Global Warming

State of Play October 2025

Albedo Index and Carbon Pollution

The **albedo index** measures the reflectivity of a surface. It is defined as the ratio of the amount of solar radiation reflected by a surface to the amount incident upon it. This index ranges from 0 to 1, where:

- 0 represents a surface that absorbs all incoming sunlight (e.g., asphalt).
- 1 represents a surface that reflects all sunlight (e.g., fresh snow or ice).

Impact of Carbon Pollution

1. **Darkening of Ice Surface:** Carbon pollution, along with other pollutants like soot and dust, can settle on ice and snow surfaces, resulting in a darker appearance. This darkening lowers the albedo index because darker surfaces absorb more sunlight rather than reflecting it.

2. **Decreased Reflectivity:** As the albedo index decreases, less solar radiation is reflected away from the Earth, leading to increased absorption of heat by the ice.

Consequences for Ice Melt

1. Increased Melt Rate: The reduction in albedo accelerates the melting of ice and glaciers. Warmer conditions caused by absorbed solar radiation contribute to a faster melt rate.

2. Feedback Loop: As ice melts, it exposes darker ocean or earth surfaces underneath, which further decreases the albedo. This creates a positive feedback loop, where the initial darkening leads to more melting and greater exposure of dark surfaces.

Implications

- Ecosystem Impact: The darkening of ice not only affects the albedo index but also disrupts ecosystems dependent on stable ice conditions.
- Climate Change Acceleration: Increased melt rates contribute to rising sea levels, intensifying global warming and its associated consequences.

Aspect	Albedo Impact	Melt Rate Effect
High Albedo (ice)	Reflective, cools surroundings	Slower melt rate
Low Albedo (darkened ice)	Absorbs heat, warms surroundings	Accelerated melt rate
Pollutants' Role	Reduces reflectivity	Creates positive feedback

The changes in the albedo index due to carbon pollution are thus critical metrics in understanding the implications of climate change and the dynamics of ice melt.

The increase in the albedo index of ice in Greenland means less radiation is reflected away from Earth's surface. This is a positive feedback effect. The less reflective the ice, the more heat is retained to melt the ice.

Greenland Ice Sheet

A **7-metre sea-level rise (≈ 23 feet)** is the amount of water stored in the Greenland ice sheet alone. The sheet is more than 1.7 km thick in places; complete loss of its ice would raise mean global sea level by **about 7 m**. Satellite observations show that Greenland has already lost about **4 trillion tonnes of ice** in the last quarter-century, and it is losing ice **seven times faster** than it was in the 1990s. For context, even **1 cm of sea-level rise exposes roughly six million additional people to coastal flooding**; thus a seven-metre rise (700 cm) would threaten billions of people and most of today's coastal cities.

Coastline impacts of a 7-metre rise

Modern coastlines have developed around present sea levels; the average height of most large deltas, estuaries and coastal plains is only a few metres above high tide. A 7-m rise would inundate almost all of the world's low-lying coastal zones. The United Nations estimates that *"nearly 900 million people – about 10 % of the global population – live in low-elevation coastal zones"*. These include huge metropolitan areas and fertile agricultural deltas. Major cities specifically named by the UN as being at risk from rising seas include **Cairo, Lagos, Maputo, Bangkok, Dhaka, Jakarta, Mumbai, Shanghai, Copenhagen, London, Los Angeles, New York, Buenos Aires and Santiago**. At seven metres of rise, large parts of these cities would lie below sea level and would be either submerged or reliant on enormous levees and pumps. Many small island states and all current atolls would disappear beneath the waves.

In addition to urban areas, 7 m of rise would drown vast swaths of the world's most productive farmland. The Nile, Mekong, Mississippi, Indus and Ganges-Brahmaputra deltas, among others, are mostly below 7 m elevation; UN briefings note that *"10 – 20 % of arable land"* in major deltas would sink even with **1 – 1.6 m** of sea-level rise by 2100. At 7 m, almost all deltaic farmland would be lost. The Netherlands – much of which already lies at or below present sea level – would be mostly submerged without massive new coastal defences. In the United States, a 7-m rise would flood much of

Florida, the **Gulf Coast**, and **low-lying parts of the Eastern Seaboard**. In **Bangladesh**, which is extremely flat and densely populated, most of the country south of Dhaka would lie underwater, threatening tens of millions of people.

Time-scale and uncertainties

Current climate models suggest that completely melting the Greenland ice sheet would take centuries to millennia under high-emission scenarios, but the process is already under way. NASA scientists emphasise that *"If [Greenland] melts completely, it could contribute up to 23 feet (7 metres) of sea-level rise"*, and that partial melting has already contributed more than a centimetre to recent sea-level rise. Because global sea-level rise is uneven – gravity from the ice sheets pulls ocean water towards them – regions far from Greenland (e.g., the southern hemisphere) would see slightly more than 7 m of rise, while regions near Greenland would see slightly less. Even so, the differences are on the order of a metre; the fundamental point is that a 7-m rise would redraw all of the world's coastlines and overwhelm almost every existing coastal defence.

Summary

- **Magnitude:** Complete loss of the Greenland ice sheet would raise global mean sea level by ~7 m.
- **Exposed population:** Each centimetre of sea-level rise now exposes ~6 million more people to coastal flooding; a seven-metre rise would imperil hundreds of millions to billions of people who currently live in low-elevation coastal zones.
- **Cities at risk:** UN reports list major metropolitan areas – including **Bangkok, Buenos Aires, Cairo, Copenhagen, Dhaka, Jakarta, Lagos, London, Los Angeles, Maputo, Mumbai, New York, Santiago and Shanghai** – as especially vulnerable to rising seas.
- **Land loss:** Most river deltas, coastal plains and small islands would be flooded; farmland in the Nile, Mekong and Ganges-Brahmaputra deltas and much of the Netherlands would vanish.
- **Time-scale:** Complete melting of Greenland would take centuries or longer, but significant sea-level rise is already under way and accelerating.

In short, a 7-m rise would push coastlines tens to hundreds of kilometres inland in many regions, submerge some of the world's largest cities, displace hundreds of millions of people and reshape global geography.

Here are some well-established numbers to help you estimate how long it would take the Greenland ice sheet to disappear, while keeping in mind the deep uncertainties that scientists like James Hansen highlight.

Current mass-balance components

- **Snow accumulation vs. melt runoff:** The surface mass budget (SMB) measures the balance between snowfall and melt/runoff. For the 2023-24 mass-balance year, scientists estimated an SMB of about **367 Gt (gigatonnes)**, close to the 1981-2010 average of 348 Gt. This means the ice sheet gained ~367 Gt through snowfall and lost almost the same amount through surface melt and runoff during that year.

- **Ice discharge (calving):** The ice sheet also loses ice when tidewater glaciers calve icebergs into the sea. During the 2024 mass-balance year, the mean solid-ice discharge through Greenland's marine-terminating glaciers was **~487 Gt yr^{-1}**, about one standard deviation above the 1991-2020 mean of 458 ± 27 Gt yr^{-1}.
- **Net mass loss:** Combining SMB and ice discharge gives the net mass balance. Gravity measurements from the GRACE-FO satellite show that Greenland **lost 55 ± 35 Gt of ice from September 2023 to August 2024**, the third-lowest loss in the 23-year record. In the previous year (2022-23), net loss was **156 ± 22 Gt**. Over 2002-23, average annual loss was **266 ± 16 Gt yr^{-1}**.
- **Historical trends:** Between 1992 and 2018, Greenland lost **3.9 trillion tonnes of ice** in total—an average of **~150 Gt yr^{-1}**. The annual loss rate increased from **34 Gt yr^{-1}** in the 1990s to **234 Gt yr^{-1}** in the 2010s. Because ~360 Gt of ice loss corresponds to 1 mm of global sea-level rise, Greenland's 1992–2018 loss contributed roughly 11 mm to sea level.

Simple linear melt-time estimates

The Greenland ice sheet contains enough ice to raise global sea level by **about 7.4 m** (≈7,400 mm). Converting this to mass requires multiplying by the ~360 Gt mm^{-1} factor. Thus the ice sheet holds roughly **≈2.6 million gigatonnes of ice**.

If the **long-term average loss of 266 Gt yr^{-1}** continued unchanged, complete melt would take (2.6 \times 10^6 / 266 ≈ 10,000) years. Using the **1992–2018 average of 150 Gt yr^{-1}** gives ~17,000 years, and using **2023-24's loss of 55 Gt** gives nearly 50,000 years. These simple divisions illustrate why most climate models project that *complete* melting would take many centuries or millennia.

Why linear extrapolation is misleading

1. **Accelerating losses:** Observations show that Greenland's mass-loss rate has already increased seven-fold since the 1990s. Surface melt and runoff are rising rapidly as the atmosphere warms and as albedo feedbacks (darkening ice surfaces) kick in. A constant-rate projection therefore underestimates future melt.
2. **Dynamic instabilities:** High glacier discharge (currently ~487 Gt yr^{-1}) reflects the fact that many outlet glaciers are speeding up or retreating. Ice-cliff failure and marine-ice-sheet instabilities, which are not fully captured in some IPCC models, could trigger more rapid ice loss.
3. **Warm-water intrusion and foehn winds:** New research highlights that melt can be driven by non-radiative energy fluxes and warm air intrusions, causing melt rates that models underestimate. For example, field campaigns have recorded daily melt rates exceeding 28 cm of surface ice during extreme events, far surpassing typical model outputs.

4. **Antarctic contribution:** Greenland is only part of the picture. Rapid loss from the West Antarctic and parts of the East Antarctic ice sheet would add additional metres of sea-level rise, and some scientists (including James Hansen) argue that these processes could unfold on century time-scales rather than millennia.

Consequences for Greenland

- Greenland's ice sheet is currently **losing hundreds of gigatonnes per year**, but the loss fluctuates with atmospheric circulation and snowfall; 2023-24 saw unusually low net loss due to above-average snowfall.
- Even if the current loss rate persisted, complete melting would take many thousands of years. However, **observed acceleration**, positive feedbacks and poorly understood ice-dynamical instabilities could dramatically shorten that time.
- Estimates based on the IPCC's surface-mass-balance scenarios suggest that Greenland will add **2–10 cm of sea-level rise by 2100** under current emissions trajectories. Critics contend that these scenarios may be conservative, but they still imply decades to centuries before Greenland contributes multiple metres of sea-level rise.
- Focusing on the *rate of change* and the *sensitivity of the ice sheet to warming*—rather than a simple linear timeline—provides more useful guidance for policy and adaptation. The fact that Greenland has already switched to a persistent state of net mass loss underscores the urgency of emission reductions to slow the pace of melting.

By combining the latest mass-balance data with an understanding of accelerating melt processes, you can convey both the scale of Greenland's potential sea-level contribution and the very real possibility that ice loss will speed up as warming continues.

Chaos Theory and Climate

While the detailed behaviours are not yet fully understood, information is available to link chaos theory, tipping points and abrupt climate change. Geomorphism and paleo climate studies indicate that abrupt climate change has occurred in the past at time-scales of only a few decades:

1. **Chaos limits weather predictability –** The "butterfly effect" discovered by meteorologist Edward Lorenz in the 1960s shows that weather is a chaotic system. Tiny differences in initial conditions (e.g., a slight change in barometric pressure or wind speed) grow over time so that two forecasts that start from almost identical states diverge until, after about ten to fifteen days, they no longer resemble each other. A 2021 Stanford University news article summarising recent work notes that rising temperatures push this limit even earlier: "the window for accurate forecasts in the mid-latitudes is several hours shorter with every degree Celsius of warming," and precipitation predictability falls by about a day for every 3 °C rise in temperature. The study's lead author, Aditi Sheshadri, explains that the chaotic nature of Earth's atmosphere imposes "insurmountable limits on forecasting" – errors propagate through weather models until the results "lose memory" of their initial conditions.

2. **Abrupt climate shifts in the geologic record –** The IPCC's Fourth Assessment Report (2007) defines abrupt climate changes as large changes occurring within less than 30 years. It notes that during the last ice age, Greenland experienced "Dansgaard-Oeschger" (D-O) events in which temperatures rose by **8–16 °C within a few decades**; cold periods that lasted hundreds or thousands of years ended with warming that took place within decades. This shows that parts of the climate system can switch rapidly from one state to another.
3. **Mechanism of abrupt shifts –** A RealClimate article by climatologist Stefan Rahmstorf explains the D-O events in more detail. It describes how ice cores from Greenland revealed "abrupt climate shifts" where temperatures jumped by **more than 10 °C within a few decades**, staying warm for centuries. The article links these rapid changes to reorganisations of ocean heat transport; when the Atlantic thermohaline circulation shifts, Greenland warms abruptly while Antarctica cools. Because these events recur many times, climate scientists view them as evidence that the climate system can flip between different attractor states on decadal time-scales.
4. **Implications for tipping-point research –** While many projected climate tipping points (collapse of the Atlantic Meridional Overturning Circulation, rapid dieback of the Amazon rainforest, loss of the West Antarctic ice sheet) might unfold over centuries once triggered, the **onset** of such transitions may occur over a few decades. Researchers therefore look for early-warning signs, such as increasing variability or slowing recovery after perturbations, that signal a system is approaching a tipping point. The fact that D-O events in the past warmed Greenland within a few decades suggests that once thresholds are crossed, climate subsystems can reorganise very quickly.
5. **Decadal-scale internal variability –** Not all decadal climate anomalies are tipping points. Internal oscillations such as the Pacific Decadal Oscillation (PDO) and Atlantic Multidecadal Variability (AMV) arise from ocean–atmosphere dynamics and produce anomalies on 10–30 year timescales. These oscillations are part of the climate system's "attractor manifold"; when external forcing (e.g., greenhouse-gas concentrations) shifts the attractor, the statistics of these modes change. The limit of weather predictability described above means that decadal predictions depend on the slow evolution of the oceans rather than initial atmospheric conditions.

Evidence for Past Shutdowns of AMOC

The **Atlantic Meridional Overturning Circulation (AMOC)** is a large system of ocean currents in the Atlantic Ocean, characterized by an intricate network of surface and deep-water flows. The AMOC plays a crucial role in transporting warm, salty water from the tropics northward to the North Atlantic, where it cools and sinks, forming cold deep-water currents that eventually flow back southwards. This circulation influences global climate, particularly in Europe and North America.

Historical Context

Evidence suggests that the AMOC has experienced significant slowdowns or even shutdowns in the past, particularly during the last glacial period and various interglacial periods.

Key Lines of Evidence

1. **Paleoceanographic Data**:
    - **Sediment Cores**: Analyzing sediment cores from the North Atlantic reveals changes in temperature and salinity over thousands of years. Data show intervals where water became less salty, indicating reduced deep-water formation linked to AMOC slowdowns.
    - **Proxy Records**: Isotopic ratios in foraminifera (tiny marine organisms) found in ocean sediments indicate past changes in temperature and ocean circulation patterns, supporting evidence of AMOC variability.
2. **Marine and Ice Core Data**:
    - **Greenland Ice Cores**: Ice cores from Greenland show abrupt climate changes, such as the Dansgaard-Oeschger events, which correspond to strong fluctuations in AMOC. Significant warming periods followed by cold spells in the cores suggest rapid shifts in ocean circulation.
    - **Antarctic Ice Cores**: Similarly, ice cores from Antarctica provide evidence of synchronous temperature changes that align with shifts in the AMOC, indicating its broader climatic significance.
3. **Computer Modeling**:
    - Climate models simulate the impact of varying atmospheric conditions and freshwater influxes (e.g., melting ice sheets) on the AMOC. These models help reproduce past AMOC behavior, showing potential shutdown scenarios under different climatic conditions.
4. **Archaeological and Historical Records**:
    - Historical records, such as the Medieval Warm Period and the Little Ice Age, correlate with shifts in the AMOC, affecting climate and weather patterns in Europe. The societal impacts of these climate changes provide additional context for understanding AMOC behaviors.

Implications of Shutdowns

- A shutdown or significant slowdown of the AMOC can lead to severe climate shifts, affecting regional climate, sea level rise, and weather patterns across the Northern Hemisphere.
- The potential for future shutdowns due to anthropogenic climate change continues to be a major area of research, given that current warming trends impact oceanic and atmospheric conditions.

Understanding the AMOC and its historical variations is critical in predicting future climate dynamics and impacts.

Recent Research on AMOC Shutdown Predictions

1. University of Copenhagen Study (2023)

A study led by researchers Peter and Susanne Ditlevsen from the **University of Copenhagen** predicts that the **Atlantic Meridional Overturning Circulation (AMOC)** could collapse as early as **2025** under current greenhouse gas emission scenarios. The study employs sea surface temperature data from the sub-polar North Atlantic, dating back to 1870, to model AMOC stability. They assert a **95% certainty** that a shutdown could happen by **2057** if fossil fuel emissions continue unabated. The findings indicate that while Europe may experience cooling, the tropics could warm significantly, exacerbating global warming effects. This study conflicts with the **IPCC's** assessment, which suggests a full AMOC collapse is unlikely within the century.

2. Potsdam Institute for Climate Impact Research (PIK) Study (2025)

Research from the **Potsdam Institute** indicates that under high-emission scenarios, the AMOC is likely to completely shut down **after 2100**. The study emphasizes a critical tipping point governed by a collapse of deep convection in the Labrador and Nordic Seas. As global temperatures rise, the atmosphere does not cool sufficiently, inhibiting vertical mixing in the ocean. This leads to lighter, less saline surface waters, which resist sinking, thereby weakening the AMOC. The researchers warn that the feedback loop created by these conditions could lead to a **complete AMOC shutdown**, shifting weather patterns globally and significantly affecting climate in northwestern Europe.

3. High-Emission Scenarios Simulation Studies (2025)

A recent examination of **CMIP6** simulations projected that the AMOC could weaken significantly by up to **43%** by the end of the century under extreme emission scenarios. This research shows that the AMOC's slowdown may occur within decades, with long-term implications for both regional and global climates. The models predict that AMOC collapse could lead to severe winters in Europe and drastic shifts in tropical rainfall patterns.

Summary of Findings

- **Collapse Timeline**: Research from 2023 suggests potential shutdown as early as **2025**, while other studies warn of shutdowns after **2100**.
- **Contributing Factors**: Rising temperatures and freshwater influx from melting ice affect the salinity and density of surface waters, exacerbating the weakening of AMOC.
- **Global Impact**: A shutdown will likely lead to more extreme winter conditions in Europe and disrupt global weather patterns.

These studies underscore the urgent need for action to reduce greenhouse gas emissions to mitigate the risks associated with AMOC disruption and subsequent climate instability.

In Summary

Chaos theory shows that weather forecasts lose skill beyond about two weeks; warming reduces this window. Evidence from ice cores reveals that during the last glacial period, Greenland warmed by 8–16 °C within a few decades during Dansgaard-Oeschger events.

These abrupt shifts, driven by changes in ocean circulation, particularly linked to the Atlantic Meridional Overturning , illustrate that the climate system can cross tipping points on decadal time-scales.

Although modern tipping elements like major ice sheets may take centuries to fully collapse, their onsets could be rapid, so early-warning research focuses on detecting attractor changes before thresholds are crossed.

From these findings, it is clear there is an elevated level of risk for disruption of human habitats due to accelerating onset of climate change.

References

- Latest study on ocean currents suggest tipping poi...cmscoms.com
- Possible North Atlantic overturning circulation sh...pik-potsdam.de
- High-emission scenarios show possible AMOC shutdow...Phys.org
- https://sustainability.stanford.edu/news/climate-chaos-why-warming-makes-weather-less-predictable
- https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch6s6-4-2.html#:~:text=Abrupt%20climate%20changes%20have%20been,Another%20type%20of%20abrupt
- https://catalyst-magazine.org/articles/greenland-and-our-rising-sea-levels/#:~:text=If%20all%20of%20Greenlands%20ice,sea%20levels%20by%207%20metres
- https://press.un.org/en/2023/sc15199.doc.htm#:~:text=including%20Cairo%2C%20Lagos%2C%20Maputo%2C%20Bangkok%2C,York%2C%20Buenos%20Aires%20and%20Santiago
- https://sealevel.nasa.gov/news/167/study-predicts-more-long-term-sea-level-rise-from-greenland-ice/#:~:text=The%20Greenland%20Ice%20Sheet%20is,Credit%3A%20NASA%20%2F%20Jefferson%20Beck

- https://arctic.noaa.gov/report-card/report-card-2024/greenland-ice-sheet-2024/#:~:text=Discharge%20of%20solid%20ice%20occurs,21
- https://www.antarcticglaciers.org/glaciers-and-climate/changing-greenland-ice-sheet/greenland-ice-sheet-mass-balance/#:~:text=Between%201992%20and%202018%2C%20the,fold%2C%20rising%20from%2034%20billion
- https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch6s6-4-2.html#:~:text=Abrupt%20climate%20changes%20have%20been,Another%20type%20of%20abrupt
- https://sustainability.stanford.edu/news/climate-chaos-why-warming-makes-weather-less-predictable