CSQ-17 Summary

Question	Knowledge Advancement Objectives	Geophysical Observables	Measurement Requirements	Tools & Models	Policies / Benefits
How is the resilience of key Earth System components changing under multiple anthropogenic pressures?	Quantify changes in resilience of the Amazon and other key biomes that might signal approaching or crossing of tipping points	• Microwave vegetation optical depth (VOD) • LAI • Biomass (e.g. from inventories for ground-truthing)	• High spatial resolution VNIR imagery (< 30m) • Synthetic aperture Radar (SAR) imagery • Low-frequency microwave for better time resolution of changes in the canopy depth • LiDAR	• Statistical approaches to derive resilience metrics • DGVMs • Machine Learning models (upscaling) • ESMs for future projections	• Identify regional hotspots of change in response to human activities → priorities for conservation / adaptation • Guide policy towards avoidance of crossing planetary boundaries / tipping points
	Quantify changes in ecosystem function and vitality due to climate change and more extreme events	• Vegetation water content • Indicators of gross primary productivity (NIRv, SIF, …) • LAI • Evapotranspiration (LST) • Net CO_2 fluxes (from in-situ or XCO_2) • Burned area	• High spatial resolution VNIR imagery (< 30m) • High temporal resolution imagery (<10 days) • Multi-spectral and hyperspectral imaging	• Atmospheric inversion modelling • Data-model integration systems (e.g. CARDAMOM) • Machine Learning models (upscaling and unobservable variables) • DGVMs (unobservable variables) • ESMs + impact models for future projections	
	Quantify trajectories in seasonal sea-ice cover in the polar regions towards approaching a tipping point	• Sea ice cover • …	TBD	TBD	

CSQ-17 Narrative

The definition of Planetary Boundaries (PBs) is highly uncertain and, to some extent, subjective but it is a powerful concept in that it facilitates communication with policy makers and societies by providing an easy-to-understand and multivariate assessment of the "state of the planet" (Rockstrom et al., 2009; Steffen et al., 2015). The definition of PBs requires the identification of processes/systems that might exhibit threshold behavior, or non-linear dynamics without a fixed threshold. This is analogous to the way the potential for tipping points is evaluated, but PBs are placed upstream of the estimated tipping/acceleration point (Figure 1).

The definition of PB, relies on a broad definition of reference states to control variables, some of which are not easily measurable in the Holocene (Running, 2012). Such reference states are, in most cases, not directly quantifiable – at least at global scales – given the limitations of global observational records, so they might be derived from a mix of modeling and expert knowledge, as done for example for the quantification of "biosphere integrity" (Alkemade et al., 2009). Even if an exact PB might be difficult to quantify, arguably it is possible to estimate how far and how fast systems are approaching a given PB by continuously observing the trajectories of the processes associated with each PB.

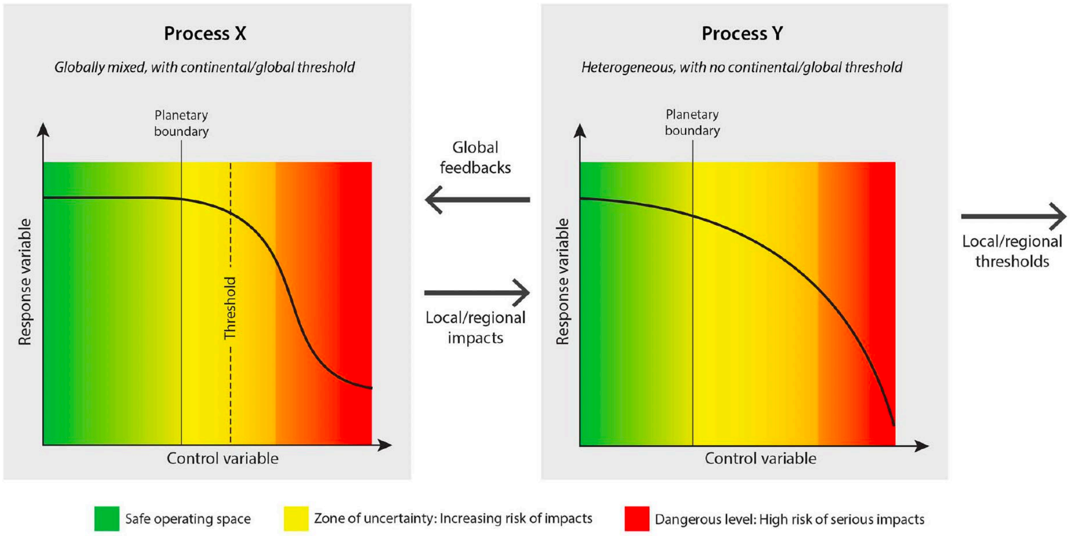

Figure 1: The conceptual framework for the planetary boundary approach, showing the safe operating space, the zone of uncertainty, the position of the threshold (where one is likely to exist), and the area of high risk. From Steffen et al. (2015).

PBs are, per definition, global, but the processes and the policy decisions influencing trajectories towards/away from PB happen mostly at local scale (e.g., tree mortality, biodiversity loss, ice-shelf collapse, coral reef mortality, …). Therefore, in order to guide policy making towards sustainable development, one needs to be able to quantify the local contributions to global-scale processes.

Earth Observation (EO) and particularly global space-based EO can play a key role in supporting the monitoring of planetary stability/destabilization from local to global scales, at least for some of the defined PBs. Furthermore, the range of defined PBs is far from exhaustive, with different communities calling for dedicated PBs in other systems (e.g. aquatic systems, (Nash et al., 2017)). Therefore, EO can also play a key role in identifying processes showing threshold behavior that are not yet considered in the PB framework, e.g., in marine biomes (Nash et al., 2017). Additionally, for processes that are not directly observable, data-driven and process-based models constrained by EO can be used to derive global estimates of relevant variables, as exemplified for ocean pH (Gregor and Gruber, 2021) or for nutrient flows (De Sisto et al., 2022).

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