CSQ-47 Summary

Question	Knowledge Advancement Objectives	Observables	Measurement Requirements	Tools & Models	Policies / Benefits
How can we improve the detection of natural variations of the energy cycle and the attribution to anthropogenic long-term change, as well as our understanding on the interlinkage between major Earth system cycles?	A) Understand sources and drivers of temporal variations for components of the global energy budget relation linking planetary heating, effective radiative forcing, surface temperature response and climate sensitivity to understand the global interplay of natural variability versus anthropogenic change.	• Ocean heat content (direct, indirect: ocean mass & sea level) • Land heat content (continental, permafrost and inland water bodies) • Atmospheric heat content • Heat available to melt ice (Ice shelf, sea ice, glaciers, snow cover) • Net flux at the top of the atmosphere (incoming & outgoing radiation) • Effective radiative forcing • Climate sensitivity (indirect observed)	• High-spatial resolution (e.g., ¼°, min. 1°) • High-temporal resolution to capture from extremes to long-term change (e.g., daily) • Sustainability to improve climate change monitoring • Multi-satellite approach • Multi-product approach (in situ, satellite, model)	Earth system models Atmospheric & oceanic & coupled assimilation systems	CC mitigation and adaptation policy CC monitoring and stocktake Improvements of CC prediction / climate models (validation, parametrization, detection & attribution)
	B) Detection and attribution studies for the global energy budget relation, allowing also for systematic observing system recommendations for the monitoring of planetary warming to support decisions on climate change action and sustainable development.				
	C) Identify and study feedbacks between climate change and the energy cycle, and between major Earth's system cycles	• List above • Recommendations for carbon & water cycle monitoring			

CSQ-47 Narrative

The Earth system cycles sustain life on Earth through the transfer, exchange & storage of heat, water, carbon, and other substances across all domains - the atmosphere, ocean, land, cryosphere and biosphere. Interactions are triggered and altered by natural variations of the climate system to maintain and balance the life-sustaining natural rhythm of the Earth system cycles, and are currently perturbed by human activities (IPCC, 2021), with adverse impacts on ecosystems and human systems (IPCC, 2022). The detection and attribution of this long-term impact is hence key, and systematic climate observations across all domains are the foundation for monitoring, understanding and predicting Earth cycles natural rhythm, their underlying processes, and future evolutions are needed to close knowledge gaps, and to support decisions on climate change action and sustainable development (Crisp et al., 2022; Dorigo et al., 2021; GCOS, 2021; von Schuckmann et al., 2020). With increasing warming, feedbacks between climate change and the Earth's system cycles become larger, intensifying related impacts and their severity (IPCC, 2021) (Fig. 4). An example of such feedback is the so-called ocean-heat carbon nexus: Carbon sinks set the airborne fraction, which sets radiative forcing that drives the additional heat in the atmosphere. The ocean sets the thermal response through ocean heat uptake. Ocean warming weakens the ocean sink, which increases the airborne fraction, and hence the radiative forcing (Forster et al., 2022). There are hence urgent advancements needed to enhance our understanding of both the natural variations and processes and the anthropogenic perturbation for the energy cycle, and the interference with other major Earth system cycles to accurately monitor, understand and predict the climate trajectory.

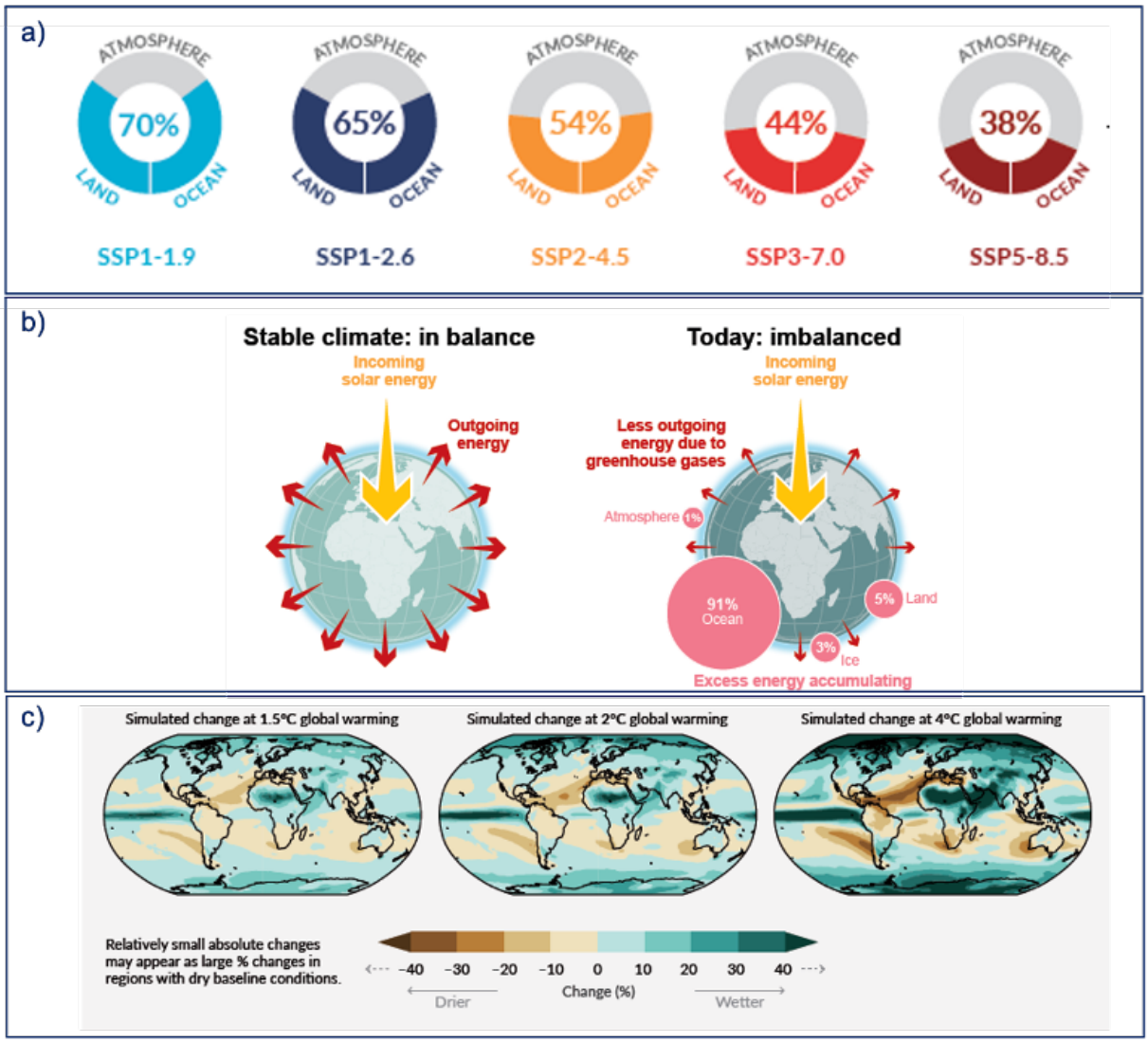

Figure 4: *Examples assessed in the IPCC 6th assessment report (Working Group I) of long-term pressure from climate change that affects the natural rhythm of all cycles across all domains. a) Carbon & nitrogen cycles: Human activity has caused an accumulation of well-mixed GHG (CO2: 47%, CH4: 156%, N2O: 23 %) (values above pre-industrial (1750) levels), lowering land & ocean sink dynamics. Figure adopted from* (IPCC, 2021)*(their Fig. SPM.7). b) Energy Cycle: Human activity has caused an imbalance of the natural energy flows, leading to an accumulation of surplus heat warming all domains: Ocean, Atmosphere, Land, Cryosphere Figure after* (Forster et al., 2022) *(Q&A 7.1). c) Water Cycle: Human activity has caused an intensification of the water cycle & is projected to further intensify, including its variability, global monsoon precipitation and the severity of wet and dry events (their Fig. SPM).*