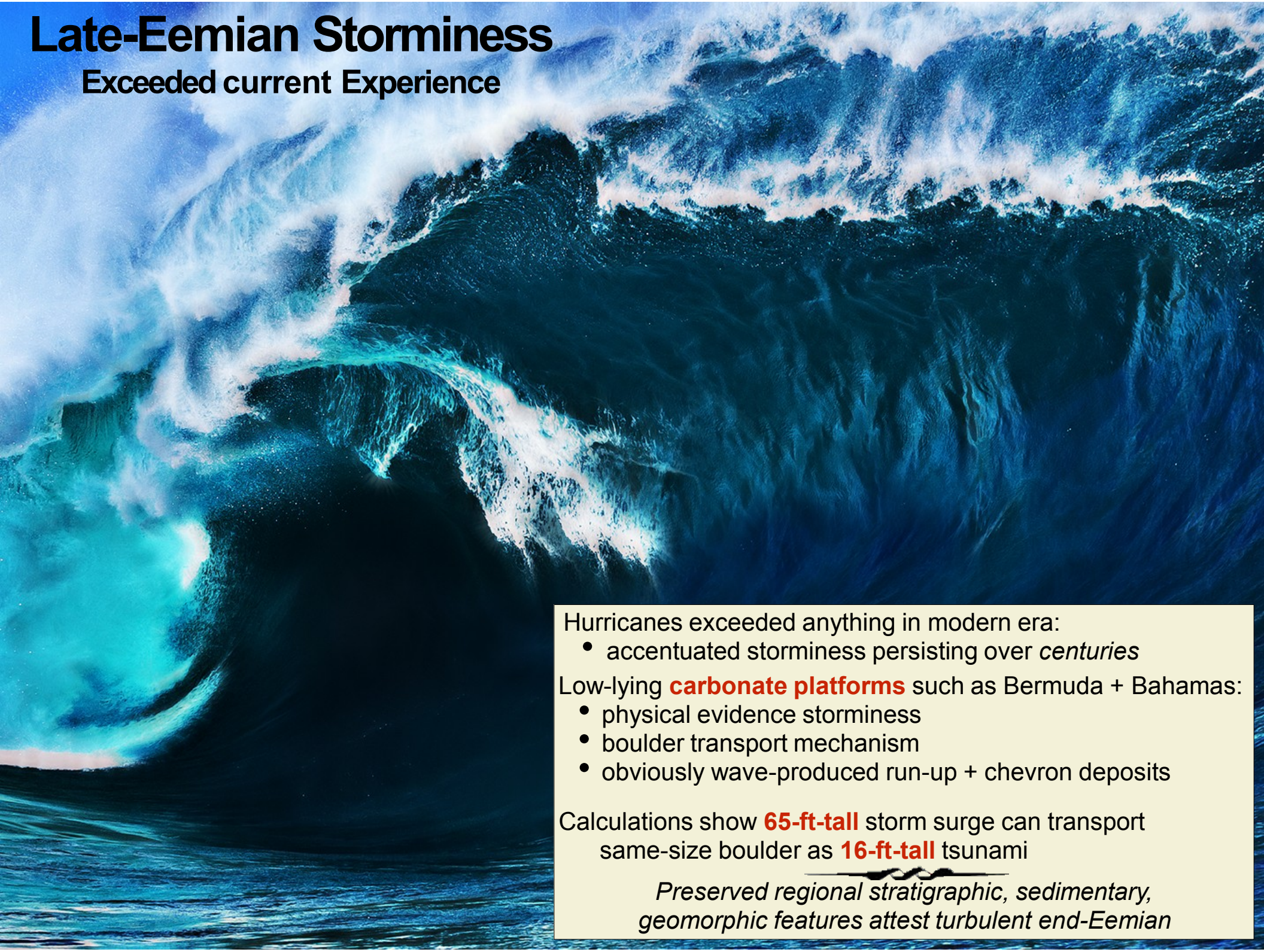


Ice core record:

- wind + drought from dust
- volcanoes + fires from ash
- conifers vs. deciduous from pollen
- temperature from stable oxygen isotopes
- methane, oxygen, CO_2 levels
- carbonyl sulfide [global vegetation]

Late-Eemian Storminess

Exceeded current Experience



Hurricanes exceeded anything in modern era:

- accentuated storminess persisting over *centuries*

Low-lying **carbonate platforms** such as Bermuda + Bahamas:

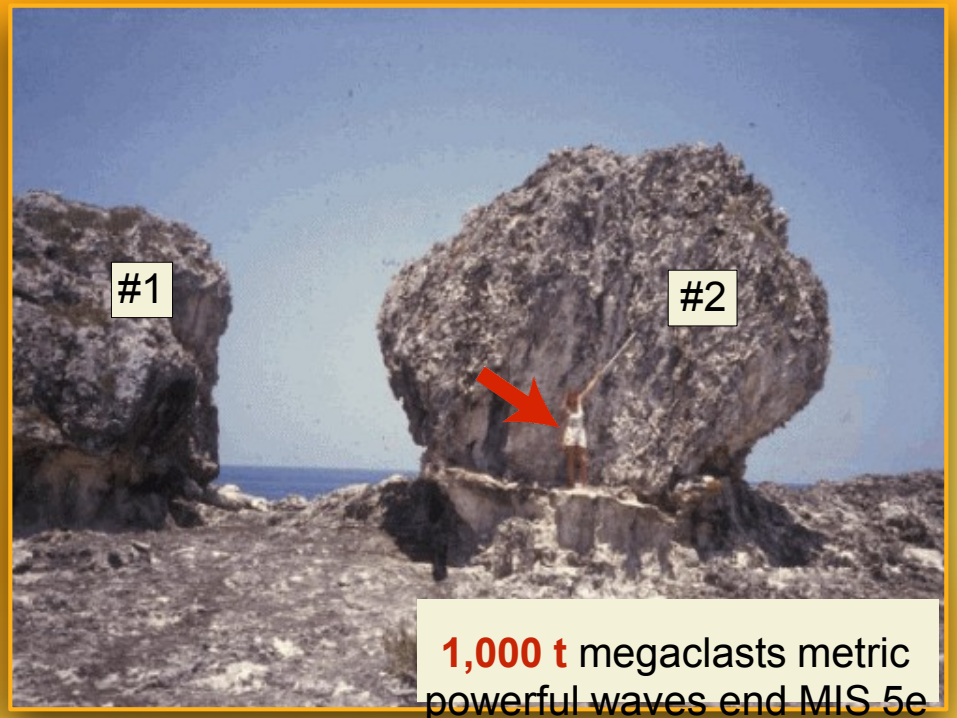
- physical evidence storminess
- boulder transport mechanism
- obviously wave-produced run-up + chevron deposits

Calculations show **65-ft-tall** storm surge can transport same-size boulder as **16-ft-tall** tsunami

Preserved regional stratigraphic, sedimentary, geomorphic features attest turbulent end-Eemian

Wave-transported Eemian Megaboulders

Storm Waves, not Tsunami Waves



North Eleuthera megaboulders #1 + #2 resting on MIS 5e eolianite:

- enormous limestone boulders plucked seaward mid-Pleistocene outcrops
- crashed onto younger Pleistocene 20 m high ridge
- person showing scale + orientation

Comparable events 2013 Typhoon Haiyan Philippines:

- longshore transport 180 t block
- lifted boulders ~24 t up 10 m

Too random + chronologically coincidental to argue trilogy of evidence [boulders, run-up deposits, chevron ridges] caused unconnected processes

'Greater age compared to underlying strata + disorientation primary bedding beyond natural in situ angles indicates boulders wave-transported'

Mechanisms Ice Mass Loss

Adjustments to Models

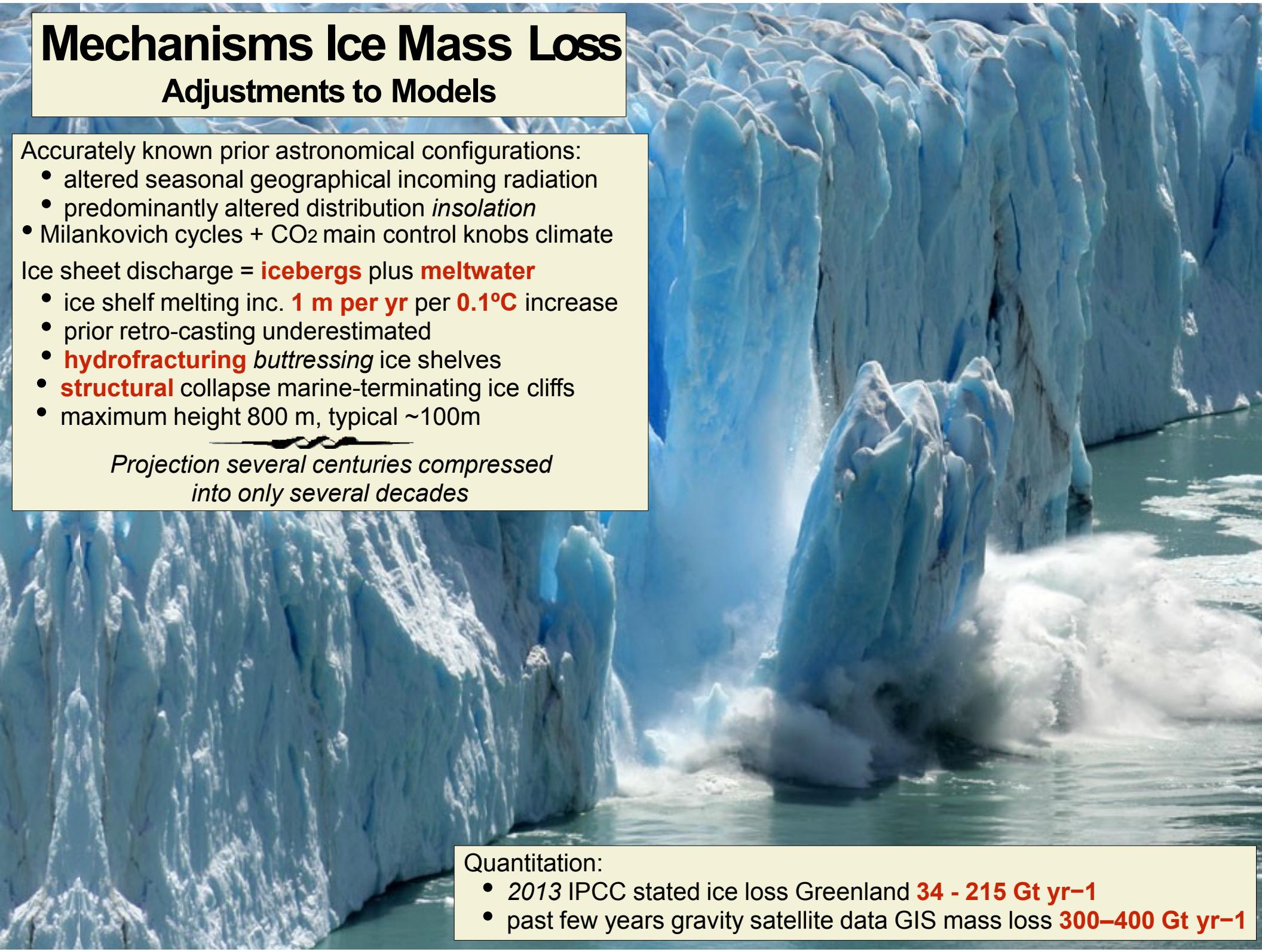
Accurately known prior astronomical configurations:

- altered seasonal geographical incoming radiation
- predominantly altered distribution *insolation*
- Milankovich cycles + CO_2 main control knobs climate

Ice sheet discharge = **icebergs** plus **meltwater**

- ice shelf melting inc. **1 m per yr** per **0.1ºC** increase
- prior retro-casting underestimated
- **hydrofracturing** *buttressing* ice shelves
- **structural** collapse marine-terminating ice cliffs
- maximum height 800 m, typical ~100m

Projection several centuries compressed into only several decades



Quantitation:

- *2013* IPCC stated ice loss Greenland **34 - 215 Gt yr−1**
- past few years gravity satellite data GIS mass loss **300–400 Gt yr−1**

Greenland Ice Sheet or GIS

Exponential Ice Mass Attrition

Greenland:

- world's largest island
- second largest ice sheet
- unimaginable amounts water either side freezing point

Comprehensive seabed mapping project:

- state of art soundings by ships + other data sources
- data NASA's "Oceans Melting Greenland" or OMG
- seabed adjacent + beneath Greenland's glaciers

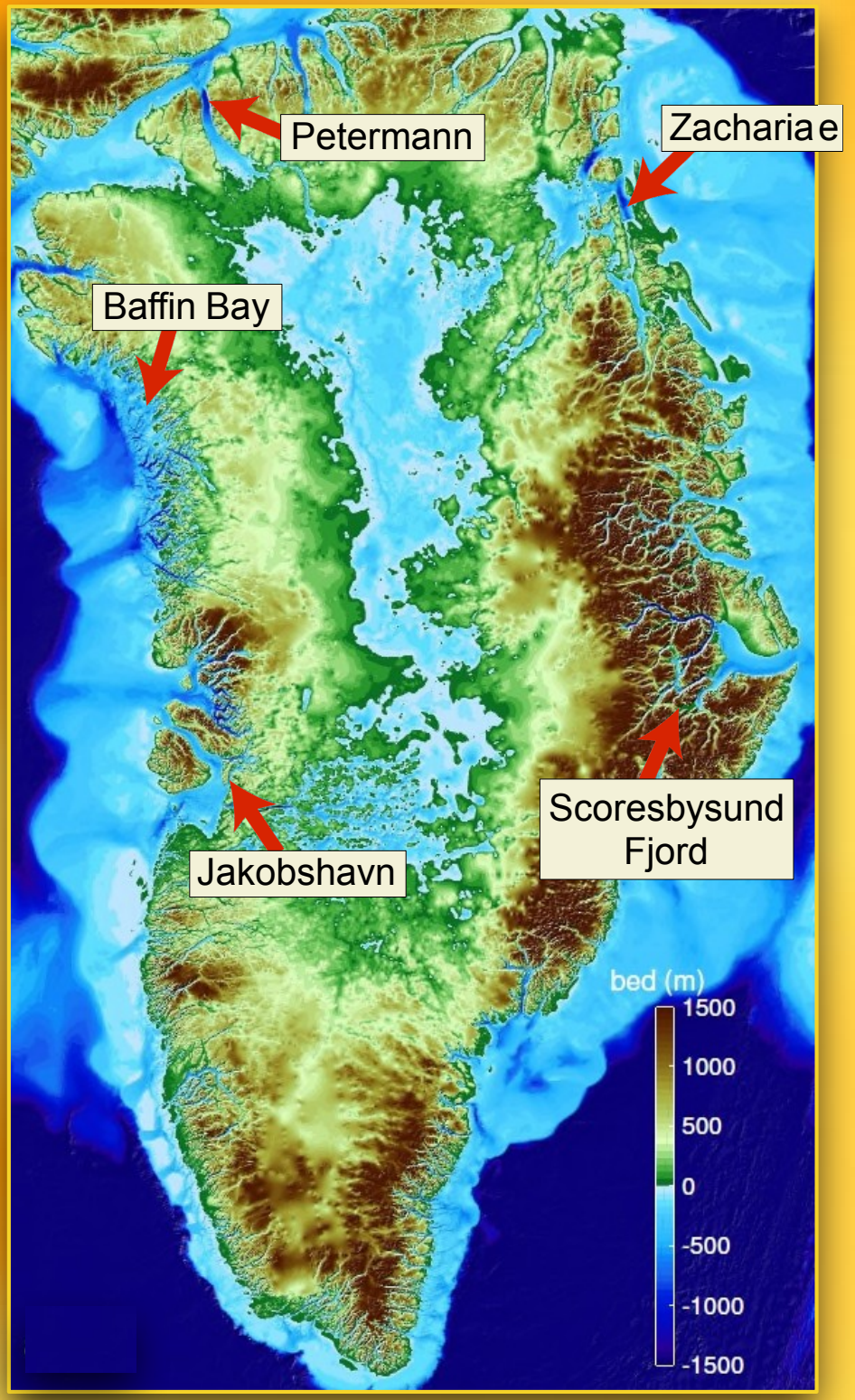
Depth + contours ocean floor beneath both:

- liquid water in fjords
- ice where ocean will someday flow

Findings:

- 30 - 100% more glaciers…potentially exposed [warm Atlantic water] than suggested previous mapping
- represents **55%** ice sheet's total drainage area
- ice above sea level capable raising sea level **24.3 ft**

GIS now raising ~~seas nearly~~ mm per yr, but exponentially increasing + ignored at our peril



Greenland Fjord

Expanding Outwash Deltas

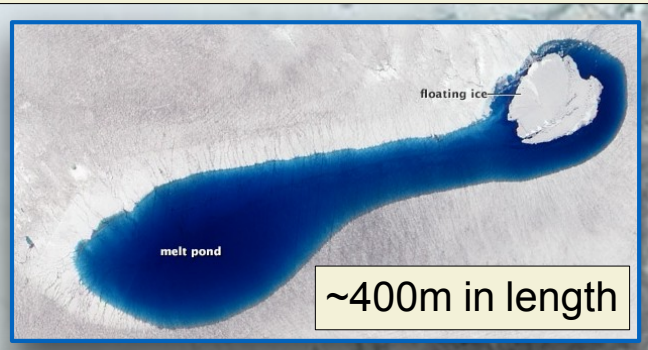
Most deltas around world diminishing due to sea level rise
Comparisons here with photos from US pilots 1940s

Greenland Meltwater Ponds

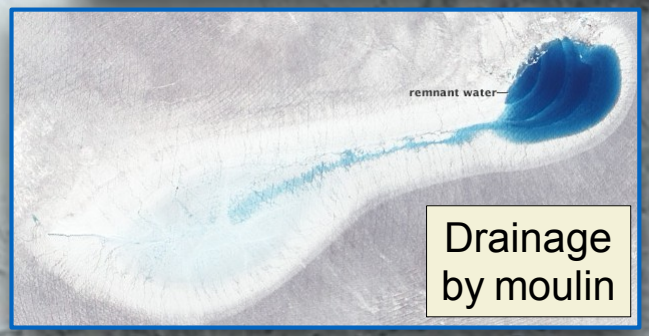
Summertime, Summertime 2016

Melt ponds proliferating:

- diminished albedo or reflectivity
- from Latin albus or dull or matte “whiteness”
- enhanced ultraviolet, visible, infrared absorption, with resultant heating



~400m in length



Drainage by moulin

Cryoconite Holes

"ice" plus "dust"

Cryoconite also proliferating:

- again diminished albedo or reflectivity
- dust, soot, bacteria, microalgae
- pigment protects from uv, inc. heating

Finnish-Swedish explorer Nils A. E. Nordenskiöld suggested nearly 150 yrs ago

AntarcticGroundingLines

RedLinecurrentContinentalMargin

Floating ice shelves buttress ice sheets

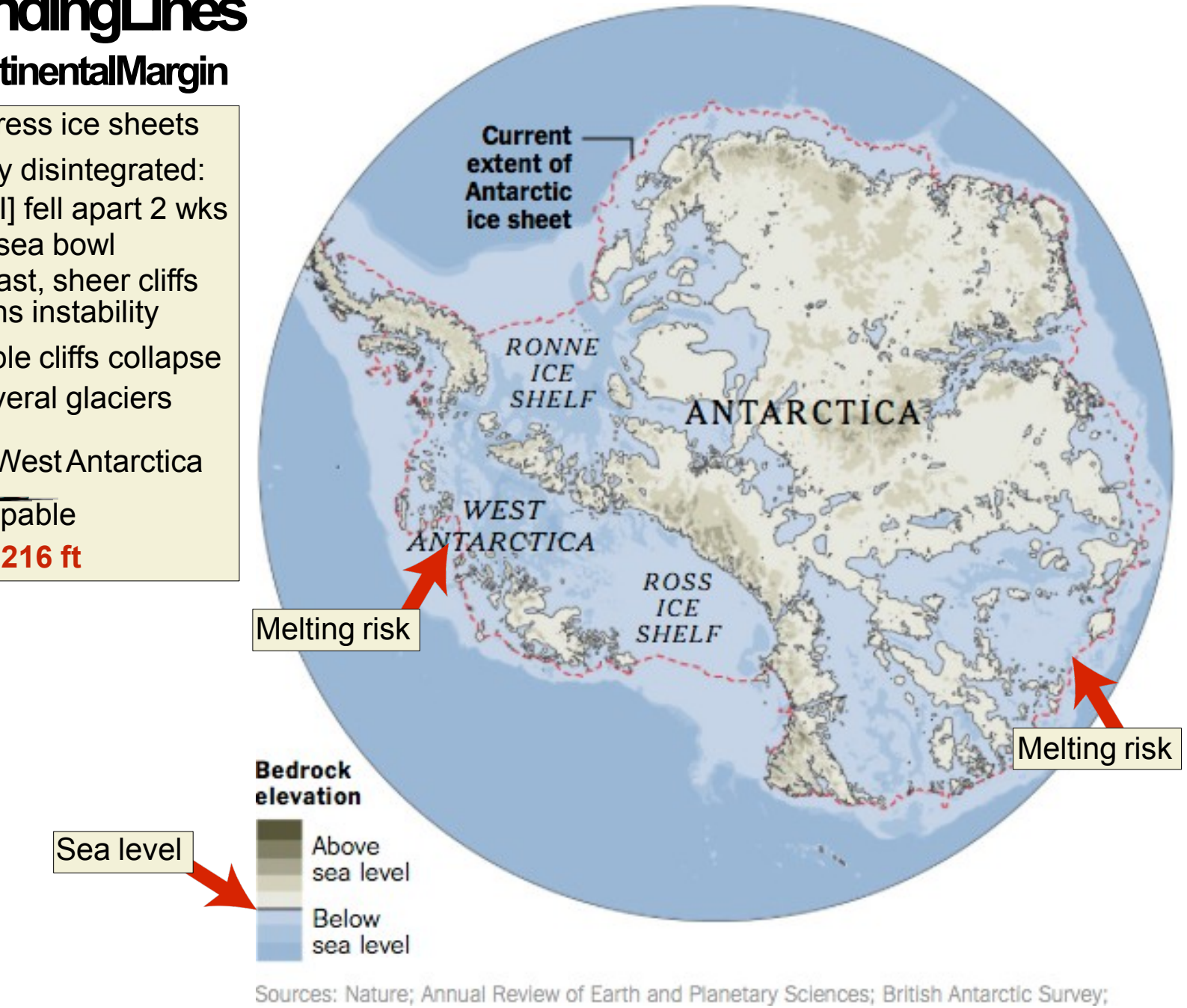
Nearby ice shelves already disintegrated:

- 2002 Larsen B [size RI] fell apart 2 wks
- WAIS sits in deep subsea bowl
- loss ice shelf results vast, sheer cliffs
- summer warming worsens instability

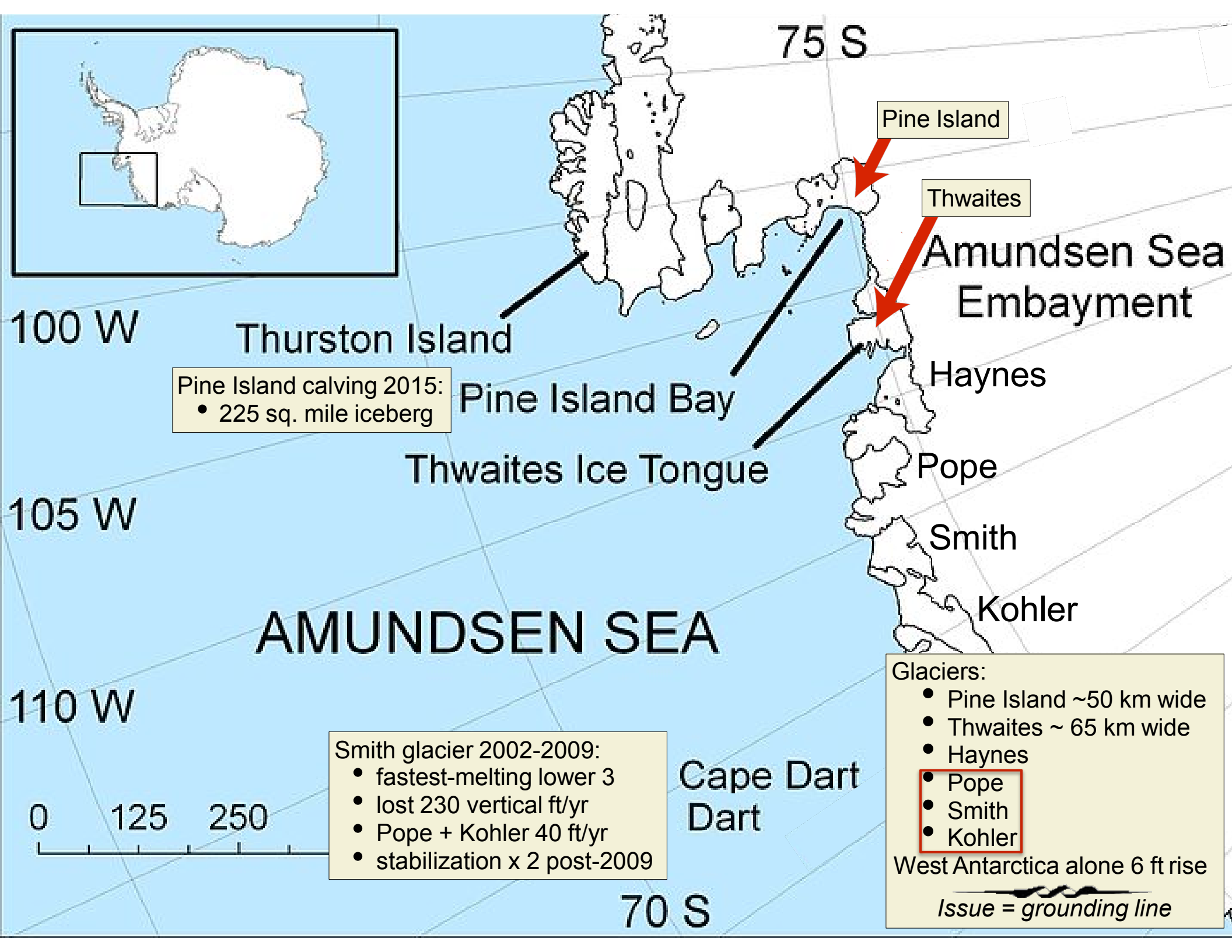
Rapid shrinkage as unstable cliffs collapse

- happening already several glaciers
- least 2 in Greenland
- bigger scale possible West Antarctica

Ice above sea level capable raising oceans **216 ft**



Antarctica fundamentally an archipelago, comparable really to Indonesia


75 S
Pine Island
Thwaites
Amundsen Sea
Embayment
100 W
Thurston Island
Pine Island calving 2015:
• 225 sq. mile iceberg
Pine Island Bay
Haynes
Thwaites Ice Tongue
Pope
105 W
Smith
Kohler
AMUNDSEN SEA
110 W
Glaciers:
• Pine Island ~50 km wide
• Thwaites ~ 65 km wide
• Haynes
• Pope
• Smith
• Kohler
West Antarctica alone 6 ft rise
Issue = grounding line
Smith glacier 2002-2009:
• fastest-melting lower 3
• lost 230 vertical ft/yr
• Pope + Kohler 40 ft/yr
• stabilization x 2 post-2009
Cape Dart
Dart
0 125 250
70 S

Miami Vulnerability

Defenseless against Sea Level Rise

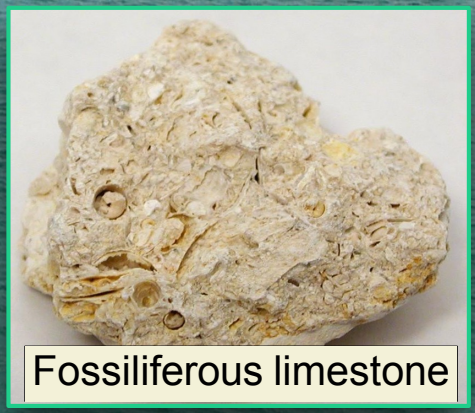
Miami from sea:

- third tallest skyline in US with > 300 high-rises
- 2010 ranked 7th in US finance, commerce, culture, entertainment, fashion, education
- largest concentration international banks in US
- Port of Miami "Cruise Capital of the World"

Geology + topography:

- broad plain Everglades to Biscayne Bay
- bedrock porous + permeable limestone
- highest point **40 ft** + mean altitude **6 ft**

Tufa limestone



Fossiliferous limestone

Southern Florida
Recurrent King Tides

Jan2016 Miami-Dade County meeting:

- Miami-area mayors + administrators
- discussion rising sea levels
- somewhere between pessimism + panic

Agenda:

- crafting flood prediction maps
- prioritizing certain roads, schools, hospitals
- threatened saltwater intrusion in aquifer
- threatened immersion **1.6 M** septic systems

Someone brought up alarming possibility sea engulfing nearby Turkey Point nuclear plant

Short-term Carbon Sinks Overflowing

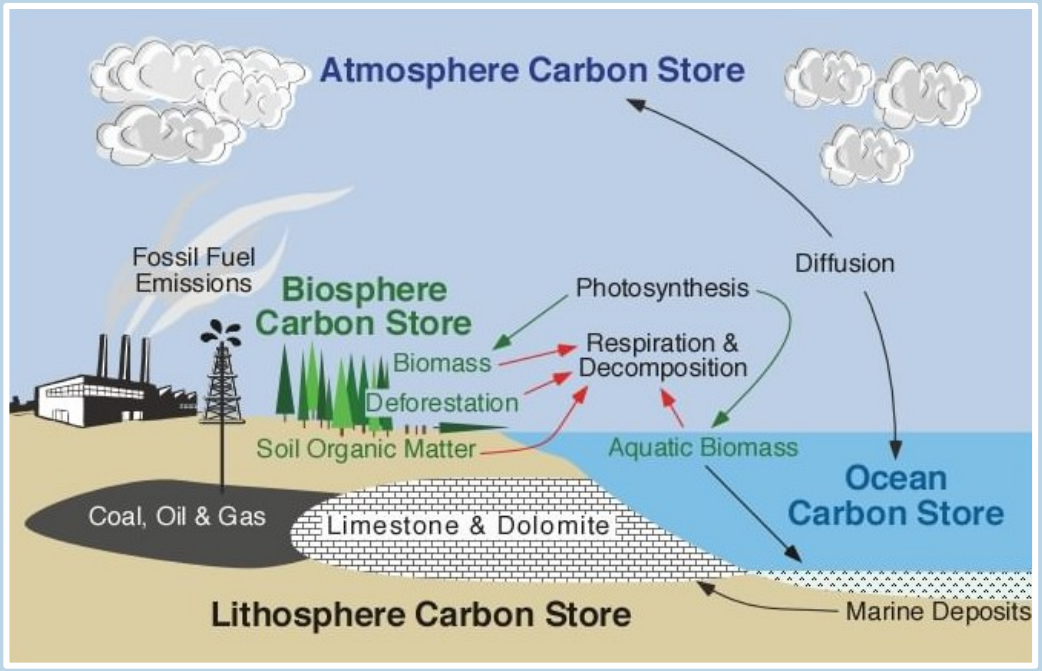
Kyoto protocol incorporates understanding that we should keep T rise under 2ºC

Key risk = positive feedbacks:

- permafrost melting
- methane clathrate emissions
- decreased albedo of melted snow/ice
- Amazonian desertification

2900 GtC is what FF corporations & countries are *absolutely* prepared to put into atmosphere + ocean [coupled with ongoing deforestation]

Nearly **11,000 GtC** remaining ultimately recoverable resources (RURR)



Nature Climate Change Feb2016 carbon budget:

- cumulative carbon emissions
- **590-1240 GT** CO_2 2015 onwards
- 2/3 chance keeping below 2°C
- 2014 up 0.7% but 2015 + 2016 *stabilized*
- 2016 absolute emissions **32 GT** from IEA

Globally these reserves should remain untouched 2010 to 2050 to meet 2°C target

- 33% of oil reserves
- 50% of gas reserves
- > 80% of current coal

Nature Jan2015

$$\frac{2900}{650} \sim 5 \text{ x tolerable reserves}$$

$$\frac{11{,}000}{1100} \sim 10 \text{ x tolerable RURR}$$

Long-term carbon sinks deep soil + oceans + carbonate rocks

So what have we learned?

How much warmer will it get?

1890s: Svante Arrhenius calculated the temperature increases from increasing the concentration of CO_2 in the atmosphere;

First prediction of global warming 1896

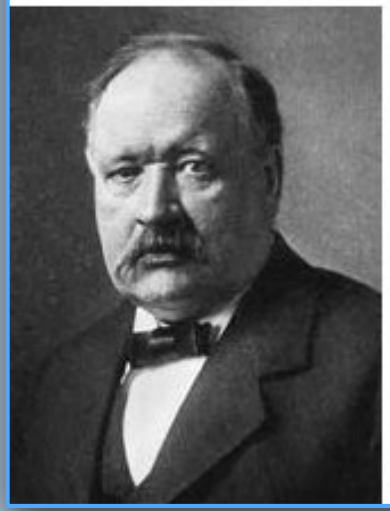


TABLE VII.—*Variation of Temperature caused by a given Variation of Carbonic Acid.*

Latitude.	Carbonic Acid = 0·67.					Carbonic Acid = 1·0.					Carbonic Acid = 2·0.					Carbonic Acid = 2·5.					Carbonic Acid = 3·0.				
	Dec., Jan., Feb.	March, April, May	June, July, Aug.	Sept., Oct., Nov.	Mean of the year	Dec., Jan., Feb.	March, April, May	June, July, Aug.	Sept., Oct., Nov.	Mean of the year	Dec., Jan., Feb.	March, April, May	June, July, Aug.	Sept., Oct., Nov.	Mean of the year	Dec., Jan., Feb.	March, April, May	June, July, Aug.	Sept., Oct., Nov.	Mean of the year	Dec., Jan., Feb.	March, April, May	June, July, Aug.	Sept., Oct., Nov.	Mean of the year
70	−29	−30	−34	−31	−31	33	34	28	26	30·5	60	61	60	61	60·5	79	80	79	80	79·5	91	92	94	94	93
60	−30	−32	−34	−33	−32·5	34	32	30	28	31·0	61	61	58	61	60·5	80	80	76	79	78·5	93	93	89	93	92
50	−32	−33	−33	−34	−33	37	36	34	37	36·0	61	61	55	60	59·3	80	79	70	79	77	93	94	86	92	91·7
40	−34	−34	−32	−33	−33·2	37	36	33	36	35·5	60	59	54	56	57	79	76	69	75	74·5	93	90	82	88	88·2
30	−33	−32	−31	−31	−31·7	35	33	32	33	33·2	56	54	50	52	53	72	70	64	67	68·2	87	83	76	79	81
20	−31	−31	−29	−31	−30·5	35	32	31	32	32·5	52	50	49	50	50·3	67	66	63	66	65·5	79	75	72	75	75·3
10	−31	−30	−30	−30	−30·2	32	32	31	31	31·5	50	50	49	49	49·5	66	64	63	64	64·3	74	73	72	73	73·0
0	−30	−30	−31	−30	−30·2	31	31	32	32	31·5	49	49	50	50	49·5	64	64	66	66	65·0	73	73	74	74	73·5
−10	−31	−31	−32	−31	−31·2	32	32	32	32	32·0	50	50	52	51	50·7	66	66	67	67	66·5	74	73	76	76	74·8
−20	−32	−32	−33	−32	−32	32	32	34	33	32·8	52	53	55	54	53·5	67	68	70	70	68·8	79	81	86	83	82·2
−30	−33	−34	−34	−33	−33·5	34	35	37	35	35·3	55	56	58	58	56·8	70	72	73	74	72·3	86	87	91	89	88·3
−40	−34	−34	−33	−34	−33·8	36	37	39	37	37·3	58	60	60	60	59·5	72	79	79	79	77·3	91	92	94	93	92·5
−50	−32	−33	—	—	—	38	37	—	—	—	60	61	—	—	—	79	80	—	—	—	94	95	—	—	—

Time for the review....
or perchance questions?

Albedo important for uv + visible light, irrelevant for infrared

Our planet is a **thermos** bottle, with energy flux in + out only via long-wave + short-wave radiation

Our planet would have been inhospitable to hominins for billions of years, until quite recently

Global mean surface temperature last 4 billion yrs constrained within **15ºC = 27ºF** range, change seemingly *imperceptible* since seasonal + even daily temperature swings often greater

Net additional anthropogenic TOA *radiant forcing* of **2.29 W/m²** sounds innocuous, but globally equivalent to 4 Hiroshima-sized weapons/second

Fossil fuel reserves held by companies + countries = approximately **5 times** amount of carbon that IPCC argues atmosphere can tolerate without exceeding 2ºC rise

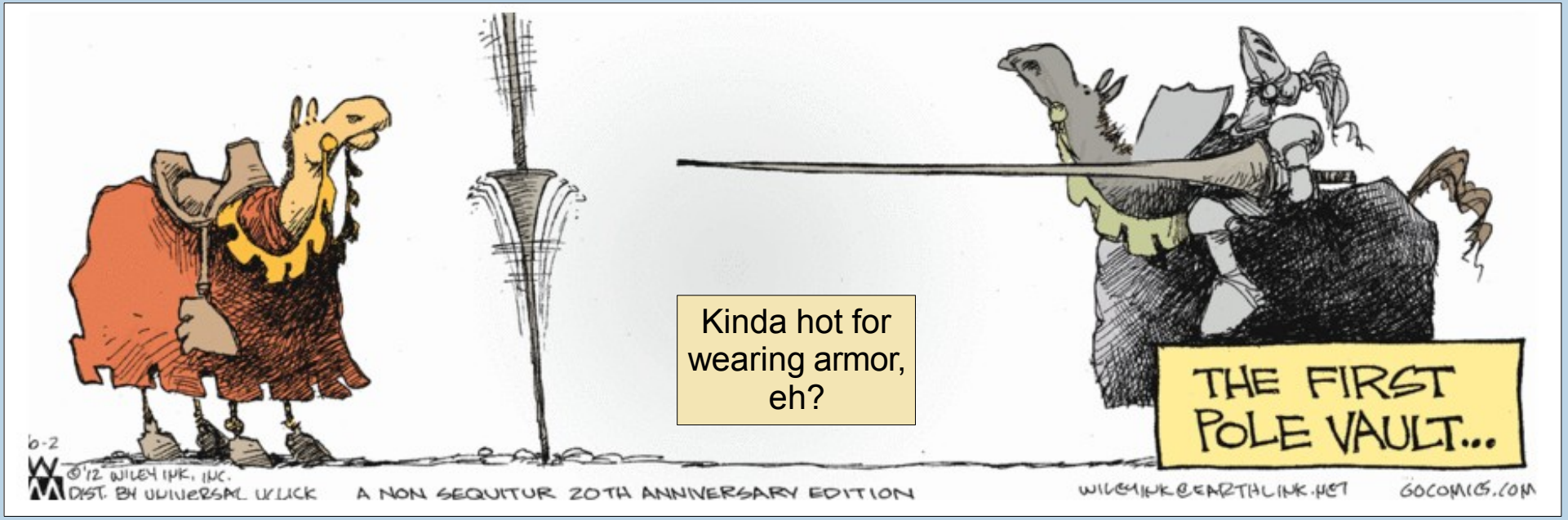
Humans send gases + aerosol particles into atmosphere

2015 only 9 CCS plants working + in construction, while we would need **16k** plants for control current CO2 alone plus **11k** more each yr to manage accelerating emissions under a scenario of 'business as usual with blinders on'

2/3 of global petroleum + NG reserves held either by 10 companies or 10 countries

If all ice melts, we lose **10%** of land surface + all our coastal cities

Interglacial periods expected to continue long as summer insolation large enough to prevent ice sheet **genesis**



Thank you!

Sandy Lawrence

sandy.george.lawrence@gmail.com