Code-Red Tipping Points

By John Benson

October 2022

1. Introduction

Merriam-Webster defines a tipping point as:

The critical point in a situation, process, or system beyond which a significant and often unstoppable effect or change takes place.[1]

An example is when a microphone, amplifier & speaker start experiencing positive feedback, and the slightest noise sets off an ear-splitting howl.

I frequently write about the primary, secondary and higher-order effects of climate change. Within the matrices of these effects are numerous tipping points, and therein lies extreme danger. Since the world's climate is a huge system, the effects of positive-feedback don't happen within seconds as with the above example, but decades to centuries. This means we don't completely understand that we've passed these points until it is too late to easily fix them.

Another type of tipping point is when society undergoes a major attitude-change. This must happen in the world's leading countries with respect to climate change if we hope to avoid many of climate change tipping points. The impact of crossing the latter could seriously damage our infrastructure and cause many deaths. Look at how bad it is already, and be prepared for it to get much worse. Examples in the present are the major heat waves this summer and, more recently, Hurricanes Ian and Fiona.

Sources that I frequently use for information are the American Association for the Advancement of Science (AAAS) and Time Magazine. Weekly I receive the AAAS on-line publication, "Science." A few weeks ago I received an issue with a really thorough exploration of the known tipping points in our climate. More recently I received a Time issue that explored society's attitude tipping points. These are the subjects of this paper.

2. Society's Tipping Point

For years, activists, politicians, and academics have tried to transition the global economy away from fossil fuels, with only mixed results. Overnight, it's as if everything has changed, and for the first time in a long time, there's a glimmer of hope. The price of renewable energy has fallen sharply, making it a more cost-effective choice in most cases. The Russian invasion of Ukraine has codified the strategic risks of reliance on fossil fuels. And at last, government has stepped in decisively. The Inflation Reduction Act in the U.S. will spend hundreds of billions of dollars to push the country closer to decarbonizing. The European Union's REPowerEU initiative will do the same across the Atlantic. Together, they will spur trillions in private investment.[2]

---

[1] Merriam-Webster definition of "tipping point," https://www.merriam-webster.com/dictionary/tipping%20point

[22] Justin Worland, Time, Sep 26 2022 Issue (hardcopy), "Climate Changes." To order a copy of a Time issue, call 800-843-8463.

The newfound sense of hope is tempered, though, with a growing sense of despair about the damage already baked in. In August, unprecedented flooding left a third of Pakistan underwater in what U.N. Secretary-General Antonio Guterres described from the ground as the worst "climate carnage" he had ever seen. In Europe, drought has left crops dead and riverbeds dry; officials implemented water restrictions in France, Germany, and Spain. Cities across California faced record-high temperatures in September, hitting 115°F in several places and leaving the state to beg residents to cut their electricity use to avoid rolling blackouts. Those who follow the science, even just loosely, know that it will get worse.

Author's comment: Forget 115°F. It hit 116° in both my home (Livermore, CA) and our state's capital (Sacramento, CA). Both of these broke all-time records for all days and all past years in which temperatures were recorded. See the paper linked below for the details of this event, and the state's response.

https://energycentral.com/c/gr/how-california-beat-heat

With climate change, as with anything else, it's hard to draw a bright line between one era and the next. But the historic investment in greening the economy and the acceleration of climate-linked devastation suggest a very different future is at hand. "Life has changed," Gina McCarthy told me on Sept. 8 before stepping down as President Biden's top climate adviser. "Everybody's trying to get their head around an entirely different paradigm."

This new world will be defined by extremes. Finally, countries are building a global green economy, offering an optimistic vision of a better future. But the tragic human costs of climate change, long warned about by scientists, are upon us and getting worse. We still have a chance to shape these two developments: our best hope is that progress will minimize despair.

Which is why this summer's passage of the Inflation Reduction Act represents such a departure. The law signals not only that the energy transition in the U.S. has begun, but that it will move quickly. Hundreds of billions of dollars in tax incentives will bring down the cost of clean energy, spurring companies to decarbonize. Modelers now expect U.S. emissions to fall 40% from 2005 levels by 2030.

Perhaps more significant is the clear signal to private companies that the economy is transitioning. Firms will invest trillions of dollars based on that signal. A report from Third Way, Boston Consulting Group, and Breakthrough Energy identifies six nascent technologies spurred by the law including electric vehicles, low-carbon hydrogen, and clean steel-that will together have a cumulative $60 trillion market by 2050. These investments mean remade cities and millions of jobs, and the potential for emissions cuts far greater than what models suggest. Even in places like Florida and Texas, the economics of renewable energy is besting ideology: it's just cheaper. Every single state submitted a plan to the Biden Administration outlining a blueprint for an electric-vehicle charging network. "Yes, Texas. Yes, Oklahoma. They didn't argue," says McCarthy. "They said, 'Damn, I have to be in this.'"

Leaders abroad are responding to the signal too. India is advancing a carbon market scheme to cut emissions, Germany approved a $180 billion program to facilitate clean energy, and Australia adopted its first climate legislation in a decade. While global tensions have hurt some green collaboration, countries including the U.S. and China are racing to own the future of clean energy, clean manufacturing, and clean transportation.

"This is a healthy competition from a climate-change point of view," says Fatih Birol, the head of the International Energy Agency (IEA).

But even as we remake the global economy, the human cost of climate change will grow quickly too. Investment and innovation will need to catch up with the destruction that we've already unleashed on the world, especially in the Global South. A tropical storm in April killed hundreds across the Philippines. A heat wave in India this spring cost farmers large shares of their crops, and a multiyear drought in East Africa has 50 million people facing extreme hunger. The dollar cost runs to the trillions: Africa loses up to 15% of annual GDP because of climate change, and could lose 30% in the coming decades, according to the Africa Development Bank…

If you've been reading and thinking about climate change, you've heard of tipping points: thresholds that, when crossed, will trigger nonlinear changes in the climate. Permafrost melting in the Arctic could release long-trapped carbon, accelerating global warming. The collapse of the West Antarctic Ice Sheet could raise sea levels up to 10 ft.

The above reference's text then mentions the primary reference for the next section, so read on.

3. Climate Tipping Points

Climate tipping points (CTPs) are a source of growing scientific, policy, and public concern. They occur when change in large parts of the climate system—known as tipping elements—become self-perpetuating beyond a warming threshold. Triggering CTPs leads to significant, policy-relevant impacts, including substantial sea level rise from collapsing ice sheets, dieback of biodiverse biomes such as the Amazon rainforest or warm-water corals, and carbon release from thawing permafrost. Nine policy-relevant tipping elements and their CTPs were originally identified by Lenton et al. (2008). We carry out the first comprehensive reassessment of all suggested tipping elements, their CTPs, and the timescales and impacts of tipping. We also highlight steps to further improve understanding of CTPs, including an expert elicitation, a model inter-comparison project, and early warning systems leveraging deep learning and remotely sensed data.[3]

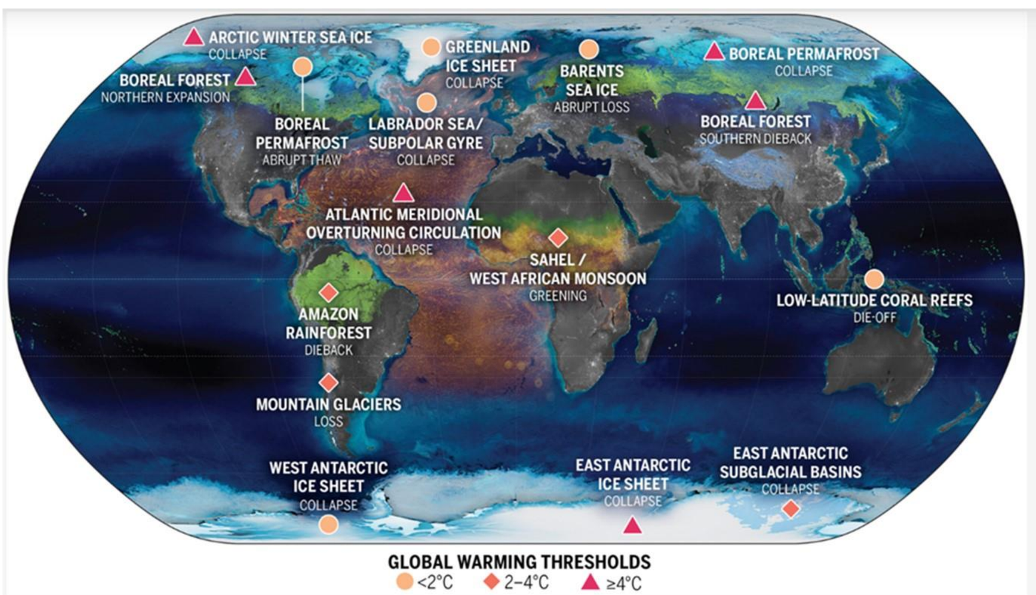
Since the original identification of tipping elements there have been substantial advances in scientific understanding from paleoclimate, observational, and model-based studies. Additional tipping elements have been proposed (e.g., parts of the East Antarctic ice sheet) and the status of others (e.g., Arctic summer sea ice) has been questioned. Observations have revealed that parts of the West Antarctic ice sheet may have already passed a tipping point. Potential early warning signals of the Greenland ice sheet, Atlantic Meridional Overturning Circulation, and Amazon rainforest destabilization have been detected. Multiple abrupt shifts have been found in climate models. Recent work has suggested that up to 15 tipping elements are now active (Lenton et al., 2019). Hence it is timely to synthesize this new knowledge to provide a revised shortlist of potential tipping elements and their CTP thresholds.

[3] David I. Armstrong Mckay, Arie Staal Jesse F. Abrams, Ricarda Winkelmann. Boris Sakschewski, Sina Loriani, Ingo Fetzer, Sarah E. Cornel, Johan Rockström, Timothy M. Lenton, Science, "Exceeding 1.5°C global warming could trigger multiple climate tipping points," 9 Sep, 2022, https://www.science.org/doi/10.1126/science.abn7950 Note that access may be limited.

We identify nine global "core" tipping elements which contribute substantially to Earth system functioning and seven regional "impact" tipping elements which contribute substantially to human welfare or have great value as unique features of the Earth system (see figure on the next page). Their estimated CTP thresholds have significant implications for climate policy: Current global warming of ~1.1°C above pre-industrial already lies within the lower end of five CTP uncertainty ranges. Six CTPs become likely (with a further four possible) within the Paris Agreement range of 1.5 to <2°C warming, including collapse of the Greenland and West Antarctic ice sheets, die-off of low-latitude coral reefs, and widespread abrupt permafrost thaw. An additional CTP becomes likely and another three possible at the ~2.6°C of warming expected under current policies.

Our assessment provides strong scientific evidence for urgent action to mitigate climate change. We show that even the Paris Agreement goal of limiting warming to well below 2°C and preferably 1.5°C is not safe as 1.5°C and above risks crossing multiple tipping points. Crossing these CTPs can generate positive feedbacks that increase the likelihood of crossing other CTPs. Currently the world is heading toward ~2 to 3°C of global warming; at best, if all net-zero pledges and nationally determined contributions are implemented it could reach just below 2°C. This would lower tipping point risks somewhat but would still be dangerous as it could trigger multiple climate tipping points.

See the graphic below:



The location of climate tipping elements in the cryosphere (blue), biosphere (green), and ocean/atmosphere (orange), and global warming levels at which their tipping points will likely be triggered.

Pins are colored according to our central global warming threshold estimate being below 2°C, i.e., within the Paris Agreement range (light orange, circles); between 2 and 4°C, i.e., accessible with current policies (orange, diamonds); and 4°C and above (red, triangles).

4. Details

Below we will address the most immediate tipping points. This information will come from reference 3 above) and other sources as referenced below.

4.1. Barents Sea Ice

The abrupt loss of Barents Sea winter ice (BARI), which occurs at ~1.6°C in two CMIP5[4] *models, is self-reinforced by an increased inflow of warm Atlantic waters, and has substantial impacts on atmospheric circulation, European climate, and potentially the Atlantic Meridional Overturning Circulation (AMOC). We consider BARI a probable regional impact tipping element (medium confidence) with a threshold of 1.6°C (1.5 to 1.7°C) (low confidence), a timescale of ~25 years (low confidence), and regional warming (high confidence)…*

4.2. Greenland ice sheet

The Greenland ice sheet (GrIS) is shrinking at an accelerated rate as a result of both net surface melt and accelerated calving and shows early warning signals consistent with approaching a tipping point in west Greenland. Both ice sheet modeling and paleoclimate data indicate that a GrIS tipping point can occur when the melt-elevation feedback gets strong enough to support self-propelling melt (as an ice sheet surface loses height, it enters warmer air and thus melts faster). Different models give a critical threshold of 0.8 to 3.2°C. Paleoclimate and model evidence shows that ice only reaches full coverage below ~0.3 to 0.5°C. Hysteresis allows GrIS to exist above this growth threshold once formed but paleo-records indicate that GrIS partially retreats above this threshold and likely collapsed during the long MIS-11 interglacial[5] *which was considerably warmer (>1.5°C). A coupled ice sheet–atmosphere model found no collapse threshold, leading AR6*[6] *to state that there is limited evidence for irreversible GrIS loss below 3°C. However, some irreversible loss occurs beyond 3.5 m sea level equivalent (equivalent to ~2 to 2.5°C), indicating self-perpetuating feedback. GrIS collapse would shift the Earth system to a unipolar icehouse state and affect other tipping elements (particularly the AMOC), hence qualifying as a global core tipping element (high confidence). Our best estimates for GrIS include a threshold of ~1.5°C (0.8 to 3°C) (high confidence) and timescales of 10,000 years(1,000 to 15,000 years) (medium confidence)… The timescale of ice sheet meltdown gets shorter the greater the temperature threshold is exceeded, with a minimum of ~1000 years.*

Author's comment: Don't be too happy about the above multi-thousand year estimate. GrIS is already melting rapidly. In fact Greenland has lost 5 trillion tons of weight since the early 2000. This is mainly from its melting ice sheet, and this is already raising sea levels and disrupting the AMOC (see below) .The real question is how much additional sea level rise is already baked into the GrIS-melt? For more details on this ice loss and sea lever rise see the reference here.[7]

4.3. West Antarctic ice sheet

Large parts of the West Antarctic ice sheet (WAIS) are grounded below sea level; if the grounding line in these marine ice sheet basins reaches retrograde slopes, this may lead

[4] Fifth Assessment Report from the IPCC, https://www.ipcc.ch/assessment-report/ar5/

[5] The marine isotopic stage 11 (MIS 11) is an extraordinarily long interglacial period in the Earth's history that occurred some 400,000 years ago and lasted for about 30,000 years.

[6] Sixth Assessment Report from the IPCC, https://www.ipcc.ch/assessment-report/ar6/

[7] Jeff McMahon, Forbes "NASA Figured Out How To Weigh Greenland—And Documented Massive Weight Loss From Melting Ice," Sep 20, 2022, https://www.forbes.com/sites/jeffmcmahon/2022/09/20/nasa-figured-out-how-to-weigh-greenland-and-documented-massive-weight-loss-from-melting-ice/?sh=7170fc307d9f
Also see Emma Newburger, CNBC, "Greenland ice loss will raise sea levels by nearly one foot by 2100, study shows," Aug 29, 2022, https://www.cnbc.com/2022/08/29/greenland-ice-loss-will-raise-sea-levels-by-nearly-one-foot-study.html

to the onset of marine ice sheet instability (MISI) and crossing of a tipping point. MISI is based on a feedback between the grounding line retreat and ice flux across the grounding line as it reaches thicker ice. This can lead to self-sustaining retreat and is hypothesized to have driven past collapses of the WAIS during previous warmer interglacial periods with high sea levels. Some glaciers in the Amundsen Sea Embayment are already close to this threshold and experiencing substantial grounding line retreat.[8] *The grounding line of Thwaites glacier is only ~30 km away from the subglacial ridge and retreating at ~1 km per year*[9]*; eventual collapse may already be inevitable. Models support irreversible retreat being underway for present levels of ocean warming and suggest that losing Thwaites glacier may destabilize much of WAIS. Under sustained 1°C warming one model shows partial WAIS collapse with mass loss peaking at ~2°C warming. Hence we retain WAIS as a core global tipping element (high confidence) with a best estimate threshold of ~1.5°C [1 to 3°C], (high confidence) and timescales of 2,000 years (500 years to 13,000) (medium confidence). Exceeding the threshold by a higher amount reduces the transition timescale to a minimum of ~500 years.*

Author's comment: Ditto the prior comment. I could not find a source that specifically estimated the Y-2100 sea-level rise caused by the WAIS, as most focused on the ultimate rise after a complete collapse. Once the Thwaites glacier crosses the above described tipping point, the collapse would then be baked-in. The estimate sea level rise for a complete collapse is 3.2 meters (about 10-1/2 feet).

4.4. Boreal permafrost

Permanently frozen soils and sediments in boreal regions contain ~1035 gigatonnes of carbon (GtC) that can be partly released as CO_2 and methane upon thawing. Although initially lacking evidence for a synchronous large-scale threshold, subsequent assessments recognized that part(s) of the permafrost could be considered a tipping element. Here we separate permafrost into three components with different dynamics: gradual thaw [PFGT; a threshold-free feedback (high confidence)]; abrupt thaw [PFAT; a regional impact tipping element (medium confidence)], and collapse [PFTP: a global core tipping element (low confidence)]. Abrupt thaw processes (PFAT) such as slope slumping and thaw-lake formation could increase emissions by 50 to 100% relative to gradual thaw, involve localized tipping dynamics (e.g., continued thaw subsidence after initiation) and could occur near-synchronously on a subcontinental scale. Our best estimates for PFAT include a tipping threshold of 1.5°C (1 to 2.3°C) (medium confidence), a timescale of 200 years (100 to 300<years) (medium confidence), and an additional ~50% emissions beyond gradual thaw (~10 to 25 GtC per °C, medium confidence). Finally, abrupt permafrost drying at ~4°C and/or sufficiently rapid regional warming (>9°C) corresponding to ~5°C globally could act as a trigger for permafrost collapse (PFTP) driven by internal heat production in carbon-rich permafrost—"the compost bomb" instability. The Yedoma deep ice- and carbon-rich permafrost (containing ~115 GtC in Yedoma deposits, ~400 GtC across the Yedoma domain) is particularly vulnerable as fast thaw processes can expose previously isolated deep

---

8 E. Rignot, J. Mouginot, M. Morlighem, H. Seroussi, B. Scheuchl, "Widespread, rapid grounding line retreat of Pine Island, Thwaites, Smith, and Kohler glaciers West Antarctica, from 1992 to 2011," Geophys. Res. Lett.41, 3502–3509 (2014), https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014GL060140

9 H. Yu, E. Rignot, H. Seroussi, M. Morlighem, Impact of iceberg calving on the retreat of Thwaites Glacier, West Antarctica over the next century with different calving laws and ocean thermal forcing. Geophys. Res. Lett.46, 14539–14547 (2019), https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019GL084066

deposits. This and other carbon-rich regions vulnerable to abrupt drying at >4°C could have considerable feedback to global temperatures. Our best estimates for PFTP include a threshold of 4°C (3 to 6°C) (low confidence), a timescale of 50 years (10 to 300 years) (medium confidence), and emissions on the order of ~125 to 250 GtC (low confidence).

Author's comment: See the post described and linked below. The whole post is relevant to the above text, but section 5 is particularly relevant (and amusing).

Positive Feedback Accelerates Sea Level Rise: *The surface air temperature of the arctic is rising twice as fast as the global air temperature. This is the result of many positive feedback forces, and causes previous simulations of how fast the Greenland ice sheet is melting to be out of date almost as soon as they are published, and not in a good way. Furthermore, Mother Nature seems to have many surprises for climatologists and many of these involve positive feedback.*

This paper will look at the positive feedback loops that we have seen recently.

https://www.energycentral.com/c/ec/positive-feedback-accelerates-sea-level-rise

4.5. Mountain glaciers

Alpine glaciers outside Greenland and Antarctica have individual mass balance thresholds and elevation feedbacks yet large-scale synchronous losses are projected in several key regions at specific global warming levels. In transient simulations, peak water from European glacier melt is expected at ~1°C with near-total loss expected to be committed at ~2°C. Global peak water occurs at ~2°C but committed eventual loss is expected at lower temperatures. Long model integrations show that global warming of 1.5 to 2°C is sufficient to lead to the eventual loss of most extra-polar glaciers (and possibly even polar glaciers). >2°C by 2100 puts most lower-latitude glaciers on a path to significant losses beyond 2100. Glaciers in High Mountain Asia last longer than elsewhere but reach peak water at ~2°C with significant social impacts for South Asia. Given the considerable human impacts of glacier loss we categorize mountain glaciers as a regional impact tipping element (medium confidence). Our best estimate includes a threshold of ~2°C (1.5 to 3°C) (medium confidence) and a timescale of 200 years (50 years to 1 ky) (medium confidence).

Southern Ocean sea ice features abrupt events in some climate models but because of uncertain dynamics and low confidence in projections it is classed as an uncertain tipping element. Marine methane hydrates are classed as a threshold-free feedback and Tibetan plateau snow is classed as uncertain.

4.6. Labrador & Irminger Seas / Subpolar Gyre

Convection in the Labrador and Irminger Seas in the North Atlantic—part of the subpolar gyre (SPG)—abruptly collapses in some models as a result of warming-induced stratification, a state which is then maintained by self-reinforcing convection feedbacks giving two alternative stable states with or without deep convection. Abrupt future SPG collapse occurs in nine runs across five CMIP5 models at 1.1 to 2.0°C, in one additional model run at 3.8°C (19, 65), and in four CMIP6 models in the 2040s (~1 to 2°C). In some *models SPG collapse affects AMOC[10] strength but SPG and AMOC have distinct feedback dynamics and patterns of impacts, and SPG collapse can occur much faster than AMOC collapse. The North Atlantic cooling trend (i.e., the "warming hole") is centered over the SPG and in models is often closely linked to SPG weakening, although others have associated it with AMOC slowdown. SPG collapse causes a concentrated North Atlantic regional cooling of ~2 to 3°C, potential global cooling of up to ~0.5°C, a northward-shifted jet stream, weather extremes in Europe, and southward shift of the intertropical convergence zone (ITCZ). Given clear tipping dynamics and global impact we class SPG as a global core tipping element (medium confidence), with a best estimate threshold of ~1.8°C (1.1 to 3.8°C) (high confidence), a timescale of 10 years (5 to 50 years) (high confidence).*

Author's comment: A really dangerous effect is described by the above subsection. The AMOC is not only one of the main ocean currents, it also is a connected part of the MOC, which is connected to all of the major ocean currents. The AMOC has already slowed by 15% in recent years.[11] See the next subsection below.

4.7. Atlantic meridional overturning circulation (AMOC)

The Atlantic meridional overturning circulation (AMOC) is self-sustaining due to salt-advection feedback (northward movement of warm water increases its density as a result of cooling and evaporation supporting the deep convection that drives the circulation). Import of salt at the southern boundary of the Atlantic also supports alternative strong and weak AMOC stable states with multiple abrupt switches between them observed in the past. Global warming increases Arctic precipitation, freshwater runoff from Greenland, and sea surface temperatures, which together slow down the AMOC by inhibiting deep convection. The AMOC is inferred from some reconstructions to have weakened by ~15% over the past ~50 years and early warning signals in indirect AMOC footprints are consistent with the current AMOC "strong" state losing stability. However, the Intergovernmental Panel on Climate Change (IPCC) gives low confidence on historical AMOC trends. The Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC, 2019) assessed AMOC collapse occurring during the 21st century to be very unlikely but physically plausible; however, this was increased to unlikely (medium confidence) in AR6. AMOC collapse is triggered in three runs of one CMIP5 model at 1.4 to 1.9°C and in two runs of an additional model at 2.2 to 2.5°C in contrast to gradual declines in other CMIP5 and CMIP6 models. However, AR6 assessed CMIP models as generally tending toward "unrealistic stability" with respect to observational constraints. They also neglect meltwater forcing from rapid Greenland Ice Sheet melt. Both factors make the AMOC more vulnerable to collapse. AMOC collapse would have global impacts on temperature and precipitation patterns including North Atlantic cooling, Southern Hemisphere warming, southward-shifted intertropical convergence zone, monsoon weakening in Africa and Asia, monsoon strengthening in the Southern Hemisphere leading to drying in the Sahel and parts of Amazonia, and reduced natural carbon sinks. Hence AMOC is retained as a core global tipping element

[10] Atlantic Meridional Overturning Circulation, see "Climate and Energy Part 1: The Future", section 2.4.1 https://energycentral.com/c/ec/climate-and-energy-part-1-future-rev-c

[11] L. Caesar, S. Rahmstorf, A. Robinson, G. Feulner & V. Saba, Nature, "Observed fingerprint of a weakening Atlantic Ocean overturning circulation," April 11, 2018, https://www.nature.com/articles/s41586-018-0006-5

(medium confidence) with a best estimate threshold of ~4°C [1.4 to 8°C] (low confidence) and timescales of ~50 years (15 to 300 years) (medium confidence).

Author's comment: I have skipped over one of the 2°C tipping points, the "Low-latitude coral reefs" as I don't feel that science has a really good understanding of this yet. On the same note, I don't feel that we have a good understanding of much that goes on in the world's oceans, mainly because we are just starting to develop and deploy the tools we need to understand this very, very large and important part of our world and its climate.

5. Final Word

I had completed my final proofing of this paper, but needed one small piece of data. Then as I was watching the lunch-time news on my television, I saw the data with an interesting article attached to it. And that is below. I've highlighted the piece of data, even though it's in two pieces.

Even as it grapples with how to protect the Embarcadero from earthquakes and climate change, San Francisco is embarking on a more expensive, almost existential task: planning how to prepare the city's bay shoreline for as much as 7 feet of sea level rise.[12]

The study being done with the U.S. Army Corps of Engineers over the next year covers an area extending from Fisherman's Wharf south to the Hunters Point shipyard, and aims to map out an adaptation strategy through 2100. Because the Army Corps is involved, the federal government could fund at least half of the long-term costs, a figure sure to run well into the billions.

The first formal presentation of the effort came Tuesday at the city's Port Commission and it will be followed by neighborhood meetings this fall along the city's eastern flank.

A tentative outline of any plan and its potential costs won't emerge before next spring. But some ideas that are in the mix — including locks on Mission Creek, and letting industrial land near the southern waterfront revert to natural conditions — hint at how profoundly the city's relationship to the bay could change in coming decades.

To draw up a potential plan, seven different response scenarios must be sorted through by the Army Corps and a half dozen city agencies. The final product would seek to protect inland resources while maintaining or improving public access to the bay. Another factor is the extent of funding that the Army Corps will provide.

"Our goals are a bit broader than the Corps'," acknowledged Elaine Forbes, director of the Port of San Francisco. "We'll overlay our values with those of the Army Corps," which focuses more narrowly on cost benefits from what gets done.

The port is the city's lead agency on the effort. This makes sense, given that the agency already is focused on strengthening the century-old Embarcadero seawall — not only because stretches are vulnerable to a major earthquake, but some areas near the Ferry Building are susceptible even now to flooding from extra-high king tides.

---

[12] John King, San Francisco Chronicle via MSN, "S.F.'s plan to protect the city from sea-level rise will 'set the stage for our future shoreline'," Oct 11, 2022, https://www.msn.com/en-us/weather/topstories/sf-s-plan-to-protect-the-city-from-sea-level-rise-will-set-the-stage-for-our-future-shoreline/ar-AA12Purv#image=AA12Qw8r|6

The scale of the new challenge, a 7.5-mile shoreline, raises the stakes much higher.

The Embarcadero is a constructed barrier of concrete and large rocks, but the overall shoreline includes large stretches of filled soil, plus rip-rap-lined creeks that are the remnants of natural bays. Some areas are in the midst of being redeveloped, such as Mission Bay and Pier 70, with plans that take higher tides into account. Others are asphalt-topped shipping terminals that, for decades, have seen little use.

And while the Embarcadero separates the bay from the city's most densely developed real estate, areas to the south include economically beleaguered neighborhoods and blocks of low-slung warehouses. Another concern: Some inland areas that were filled haphazardly could be susceptible to flooding from groundwater — even if they aren't along the shore…

As with the planning strategy that has evolved during the past two years along the Embarcadero, early investments would focus on reducing the potential damage from earthquakes, since a temblor as large as the one that hit the city in 1906 could strike without warning. Larger moves to adapt the shoreline would occur over decades, and as funding becomes available.

Possible response strategies could include raising the shoreline along roadways such as the Embarcadero, or Mission Bay's Terry Francois Boulevard — not simply by building a levee to repel water, but with terracing to both the east and west to allow for landscaped public promenades while adding discreet vertical buffers.

"We started with an urban design assumption of keeping views and access from the city to the bay," said Brad Benson, the waterfront resilience director for the port.

Looking toward 2100, particularly if sea level rise is at the higher range of current projections, the interventions could be startling.

Tidal barriers to keep out major storm surges might be required where Mission Creek enters China Basin, in the Mission Bay neighborhood, and also for Islais Creek, on the southern shoreline between Dogpatch and Bayview. These are dam-like structures that can be built to remain open most of the time, but be locked tight when storm surges or extra-high tides are feared.

Another approach might be to clean the soils along Islais Creek, buy out private property owners and then let the bay reclaim stretches of land alongside it. Mission Bay could see parks double as water retention basins; canals could be added to move water through the relatively young neighborhood…

Final author's comment: I'm sure a large majority of my readers are not that familiar with San Francisco, but I wanted to include most of the above article for several reasons. First is the above highlighted text. Second is the above cost "…well into the billions…" Third to state that most of San Francisco is well above sea level (much more than seven feet). Fourth to state that San Francisco is one of the most affluent cities in the U.S., given its population (about 815,000), so they can afford this. Finally so that readers can get a feel for the complexity of this project.