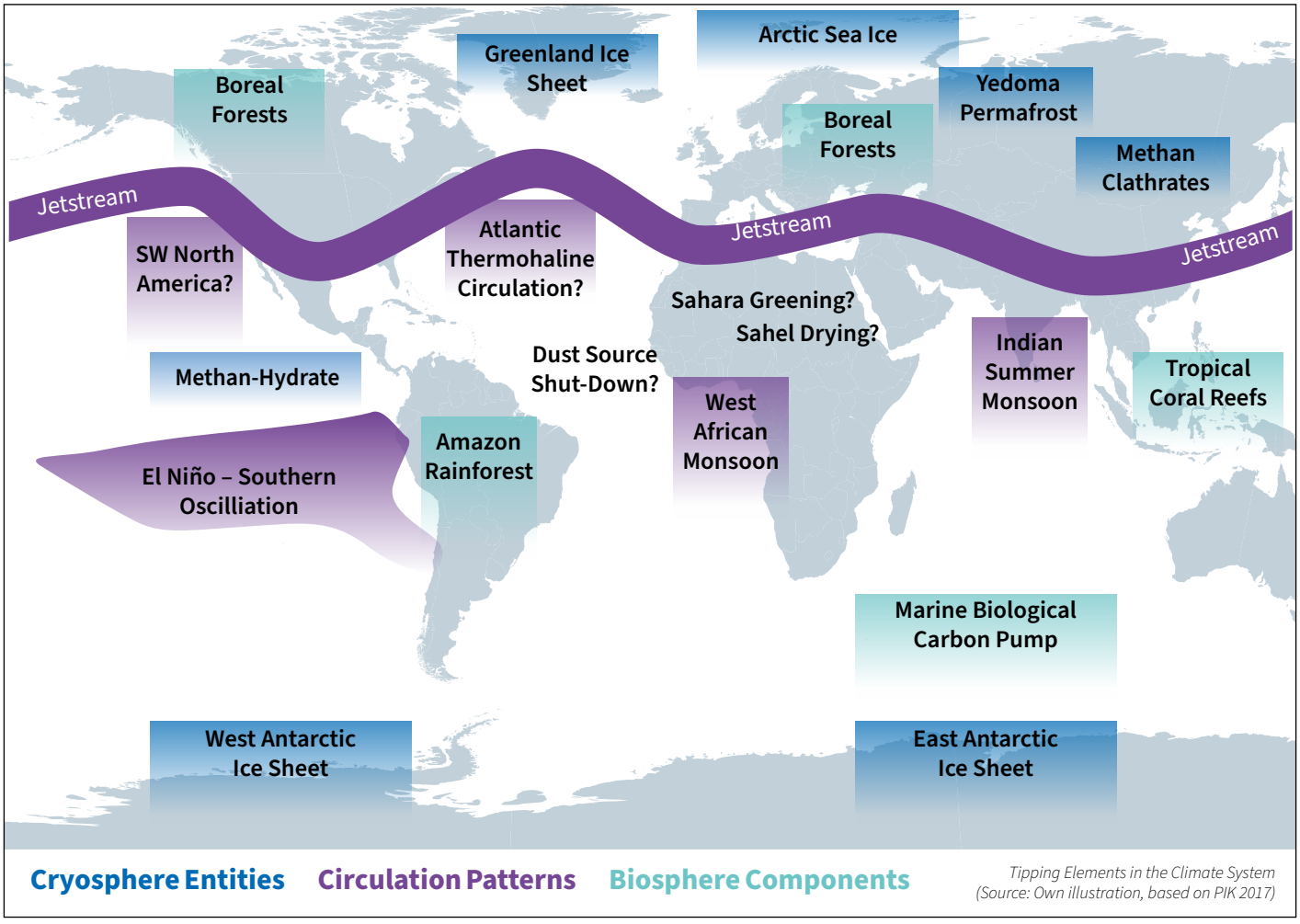
An early warning system for tipping points in the climate system

The climate crisis is already a reality: the latest Intergovernmental Panel on Climate Change (IPCC) reports clearly show how extreme weather events and slow-onset processes are putting human security at risk. Almost half of the world's population (3.3–3.6 billion people) is living in circumstances highly vulnerable to climate change impacts[1]. At the same time, sufficient and appropriate support for dealing with these impacts is lacking[2]. The recent World Meteorological Organisation (WMO) report, in fact, confirms this situation is worsening. The past seven years have been the warmest on record, and in 2021, the average global temperature was about 1.11°C (±0.13°C) above pre-industrial levels[3].

However, the increasing climate crisis' consequences are not developing linearly. Rather, over the medium and long term, a completely different magnitude of climate change consequences is emerging. If the thresholds within individual ecosystems, flow systems, or ice bodies are exceeded because of temperature rise (and other harmful effects due to human activity), they can 'tip' out of their original state. This sets in motion irreversible and often mutually reinforcing and accelerating developments, which can have massive consequences for individual regions, entire continents, and even globally[4]. The IPCC indicates particular tipping points could already be crossed between 1°C and 2°C of global warming[5]. Consequent-



Tipping Elements in the Climate System
(Source: Own illustration, based on PIK 2017)

01 IPCC (2022), S. 14.
02 For example, the IPCC identifies a gap in the management of climate risks and damages, for reasons such as an increasing discrepancy between the estimated costs of adaptation and the documented financial resources allocated to adaptation (ibid. p. 22). Insufficient funding hinders implementation of adaptation options, especially in developing countries (ibid. p. 28).
03 WMO (2022a).
04 Lenton, T. M. et al (2019).
05 IPCC (2018), IPCC (2019), Lenton, T. M. et al (2019).

ly, even achieving the Paris Agreement goal (limiting the global temperature increase to well below 2°C and preferably below 1.5°C) would not provide full security. This illustrates how greatly every 0.1°C of warming avoided counts for minimising risks and damages.

Concretely, a 0.8–3.2°C rise, for example, may trigger a tipping point for the Greenland Ice Sheet[6]. Even though scientific studies, modelling, and the interpretation of early warning indicators are increasing the possibility of narrowing down a precise tipping point, great uncertainty remains. This necessitates a regular review of the scientific status quo. Ultimately, sea level rise resulting from melting poses enormous risks to infrastructure, agricultural land, and cities in low-lying areas. Consequently, forced migration and displacement from flooded areas, immense economic damage, and possible conflicts threaten human security[7].

Outstanding scientific research is exploring tipping points' development and dynamics[8]. Systems have been found to change their behaviour when they approach a tipping point. Early warning indicators show this change. Interpreting the indicators can aid in achieving timely actions that help avoid crossing a tipping point. Lacking, however, is a systematic approach that translates the scientific research (with all the intrinsic uncertainty of these highly complex systems) into concrete recommendations. Also lacking are targeted calls for action for political decision-makers in affected countries and regions, as well as the international community.

An early warning system in the form of a regular report could fill this gap. Such a report should:

1. Regularly show which (sub-)systems have already advanced out of their balanced state and are evolving towards tipping points (essentially based on existing research)

2. Translate these research findings for assessing risks to humanitarian security (also focussed on different regions)

3. Make concrete proposals for early and timely action by different actors (regional, national, and international). This should prevent crossing of the corresponding tipping point, contain the magnitude or speed of the consequences of crossing, or prepare for dealing with expected consequences.

What are tipping points in the climate system?

Characteristics and challenges

As global warming intensifies, so does the risk of crossing tipping points. If a critical threshold, such as a temperature threshold, is exceeded, a barely controllable, often irreversible internal dynamic in tipping elements such as the Greenland Ice Sheet sets in. Such changes' impacts can be massive and continental in scale and imply extensive risks and consequences for human systems and, ultimately, human security. The scale, as well as the dynamics' irreversibility, indicates loss of control in influencing those developments.

Once a tipping point is crossed, in some systems, the chance of influencing the scale of consequences is very limited. In other tipping points, the extent of the consequences or speed of their occurrence can still be hugely influenced. The latter applies, for example, to the melting rate of the world's large ice sheets, which are highly sensitive to temperature increases. Here, 0.5°C of avoided temperature increase can shift the corresponding peak in sea level rise to hundreds of years later. Enhancing this period can be crucial for taking precautionary and preparatory measures to protect people.

Recent research has identified indicators of tipping points being more likely to be crossed than previously thought, and that these are often feedback with each other, potentially

06 Boers et al (2021).
07 IPCC (2022) S.11; Joint statement on climate change and conflict in IPCC report (2022).
08 Such as scientists from the Potsdam Institute for Climate Impact Research, Stockholm University Resilience Centre, University of Exeter, University of Colorado Boulder and others.

exposing the Earth to long-term, irreversible changes in the near future[9].

An early warning system offers the chance to avoid major risks or to gain time to prepare for the consequences of crossing tipping points. This can happen even with remaining uncertainties in concretely determining the critical thresholds that cause the corresponding systems to tip, as well as regarding the time remaining until that occurs.

Findings of theories of complex systems and analysing critical thresholds and corresponding signals in past events (e.g. from previous geological eras) can play a significant role[10] in building an early warning system for tipping points. However, it is vital that these findings are also translated into concrete proposals for action to prevent or mitigate humanitarian security risks. Forward-looking risk management is a key focus here.

In many cases, 'compound risks' – i.e. the interaction of climatic and non-climatic factors – are critical, especially regarding possible human influence, such as with global temperature rise and deforestation in the Amazon rainforest. Behavioural changes in different areas (climate protection and halting of deforestation) can thus reduce risks and prevent crossing of tipping points.

West Antarctic Ice Sheet

The West Antarctic Ice Sheet is in danger of becoming unstable because of its location and condition, as well as global temperature rise[11]. Exceeding a threshold could lead to an irreversible retreat of individual glaciers, and thus to the ice sheet's collapse or even complete melting. There are increasing indications that such a process may have already begun[12]. The Pine Island and Thwaites Glaciers' size makes them particularly important. Together, they account for about 10% of the current global sea level rise[13].

A 2021 study showed for the first time that a critical threshold may have already been exceeded for the former. The study researchers modelled the glacier's melt and ice flow, which are early warning indicators of the onset of ice sheet instability ('critical slowing down'), and calculated tipping points at which ice loss could be irreversible. Their calculations showed a ~1.2°C warming of the ocean water leads to the entire glacier's retreat, which could trigger the collapse of the whole West Antarctic Ice Sheet[14].

Recent research also shows the Thwaites Glacier in rapid retreat. The warming ocean is causing the glacier to melt from below, accelerating runoff and leading to instability through fractures and cracks. This situation threatens to collapse the glacier and destabilise large parts of the West Antarctic Ice Sheet[15]. The glacier's collapse and that of the ice sheet would lead to global sea level rise of more than three metres[16] over a long period – centuries to millennia.

Resulting humanitarian risks for millions of people in coastal areas and cities – from flooding of entire areas to coastal regions becoming inhabitable – could result. However, for these consequences and adaptation options, it is highly relevant that the time scale and, thus, the speed of melting can still be influenced.[17] At 1.5°C global warming, it could take 10,000 years;[18] at >2°C, it could be <1,000 years.[19]

09 IPCC (2019).
10 Scheffer, M. et al (2009).
11 Weertman, J. (1974).
12 Favier, Lionel, et al. (2014), Joughin, I. et al (2014), Mouginot, J. et al (2014), IPCC (2019).
13 Northumbria University Newcastle (2021).
14 Rosier, S.H.R. et al (2021).
15 Alley et al (2021).
16 Fretwell et al. (2013), Feldmann et al (2015).
17 Lenton, T. et al (2019), CIRES (2022).
18 Ebd.
19 Aschwanden, A. et al. (2019).

The Amazon rainforest

In the Amazon rainforest, the compound risks of global warming and human activities such as massive deforestation are leading to a vicious circle of destabilisation. There are signs the Amazon is already nearly crossing its tipping point from rainforest to savannah. One indicator is that parts of the forest in 2010–2019 emitted more carbon dioxide than they absorbed[20]. In other words, they changed from a carbon sink to a carbon source in this period; an outcome that earlier research indicated was not expected until the year 2050.[21] Estimates of exactly where the threshold lies for the rainforest to turn into a savannah range from 20–40% deforestation.[22] A temperature rise of just over 3°C is also considered a tipping point.[23] Research indicated that about 17–19% of the forest cover has been lost since 1970, when large-scale deforestation began.[24] A tipping point could therefore be imminent. Research has also shown that over three-quarters of the forest has lost resilience since the early 2000s due to increased drought as well as increased land use, further promoting dieback.[25]

Crossing the tipping point would bring massive impacts. In addition to biodiversity loss, (10% of the world's known species are native to this area), large amounts of carbon would be released into the atmosphere. One of the world's central carbon stores would be destroyed, immensely fuelling climate change at a global scale. The Paris Climate Agreement's goals would become far out of reach.

Concrete humanitarian risks also exist at the regional level. The Amazon rainforest powerfully influences the regional (as well as supra-regional to global) water cycle. This is because huge amounts of water originate from it. These, in the form of rain clouds that serve as `flying rivers,' influence precipitation volume throughout South America. Its collapse would dramatically impact the region's water supply and thus its agriculture, food production, and energy generation.

Functions and objectives of an early warning system

An early warning system would do the following.

1. Translate scientific findings into policy recommendations, take account of new findings at the earliest possible stage, and prevent policy action delays

2. Formulate concrete recommendations for action to be taken to:

- Prevent crossing of the tipping point (through accelerated climate protection and further measures)
- Limit the speed and scale of subsequent processes and consequences to the extent possible after the tipping point is crossed
- Prepare for dealing with possible consequences of exceeding the tipping point (with the most effective adaptation and risk management measure possible, including development of contingency plans)
- Assess the humanitarian security risks associated with crossing the tipping point, as well as risks of conflict and war
- Close gaps in climate protection, adaptation, and dealing with climate-related loss and damage, as well as comprehensive climate, foreign, and security policy strategies that go beyond this

3. Illustrate the significance of tipping points and their consequences

4. Facilitate cooperation amongst different disciplines and regional linkages

5. Generate overall global public awareness of the risks and options for action regarding tipping points

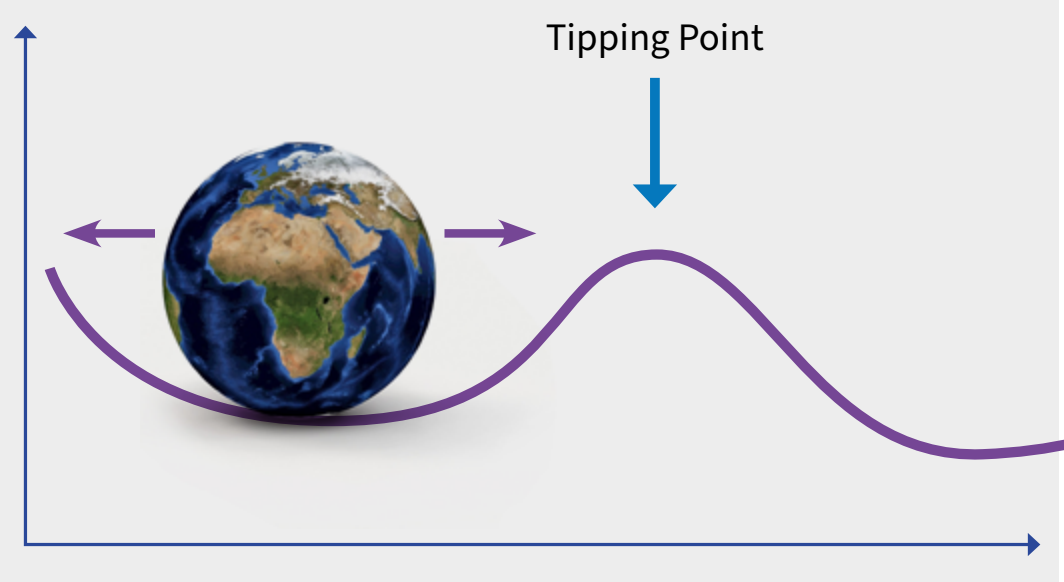
6. Contribute to (human) security

20 Qin, Y. et al (2021).
21 Cox PM et al (2000).
22 Lovejoy, T. E. et al (2018).
23 Schellnhuber et al (2016).
24 Lenton, T. et al (2019), Amigo, I. (2020).
25 Boulton, C.A. et al (2022).

A report for regular review

A regular, annually updated report would act as an early warning system for tipping points. It should provide a comprehensive overview of the state of scientific knowledge and translate it into proposals for effective and timely action. In this way, it can help inform policymakers on the latest findings on subsystems that are advancing towards tipping points. This can ensure that new findings with indications of the speed of change are not overlooked.

This report, complementary to the IPCC's Assessment Reports and Special Reports, should formulate concrete policy recommendations with a specific focus on tipping points. This should go beyond the IPCC mandate, which is to prepare information for decision-makers though does not permit the formulation of recommendations. In addition to the state of research, the report should compile information on the expected region-specific (socio-economic) consequences and risks and scope of action that crossing of tipping points would trigger, including continually updated probabilities and possible time scales for global and regional action. Recommendations for action should be made (see functions) based on this information.



These recommendations should address foreign, security, and climate policy actors at different levels and be tailored to their fields of action. The early warning system would support and complement existing calls for improvements in the climate security architecture. For example, the call for a United Nations Climate Emergency Plan[26] or call by the United Nations Security Council's Group of Friends on Climate and Security for systematic strengthening of awareness of the security policy implications of climate change, including through a regular report by the UN Secretary-General with a focus on country- or region-specific contexts.[27] There are also synergies with the joint statement of more than a dozen leaders from the fields of climate science, peace-building and security, policy-making, and implementing programmes.[28]

Their demands and proposals focus on an effective fight against climate change and efforts to prevent or respond meaningfully to conflicts in order to mitigate future loss and damage while promoting peace and stability. The early warning system for tipping points can work together here concretely with the call for locally informed climate (security) risk assessments (the results of which are to be made usable for various early warning systems) in development cooperation and peace-building operations.[29] Here, the focus on the greatest risks – the tipping points – would quite effectively complement the other important focus, on particularly vulnerable regions.

The G7 also recently recognised crossing tipping points' threat of destabilising affected regions, and the need for scientific studies and scenario planning, as crucial elements of preventive and climate-sensitive climate and foreign policy.[30]

26 E3G/Born, C. (2019).
27 Auswärtiges Amt (2021).
28 Joint statement on climate change and conflict in IPCC report (2022) (im Kontext des Projektes „Weathering Risk").
29 Ebd.
30 Auswärtiges Amt (2022).

Institutional linkages

In addition to its international anchoring, the early warning system should operate at various political levels. This operation should include the following and other institutions:

Global:
Including the United Nations General Assembly, United Nations Security Council (UNSC), including its informal Expert Group on Climate and Security of Members of the United Nations Security Council (IEG) and its Group of Friends for Climate and Security, United Nations Climate Security Mechanism (CSM), United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA), World Food Programme (WFP), United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP), United Nations Framework Convention on Climate Change (UNFCCC), United Nations High Commissioner for Refugees (UNHCR)

Regional
Including the EU Foreign Affairs Council, Organization for Security and Co-operation in Europe (OSCE),[31] Alliance of Small Island States (AOSIS), Peace and Security Council (PSC) of the African Union, Council of Foreign Ministers of the Union of South American States (UNASUR Consejo de Ministras y Ministros de Relaciones), Meeting of the Consultation of Ministers of Foreign Affairs of the Organization of American States (OAS), ASEAN Foreign Ministerial Meetings (AMM)/ASEAN Political-Security Community (APSC)

National
Including ministries of foreign affairs, environment, climate, finance, economy, and interior; and where existing, national crisis mechanisms/personnel and national scientific advisory councils

Next steps

1) **Identify research gaps,** including on (a) the current risk of crossing important tipping points or the possibility of limiting the dramatic consequences through timely action after crossing; (b) comprehensive information on concrete region-specific climatic, physical, and socio-economic consequences in case tipping points are crossed; (c) concrete impacts on human systems and human security; and (d) timely response options at the regional and global levels.

2) **Develop concrete design** of an appropriate body, with clear synergies with existing institutions, instruments, programmes, and projects, along with its institutional linkage and mandate.

31 Building on Decision No. 3/21 - Strengthening cooperation to address the challenges posed by climate change: https://www.osce.org/files/f/documents/6/0/508592_0.pdf.

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References

Amigo, I. (2020): When will the Amazon hit a tipping point? The Amazon´s fragile future. In: Nature, Vol 578: https://www.nature.com/articles/d41586-020-00508-4 /.

Aschwanden, A.; Fahnestock, M.A.; Truffer, M.; Brinkerhoff, D.J.; Hock, R.; Khroulev, C.; Mottram, R.; Abbas Khan, S. (2019): Contribution of the Greenland Ice Sheet to sea level over the next millennium. In: Sci. Adv. 5, eaav9396.

Alley, K. E.; Wild, C. T.; Luckman, A.; Scambos, T. A.; Truffer, M.; Pettit, E. C.; Muto, A.; Wallin, B.; Klinger, M.; Sutterley, T.; Child, S. F.; Hulen, C.; Lenaerts, J. T. M.; Maclennan, M.; Keenan, E.; Dunmire, D. (2021): Two decades of dynamic change and progressive destabilization on the Thwaites Eastern Ice Shelf. In: The Cryosphere, 15, 5187–5203, https://doi.org/10.5194/tc-15-5187-2021; https://tc.copernicus.org/articles/15/5187/2021/#abstract.

Auswärtiges Amt (2021): Rede von Außenminister Heiko Maas im Namen der Freundesgruppe „Klima und Sicherheit“ in der offenen Debatte des VN-Sicherheitsrats zum Thema Klima und Sicherheit; https://www.auswaertiges-amt.de/de/newsroom/maas-uno-klima-und-sicherheit/2443838.

Auswärtiges Amt (2022): G7 Foreign Ministers Communique; https://www.auswaertiges-amt.de/en/newsroom/news/-/2531266.

Boers, N.; Rypdal, M. (2021): Critical slowing down suggests that the western Greenland Ice Sheet is close to a tipping point. In: Proceedings of the National Academy of Sciences, Vol. 118, No. 21 e2024192118; https://doi.org/10.1073/pnas.202419211.

Boulton, C.A.; Lenton, T.M.; Boers, N. (2022): Pronounced loss of Amazon rainforest resilience since the early 2000s. In: Nature Climate Change 12, S. 271–278, https://doi.org/10.1038/s41558-022-01287-8; https://www.nature.com/articles/s41558-022-01287-8.

CIRES (Cooperative Institute for Research in Environmental Sciences at the University of Colorado Boulder) (2021): Pressemitteilung 13.12.2021: The Threat from Thwaites: The Retreat of Antarctica’s Riskiest Glacier; https://cires.colorado.edu/news/threat-thwaites-retreat-antarctica%E2%80%99s-riskiest-glacier

CIRES (2022) – Statement added to Pressrelease “The Threat from Thwaites: The Retreat of Antarctica’s Riskiest Glacier” (31.01.2022): https://cires.colorado.edu/news/threat-thwaites-retreat-antarctica%E2%80%99s-riskiest-glacier)

Cox, PM; Betts, RA; Jones, CD, Spall, SA, Totterdell, IJ (2000): Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. In: Nature. Nov 9; 408(6809):184-7. doi: 10.1038/35041539. PMID: 11089968. https://pubmed.ncbi.nlm.nih.gov/11089968/.

E3G/Born, Camilla (2019): The UN needs a Climate Emergency Plan, Briefing Paper, E3G; https://avaazmedia.s3.amazonaws.com/E3G%20Briefing_UN%20Climate%20Emergency%20Plan.pdf.

Favier, L.; Durand, G.; Cornford, S.L.; Gudmundsson, G.H.; Gagliardini, O.; Gillet-Chaulet, F.; Zwinger, T.; Payne, A.J.; Le Brocq, A.M. (2014): “Retreat of Pine Island Glacier controlled by marine ice-sheet instability.” Nature Climate Change 4.2: 117-121.

Feldmann, J.; Levermann, A. (2015), Collapse of the West Antarctic Ice Sheet after local destabilization of the Amundsen Basin. In: Proceedings of the National Academy of Sciences USA 112, 14191–14196.

IPCC (2018): Masson-Delmotte, V.;Zhai, P.; Pörtner,H.-O.; Roberts, D.; Skea, J.; Shukla, P.R.; Pirani, A.; Moufouma-Okia, W.; Péan, C.; Pidcock, R.; Connors, S.; Matthews, J.B.R.; Chen, Y.; Zhou, X.; Gomis, M.E.; Lonnoy, E.; Maycock, T.; Tignor, M.; Waterfield, T. (eds.): Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, Summary for Policymakers. Cambridge University Press. In Press https://www.ipcc.ch/sr15/.

IPCC (2019): Pörtner, H.-O.;Roberts, D.; Masson-Delmotte, V.; Zhai, P.; Tignor, M.; Poloczanska, E.; Mintenbeck, K.; Alegría, A.; Nicolai, M.; Okem, A.; Petzold, J.; Rama, B.; Weyer, N. (eds.): IPCC Special Report on the Ocean and Cryosphere in a Changing Climate, Summary for Policymakers. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–35. https://doi.org/10.1017/9781009157964.00: https://www.ipcc.ch/srocc/.

IPCC (2022): Pörtner, H.-O.; Roberts, D.C.; Poloczanska, E.S.; Mintenbeck, K.; Tignor, M.; Alegría, A.; Craig, M.; Langsdorf, S.; Löschke, S.; Möller, V.; Okem, A. (eds.): Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Summary for Policymakers. Cambridge University Press. In Press, https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_SummaryForPolicymakers.pdf

Joint statement on climate change and conflict in IPCC report (2022): signed by Abdenur, Adriana Erthal; Brady, Cynthia; Carius, Alexander; Day, Adam; Edenhofer, Ottmar; Ero, Comfort; Gilmour, Andrew; Huq, Saleemul; Keating, Michael; Läderach, Peter; Ischinger, Wolfgang; Maunganidze, Ottilia Anna; Middendorp, Tom; Nugee, Richard; Pasisi, Coral; Tubiana, Laurence; Rockström, Johan; Fan, Shenggen; Hodder, Christophe; Berti, Benedetta, Institute for Security Studies: https://www.weatheringrisk.org/en/event/IPCC-Climate-Conflict-Joint-Statement#_edn3

Joughin, I.; Smith, B.E.; Medley, B. (2014) "Marine ice sheet collapse potentially under way for the Thwaites Glacier Basin, West Antarctica." Science 344.6185: 735-738.

Lenton, T. M.; Held, H; Kriegler, E.; Hall, J.; Lucht, W.; Rahmsdorf, S.; Schllenhuber, H.J. (2008): Tipping elements in the Earth's climate system. In: Proceedings of the National Academy of Sciences USA 105, 1786–1793.

Lenton, T. M.; Rockström, J.; Gaffney, O.; Rahmstorf, S.; Richardson, K.; Steffen, W.; Schellnhuber, H. J. (2019): Climate tipping points — too risky to bet against. In: Nature, Vol 575; https://www.nature.com/articles/d41586-019-03595-0

Lovejoy, T.E; Nobre, C. (2018): Amazon Tipping Point. Sciences Advances4, eaat2340; https://www.science.org/doi/pdf/10.1126/sciadv.aat2340

Mouginot, J., Rignot, E.; Scheuchl, B. (2014): "Sustained increase in ice discharge from the Amundsen Sea Embayment, West Antarctica, from 1973 to 2013." Geophysical Research Letters 41.5: 1576-1584

Northumbria University Newcastle (2021): Pressemitteilung: Evidence of Antarctic glacier's tipping point confirmed for first time (01.04.2021): https://www.northumbria.ac.uk/about-us/news-events/news/antarctic-tipping-point/

Qin, Y., Xiao, X., Wigneron, JP. (2021) : Carbon loss from forest degradation exceeds that from deforestation in the Brazilian Amazon. Nature Climate Change 11, 442–448 (2021). https://doi.org/10.1038/s41558-021-01026-5; https://www.nature.com/articles/s41558-021-01026-5#citeas.

Rosier, S. H. R., Reese, R., Donges, J. F., De Rydt, J., Gudmundsson, G. H., and Winkelmann, R. (2021): The tipping points and early warning indicators for Pine Island Glacier, West Antarctica. In: The Cryosphere, 15, 1501–1516, https://doi.org/10.5194/tc-15-1501-2021, https://tc.copernicus.org/articles/15/1501/2021/.

Scheffer, M., Bascompte, J., Brock, W. (2009).: Early-warning signals for critical transitions. Nature 461, 53–59. https://doi.org/10.1038/nature08227; https://www.nature.com/articles/nature08227.

Schellnhuber, H.J.; Rahmstorf, S.; Winkelmann, R. (2016): Why the right climate target was agreed in Paris. In: Nature Climate Change, Vol 6, July.

WBGU (2007): Welt im Wandel - Sicherheitsrisiko Klimawandel. Springer, Berlin, Heidelberg, New York, S. 77. http://www.wbgu.de/wbgu_jg2007.html.

Weertman, J. (1974): Stability of the Junction of an Ice Sheet and an Ice Shelf, J. Glaciol., 13, 3–11, https://doi.org/10.3189/S0022143000023327, 1974.

WMO (2022a): State of the Global Climate in 2021, WMO-No. 1290: https://library.wmo.int/doc_num.php?explnum_id=11178.

WMO (2022b): Press release "Four key climate change indicators break records in 2021" https://public.wmo.int/en/media/press-release/four-key-climate-change-indicators-break-records-2021.