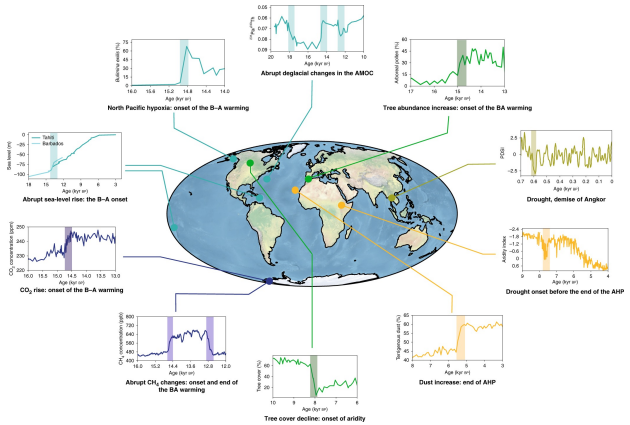
Evidence for Abrupt Changes, Tipping Points & Cascading Impacts in the Earth System

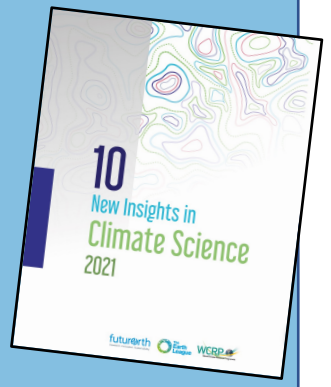
The geological record shows that warming temperatures can lead to disintegration of ice sheets, permafrost thaw, slowdown of ocean circulation, forest dieback, and ocean deoxygenation. These abrupt changes can occur on timescales short enough to challenge society's capacity to adapt. Geologic archives like ice and sediment cores provide a test-bed for understanding abrupt changes or tipping points in the past 20,000 years. Here we synthesize paleo-records to illustrate the cascading impacts of abrupt change in cryosphere-ocean interactions and hydroclimate variability on ecological and societal systems. We review useful indicators of upcoming abrupt changes or early warning signals from observations.



➢ **The paleo record provides evidence of the climate system's capacity to abruptly change between one stable state to another in atmospheric (purple), oceanographic (blue), ecological (green), and societal (lt. green) domains.**

Volcanic Eruption → Abrupt Cooling → Famine and societal reorganization

➢ Abrupt change can trigger impacts that cascade through coupled climate-ecological-social systems. E.g. volcanic eruptions were probably responsible for abrupt cooling in the sixth century that led to famine and societal reorganization in Europe (transformation of the eastern Roman Empire) and Asia (rise of the Arabic Empire).



➢ Significant destabilization of several key climate tipping elements is already observed today.

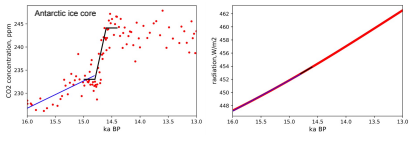
➢ The dominant driver of destabilization in many cases is global warming. But human influence on land cover change, such as deforestation/forest degradation, can play an equal or even stronger role.

➢ Some tipping elements influence each other, for example melting ice sheets and changes to ocean currents. Interactions among tipping elements can ultimately cause shifts to happen at lower levels of global warming than anticipated.

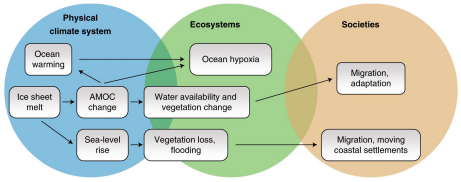
➢ See full policy report: https://10insightsclimate.science

Cascading impacts of cryosphere - ocean interactions

➢ *Slow forcing rapid response: Rapid increase in CO_2/CH_4*



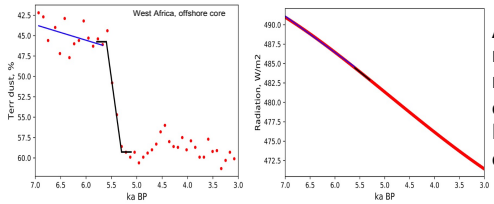
The abruptness of change in atmospheric CO_2 (left panel) relative to the orbital forcing (right panel) illustrates a threshold response to slowly varying orbital forcing.



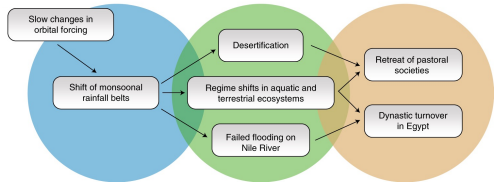
The strengthening of ocean circulation, rapid sea-level rise from icesheet melt, and abrupt increase in GHG led to abrupt changes that cascaded through the Earth system.

Cascading impacts of hydroclimate variability

➢ *Slow forcing rapid response: Fast reduction in rainfall*



Abrupt, local-scale declines in rainfall (left panel) occurred in response to the southward retreat of the monsoon rainfall belts in North Africa mainly related to orbital changes (right panel).



Shifts in rainfall impacted agricultural societies dependent on land productivity. Pre-existing vulnerabilities created by societal dynamics determined a society's ability to adapt to hydroclimatic changes.

➢ The complex picture of feedbacks and linkages between Earth system components calls for a synthesis of data during periods of abrupt changes. Constraining Earth system models to better simulate past abrupt changes is a joint task for modellers and data-gatherers.

Conclusion

➢ Abrupt changes over the last 20,000 years show how tipping points, preceded by early warning signals, could occur in future.

➢ It is essential to improve our knowledge of the precursors of abrupt change, for example, through a thorough analysis of paleo-environmental records of improved precision, resolution, spatial coverage and reproducibility.

References

Brovkin, V., et al. (2021). Past abrupt changes, tipping points and cascading impacts in the Earth system. Nature Geoscience, doi: 10.1038/s41561-021-00790-5.

Martin, M., et al. (2021). Ten new insights in climate science 2021 - a horizon scan. Global Sustainability, 1-39. doi 10.1017/sus.2021.25

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