Climate tipping points: Earth observations to address a key climate uncertainty

Sophie Hebden[1,2], Annett Bartsch[3], Hannah Liddy[4,5], Mike Rast[6], Narelle van der Wel[7], Richard Wood[8], Victor Brovkin[9], Tim Lenton[10]

[1] European Space Agency Climate Office, UK, [2]Future Earth, Sweden, [3] b.geos GmbH, Austria, [4]Columbia University, USA, [5]NASA Goddard Institute for Space Studies, USA, [6]International Space Science Institute (ISSI), Switzerland, [7]World Climate Research Program, Switzerland, [8]Met Office Hadley Centre, UK, [9]Max Planck Institute for Meteorology, Germany, [10]University of Exeter, UK

In October 2022, experts in remote sensing and climate modeling participated in a workshop on 'Tipping Points and Understanding EO data needs for a TIPping Element Model Intercomparison Project (TIPMIP)'. The workshop was hosted at the International Space Science Institute (ISSI) in Bern, Switzerland and supported by the European Space Agency (ESA)-Future Earth joint program.

It's fair to say that climate tipping points — defined by the Intergovernmental Panel on Climate Change (IPCC) as critical thresholds in a system that, when exceeded, can lead to a significant change in the state of the system — are by now a familiar concept, often used to convey the urgency of addressing climate change. World leaders at the COP27 climate conference of the UNFCCC in Sharm el-Sheik in November 2022 agreed on the need to understand the impact of tipping points on the cryosphere.

The growing popularity of this concept for motivating climate action also underscores the need for the scientific community to better understand the risks posed by self-reinforcing and difficult-to reverse processes taking place in the climate system. We need to understand the impacts that tipping points will have at different levels of global warming in order to guide mitigation and adaptation efforts.

The risks gaining particular attention include shifts in the Amazon from rainforest to savanna, a slowing- and potential shutting down of the Atlantic Meridional Overturning Circulation (AMOC), ice loss from the Greenland and Antarctic ice sheets as well as growing CO_2 and CH_4 emissions from thawing permafrost. Our best global climate models don't yet include all potential climate tipping processes. This limits the scientific information available to guide policies to manage the risks to social systems, and we are still a long way from implementing an observing system that can monitor the onset of tipping points.

Figure 1. Workshop participants at the International Space Studies Institute (ISSI) in Bern, Switzerland.

Future Earth has been working closely with the World Climate Research Program (WCRP) through the Earth Commission and the AIMES global research network to build the research agenda in this area, hosting a series of webinars focused on different climate tipping elements. One key research activity is to improve climate model representation of tipping elements through a model intercomparison exercise. From the observations side, researchers came together with climate modelers at a workshop hosted at the International Space Science Institute in Bern, Switzerland in October 2022, supported by the European Space Agency (ESA)-Future Earth joint program.

Animated discussions covered how Earth Observation (EO) together with modelling efforts can support monitoring and process understanding of tipping points and their interactions, climate feedbacks, and abrupt climate change more broadly. The EO and modeling communities have operated somewhat in silos. This workshop illustrated how important it is to get scientists from both communities into one room to understand one another's challenges and priorities. This is what was achieved in the ISSI Bern Workshop, and it highlighted how exciting it is to examine research questions from observational, modeling and theoretical perspectives.

What is TIPMIP?

Coordinated coupled-model intercomparison projects are a useful approach to assess our understanding of climate processes by providing a standard set of experiments and initialization data that can be run by individual climate modeling centers around the world. The differences in the model outputs create an ensemble of simulated climate behavior that can be used to explore the robustness or uncertainty – both spatially and temporally – of the processes involved. The 'TIPMIP' – TIPping element Model Intercomparison Project initiative, led by Earth Commissioner Ricarda Winkelmann, who is based at the Potsdam Institute for Climate Impact Research, will outline a set of experiments to explore the sensitivity of tipping behavior in response to rising levels of carbon dioxide in the atmosphere.

There is not a strong quantitative understanding within the climate research community about the drivers or processes involved in triggering climate tipping points, since they often fall into the category of 'High Impact, but Low Likelihood' events, and so are seen fairly infrequently in model results. Therefore, the first phase of TIPMIP experiments will take a highly idealized approach that can be easily run by a range of models. It will begin with a set of experiments that provide a strong forcing of the climate system, with an increase in atmospheric CO_2 of 1% per year. In addition, three more experiments will be defined to assess the impacts associated with specific levels of CO_2. These experiments will lay the groundwork for understanding climate tipping behaviour and how societal activity can both drive and be impacted by abrupt change.

Earth Observations for Direct Monitoring of Tipping Behavior

The limited temporal extent of the satellite record – spanning 4-5 decades at best – means that direct monitoring of trends and indicators for the onset of tipping points is restricted to 'fast' tipping points that occur over decades, that would apply to winter sea ice in the Arctic, the subpolar gyre, the Sahel/Monsoon system, forest dieback – both tropical and boreal, freshwater ecosystems, and Arctic permafrost. The workshop heard of the potential to develop proxy indicators of tipping behavior and instabilities, for example to indicate the triggering of collapse of the Antarctic Ice Sheet.

A major strength of EO is the ability to capture multiple temporal and spatial scales of tipping behavior, from local to regional to global, and from daily to interannual. Across these scales, there is potential for studying feedbacks in the Earth system that can lead to tipping points. There is opportunity to exploit satellite observations of the timing of events, to study extreme events and their impacts – including impacts on society, as well as cascading impacts and pace of change. The workshop identified the value of indicators with multiple variables that combine information from different sources to build a fuller picture of the processes occurring; for example to study the pressures affecting vegetation. It also called for better integration of EO data and platforms to facilitate the detection of tipping events.

Earth Observations for Modeling

EO has a key role to play in improving the ability of climate models to project possible climate futures. Climate models rely on long-term EO datasets like the Essential Climate Variables (ECVs), many of which are based on remote sensing data. ECVs developed by programs like the ESA Climate Change Initiative are used for model development, to assess model skill, (judged by how well models can reproduce past observations) and to constrain models – helping to determine certain parameters, for example, and to set initial conditions of part of the climate system at the start of a model simulation. The Global Climate Observing System (GCOS) is an international scientific body that maintains the definitions of the ECVs required for systematic observations of the Earth's climate. The goal is to help solve research challenges like climate tipping points, and to underpin climate services and adaptation measures.

Applied to tipping points, there is huge scope to 'assimilate' — a statistical approach that brings the model's outputs closer to the observational data — EO to improve process-based models. For example, ocean color and sea surface temperature data could be used to better constrain biogeochemical or ecosystem processes in ocean ecosystem models to lower the uncertainty of predictions of thresholds and timescales of regime shifts.

Research Frontiers

Recent wildfire and flooding events have highlighted society's fragility in the face of worsening climate extremes. Society also faces compound climate extremes whereby multiple hazards occur in the same location, or concurrent extremes occur at different locations. An open question is how extreme events might interplay with tipping points to drive worse impacts on society. Research frontiers will push our current EO datasets and modeling tools into new territory, in combinations that enable an exploration of the interactions between tipping points in the climate and society.

Through this workshop and other coordinated efforts by Future Earth and WCRP, there will be more opportunities to engage with the tipping point research community and TIPMIP initiative. Recordings of past webinars and information about those upcoming can be accessed here. Moreover, scientific sessions and meetings at EGU in April 2023 will be another opportunity for building bridges across scientific communities to enable us to better characterize the interfaces and identify and constrain the risks posed by tipping points. ▫