**“Impacts Happening Ahead of Projection or Greater than Projections”:**

**A list of summaries and references
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*(This list and the details and links below is an ongoing project of Bruce Melton and the Climate Change Now Initiative. If you have citations or interpretations that could be added to this list, please email them to Bruce at the email address above.)*

**Ahead of Projections Summary (no links) 15 climate change effects**
Major hurricane intensity, 50 years ahead
Gulf Stream reduction, 90 years ahead
Amazon flip, 70 years ahead
Antarctic collapse, 100 years ahead
Arctic sea ice, 70 years ahead
Permafrost collapse, 70 years ahead
Upper ocean stratification, 6 times faster than projected
Ocean acidity, 62 years ahead
Ocean temperature, 40 years ahead
Winter storms, 80 years ahead in Southern hemisphere
Air temperature in the Arctic, up to 80 years ahead
Thermokarst lake drainage ahead, 60 to 80 years ahead
Average 30-year Houston rainfall, 80 years ahead
Sea level rise, 80 percent greater than projected
Ocean heat uptake, 50 percent greater than projected
Half of known tipping points are up to 100 years ahead of projections

*(The following are details and short discussions/summaries of the findings and reports used to define "ahead of, greater, or faster than projections." This informal documentation is by no means a complete list.)*

**Hurricanes**

**Major Hurricanes Increased intensity of 32% average, up 60 percent 1979-2017, Cat 3 to 5, globally…** Increase in hurricane strength 50 plus years ahead of projections. See Knutson 2020 for theoretical projections.
Kossin et al, Global Increase in Major Tropical Cyclone Exceedance Probability Over the Last Four Decades, PNAS, May 4, 2020.pdf
(Paywall) <https://www.pnas.org/content/117/22/11975>
PNAS Press Release:
Trends in tropical cyclone intensity
<https://www.eurekalert.org/pub_releases/2020-05/potn-tit051320.php>
Theoretical increase of only 15% average for major hurricanes Cat 4 and 5 with 2 degrees C warming.
Knutson et al., Tropical Cyclones and Climate Change - Part II, Projected Response to Anthropogenic Warming, BAMS, March 2020.
<https://journals.ametsoc.org/bams/article/101/3/E303/345043/Tropical-Cyclones-and-Climate-Change-Assessment>

**Gulf Stream**

**Gulf Stream Shutdown First Warning…**at least 90 years ahead of projectionsMcCarthy et al., Observed interannual variability of the Atlantic meridional overturning circulation at 26.5N, Geophysical Research Letters 2012
<https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2012GL052933>

**(Gulf Stream) Large scale changes of ocean circulation not until after 2100…** Abrupt climate changes, such as the collapse of the West Antarctic Ice Sheet, the rapid loss of the Greenland Ice Sheet or large-scale changes of ocean circulation systems, are not considered likely to occur in the 21st century.

IPCC Fourth Assessment, 2007, Frequently Asked Questions.
<https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/faq-10-2.html>

**Amazon Flip**

**Amazon emissions of 0.67 Pg C (2.45 Gt CO2eq) from 2010 to 2019 based on satellite canopy density, with forest degradation 3X the loss of deforestation…**"During 2010-2019, the Brazilian Amazon had a cumulative gross loss of 4.45 Pg C against a gross gain of 3.78 Pg C, resulting in net AGB loss of 0.67 Pg C. Forest  degradation (73%) contributed three times more to the gross AGB loss than deforestation (27%), given that the areal extent of degradation exceeds deforestation. This indicates that forest degradation has become the largest process driving carbon loss and should become a higher policy priority."

Qin et al., Carbon loss from forest degradation exceeds that from deforestation in the Brazilian Amazon, Nature Climate Change, April 29, 2021.
preprint - <https://www.researchgate.net/publication/361323731_Carbon_loss_from_forest_degradation_exceeds_that_from_deforestation_in_the_Brazilian_Amazon>

Paywall - <https://www.nature.com/articles/s41558-021-01026-5>

**Amazon emitting, not absorbing, 1 Gt CO2 annually on average from 2010 to 2018… based on atmospheric measurements over time…** "Considering the upwind areas of each site, we combine fluxes from all sites to calculate a total Amazonia carbon balance for our nine-year study period (see Methods) of 0.29±0.40 Pg Cyr−1 (FCTotal=0.11±0.15gCm−2d−1), where fire emissions represent 0.41±0.05PgCyr−1 (FCFire=0.15±0.02gCm−2d−1), with NBE removing −0.12±0.40PgCyr−1 (31% of fire emissions) from the atmosphere (FCNBE=−0.05±0.15gCm−d−1). The east (region 1 in Extended Data Fig.6), which represents 24% of Amazonia (of which 27% has been deforested), is responsible for 72% of total Amazonian carbon emissions, where 62% is from fires. One recent study showed cumulative gross emissions of carbon of about 126.1MgCO2 ha−1 for 30yr after a fire event, where cumulative CO2 uptake from forest regrowth offsets only 35% of the emissions. Another recent study13 reported that fire emissions from Amazonia are about 0.21±0.23PgCyr−1. Recently, vander Werf etal.24 estimated for the period 1997–2009 that globally, fires were responsible for an annual mean carbon emission of 2.0PgCyr−1, where about 8% appears to have been associated with South American forest fires, according to estimates from the Global Fire Emission Data set (GFED V.3). The Amazon Forest Inventory Network (RAINFOR) project showed a decline in sink capacity of mature forests due to an increase in mortality1–3. Adjusting the three RAINFOR studies to a consistent area (7.25×106km2) and taking their mean yields a basin-wide sink for intact forests of about −0.57, −0.41 and −0.23PgCyr−1 for 1990–1999, 2000–2009 and 2010–2019, respectively. The NBE from this study is consistent with the RAINFOR results for the last decade, because NBE represents the uptake from forest but also all non-fire emissions, such as decomposition, degradation and other anthropogenic emissions (see Supplementary Table 3)."

Gatti et al., Amazonia as a carbon source linked to deforestation and climate change, Nature, July 14, 2021.

<https://pure.rug.nl/ws/files/176729920/s41586_021_03629_6.pdf>

<https://www.nature.com/articles/s41586-021-03629-6.epdf?sharing_token=lsfPlVRsW05dUMB_VD-zItRgN0jAjWel9jnR3ZoTv0NILaci0q8CXtVe4JKM-xF0Z0ZQpmJpnpSclAjJeIV-vCjviXK_Mb9hvvU5C3CiJVgu82-RGuHR01gFiQZAVMzDCCxiRyvlh0MBQxTvGN2oHmf2jIOC7MEEGXrOPGIblsh57v9qXkkZbM7U0OH8zbdQ4jnVO1zD9R1jeDcUVBS22YVLkjWEvC5vrNMdQ416fmEBL9kIHYs2ptVibFKXLxEuh-TQ08w-QGSFzN6221KgguYTe0Q9FoZ1J-Wksf4tWXrjv-xu34UpgYqxQWwLTTbTgHYTuglT_tSVd4WaweL9fg%3D%3D&tracking_referrer=www.theguardian.com>

**Guardian article above based on Gatti 2021…** "The study found fires produced about 1.5bn tonnes of CO2 a year, with forest growth removing 0.5bn tonnes. The 1bn tonnes left in the atmosphere is equivalent to the annual emissions of Japan."Carrington, Amazon rainforest now emitting more CO2 than it absorbs, Guardian, July 14, 2021.
<https://www.theguardian.com/environment/2021/jul/14/amazon-rainforest-now-emitting-more-co2-than-it-absorbs>

**The Amazon is flipping from carbon sink to source 70 years ahead of projections…** The Amazon has flipped from carbon sink to carbon source three times 2005, 2010, 2016, with 100-year or more extreme drought, each increasing in severity from the previous event. Flipping three times is a fair enough interpretation. In 2010, the Amazon was near neutral with carbon emissions of 0.07 gigaton C (256 megatons CO2 equivalent.) The 2005 drought created emissions of 0.43 gigaton C (1.6 PgC reduction – 1.1 PgC) or 1.6 gigatons C. The 2016 drought was more severe than either, but the quantity of emissions has not yet been published.

2005 and 2010 Droughts… (Abstract) “Based on these ground data, live biomass in trees and corresponding estimates of live biomass in lianas and roots, we estimate that intact forests in Amazonia were carbon neutral in 2010 (-0.07 Pg C yr1 CI: -0.42, 0.23), consistent with results from an independent analysis of airborne estimates of land-atmospheric fluxes during 2010. Relative to the long-term mean, the 2010 drought resulted in a reduction in biomass carbon uptake of 1.1 Pg C, compared to 1.6 Pg C for the 2005 event.” Therefore, if the 2010 drought was carbon neutral, the 2005 drought resulted in carbon emissions.

Feldpausch, Amazon forest response to repeated droughts, Global Biogeochemical Cycles, July 1, 2016.

<https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2015GB005133>
Press Release - <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2015GB005133>

Yang et al. 2018, say that the 2005 Amazon drought continued to create carbon emissions through 2008 of 1.1 gigatons CO2 per year…

Yang et al., Post-drought decline of the Amazon carbon sink, Nature, August 9, 2018.

<https://www.nature.com/articles/s41467-018-05668-6>

**2016 Drought…** (Abstract) Tropical and sub-tropical South America are highly susceptible to extreme droughts. Recent events include two droughts (2005 and 2010) exceeding the 100-year return value in the Amazon and recurrent extreme droughts in the Nordeste region, with profound eco-hydrological and socioeconomic impacts. In 2015–2016, both regions were hit by another drought. Here, we show that the severity of the 2015–2016 drought ("2016 drought" hereafter) is unprecedented based on multiple precipitation products (since 1900), satellite-derived data on terrestrial water storage (since 2002) and two vegetation indices (since 2004). The ecohydrological consequences from the 2016 drought are more severe and extensive than the 2005 and 2010 droughts. Empirical relationships between rainfall and sea surface temperatures (SSTs) over the tropical Pacific and Atlantic are used to assess the role of tropical oceanic variability in the observed precipitation anomalies. Our results indicate that warmer-than-usual SSTs in the Tropical Pacific (including El Niño events) and Atlantic were the main drivers of extreme droughts in South America, but are unable to explain the severity of the 2016 observed rainfall deficits for a substantial portion of the Amazonia and Nordeste regions. This strongly suggests potential contribution of nonoceanic factors (e.g., land cover change and CO2-induced warming) to the 2016 drought.

Erfanian et al., Unprecedented drought over tropical South America in 2016 significantly under-predicted by tropical SST, Nature Scientific Reports, July 19, 2017.

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5517600/>

**The Amazon has flipped from a carbon sink to a carbon source …** A personal email correspondence with Lewis helped with the math… 2.2 and 1.6 Gt of Carbon (C) were killed in 2010 and 2005. It takes four years for half to decay and another 25 for the rest to decay resulting in 0.475 Gt emissions the first four years spread out non-linearly thereafter. The Amazon normally captures 0.4 Gt C in a non-drought year, so for the first +/- ten years after 2010 emissions will be greater than captured C.

Lewis et al., The 2010 Amazon Drought, Science, February, 2011.

Abstract only: <http://www.sciencemag.org/content/331/6017/554>

Press Release: <https://www.eurekalert.org/news-releases/593178>

**Over 2 billion trees...** Lewis is quoted in the Guardian “in the low billions of trees.” <http://www.theguardian.com/environment/2011/feb/03/tree-deaths-amazon-climate>

Amazon ahead of schedule up to a century… The Amazon was not supposed to flip until over 4 degrees C of warming (Lovejoy and Nobre 2018) that under most worst-case business as usual scenarios would not occur until beyond the end of the 21 century. Lovejoy and Nobre 2019 now tell us that, "The increasing frequency of unprecedented droughts in 2005, 2010, and 2015/16 is signaling that the tipping point is at hand."

**The Amazon tipping point - historic tipping was 4 C warming, 70 years ahead of projections…** Considering 4 C warming under BAU near the end of the century, the Amazon has flipped 70 years ahead of projections. "Many studies show that in the absence of other contributing factors, 4 degrees Celsius of global warming

would be the tipping point…"
Lovejoy and Nobre, Amazon Tipping Point, Science advances, February 21, 2018.

<https://advances.sciencemag.org/content/advances/4/2/eaat2340.full.pdf>

**Last change for action…**  Lovejoy and Nobre, Amazon tipping point, Last chance for action, Science Advances, December 20, 2019.

<https://advances.sciencemag.org/content/advances/5/12/eaba2949.full.pdf>

**Antarctic Ice Loss**

**Antarctica has begun to lose ice 100 years or more ahead of IPCC predictions. The 2007 IPCC report said Antarctica would not begin to lose ice until after 2100…** Antarctic surface mass balance (SMB) in the 2007 IPCC Report was supposed to increase, not decrease, for all scenarios, through 2100. This means that snow accumulation was supposed to be more than melt, evaporation and iceberg discharge combined: “All studies for the 21st century project that Antarctic SMB changes will contribute negatively to sea level, owing to increasing accumulation exceeding any ablation increase (see Table 10.6).”
Intergovernmental Panel on Climate Change, Fourth Assessment Report, Climate Change 2007: Working Group I: The Physical Science Basis, 10.6.4.1, Surface Mass Balance, fifth paragraph.
<https://www.ipcc.ch/report/ar4/wg1/>

**The 2013 IPCC report tells us that Antarctic ice loss has begun and almost caught up with Greenland…** Summary for Policy Makers, E.3 Cryosphere, page 9, third bullet. “The average rate of ice loss from the Antarctic ice sheet has likely increased from 30 [–37 to 97] Gt yr–1 over the period 1992–2001 to 147 [72 to 221] Gt yr–1 over the period 2002 to 2011.” Greenland, second bullet: “The average rate of ice loss from the Greenland ice sheet has very likely substantially increased from 34 [–6 to 74] Gt yr–1 over the period 1992 to 2001 to 215 [157 to 274] Gt yr–1 over the period 2002 to 2011.”
<http://www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf>

**First Warning - Negative Antarctic Ice mass balance since at least 1994…** "A revised melt rate for ice shelves in the Southeast Pacific sector raises circumpolar ice shelf melting to 756 Gt yr−1. Given prior estimates of surface accumulation and iceberg calving, this suggests that the Antarctic Ice Sheet is currently losing mass to the ocean."
Jacobs et al., Antarctic ice sheet melting in the Southeast Pacific , Geophysical Research Letters, May 1, 1996, last Sentence of abstract. <https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/96GL00723>

**Dynamical Ice Sheet collapse is not included in sea level rise projections of the IPCC**… “Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause GMSL to rise substantially above the likely range during the 21st century.” The likely range for RCP8.5 by 2100 is 0.63 meters, or two feet.  IPCC 2013, Scientific Basis Technical Summary, page 49. <http://www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf>

**Arctic Sea Ice**

**Arctic Sea Ice decline 70 years ahead of schedule…** Summertime melting of Arctic sea-ice has ‘‘accelerated far beyond the expectations of climate models.’’ Using unusually vivid language, the authors note that the record for previous Arctic sea ice summer minimum extent was ‘‘shattered’’ in 2007, ‘‘something not predicted by climate models . . . This dramatic retreat has been much faster than simulated by any of the climate models assessed in the IPCC AR4 (fourth IPCC report)’’ with summer sea ice now well below the IPCC worst case scenario. Allison 2009, pp. 29–30. Summer minimum sea ice was higher in subsequent years, but still fell near or below the long-term observed downward trend. In 2012, another record minimum was set. The 70 years faster than projections statement comes from comparing IPCC AR4 projections with current data from Stroeve et al. Allison et al., The Copenhagen Diagnosis: Updating the World on the Latest Climate Science, University of New South Wales Climate Change Research Center, 2009.
<http://www.ccrc.unsw.edu.au/Copenhagen/Copenhagen_Diagnosis_HIGH.pdf>
Stroeve et al, The Arctic’s rapidly shrinking sea ice cover—A research synthesis, Climatic Change, 110, 1005-1027, 2012, published online June 2011.
<http://www.springerlink.com/content/c4m01048200k08w3/fulltext.pdf>

**Arctic Sea Ice Collapse First Warning…** "Thin ice and open water allow more surface solar heating because of a much reduced surface albedo, leading to amplified ice melting. The Arctic Ocean lost additional 10% of its total ice mass in which 70% is due directly to the amplified melting and 30% to the unusual ice advection, causing the unprecedented ice retreat. Arctic sea ice has entered a state of being particularly vulnerable to anomalous atmospheric forcing."Zhang et al., What drove the dramatic retreat of arctic sea ice during summer 2007, Geophysical Research Letters, 2008.
<https://courses.seas.harvard.edu/climate/seminars/pdfs/zhang_etal_2008.pdf>

**Permafrost**

**Randers and Goluke 2020, permafrost 0.5 C…** The authorshave identified a tipping point with permafrost collapse of 0.5 C warming. "We did experiments with ESCIMO (see Supplement Figure 13) to explore (contra-factually) in what year man-made emissions must stop to avoid self-reinforcing melting of the permafrost. The answer is that all man-made emissions would have had to be cut to zero sometime between 1960 and 1970—when global warming was still below some + 0.5 °C.
 Finally, we explored another strategy to stop self-sustained melting. We asked how much CO2 humanity must remove from the atmosphere every year from 2020 in order to avoid self-sustained temperature rise in the centuries ahead. The answer, in ESCIMO, proved to be at least 33 GtCO2e per year, for example through direct CO2 capture or biomass CCS (see Supplement Figure 14 (a) and (b)). In other words, building 33,000 big CCS plants and keep them running for ever.
Randers and Goluke, An earth system model shows self-sustained melting of permafrost even if all man-made GHG emissions stop in 2020, Nature Scientific Reports, November 12, 2020.
<https://www.nature.com/articles/s41598-020-75481-z>

**Permafrost collapse 70 years ahead of projections...** "Observed maximum thaw depths at our sites are already exceeding those projected to occur by 2090 under representative concentration pathway version 4.5."
Farquharson et al., Climate Change Drives Widespread and Rapid Thermokarst Development in Very Cold Permafrost in the Canadian High Arctic, Geophysical Research Letters, June 10, 2019.
<https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2019GL082187>

**Ocean Stratification**

**Upper ocean stratification increasing six times faster than projected…** Ocean stratification has implications for carbon sequestration, where increased stratification limits carbon sinking into the abyss. "Using a physically based definition of upper-ocean stability that follows different dynamical regimes across the global ocean, we find that the summertime density contrast increased by 8.9±2.7 per cent per decade (10−6–10−5 persecond squared per decade, depending on region), more than six times greater than previous estimates. Whereas prior work has suggested that a thinner mixed layer should accompany a more stratified upper ocean, we find instead that the summertime mixed layer deepened by 2.9±0.5 per cent per decade, or several metres per decade (typically 5–10 metres per decade, depending on region). A detailed mechanistic interpretation is challenging, but the concurrent stratification and deepening of the mixed layer are related to an increase in stability associated with surface warming and high-latitude surface freshening, accompanied by a wind-driven intensification of upper-ocean turbulence."
Sallee et al.,  Summertime increases in upper-ocean stratification and mixed-layer depth, Nature, March 24, 2021.
<https://www.nature.com/articles/s41586-021-03303-x.epdf?sharing_token=XlKX9VCiIgSQTw2tGjb099RgN0jAjWel9jnR3ZoTv0PrbOhVC9HiOzy2kA3717nTIai2p2njuhAj72RwpttABzK6dU3sYwCcIH3ijNB62fN2MrQTgCxvuKUa1vm4fDHYlkWB37EYggQQgepBK_r-KZFQo2q8BRF_sfQDf39Wa9o%3D>

**Ocean Acidity**

**Ocean Acidity increasing 42 to 62 years ahead of schedule in the Southern Ocean…** Proceedings of the National Academies of Science, published by a scientists named McNeil from the University of New South Wales in Australia, has discovered that the great Southern Ocean is acidifying 42 to 62 years faster than predicted.
McNeil and Matear, Southern Ocean Acidification A tipping point at 450 ppm atmospheric CO2, PNAS November 2008.
[http://www.pnas.org/content/early/2008/11/20/0806318105.full.pdf+html](http://www.pnas.org/content/early/2008/11/20/0806318105.full.pdf%2Bhtml)

**Ocean Temperature**

**Ocean temperatures affecting El Nino and La Nina 40 years ahead of projections…** Resulting in more and bigger floods and droughts.
Geng, Emergence of changing Central-Pacific and Eastern-Pacific El Niño-Southern Oscillation in a warming climate, Nature Communications, November 15, 2022.
<https://www.nature.com/articles/s41467-022-33930-5>
Phys.org review…
<https://phys.org/news/2022-11-climate-eastern-pacific-weather-patterns.html>

**Winter Storms**

**Winter Storms 80 years ahead of schedule in Southern Hemisphere…**"Storm intensification over recent decades has already reached levels projected to occur in the year 2080… One example of this is the role the storms play in regulating the temperature at the Earth's poles. Winter storms are responsible for the majority of the heat transport away from tropical regions toward the poles. Without their contribution, the average pole temperatures would be about 30°C lower… An analysis of the growth rate of the storms showed that changes in atmospheric jet streams over the past few decades have caused these escalations, and current climate models are unable to reflect these changes accurately

New data reveals climate change might be more rapid than predicted, Phys.org, May 26, 2022

<https://phys.org/news/2022-05-reveals-climate-rapid.html>

Full - Chemke, The intensification of winter mid-latitude storm tracks in the Southern Hemisphere, Nature Climate Change, May 26, 2022.
<https://arxiv.org/pdf/2201.10413.pdf>

 **Arctic Air Temperature**

**The Arctic is waring four times faster than the rest of the world…** Continued warming means that the Arctic is not warming twice as much as the global average any longer, but four times as much. In the 2004 Arctic Impact Assessment we first learned that the Arctic was warming twice as much as the rest of the world. In 2009 in the Journal Cryosphere we learned the Arctic was warming two to three times as fast as the rest of the world. Now in 2022, we understand that the Arctic is warming four times as fast as the rest of the world.
Twice as fast in 2004 - ACIA, Impacts of a Warming Arctic: Arctic Climate Impact Assessment. Cambridge University Press, 2004.
[https://www.amap.no/documents/download/1058/inline](https://www.amap.no/documents/download/1058/inline%20%20)
Three times as fast – The arctic is warming 2 to 3 times as fast as the global average.
Serreze at al., The emergence of surface-based Arctic amplification, The Cryosphere, February 4, 2009.
[https://tc.copernicus.org/articles/3/11/2009/tc-3-11-2009.pdf](https://tc.copernicus.org/articles/3/11/2009/tc-3-11-2009.pdf%20)

Four times as fast - Rantanen et al., The Arctic has warmed nearly four times faster than the globe since 1979, Nature Communications, August 11, 2022.
[https://www.nature.com/articles/s43247-022-00498-3](https://www.nature.com/articles/s43247-022-00498-3%20)

**Air temperatures in the arctic have warmed 40 to 80 years ahead of projections…** "Temperature and precipitation for northern and western Alaska, the dramatic lake dynamics described here provide an early glimpse of the potentially massive changes in hydrology, permafrost and topography to be expected in a warmer Arctic in similarly ice-rich permafrost landscapes. With mean annual air temperature (MAAT) around 0 C, the years 2017 to 2019 already matched the MAAT projected for this region in 2060 (RCP8.5) to beyond 2100 (RCP4.5) and precipitation projections for 2080 (RCP8.5). This mismatch indicates that local to regional permafrost landscapes may experience much more severe and earlier impacts in a warming Arctic than what climate models are capable of predicting at fine scales… These weather conditions

matched average model projections for the years 2060 (RCP8.5) to 2100 (RCP4.5), suggesting that on these local to regional scales, our climate forecast capabilities are not sufficient to project the full consequences of warming scenarios."

Nitze et al., The catastrophic thermokarst lake drainage events of 2018 in northwestern Alaska, fast-forward into the future, The Cryosphere, December 1, 2020.
<https://tc.copernicus.org/articles/14/4279/2020/tc-14-4279-2020.pdf>

**Thermokarst Lake Drainage**

**Thermokarst lake drainage 60 to 80 years ahead of projections…** Thawing permafrost in alluvium (gravels) surrounding arctic lakes has created sudden lake drainage across the Arctic. "Temperature and precipitation for northern and western Alaska, the dramatic lake dynamics described here provide an early glimpse of the potentially massive changes in hydrology, permafrost and topography to be expected in a warmer Arctic in similarly ice-rich permafrost landscapes. With mean annual air temperature (MAAT) around 0 C, the years 2017 to 2019 already matched the MAAT projected for this region in 2060 (RCP8.5) to beyond 2100 (RCP4.5) and precipitation projections for 2080 (RCP8.5). This mismatch indicates that local to regional permafrost landscapes may experience much more severe and earlier impacts in a warming Arctic than what climate models are capable of predicting at fine scales… These weather conditions matched average model projections for the years 2060 (RCP8.5) to 2100 (RCP4.5), suggesting that on these local to regional scales, our climate forecast capabilities are not sufficient to project the full consequences of warming scenarios."
Nitze et al., The catastrophic thermokarst lake drainage events of 2018 in northwestern Alaska, fast-forward into the future, The Cryosphere, December 1, 2020.
<https://tc.copernicus.org/articles/14/4279/2020/tc-14-4279-2020.pdf>

**Houston Rainfall – Explanation of Increased Rainfall From Warming Using NOAA's New Rainfall Frequency and Intensity Evaluation for Texas, Atlas 14**

**In Houston, actual rainfall today is 39 percent greater than it is supposed to be in 2081-2100, or 60 to 80 years ahead of projections…**An example of how significantly the climate science consensus understates comes from the 2013 IPCC report. This report tells us that by 2081 to 2100, Houston will see up to a ten percent increase in total 5-day, 20-year precipitation accumulation. The USGS published total 5-day precipitation for the 25-year storm in our old climate was about 12 inches in Houston. In Atlas 14, the 25-year, 5-day storm depth is about 16 inches (interpolated), an increase of 39 percent — already, in 2018, not 2081 to 2100. The actual measured increase in precipitation extremes are 60 to 80 years ahead of schedule and three times as much as IPCC projected for 2100.
Austin increase ahead of projections: IPCC fig 12.26 shows up to a 10 percent increase in 5-day, 20-year precipitation maximum precipitation. Austin's 2004 5-day, 25-year was 9.5 inches. Atlas 14 shows the 5-day 25-year at about 11.4 inches (interpolated), an increase of 20 percent, double what IPCC projected for 2100.

The AR6 Science Basis in August 2021 chose not to recreate conditions in AR5 and only reported seasonal change in precipitation. For Houston, the seasonal change for the winter and summer quarters, December through February and June through August, for two of the middle scenarios, SSP1-2.6 and SSP3-7.0, for the period 2018 to 2100, was from -10 percent to +10 percent .

**Austin, the 100-year storm is now the 25-year storm...**"The study, published as NOAA Atlas 14, Volume 11 Precipitation-Frequency Atlas of the United States, Texas, found increased values in parts of Texas, including larger cities such as Austin and Houston, that will result in changes to the rainfall amounts that define 100-year events, which are those that on average occur every 100 years or have a one percent chance of happening in any given year. In Austin, for example, 100-year rainfall amounts for 24 hours increased as much as three inches up to 13 inches. 100-year estimates around Houston increased from 13 inches to 18 inches and values previously classified as 100-year events are now much more frequent 25-year events."
NOAA updates Texas rainfall frequency values, National oceanic and Atmospheric Administration, September 27, 2018.
https://www.noaa.gov/media-release/noaa-updates-texas-rainfall-frequency-values

**Atlas 14 increases storm flows by 50%, Leander, Texas (Austin Region)…** The Leander Flood Study shows Atlas 14 alone increases runoff flows through the study area by an average of 48 to 60 percent because of increasing rainfall intensity and frequency, and when impervious cover changes were included the increase was 50 to 100 percent. From page 2, paragraph 2, "In order to provide some initial context to the increases in flow associated with the model updates completed with this study, KFA performed a check run of the effective hydrologic model with no changes except for the use of Atlas 14 rainfall. Those results were compared to the results of the fully updated hydrologic model. That comparison shows that the average flow increases by approximately 48% due to Atlas 14 rainfall, while the average flow increases by approximately 60% with all the model updates performed with this study."
City of Leander Floodplain Model and Mapping Updates, Hydrologic and Hydraulic Technical Report, K.Frieze Associates, September 2021.
(Not on line)
IPCC AR5 2081 to 2100 precipitation projection: Scientific Basis, Chapter 12, Figure 12.26, page 1083.
<https://www.ipcc.ch/report/ar5/wg1/>

IPCC AR6, 2081 to 2100 precipitation projection: Scientific Basis, Chapter 4, Figure 4.24.
<https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter_04.pdf>
USGS, 5-day, 25-year event, 12 inches in Houston.
Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas, USGS, 2004, Figure 50, page 57.
<https://pubs.usgs.gov/sir/2004/5041/pdf/sir2004-5041.pdf>
NOAA Atlas 14, 5-day, 25-year event, 16 inches.
<https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html>

 **Sea Level Rise and Ocean Heat Uptake**

**Rapid Acceleration of Sea Level Rise on the US East and Gulf Coasts From Slow Down of Gulf Stream...** from Yin 2023, "Both the century-long tide gauge data and the more recent altimetry data reveal a rapid decadal acceleration of SLR during 2010-2022 along the U.S. East Coast and the Gulf of Mexico coast. The acceleration is most notable on the Southeast and Gulf Coasts, as quantified by the decadal rise rate, extreme annual sea level departure from the long-term trend, as well as the sea level record-breaking frequency and magnitude. Our analysis suggests that this SLR acceleration is largely a lagged response to the observed slowdown of the Atlantic meridional overturning circulation in 2009-2010."

Yin, Rapid Decadal Acceleration of Sea Level Rise along the U.S. East and Gulf Coasts during 2010-2022 and Its Impact on Hurricane-Induced Storm Surge, Journal of Climate, March 2, 2023.

Full - <https://journals.ametsoc.org/view/journals/clim/aop/JCLI-D-22-0670.1/JCLI-D-22-0670.1.xml>

NOAA Press Release - <https://cpo.noaa.gov/News/ArtMID/7875/ArticleID/2820/Rapid-Sea-Level-Rise-along-the-US-East-and-Gulf-Coasts-during-2010-2022-and-Its-Impact-on-Hurricane-Induced-Storm-Surge>

**Sea level rise rate of 10 mm per year over the last decade exceeds model predictions from Cape Hatteras to the Western Gulf of Mexico...** Dangedorf 2023 tells us sea level rise rates on the US East Coast from Hatteras to the western Gulf of Mexico of 10 mm per year over the last decade exceed climate model projections. They find internal variability and external forcing are the cause, and will likely return to within future modeling projections within the next decade or so. However, they authors state, "Our results imply that the early detection of acceleration signals, which are needed for near-term planning and decision-making, still represents a major challenge and that comparisons with climate model projections, specifically locally, need to be undertaken with care. More generally, our findings highlight the critical role of a mechanistic understanding of MSL accelerations at the regional scale and its importance for sea-level projections."

Dangedorf et al., Acceleration of U.S. Southeast and Gulf coast sea-level rise amplified by internal climate variability, Nature Communications, April 10, 2023.

<https://www.nature.com/articles/s41467-023-37649-9>

**The sea level rise rate has increased 750 percent since 1900, mostly since 2000…**The World Meteorological Organization tells us in their State of the Global Climate 2021, sea level is now rising at 4.5 mm per year.  Columbia University's Sea Level Rise Page tells us that 1900 to 1930 sea level rise was 0.6 mm per year, a 750 percent increase. with most of the increase happening since the turn of the twenty-first century.

State of the Global Climate 2021, World Meteorological Organization, May 2021.

<https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate>

Columbia University's Sea Level Rise Page.

<http://www.columbia.edu/~mhs119/SeaLevel/>

**Sea level rise 80 percent greater than expected, ocean heat uptake 50 percent greater than predicted…**From page 328, section 2.4: “[The Copenhagen Diagnosis] reviewed ‘‘hundreds of papers . . . on a suite of topics related to human-induced climate change’’ since the drafting of AR4, and, like the NRC report, found that key changes were happening either at the same rate as, or more quickly than, anticipated. Among their key findings were that global temperature increases over the past 25 years have been consistent with model predictions of 0.19 C per decade, virtually the same rate as for the 16 years mentioned in Rahmstorf et al., 2007), while other important impacts are proceeding faster than expected, including CO2 emissions, increased rainfall in already rainy areas, continental ice-sheet melting, arctic sea-ice decline, and sea level rise. The data examined here overlap substantially with those analyzed by the Rahmstorf team, and it is noteworthy that an independent analysis by a different group of scientists comes to much the same judgment.” Key findings of the Copenhagen Diagnosis:

1. Rainfall has become more intense in already rainy areas, and ‘‘recent changes have occurred faster than predicted’’ (Allison et al., 2009, p. 15; see also Wentz et al., 2007; Allan and Soden, 2008; Liu et al., 2009).
2. Sea level rise has far exceeded predictions: ‘‘satellites show recent global average sea level rise (3.4 mm/yr over the past 15 years)—to be "80% above past IPCC predictions’’ (Allison et al., 2009, p. 7).
3. Surface ocean heat uptake between 1963 and 2003 was 50% higher than expected based on previous calculations. This difference helps explain why sea level rise (from thermal expansion) is also greater than expected (Allison et al., 2009, p. 35; see also Domingues et al., 2008; Bindoff et al., 2007).
4. Studies also show that deep ocean warming is more widespread than previously thought (Allison et al., 2009, p. 35; see also Johnson et al., 2008a,b).
5. Summertime melting of Arctic sea-ice has ‘‘accelerated far beyond the expectations of climate models’’ (Allison et al., 2009, p. 7; see also Stroeve et al., 2007). Indeed, using unusually vivid language, the authors note that the record for previous Arctic sea ice summer minimum extent was ‘‘shattered’’ in 2007, ‘‘something not predicted by climate models . . . This dramatic retreat has been much faster than simulated by any of the climate models assessed in the IPCC AR4’’—with summer sea ice now well below the IPCC worst case scenario (Allison et al., 2009, pp. 29–30). Summer minimum sea ice was higher in subsequent years, but still fell near or below the long-term observed downward trend (which, as just noted, declines faster than the model predictions). Then, in 2012, another record minimum was set (Stroeve et al., 2007).
6. CO2 emissions were also tracking the high-end scenarios developed in 1999 and applied in AR4, showing that scientists’ ‘‘worst-case scenario’’ has in fact been realized (Allison et al., 2009, p. 9; see also Nakicenovic et al., 2000), for the decade before the global financial disruption. Some people have pointed out that the emissions projections were not meant to be reliable in the short term, but it is interesting to note that, so far as these data may be relevant, they fit the pattern of underestimation.

Allison, et al., The Copenhagen Diagnosis, 2009: Updating the world on the Latest Climate Science, The University of New South Wales Climate Change Research Centre (CCRC), Sydney, Australia.

<https://www.preventionweb.net/files/11989_CopenhagenDiagnosisLOW.pdf>

**Tipping Activation**

**More than half of known tipping points are now active up to 100 years ahead of projections…**  Nine Earth systems collapses have been identified by scientists as active: Arctic sea ice, Greenland ice sheet, boreal forests, permafrost, the Gulf Stream, the Amazon, coral, the West Antarctic Ice Sheet and parts of the East Antarctic Ice Sheet. Until 2018, the Intergovernmental Panel on Climate Change (IPCC) has assumed that tipping would not occur before 5 C of warming above preindustrial times, something that the worst-case scenario put well into the 22nd century. In 2018 however, IPCC lowered this limit to between 1 and 2 C above preindustrial times in both the 1.5 C Report and the Cryosphere Report.  Lenton tells us, "The Intergovernmental Panel on Climate Change (IPCC) introduced the idea of tipping points two decades ago. At that time, these ‘large-scale discontinuities’ in the climate system were considered likely only if global warming exceeded 5 °C above pre-industrial levels. Information summarized in the two most recent IPCC Special Reports (published in 2018 and in September this year) suggests that tipping points could be exceeded even between 1 and 2 °C of warming."  Climate tipping is now active greater than 100 years ahead of projections.
Lenton et al., Climate tipping points-too risky to bet against, Nature, November 27, 2019

<https://www.nature.com/articles/d41586-019-03595-0>

University of Exeter Press -

<http://www.exeter.ac.uk/news/featurednews/title_767753_en.html>