Tipping elements in the Earth's climate system

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Arctic Sea-Ice.

As sea-ice melts, it exposes a much darker ocean surface, which absorbs more radiation–amplifying the warming. Energy-balance models suggest that this ice-albedo positive feedback can give rise to multiple stable states of sea-ice (and land snow) cover, including finite ice cap and ice-free states, with ice caps smaller than a certain size being unstable (13). This small ice-cap instability is also found in some atmospheric general circulation models (AGCMs), but it can be largely eliminated by noise due to natural variability (14). The instability is not expected to be relevant to Southern Ocean sea-ice because the Antarctic continent covers the region over which it would be expected to arise (15). Different stable states for the flow rate through the narrow outlets that drain parts of the Arctic basin have also been found in a recent model (16). For both summer and winter Arctic sea-ice, the area coverage is declining at present (with summer sea-ice declining more markedly; ref. 17), and the ice has thinned significantly over a large area. Positive ice-albedo feedback dominates external forcing in causing the thinning and shrinkage since 1988, indicating strong nonlinearity and leading some to suggest that this system may already have passed a tipping point (18), although others disagree (19). In IPCC projections with ocean-atmosphere general circulation models (OAGCMs) (12), half of the models become ice-free in September during this century (19), at a polar temperature of −9°C (9°C above present) (20). The transition has nonlinear steps in many of the models, but a common critical threshold has yet to be identified (19). Thinning of the winter sea-ice increases the efficiency of formation of open water in summer, and abrupt retreat occurs when ocean heat transport to the Arctic increases rapidly (19). Only two IPCC models (12) exhibit a complete loss of annual sea-ice cover under extreme forcing (20). One shows a nonlinear transition to a new stable state in <10 years when polar temperature rises above −5°C (13°C above present), whereas the other shows a more linear transition. We conclude that a critical threshold for summer Arctic sea-ice loss may exist, whereas a further threshold for year-round ice loss is more uncertain and less accessible this century. Given that the IPCC models significantly underestimate the observed rate of Arctic sea-ice decline (17), a summer ice-loss threshold, if not already passed, may be very close and a transition could occur well within this century.

RANKING THE THREAT.

We conclude that the greatest (and clearest) threat is to the Arctic with summer sea-ice loss …