NEW INSIGHTS IN CLIMATE SCIENCE:
A 2017-2019 SUMMARY

Produced by **Future Earth** and **the Earth League** for the **United Nations Climate Action Summit**, September 2019

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EXECUTIVE SUMMARY

Time is running out to limit global temperature rise to well below 2°C, aiming for 1.5°C. To do so, emissions must peak as soon as possible and decline sharply until 2050 but the world is not on that path. Future Earth and the Earth League collated the most up-to-date science since 2017, on the drivers and impacts of climate change, to make the case that achieving the Paris Agreement is not only necessary, but possible. Meeting the goals of the Agreement entails conserving and sustainably using nature, requires fundamental shifts in technological, economic and social paradigms, and compels new governance models and improved capacity to adapt to climate change. Here we lay out the key findings.

Unequivocal evidence

- Consolidated evidence (on climate, extreme weather, oceans and land) reinforces human influence as the dominant cause of changes to the Earth system, in a new geological epoch, the Anthropocene.
- Growing climate impacts increase the risks of critical tipping points that, if crossed, lead to far-reaching, and/or irreversible consequences for the stability of life on Earth. Furthermore, we now know there are large differences in climate change impacts between 1.5°C and 2°C of warming.

Emerging insights

- Key processes that currently keep the climate stable are weakening, risking the establishment of feedback loops (e.g. loss of Arctic sea ice or forest dieback) that could hinder efforts to stabilize the climate, even as emissions are reduced.
- There is a growing recognition that the risk of increased warming has been underestimated, as climate impacts are hitting harder and sooner than anticipated.
- As climate change intensifies, cities are particularly vulnerable to impacts such as heat stress and can also play a key role in reducing emissions locally and globally.

The way forward

- Strategies for mitigation and for upscaling adaptive risk management are necessary going forward. Neither is adequate in isolation given the pace of climate change and magnitude of its impacts.
- Only immediate and all-inclusive action will enable us to meet the Paris Agreement target of well below 2°C. Action must encompass:
  - deep decarbonization complemented by ambitious policy measures,
  - protection and enhancement of carbon sinks and biodiversity, and
  - efforts to remove CO_2 from the atmosphere.

INTRODUCTION

Human livelihoods, stable economies, good health, and high quality of life all hinge on a stable climate and Earth system, and on a diversity of species and ecosystems. Yet biodiversity is declining faster than at any point in human history[1] and time is running out to limit global temperature rise to well below 2°C and to aim for 1.5°C. To do so, emissions must peak as soon as possible and decline sharply until 2050[2] but the world is not on that path.[3,4]

Future Earth and the Earth League have collated the most up-to-date science since 2017, on the drivers and impacts of climate change, to show that achieving the Paris Agreement is not only necessary, but possible. Achieving the goal to limit temperature rise to well below 2°C entails conserving and sustainably using nature, requires fundamental shifts in technological, economic and social paradigms, and compels new governance models and stronger adaptive capacity. Here we lay out the latest facts and plausible pathways towards this transformation. Key findings are bolded followed by supporting evidence.

UNEQUIVOCAL EVIDENCE

Consolidated evidence (on climate, extreme weather, oceans and land) reinforces human influence as the dominant cause of changes to the Earth system, in a new geological epoch, the Anthropocene.[5]

New research shows that the current CO2 concentration in the atmosphere is unprecedented over the past three million years and that global temperature never exceeded the preindustrial value by more than 2°C during that time.[6] A combination of Earth's orbital cycles in constant interplay with biogeochemical processes such as greenhouse gas regulation on land and in the ocean, accounted for the long-term stability during that time, and there is new understanding that these interactions are changing.[7]

The frequency and intensity of extreme weather events (e.g. flooding, heatwaves and droughts) are increasing and are now clearly attributable to climate change.[8,9,10,11,12,13] Science has improved our understanding of how interconnections between ocean currents, ice sheets, and heat exchange in the atmosphere and land, play a major role in accelerating warming and extreme weather events.[14,15,16] Recent examples include confirmation that the unprecedented heatwaves across North America, Europe and Asia in 2018 and 2019 are linked to a slowdown of the jet stream – fast moving winds at the attitude jets fly – which is linked to warming in the Arctic.[17] A series of extreme rainfall events that were connected, despite being thousands of kilometers apart were also linked to the jet stream pattern.[18]

Sea-level rise and ocean acidification are other important indicators of climate change, both are accelerating with major consequences for coastal communities and habitats.[19] The current rate of sea level rise now exceeds 3mm/year.[20] Ocean acidification, due to the uptake of larger amounts of carbon dioxide, is progressing an order of magnitude faster today than at any time in tens of millions of years.[21]

Finally, we now know that human land use directly affects more than 70% of Earth's ice-free land surface and that an estimated 23% of total greenhouse gas emissions (2007-2016) derive from agriculture, forestry and other land use activities.[22] Land use and land use change also impacts systems beyond climate, causing loss of biodiversity and ecosystem services.[23,24]

Growing climate impacts increase the risk of crossing critical tipping points. Furthermore, we now know there are large differences in climate change impacts between 1.5°C and 2°C of warming.

Tipping points in the Earth System refer to thresholds that, if crossed, lead to far-reaching, in some cases abrupt and/or irreversible changes. With continued warming, systems can reach tipping points where they rapidly collapse or a major, largely unstoppable transformation is initiated. For example, coral reefs are already experiencing mass mortality, a major concern for the estimated 500 million people depending on them for food, income, coastal protection, and more.[25,26] Scientists have identified plausible pathways to a "Hothouse Earth" scenario, where interacting tipping points could potentially lead to a cascading effect where Earth's temperature heats up to a catastrophic 4-5°C.[27] Another study estimates that unmitigated emissions could reverse a multimillion-year cooling trend in less than two centuries.[28]

Furthermore we now know that the magnitude and risk of climate change impacts increase significantly between 1.5°C and 2°C (Figure 1).[29] For example, limiting warming to 1.5°C relative to 2°C can avoid the inundation of lands currently home to about five million people, including 60,000 people currently residing in Small Island Developing States.[30] More generally, it is estimated that limiting global warming to 1.5°C, compared with 2°C, could reduce the number of people both exposed to climate-related risks and susceptible to poverty by up to several hundred million by 2050.[31]

Half a degree of additional warming can also significantly heighten risk in our social systems with impacts like large-scale migration and civil unrest. Especially in cases of existing political instability, extreme and changing weather can undermine livelihoods, threaten infrastructure, increase food insecurity, and compromise the ability of states to provide conditions for human security.[32,33,34,35,36]

Differences in ***impact*** between... Impact of 1.5°C and 2°C, respectively (IPCC 2018)	1.5°C	2°C
Additional increase in temperature for extremely warm days on land at mid-latitudes (deg C)	3°C	4°C
Billion persons exposed to severe heat waves at least once per 5 years	1 billion	2.7 billion
Billion persons exposed to water stress	3.3 billion	3.7 billion
Land area projected to undergo a transformation of ecosystems from one type to another (million km²)	9 million km²	17 million km²
Species projected to lose over half of their range (%)		
Vertebrate	4%	8%
Plant	8%	16%
Insect	6%	18%
Coral reefs experiencing long-term degradation (%)	70-90%	>99%
Differences in ***mitigation*** Emissions reductions by 2030 (compared to 2010)	-45%	-20%
Year of ***zero net emissions***	2050	2075

Figure 1. Differences in impact between 1.5°C and 2°C. Source: 10 New Insights in Climate Science 2018, Future Earth and Earth League.

EMERGING INSIGHTS

Key processes that currently keep the climate stable are weakening, risking the establishment of feedback loops (e.g. loss of Arctic sea ice or forest dieback) that could hinder efforts to stabilize the climate, even as emissions are reduced.

The stability of the Earth system is influenced by feedbacks between the climate system and other carbon-regulating processes such as frozen soils in permafrost or carbon uptake by forests. There is a growing understanding of the critical role of these biosphere carbon feedbacks in stabilizing the climate system and that those processes are weakening, risking the establishment of self-reinforcing feedback loops that could hinder efforts to stabilize the climate, even as emissions are reduced.[37] Two notable examples include the reduced efficiency in the capacity of land and oceans to absorb CO2 emissions[38] and the release of CO2 and methane from thawing permafrost soils. Another crucial mechanism would be the ongoing loss of Arctic sea ice that normally regulates the Earth's solar energy balance. The extreme case of a complete disappearance of Arctic sea ice during the sunlit part of the year, while unlikely in the short term, could accelerate warming by 25 years.[39]

There is a growing recognition that the risk of increased warming has been underestimated, as climate impacts are hitting harder and sooner than anticipated.

Since 2001, the Intergovernmental Panel on Climate Change (IPCC) has published a science-based risk assessment of several Reasons for Concern to illustrate the impacts of different levels of warming for people, ecosystems and economies worldwide.

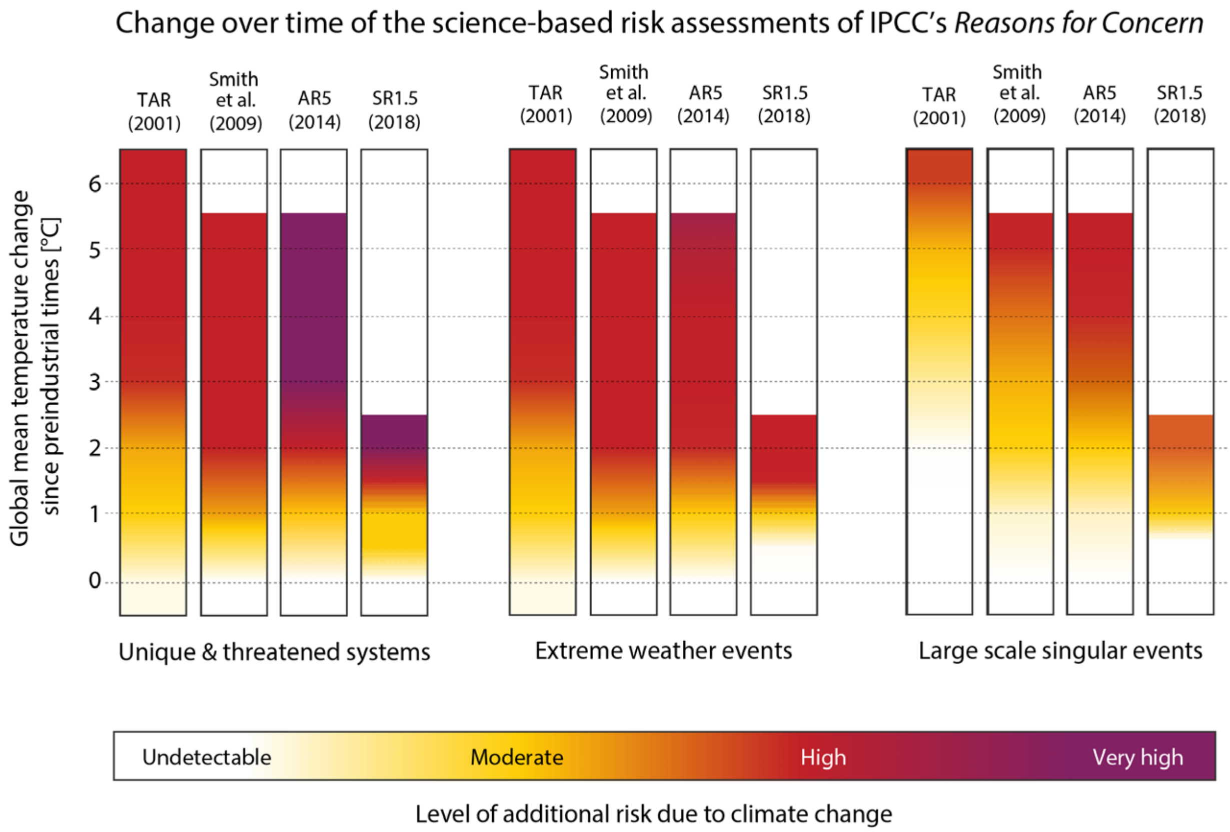

Figure 2. Reproduction of three of the five IPCC Reasons for Concern, consolidated for a comparison of the different versions.
Notes: A version of this figure was first introduced in the Third Assessment Report (TAR, 2001) of the IPCC, omitted in Assessment Report 4 (AR4) in 2007, published as an update by Smith et al. in 2009, enriched by a new color (purple) indicating very high risk in Assessment Report 5 (AR5) in 2014 and produced for a smaller warming range (<3°C) by the IPCC Special Report on Global Warming of 1.5°C (SR1.5) in 2018. The temperature change since preindustrial times is relative to 1850-1900, colour scales for TAR and Smith et al. have been shifted accordingly. There are slight differences in the colour legend descriptions among the different versions – here, AR5 and SR1.5 wording has been adopted. Reproduction Details: The colormaps from AR5 and SR1.5 were reproduced using rgb-value measurement. Colormaps from TAR and from the Smith et al. 2009 publication (PNAS) were measured and mapped onto the reproduced colormap for comparison. A shift in temperature scale of ~0.6°C between TAR/Smith et al. and AR5/SR1.5 was taken into account during color measurements.[7, 36, 41, 42]

A comparison of these Reasons for Concern from 2001 to 2018 shows the evolution of the assessment, with risk increasing over time (Figure 2). One recent analysis proposes that uncertainty in the climate response to additional admissions of greenhouse gases means that 1.5°C of warming may occur a decade earlier than projected by the IPCC in its most recent report.[40]

As climate change intensifies, cities are particularly vulnerable to impacts such as heat stress and can play a key role in reducing emissions locally and globally.

Heatwaves now pose a recurring challenge on all inhabited continents and generate an increasing range of threats to human lives and well-being,[43] particularly in cities where built environments magnify heat exposure.[44] This matters because close to 70% of the world's population is expected to live in cities by 2050 and will be exposed to extreme heat if no actions are taken to modify urban environments.[45]

Heat-related mortality is also expected to be higher in cities, particularly those characterized by high population density, inequalities, limited access to health care, high pollution levels and fewer green spaces.[46] A study of the 1692 largest cities in the world found that about 60% of the urban population has already experienced warming twice as large as the world during the 1950-2015 period.[47]

As cities consume about 78% of the world's energy and produce more than 60% of all CO2 emissions[48] their actions are central to minimizing the rise in global mean temperature. In particular, shifts towards cleaner energies will not only reduce GHG emissions, but will also reduce localized air pollution and heat island effects within cities.[49,50]

The cities of the world are thus key players for stepping up climate action. Commitments have been made by more than 9000 cities from 128 countries and around 240 states and regions from more than 40 countries.[51] Commitments have also been made by more than 6000 businesses in 120 countries representing $36 trillion USD.[51]

THE WAY FORWARD

Strategies for mitigation and for upscaling adaptive risk management are necessary going forward. Neither is adequate in isolation given the pace of climate change and magnitude of its impacts.[52]

A mitigation-only strategy will not be effective because many changes are already under way and are now unavoidable. Similarly, an adaptation-only strategy will become more costly (the annual cost of adaptation is estimated in the range of US$140-300billion by 2030[53]) as the magnitude of climate change increases. Currently only 40 developing countries have quantifiable adaptation targets in their current Nationally Determined Contributions and many existing targets are relatively short-term, not going beyond 2020.[53] So, our resilience and adaptive capacities must still be strengthened to deal with committed climate impacts and to plan to manage residual risks that will remain in the long term despite mitigation actions.

Lower death tolls from extreme events in 2018 could indicate the efficacy of adaptations responses like improved standards of living and disaster management but might also reflect poor reporting. Indeed, accurately reported death tolls indicate the severity of a natural disaster but can also point to ineffectual (and potentially politically damaging) disaster management and relief efforts, and to underlying poverty and inequality in the affected population. Improved data collection and reporting are necessary to improve adaptation response. Thus mitigation and, more so, adaptation efforts would benefit enormously from high quality, robust and transparent policy informed by evidence.[54] It is also critical to avoid complacency towards gaps in resilience, particularly for weather-related disasters.[55]

Box 1. Essential elements for a successful climate policy strategy to drive decarbonization

Fiscal Reform: Fiscal reforms are a central mechanism available to governments to achieve the Paris Agreement.[68] To-date, half of all carbon emissions are not priced at all, and only 10% are priced above 34€/tCO_2, the minimum to be compatible with the 2°C guardrail. Both tax reforms and emissions trading systems (ETS) can be elements of the necessary transformation towards a single, cross-sectoral carbon price,[69] but options must be designed such that they realistically shape expectation on future climate policy (an 'all or nothing' principle).[70] ETS require a minimum price and in the long term, international harmonization. Reducing fossil fuel subsidies is also essential for a successful fiscal reform; In 2017, government consumption-based subsidies to fossil fuels were more than $300 billion USD/year.[71] Policy reforms to phase out these subsidies can reduce global carbon emissions up to 10%.[72]

Sector-specific climate policy instruments: Sector-specific measures like information programs, building standards, or innovation funding must complement carbon pricing to mediate market or policy failures. For example, in the heating and cooling sector, incentives for the energy-efficient renovation of buildings would complement a carbon price, as would new practices to combat congestion, noise and air pollution in the transport sector.[73] Moratoriums on coal power, together with market support for energy-efficient and low-carbon technology and infrastructure can also support an energy system transformation.[74, 75]

Social Balance: In the context of rising carbon prices, social acceptability is achievable by introducing a carbon tax or emissions trading systems, that generate revenues for the state and which can be refunded to households in a revenue-neutral way – unlike regulation and subsidy programmes.[76] Low-income households could economically benefit, while hardship clauses, for instance for long-distance commuters, can improve acceptance levels.[77]

International Coordination: Global cooperation on climate markets can play an important role in increasing ambition for mitigation actions, and in mobilizing resources by crowding in public and private funding. While emission reduction goals have been the focus of past international climate negotiations, international coordination going forward should be directed towards an international price for CO_2 (even without a common price for carbon currently). Different national or regional approaches are a prerequisite for international negotiations and can flexibly adapt to different strategic scenarios.[78]

Only immediate and all-inclusive action encompassing: deep decarbonization complemented by ambitious policy measures, protection and enhancement of carbon sinks and biodiversity, and efforts to remove CO2 from the atmosphere, will enable us to meet the Paris Agreement target of well below 2°C.

Each of these avenues is outlined below.

Deep decarbonization: Pathways to limit warming to well below 2°C, aiming for 1.5°C require halving global emissions every decade from 2020 onward[56] and respecting a global carbon budget – around 420-570 billion tons total net CO2 emitted to the atmosphere.[57]Such deep decarbonization also requires major transformations in all of society's socio-technical systems[58] for example, in the energy and food sectors as pivotal first adopters (while ideally all sectors will work in parallel).

In the energy sector, social and technological innovations coupled with strong efficiency standards can potentially reduce the energy demand without compromising global living standards,[59] especially as readily-available technological substitutions already exist for ~73% of today's emissions.[60] The speed of the transformation will also be decided by the growing political, technological and economic momentum of renewable energy.[61] For example, between 2006 and 2016, solar and wind power have gone from a combined 0.7% to 5% share of global electricity production, doubling their output every 3 years[62, 63] while dropping in price.[64]

In the food sector, new research confirms that a transformation of global diets encompassing reduced meat and dairy consumption, combined with sustainable intensification of agricultural practices and reduced food waste, are critical to achieve the Paris Agreement, potentially averting up to 11 million deaths per year, and theoretically reducing food's land use by up to 76% and food's greenhouse gas emissions by up to 49%.[65,66]

Ambitious policy measures: Stronger and more diverse policy measures for rapid decarbonization, such as fiscal reforms (including a well-designed carbon price)[67] and sector-specific policy instruments, that account for both social acceptability and international cooperation, would also help reduce climate risks (see Box 1 for details).

Protecting and enhancing carbon sinks and biodiversity: Protecting our existing carbon sinks and biodiversity, and expanding lands from source to sink, is possible via natural solutions that promote conservation of landscapes, restoration of degraded forested land at global scale, and improved land management actions.[79,80] Such actions could provide over one-third of the climate mitigation needed between now and 2030 to stabilize warming to below 2°C[81] and can help reverse some of the adverse impacts of climate change on land degradation.[82]

Removing CO2 from the air: To achieve the 1.5°C target, approximately 100-1000 billion tons of CO2 must be removed from the air during this century. To do so, a range of negative emissions technologies (NETs) have been proposed, from re- and afforestation to bioenergy with carbon capture and storage (BECCS) or direct air capture of CO2. These differ widely in terms of maturity, potentials, costs, risks, co-benefits and trade-offs.[83] NETs play an essential role in mitigation scenarios that are consistent with the Paris Agreement targets – but to a scale much larger than currently tested and deployed. There is also a risk that they may be used to delay implementing emissions reduction policies.[84] While NETs will be indispensable in combination with other mitigation efforts – especially to offset hard-to-stop emissions such as from aircraft or cattle[85] – large-scale deployment options are limited with feasibility constraints and increasing sustainability trade-offs.[86] Furthermore, new assessments indicate that few of these large-scale removal options could be available before 2050, thus such techniques cannot be relied on over the next several decades, which is the timescale relevant for achieving the Paris Agreement.[87]

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