CSQ-31 Summary

Question	Knowledge Advancement Objectives	Geophysical Observables	Measurement Requirements	Tools & Models	Policies / Benefits
What are the physical / mathematical mechanisms that generate the behaviour of tipping points in climate models? Can models be improved using more precise observations?	A) More detailed modelization of the physical / mathematical mechanisms leading to tipping point behaviour	• Long time series of several (preferably uncorrelated) geophysical observables, depending on the tipping points being studied, but including at least the following tipping elements: **Cryosphere:** ✓ Greenland ice sheet ✓ Arctic winter sea ice ✓ West Antarctic ice sheet ✓ East Antarctic ice sheet and subglacial basins ✓ Mountain glaciers ✓ Boreal permafrost ✓ Barents Sea ice **Ocean-Atmosphere circulation:** ✓ Atlantic Meridional Overturning Circulation ✓ North Atlantic subpolar gyre / Labrador-Irminger Sea Convection collapse **Biosphere:** ✓ Low-latitude Coral Reefs ✓ Sahel & the West African Monsoon	• Surface temperature (land and ocean) • Ice sheet extend • Forest vegetation cover extension and inter-annual variability • Temporal and spatial variability in ocean currents • Ocean salinity • Extension and dynamics of mountain glaciers	Existing climate models can take into account tipping point behaviour, at least for some tipping elements.	Better predictability in climate models would allow more precise and effective mitigation or adaptations approaches.

		✓ Boreal forest (southern dieback and northern expansion) ✓ Amazon rainforest			
	B) Sensitivity analysis of model input variables to predict tipping point behaviour	• Specific studies are needed to test model sensitivity in particular to input variables associated to tipping points, using key geophysical variables with well-known uncertainty and properly validated (Essential Climate Variables), particularly in the form of time series.	• Focus on key Essential Climate variables with well-characterised uncertainties	Filter models by using the adequacy to describe tipping point behaviour, as a particular feature of the different available models used for sensitivity studies	
	C) Identification of variables used by models not yet provided in spatial maps but only from punctual ground measurements	• Geophysical variables currently provided only by punctual field measurements but that can be potentially derived as spatial maps from EO data or using EO data to refine spatial gridding • Direct observables from EO data are already provided in the form of spatial maps and can replace (sometimes as proxys) data from ground networks • Focus on defined Essential Climate Variables, but also addressing new type of information when time series are already available	• Focus on data from surface networks with well-characterised uncertainties	Data exist, but reanalysis needed to use such time series in tipping points research	
	D) Identification of specific aspects in the climate models that can be improved by using more	• Running models under different scenarios to identify the critical elements in the models where observations (particularly in the	• Model inter-comparison exercises	Filter models by using the adequacy to describe tipping point behaviour, as a	

	precise, focused or dedicated observations	form of spatial maps) would be more beneficial.	particularly welcome	particular feature of the different available models	

CSQ-31 Narrative

The identifications of tipping elements and the corresponding tipping points are completely determined by the climate models used to forecast future trends and to identify future turning points in the climate system, by exploiting the predictive capabilities of the models.

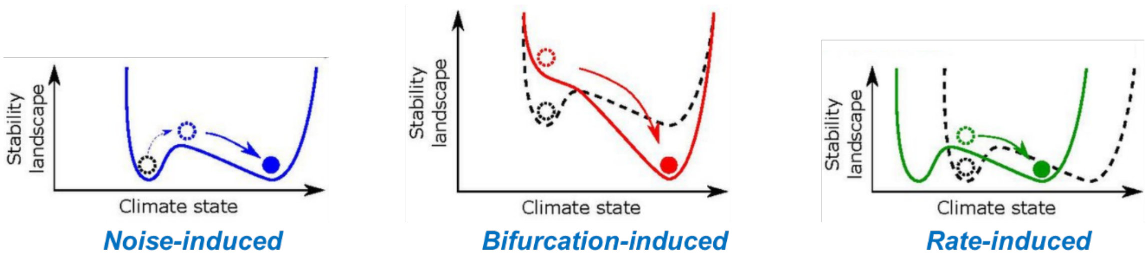

Fig. 4-1: Three main physical / mathematical mechanisms that generate the behaviour of tipping points in climate models

As illustrated in Fig. 4-1, three main different mechanisms are suggested to characterize the dynamics of tipping points:

(a) Noise-induced tipping is the transition from one state to another due to random fluctuations or internal variability of the climate system, the most common one. Noise-induced transitions are unpredictable, because the underlying potential does not change and there are no early warning signals.
(b) Bifurcation-induced tipping happens when a particular parameter in the climate system passes a critical level, where a bifurcation takes place, passing from one stable conditions to another stable condition, but quite different. This is the most typical case of tipping point behaviour.
(c) Rate-induced tipping occurs when a change in the environment is faster than the force that restores the system to its stable state. The states themselves do not change, is a change in the background potential what induces the tipping behaviour.

The reliability and accuracy of the predictions about climate tipping points depend very much on the physical understanding of the underlying processes and in the ability to represent such processes by means of mathematical models, to be more confident in the predictions.

Deficiencies in the models that describe such type of behaviours have been identified. Whether such potential deficiencies in the models can invalidate the predictive alerts for tipping points in the climate system is unlikely, but the actual magnitude of the effects may have a large uncertainty.

Can those models be improved or be better validated, by using more precise observations? Global satellite observations can help not only to identify tipping elements but also the geographical spatial extend of the identified tipping elements, and also the corresponding spatial variability (geophysical spatial patterns and associated spatial and temporal variances). The simple example shown in Fig. 4-2 is illustrative. It is based on one of the used models for forest dieback.

$$\frac{dv}{dt} = gv(1-v) - \gamma v \qquad g = g_0\left[1-\left(\frac{T_l - T_{opt}}{\beta}\right)^2\right]$$

v = fractional vegetation cover

$$T_l = T_f + (1-v)\alpha$$

Fig. 4-2: Simple forest dieback model (Ritchie P. D. L., et al., 2021)

The model assumes a single type of vegetation layer, and the governing equation for the driving parameter, the vegetation fraction *v*, accounts for a growth term, *g*, which is assumed to be parabolic in the local temperature, T_l, and a disturbance rate, □. There is an optimal temperature for which growth is maximal and β determines the dependence with temperature vegetation growth. Negative growth rate implies tree mortality. There is an additional feedback on the local temperature, T_l: a decline in vegetation results in an increase in temperature. The temperature T_f is used as the forcing parameter, and is modulated by the vegetation cover and the temperature difference between total forest cover and bare soil, given by □.

This elementary example illustrate two things: one is that models are many times too simple and very empirical, easy to improve, but also that global Earth Observation data can definitely help to derive much better models, particularly for the example here presented of forest dieback, because most of the key variables in the model can be effectively measured by satellites, and many of such data are even already available.

Global models necessarily must assume some simplifications when running over long time scales, but validation of the pieces of the global models by means of regional models, which can be more detailed in the representation of processes and can also be better constrained by available observations, is definitely a way to improve the global models in the way of describing the different processes.

References

McKay, D. I. Armstrong et al. (2022), "*Exceeding 1.5°C global warming could trigger multiple climate tipping points"*, Science, Vol. 377/6611, , eabn7950 (2022) DOI: 10.1126/science.abn7950, https://doi.org/10.1126/science.abn7950.

Ritchie Paul D L, Joseph J Clarke, Peter M Cox, Chris Huntingford. (2021). *"Overshooting tipping point thresholds in a changing climate"*. Nature, vol 592, p 517-523, 2021. DOI: 10.1038/s41586-021-03263-2

Liu, T., Chen, D., Yang, L. et al. *"Teleconnections among tipping elements in the Earth system".* Nature Climate Change. 13, 67–74 (2023). https://doi.org/10.1038/s41558-022-01558-4

Cardil et al. *"Climate teleconnections modulate global burned area",* Nature Communications, 2023

OECD (2022), ·*"Climate Tipping Points: Insights for Effective Policy Action",* OECD Publishing, Paris, https://doi.org/10.1787/abc5a69e-en.

Lenton, T.M.. *"Beyond 2ºC: Redefining dangerous climate change for physical systems".* Wiley Interdisciplinary Reviews: Climate Change 2: 451–461, 2011a.

Lenton, T.M., *"2ºC or not 2ºC? That is the climate question".* Nature 473: 7, 2011b

Lenton, T.M., *"Early warning of climate tipping points"*. Nature Climate Change, 1: 201–209, 2011c.

Lenton, T.M., H. Held, E. Kriegler, J. Hall, W. Lucht, S. Rahmstorf, and H.J. Schellnhuber. *"Tipping Elements in the Earth's Climate System".* Proceedings of the National Academy of Sciences of the United States of America 105: 1786–1793, 2008.

Lenton, T.M*., "Arctic Climate Tipping Points",* AMBIO 41:10–22, DOI 10.1007/s13280-011-0221, 2012.

Lenton, T.M., Rockstrom, J., Gaffney, O., Rahmstorf, S., Richardson, K., Steffen, W., and Schellnhuber, H.J. (2019). *"Climate tipping points-too risky to bet against".* Nature vol. 575/7784, pp. 592-595, https://doi.org/10.1038/d41586-019-03595-0.

William J. Ripple, Christopher Wolf, Timothy M. Lenton, Jillian W. Gregg, Susan M.Natali, Philip B. Duffy, Johan Rockström, and Hans Joachim Schellnhuber, *"Many risky feedback loops amplify the need for* *climate action"*, One Earth - Commentary, Vol. 6, Issue 2, p. 86-91, February 17, 2023, https://doi.org/10.1016/j.oneear.2023.01.004

Zhou, D., Gozolchiani, A., Ashkenazy, Y. & Havlin, S. *"Teleconnection Paths via Climate Network Direct Link Detection".* Physical Review Letters 115, 268501 (2015)