Tipping elements in the Earth's climate system

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Anthropogenic forcing could push the Earth's climate system past critical thresholds, so that important components may "tip" into qualitatively different modes of operation. In the renowned magazine *Proceedings of the National Academy of Sciences* (PNAS) an international team of researchers describes, where small changes can have large long-term consequences on human and ecological systems.

"Society may be lulled into a false sense of security by smooth projections of global change," the researchers around Timothy Lenton from the British University of East Anglia in Norwich and Hans Joachim Schellnhuber from the Potsdam Institute for Climate Impact Research report. Global change may appear to be a slow and gradual process on human scales. However, in some regions anthropogenic forcing on the climate system could kick start abrupt and potentially irreversible changes. For these sub-systems of the Earth system the researchers introduce the term “tipping element”.

Drawing on a workshop of 36 leading climate scientists in October 2005 at the British Embassy, Berlin, Germany, a further elicitation of 52 experts in the field, and a review of the pertinent literature, the authors compiled a short-list of nine potential tipping elements. These tipping elements are ranked as the most policy-relevant and require consideration in international climate politics.

Arctic sea-ice and the Greenland Ice Sheet are regarded as the most sensitive tipping elements with the smallest uncertainty. Scientists expect ice cover to dwindle due to global warming. The West Antarctic Ice Sheet is probably less sensitive as a tipping element, but projections of its future behavior have large uncertainty. This also applies to the Amazon rainforest and Boreal forests, the El Niño phenomenon, and the West African monsoon. “These tipping elements are candidates for surprising society by exhibiting a nearby tipping point,” the authors state in the article that is published in PNAS Online Early Edition. The archetypal example of a tipping element, the Atlantic thermohaline circulation, could undergo a large abrupt transition with up to ten percent probability within this century, according to the UN climate report from 2007.

Given the scale of potentially dramatic impacts from tipping elements the researchers anticipate stronger mitigation. Concepts for adaptation that go beyond current incremental approaches are also necessary. In addition, “a rigorous study of potential tipping elements in human socio-economic systems would also be welcome,” the researchers write. Some models suggest there are tipping points to be passed for the transition to a low carbon society.

Highly sensitive tipping elements, smallest uncertainty

Greenland Ice Sheet - Warming over the ice sheet accelerates ice loss from outlet glaciers and lowers ice altitude at the periphery, which further increases surface temperature and ablation. The exact tipping point for disintegration of the ice sheet is unknown, since current models cannot capture the observed dynamic deglaciation processes accurately. But in a worst case scenario local warming of more than three degrees Celsius could cause the ice sheet to disappear within 300 years. This would result in a rise of sea level of up to seven meters.

Arctic sea-ice - As sea-ice melts, it exposes a much darker ocean surface, which absorbs more radiation than white sea-ice so that the warming is amplified. This causes more rapid melting in summer and decreases ice formation in winter. Over the last 16 years ice cover during summer declined markedly. The critical threshold global mean warming may be between 0.5 to 2 degrees Celsius, but could already have been passed. One model shows a nonlinear transition to a potential new stable state with no arctic sea-ice during summer within a few decades.

Intermediately sensitive tipping elements, large uncertainty

West Antarctic Ice Sheet - Recent gravity measurements suggest that the ice sheet is losing mass. Since most of the ice sheet is grounded below sea level the intrusion of ocean water could destabilize it. The tipping point could be reached with a local warming of five to eight degrees Celsius in summer. A worst case scenario shows the ice sheet could collapse within 300 years, possibly raising sea level by as much as five meters.

Boreal forest - The northern forests exhibit a complex interplay between tree physiology, permafrost and fire. A global mean warming of three to five degrees Celsius could lead to large-scale dieback of the boreal forests within 50 years. Under climate change the trees would be exposed to increasing water stress and peak summer heat and would be more vulnerable to diseases. Temperate tree species will remain excluded due to frost damage in still very cold winters.

Amazon rainforest - Global warming and deforestation will probably reduce rainfall in the region by up to 30 percent. Lengthening of the dry season, and increases in summer temperatures would make it difficult for the forest to re-establish. Models project dieback of the Amazon rainforest to occur under three to four degrees Celsius global warming within fifty years. Even land-use change alone could potentially bring forest cover to a critical threshold.

El Niño Southern Oscillation (ENSO) – The variability of this ocean-atmosphere mode is controlled by the layering of water of different temperatures in the Pacific Ocean and the temperature gradient across the equator. During the globally three degrees Celsius warmer early Pliocene ENSO may have been suppressed in favor of persistent El Niño or La Niña conditions. In response to a warmer stabilized climate, the most realistic models simulate increased El Niño amplitude with no clear change in frequency.

Sahara/Sahel- and West African monsoon - The amount of rainfall is closely related to vegetation climate feedback and sea surface temperatures of the Atlantic Ocean. Greenhouse gas forcing is expected to increase Sahel rainfall. But a global mean warming of three to five degrees Celsius could cause a collapse of the West African monsoon. This could lead either to drying of the Sahel or to wetting due to increased inflow from the West. A third scenario shows a possible doubling of anomalously dry years by the end of the century.

Indian summer monsoon - The monsoon circulation is driven by a land-to-ocean pressure gradient. Greenhouse warming tends to strengthen the monsoon since warmer air can carry more water. Air pollution and land-use that increases the reflection of sunlight tend to weaken it. The Indian summer monsoon could become erratic and in the worst case start to chaotically change between an active and a weak phase within a few years.

Lowly sensitive tipping elements, intermediate uncertainty

Atlantic thermohaline circulation - The circulation of sea currents in the Atlantic Ocean is driven by seawater that flows to the North Atlantic, cools and sinks at high latitudes. If the inflow of freshwater increases, e.g. from rivers or melting glaciers, or the seawater is warmed, its density would decrease. A global mean warming of three to five degrees Celsius could push the element past the tipping point so that deep water formation stops. Under these conditions the North Atlantic current would be disrupted, sea level in the North Atlantic region would rise and the tropical rain belt would be shifted.

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