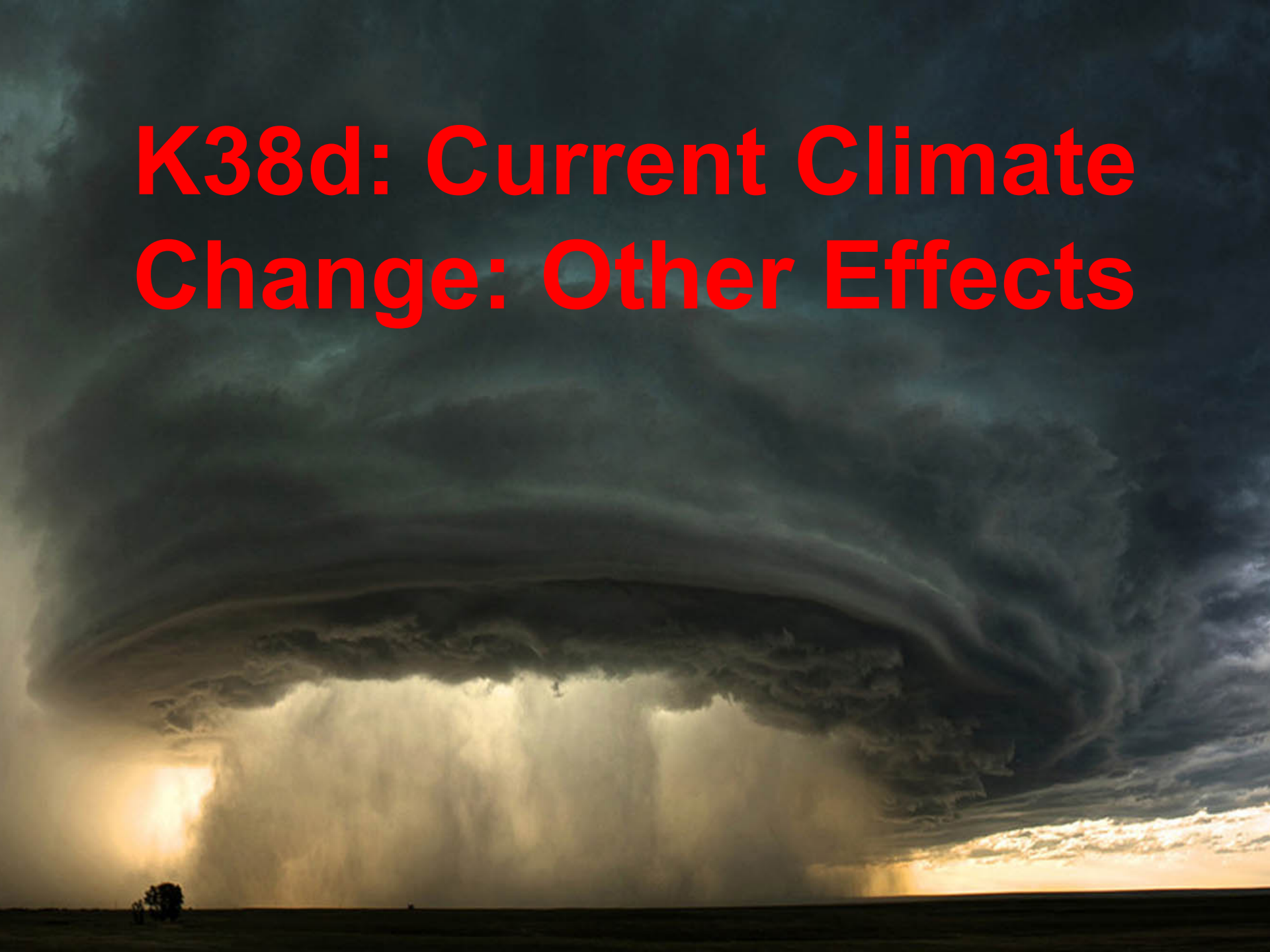


K38d: Current Climate Change: Other Effects

- 1. Global phytoplankton decline
- 2. Slowdown of Ocean Currents
- 3. Declining oxygen in air and oceans
- 4. Rising nighttime vs daytime temps
- 5. Stronger hurricane winds
- 6. Mass extinctions
- 7. Ocean acidification and death of coral reefs
- 8. Rising methane levels
- 9. Poleward expansion of deserts
- 10. Tropical diseases spreading north

1. Global Phytoplankton in Decline

- Marine phytoplankton account for 46% of the primary productivity of the Earth
- An early estimate of 40% phytoplankton decline since 1950 was too high, and re-analysis by the same and conflicting authors together shows regionally varying and much smaller rates of change (Boyce *et al.* 2014)
- What might cause phytoplankton loss?
- Surface-warmed and more stratified oceans inhibit nutrient upwelling from below and thus limit growth, for one

Boyce *et al.* 2014: Most Oceans Show Declining Chlorophyll in Surface Waters

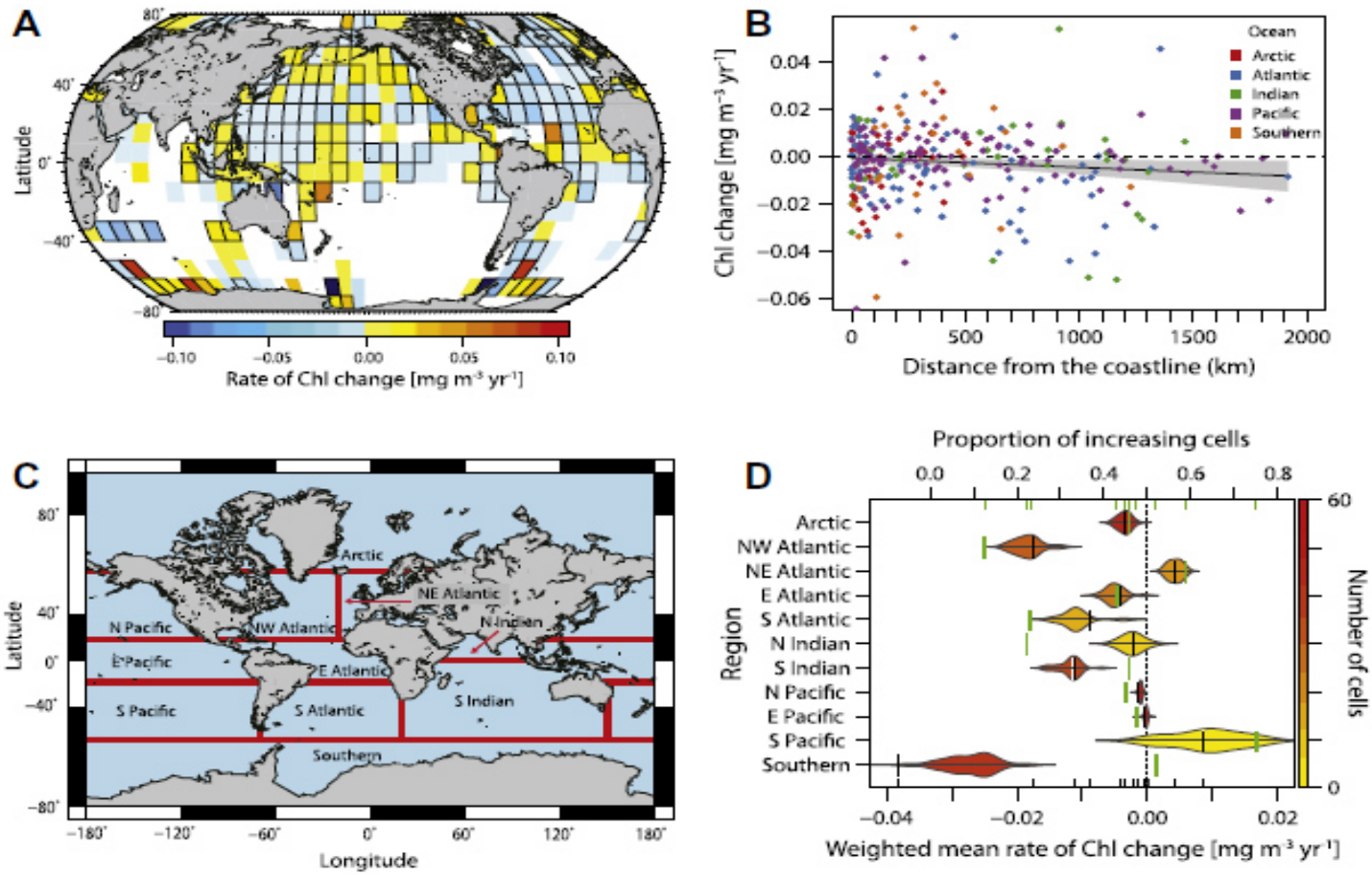


Fig. 1. Local-scale phytoplankton trends. (A) Estimated instantaneous linear rate of Chl change in each 10° × 10 cell (n = 280). Color coding indicates the average rate of change over the available time series. Cells bordered in black denote statistically significant rates of change ($P < 0.05$) and white cells indicate cells with insufficient data. (B) Chl change in each 10° × 10 cell as a function of distance from the nearest coastline (km). Colours indicate the ocean where the cell was located. Solid trend line was derived from a weighted linear model; shaded area is the 95% confidence interval; dashed line represents no change in Chl. (C) Ocean regions (n = 11) used to estimate regional trends in Chl (D) Weighted mean Chl changes estimated by aggregating local estimates within each region. Shapes ('Raindrops') represent the probability distribution of the individual local estimates. The weighted mean rates of Chl change are depicted as black vertical lines, and the width of the raindrops and gray horizontal lines are the 95% confidence limits about the means. The colours of the raindrops depict the number of cells within each region. Green vertical lines are the proportion of increasing cells within each region. Black and green tick marks on the axes represent the individual rates or proportions of change, respectively. Dashed line represents no change.

Boyce *et al.* 2014: Sample-weight phytoplankton trends Shaded. Most Oceans Show Decline

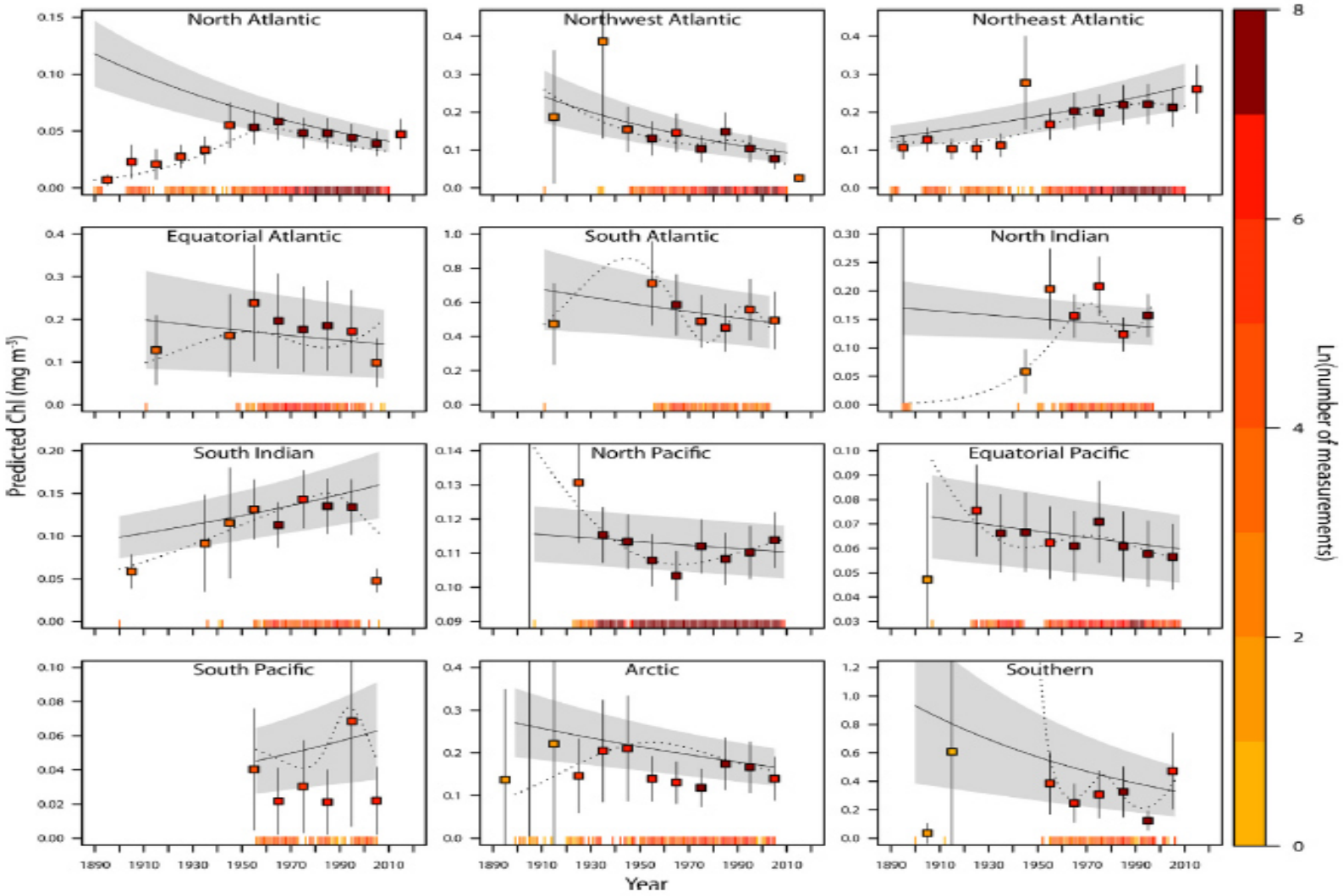
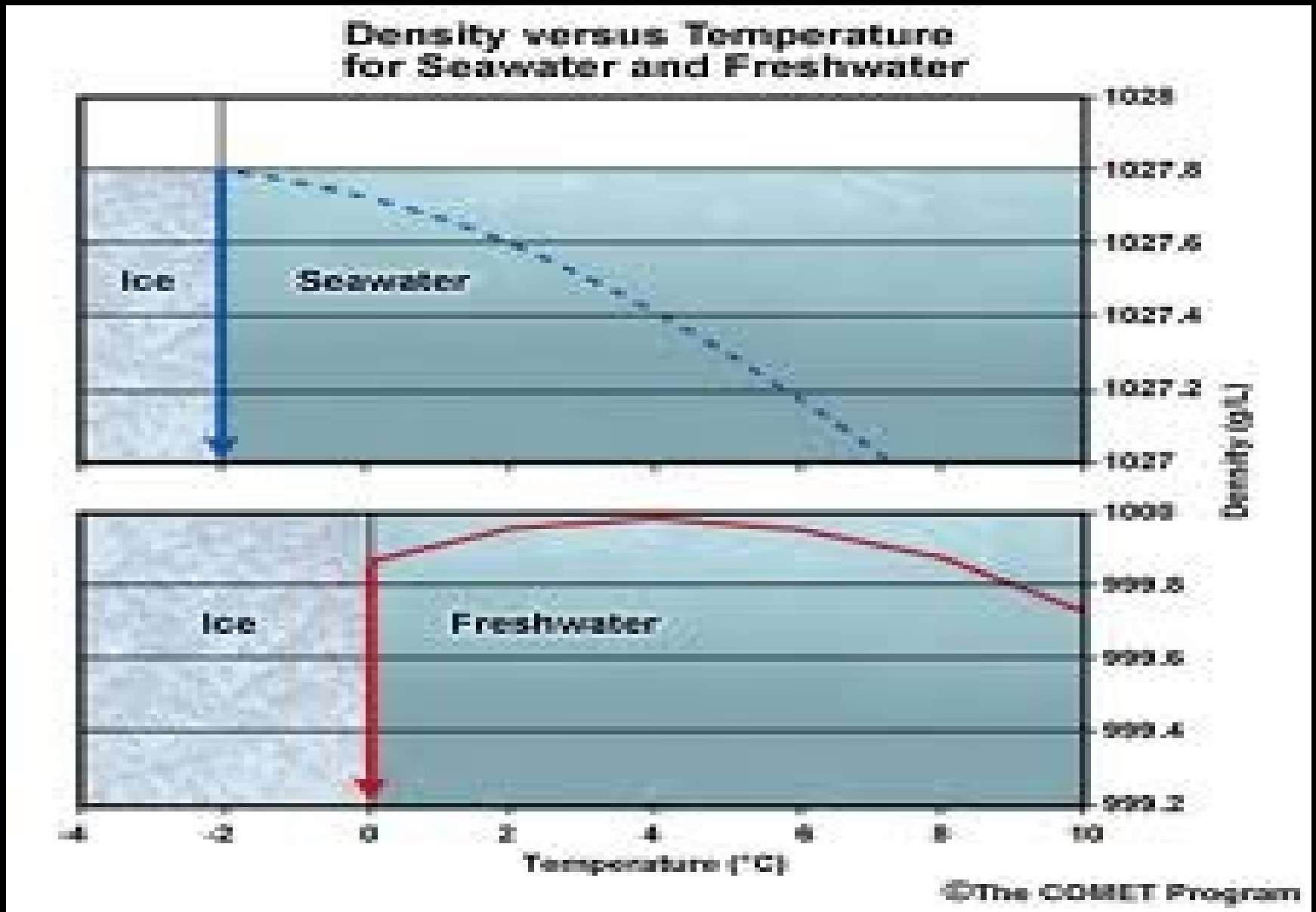


Fig. 2. Temporal trajectories of phytoplankton. Estimates of relative Chl as a discrete (square points), log-linear (lines), and smooth (dotted lines) function of temporal variability in each region ($n = 11$). Tick marks on the x-axis represent the availability of data through time. The color of tick marks and points represents the scaled number of observations available in each year (tick) and decade (point). Shaded areas represent approximate 95% Bayesian credible limits around each log-linear trend. The magnitudes of predicted Chl are not exact, but rather representations which depend on the values of the model covariates selected for prediction.

2. AMOC Slowdown: Another Predicted Effect of Polar Melt and Increasingly Stratified Oceans

- Since 2004 we've had a set of 22 sensors deployed in the tropical Atlantic to monitor the strength of the **AMOC (Atlantic Meridional Overturning Current**).
- They find a **large 3% per year decline in the strength of the AMOC current (linked to polar climate scientist Stefan Rahmstorff in RealClimate.org)**
- *"If our analysis is correct, then this indicates that climate models underestimate the weakening of the Atlantic circulation in response to global warming – probably because the flow in these models is too stable (see Hofmann and Rahmstorf 2009).* ***Although these models predict a significant weakening for the future, they do not suggest this as early as the observations show it*** *(see Fig. 2 of our paper). That the real flow may be more unstable than previously thought would be bad news for the future."*

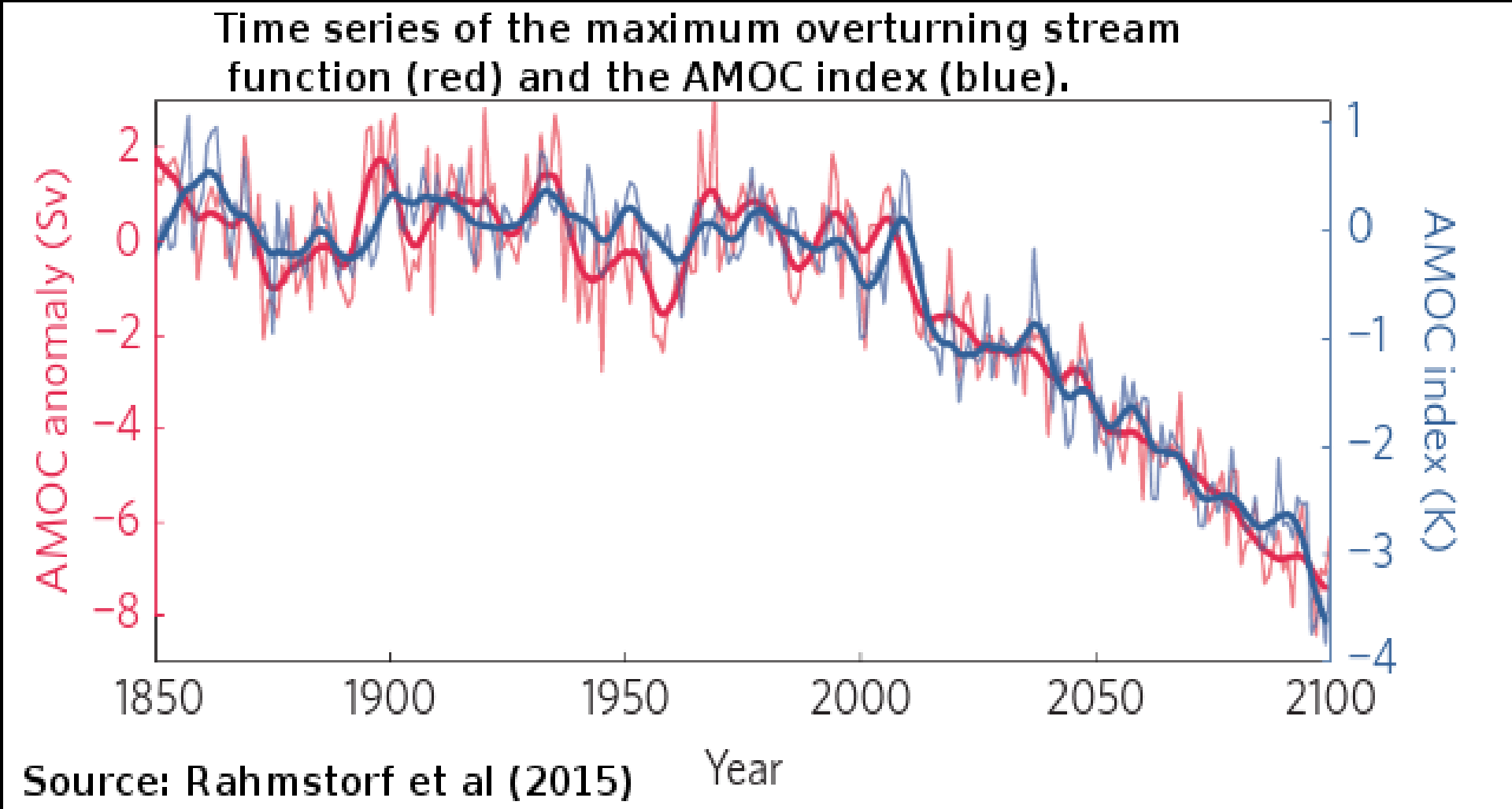
Fresh Meltwater is 2.7% Less Dense than Seawater, Inhibiting Polar Sinking and Global Conveyor Currents



Rahmstorf Continues

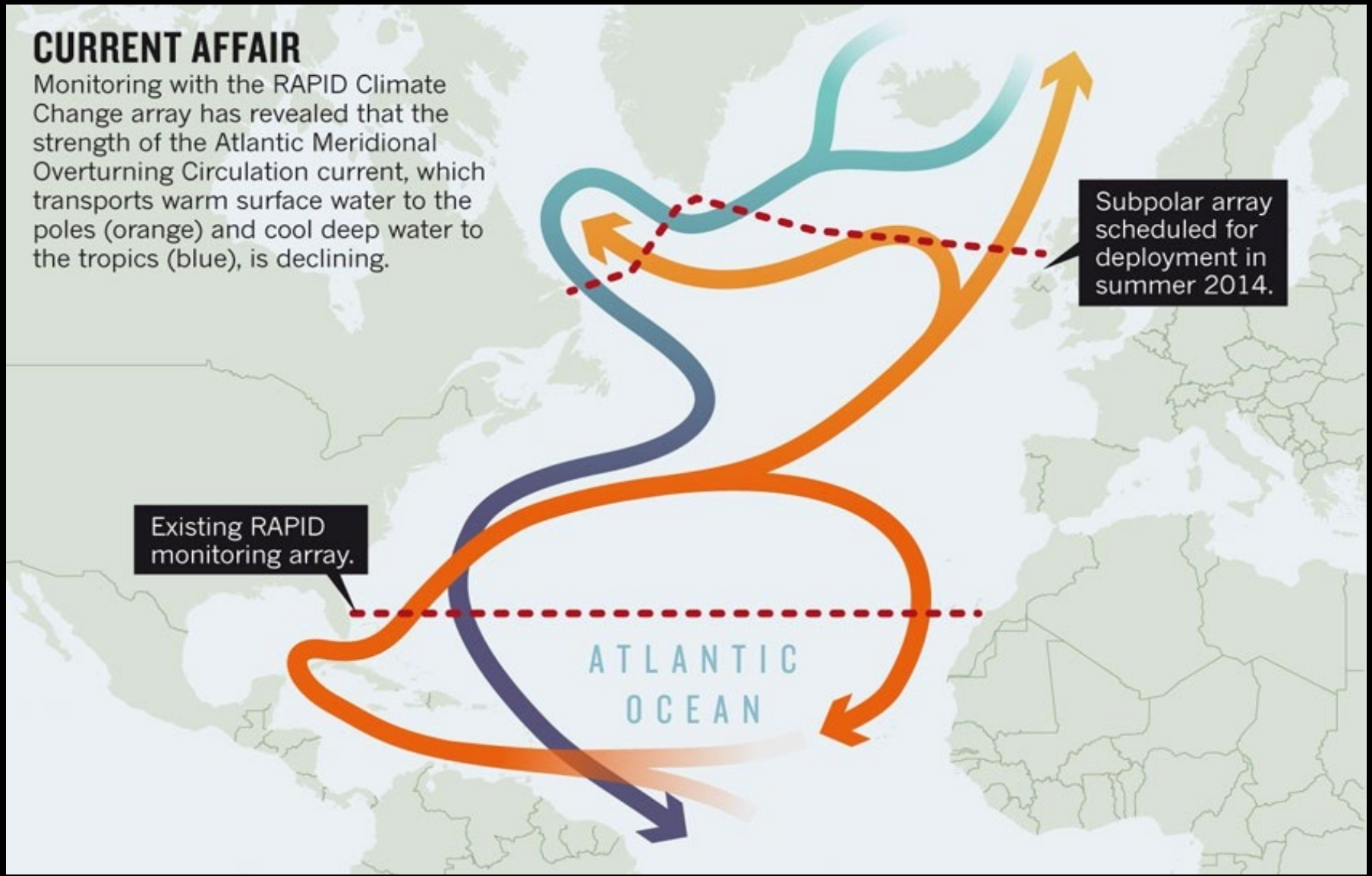
- *"If the circulation weakens too much it can even completely break down – the AMOC has a well-known "tipping point" (Lenton et al., 2008). The latest IPCC report (just like the previous one) estimates a probability of up to 10% that this could happen as early as this century. However, this assessment is based on models that may underestimate the risk, as mentioned above. Expert surveys indicate that many researchers assess the risk higher than the (generally conservative) IPCC, as is the case for sea level. In a detailed survey (Kriegler et al. 2009), the 16 experts interviewed saw already at moderate global warming (+2-4 °C) a* ***probability of a 'tipping' (major re-organization) of the flow between 5 and 40 percent. With strong global warming (4-8 °C) this probability was even estimated as between 20 and 65 percent."***

The strength of the AMOC is declining, and predicted to continue (Rahmstorf *et al.* 2015)



Source: Rahmstorf et al (2015)

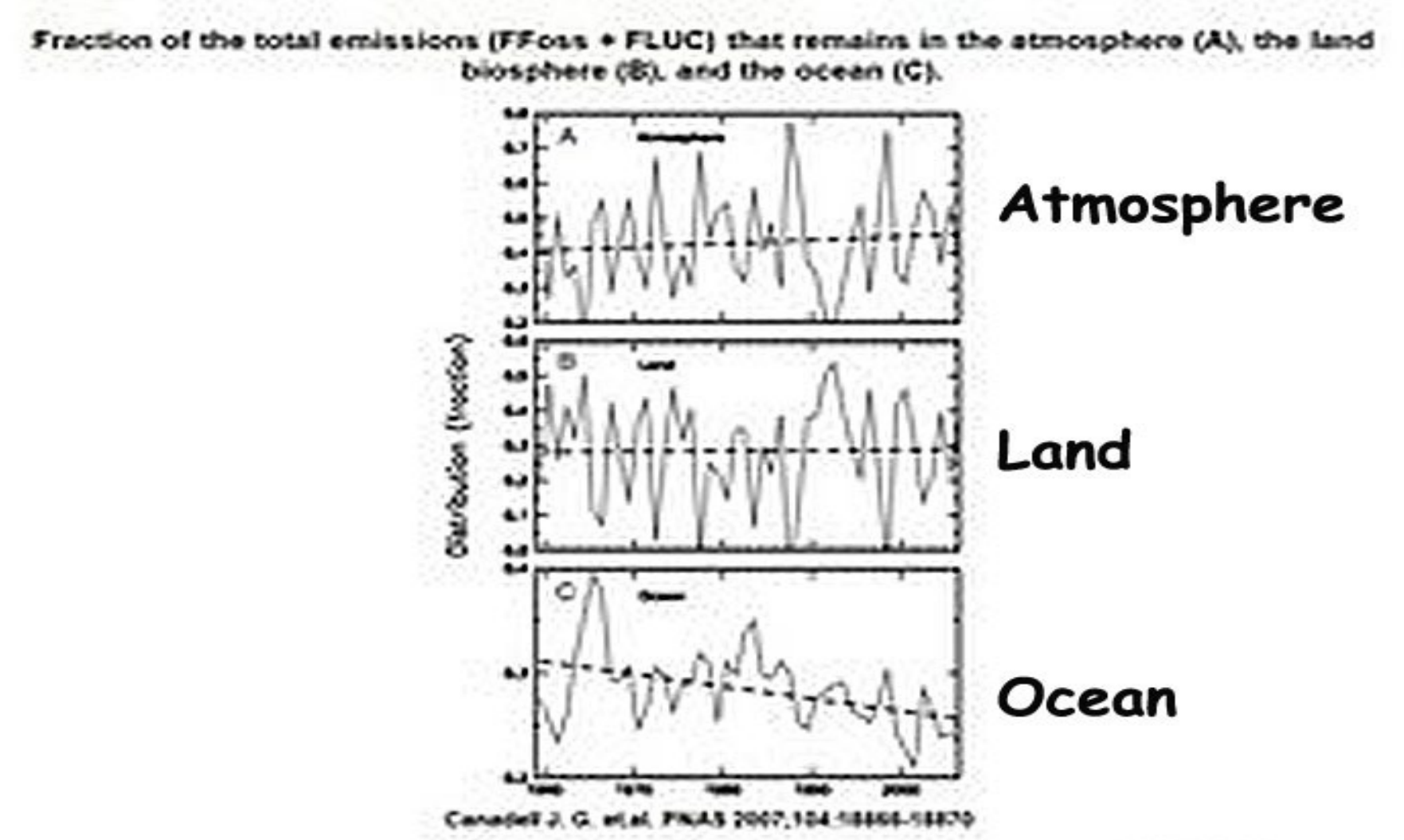
New studies as of 2018… Continued Weakening, but better data show complex flow patterns, raise uncertainties in absolute total flow.



3. Oxygen Content of the Air and Oceans is Dropping

- More of our atmospheric oxygen is getting bound up with carbon to become CO2 – a very tough, tightly bound molecule
- Warmer oceans can hold less dissolved oxygen (and less dissolved CO2 as we saw)
- Increasing ocean stratification due to slowing thermohaline current and to lessened resulting upwelling is starving the phytoplankton which produces ½ of our oxygen.

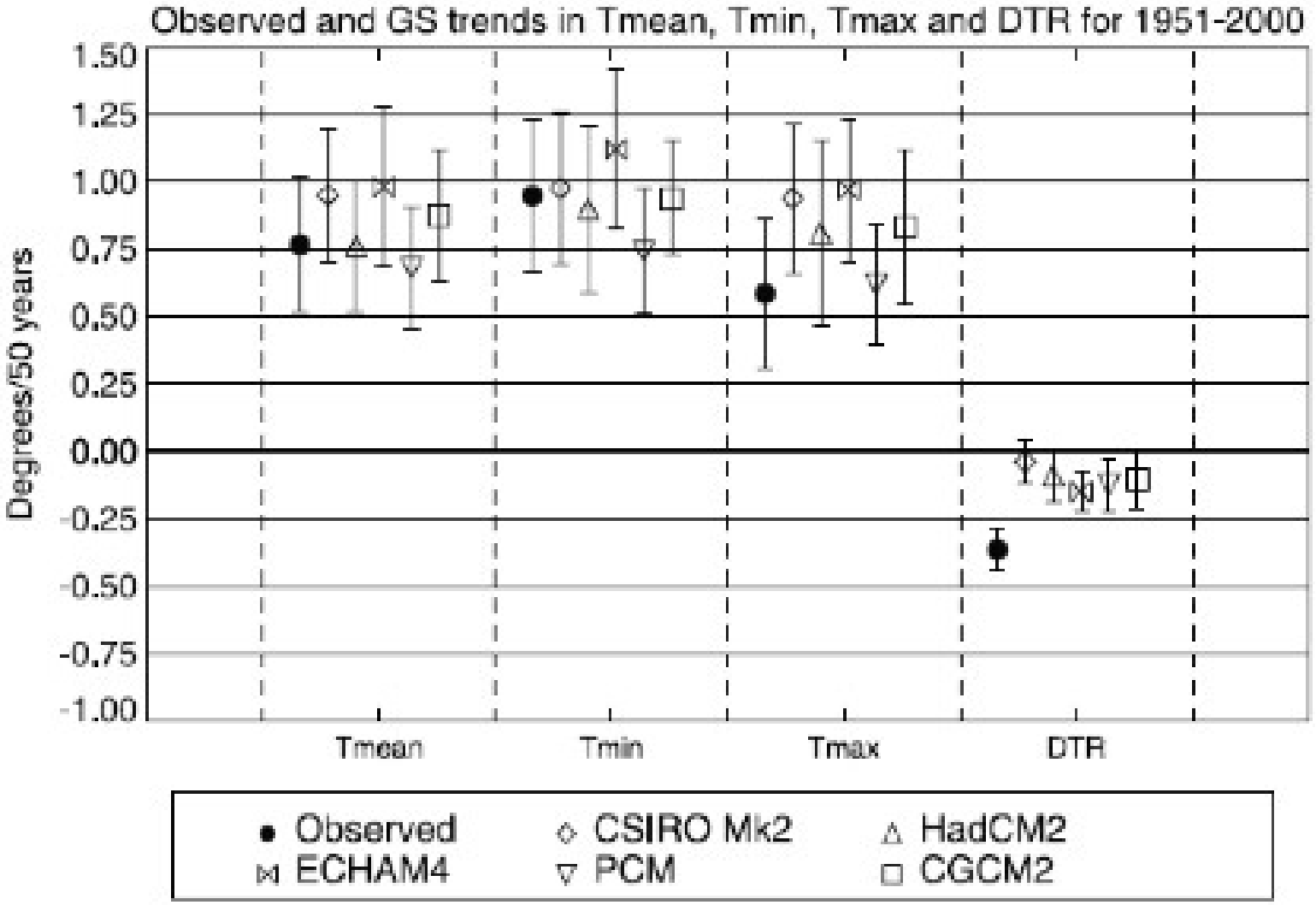
Bottom axis= time 1960-2007. Vertical axes: Fraction of total emission of carbon which remains in the atmosphere (top), taken up by land biosphere (middle), and taken up by ocean (bottom). Note as the ocean absorbs more CO2 and warms, it is becoming less effective at soaking up additional CO2. Land more complicated, as CO2 helps plants early on, but eventually dries soils and rapid growing zone shifts cripples plants (sorry for the terrible copy of this tiny graph.)



4. Night temperatures rising faster than Day temperatures, as predicted…

- …causes a decrease in the daily temperature range (DTR) (Braganza 2004).
- This too is a unique prediction of greenhouse effect warming (Alexander 2006). Why? Because temperatures reflect the integrated heating that has already happened during the day, so that peak temperatures occur in the late afternoon, not at noon as you'd naively expect if there were no lag. The hot ground can't then efficiently radiate away this heat into the evening because it is trapped by CO2, and this keeps night-time temperatures warmer.
- Daytime temperatures are warmer too but not as much as night time temps, because it is not increased incoming sunlight that is causing Global Warming, it is human-caused greenhouse gases inhibiting re-radiated cooling, which happens mostly late evening.

Night-time minimum temps are rising faster than are daytime maximum temps, although both are rising. This is a classic signature of greenhouse warming.



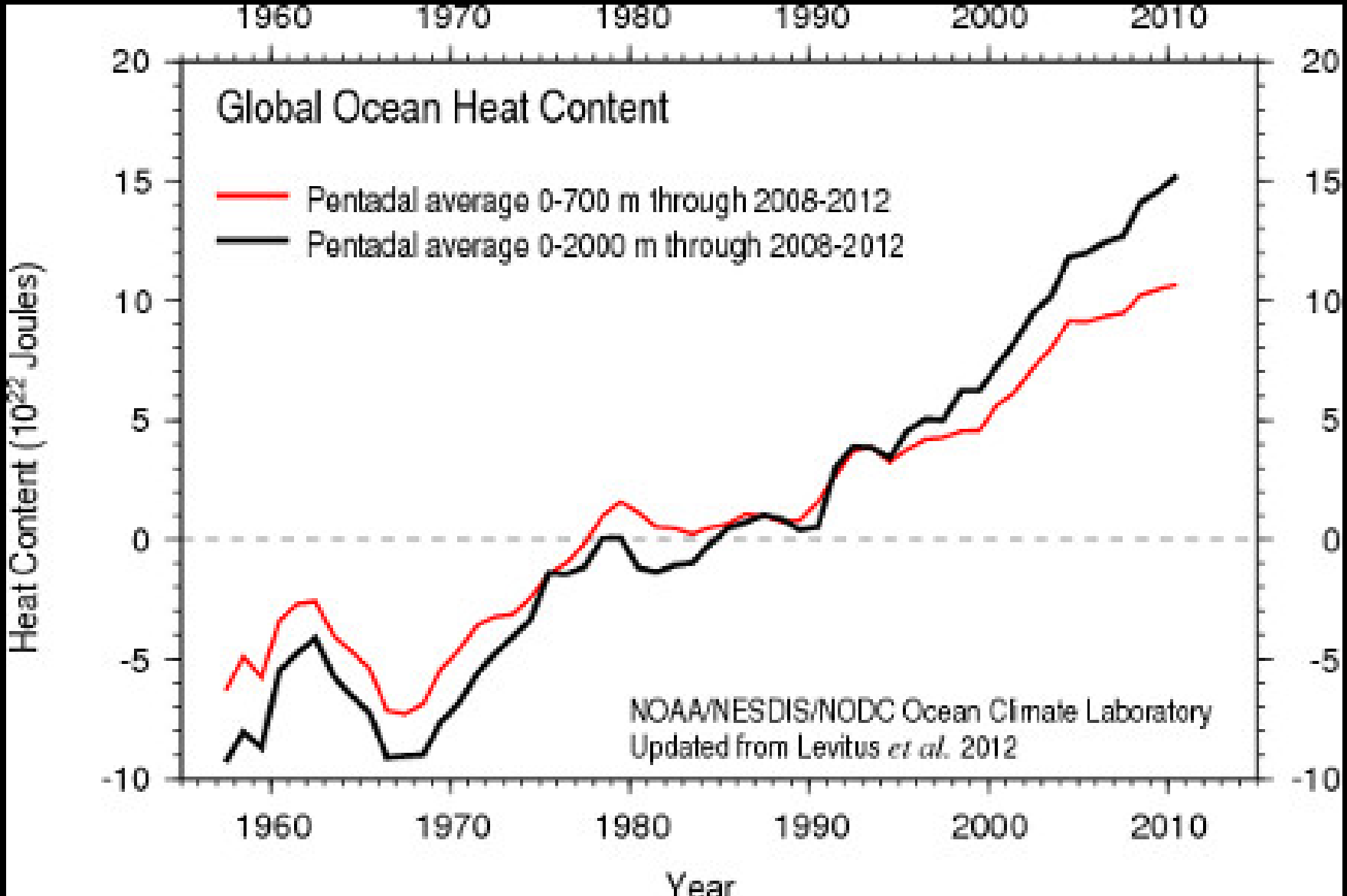
This is Bad.

- **Since it is the cold temperatures at night which controlled pine bark beetles, zika mosquitoes, and many other pests.**
- Note in the mid/late 20th century data cooling by human-generated aerosol pollution and the PDO cool phase caused daytime temperatures to stay roughly constant in spite of increasing CO2, while nighttime temperature increased (**Wild, Ohmura, and Makowski 2007**).
- **However, the DTR is a subtraction of two datasets which both have noise, and is therefore noisier. Also, rising human-caused aerosols also affect night *vs* day temperatures in ways not well quantified yet.**

Preferentially Rising Night Temps: Implications

- A study in 2015 **(post IPCC AR5)** shows that rising night time temperatures will **decrease** the amount by which forests can sequester CO2.
- Plants and trees give back some photosynthesized CO2 to the atmosphere at night, and the higher temperatures will alter the balance between photosynthesis and respiration.
- **This could cause forests to stop their net sequestering carbon entirely in the future.**

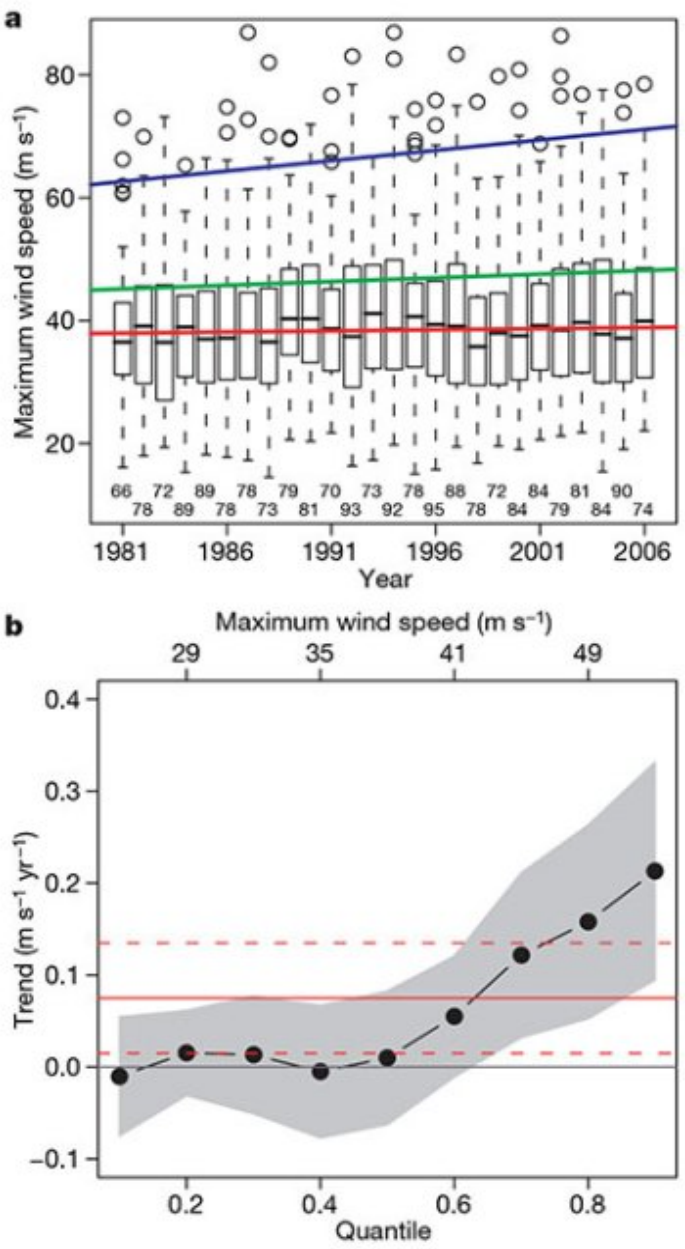
5. Rising Hurricane Winds. Rising Ocean Heat Content has consequences…



Rising Ocean Temperatures Equal More Thermal Energy – Models Predict Rising Hurricane Power, which we are seeing

- Rising ocean temperatures are not predicted to make MORE hurricanes, but they ARE predicted to (on average) make them **stronger**.
- Higher sea surface temperatures drive stronger convection and hence more powerful storms, by straightforward physics, and this is confirmed by data for the past 30 years…

Stronger Hurricane Winds

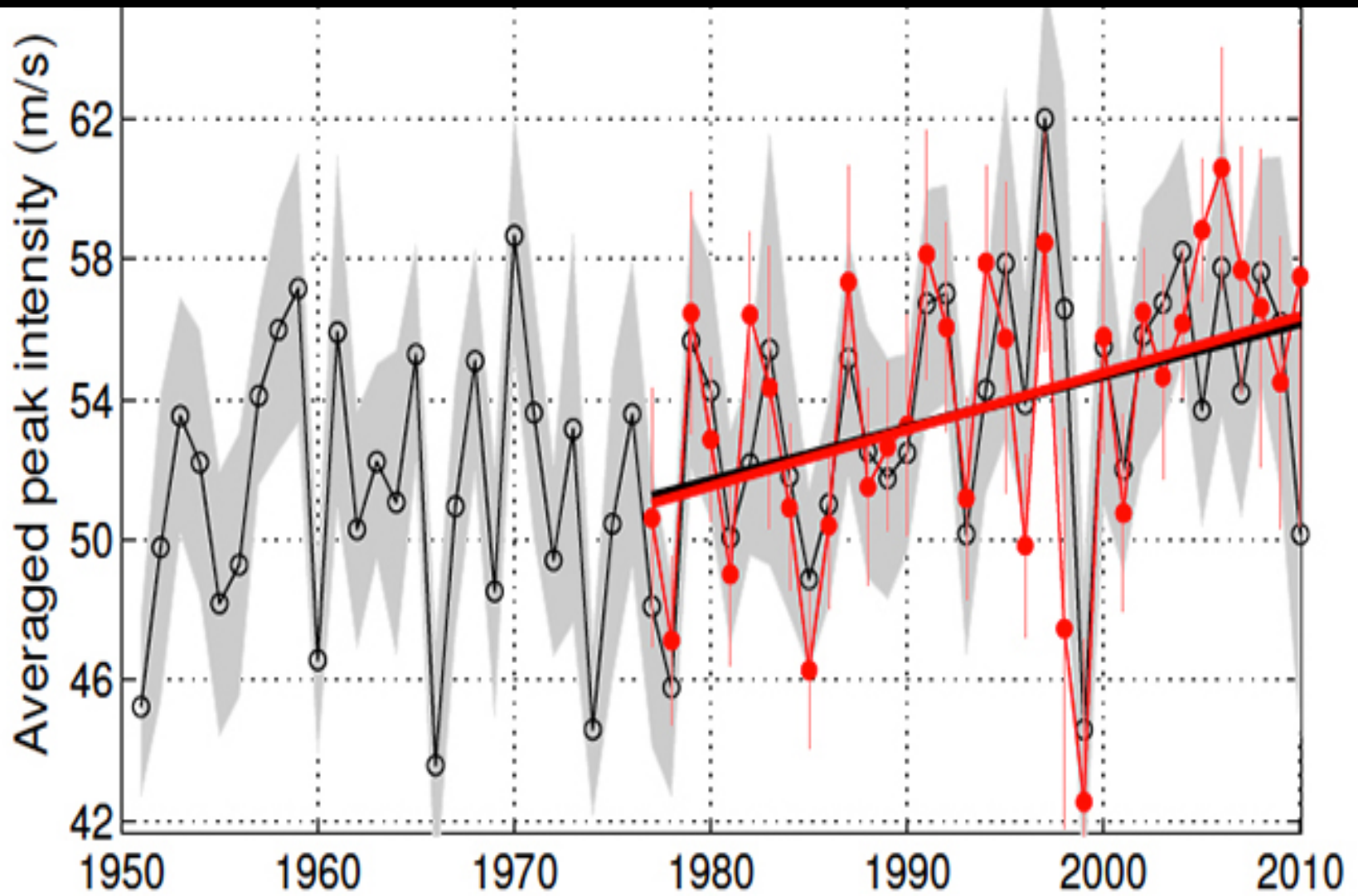


Analysis and model results of satellite-derived tropical cyclone lifetime-maximum wind speeds.

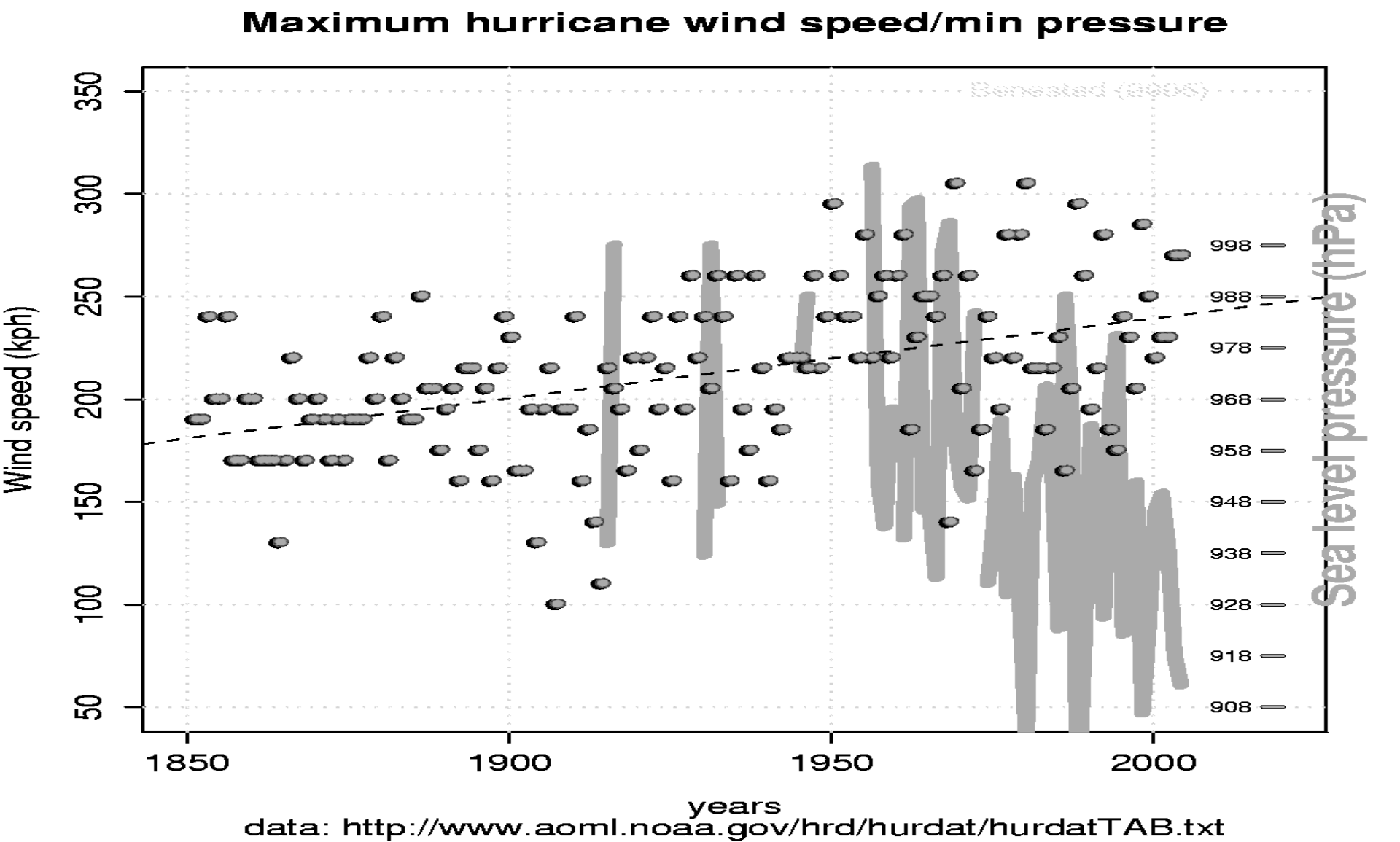
a: Box plots by year. Trend lines are shown for the median, 0.75 quantile, and 1.5 times the interquartile range.

b: Trends in global satellite-derived tropical cyclone maximum wind speeds by quantile, from 0.1 to 0.9 in increments of 0.1. Trends are estimated coefficients from quantile regression in units of metres per second per year. The point-wise 90% confidence band is shown in grey, under the assumption that the errors are independent and identically distributed. The solid red line is the trend from a least-squares regression of wind speed as a function of year and the dashed red lines delineate the 90% point-wise confidence band about this trend.

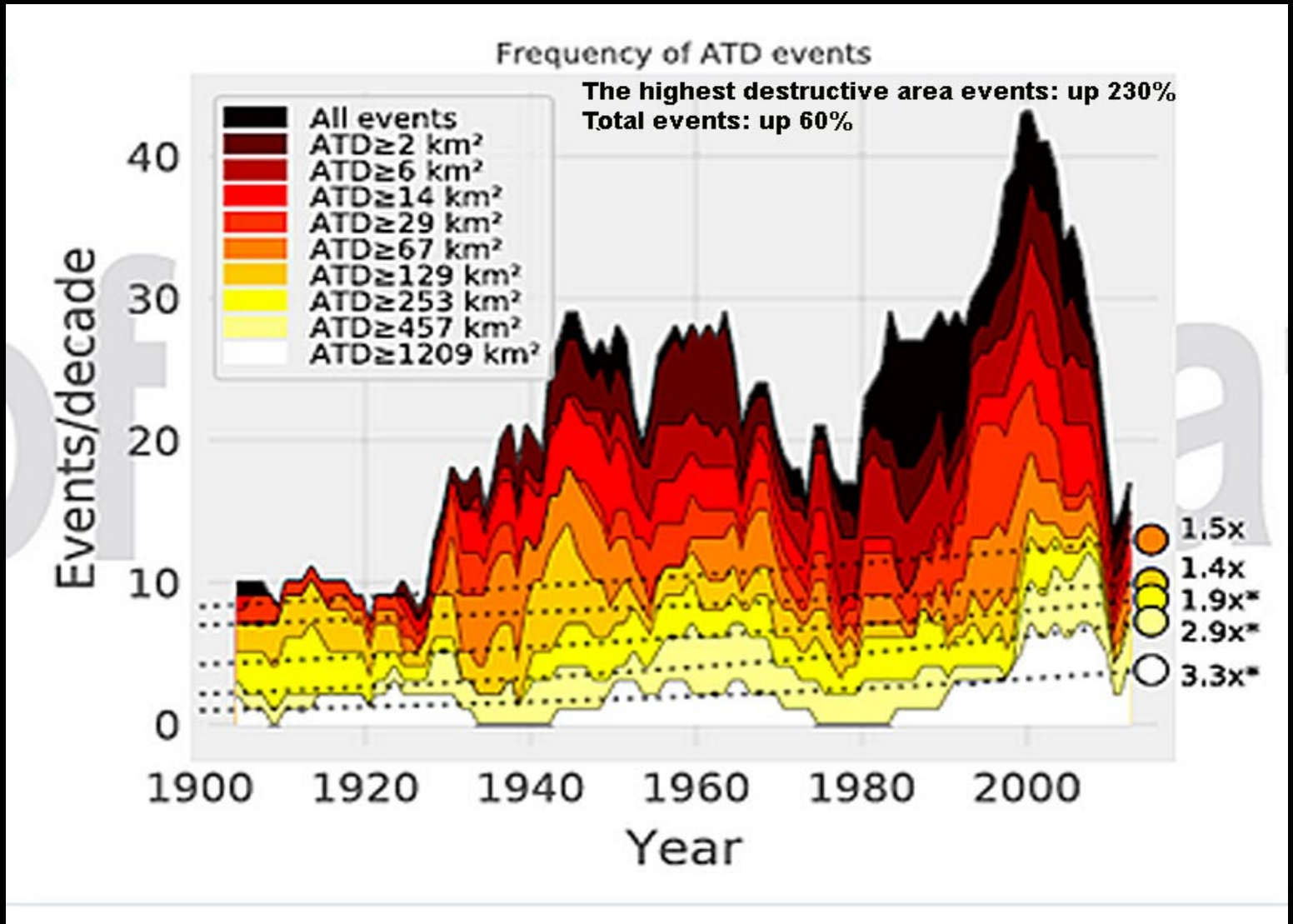
Pacific Hurricanes (Typhoons) – Same trend (Mei *et al.* 2015)



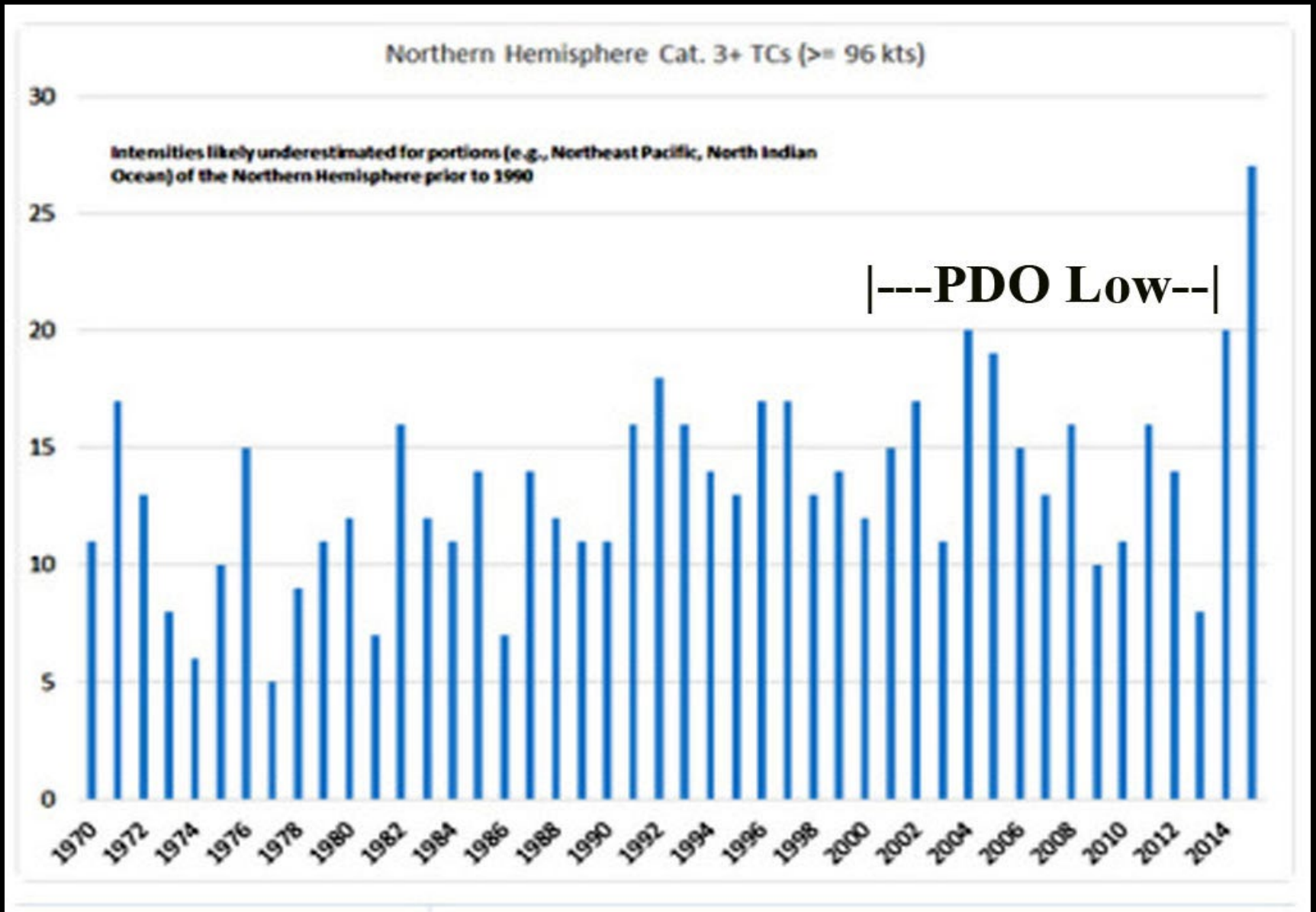
Stronger Convection -> Low Pressure Eye of Storm Deepens (gray) -> Driving Stronger Winds (dots)



ATD “Area of Total Devastation” – grown 50% for small-area events, but grown over 300% for biggest area catastrophic events (Grinsted et al. 2019)

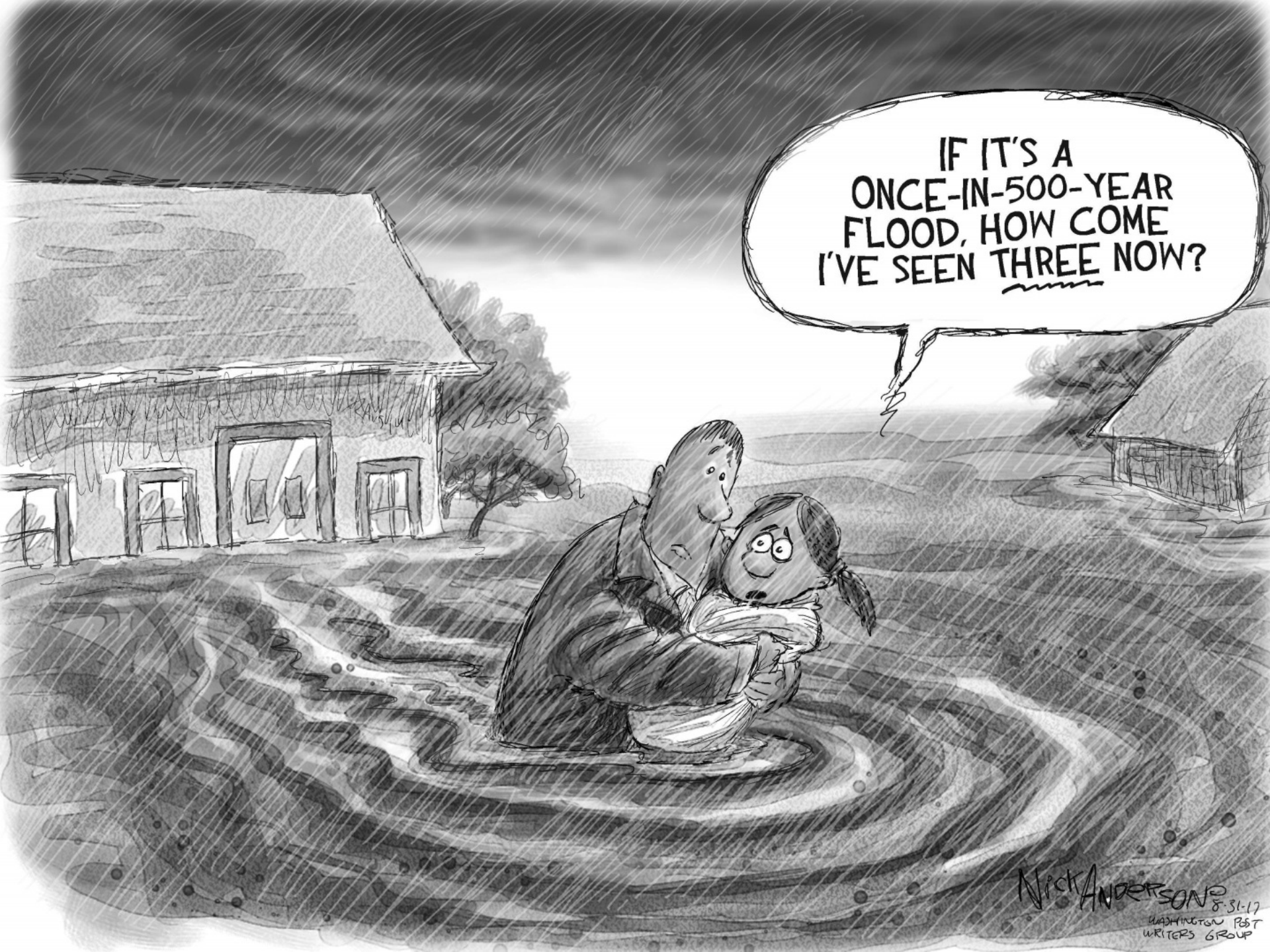


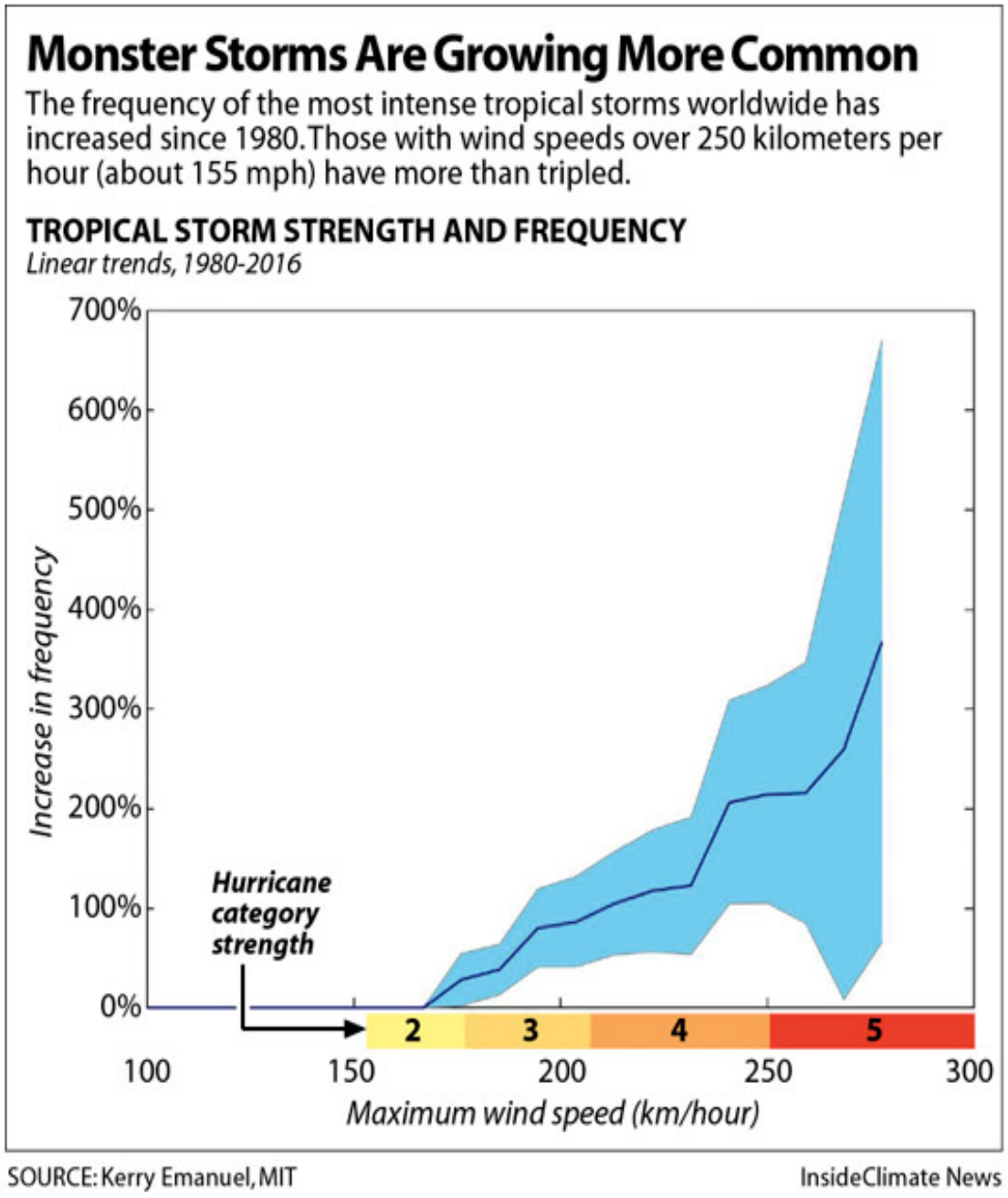
The number of Category 3 or higher tropical storms is rising. (Trend interrupted by cool phase of PDO in recent decade till 2014. Newer data (not shown) amplifies this trend)



With stronger winds, higher humidities, and deeper hurricane pressure gradients…

- … no surprise that we're seeing storms of unprecedented power.
- Hurricane Harvey in 2017 delivered a **once-in-25,000 year deluge to SE Texas.**
- What's more, this same area had a once-in-500 year storm just a year earlier in 2016, and another once-in-500 year storm the year before that – in 2015.
- But, as always… our attention span's only for as long as the standard news cycle, then we tune out.


IF IT'S A ONCE-IN-500-YEAR FLOOD, HOW COME I'VE SEEN THREE NOW?
NICK ANDERSON 8-31-17
WASHINGTON POST WRITERS GROUP

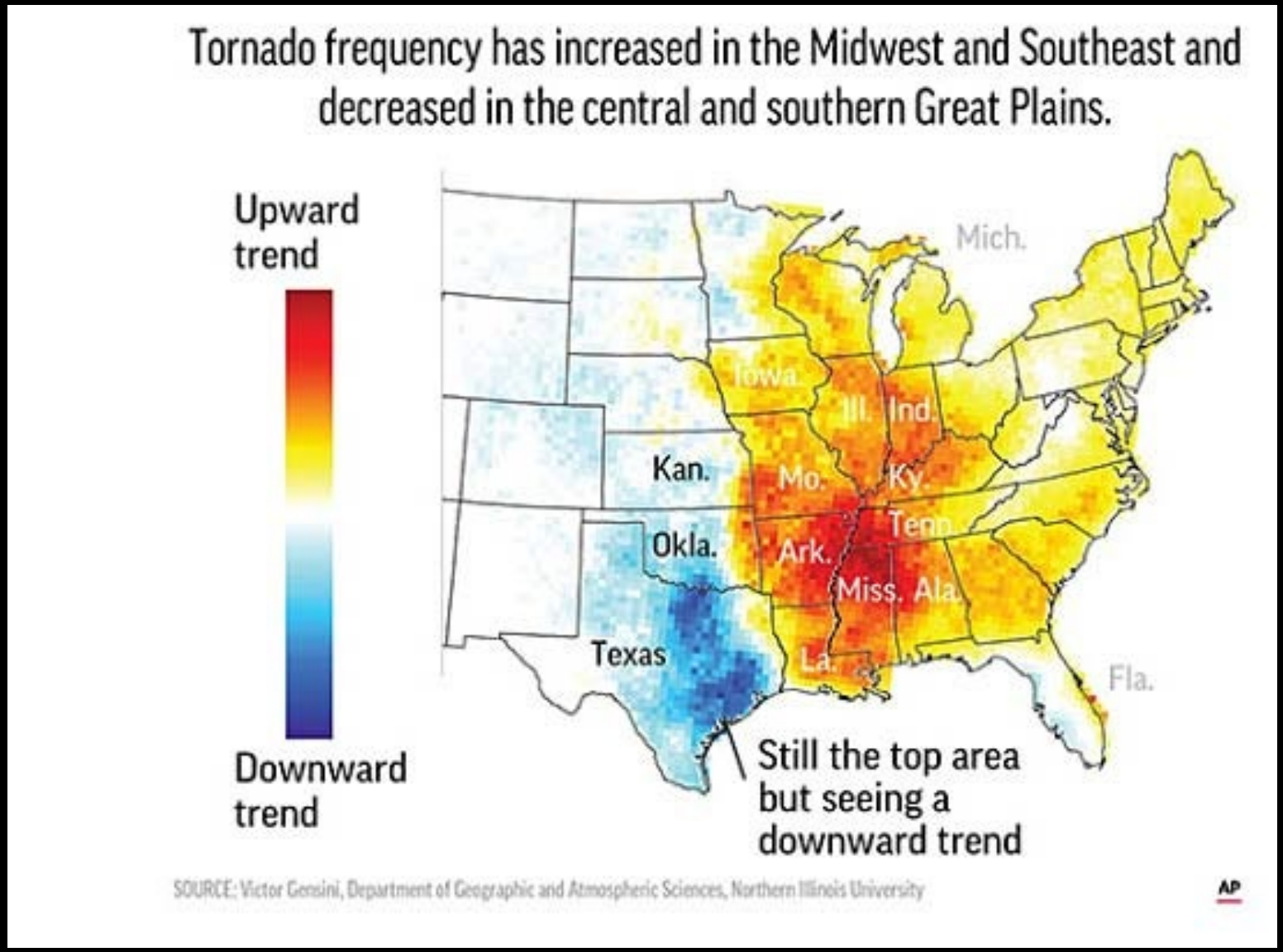


- Hurricanes with wind speeds above 250 km/hr have quadrupled (300%) since 1980 (**Rahmstorff *et al.* 2018 left).**
- Michael Mann has urged: *"The current intensity scale doesn't capture the fact that a 10 mph increase in sustained wind speeds* ***ups the damage potential by 20 percent,"*** *Mann said. "That's not a subtle effect. It's one that we can see." Based on the spacing of Categories 1-5, there should be a Category 6 approaching peak winds of 190 mph"*
- *Expect official recognition of "Category 6" soon.*

What About Tornadoes?

- Tornadoes are smaller and occur over land, and therefore without the same water-condensation energy driver as hurricanes.
- Data is not good enough yet to say whether we see, or expect to see, stronger tornadoes as global warming ramps up.
- Disregard **Richard Muller's simplistic claim** that tornadoes are perhaps weakening with global warming – he doesn't seem to understand how to interpret the data. See links within story above.

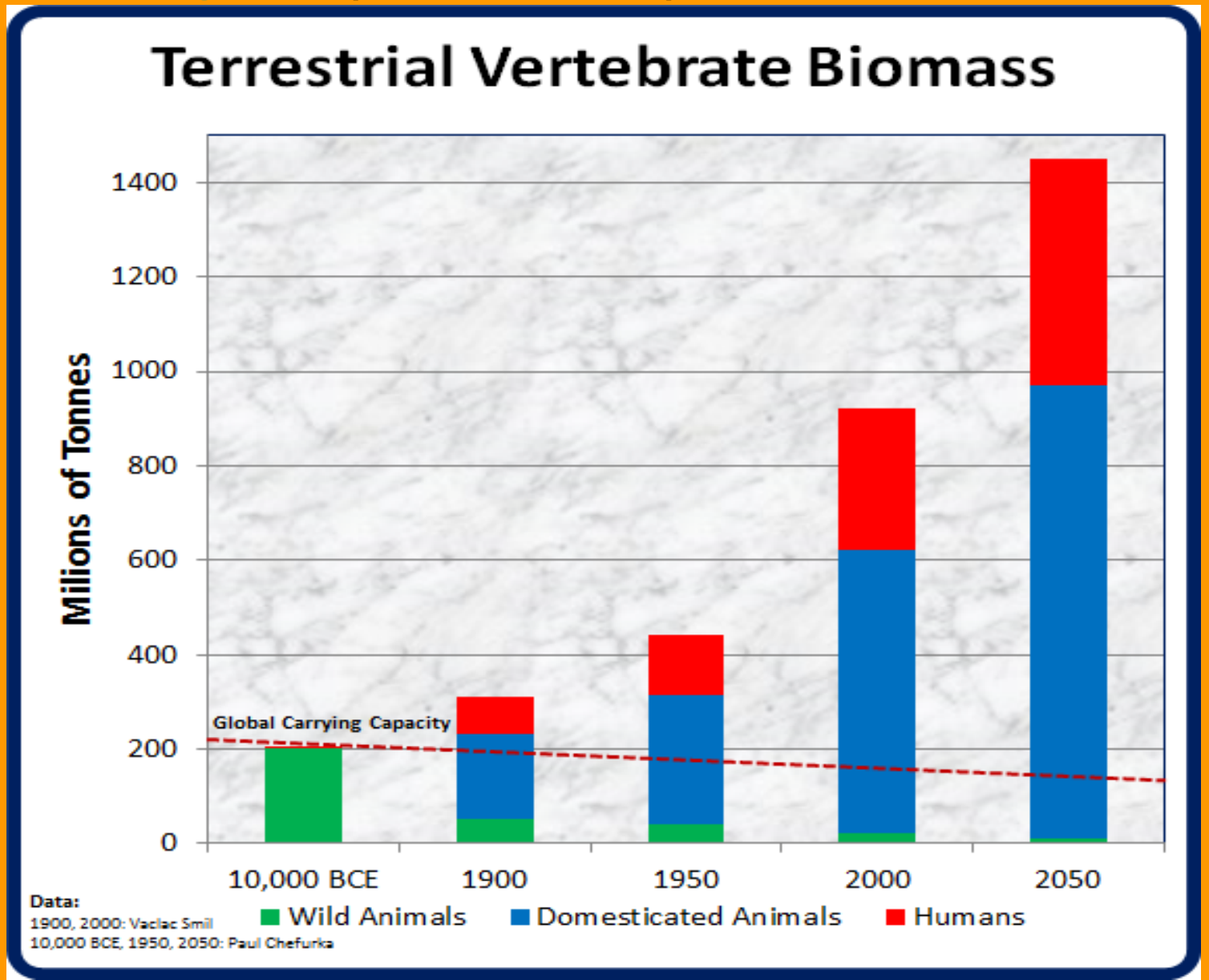
U.S. tornadoes are shifting East to wider, more populated regions



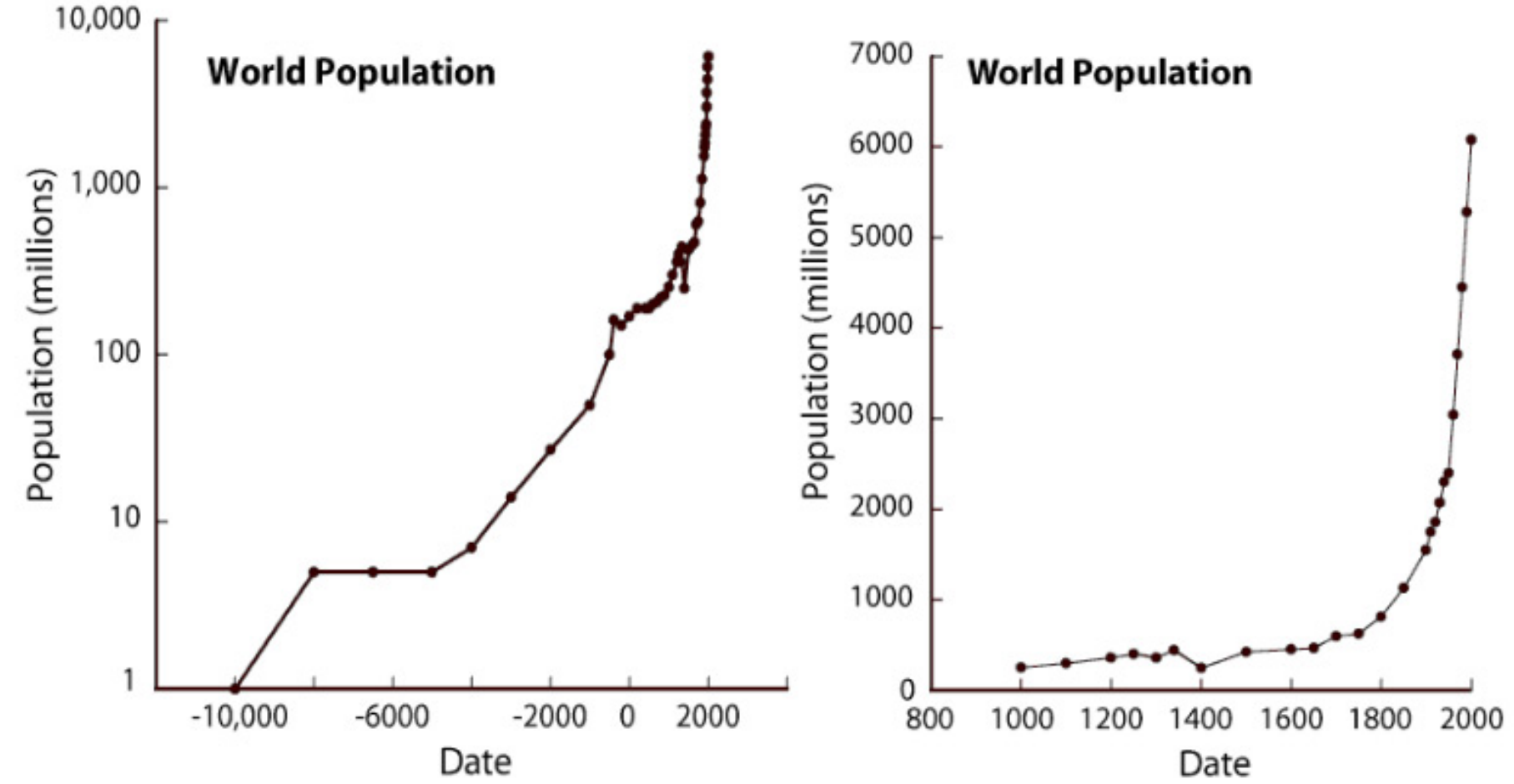
Humans: Total Domination over Earth's Ecosystems

- As recently as 1900, wild vertebrates made up ~50% of the total vertebrate biomass, on land. Now, only 3%.
- **Today, humans and their livestock make up 97% of the vertebrate biomass on land** (Bodley 2008), and 72% of ALL vertebrate biomass on Earth. 90% of the large fish have already been fished out. The *Star Trek* Borg…**"You. Will. Be. Assimilated"** … is what other species are experiencing.
- **36% to 40% of the primary productivity of the entire planet has been diverted to humans** (Haberl, *et al.* 2012) and Hannah *et al.,* while at the same time we have diminished global primary productivity on land since 1950 by 20-55% depending on region.
- **We're crowding out all other species. Mass extinctions are the expected result, and have begun.**

Humans and their livestock rising far beyond the declining carrying capacity of Earth. In 2050; can you still see the tiny sliver of green (wild animals) crushed at the bottom?

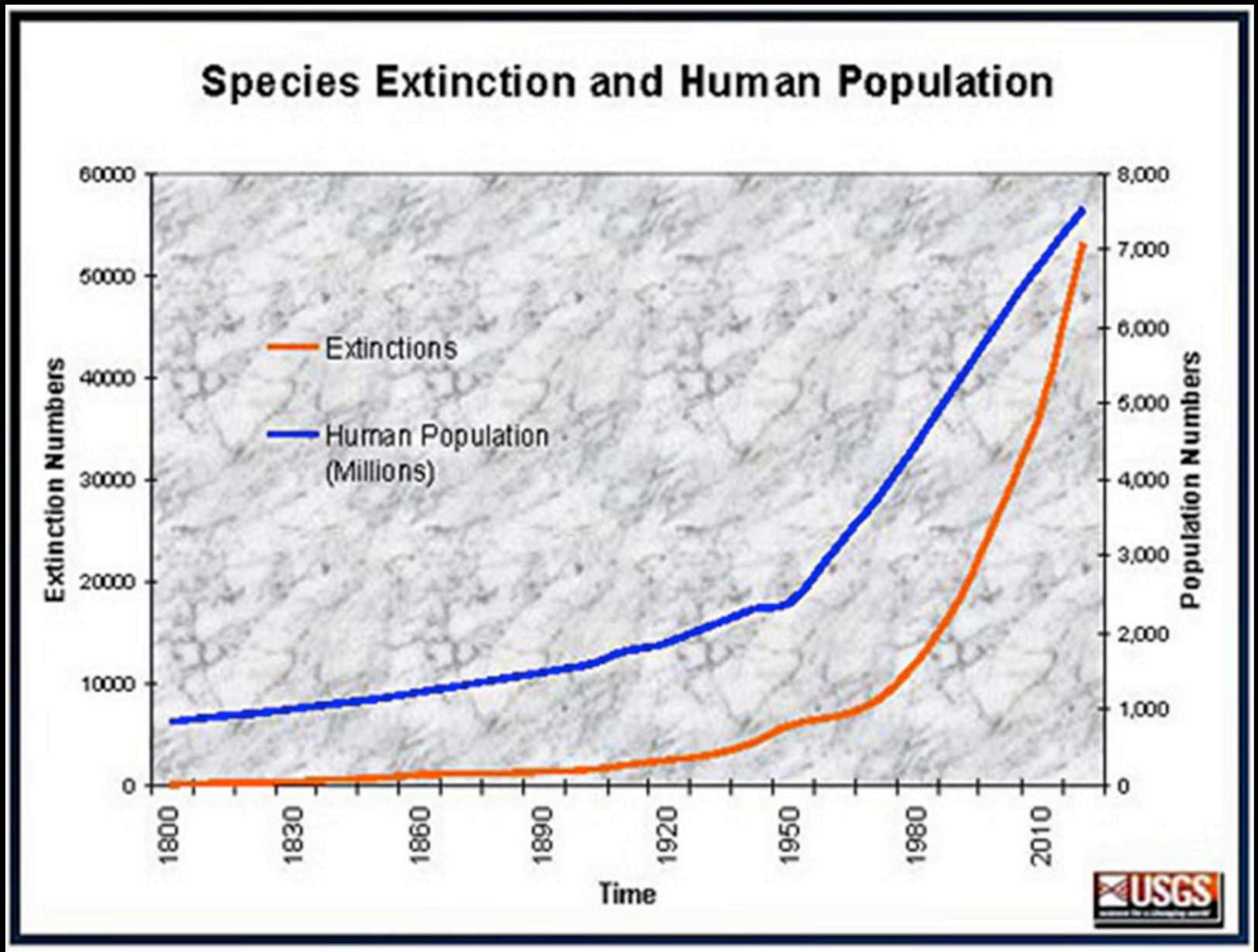


This 2008 graph is already out of date. Population passed 7 billion in 2012, and 7.8 billion in 2020. Human population is rising at an unsustainable rate of 1 billion additional people every 13 years. Mostly since fossil carbon energy was discovered, powering our domination



World Population: Left: *Since prehistoric times (log scale),* **Right:** *Since 800 AD (linear scale). Drawn using data from US Census Bureau, Historical Estimates of World Population, and World Population 1950-2050. The recent, rapid increase of population led to the anthropocene. Note that the population is now increasing at the rate of one billion people every 13 years.*

Humans – Multiplying. Other Species – Driven to Extinction. From U.S. Geologic Survey Data



7. Ocean Acidification and the death of Coral Reefs

Corals suffer from climate change for two reasons

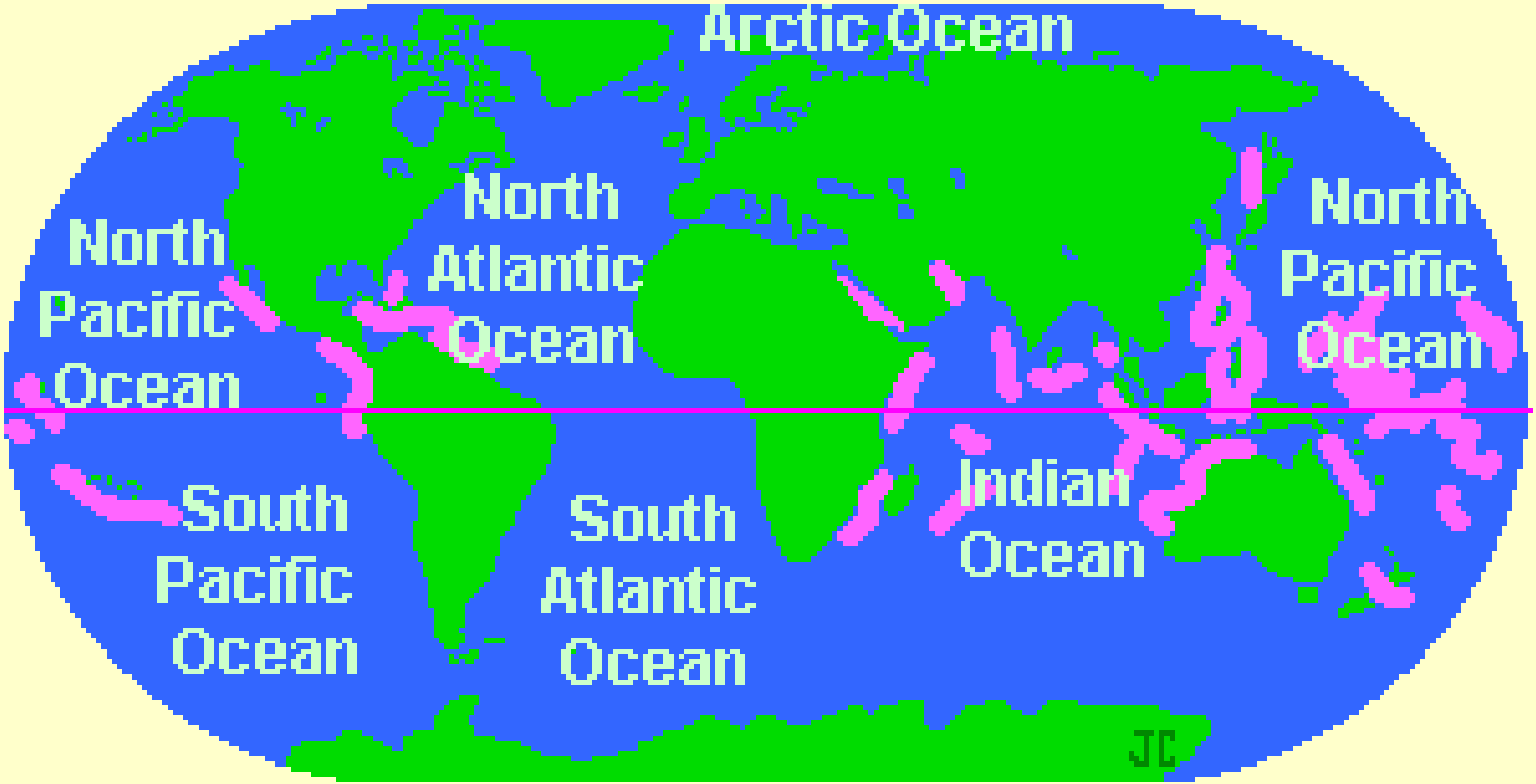
- **1.** Rising heat causes the corals to lose their colorful symbiotic algae, which produce oxygen and other nutrients for the coral polyps
- **2.** Rising acidity is hurting the ability of aragonite corals and other aragonite species to pull CO_2 out of the ocean and create the $CaCO_3$ which constitute their exoskeleton
- This inability to create $CaCO_3$ raises the saturation of CO_2 in the ocean and hurts the ability of the oceans to absorb atmospheric CO_2

Rising Acidity of the Oceans is Expected to Kill ~all Aragonite Corals by 2050

- Aragonite is a form of calcium carbonate which is created by corals
- Aragonite corals are the beautiful multi-varied tropical corals we all think of, and which provide habitat for most of the ocean's fish at some point in the fish's life cycle (There are also soft corals, which are not threatened) (EarthTouch video 12:39)
- Already, 83% of the original Caribbean coral reefs have died

Coral Reefs

= Coral Reef



It may be happening faster… 2016's record heat is bleaching virtually all of the aragonite coral Northern Great Barrier Reef – a thousand kilometers long – this is the largest coral reef in the world, now bleached white …

…and ~half expected to be dead soon

And now, near the end of 2016:

- ***"The Great Barrier Reef of Australia passed away in 2016, after a long illness. It was 25 million years old."***
- **That startling first sentence leads a must-read obituary by Rowan Jacobsen for *Outside Magazine* online.**
- *"For most of its life, the reef was the world's largest living structure, and the only one visible from space. It was 1,400 miles long, with 2,900 individual reefs and 1,050 islands. In total area, it was larger than the United Kingdom, and it contained more biodiversity than all of Europe combined. It harbored 1,625 species of fish, 3,000 species of mollusk, 450 species of coral, 220 species of birds, and 30 species of whales and dolphins. Among its many other achievements, the reef was home to one of the world's largest populations of dugong and the largest breeding ground of green turtles."*
- **However, in fairness, the reef is not yet quite dead, only 93% of the reef has been bleached in 2016, mostly at the warmer northern end.**
- **Now in 2017, the Reef's again being bleached, now reaching the middle, with recovery less likely (video 1:20)**

March 2016 left, and 2 months later, in May 2016 at right, coral bleaching and death at Lizard Island on Australia's Great Barrier Reef. Warm water kills the symbiotic algae, followed by death of the coral animals if waters stay too warm

Why Haven't You Been Hearing About the Great Barrier Reef's Imminent Death?

- *"No one knows if a serious effort could have saved the reef, but it is clear that no such effort was made. On the contrary, attempts to call attention to the reef's plight were thwarted by the government of Australia itself, which in 2016, shortly after approving the largest coal mine in its history, successfully pressured the* ***United Nations to remove a chapter about the reef from a report on the impact of climate change on World Heritage sites."***
- ***(This is the same UN which controls the publications of the scientists of the IPCC)***

“It’s Just Business”

- *“Australia’s Department of the Environment explained the move by saying, ‘experience had shown that negative comments about the status of World Heritage-listed properties impacted on tourism.’*
- *In other words, if you tell people the reef is dying, they might stop coming.”*

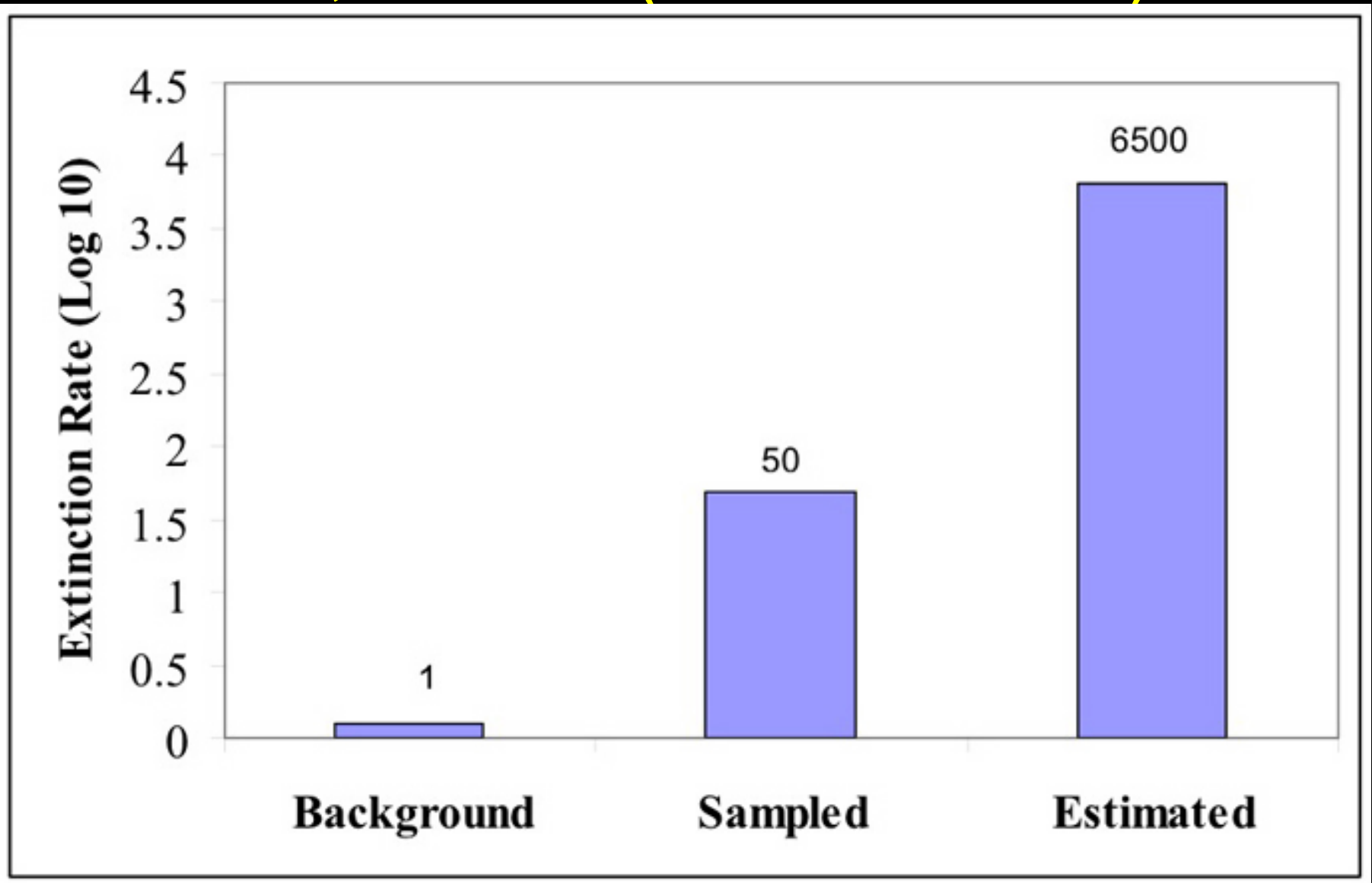
On the Rapid Loss of our Coral Reefs…

- *"This isn't something that's going to happen 100 years from now. We're losing them right now," said marine biologist Julia Baum of Canada's University of Victoria. "We're losing them really quickly, much more quickly than I think any of us ever could have imagined."*
- *"To lose coral reefs is to fundamentally undermine the health of a very large proportion of the human race," said Ruth Gates, director of the Hawaii Institute of Marine Biology."They populate a tiny fraction of the ocean but provide habitats for one in four marine species."*

Not just Australia, but American Samoa…

…and Hawaii

Current Extinction Rate: Estimated at 1,000 Times the Normal Historical Background Rate, Rising to 10,000 Times (de Vos *et al.* 2014)



Since 1970, North America has lost 30% of its birds (Rosenburg *et al.* 2019)

- This summary describes the major contributors as habitat destruction by human populations, and pesticides.
- Plunging insect populations are only part of the story, as birds of all kinds, even those who are not insectivores, are all dying.
- Climate change is a major contributor as well, disrupting migrations

90% of all large fish are already gone.

- Why? Over-fishing, death of coral reefs (needed by ~half of all fish species at some point in their life cycle) dying due to CO2 induced ocean acidification and warming. Phytoplankton at base of food chain in decline
- McClennahan (2009) has documented how the loss of coral reef systems has affected the size and species mix of fish using historical photographs from Florida “trophy” fishing businesses over the past 50 years. The progression is startling…

1956


CAUGHT ON
BOAT
GREYHOUND II
GOING FISHING?
YOU CAN BUY
YOUR BEER RIGHT HERE

1957


ALL DAY DEEP SEA FISHING
YACHT GULF STREAM
CAUGHT ON THE
YACHT
GULFSTREAM
Key West Fla


SEA FISHING
GULFSTREAM II
9:30 to 4:30
Capt. Tommy Lones
FARE 12.00
Ph. 296-8494

1965


GULF STREAM II
DEEP SEA FISHING
PHONE
296-8494
DAILY
9:00 AM TO
4:00 PM
CAPT. TOMMY JONES
FARE $10.00

1978

1983


GULF STREAM III
Capt. Tommy Lones
LEAVE 930 AM - RETURN 430 P.M.
Ph. 296-8494

2008

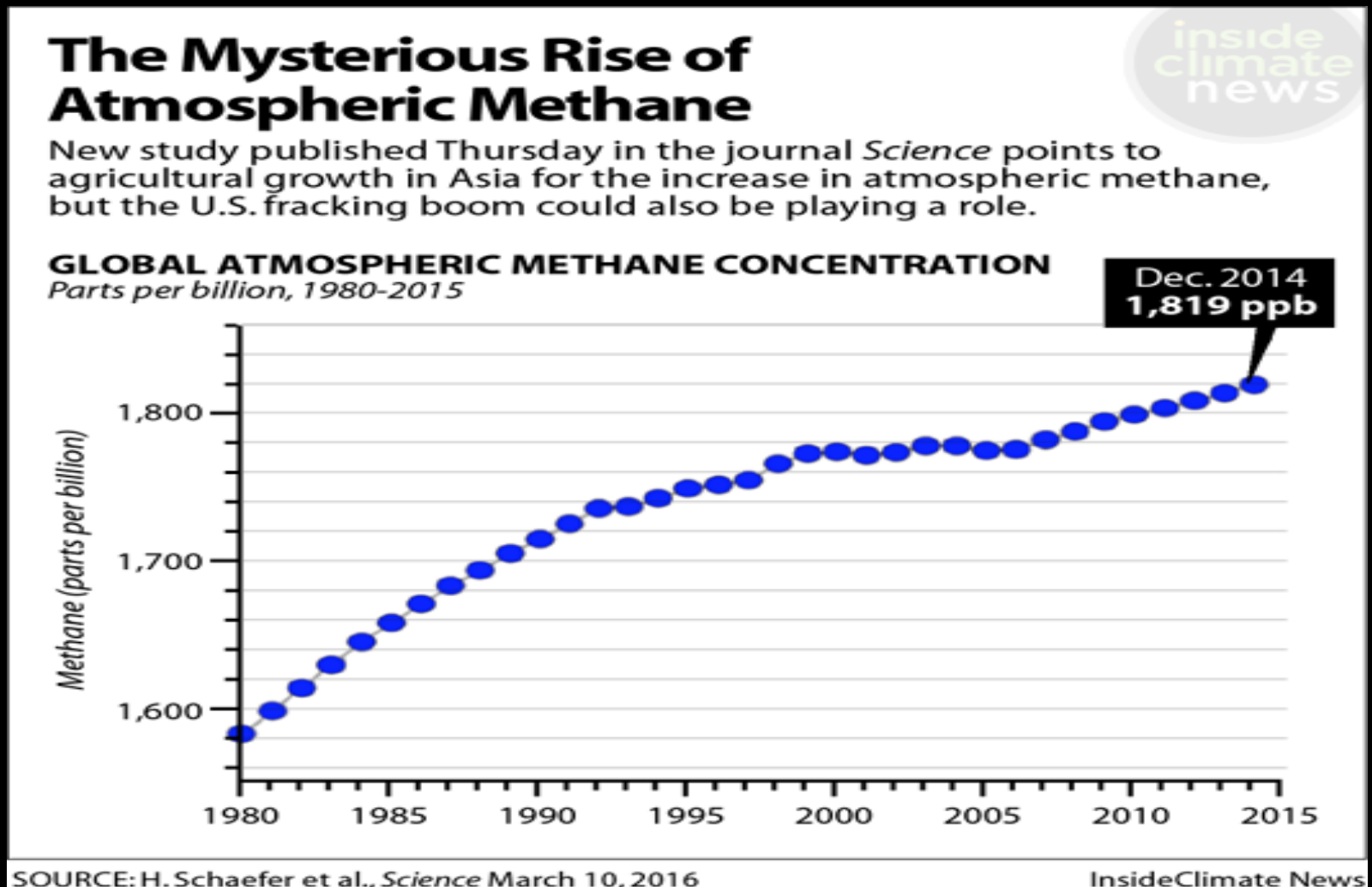
Today: increasingly it's jellys…

There are people trying to figure out how to eat them. They already do, in some poor Asian countries.

And a company is trying to make diapers out of them, and tampons

- I'm trying hard to look for the silver lining here.
- Sounds pretty uncomfortable to me, but "enviro-faith requires sacrifice"
- At the very least, a hefty marketing challenge.

8. Methane Concentrations and effects on Climate



Methane=CH_4: And from domesticated cattle, from melting permafrost, and peat, is ~25x more powerful as a greenhouse gas than CO2, pound for pound (avg'ed over 100 yrs)

- Melting Permafrost Accelerating Global Warming – methane trapped in melting Arctic Lakes is being released. Still a minor source of global methane emission today, but rising, and a long term major threat (see "K42: the Future)
- K. Anthony (U. Fairbanks) on Arctic lake methane

- Note, Methane oxidizes to water + CO2. The half-life residence time of a CH_4 molecule in the atmosphere is about 10 years. Both water and CO2 are less powerful greenhouse gases than methane.

Methane Bubbles Frozen in Arctic Lakes

It is calculated that there's potentially as much or more methane in these thawing lakes than already exists in the entire atmosphere, and estimates are rising.

Methane explosion craters are now appearing in Siberian Permafrost, which is getting extraordinary warming.

Researchers Ice-Climbing the Walls of a Methane Crater. Atmospheric methane content at bottom of crater is 50,000 times normal

It would take a million such explosions before dominating Earth climate, it is estimated. But more are being discovered….

The amount of additional greenhouse warming is not well determined yet; but certainly significant , since methane is ~100 times more powerful than CO_2, pound for pound when emitted. Ongoing research hopefully will clarify

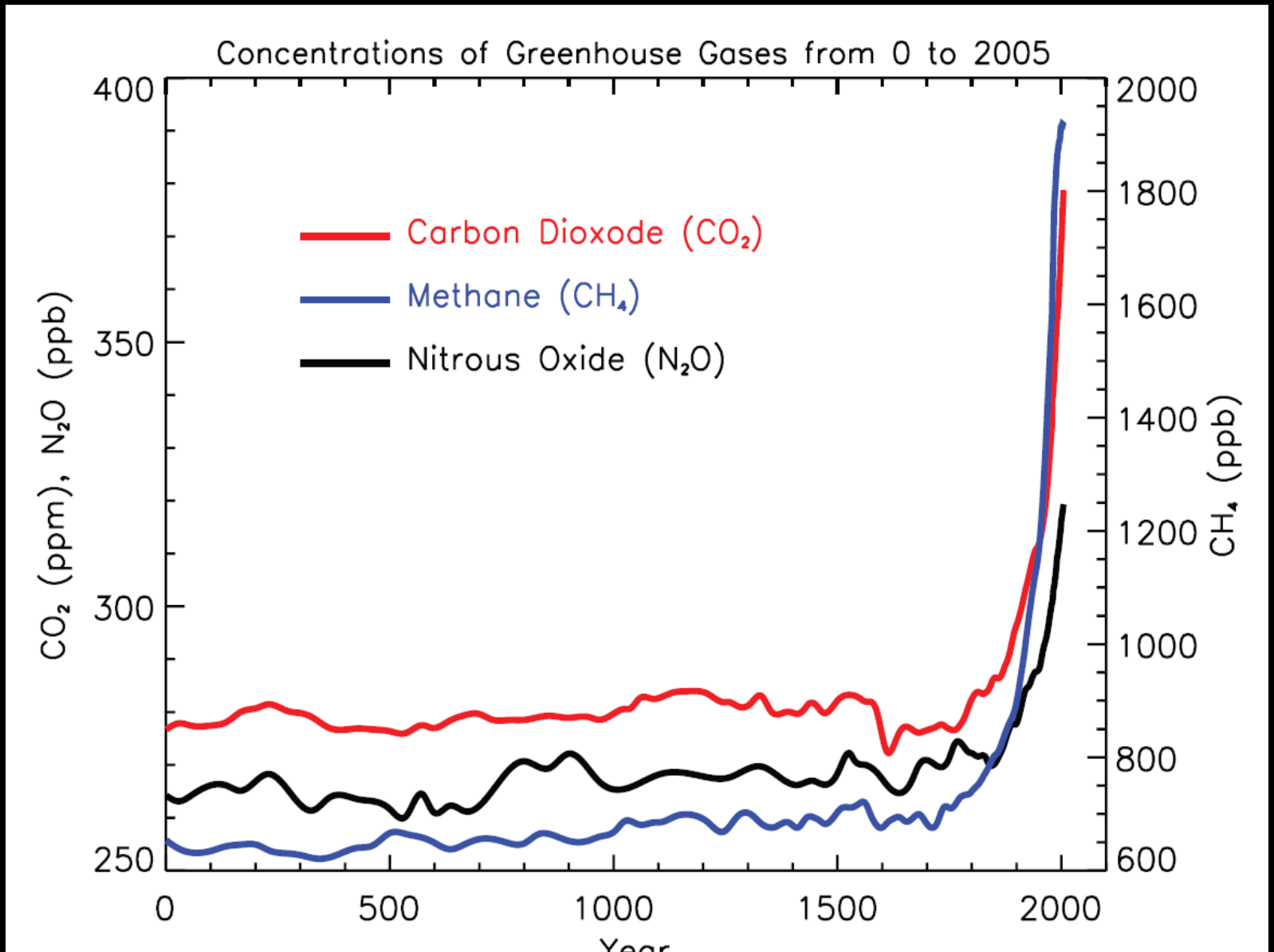
Mechanism of Crater Formation

- “Pingos”, which are cores of ice in the permafrost, are melting due to warming of the Siberian Arctic
- The water flows into the water table, leaving the subsurface volume to fill with methane from the microbes feasting on the thawed soil carbon.
- When pressure is too high, this explodes
- Craters discovered so far, are up to 200 feet in size

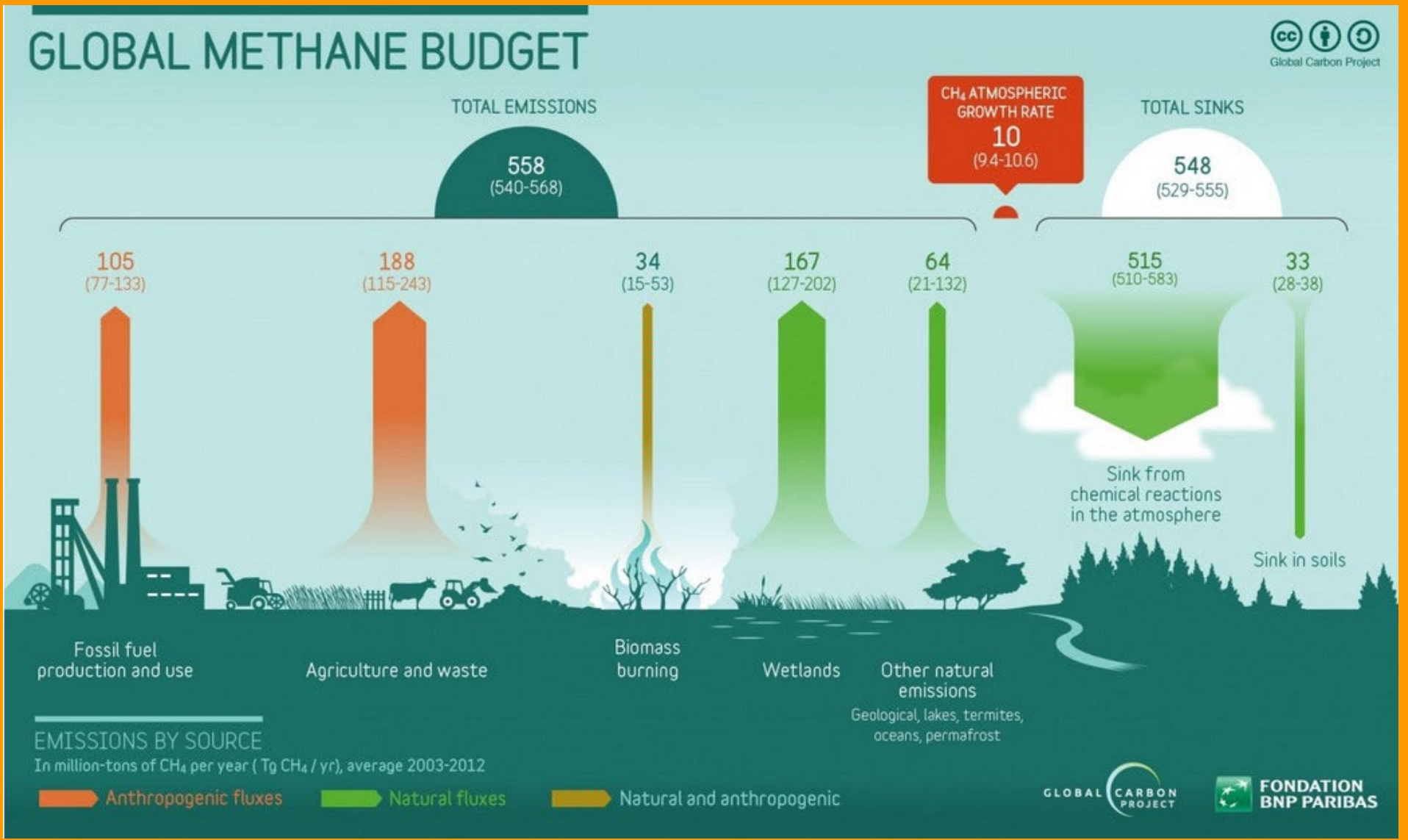
Now in 2017, scientists are discovering…

- …Over **7,000 new domes filled with methane** and *"are ready to explode"*, in the Yamal and Gydan Peninsulas of Russia alone

Since the Pre-Industrial, CO2 has risen 50%, but methane has risen 300%



Disturbing as the future rise of permafrost CO2 and methane is (see separate powerpoint on "Post IPCC Climate Science"), the evidence as of 2012 was that it was a minor part of our methane rise. Mostly it was due to tropical wetlands and our agriculture and livestock



After the post 2000 pause, methane began to rise again, starting in 2006, but at that time not yet dramatically

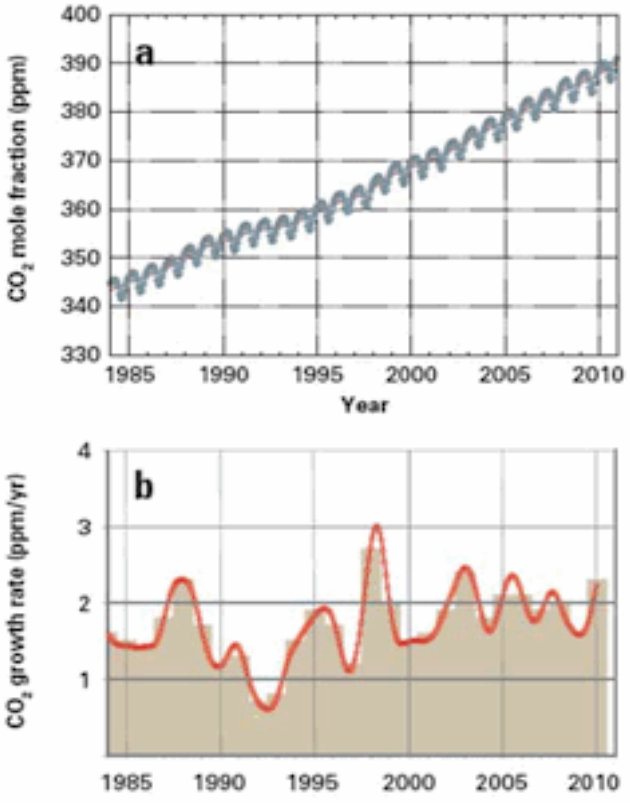


Figure 3. Globally averaged CO_2 mole fraction (a) and its growth rate (b) from 1984 to 2010. Annually averaged growth rate is shown by columns at (b).

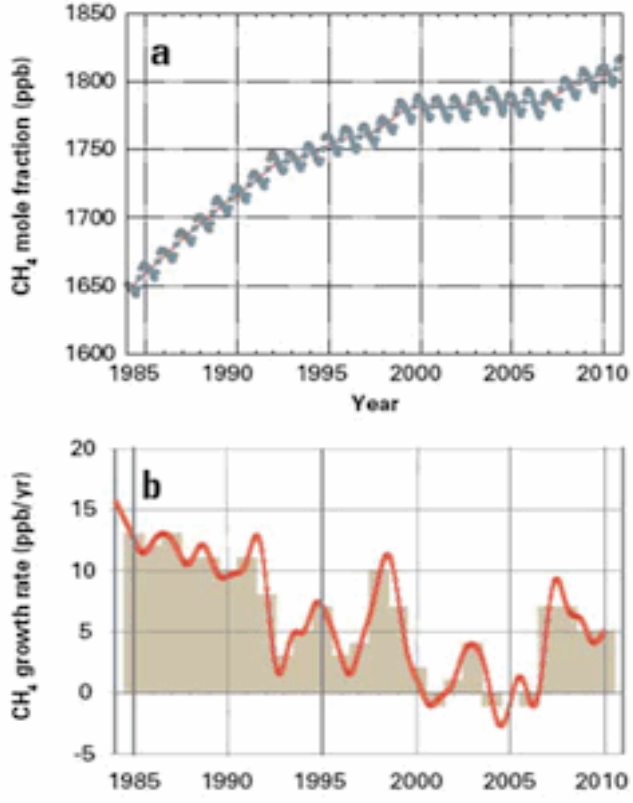
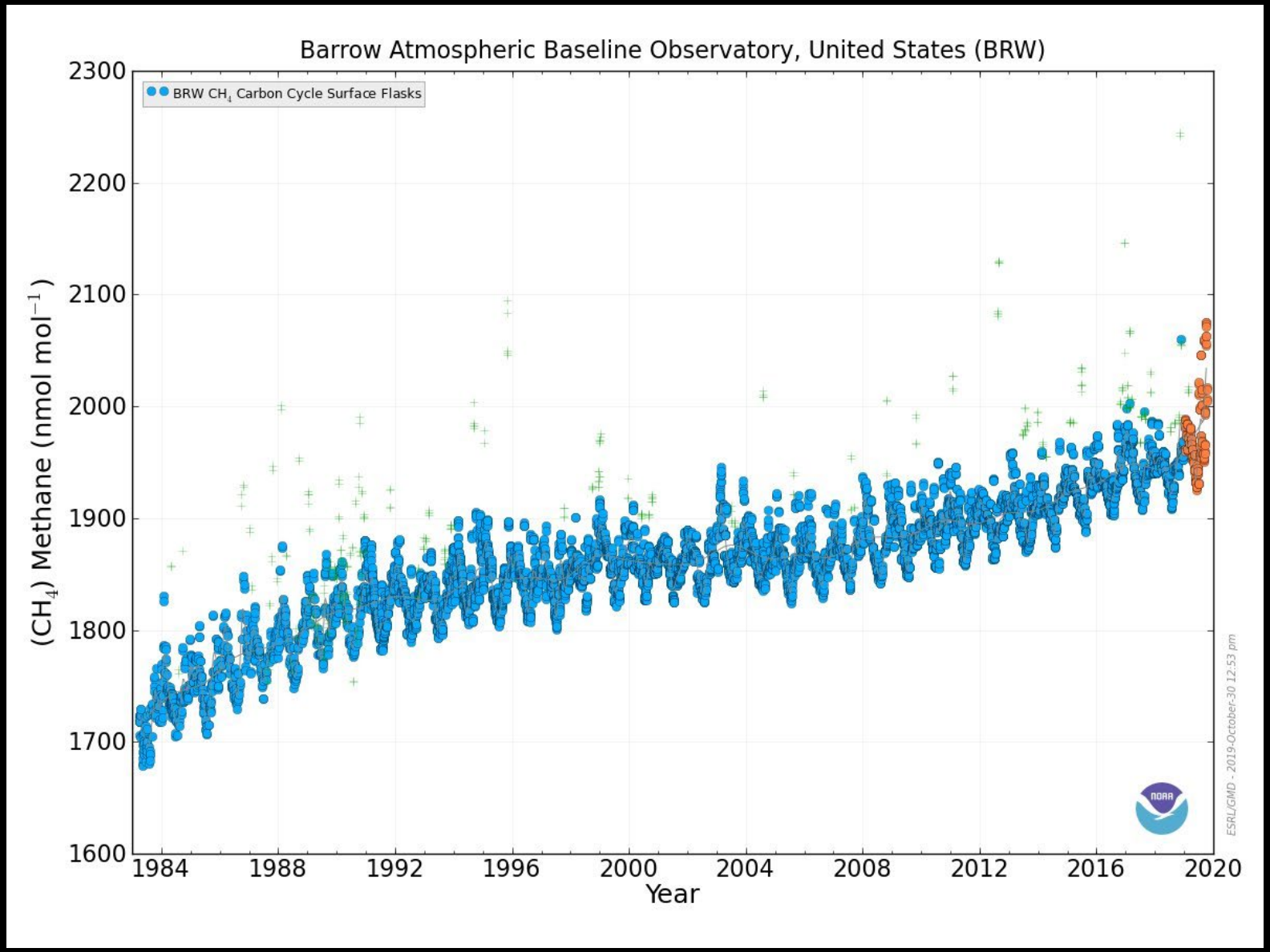


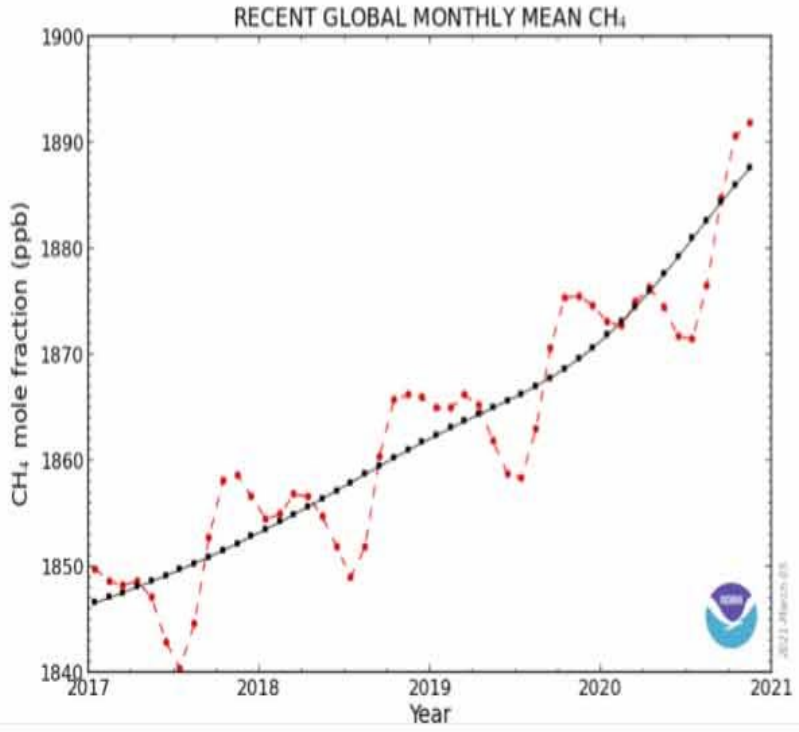
Figure 4. Globally averaged CH_4 mole fraction (a) and its growth rate (b) from 1984 to 2010. Annually averaged growth rate is shown by columns at (b).

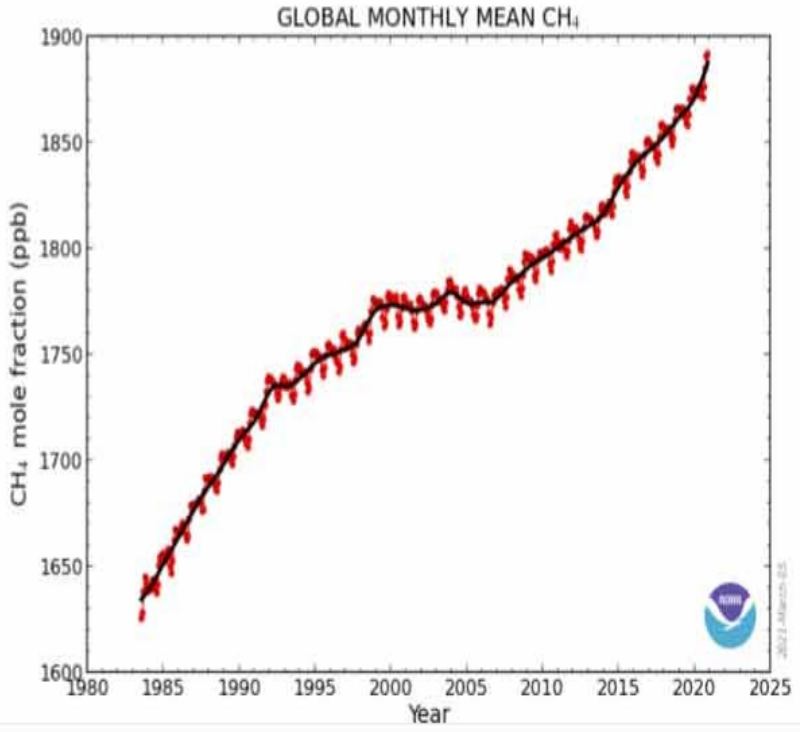
That's changing, in the Arctic



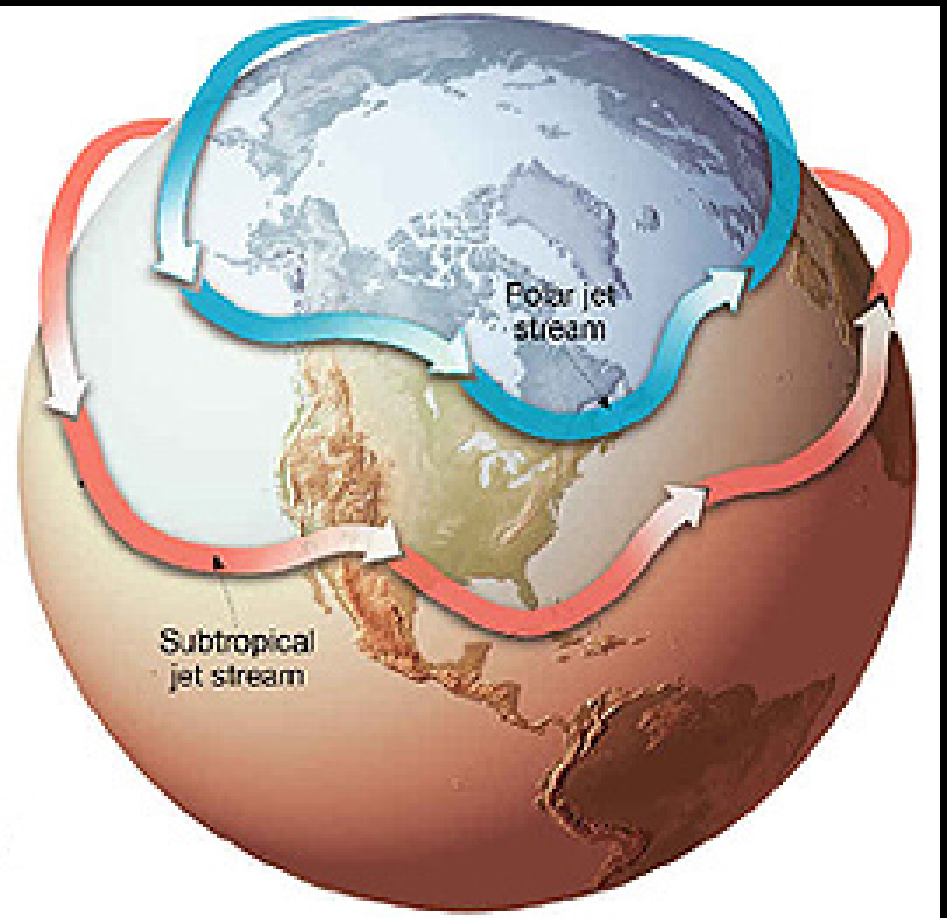
And Now, 2020, Globally as Well

November 2020: 1891.9 ppb
November 2019: 1875.6 ppb
Last updated: March 05, 2021





9. The Poleward Expansion of the Deserts

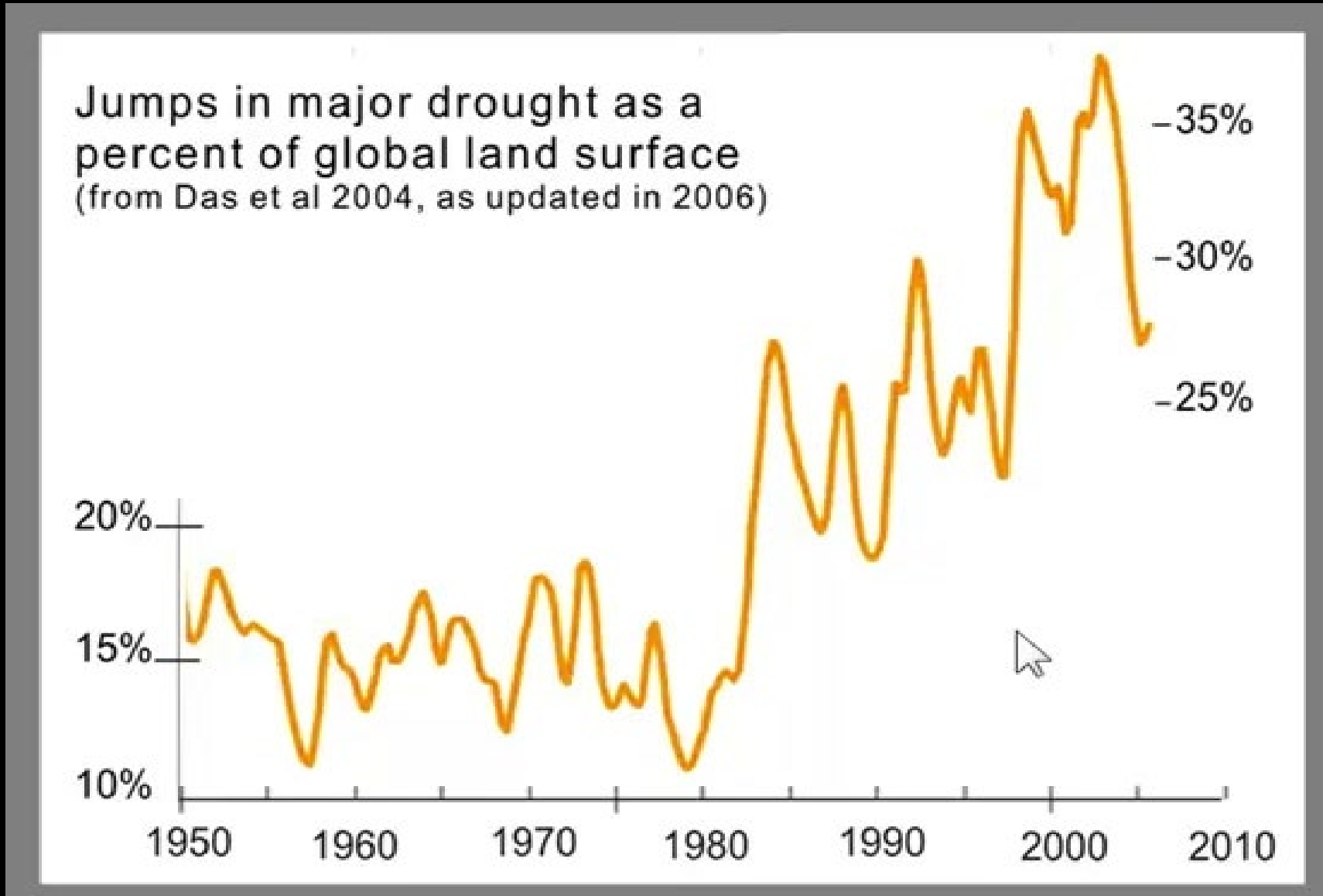


- The boundaries between cells, where air pressure differences can drive fast winds, are called the “Jet Streams”. If the winds are fast, the streams tend to be straighter-going west-to-east. If they weaken, they can meander north and south more (as seems to be happening with current climate change). They also tend to get “stuck” for long periods; even years

The Boundary Between the Polar Cell and the Ferrel Cell is the Polar Jet Stream

- The steep temperature gradient between these cells means a steep pressure gradient (density difference between cold dense air and warmer less dense air)
- This causes high winds in the upper troposphere – the Jet Stream (short video animation)
- The jet stream guides mid-latitude low-pressure (storm) systems.

More and more of the Earth's surface is experiencing major droughts

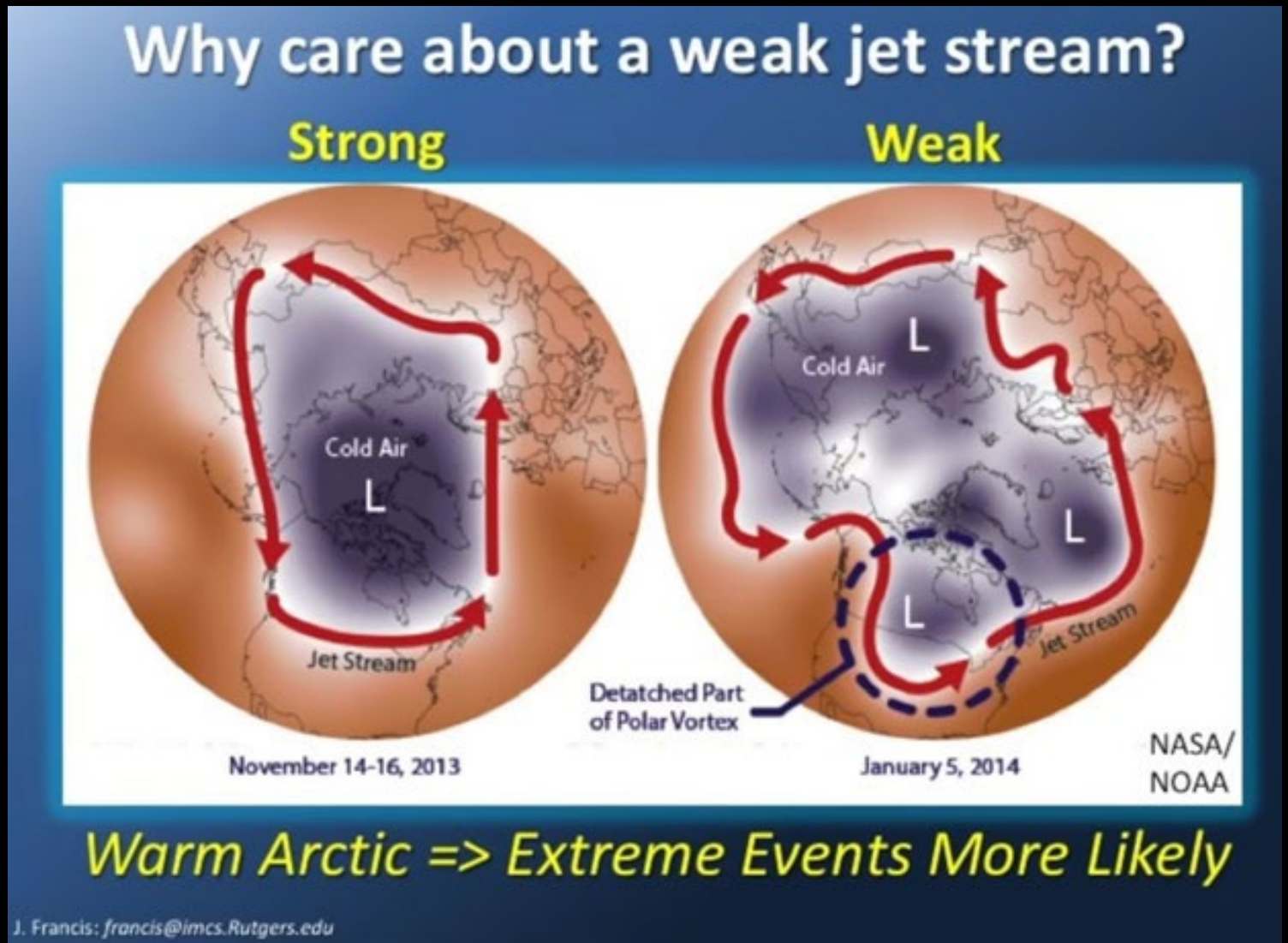


And Floods: When storms happen, the rising humidity enabled by hotter air, together with slower the jet stream from amplification of global warming in the Arctic *vs.* the tropics, means increasingly severe floods.

If the temperature gradient between the Polar and Ferrel cells in the Pacific decreases

- … it makes for a weaker Polar Cell
- … it makes for a weaker Polar Jet Stream, which then meanders more in latitude but on average migrates poleward.
- It will also cause the tropical cell to expand (more heating) and the desert band to migrate northward in the Northern Hemisphere.
- This has already been observed.

Weakening Jet Stream -> Meandering Jet Stram: so longer lasting storms and droughts



Expansion of the Hadley Tropical Cell

- In a variety of climate models (Barnes and Polvani 2013, a doubling of CO2 from 280 ppm to 560 ppm, (which seems virtually unavoidable) indicates the northern hemisphere jet stream boundary migrates north by 1 degree (112 km), and twice that in the Southern Hemisphere (Bengtsson *et al.* 2005) .
- However, Hansen says observations actually indicate as much as a 4 degrees (270 miles) of north shift has already happened (17 min into this talk)
- Currently, at 410 ppm, we're 46% of the way towards a doubling of pre-industrial level CO2 concentrations.
- **Observations are outpacing by 200% the models' northward migration; meaning a factor of 3.**

Hadley Cells and the Rising Temperature of the Oceans

- Rising ocean temperatures is raising the energy of the Tropical Cell by 570 billion watts per year, since 1979 (Huang & McIlroy 2014)
- Combined with the weakening cold of the Arctic polar cell, this is causing the polar cell boundary (polar jet stream) to migrate poleward, carrying "horse latitude" desert northward as well
- Southern California's climate will become Northern California's climate, it is predicted.

10. Tropical Diseases Spreading North

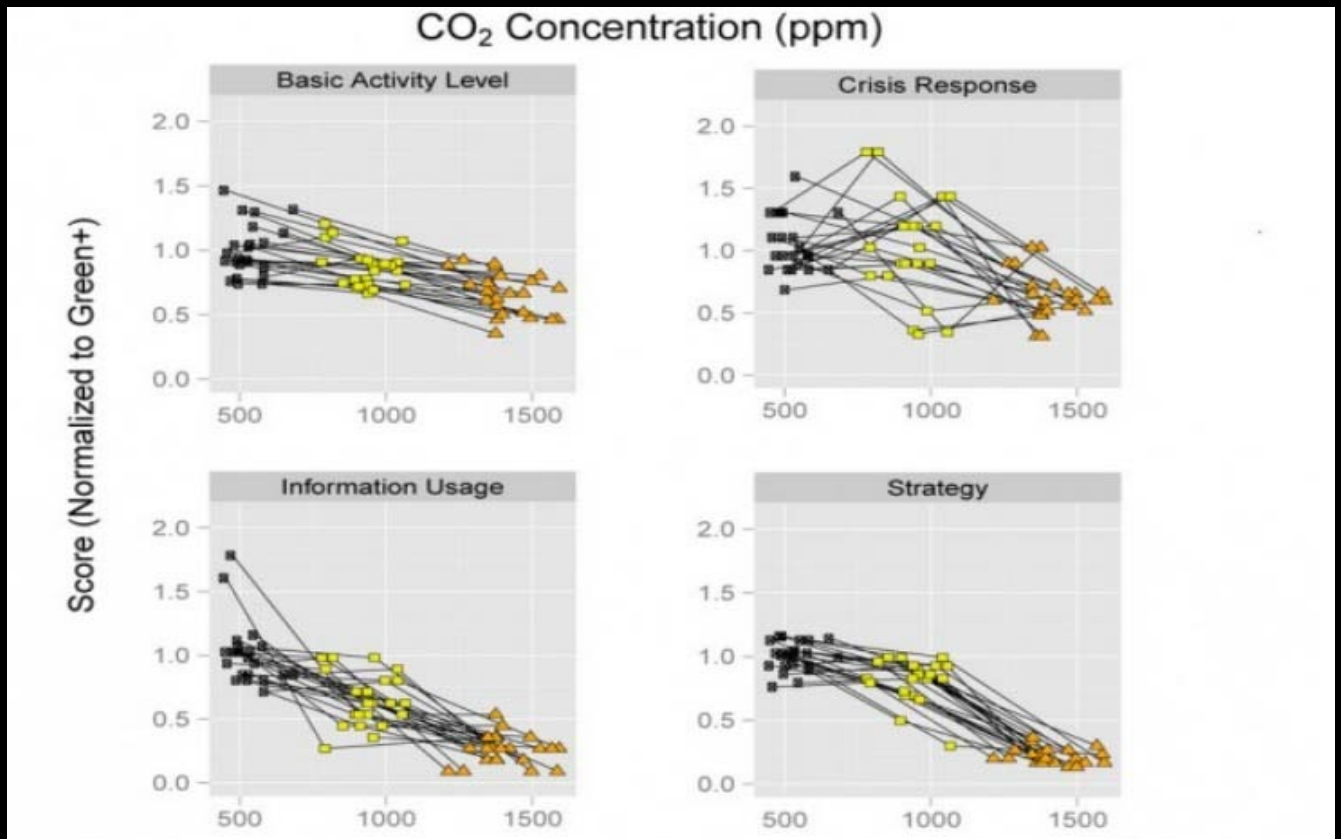
- As hot temperatures rise in the tropics and spread north and south to formerly temperate latitudes, **tropical disease rates are rising steeply…**
- Dengue fever cases have risen 2000% in Brazil since 1990
- Tropical diseases are spreading north into the U.S. (**Scientific American article**)
- Dengue fever, malaria, Lyme disease, chagas disease, among others

And now - Zika Virus as well, which causes microencephaly and severe brain damage in the unborn

It isn't just these tragic Zika victims who will suffer mental handicaps

- Satish *et al.* 2012 (and discussed further here) show that all of us will suffer a strikingly large 21% reduction in decision-making ability when CO2 levels reach 560ppm, and accelerating worse with higher levels.
- When we need clear thinking most, we will be even less able to pick competent leaders, (if that is possible).

From Satish *et al.* 2012. Multiple measures of mental functioning decline with rising CO2



Normalized cognitive function scores by participant and corresponding CO2 levels in their cubicle. The Green+ case had CO2 in the 500 ppm range due to high levels of outside air. It was compared to office settings in the 930 ppm range (yellow squares) and in the 1400 ppm range (orange triangles).

Bees suffering as well. Protein content of pollen is dropping due to rising CO_2

Fans of carbon sequestration in soils? Realize that rising temperatures are strongly doing the exact opposite

- From the Netherlands, Dr. Thomas Crowther speaks for a team of 50 world scientists all warning the official climate projections are missing an important carbon feed-back. As we warm, the soil will release carbon dioxide and methane **equivalent to the greenhouse gas emissions of the entire United States.**
- "*We estimated that the carbon emissions from the soil are going to be approximately equivalent to 17 percent of current anthropogenic emissions. So every year, humans will emit a certain amount, and then the soil will be responsible for an extra 17%. Whereas at the moment, the U.S. is also 17% of the total anthropogenic emissions. So it's really on that same order of magnitude: every year the soils will emit about an equivalent amount of carbon that we expect to be emitted from the US.*" (**source**)
  – Dr. Thomas Crowther

Compounding Pollution from Rising Seas

- Louisiana's Big Oil counted on barrier islands and swamps to prevent exposure of oil pipeline infrastructure from corrosive seawater and storm surges
- Maybe they should have thought about rising sea levels caused by their business models destroying that "protection" – and the looming $100 billion nightmare now just beginning to unfold
- Stories like this will multiply of course. Not time in this course to list them all

A New Climate Danger Not Yet in Climate Models…

- "Coastal Darkening" – increasing run off pollution and soil erosion is causing large areas of our seas to be darker than pre-industrial.
- Lower albedo = increased solar heating of ocean, hurting CO2 solubility, hurting phytoplankton conversion to CaCO3.
- Only beginning now to be appreciated as something to worry about, and another amplifying feedback.

And perhaps most disturbing of all – Our earthworm friends have turned against us.

- Lubbers *et al.* 2013 find that earthworms' net effect, even after improving soil quality, is to **increase** CO2 emissions.
- Cameron and Bayne (2009) find that these worms are already occupying 10% of Alberta's northern boreal forest, and will occupy 50% by 2060.
- They are found right up to the receding edge of the permafrost (Shaw, discussed here)

The world's boreal forests have been largely earthworm-free since the last Ice Age. But as invaders arrive and burrow into the leaf litter, they free up carbon and may accelerate climate change. Cristina Gonzalez Sevilleja

Non-native earthworms are invading the North American boreal forest

- They feed exclusively in the shallow leaf litter, thus releasing carbon directly to the atmosphere.
- Cameron *et al.* 2015 find these worms alone will turn 50-94% of boreal forest floor carbon into atmospheric CO2 in the next century, with most damage happening in the first ~37 years.
- This has not been included in climate models yet.

Key Points: K38d – Current Climate Change: Other Effects

- Ocean phytoplankton in decline since 1950, and continuing to worsen
- Hurricane wind speeds are rising, as predicted
- Stratosphere cooling while troposphere warming: a signature of greenhouse warming
- Night temps rising faster than day temps: a signature of greenhouse warming
- Aragonite corals to disappear by ~2050 with unknown but significant extinctions of fish populations which depend on them, due to ocean acidification
- Most large wild fish – gone. Most vertebrate wild animals – gone. We and our livestock are 97% of all global land vertebrates today.
- Methane at 2x pre-industrial levels, mostly from livestock and tropical swamps from *e.g.* new dams, but rapidly rising fraction from fracking, and from melting permafrost
- Methane emissions rising rapidly, and need much more research
- Mental abilities decline with rising CO2
- Tropical diseases moving north as Earth warms