CSQ-32 Summary

Question	Knowledge Advancement Objectives	Geophysical Observables	Measurement Requirements	Tools & Models	Policies / Benefits
Where are the alerts (pointed out by predictive models) where observations can be focused, and how can observations be guided to verify the trends to tipping points indicated by the models?	A) Identification of the alerts pointed out by predictive models, and the associated geographical extension and temporal scales of each alert	• As an output from model results, key geophysical variables where models are more sensitive to changes can be identified. • The conclusions can be model-dependent and probably require some reanalysis given the different sensitivity of each model to different geophysical inputs.	• Critical dependence on model capability to simulate some of the effects, particularly for regional sales	Models exist, but global models must be complemented with regional models to make possible a direct coupling to more detailed observations	New observations leading to an improved knowledge of tipping points effects, temperature threshold and spatial and temporal scales of the predicted effects, will be extremely beneficial to establish potential actions early enough to be effective.
	B) Identification of observations explicitly oriented to verify specific trends suggested by the models	• Since models need to be validated with current available datasets before they can be used in a predictive mode for the future, key current observations are: ✓ Time series of surface temperature over extended geographical areas ✓ Time series of sea area extend ✓ Time series of glacier extension and motions ✓ Time series of vegetation fraction al cover over boreal forest and Amazonian rainforest	• Time series long enough (ideally more than 30 years). This is possible for some records, even satellite data, but not for all the variables needed as inputs by the climate models • Accuracy in some key geophysical variables may be bot enough to be used for tipping points, due to the high sensitivity to small changes in input variables	Tools are available, both in terms of data (time series with associated uncertainties) and in terms of models, but the length and accuracy of the datasets may be not adequate for this type of models with high sensitivity to inputs variables (tipping behaviour).	

	C) Exploitation of current available time series and datasets to validate model behaviour at the associated spatial scales	• While time series for some geophysical variables already exist, the usage in tipping point models is not straightforward, due to the specific sensitivity of tipping point behaviour to small changes in input data.	• Accuracy in time series must be adequate to detect the small changes that are characteristic of tipping point behaviour	Model exist, but sensitivity to small changes in input parameters need to be analysed in more detail	
	D) Usage of guided observations to reduce uncertainties in model predictions	• New observations (either field, airborne, or satellite observations) can be explicitly planned to test specific model predictions and to improve model implementation	• Time series are needed in all cases, and the accuracy required to detect trends to tipping points can be quite demanding, particularly for time series with less than 30 year records.	Model exists, but uncertainty still too high to make possible the coupling to specific observations	

CSQ-32 Narrative

Tipping points are not directly measurable, but are predicted by climate models, ideally over long-term scales with enough anticipation to be still in time to establish corrective actions. What is really important is the identification of how the system changes before reaching the tipping point, or the pathways that may lead to the risk of being close to a tipping point, then introducing mitigation actions over such pathways that may lead to a tipping point well before there is too late.

Given the fact that identification of tipping elements, and the associated tipping points, must rely necessarily in climate models, the output of such models should guide the observations, focusing them on the most critical geographical areas, and spatial and temporal scales where observations are more critical, or focusing the observations on specific processes pointed out by the alerts provided by the climate models. Being able to measure how resilient the system is when approaching a tipping point is also relevant to focus the observational strategies.

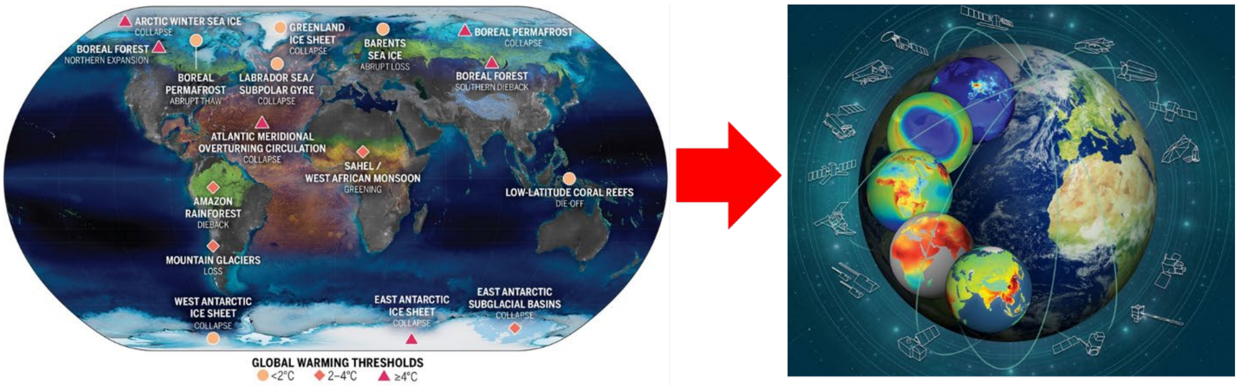

Fig. 5-1: (left) Location of climate tipping elements in the cryosphere (blue), biosphere (green), and ocean/atmosphere (orange), and global warming levels at which their tipping points will likely be triggered. (right) Earth observations pointed out to better monitor the behaviour of tipping points.

In a first step, such observations can mostly serve to validate the models using current data and to help developing models with a better description of geographical extensions and spatial and temporal variances. Over time, the observations can verify the model predictions and help refining the models as needed. An important aspect in all cases is to account for uncertainties and error propagation, both the in the models and in the observations, something often not accounted for in a proper manner.

Identification of areas where changes are more likely to happen, and what changes can readily be observed, is already a major step. But dealing with tipping point effects and identification of thresholds and impacts will probably require the development of new observation capabilities. The identified deficiencies in the models, or areas in the models known to have a large uncertainty, can guide the definition of new global observing systems. In the case of tipping points, long time series to detect trends in changes is more important than short-term sophisticate new technologies to measure new type of information, but new temporal observation strategies can be explored, and also the role of data processing and model-data integration should be improved as well.

An important aspect on where to focus observations is the definition of safe boundaries for interactions of multiple tipping points. This is a topic that is deserving special attention in the last years, related to the possibility of activating several multiple tipping points at the same time and what would be the effects. The combined analysis of multiple tipping points also tries to determine which the dominant ones are or which are the ones that due to particular risk deserve the focus of the attention in order to focus observation strategies.

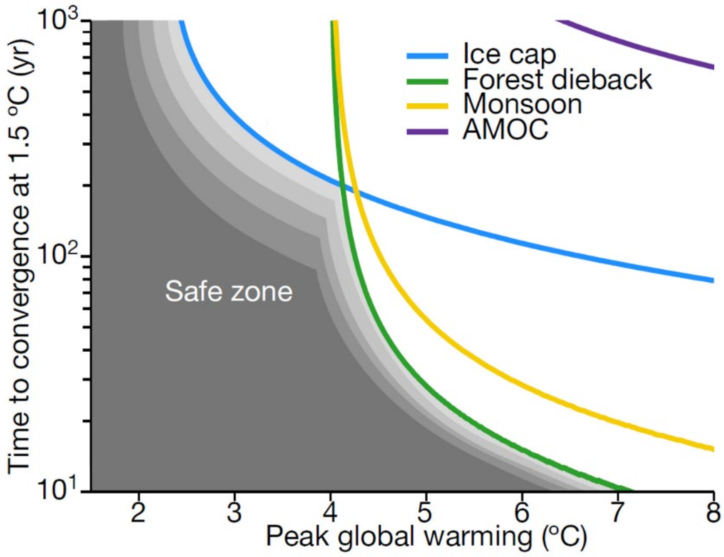

Fig. 5-2: Boundaries of safe overshoots for multiple tipping points (Ritchie P. D. L., et al., 2021)

The diagram in Fig. 5-2 shows the boundaries of safe overshoots for multiple tipping points, as a function of the peak global warming temperature and the time to convergence at 1.5 degrees warming goal. Above and right of the individual curves the tipping cannot be avoided, below and left indicate the safe zone. The grey-shaded region indicates the safe zone for all tipping points. Different grey shades indicate the boundary of the safe zone if the threshold for all tipping elements were 0.1 °C lower.

As indicated by the results plotted in the Fig. 5-2, one can conclude that ice cap and forest dieback dominate the safe zone. Then, those two would be the critical ones to be studied in more detail, and where observations can be definitely focused.

However, results are for sure model-dependent and should be interpreted with caution, more research is needed before coming to premature conclusions.

Given the limited temporal extent of time series of satellite data, covering 4-5 decades in the best cases, the direct monitoring of trends and indicators for the activation of tipping points is restricted to tipping points with fast evolution over decadal time scales (such as winter sea ice in the Arctic, forest dieback for both tropical and boreal forest, or Arctic permafrost), although some potential proxy indicators can be also used to monitor processes when direct observations are not possible. Moreover, current time series of observations can also serve to better validate models and the use the model in a more precise predictive way.

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)