CSQ-28 Summary

Question	Knowledge Advancement Objectives	Geophysical Observables	Measurement Requirements	Tools & Models	Policies / Benefits
Are there tipping points/elements in the climate system not yet identified?	A) Identification of all potential tipping elements in the climate system, including those currently assumed as potential or even unlikely	• While most actual or potential tipping points are currently known, there are potential tipping elements, not yet confirmed, where observations should be focus: ✓ Southern Ocean sea-ice ✓ Tibetan Plateau Snow ✓ Indian summer monsoon ✓ Indian Ocean upwelling ✓ Equatorial stratocumulus clouds and other cloud feedbacks ✓ Ocean deoxygenation ✓ Antarctic bottom water ✓ Temperate forests, Congo forest	• Given the unknown properties of such new tipping points, it is difficult to establish precise requirements for each individual measurement, also because of the largely unknown sensitivity of the inputs variables in climate models related to such new tipping points • Focus observations on: ✓ Spatial and temporal extend of sea ice (arctic summer sea ice) ✓ Optical spectroscopy to study the chemistry of the ocean surface (ocean biological pump and ocean	Models exist, but most likely not adequate enough to deal with new tipping points not yet identified by the climate models	Knowledge of new, currently unknown, tipping points would increase the possibilities to establish corrective actions, in terms of adaptation and mitigation, with enough time in advance to react.

			carbon sink, marine methane hydrates) ✓ Ocean temperature, waves and currents (El Niño Southern Oscillation ✓ Better resolved land cover dynamics (gradual thaw of boreal permafrost) ✓ Better characterization of land carbon exchanges (land carbon sink) ✓ Continue and improved atmospheric ozone monitoring (arctic ozone hole)		
	B) Association of potential tipping elements that can be activated together (cascade effects)	• From the list above about potential tipping points, together with the list of currently assumed tipping points, associations among them in terms of cascade effects and teleconnections can	• Requires previous knowledge of specific properties of each tipping point before	Models exist, but they may not be particularly suitable when dealing with new tipping points associated to	

		be determined by combination of time series of observations and dynamical predictive models	associations can be established. • Basic underlying variables (surface temperature, sea ice extend, forest vegetation factional cover evolution, etc.) may serve to check potential couplings among tipping points	processes not yet properly described by the models.	
	C) Identification of Extreme Events and Planetary Boundaries that can be indicative of potential tipping points	• Analyse time series and geographical maps with locations of Extreme Events potentially indicative of evolution towards a tipping point • Explore Planetary Boundaries that can be indicate of where a tipping point may occur • Focus observation on processes related to potentially irreversible transformations associated to tipping point behaviour.	• Observations of extreme events and trend to planetary boundaries are already available (for instance, time series of sea ice extend, time series of forest burned areas), and can be used to check potential trends to tipping points	Data and models are available, but probably time series are not yet long enough to see trends associate to tipping point behaviour.	
	D) D) Discard phenomena that can lead to false positives towards the identification of tipping points	• Some elopement currently considered as generating tipping points may result in false alarms and some elements currently considered as unlikely to generate tipping points may become	Type of observations are very extensive to establish precise requirements for each individual measurement, also		

		tipping points as models and observations are available. • Focus observations on elements currently assumed to be unlikely, such as: ✓ Arctic ozone hole ✓ El Niño Southern Oscillation ✓ Northern polar jet stream ✓ Arctic summer sea ice ✓ Marine methane hydrates ✓ Boreal permafrost (gradual thaw) ✓ Ocean biological pump and ocean carbon sink ✓ Land carbon sink	because of the largely unknown sensitivity of the inputs variables in climate models to such processes linked to the new tipping points		

CSQ-28 Narrative

There is a growing evidence that overshooting 1.5°C may push the Earth over a number of so called “tipping points”, leading to irreversible and severe changes in the climate system, with potential large effects, and challenges for rapid adaptations.

By definition (Fig. 1-1), a tipping point, for a tipping element of the climate system, is a critical threshold beyond which global or regional climate changes from one stable state to another stable state, and the climate system reorganizes, often in a non-linear manner, abruptly and irreversibly, with dangerous impacts and serious implications for humanity. There are several definitions in the literature, but the key idea is that the system arrives to an unstable point in between two stable states, so that a small change in the properties may result in the system turning to one or another state, both with very different properties. Tipping points represent a level of change in system properties beyond which changes in a part of the climate system become self-perpetuating, and the system does not return to the initial state, although the irreversible behaviour is now questioned, at least for some tipping elements.

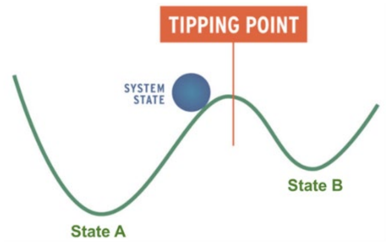

Fig. 1-1: Typical behaviour of a climate tipping point as an unstable transition point between two stable states

A consensus on what tipping points are the most critical ones is not yet available in the literature, since the determination of the tipping point (estimated range for the temperature threshold) for each tipping element (component of the Earth System subject to tipping behaviour) remains controversial, and even the identification of tipping elements is evolving in recent years according to scientific literature (see references below). For instance, gradual versus abrupt permafrost lose will have impacts in very different time scales, but still large uncertainty exists in model predictions and impact estimates. The list of potential tipping elements is open to changes as there is progress in the research.

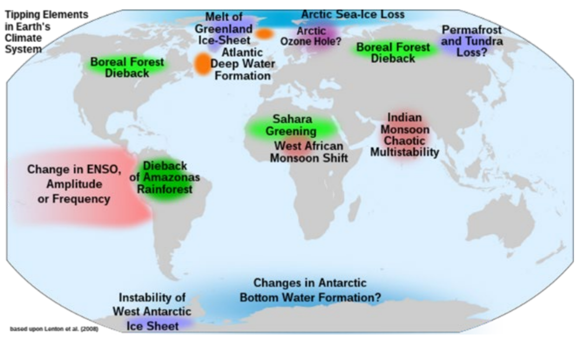

Fig. 1-2. Identified tipping elements in the climate system

Recent work has suggested that up to 15 tipping elements are now active, in the order of 9 global “core” tipping elements, plus about 7 regional “impact” tipping elements which contribute substantially to the Earth system functioning.

Additional tipping elements have been proposed (e.g., parts of the East Antarctic ice sheet) and the status of others (e.g., Arctic summer sea ice) has been questioned. Some formerly considered tipping points are now discarded. Identification of tipping points is still an open issue.

The list of tipping elements is open to changes as there is progress in the research, but the question is if all “potential” tipping points are already identified. The link between Planetary Boundaries and Tipping Points plays also a role here. One would expect that when all Planetary Boundaries are identified, those leading to Tipping Points can be also identified, but this is not so straightforward. The identification of tipping points in the climate system through climate models, or tipping elements subject to such type of transformations, remains in discussion, and some critical tipping points may still remain unidentified.

At least it would be important to identify tipping elements, and then figure out the tipping point corresponding to each element. The focus can be on those tipping elements now considered as “potential / uncertain” tipping element candidates. Particular focus should be put on those now considered “unlikely” tipping elements, because some of them were previously considered Tipping elements in the past and this classification may evolve with time.

The way of identifying new potential tipping points is to focus on those elements that have been already considered but where evidence of tipping behavior is not yet demonstrated. Moreover, there is no consensus on the research community if some of such elements may or not develop a tipping point, so that focusing on such elements which are at the moment considered potential / unlikely tipping elements should be a research priority. The observations needed for such tipping point candidates are:

- ✓ Spatial and temporal extend of sea ice (arctic summer sea ice)
- ✓ Optical spectroscopy to study the chemistry of the ocean surface (ocean biological pump and ocean carbon sink, marine methane hydrates)
- ✓ Ocean temperature, waves and currents (El Niño Southern Oscillation
- ✓ Better resolved land cover dynamics (gradual thaw of boreal permafrost)
- ✓ Better characterization of land carbon exchanges (land carbon sink)
- ✓ Continue and improved atmospheric ozone monitoring (arctic ozone hole)

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