Key findings and recommendations from the H2020 projects on Tipping Points:

TiPES, COMFORT, TiPACCs

TIPPING POINTS IN THE EARTH SYSTEM

Our common future ocean in the Earth system

Tipping Points in Antarctic Climate Components

Background

We live today under the threat of imminent abrupt and irreversible transitions in the Earth system - especially tipping points of ice sheets, ocean circulation systems, rainforests, or monsoon systems, as well as ocean warming, acidification and deoxygenation, processes leading to fast and abrupt changes in marine ecosystems. This must be tackled urgently through political, economic, and societal action by reducing greenhouse gas (GHG) emissions and mitigating land-use change. The time window to address these issues is closing rapidly.

Considerable knowledge gaps remain concerning the processes underlying the dynamics of tipping elements, especially regarding uncertainties of their associated tipping points and the irreversibility, the couplings between them, and the associated risk of potential tipping cascades when one tipping element may trigger another one to shift into a new state. These knowledge gaps cascade to the identification of safe operating spaces and mitigation pathways needed to avoid large-scale tipping events.

Tipping-point:

"A level of change in system properties beyond which a system reorganises, often abruptly, and does not return to the initial state even if the drivers of the change are abated. For the climate system, it refers to a critical threshold when global or regional climate changes from one stable state to another stable state." [1]

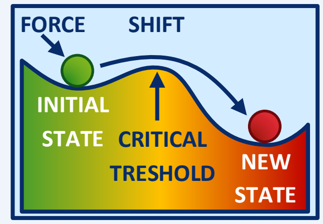


Figure1. Illustration of a shock-induced tipping point

Tipping Elements:

"Large-scale components of the Earth system that may pass a tipping point."[2]

Three Horizon2020 projects have been investigating tipping behaviour in the Earth system with a focus on (i) the underlying theory, empirical evidence, and how to model tipping behaviour in the Earth System (**TiPES**); ii) tipping points in marine systems, safe operating spaces and mitigation pathways (**COMFORT**), and iii) tipping points in Antarctic climate components (**TiPACCs**). In the following, we present the key findings to date from these projects. On that basis, we jointly formulate persisting knowledge gaps as well as policy recommendations.

Key Findings

- **New observational evidence for the destabilisation of major Earth system tipping elements** such as the Greenland Ice Sheet, the Atlantic Meridional Overturning Circulation (AMOC) and the Amazon rainforest [3-5]. These tipping elements have significantly lost stability in the last decades and have thus moved closer to critical thresholds at which they might tip.

- **Growing paleoclimate evidence for the possibility of crossing tipping points in the near future**. The quality, resolution, and spatial coverage of paleoclimate proxy records evidencing abrupt climate transitions during past climate conditions have increased strongly in recent years. Records from ice cores, mineral deposits in underground caverns and marine sediments leave little doubt that several components of the Earth system may respond with abrupt large-scale transitions to ongoing increases in atmospheric CO_2 concentrations [6-8].

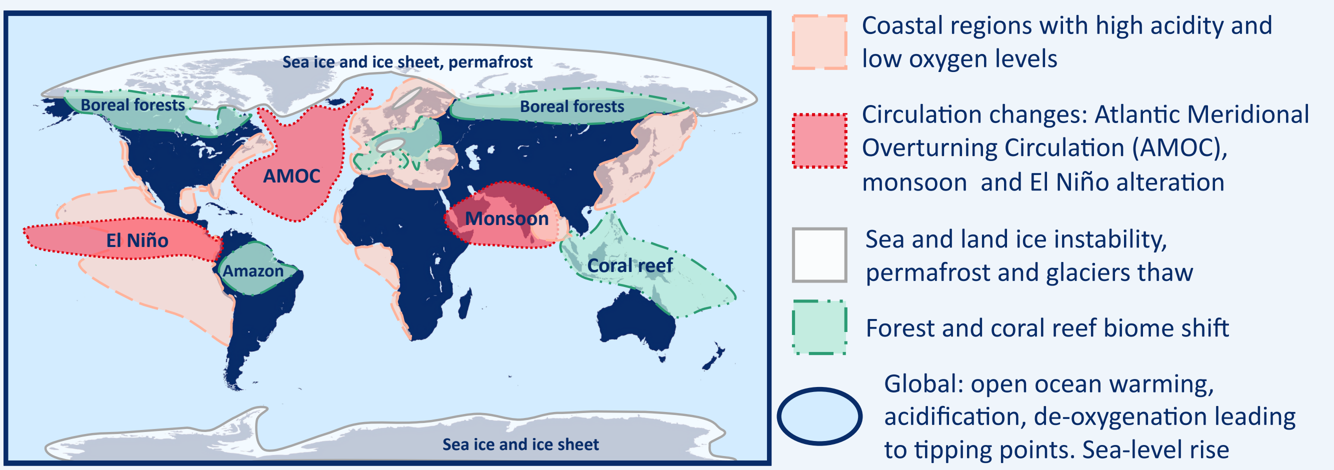
- **New generation of Earth System Models (ESMs) able to capture the dynamics of tipping elements**. Comprehensive ESMs are now capable of reproducing some abrupt climate transitions evidenced in paleoclimate proxy records, such as the abrupt desertification of the Sahara 6,000 years ago [9] or abrupt warming events during the last glacial [10]. New simulations show that a**tmospheric CO2 concentration is a key player in generating these warming events**.

- **Novel (never experienced) environmental conditions are expected to emerge in the next decades if the global climate is not kept below 2°C warming** [11-12]. Consequences include the decline of the catch potential of tropical fish stocks by up to 40% in 2050, covering regions currently responsible for 8% (by 2050) and 30% (by 2100) of global marine fisheries catch, under a high emission scenario (RCP 8.5) [13-17].

- **Extreme events such as marine heatwaves, and extreme events of acidification and de-oxygenation, separately or combined, will strongly increase in extent and frequency in future scenarios**. These may lead to reorganisations of ecosystems (regime shifts) through crossing shock-induced tipping points [18-19]. Reduced GHG emissions will lessen the extent and frequency of such events, and thus minimise the expected damage [19].

- Human-induced changes in ocean biogeochemistry conditions towards **warmer, low oxic, and more acidic environments** have consequences for many marine species such as fish and warm and cold-water corals [13-17,20-21]. Delayed mitigation will have a legacy effect since these altered conditions are partly irreversible during human life span and recovery can occur only on millenial to multi-millennial time scales [22]. GHG emissions reduction is not only needed urgently but is also the preferable mitigation pathway over carbon dioxide removal techniques [23].

Figure 2. Candidates for tipping elements



Please note that regions are only indicative, not precise.
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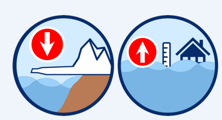
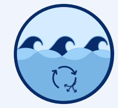
Greenland ice-sheet (GrIS) melting rates have accelerated non-linearly in recent decades and substantially enhanced melting is expected in the future, moving the GrIS closer to a critical threshold at which the ice sheet state is not maintainable. Mass reductions of the GrIS have substantial impacts on global sea level and the strength of the Atlantic Meridional Overturning Circulation (AMOC) [3].

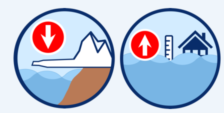


Observational evidence suggests that the AMOC has lost stability during the last century [4]. Modelling studies show that **not only the amount of warming but also the rate of warming determines if the AMOC collapses**, which is crucial in the context of anthropogenic climate change and in predicting future tipping events [25].

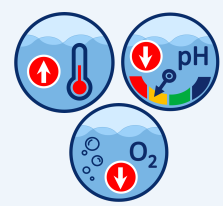


Deforestation and climate change, via increasing dry-season length and drought frequency, may already have pushed the Amazon close to a critical threshold of rainforest dieback. Empirical evidence reveals that the **Amazon rainforest has been losing resilience, risking dieback with profound implications for biodiversity, carbon storage and climate change on a global scale** [5].

Over the past decades, the Antarctic Ice Sheet has been losing mass at an accelerated rate. The Southern Ocean is changing, and relatively warm ocean waters have already reached some sectors of the Antarctic Ice Sheet, melting the ice shelves rapidly from below. If a tipping point is crossed triggering a shift of the coastal sea from a cold to a warm regime, an unstoppable collapse of the ice sheet can follow. This ocean-driven **collapse or unstoppable retreat of the Antarctic Ice Sheet has the potential to increase sea level by several metres worldwide**. [26-27]



Human-induced **warming, acidification, and lower oxygen levels** in the oceans increase the possibility of passing critical thresholds. Once crossed, physical, chemical, and biological, changes may result in food web reorganisations and regime shifts [28-29]. These **regime shifts, although regional, add up to a problem of global dimensions** [30].



Knowledge gaps

Comprehensive assessments of both the mechanisms and couplings underlying abrupt climate transitions, as well as of the overall hazards, exposures, and vulnerabilities associated with the crossing of tipping points, are urgently needed. In particular, we identify two key knowledge gaps:

Representing tipping behaviour in comprehensive Earth System Models

The critical forcing levels at which tipping elements such as the polar ice sheets, the Atlantic Meridional Overturning Circulation, or the Amazon rainforest, might tip to alternative states are unknown to a large extent. Observation-based evidence has shown that these subsystems have moved closer to such thresholds, but to determine the values of the thresholds and the associated uncertainties, comprehensive process-based models are urgently needed.

Progress has been made to further advance intermediate-complexity and comprehensive Earth System Models (including coupled ocean - ice sheet models) both in terms of their mathematical formulation and in terms of improving the implementation of physical, chemical, and biological processes. However, substantial further work is needed in order for these models to be able to accurately represent present-day / future tipping elements and to predict when the individual subsystems might cross tipping points for given scenarios of anthropogenic greenhouse gas emissions.

Marine tipping points

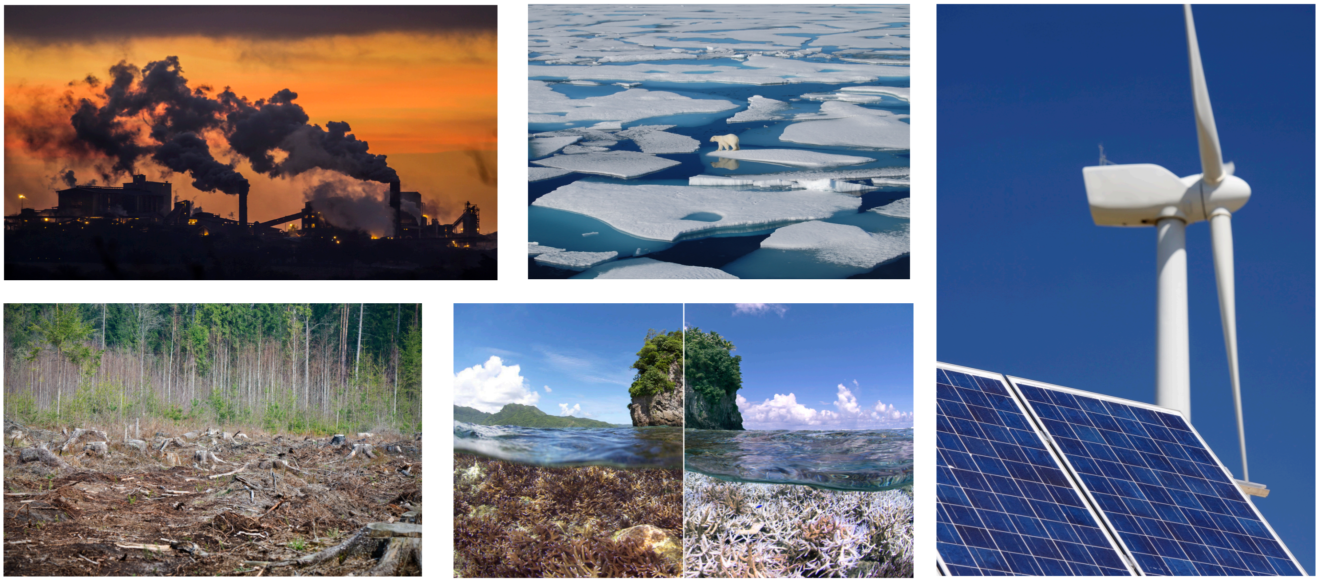
Assessments of the hazards associated with marine tipping points (examples given in Figure 2) require more research also in connection with biodiversity loss and other drivers such as global perturbations of the nitrogen cycle and plastic pollution.

More reliable projections of extreme events and their risk for shock-induced tipping points for marine ecosystems require both, higher-resolution Earth system models with improved representation of ecosystems as well as a better observational database concerning long time-series measurements both in-situ and remotely sensed.

Transdisciplinary research on feasible mitigation pathways toward limiting long-term adverse effects of climate change is needed to close a critical knowledge gap and to provide robust advice for future mitigations.

Policy recommendations

1. **A special report focussing on Tipping Points in the IPCC context is urgently needed** to synthesise existing knowledge across the different scientific communities and inform policy makers and the general public about the risks of crossing tipping points in response to anthropogenic climate change.
2. **Urgent implementation of a drastic reduction of GHG emissions**, which are the primary cause of global warming and ocean acidification, in order to avoid further stability loss of major Earth system tipping elements and long-lasting changes in ocean properties.
3. **Reduction of deforestation rates in both tropical and boreal forests** alongside efforts toward binding international agreements to limit land-use change to sustainable levels. A global satellite-based monitoring system should also be implemented to assess health of terrestrial ecosystems. At the same time, large-scale ecosystem protection and reforestation will help reduce atmospheric greenhouse gas concentrations globally and reduce drought risk regionally.
4. **Appropriate global resource management** needs to be implemented to achieve GHG emission reductions in line with the Paris Agreement, and to avoid problematic path dependencies and lock-in situations. Human societies must engage in the transformation towards i) green **energy** production, ii) sustainable exploitation and **food** production both on land and in the ocean, and iii) climate-friendly **land use and urban planning and development**.
5. **Climate-neutral transformations need to be achieved urgently**: there is already progress underway, such as the notable European Union Green Deal, including the goal to become climate neutral by 2050 supported by the ‘Restore our Ocean and Waters by 2030’ Mission, as well as the European Climate Pact. However, it is critical that these processes are accelerated to prevent the cumulative and compounding negative societal and Earth system impacts.



Implementation of a drastic reduction of GHG emissions and deforestation rates is needed urgently in order to avoid further stability loss of major Earth system tipping elements and long-lasting changes in ocean properties. Climate-neutral transformations and large-scale marine and land ecosystem protection and reforestation need to be achieved urgently.

H2020 projects in numbers

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Our common future ocean in the Earth system

Tipping Points in Antarctic Climate Components

www.tipes.dk | www.comfort-project.eu | www.tipaccs.eu

13 European countries, 3 non-EU countries

47 Research organisations

21.6M EUR EU funding

>200 Scientists

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