Exhibit C

Supplemental
Public correspondence received as of
July 9, 2020

Oregon Coordinating Council on Ocean Acidification & Hypoxia

Date: July 9th, 2020

To: Oregon Fish and Wildlife Commission

Re: Letter of Support for Adoption of the Oregon Department of Fish and Wildlife Agency Climate and Ocean Change policy

Good afternoon,

As a Co-Chair of the legislatively created Oregon Coordinating Council on Ocean Acidification and Hypoxia (or "OAH Council"), I appreciate the opportunity to offer a letter of support for the Oregon Department of Fish and Wildlife's newly drafted Climate and Ocean Change policy. This proposed agency policy relates to ongoing adaption and resiliency goals within the Oregon OAH Action Plan 2019-2025, and will aid the State in supporting prioritization of OAH research and science-based management of key species and habitats in light of changing climate and ocean conditions. As a co-chair of the OAH Council, I highly encourage the Oregon Fish and Wildlife Commission to vote "yes" on adopting this important climate and ocean policy directive. To build the brightest future for the ocean and its species and the communities that depend on them, and, despite uncertainty, we can and must act now in a pro-active way that will improve ecosystem and community outcomes for resilience.

Oregon is among the first places in the world to observe direct impacts of OAH, due to our unique geographic and oceanographic context, putting our fragile marine ecosystems and coastal communities at risk. Our nearshore waters are home to sport and commercial fisheries, and contain critical nursery grounds for important species including Dungeness crab, salmon, sea urchin, abalone, rockfish, oysters, and others – all critical marine resources which are managed by the agency. Ocean and climate change, including OAH, are expected to increasingly hinder Oregon Department of Fish and Wildlife's ability to achieve its agency mission and meet its statutory mandates to our native fish and wildlife.

In September 2018, the OAH Council submitted their first biennial report to the Oregon Legislature, which directly identified the need to reduce carbon dioxide and other emission sources, support resiliency within Oregon's ecosystems, and coordinate climate and ocean management coordination (see Theme 2, Theme 3, and Theme 5 of the 2018 report). The currently proposed policy would offer an enormous opportunity to ensure that ODFW implements a strategic response that improves protections for our fish and wildlife while providing critical management framework for our state's understanding of larger regional climate change impacts.

The OAH Council appreciated the ODFW's inclusive and transparent process in developing the Climate and Ocean Policy and for allowing the wider environmental community to provide feedback on early drafts of the policy. The results of increasing OAH have had far-reaching consequences, for both the ocean ecosystem and the economy, consequences that we, as a society, are only just beginning to understand and quantify. Shifting food webs, loss of fishery productivity and lost economic opportunities are just some of the many impacts we are expecting to see because of increasing OAH. The proposed policy will help ensure a healthy Oregon marine ecosystem on which Oregon's fishing industry relies.

In summary, as a Co-Chair of Oregon's OAH Council I strongly support the Oregon Department of Fish and Wildlife's newly drafted Climate and Ocean Change policy. The Climate and Ocean Policy will allow the State to continue to characterize OAH vulnerabilities and pursue science-based adaptation/resilience strategies for preserving Oregon's marine ecosystem and socio-economic assets. Through scientific understanding and awareness, we can work together to combat the threat of climate and ocean change to Oregon's marine ecosystem and coastal economies.

Thank you for your consideration of this letter of support and welcome any questions.

Sincerely,

John A Barth

John Barth, PhD

Oregon State University

Executive Director
Marine Studies Initiative
Oregon State University

Email: jack.barth@oregonstate.edu

TROUT UNLIMITED

July 9, 2020

Oregon Fish and Wildlife Commission
Chair, Mary Wahl
4034 Fairview Industrial Drive SE
Salem, OR 97302-1142

RE: Exhibit C: ODFW Climate and Ocean Change Policy

Dear Chair Wahl and Members of the Commission,

Trout Unlimited (TU) appreciates the opportunity to provide comments on the Oregon Department of Fish and Wildlife's (ODFW) Climate and Ocean Change Policy. TU is a non-profit organization dedicated to the conservation of cold-water fishes, such as trout and salmon, and their habitats. Trout Unlimited has more than 300,000 members and supporters nationwide including over 3,000 in Oregon.

TU supports the adoption of this policy. This effort is timely and critical as Oregon's natural resources, including our fish and wildlife, face daunting pressures as a result of climate change. In short, the best available scientific information indicates that, as a result of climate change, habitat conditions (especially for cold-water fish species) are changing and expected to further change for the worse. Oregon must work to ensure that its natural resources can adapt to the changes that climate change is causing and will continue to cause. Leadership is needed to push all levels of government to engage in adaptation planning, to advocate for funds for the purpose of implementing climate change adaptation and resiliency actions for natural resources and to educate decision-makers and the public about the consequences of inaction. ODFW is well-suited to provide leadership on climate issues and this policy is a positive step in the right direction. TU does, however, have a few concerns as well as a few recommendations to improve the policy.

TU supports the purpose and goals articulated in the policy. In part, the goals indicate that ODFW will take action to improve its understanding of climate change risks and incorporate that understanding into its decision-making but ODFW will also engage with other decision-makers to help ensure a coordinated response to minimize the impacts of a changing climate on resources. These are both critical pieces of an effective strategy given that many other entities besides ODFW make decisions and take actions that have an effect on natural resources. TU often engages in these other decision-making forums and believes that their outcomes are improved when ODFW staff is engaged and able to provide information and recommendations regarding species needs. The key section that provides guidance on how ODFW would affect climate change policy outside of its own agency is Section 635-900-0010 entitled "Statewide Coordination of a Climate and Ocean Change Response." This section would benefit from additional detail and clarity especially for the sections regarding how ODFW will engage with other agencies. The language should more clearly state that ODFW will not only help these agencies determine clear priorities for fish and wildlife resources but will also: 1) help these agencies identify the best available scientific information regarding those priorities, 2) provide guidance/tools/strategies regarding how that information can inform their management decisions/projects/programs, 3) meaningfully engage in relevant regulatory/collaborative processes and 4) offer recommendations that are consistent with the policy and other ODFW mandates and 5) encourage, where appropriate, robust adaptive management such that decisions can be revised as conditions change and information improves.

TU also has concerns with the language in Section 5 of the "Climate and Ocean Change Key Species and Habitat Management Principles" section. More clarity should be provided regarding what thresholds or information will be required to make a determination that a native species is no longer able to "persist in an area because the impacts of changing climate and ocean conditions are practicably irreversible." In this scenario, modification of the conservation approach is allowed as long as healthy populations of the species exist elsewhere in the range. This sentence presents questions regarding what constitutes a healthy population or whether existence of a species anywhere else in the range is the most scientifically sound criteria for abandoning a conservation approach.

Finally, robust implementation of this policy will be key to establishing it as an effective and enduring document. ODFW has an opportunity right now with its Rogue-South Coast Management Plan to demonstrate how its climate change policy is incorporated into its decision-making processes. As a participant in that effort, TU looks forward to engaging in those discussions.

TU appreciates the opportunity to comment on this policy and the work of ODFW staff on this effort. Thank you for the opportunity to provide comments.

Chandra Ferrari

Chandra Ferrari
Senior Policy Advisor and Staff Attorney
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(916) 214-9731

Roxann B Borisch

From:	Kirk Blaine <kirk@nativefishsociety.org>
Sent:	Thursday, July 9, 2020 1:52 PM
To:	ODFW.Commission@state.or.us
Subject:	Climate and Ocean Change Policy Comments

Chair Wahl, Commissioners, and Director Melcher,

Thank you for the opportunity to submit written comments on the Climate and Ocean Change Policy. My name is Kirk Blaine and I write to you on behalf of Native Fish Society, a non-profit working to restore abundant wild fish, free-flowing rivers, and thriving local communities. Native Fish Society supports the adoption of the proposed Climate and Ocean Change Policy being presented to the Commission on July 10th. This policy will add science-based management related to the threats of climate and ocean change to the current planning and execution of department goals and objectives.

Native Fish Society does have concerns. We ask that the commission and department uphold actions indicated in the policy ensuring a science-based approach to Climate and Ocean Change is integrated in all planning, prioritization, and implementation of the Department's Key Principles. Native Fish Society strongly encourages the department to craft detailed implementing regulations that provide adequate adaptive management frameworks and ensure that there are no sacrifice rivers, zones, or native fish populations. The department must be held accountable for the goals outlined in this policy and the actions they take to reach the specific policy goals. When these goals are attained or failed to be attained specific actions must be laid out to achieve success.

Establishing and ensuring sustainable funding for an ODFW Habitat Division is crucial to seeing this policy positively impact wild native fish. Securing funding for both the Habitat Division and population monitoring work will be critical to meaningfully implementing this policy.

Native Fish Society would like to see the Climate and Ocean Change Policy be mandatory in all stages of future planning and management of fish and wildlife species. For example, through the current stakeholder process for the Rogue South Coast Multi-species management plan, there has been no substantive integration of Climate or Ocean Change science into fishery and hatchery proposals by the state. Utilizing this policy as the foundation for planning the management and conservation of those species is critical to future success.

Again, I would like to thank you for the opportunity to submit a comment. Native Fish Society is excited to see direct details implemented from this policy to help restore our wild native fish for all Oregonians to enjoy now and into the future.

Best,
Kirk Blaine

Kirk Blaine
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Roxann B Borisch

From: ODFW Commission
Subject: FW: Comment on Exhibit C Fish and Wildlife Commission Mtg July 10

From: Mary Anne Cooper <maryannecooper@oregonfb.org>
Sent: Thursday, July 9, 2020 11:34 AM
To: ODFW.Commission@state.or.us
Cc: jenny@pacounsel.org; Kyle Williams <kyle@ofic.com>
Subject: Comment on Exhibit C Fish and Wildlife Commission Mtg July 10

Commissioners,

Thank you for the opportunity to comment on the proposed Division 900 rules adopting a climate policy for the Oregon Department of Fish and Wildlife (the Department). Oregon Farm Bureau and Oregon Forest and Industries Council appreciate the hard work and thoughtfulness that went into developing these rules, and appreciate the general approach taken by the rules. We agree that climate change is going to be a challenge into the future.

As you are aware, our groups had significant concerns about the proposed climate legislation considered by the legislature in the 2019 and 2020 legislative session. The proposal would have had an imperceptible impact on climate change in Oregon, but would have cost our industries and all Oregonians hundreds of millions of dollars to implement. The investment priorities under the legislation were unclear in some cases and unworkable for working landscapes in other cases. As such, we have strongly encouraged the Governor to rethink the approach outlined in Executive Order 20-04, which would result in her agencies imposing many of those same costs on Oregonians.

In reviewing the proposed policy advanced by the Department, we generally support the Department including climate change adaptation in their policies and support the Department evaluating its own environmental and carbon footprint in its implementation of its statutes and rules. However, we found some aspects of the policy to be vague as to the outcome anticipated. For example, OAR 635-900-0010(2) and (4) talk about inventories of natural resources and developing priorities for vulnerable natural resources. It is not clear whether the policy would extend beyond fish and wildlife species (specifically whether the inventories and prioritizations would include agriculture or forestry lands or resources) and how those inventories and priorities will be developed. We have concerns about adoption of such a broad directive without additional information on the scope of the directive and how it will be implemented. The Department must ensure that any programs or work that results from his policy have robust landowner engagement, acknowledge the important positive effect working lands can have on increasing climate resiliency, and ensure that any actions taken by the Department are transparent and are based on achievable goals. We would appreciate these sideboards being incorporated into the proposed rules so that stakeholders now and in the future are clear what the sideboards and approach for this work will be.

Thank you for the opportunity to comment on this policy and please contact us if you have any questions.

Kyle Williams
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Roxann B Borisch

From:	Danielle Moser <dm@oregonwild.org>
Sent:	Thursday, July 9, 2020 11:56 AM
To:	odfw.commission@state.or.us; Michelle Tate
Subject:	Comment on Climate and Ocean Change Policy
Attachments:	Letter to Commission on Climate and Ocean Policy Final.pdf

Good Afternoon,

On behalf of the Oregon Wildlife Coalition, we would like to submit the attached comment about the proposed Climate and Ocean Change Policy for the Commission's consideration.

Thank you,

--
Danielle Moser
(she/her/hers)
Wildlife Program Coordinator
Oregon Wild
Phone: 503-975-0482

Oregon Wildlife Coalition

July 9, 2020

Oregon Fish and Wildlife Commission
4034 Fairview Industrial Drive, SE
Salem, OR 97302

Sent electronically to odfw.commission@state.or.us

Re: Oregon Wildlife Coalition Comments on Proposed Climate and Ocean Change Policy

Dear Chair Wahl, Vice Chair Wolley, and Members of the Commission:

On behalf of the Oregon Wildlife Coalition -- a group of nine wildlife conservation groups working proactively and collaboratively to advocate for policies that are science based and humane, and reflect the state's conservation values -- we submit this comment for your consideration regarding the proposed Climate and Ocean Change Policy ("Climate Policy").

We appreciate that the Oregon Department of Fish and Wildlife ("ODFW") has developed guidance to better address the needs of our state's fish, wildlife and their habitat in the face of unprecedented climate and ocean change. Adopting such a policy is consistent with ODFW's statutory mission and the state's wildlife policy (ORS 496.012) which requires the agency to prevent the serious depletion of any indigenous species and to provide the optimum recreational and aesthetic benefits for present and future generations. Twenty years ago, the Attorney General issued an opinion saying that it is "the Commission's and the Department's overriding obligation to manage and prevent the serious depletion of any indigenous species." The Climate Policy rightly reinforces that ODFW's overriding priority must be the conservation of the state's wildlife and its habitat.

The Climate Policy under your consideration provides OFDW tools to mitigate some of the worst impacts of climate and ocean change affecting our state's wildlife. However, there are a few changes we recommend before the Commission formally adopts this policy into rule:

- While the Climate Policy provides a solid framework and approach for the agency, at times the language is quite broad and vague. Although we understand the need for flexibility, we are concerned about the inconsistent application of key principles. We recommend editing language that is merely suggestive to be more direct. One such example is replacing the word 'should' with 'will' or 'shall' or 'must'. This will provide more clarity to ODFW, ensure accountability to the public, and enable consistent application of the provisions of the Climate Policy.

- As one example that could be replicated throughout the Climate Policy, we suggest modifying section 635-900-0010(2)as follows:
  - *The Department should work with other executive branch natural resource agencies and appropriate federal, tribal, and local partners to complete inventories of the State's natural resource assets.*
  - *The Department shall work with other executive branch natural resource agencies and appropriate federal, tribal, and local partners to complete inventories of the State's natural resource assets.*

- Pursuant to ORS 496.012, it is the primary responsibility of ODFW to prevent the serious depletion of any indigenous species. There are two instances in which the Climate Policy deprioritizes protective measures for the most vulnerable species and habitats.
  - Under Climate and Ocean Change Key Species and Habitat Management Principles (635-900-0017) section 7, the Climate Policy essentially adopts a triage approach for prioritizing conservation and management activities. It gives priority first to protecting fish and wildlife habitat that is currently high functioning, and second to those habitats that could become high functioning through enhancement and restoration. It assigns the least priority to habitats where species may not be able to persist due to climate or ocean change.
  - Although this approach provides a mechanism for allocating limited agency resources, it denies necessary protections for our state's most vulnerable species and habitats. Habitat conservation and species protection has been woefully underfunded for many years. Oregon's failure to invest in proactive protection for vulnerable species and habitats has placed them in even greater peril in the face of a changing climate. As currently drafted, the Climate Policy writes off those species and habitats that human activities have pushed to the brink. We cannot permit our past failures of investment and action to determine whether Oregon's native wildlife persists or vanishes.

  - Additionally, in section 635-900-0017(5) it states that, "*The Department should prioritize conservation actions for native species and their habitats to be most efficient in achieving conservation outcomes. In some instances, naturally-produced, native species will be unable to persist in an area because the impacts of changing climate and ocean conditions are practically irreversible. In these instances, the Department, only through the Commission, may consider modification of the conservation approach as long as healthy populations of the species exist elsewhere in the range and the modification is in compliance with other state and federal laws.*" This implies that investing in the prevention of local extinction of a species is not worth the time and resources, so long as the species is found elsewhere in the range. This contradicts the agency's own wildlife policy. The provision is also overly vague with no definition of what may constitute 'healthy populations.' Likewise, the Commission appears to have broad discretion here to modify the conservation approach. We believe this provision should be clarified or removed. We advocate for robust investment and allocation of resources to vulnerable species instead of allowing extirpation.

Developing a framework and guiding principles for ODFW to address the growing concerns related to climate and ocean change is vital if we want to see Oregon's fish and wildlife populations thrive for generations to come. As laid out in the Key Assumptions section, the challenges facing our state's fish and wildlife are significant, which is why we need creative solutions to overcome them. As you continue to develop policies and programs for ODFW to address climate and ocean change, we urge you to consider how the recovery of certain keystone species, like beavers and sea otters, could not only help mitigate the impacts of climate change but also aid in the recovery of other fish and wildlife.

Finally, we urge the Commission and ODFW to allocate more resources to conservation, especially the implementation of the Oregon Conservation Strategy. By fully investing in these programs and projects proactively, we can ensure our state has more resilient fish and wildlife populations and healthier ecosystems to support those species, especially in the face of major challenges like climate and ocean change. It should never have to come to choosing which species gets to thrive and which species gets left behind.

Thank you for your consideration of our input.

PACIFIC COAST FEDERATION of FISHERMEN'S ASSOCIATIONS

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8 July 2020

TO: Oregon Dept. of Fish & Wildlife
Attn: Fish & Wildlife Commission
Email: odfw.commission@state.or.us

RE: PCFFA/IFR Support for Proposed "Climate and Ocean Change Policy" Rules

To the Commissioners:

These are the written comments of both the Pacific Coast Federation of Fishermen's Associations (PCFFA), a coastwide ocean commercial fishing industry trade association, and its sister organization, Institute for Fisheries Resources (IFR), on proposed "Climate and Ocean Change Policy" regulations to be considered by the Commission in its 10 July 2020 meeting.

On behalf of the west coast commercial fishing industry and the hundreds of commercial fishing-dependent families and fishing business operations that our two organizations work with and represent, **we support the draft rules on this issue currently before you.** These proposed rules are a very good beginning – although of course only a beginning -- for the guidance of organized future efforts of the State of Oregon to respond to the accelerating problems of climate change on its fish and wildlife resources, including addressing increasing ocean acidification, already triggering major, serious and potentially highly destructive changes in ocean ecosystems. **We urge you to adopted these proposed rules.**

Please place these comments in the official public record for the upcoming hearing on these proposed regulations. Both our organizations were involved in earlier drafting efforts, and we both intend to remain involved in implementing these important policy rules once it is adopted.

General Comments on the Proposed Policy

(1) The science today is very clear that, regardless of whether or not the Earth as a whole can meet *Paris Agreement* decarbonization targets (itself increasingly unlikely), it is already too late to prevent worldwide ocean sea level rises and increasing ocean acidification, as well as considerable terrestrial climate disruption (see Attachments 1 and 2), for at least the next 100 years. In absence of prevention (in addition, of course, to not digging this hole any deeper by reducing greenhouse gas levels generally), we must therefore anticipate, mitigate and adapt as

best we can as a society to changes we know are already coming regardless, including planning for a far longer term than most of our current institutions typically envision. We are thus happy to see that a "long-view" precautionary principle has been built into the management goals and strategies that will be developed under this policy (e.g., in Sec. 635-900-0017(2) & (4)).

(2) A broad "whole ecosystem conservation" approach needs to be employed, in order to encompass board-based habitat conservation efforts for multiple species, rather than a fragmented species-by-species approach as has more often been the case in the past. This is also the most efficient way to use always limited resources. The emphasis in the proposed regulations on long-term "habitat conservation" efforts, especially adapting through shifting future habitat conditions, and particularly dealing with projected changes of species' ranges, goes a long way toward the "whole ecosystem" protection approach (e.g., Sec. 635-900-0015(1)-(3)).

(3) Since ODFW's jurisdiction is limited, a state-wide (even region-wide) and multi-agency coordination effort is sorely needed. We are gratified to see the emphasis in the proposed policy on coordinating both state-based and regional responses, as well as a multi-stakeholder approach to all these issues, which of course are regionwide (e.g., Sec. 635-900-0005(2)).

(4) Oregon's coastal commercial fisheries are in deadly peril from the future combination of loss of infrastructure in coastal communities due to rising sea levels, soaring ocean temperatures and the accelerating impacts of ocean acidification. These latter two factors also synergistically power the spread of massive de-oxygenated "dead zones" as well as rapidly changing species redistributions. Much work has already been done on dealing with these issues, however, in California, where many are already hitting hard. A recent summary of California efforts and thoughts about adapting commercial fisheries to climate and ocean changes is included by reference as "Readying California Fisheries for Climate Change," published June, 2017, which may contain many good ideas for Oregon to use and expand upon. This document is too big to upload from our email system, but it is available from the following URL: https://escholarship.org/uc/item/2kr7839k. We hereby incorporate that document into our comments by reference.

*****

Thanks for the opportunity to comment, and our industry will continue to be engaged in these vitally important issues.

Sincerely,

Glen H. Spain

NW Regional Director
PCFFA/IFR

Attachment 1: Various articles and studies on projected sea-level impacts through year 2300.
Attachment 2: "World Scientists' Warning of a Climate Emergency," Nov. 2019.

Attachment 1: Various articles and studies on sea-level impacts through year 2300

The Guardian

Sea levels set to keep rising for centuries even if emissions targets met

Generations yet unborn will face rising oceans and coastal inundations into the 2300s even if governments meet climate commitments, researchers find

A potential scenario of future sea level rise in South Beach, Miami, Florida, with a global temperature rise of 2C. Photograph: Nickolay Lamm/Courtesy Climate Central

Oliver Milman *in New York*

Wed 6 Nov 2019 05.00 EST

Sea level rise is set to challenge human civilization for centuries to come, even if internationally agreed climate goals are met and planet-warming emissions are then immediately eliminated, researchers have found.

The lag time between rising global temperatures and the knock-on impact of coastal inundation means that the world will be dealing with ever-rising sea levels into the 2300s, regardless of prompt action to address the climate crisis, according to the new study.

Even if governments meet their commitments from the landmark 2015 Paris climate agreement, the first 15-year period of the deal will still result in enough emissions that would cause sea levels to increase by around 20cm by the year 2300.

This scenario, modeled by researchers, assumes that all countries make their promised emissions reductions by 2030 and then abruptly eliminate all planet-warming gases from that point onwards. In reality, only a small number of countries are on track to meet the Paris target of limiting global heating to 2C above the pre-industrial era.

"Even with the Paris pledges there will be a large amount of sea level rise," said Peter Clark, an Oregon State University climate scientist and co-author of the study, published in Proceedings of the National Academy of Sciences.

"Sea level rise is going to be an ongoing problem for centuries to come, we will have to keep on adapting over and over again. It's going to be a whole new expensive lifestyle, costing trillions of dollars.

"Sea level has a very long memory, so even if we start cooling temperatures the seas will continue to rise. It's a bit like trying to turn the Titanic around, rather than a speedboat."

Researchers used a computer model that simulates sea level rise in response to various emissions levels, looking both at historical emissions since 1750 and also what the emissions scenario would be from 2015 to 2030 if countries met their Paris agreement obligations.

About half of the 20cm sea level rise can be attributed to the world's top five greenhouse gas polluters - the US, China, India, Russia and the European Union - according to the researchers. The US was a key architect of the Paris deal but this week Donald Trump formally triggered its exit from the agreement.

"Our results show that what we do today will have a huge effect in 2300. Twenty centimetres is very significant; it is basically as much sea-level rise as we've observed over the entire 20th century," said Climate Analytics' Alexander Nauels, lead author of the study. "To cause that with only 15 years of emissions is quite staggering."

The results reveal the daunting prospect of a near-endless advance of the seas, forcing countries to invest huge resources in defending key infrastructure or ceding certain areas to the tides. Many coastal cities around the world are already facing this challenge, with recent research finding that land currently home to 300 million people will flood at least once a year by 2050 unless carbon emissions are drastically slashed.

As the world heats up, ocean water is expanding while land-based glaciers and the two great polar ice caps are melting away, causing the oceans to swell.

According to the UN's climate science panel, the global sea level rise could reach as much as 1.1 metres by the end of the century if emissions aren't curbed. Clark pointed out the real situation could be even worse if the melting of the Antarctic turns out to be on the dire end of the spectrum of uncertainty.

"People are going to become less inclined to live by the coast and there are going to be sea level rise refugees," Clark said. "More severe cuts in emissions are certainly going to be required but the current Paris pledges aren't enough to prevent the seas from rising for a long, long time."

Attributing long-term sea-level rise to Paris Agreement emission pledges

Alexander Nauels[a,b,1], Johannes Gütschow[c], Matthias Mengel[c], Malte Meinshausen[b,c], Peter U. Clark[d,e], and Carl-Friedrich Schleussner[a,c,f]

[a]Climate Analytics, 10969 Berlin, Germany; [b]Australian-German Climate & Energy College, The University of Melbourne, Parkville, VIC 3010, Australia; [c]Potsdam Institute for Climate Impact Research, D-14412 Potsdam, Germany; [d]College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, Corvallis, OR 97331-5503; [e]School of Geography and Environmental Sciences, University of Ulster, BT52 1SA Coleraine, Northern Ireland, United Kingdom; and [f]Integrative Research Institute on Transformations of Human–Environment Systems (IRI THESys), Humboldt-Universität zu Berlin, 10099 Berlin, Germany

Edited by Arild Underdal, University of Oslo, Oslo, Norway, and approved September 19, 2019 (received for review April 30, 2019)

The main contributors to sea-level rise (oceans, glaciers, and ice sheets) respond to climate change on timescales ranging from decades to millennia. A focus on the 21st century thus fails to provide a complete picture of the consequences of anthropogenic greenhouse gas emissions on future sea-level rise and its long-term impacts. Here we identify the committed global mean sea-level rise until 2300 from historical emissions since 1750 and the currently pledged National Determined Contributions (NDC) under the Paris Agreement until 2030. Our results indicate that greenhouse gas emissions over this 280-y period result in about 1 m of committed global mean sea-level rise by 2300, with the NDC emissions from 2016 to 2030 corresponding to around 20 cm or 1/5 of that commitment. We also find that 26 cm (12 cm) of the projected sea-level-rise commitment in 2300 can be attributed to emissions from the top 5 emitting countries (China, United States of America, European Union, India, and Russia) over the 1991–2030 (2016–2030) period. Our findings demonstrate that global and individual country emissions over the first decades of the 21st century alone will cause substantial long-term sea-level rise.

sea-level rise | Paris Agreement | emission pledges

Future global mean sea-level rise (GMSLR) poses a threat to ecosystems (1), the livelihoods of hundreds of millions of people (2), and world heritage (3, 4) along the Earth's coasts. Global mean sea level has risen by around 20 cm since 1900, with accelerating current rates of around 3 mm/y (5–7). The key contributors to sea-level change are ocean thermal expansion, glaciers, and the Greenland and Antarctic ice sheets, all of which are now contributing to current sea-level rise at an increasing rate in response to ongoing global warming (5). These contributors respond to warming on multiple timescales, ranging from decades to centuries for glaciers and centuries to millennia for thermal expansion and ice sheets (8, 9). Due to this long integrated response time, the GMSLR from anthropogenic greenhouse gas emissions is now only in its initial stages. A focus on the scenario dependency of GMSLR for the 21st century thus does not reflect the sensitivity of future long-term GMSLR to historical and future emissions as the full response to these emissions will only materialize on a millennial timescale (9–12).

For the near-term future up to 2030, aggregated Nationally Determined Contributions (NDCs), as submitted under the Paris Agreement framework, reflect the global mitigation ambition and result in quantifiable emission trajectories. The level of ambition implied by the NDCs is routinely compared to 2030 emission scenarios in line with 1.5 or 2 °C scenarios (13). Alternatively, the aggregated NDCs are translated into a Global Mean Temperature (GMT) signal up to 2100 for benchmarking against the Long-term Temperature Goal of the Paris Agreement (14). In contrast, the aspect of locked-in post-2100 consequences of near-term emissions has not been a central part of high-level political discourse. In this study, we use GMSLR modeling that can handle emission scenarios flexibly (15, 16) to establish the link between pledged NDC emissions and GMSLR until 2300, thus highlighting the longer-term climate change implications of current climate mitigation efforts. We simulate the GMSLR commitment of greenhouse gas (GHG) emissions over the historical period (from 1750) and up to 2030, globally and for the 5 highest-emitting countries individually.

Attributing Global Mean Sea-Level Change to NDC Emission Pledges

We use a sea-level emulator (15) that includes contributions from thermal expansion, global glaciers, the Greenland Ice Sheet (GIS), the Antarctic Ice Sheet (AIS), and land-water storage. The emulator is part of the MAGICC simple climate model (17). Each component is calibrated to process-based projections consistent with the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5) (5) using a maximum likelihood optimization technique. In addition to the IPCC AR5 consistent AIS representation that captures surface mass balance effects (18) as well as solid ice discharge contributions with fast dynamics (19), we also implement an alternative version for AIS loss (20) that captures the higher sensitivity to future global warming from additional nonlinear processes related to Marine Ice Cliff Instability (MICI) (21). We use the MICI version to identify the potential for risk from higher sea-level rise not covered by our main results, but emphasize that the understanding of MICI and its triggers is still limited (22). Our sea-level emulator allows us to project GMSLR for emission scenarios until 2300. No estimates are provided

Significance

Sea-level rise poses a threat to coastal areas and will continue for centuries, even after global mean temperature has stabilized. Research assessing the implications of current international climate mitigation efforts usually focuses on 21st century climate impacts. The multicentennial sea-level rise commitment of pledged near-term emission reduction efforts under the Paris Agreement has not been quantified yet. We here estimate this sea-level rise commitment and find that pledged emissions until 2030 lock in 1-m sea-level rise in the year 2300. Our analysis highlights the defining role of present-day emissions for future sea-level rise and points to the potential of reducing the long-term sea-level-rise commitment by more ambitious national emission reduction targets.

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Data deposition: Pathway as well as projection data and code to reproduce the results shown in this study can be accessed at: https://gitlab.com/anauels/ndc_slr_attribution.

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beyond this time horizon, as some information from process-based models used for the calibration (i.e., Antarctic solid ice discharge) is not available beyond 2300 (15).

Current NDCs are provided until the year 2030. With respect to GMT rise, the recent IPCC Special Report on Global Warming of 1.5 °C concluded that "pathways reflecting these ambitions would not limit global warming to 1.5 °C" (23). More specific projections regarding the long-term GMT implications of the NDCs are strongly dependent on assumptions about emissions after 2030. Assessments of the end-of-century temperature implications of NDCs commonly assume some form of continuation in ambition reflected in pledged climate mitigation targets (24).

Here we follow a different approach that aims to avoid uncertainties regarding future ambition levels by analyzing stylized emission scenarios with zero Kyoto-GHG emissions after the end of the NDC accounting period in 2030. Assuming abrupt zero aerosol emissions would lead to a short-term increase in GMT (Fig. 1*B*). In order to avoid artifacts of such abrupt warming on long-term sea-level rise (Fig. 1*C*), we decrease aerosols and all other gases not regulated under the Kyoto protocol until 2075 (*Methods*). This stylized approach allows us to isolate the effects of NDCs and country-level emissions on longer-term GMSLR without making assumptions about global or individual country emissions pathways after 2030.

Cumulative NDC CO_2 emissions relative to preindustrial are estimated to reach around 765 gigatonnes of carbon (GtC) in 2030. Fig. 1 depicts total anthropogenic CO_2 emission estimates (*A*) and resulting probabilistic 2100 GMT (*B*) and GMSLR (*C*) responses for our 2030 NDC pathway. For illustration purposes, we also provide estimates for a representative 2 °C warming comparison pathway (RCP2.6) and the NDC extension pathway by the Climate Action Tracker (CAT) consortium (24, 25). For the GMT response, we can identify the diminishing influence of short-term climate forcers in the first decades after the year of zero emissions.

The global 2030 NDC pathway allows us to quantify the NDC GMSLR commitment in 2100 and 2300, accounting for historical emissions since 1750. The chosen time frame up to 2030 further allows us to assess the contribution of individual emitters. To isolate country-level emission shares, we define 2 emission accounting periods for which country-level information is available (*Methods*). We call the first period from 1991 to 2030 the "IPCC period" as the first IPCC report was published in 1990. The second period from 2016 to 2030 is termed the "Paris period" as it exclusively covers the emissions after the 2015 Paris Agreement until 2030 (pre-2020 commitments and NDCs). For both accounting periods, emissions of the 5 biggest emitters (China, United States of America [USA], European Union [EU28], India, and Russia) are individually removed from the reference 2030 NDC pathway (Fig. 2). We estimate that China is responsible for 83 (44) GtC, the USA for 59 (21) GtC, the EU28 for 41 (13) GtC, India for 19 (11) GtC, and Russia for 18 (7) GtC of CO_2 emissions over the IPCC (Paris) periods (25, 26).

For our global NDC pathway, we project a median peak warming of around 1.5 °C (66% range: 1.3 to 1.7 °C) relative to 1750 for the year 2035, then declining to a committed warming of around 1.3 °C (1.0 to 1.7 °C) in 2100 (Fig. 1*B*). For the top 5 emitters combined, historical and pledged emissions until the end of the first NDC period cause a 2100 warming of 0.45 and 0.2 °C for the IPCC and Paris periods, respectively (Fig. 2 *B* and *E*).

National-Level GMSLR Commitments

In response to the warming trajectories of historical emissions, pledged NDC emission reductions, and zero GHG emissions after 2030, we estimate that, relative to the IPCC AR5 reference period 1986–2005, GMSLR will rise by 43 cm (66% range: 34 to 54 cm) in 2100 and continue to increase by 105 cm (79 to 135 cm) in 2300 (Fig. 2 and Table 1). The 2300 GMSLR commitments of global emissions prior to the IPCC (1991) and Paris (2016) periods yield around 60 (48 to 75) cm and 84 (66 to 109) cm, respectively. Using the IPCC accounting period (1991–2030), pathways that exclude 1 of the top 5 emitters reduce median 2300 GMSLR by around 10 cm for China, 7 cm for the USA, 5 cm for the EU28, and 2 cm for India and Russia (Table 2). For this 40-y period, the top 5 emitters are therefore responsible for a median of around 26 cm GMSLR in 2300, which is more than the roughly 20 cm observed since the beginning of the 20th century and about 25% of the total 2300 GMSLR NDC commitment. Using the Paris accounting period (2016–2030), the median 2300 GMSLR contribution ranges from roughly 6 cm for China, 3 cm for the USA, 2 cm for the EU28, and about 1 cm for India and Russia. For the 15-y Paris timeframe, the top 5 emitters thus commit GMSLR to a median of around 12 cm, more than 50% of the observed 20th century GMSLR.

For both accounting periods, country-level GMSLR contributions reflect changes in relative emission shares and therefore underline the overall sensitivity of 2300 GMSLR to changes in near-term emissions (Fig. 3). The fossil-fuel-intensive histories of the USA and EU28, for example, move both their CO_2 emission

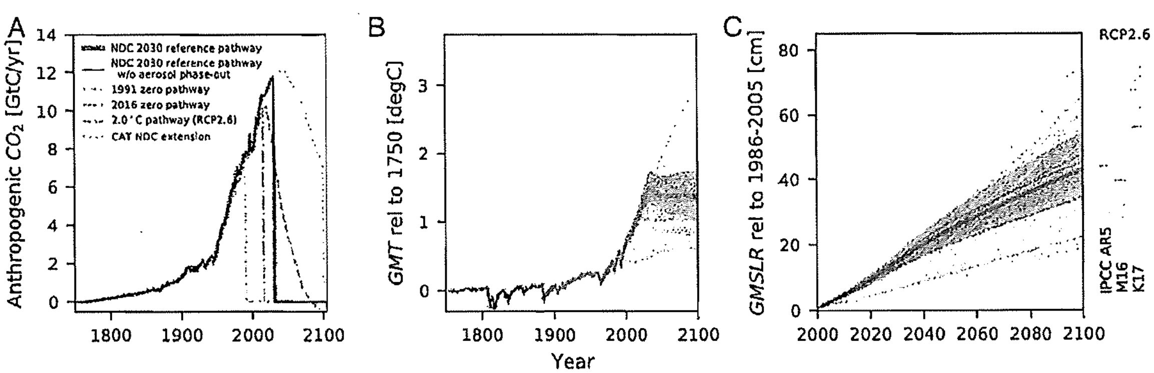

Fig. 1. Total annual CO_2 emissions including land use (GtC/y) (*A*), resulting median GM (*B*), and GMSLR (*C*) projections for the stylized zero 2030 NDC reference pathway (solid), zero 1991 and 2016 pathways (dash-dotted), as well as 2 °C (dashed) and NDC extension comparison pathways (light dotted). In 1991, 2016, and 2030 zero pathways, all GHG are set to zero in respective years except for aerosols and non-Kyoto gases which are phased out exponentially until 2075 (*Methods*). The median GMT and GMSLR responses for the 2030 NDC reference pathway without aerosol phase-out are also shown (dotted). Projected 2100 GMSLR median and 66% ranges under RCP2.6 from IPCC AR5, M16 (16), and K17 (41) are shown for comparison. GMT is provided in °C relative to 1750, IPCC AR5-consistent GMSLR is provided in cm relative to the 1986–2005 average. Shaded GMT and GMSLR uncertainties reflect the 66% model ranges.

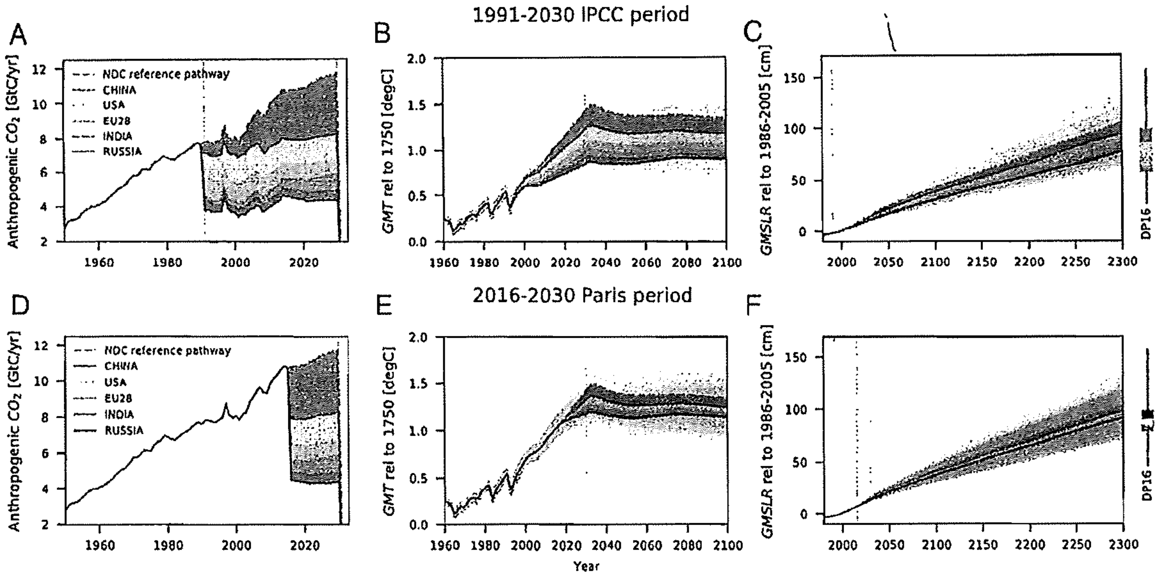

Fig. 2. Country-specific total CO_2 emission shares (GtC/y) of the biggest 5 emitters (*A* and *D*) and resulting median 2100 GMT (*B* and *E*) and 2300 GMSLR (*C* and *F*) contributions for the IPCC (1991–2030) and Paris (2016–2030) emission accounting periods. GMT is provided in °C relative to 1750; IPCC AR5-consistent GMSLR is provided in centimeters relative to the 1986–2005 average. Shaded GMT and GMSLR uncertainties reflect the 66% model ranges. Bars on the right show median 2300 GMSLR projections, country shares, and overall 66% uncertainty range based on the alternative DeConto and Pollard (DP16) parameterization (19).

and resulting GMSLR shares closer to China for the IPCC period, while for the Paris period, the projected decrease in fossil-fuel intensity for the EU28 shifts the country group toward the growing CO_2 emissions and respective GMSLR contributions of the developing economy of India (Fig. 3). Unlike historical emissions until 1991 or 2016, pledged national emissions until 2030 are not yet locked in, but if they are followed, they will cause ~20 cm of GMSLR in 2300. When focusing on the Paris period, the attributable country contributions to projected long-term GMSLR emphasize the impact of countries' emissions during both the IPCC and Paris periods and clearly point to the potential of reducing the future GMSLR commitment by more ambitious national emission reduction targets.

We also tested our results to the sensitivity of model choice for Antarctic ice discharge by including the MICI mechanism (20, 21), denoted DP16 in the following. Median sea-level estimates and uncertainties for 2300 are shown as vertical bars in Fig. 2. Based on this sensitivity test, the top 5 emitters would be responsible for around 41 cm GMSLR in 2300, using the IPCC accounting period (Fig. 2). For the Paris period, the top 5 emitters together would cause a GMSLR commitment of about 20 cm.

While the median GMSLR commitments resulting from the DP16 sensitivity test (20, 21) are lower than in our main results,

Table 1. GMSLR commitment in 2100 and 2300 for cumulative CO_2 emissions until 1991, 2016, and 2030

	CO_2 emissions, GtC	2100 GMSLR, cm	2300 GMSLR, cm
Global			
1991	385	22.2 (18.2 to 27.3)	58.8 (47.7 to 74.6)
2016	608	34.6 (27.2 to 43.6)	84.2 (65.5 to 109.4)
2030	765	43.0 (33.8 to 54.4)	104.6 (78.5 to 135.4)

IPCC AR5-consistent GMSLR median projections and 66% ranges are provided relative to the 1986–2005 average. Estimates for anthropogenic CO_2 emissions including land use are calculated relative to 1750.

they also show a wider sea-level response range to carbon emissions. This reflects the fact that our MAGICC ensemble has a wider range of temperature responses than the temperature responses used in DP16, with rare strong warming triggering MICI-style ice loss, and that the emulated DP16 reference data contain individual ensemble members that do not show ice loss until 2300 under strong mitigation (20). We note, however, that the temperatures identified by DP16 for triggering MICI are anomalously low with respect to projections using a combination of satellite observations, an established polar regional climate model, and climate models from the Coupled Model Intercomparison Project 5 (27). This suggests that the temperature thresholds for triggering MICI in the sea-level emulator should be higher than used here, making it even less likely that MICI would be triggered by the warming associated with the global NDC pathway used in our study. Recent work has also pointed to other uncertainties associated with the MICI hypothesis, including the strength of the MICI feedback, how it might vary in different locations, and the possibility that it might be mitigated by associated responses (freshwater entering the ocean, buttressing by ice mélange, changes in relative sea level from gravitational and solid-Earth effects) (22). Given that the MICI hypothesis is based on only 1 study and is subject to a wide range of uncertainties, further work is required to assess the implications of this ice-sheet instability mechanism for our results.

Estimating the sea-level contributions for pledged emission reductions of individual countries relies on a set of assumptions and caveats. Our scenarios are simplified and stylized as Kyoto-GHG emissions are reduced to zero after 2030 to isolate the sensitivity of GMSLR to IPCC and Paris-period-only emissions. While a real-world energy system cannot produce such a step-change reduction, it is appropriate for our attribution design, which focuses mainly on identifying differences in sea-level responses. Emissions are not a state variable, but a flux. The flux step change can be handled by models like MAGICC, resulting in peak-and-decline temperature responses (28). Projected GMT changes have been the subject of several similar experimental designs (29, 30).

Table 2. **GMSLR commitments in 2100 and 2300 for CO_2 emission shares of the 5 highest-emitting countries over the specific IPCC (1991–2030) and Paris (2016–2030) accounting periods**

	CO_2 emissions, GtC		2100 GMSLR, cm		2300 GMSLR, cm	
	1991–2030, IPCC period	2016–2030, Paris period	1991–2030, IPCC period	2016–2030, Paris period	1991–2030, IPCC period	2016–2030, Paris period
Top 5	220	95	12.3 (9.2 to 16.7)	5.3 (4.0 to 7.0)	26.2 (18.5 to 37.8)	11.8 (8.4 to 16.9)
China	83	44	4.6 (3.5 to 6.2)	2.4 (1.8 to 3.2)	10.0 (7.0 to 14.3)	5.5 (3.8 to 7.7)
USA	59	21	3.1 (2.4 to 4.3)	1.1 (0.8 to 1.5)	6.8 (4.8 to 9.8)	2.5 (1.8 to 3.6)
EU28	41	13	2.2 (1.6 to 3.0)	0.7 (0.5 to 0.9)	4.7 (3.3 to 6.8)	1.5 (1.1 to 2.2)
India	19	11	1.2 (0.9 to 1.6)	0.6 (0.5 to 0.8)	2.4 (1.7 to 3.5)	1.4 (1.0 to 2.0)
Russia	18	7	1.2 (0.9 to 1.7)	0.5 (0.4 to 0.7)	2.4 (1.7 to 3.5)	1.0 (0.7 to 1.4)

IPCC AR5-consistent GMSLR median projections and 66% ranges are provided relative to the 1986–2005 average. GMSLR contributions and estimates for anthropogenic CO_2 emissions including land use are calculated for the 5 highest-emitting countries individually and in an aggregated way (Top 5).

Our experiment of assuming no further emissions beyond 2030 provides a lower bound for future sea-level-rise impacts. Reaching net-zero GHG emissions from current NDC levels will take several decades (23), which indicates that the real risks implied by 2030 NDC levels will be substantially higher. Our main results exclude the higher sensitivity to global warming introduced by MICI and hydrofracturing processes, but our sensitivity tests indicate that, as currently understood, MICI can increase the contribution of the Antarctic ice sheet for stronger global warming. Finally, our approach does not cover the possibility of greater emissions by 2030 than currently pledged by the NDCs, which may lead to an underestimation of the presented sea-level commitments.

The assessment of future sea-level change needs to address the associated high uncertainties. While the future responses of thermal expansion and glaciers are reasonably well understood, the future responses of the ice sheets, in particular the AIS with its multimeter GMSLR potential, remain poorly constrained. The MICI hypothesis, which was proposed after IPCC AR5, leads to higher estimates for the future AIS GMSLR contribution, especially under strong future global warming (21, 22). However, because MICI is still under debate (22) and new insights are expected from future work, we present sea-level-rise estimates including MICI only as a sensitivity test.

Furthermore, our applied methodology includes a parameterization for the sea-level contribution from land-water storage which is not dependent on climate change (15). This scenario-independent median land-water contribution of around 21 cm for 2300 is based on the extrapolation of the modeled end-of-21st-century response (31). The total NDC GMSLR commitment presented here encompasses this land-water estimate and is sensitive to its changes, highlighting the large uncertainties associated with absolute GMSLR projections. The derived relative GMSLR commitments for the top 5 emitters, however, would not change as they are not sensitive to the absolute land-water contribution but only determined by the climate-driven sea-level responses to the 2030 NDC reference pathway.

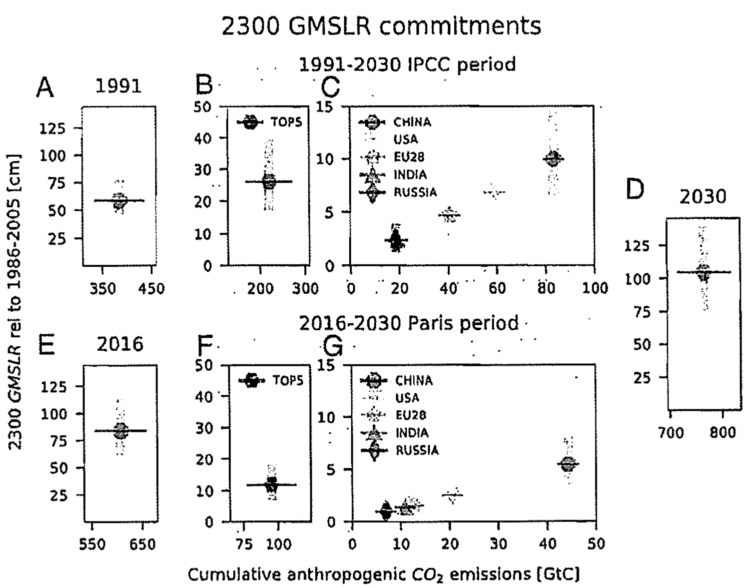

Fig. 3. GMSLR commitments and 66% uncertainty bars for the year 2300, as well as corresponding cumulative anthropogenic CO_2 emissions for the top 5 emitters, using the 1991–2030 IPCC (*B* and *C*) and 2016–2030 Paris emission accounting periods (*F* and *G*). In addition, 2300 GMSLR commitments for cumulative emissions until 1991 (*A*) and 2016 (*E*) are provided together with projected total 2030 GMSLR commitment (*D*) based on available 2030 NDC emission pledges. IPCC AR5-consistent GMSLR is provided in centimeters relative to the 1986–2005 average. Please note the different *y*-axis scaling for global GMSLR commitments provided in *A*, *D*, and *E* and the specific emission accounting periods in *B*, *F*, *C*, and *G*.

The 2300 Sea-Level Legacy of Near-Term Emissions

Sea levels will continue to rise long beyond 2300 (9, 12). Constrained by our methodological setup, however, 2300 emerges as a pragmatic focal point for the analysis of commitments as it allows us to assess GMSLR differences for near-term emission reduction trajectories. Our analysis demonstrates that even GHG emissions over the first decades of the 21st century will shape coastlines around the globe for centuries to come. Previous research conducted with different sea-level models and experimental setups reached similar conclusions (11, 12). By linking 2300 GMSLR with combined historical emissions and 2030 NDC emission reduction pledges on a country level, we provide an angle to assess the climate impact implications of near-term national emission reduction targets, extending the scope beyond, for example, NDC implications of extreme temperature (32).

Our findings also underscore the relevance of present-day emissions in shaping the multicentury sea-level-rise response. About 44% (20%) of the total 2300 GMSLR commitment for emission from preindustrial until 2030 can be attributed to emissions of the IPCC (Paris) period. GHG emissions by the top 5 emitting countries over the same periods contribute to 25% (12%) of the 2300 total. The 15 y from 2016 to 2030 commit about 8 cm of additional sea-level rise in 2100 or 20 cm of additional sea-level rise in 2300 (Table 1), with the latter estimate being roughly equivalent to what has occurred since the preindustrial period. Only stringent near-term emission reductions in line with achieving the 1.5 °C long-term temperature goal of the Paris Agreement would provide a chance of limiting long-term sea-level rise to below 1 m (11). Since the adoption of the Paris Agreement, however, global GHG emissions have not shown a sign of peaking (33), while the current NDCs are inadequate to put the global community on track to meet the Paris Agreement Long-term Temperature Goal by the end of the 21st century (14).

Attributing GMSLR to pledged emission reductions not only highlights the importance of strong near-term mitigation efforts, but also emphasizes the inevitability of future coastal adaptation as well as loss and damage needs related to committed multicentennial GMSLR. Our ability to quantify and attribute such global sea-level commitments raises highly policy-relevant questions with respect to the need and responsibilities of supporting adaptation and loss and damage responses in low-lying coastal zones and small islands that will experience the most severe impacts.

Methods

We use both observed and projected GHG emissions to generate the suite of 2030 pathways used in this study. Until 2014, MAGICC was used to derive emissions from the CMIP6 historical GHG concentrations (34–36). The 2015–2030 emissions consistent with Paris Agreement NDCs are taken from the CAT high-pledge scenario (25). The 2030 NDC pathway is extended until 2100 using the constant quantile extension described in Gütschow et al. (24). The translation of the obtained pathway into the individual GHG input for the simple climate carbon-cycle model MAGICC (17) is based on an updated Equal Quantile Walk (EQW) method described in Meinshausen et al. (37). The updated EQW method uses recent scenario databases (AR5, Shared Socioeconomic Pathways, and IPCC special report on 1.5 °C of global warming) but the same methodology as the original EQW which is based on older scenarios like the IPCC Special Report on Emissions Scenarios.

We harmonize the CAT emissions to historical emissions with a harmonization factor linearly fading out until 2030 such that we obtain a smooth transition from historical emissions to the CAT NDC emissions levels. After 2030, we set all Kyoto-GHG (CO_2, CH_4, N_2O, and fluorinated gases) to zero and fade out emissions from other substances (SO_X, NO_X, CO, OC, nonmethane volatile organic compounds, BC, and NH_3) exponentially from 2030 until 2075 to avoid a rapid temperature increase after 2030 because of the sudden removal of substances with short-term effects. The pathway obtained by this procedure is our NDC reference pathway.

In order to derive the country-emission shares of the top 5 emitters for the 2016–2030 period, the relative Kyoto-GHG contribution of the NDCs is normalized to the emissions of the year 2015. For each GHG input, the following temporary pathway is generated:

$$Et_{c,g}(y) = E_{c,g}(2015) \times G_{global,g}(y) \times G_c(y),$$

where $E_{c,g}(y)$are the emissions of country c for gas g in year y,

$$G_c(y) = E_{c,KyotoGHG}(y) / E_{c,KyotoGHG}(2015),$$

is the time series of the country relative to 2015, and

$$G_{global,g}(y) = (E_{global,g}(y) / E_{global,g}(2015)) / (E_{global,KyotoGHG}(y) / E_{global,KyotoGHG}(2015))$$

is the global time series for the gas g, relative to 2015 and relative to the aggregate Kyoto gas time series. This temporary pathway is scaled such that the sum for all gases matches the CAT scenario for the country for all years:

$$E_{c,g}(y) = Et_{c,g}(y) / \mathrm{sum}_g(Et_{c,g}(y)) \times \mathrm{CAT}_c(y).$$

Before 2016, we directly use the historical gas shares as available from the PRIMAP-hist dataset (26, 38). Two scenarios are created for each of the top 5 emitting countries, one where the country's emissions are removed starting in 1991 and one where they are only removed starting in 2016. We only remove Kyoto GHGs and phase out non-Kyoto gases as done for the 2030 reference pathway, as changes in historical emissions for other substances influence the internal calibration of MAGICC. To quantify the global GMSLR commitment until 1991 and 2016, zero Kyoto-gas pathways are designed starting for these years by applying a similar methodology to the 2030 reference pathway design. Here, non-Kyoto gases are phased out as early as possible for the 1991 pathway starting in 2006 (to not affect the internal MAGICC calibration), and for the 2016 zero pathway starting regularly in 2016. For all pathways, radiative forcing is held constant after 2100 until 2300.

We use the simple climate carbon-cycle model MAGICC version 6 (17) to translate generated GHG emission pathways into GMT responses. For every pathway, probabilistic GMT projections are generated with a historically constrained ensemble of 600 runs, derived by a Metropolis–Hastings Markov chain Monte Carlo approach (39). Model parameters of the ensemble are chosen to capture IPCC AR5 equilibrium climate sensitivity estimates (40, 41) and carbon-cycle uncertainties (42). As such, the probabilistic MAGICC modeling framework consistently covers model and climate-related uncertainties. The model is run for the period 1750–2300.

The MAGICC sea-level model (15) is one of several existing simplified approaches to project sea-level change (16, 43–45) and emulates IPCC AR5 process-based SLR projections (5) and provides GMSLR estimates for all major climate-driven sea-level components including thermal expansion, global glacier mass changes, the surface mass balance, and solid ice discharge components of the Greenland and Antarctic ice sheets, as well as the non–climate-driven land-water storage contribution. For each of the probabilistic 600 ensemble members, calibrated sea-level parameters are sourced randomly for every sea-level component. The Antarctic ice sheet solid ice discharge component was extended (20) to include a threshold-temperature parameterization to capture potentially higher Antarctic sensitivity through hydrofracturing and subsequent MICI that would substantially increase future SLR projections under high-emission scenarios (21). Since the MICI hypothesis is subject to ongoing scientific debate (22, 46), we only use these projections for a sensitivity test. The MAGICC sea-level model provides projections from 1850 to 2300, constrained by the availability of reference data, in particular for the Antarctic solid ice discharge response (19).

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'Horrifying' new research shows rising sea levels could wipe out major cities and displace 150 million people by 2050

alternet.org/2019/10/horrifying-new-research-shows-rising-sea-levels-could-

Jake Johnson October 30, 2019

Ho Chi Minh City, along with the rest of southern Vietnam, "could all but disappear" by 2050.

Bangkok, Thailand, currently home to over eight million people, is under severe threat.

Basra, Iraq, the nation's second-largest city, "could be mostly underwater" by mid-century.

Those are just some of the alarming conclusions of a new research paper on the dire global consequences of rising sea levels driven by the climate crisis.

According to the study, published Tuesday in the journal *Nature Communications*, "chronic coastal flooding or permanent inundation" due to rising seas could threaten three times more people than scientists previously believed if urgent action is not taken to establish protections and confront the underlying crisis.

The authors of the paper "developed a more accurate way of calculating land elevation based on satellite readings, a standard way of estimating the effects of sea level rise over large areas, and found that the previous numbers were far too optimistic," the *New York Times* reported. "The new research shows that some 150 million people are now living on land that will be below the high-tide line by mid-century."

Dina Ionesco of the International Organization for Migration told the *Times* that nations must begin preparing for massive internal relocations of citizens.

"We've been trying to ring the alarm bells," Ionesco said. "We know that it's coming."

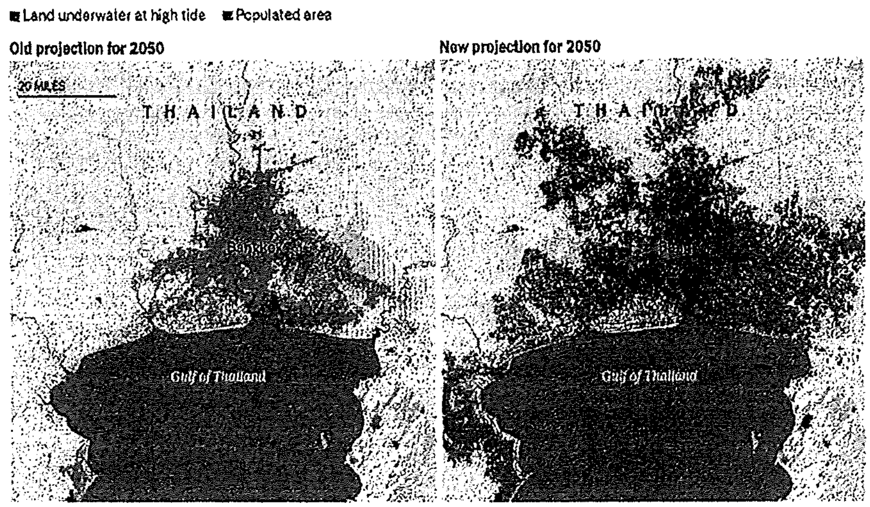
The *Times* published striking graphics that contrasted the amount of land that could be underwater by 2050 under the old projections with the "horrifying" new projections.

Bangkok, Thailand

Jacob Ward @byjacobward · Oct 29, 2019
Replying to @byjacobward
The new report instead uses AI to do error-correction, and to more accurately estimate land heights. And man, suddenly the estimates were very scary.

Jacob Ward
@byjacobward

The @nytclimate folks have horrifying visuals they've put together. Here's Bangkok. The term the Times used was "erase," which is pretty much right. nytimes.com/interactive/20...



2,356 3:18 PM - Oct 29, 2019

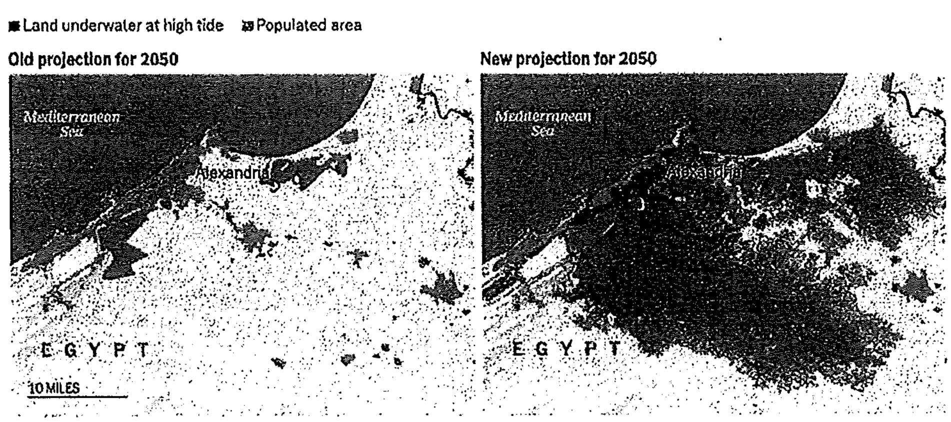
1,477 people are talking about this

Alexandria, Egypt

Christopher Flavelle
@cflav

The effects of rising seas will be far worse than previously thought, wiping out entire cities by 2050, new data shows.

This is Alexandria, Egypt, under the old and new projections.nytimes.com/interactive/20... @DeniseDSLu



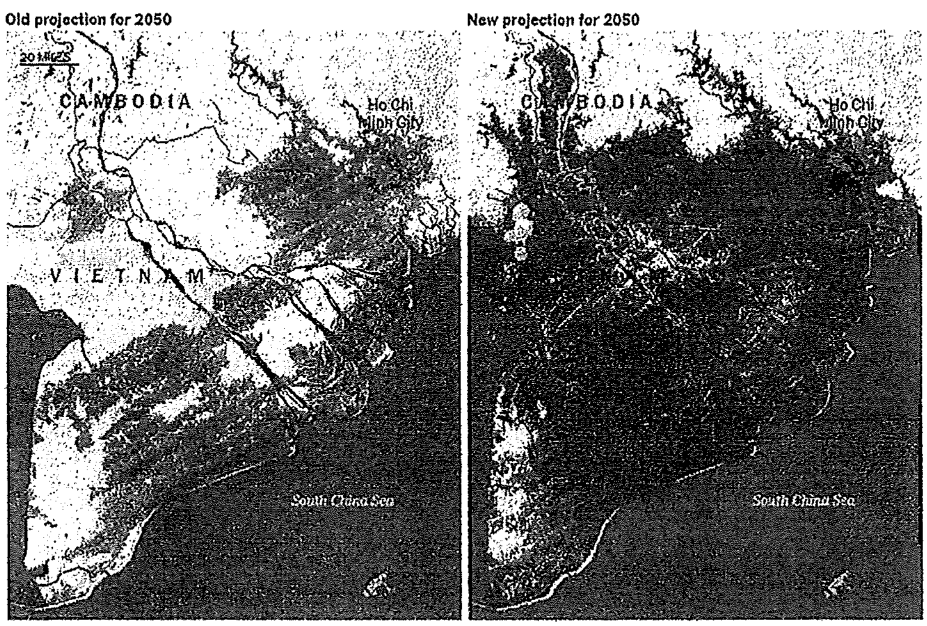
5,578 10:37 AM - Oct 29, 2019

4,321 people are talking about this

Vietnam

Joel Tozer
@jttozer

Image shows new predictions for sea level rise by 2050. The blue shows the land underwater at high tide. Southern Vietnam almost completely under water. nytimes.com/interactive/20...



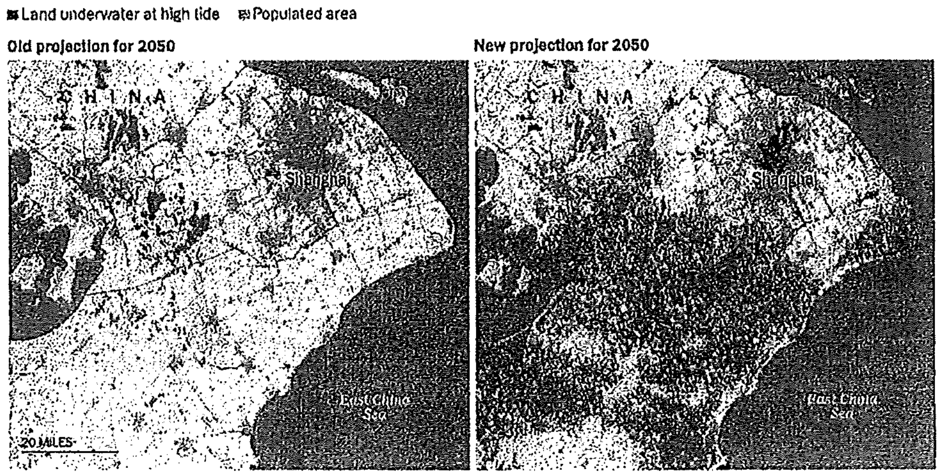
1,208 3:37 PM - Oct 29, 2019

1,071 people are talking about this

Shanghai, China

Cornie Huizenga
@CornieHuizenga

Big wow! Rising Seas Will Erase More Cities by 2050, New Research Shows nyti.ms/2NkOqOQ. see example of #Shanghai



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See Cornie Huizenga's other Tweets

"Climate change is shrinking the planet, in the scariest possible way," Bill McKibben, founder of 350.org, tweeted in response to the new research.

Climate scientist Peter Kalmus noted that he was concerned about "being labeled 'alarmist'" when he first started speaking out about the climate crisis.

"Now I embrace the term," said Kalmus, linking to the *Times* graphics. "I'm here to sound the alarm. For good reason."

Attachment 2: “World Scientists’ Warning of a Climate Emergency,” Nov. 2019

World Scientists' Warning of a Climate Emergency

WILLIAM J. RIPPLE, CHRISTOPHER WOLF, THOMAS M. NEWSOME, PHOEBE BARNARD, WILLIAM R. MOOMAW, AND 11,258 SCIENTIST SIGNATORIES FROM 153 COUNTRIES (LIST IN SUPPLEMENTAL FILE S1)

Scientists have a moral obligation to clearly warn humanity of any catastrophic threat and to "tell it like it is." On the basis of this obligation and the graphical indicators presented below, we declare, with more than 11,000 scientist signatories from around the world, clearly and unequivocally that planet Earth is facing a climate emergency.

Exactly 40 years ago, scientists from 50 nations met at the First World Climate Conference (in Geneva 1979) and agreed that alarming trends for climate change made it urgently necessary to act. Since then, similar alarms have been made through the 1992 Rio Summit, the 1997 Kyoto Protocol, and the 2015 Paris Agreement, as well as scores of other global assemblies and scientists' explicit warnings of insufficient progress (Ripple et al. 2017). Yet greenhouse gas (GHG) emissions are still rapidly rising, with increasingly damaging effects on the Earth's climate. An immense increase of scale in endeavors to conserve our biosphere is needed to avoid untold suffering due to the climate crisis (IPCC 2018).

Most public discussions on climate change are based on global surface temperature only, an inadequate measure to capture the breadth of human activities and the real dangers stemming from a warming planet (Briggs et al. 2015). Policymakers and the public now urgently need access to a set of indicators that convey the effects of human activities on GHG emissions and the consequent impacts on climate, our environment, and society. Building on prior work (see supplemental file S2), we present a suite of graphical vital signs of climate change over the last 40 years for human activities that can affect GHG emissions and change the climate (figure 1), as well as actual climatic impacts (figure 2). We use only relevant data sets that are clear, understandable, systematically collected for at least the last 5 years, and updated at least annually.

The climate crisis is closely linked to excessive consumption of the wealthy lifestyle. The most affluent countries are mainly responsible for the historical GHG emissions and generally have the greatest per capita emissions (table S1). In the present article, we show general patterns, mostly at the global scale, because there are many climate efforts that involve individual regions and countries. Our vital signs are designed to be useful to the public, policymakers, the business community, and those working to implement the Paris climate agreement, the United Nations' Sustainable Development Goals, and the Aichi Biodiversity Targets.

Profoundly troubling signs from human activities include sustained increases in both human and ruminant livestock populations, per capita meat production, world gross domestic product, global tree cover loss, fossil fuel consumption, the number of air passengers carried, carbon dioxide (CO_2) emissions, and per capita CO_2 emissions since 2000 (figure 1, supplemental file S2). Encouraging signs include decreases in global fertility (birth) rates (figure 1b), decelerated forest loss in the Brazilian Amazon (figure 1g), increases in the consumption of solar and wind power (figure 1h), institutional fossil fuel divestment of more than US$7 trillion (figure 1j), and the proportion of GHG emissions covered by carbon pricing (figure 1m). However, the decline in human fertility rates has substantially slowed during the last 20 years (figure 1b), and the pace of forest loss in Brazil's Amazon has now started to increase again (figure 1g). Consumption of solar and wind energy has increased 373% per decade, but in 2018, it was still 28 times smaller than fossil fuel consumption (combined gas, coal, oil; figure 1h). As of 2018, approximately 14.0% of global GHG emissions were covered by carbon pricing (figure 1m), but the global emissions-weighted average price per tonne of carbon dioxide was only around US$15.25 (figure 1n). A much higher carbon fee price is needed (IPCC 2018, section 2.5.2.1). Annual fossil fuel subsidies to energy companies have been fluctuating, and because of a recent spike, they were greater than US$400 billion in 2018 (figure 1o).

Especially disturbing are concurrent trends in the vital signs of climatic impacts (figure 2, supplemental file S2). Three abundant atmospheric GHGs (CO_2, methane, and nitrous oxide) continue to increase (see figure S1 for ominous 2019 spike in CO_2), as does global surface temperature (figure 2a–2d). Globally, ice has been rapidly disappearing, evidenced by declining trends in minimum summer Arctic sea ice, Greenland and Antarctic ice sheets, and glacier thickness worldwide (figure 2e–2h). Ocean heat content, ocean acidity, sea level, area burned in the United States, and extreme weather and associated damage costs have all been trending upward (figure 2i–2n). Climate change is predicted to greatly affect marine, freshwater, and terrestrial life, from plankton and corals to fishes and forests (IPCC 2018, 2019). These issues highlight the urgent need for action.

Despite 40 years of global climate negotiations, with few exceptions, we have generally conducted business

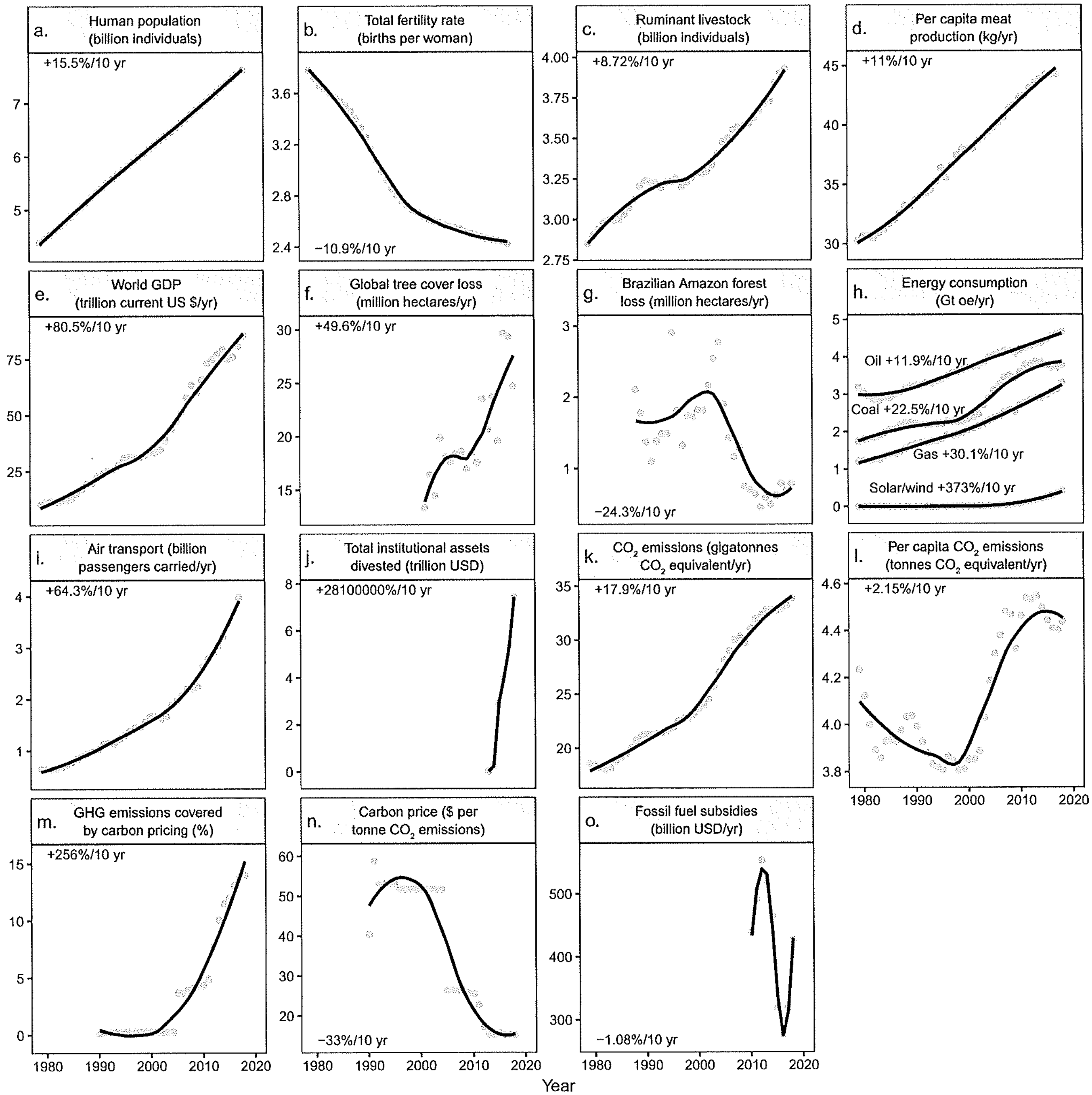

Figure 1. *Change in global human activities from 1979 to the present. These indicators are linked at least in part to climate change. In panel (f), annual tree cover loss may be for any reason (e.g., wildfire, harvest within tree plantations, or conversion of forests to agricultural land). Forest gain is not involved in the calculation of tree cover loss. In panel (h), hydroelectricity and nuclear energy are shown in figure S2. The rates shown in panels are the percentage changes per decade across the entire range of the time series. The annual data are shown using gray points. The black lines are local regression smooth trend lines. Abbreviation: Gt oe per year, gigatonnes of oil equivalent per year. Sources and additional details about each variable are provided in supplemental file S2, including table S2.*

as usual and have largely failed to address this predicament (figure 1). The climate crisis has arrived and is accelerating faster than most scientists expected (figure 2, IPCC 2018). It is more severe than anticipated, threatening natural ecosystems and the fate of humanity (IPCC 2019). Especially worrisome are potential irreversible climate tipping points and nature's reinforcing feedbacks (atmospheric, marine, and terrestrial) that could lead to a catastrophic "hothouse Earth," well beyond the control of humans (Steffen et al. 2018). These climate

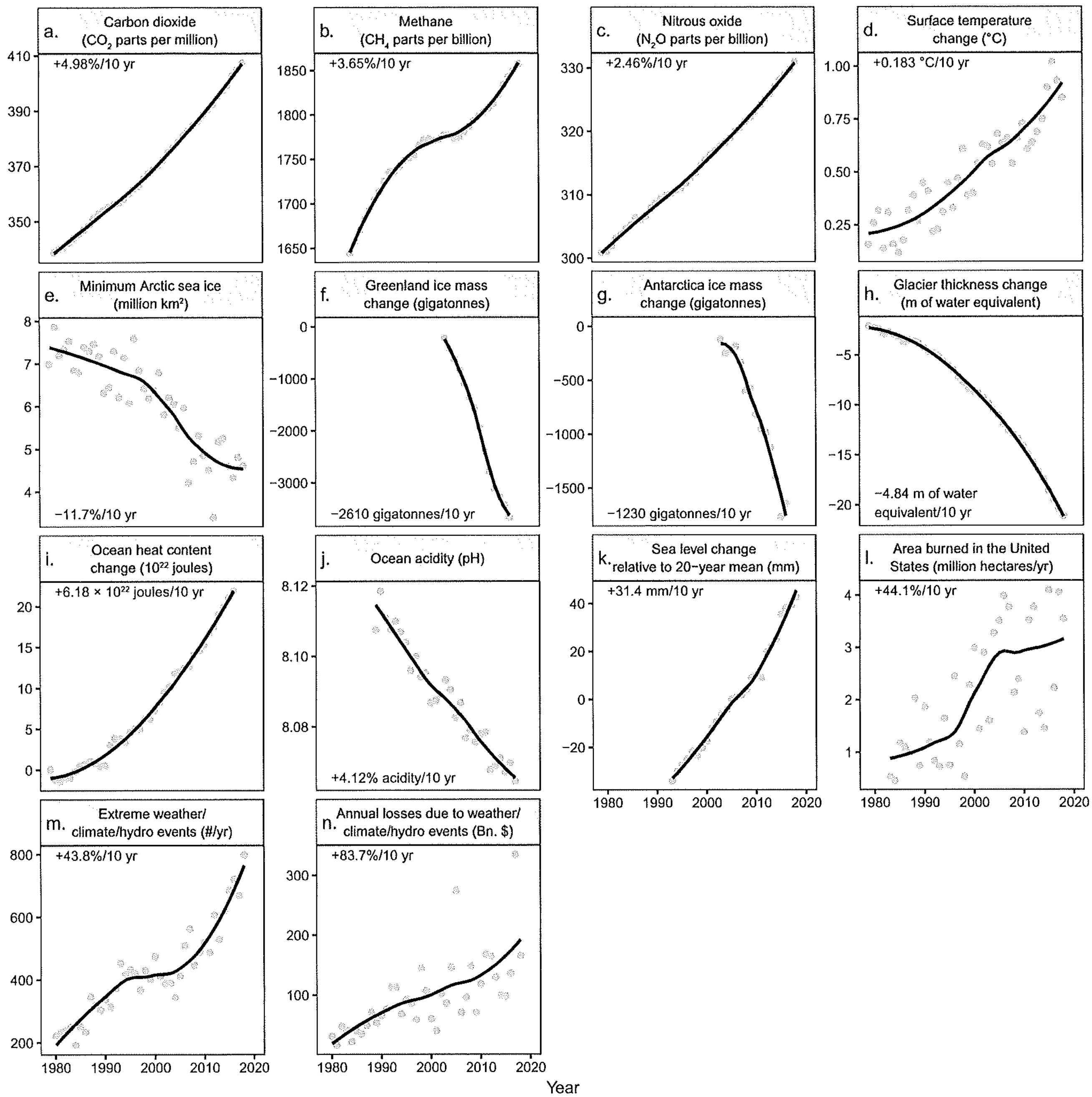

Figure 2. ***Climatic response time series from 1979 to the present. The rates shown in the panels are the decadal change rates for the entire ranges of the time series. These rates are in percentage terms, except for the interval variables (d, f, g, h, i, k), where additive changes are reported instead. For ocean acidity (pH), the percentage rate is based on the change in hydrogen ion activity, a_{H^+} (where lower pH values represent greater acidity). The annual data are shown using gray points. The black lines are local regression smooth trend lines. Sources and additional details about each variable are provided in supplemental file S2, including table S3.***

chain reactions could cause significant disruptions to ecosystems, society, and economies, potentially making large areas of Earth uninhabitable.

To secure a sustainable future, we must change how we live, in ways that improve the vital signs summarized by our graphs. Economic and population growth are among the most important drivers of increases in CO_2 emissions from fossil fuel combustion (Pachauri et al. 2014, Bongaarts and O'Neill 2018); therefore, we need bold and drastic transformations regarding economic and population policies. We suggest six critical and interrelated steps (in no particular order) that governments, businesses, and the rest of humanity can take to lessen the worst effects of climate change. These are important steps but are not the only actions needed or possible (Pachauri et al. 2014, IPCC 2018, 2019).

Energy

The world must quickly implement massive energy efficiency and conservation practices and must replace fossil fuels with low-carbon renewables (figure 1h) and other cleaner sources of energy if safe for people and the environment (figure S2). We should leave remaining stocks of fossil fuels in the ground (see the timelines in IPCC 2018) and should carefully pursue effective negative emissions using technology such as carbon extraction from the source and capture from the air and especially by enhancing natural systems (see "Nature" section). Wealthier countries need to support poorer nations in transitioning away from fossil fuels. We must swiftly eliminate subsidies for fossil fuels (figure 1o) and use effective and fair policies for steadily escalating carbon prices to restrain their use.

Short-lived pollutants

We need to promptly reduce the emissions of short-lived climate pollutants, including methane (figure 2b), black carbon (soot), and hydrofluorocarbons (HFCs). Doing this could slow climate feedback loops and potentially reduce the short-term warming trend by more than 50% over the next few decades while saving millions of lives and increasing crop yields due to reduced air pollution (Shindell et al. 2017). The 2016 Kigali amendment to phase down HFCs is welcomed.

Nature

We must protect and restore Earth's ecosystems. Phytoplankton, coral reefs, forests, savannas, grasslands, wetlands, peatlands, soils, mangroves, and sea grasses contribute greatly to sequestration of atmospheric CO_2. Marine and terrestrial plants, animals, and microorganisms play significant roles in carbon and nutrient cycling and storage. We need to quickly curtail habitat and biodiversity loss (figure 1f–1g), protecting the remaining primary and intact forests, especially those with high carbon stores and other forests with the capacity to rapidly sequester carbon (proforestation), while increasing reforestation and afforestation where appropriate at enormous scales. Although available land may be limiting in places, up to a third of emissions reductions needed by 2030 for the Paris agreement (less than 2°C) could be obtained with these natural climate solutions (Griscom et al. 2017).

Food

Eating mostly plant-based foods while reducing the global consumption of animal products (figure 1c–d), especially ruminant livestock (Ripple et al. 2014), can improve human health and significantly lower GHG emissions (including methane in the "Short-lived pollutants" step). Moreover, this will free up croplands for growing much-needed human plant food instead of livestock feed, while releasing some grazing land to support natural climate solutions (see "Nature" section). Cropping practices such as minimum tillage that increase soil carbon are vitally important. We need to drastically reduce the enormous amount of food waste around the world.

Economy

Excessive extraction of materials and overexploitation of ecosystems, driven by economic growth, must be quickly curtailed to maintain long-term sustainability of the biosphere. We need a carbon-free economy that explicitly addresses human dependence on the biosphere and policies that guide economic decisions accordingly. Our goals need to shift from GDP growth and the pursuit of affluence toward sustaining ecosystems and improving human well-being by prioritizing basic needs and reducing inequality.

Population

Still increasing by roughly 80 million people per year, or more than 200,000 per day (figure 1a–b), the world population must be stabilized—and, ideally, gradually reduced—within a framework that ensures social integrity. There are proven and effective policies that strengthen human rights while lowering fertility rates and lessening the impacts of population growth on GHG emissions and biodiversity loss. These policies make family-planning services available to all people, remove barriers to their access and achieve full gender equity, including primary and secondary education as a global norm for all, especially girls and young women (Bongaarts and O'Neill 2018).

Conclusions

Mitigating and adapting to climate change while honoring the diversity of humans entails major transformations in the ways our global society functions and interacts with natural ecosystems. We are encouraged by a recent surge of concern. Governmental bodies are making climate emergency declarations. Schoolchildren are striking. Ecocide lawsuits are proceeding in the courts. Grassroots citizen movements are demanding change, and many countries, states and provinces, cities, and businesses are responding.

As the Alliance of World Scientists, we stand ready to assist decision-makers in a just transition to a sustainable and equitable future. We urge widespread use of vital signs, which will better allow policymakers, the private sector, and the public to understand the magnitude of this crisis, track progress, and realign priorities for alleviating climate change. The good news is that such transformative change, with social and economic justice for all, promises far greater human well-being than does business as usual. We believe that the prospects will be greatest if decision-makers and all of humanity promptly respond to this warning and declaration of a climate emergency and act to sustain life on planet Earth, our only home.

Contributing reviewers

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Project website

To view the Alliance of World Scientists website or to sign this article, go to https://scientistswarning.forestry.oregonstate.edu.

Supplemental material

Supplemental data are available at *BIOSCI* online. A list of the signatories appears in supplemental file S1.

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