# Towards a quantification of the water planetary boundary

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# Summary

The planetary boundaries (PB) framework defines nine Earth system processes that together demarcate a safe operating space for humanity at the planetary scale based on deviation from Holocene-like conditions, the only conditions that we know are able to support agriculture-based civilizations. In the original PB papers (Rockström et al., 2009; Steffen et al., 2015), “the PB for freshwater use” is represented by water withdrawal from surface and groundwater, and assessed in relation to environmental flow requirements and impacts to aquatic ecosystems.

To better reflect different key aspects of water’s role for vital Earth system processes, such as carbon balance and terrestrial ecosystems, we recently proposed to instead represent the water planetary boundary through multiple sub-boundaries based on the five primary water stores, i.e., atmospheric water, soil moisture, surface water, groundwater, and frozen water (Gleeson et al., 2020ab).

We are now, in our work of progress, proposing two water sub-boundaries: a blue water sub-boundary whose quantification depend on streamflow impacts on aquatic biodiversity, and a green water sub-boundary whose quantification depend on both climatic and ecological consequences.

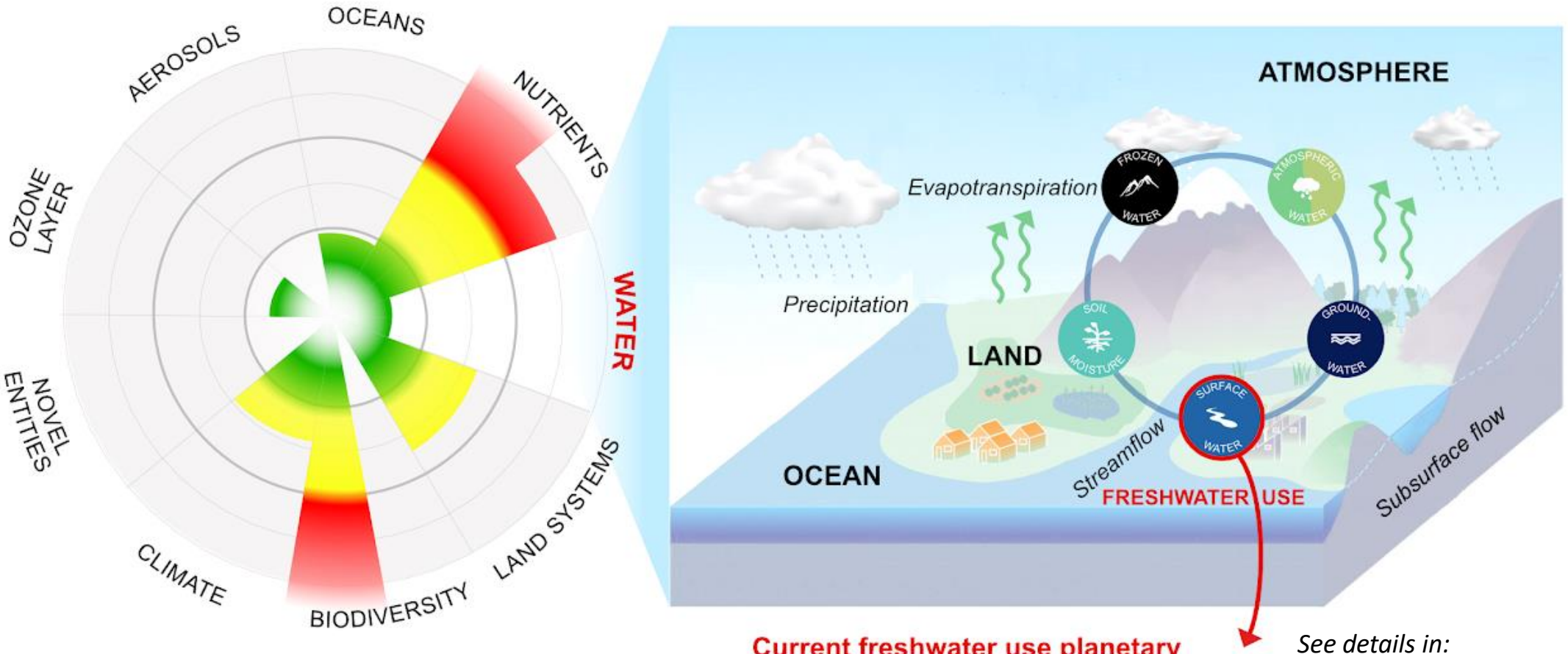
For the green water PB, we are possibly converging towards using a vegetation stress and soil moisture related metric for defining the control variable, based on literature review and a revised evaluation framework (with regard to Characterization of Holocene-Anthropocene transition, Impacts on Earth system stability, Measurability, Actionability, and Parsimony).

Discussions welcome!

# Aim

to propose and map interim water planetary sub-boundaries variables, i.e., variables for monitoring water cycle changes that affect the capacity of the Earth systems to cope with perturbations consistent with the planetary boundary framework.

Gleeson et al., (2020), One Earth

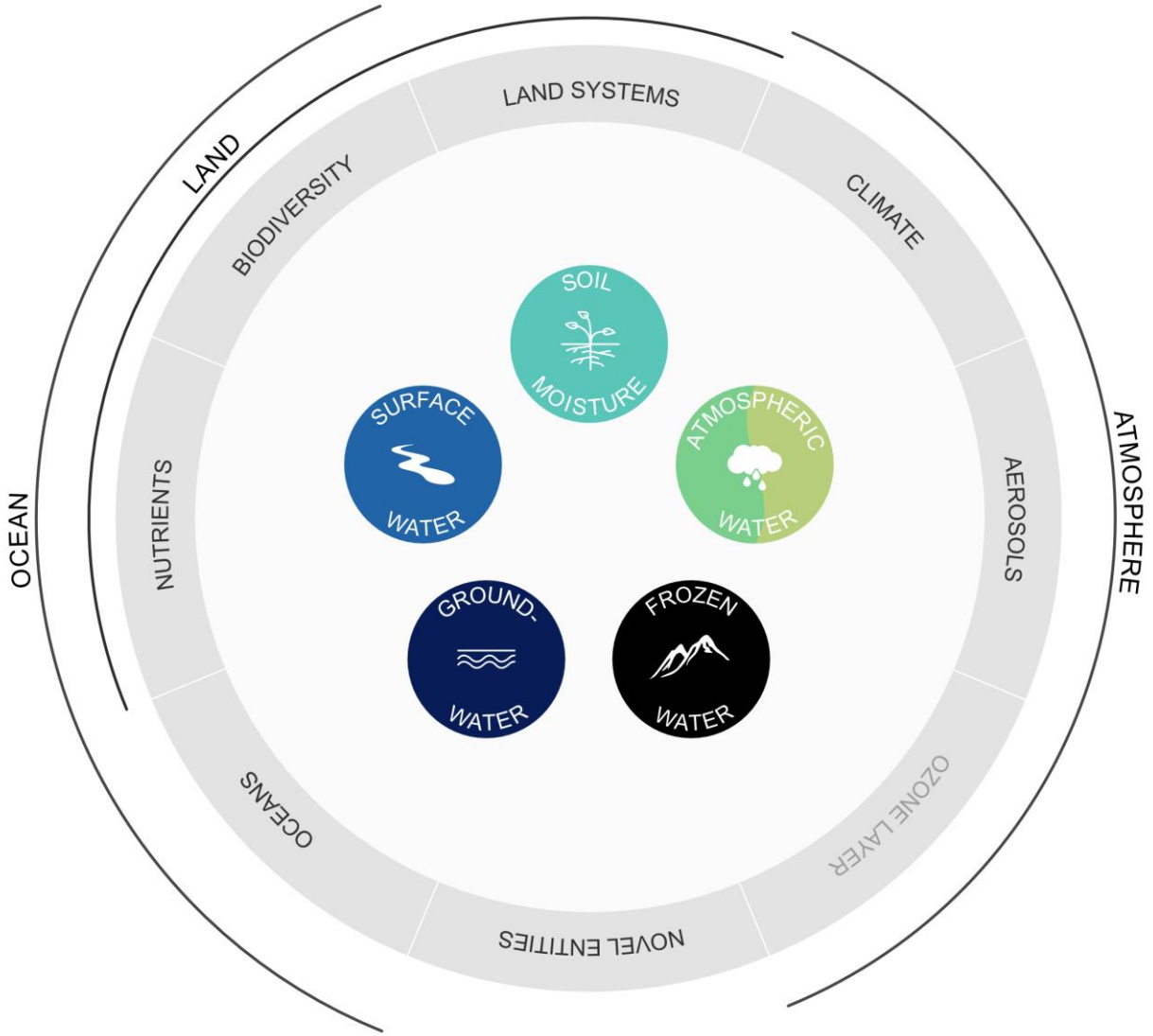



**Current freshwater use planetary boundary only considers streamflow impacts on aquatic biodiversity.**

*See details in:*
Rockström et al., (2009), E&S
Gerten et al., (2013),
Steffen et al., (2015), Science

Gleeson et al., (2020), One Earth
Adapted by Miina Porkka

# Earth system functions of water stores



Gleeson et al., (2020), One Earth
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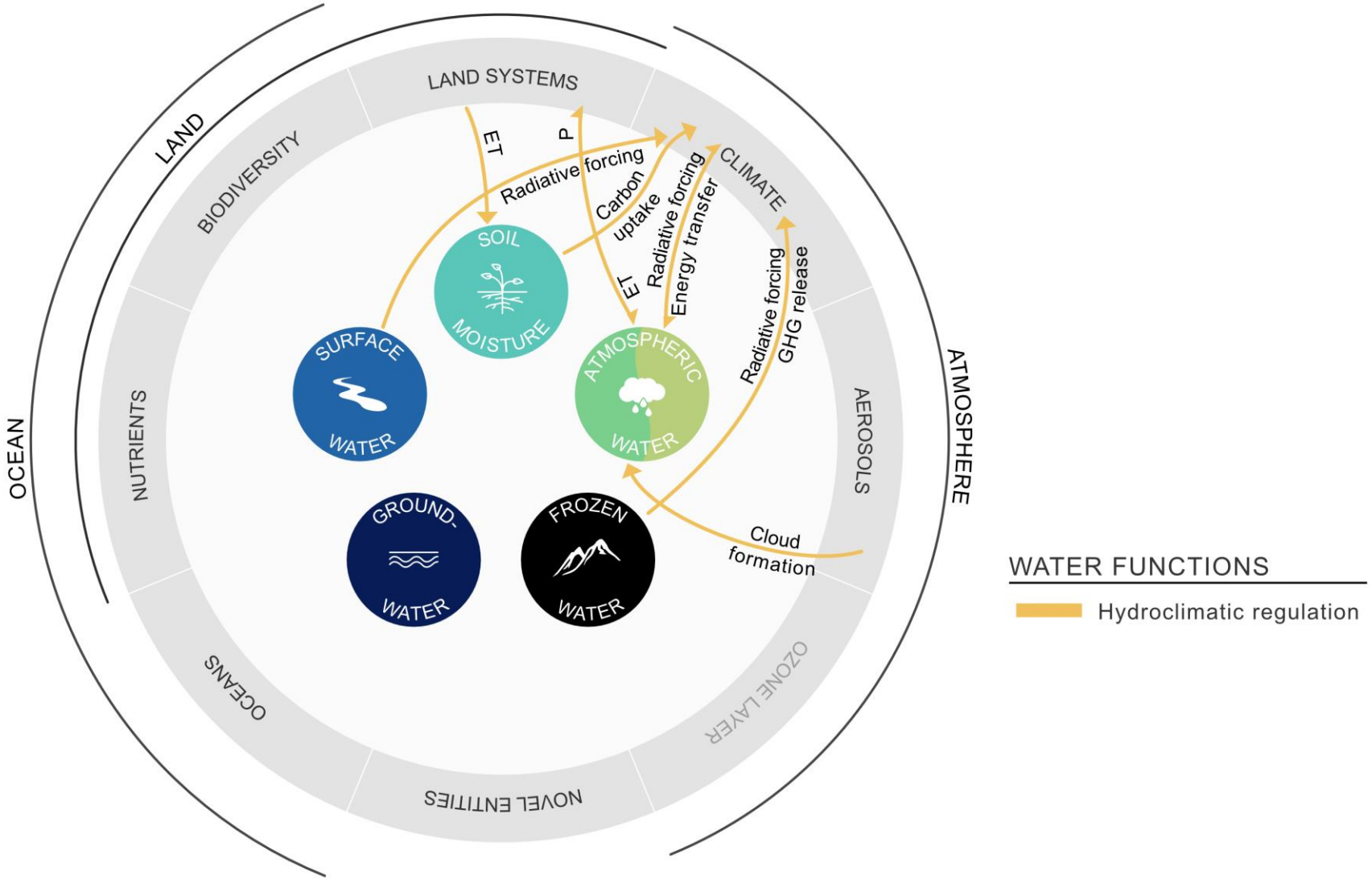
# Hydroclimatic regulation function



Gleeson et al., (2020), One Earth
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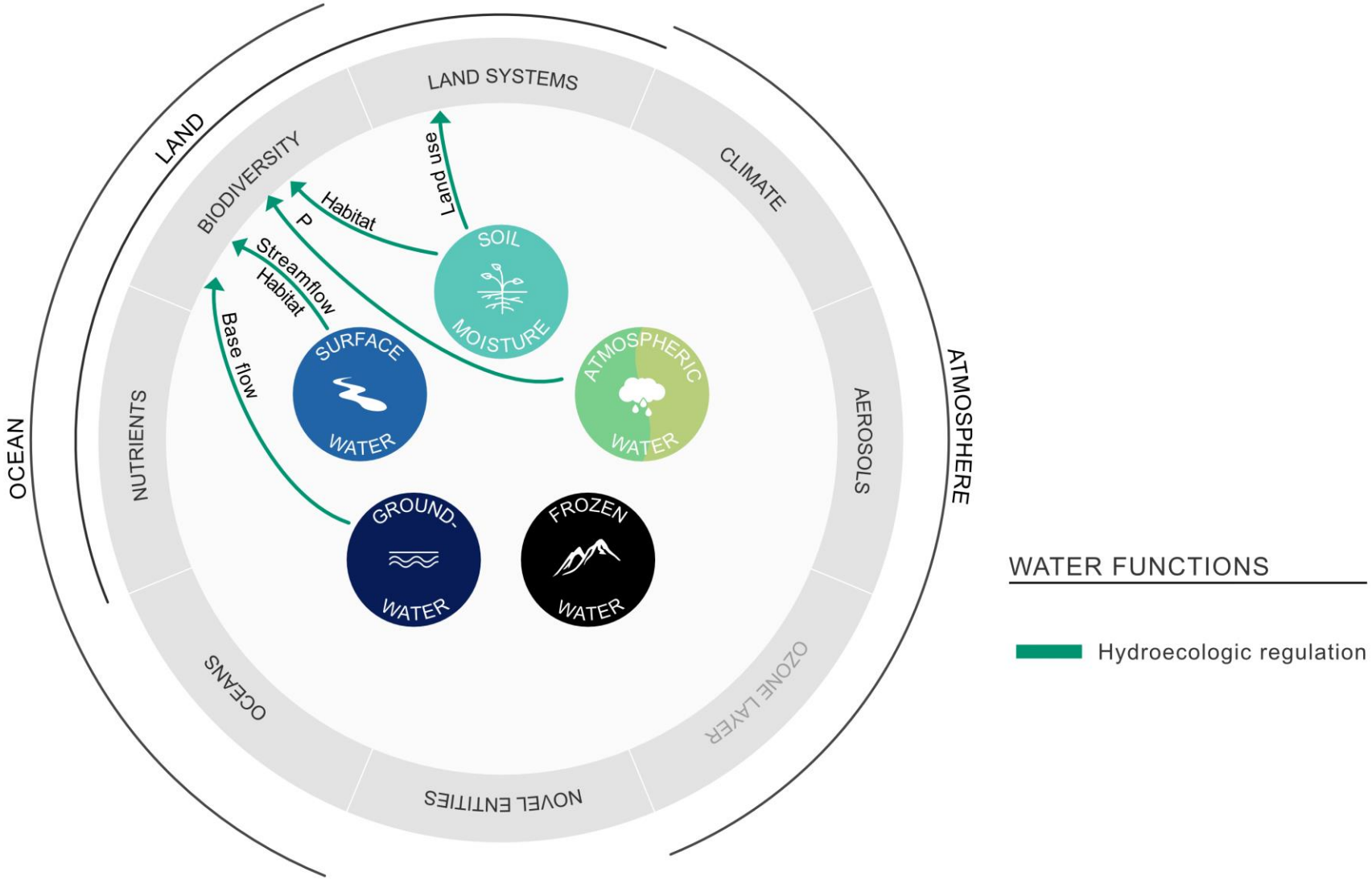
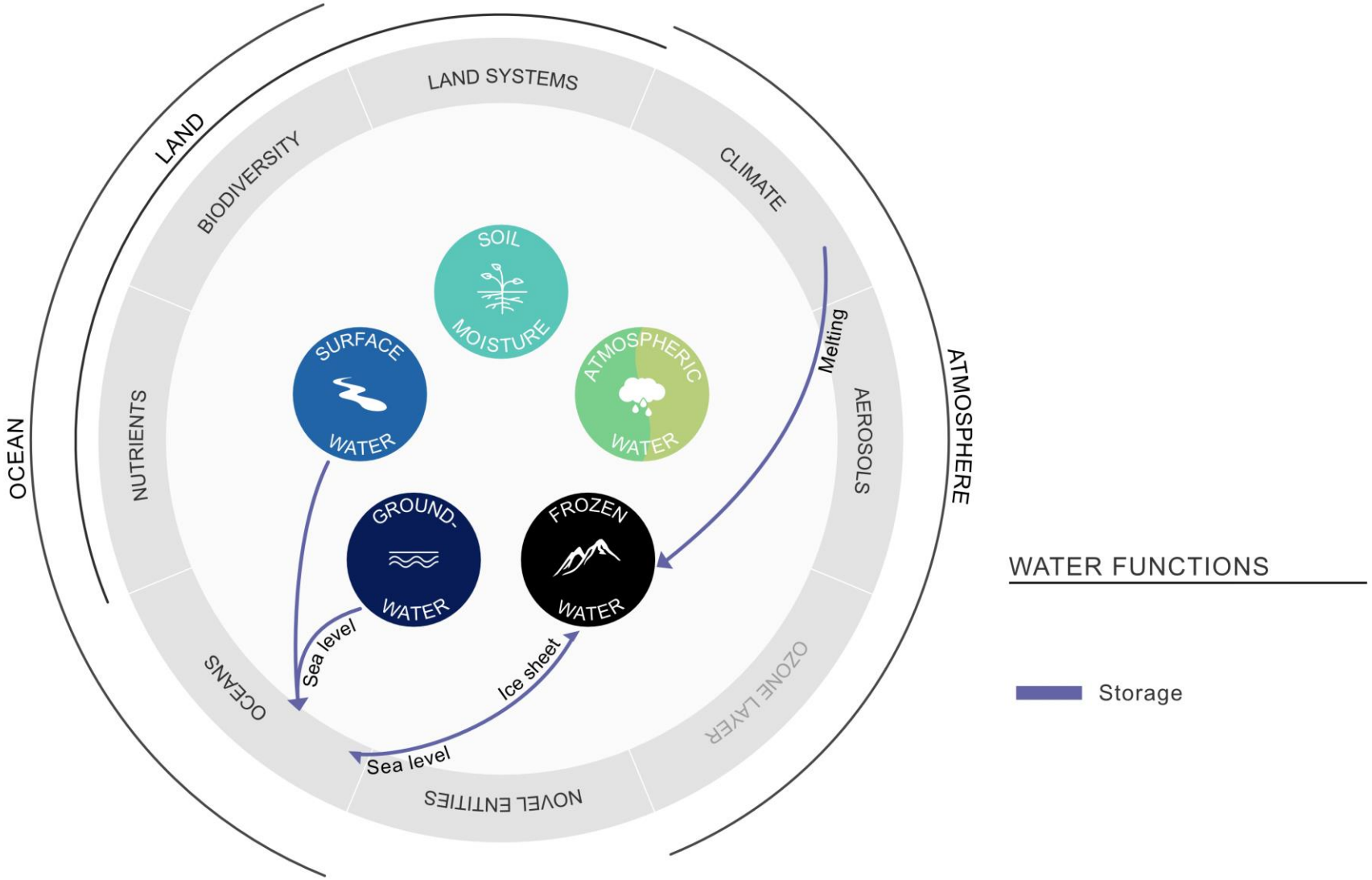
# Hydroecologic regulation function



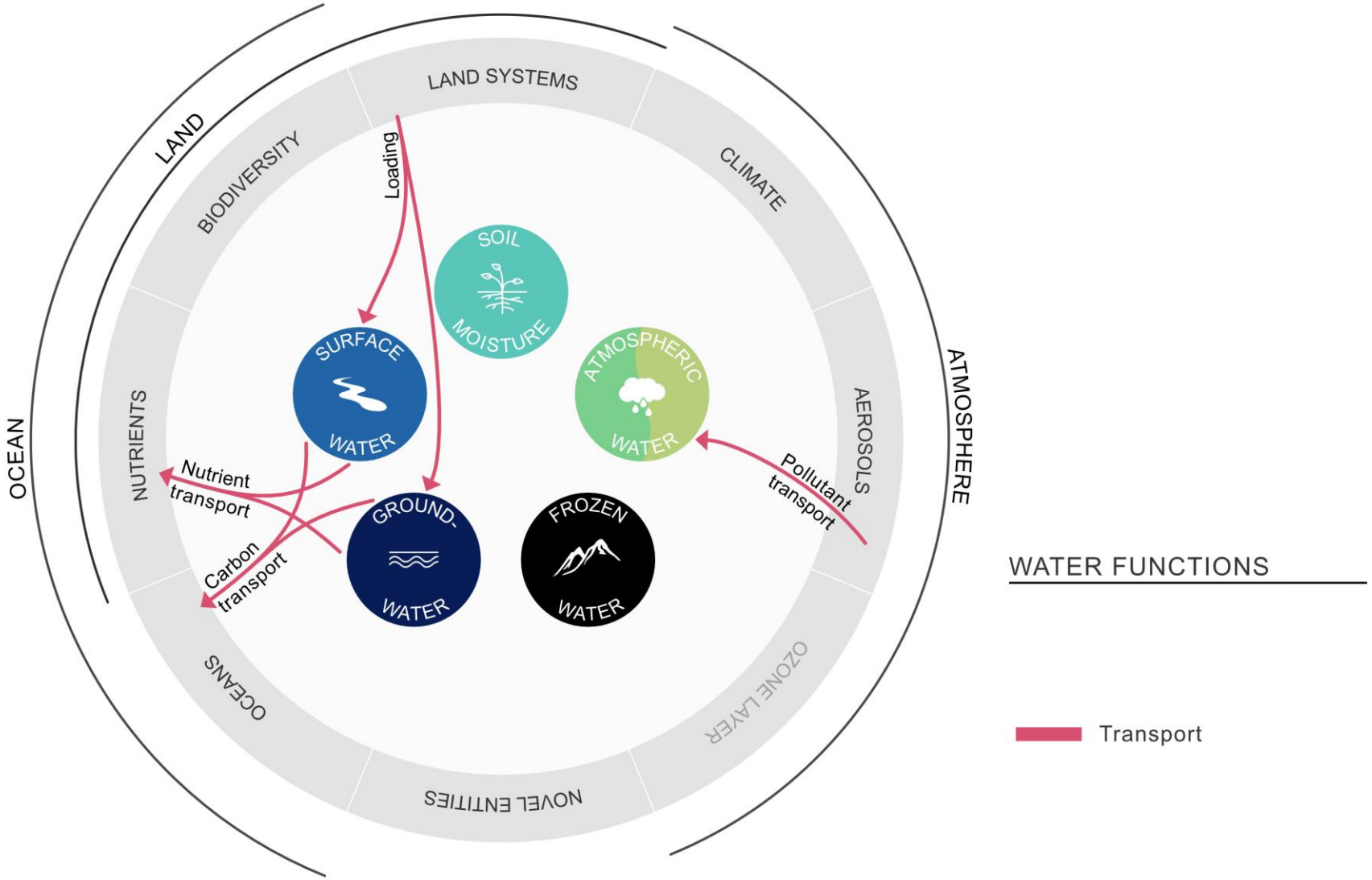
Gleeson et al., (2020), One Earth
Adapted by Miina Porkka

# Storage function



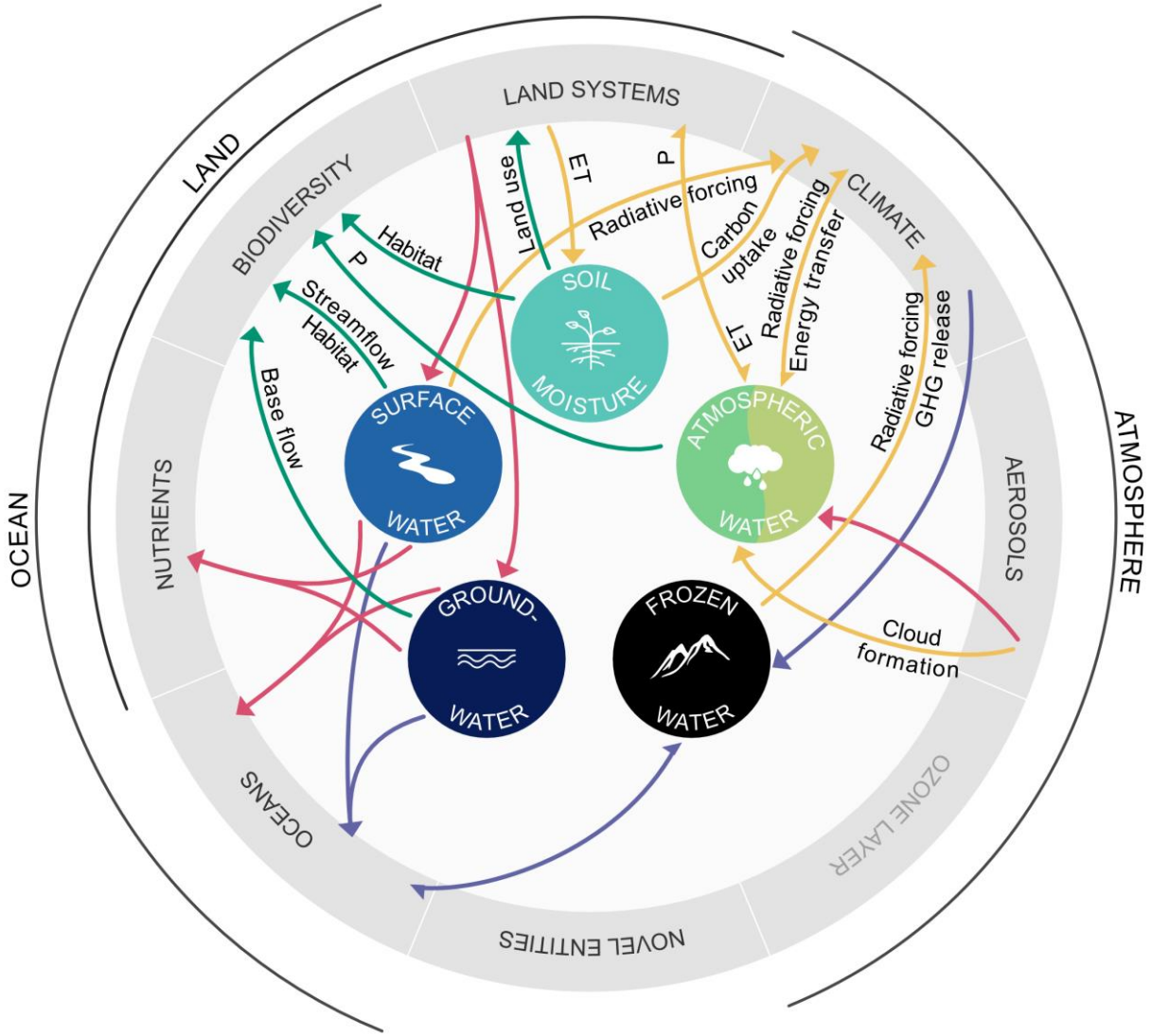
Gleeson et al., (2020), One Earth
Adapted by Miina Porkka

# Transport function



Gleeson et al., (2020), One Earth
Adapted by Miina Porkka

# Key water functions and processes

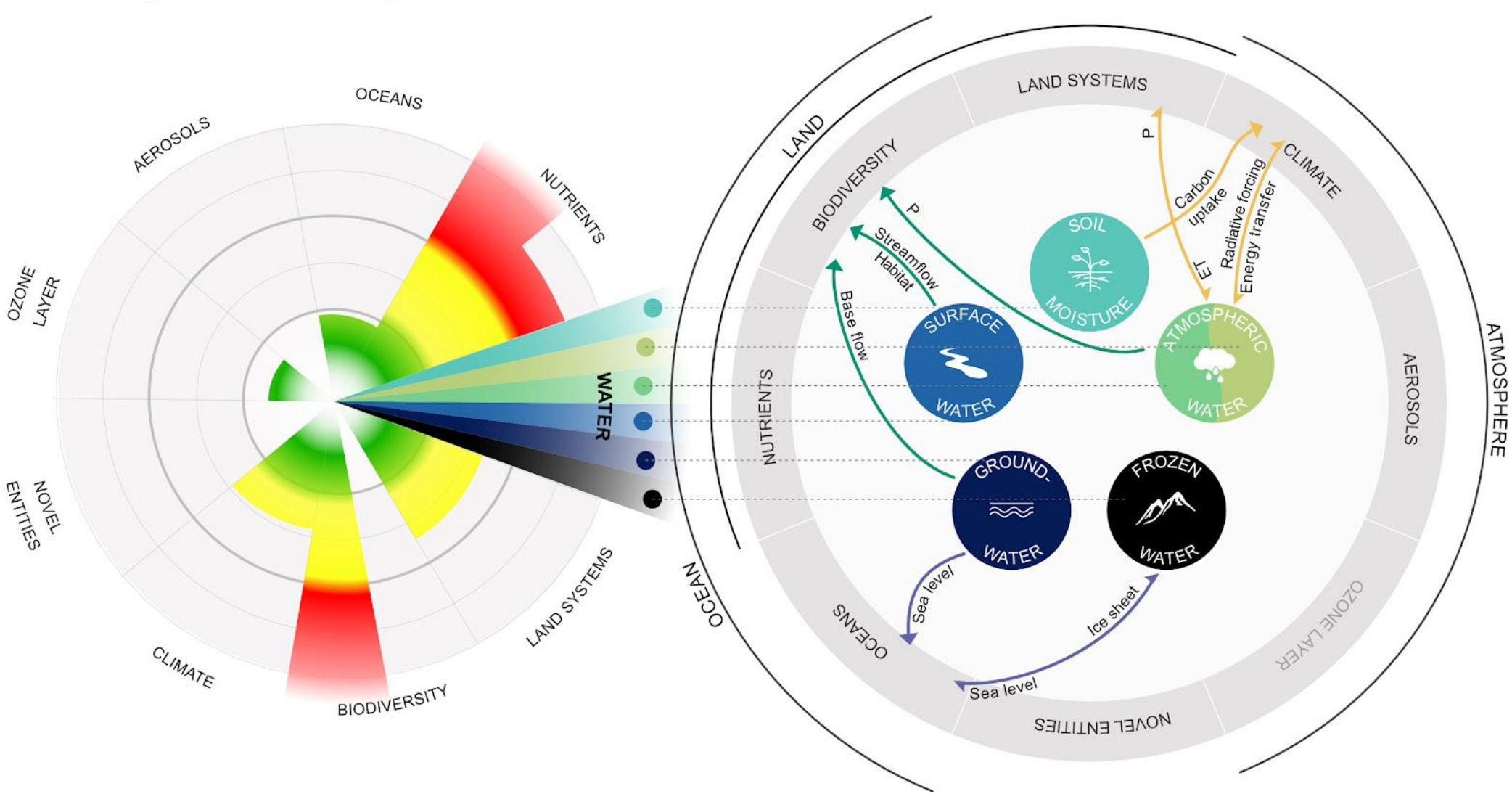



**Most water functions and processes are not represented**

WATER FUNCTIONS

- Hydroclimatic regulation
- Hydroecologic regulation
- Storage
- Transport

Gleeson et al., (2020), One Earth
Adapted by Miina Porkka



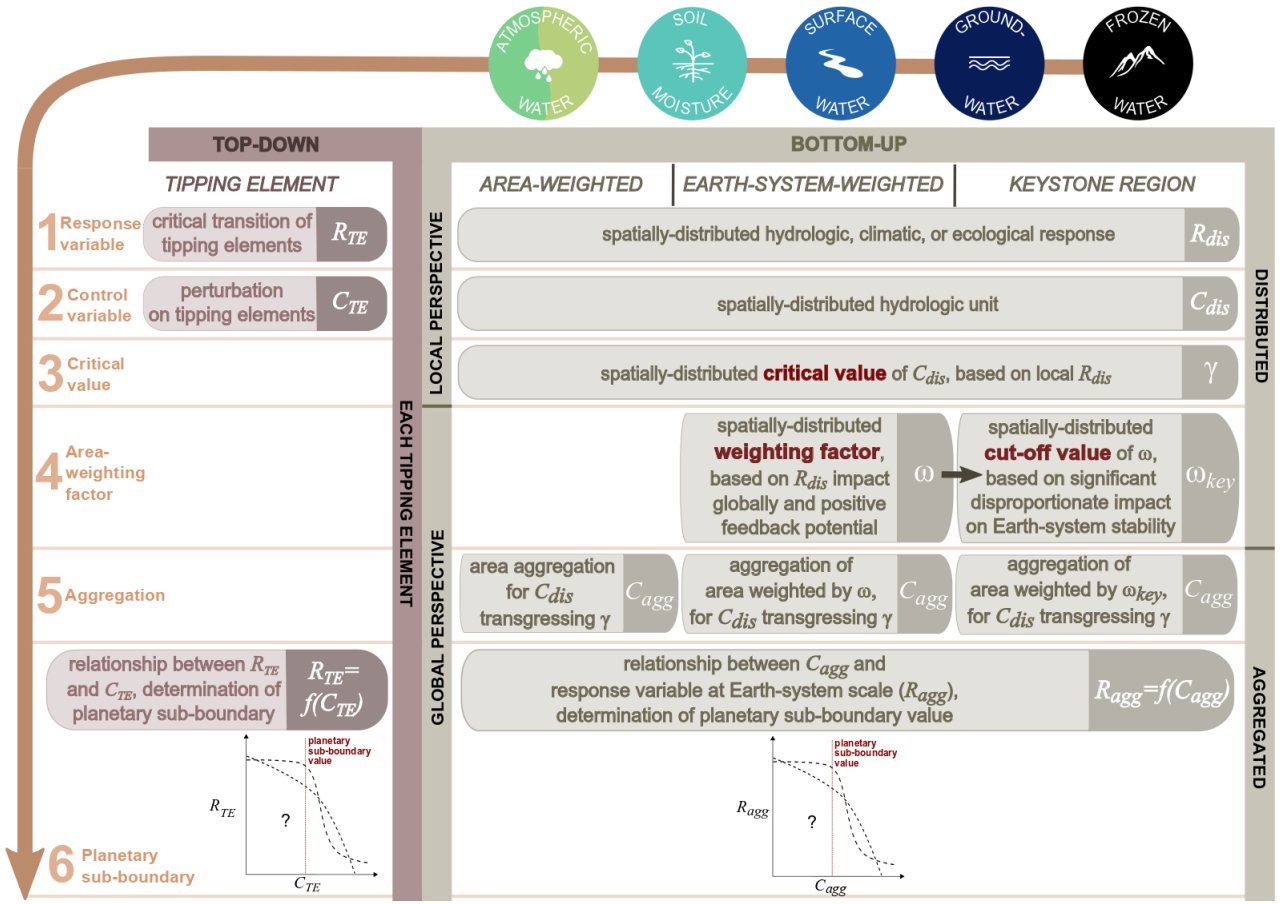
# Approaches

**Top-down approach**

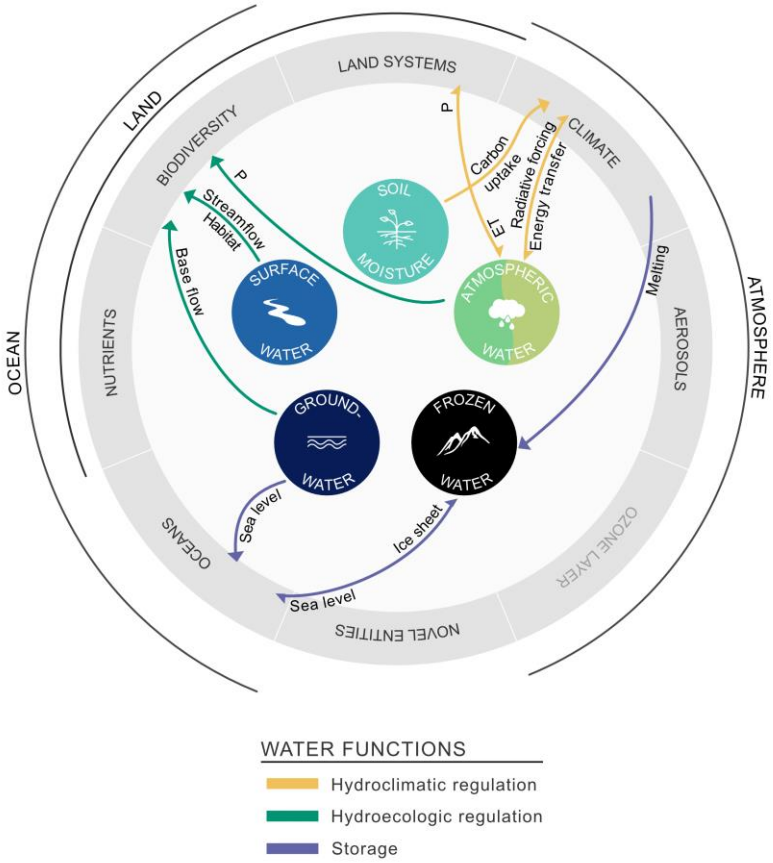
- Tipping element (e.g., Lenton et al., 2008)
- Biome based (e.g., Land system PB, Steffen et al.., 2015)
- Process based (e.g., Carpenter and Bennett, 2011)

**Bottom-up approach**

- Non-weighted
- Weighted
- Keystone region



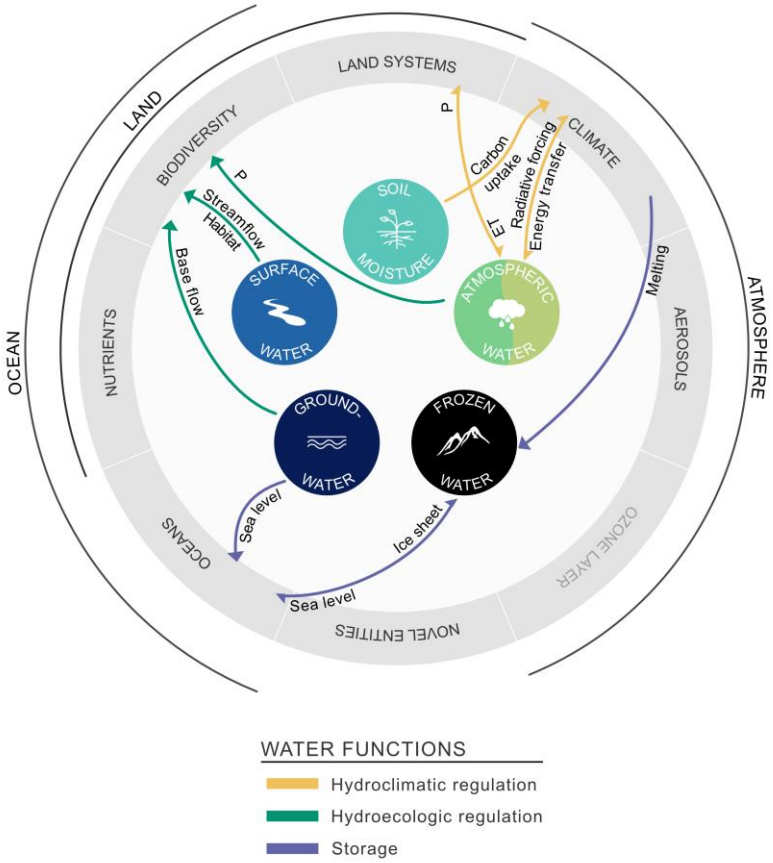
# Alt A: 6 sub-boundaries




Gleeson et al., (2020), One Earth

| | | |
|---|---|---|
| Evaporation change | ATMOSPHERIC WATER | Climate pattern stability |
| Precipitation change | ATMOSPHERIC WATER | Terr. biosphere integrity |
| Net primary production | SOIL MOISTURE | Carbon uptake |
| Basins within environmental flow limits | SURFACE WATER | Aquatic biosphere integrity |
| Basins with low flows | GROUNDWATER | Biosphere integrity or sea level rise |
| Volume of ice melt | FROZEN WATER | Sea level rise |

# Our suggestion




Gleeson et al., (2020), One Earth

# Alt B: 2 sub-boundaries

## Green water PB

| | | |
|---|---|---|
| Evaporation change | ATMOSPHERIC WATER | Climate pattern stability |
| Precipitation change | ATMOSPHERIC WATER | Terr. biosphere integrity |
| Net primary production | SOIL MOISTURE | Carbon uptake |

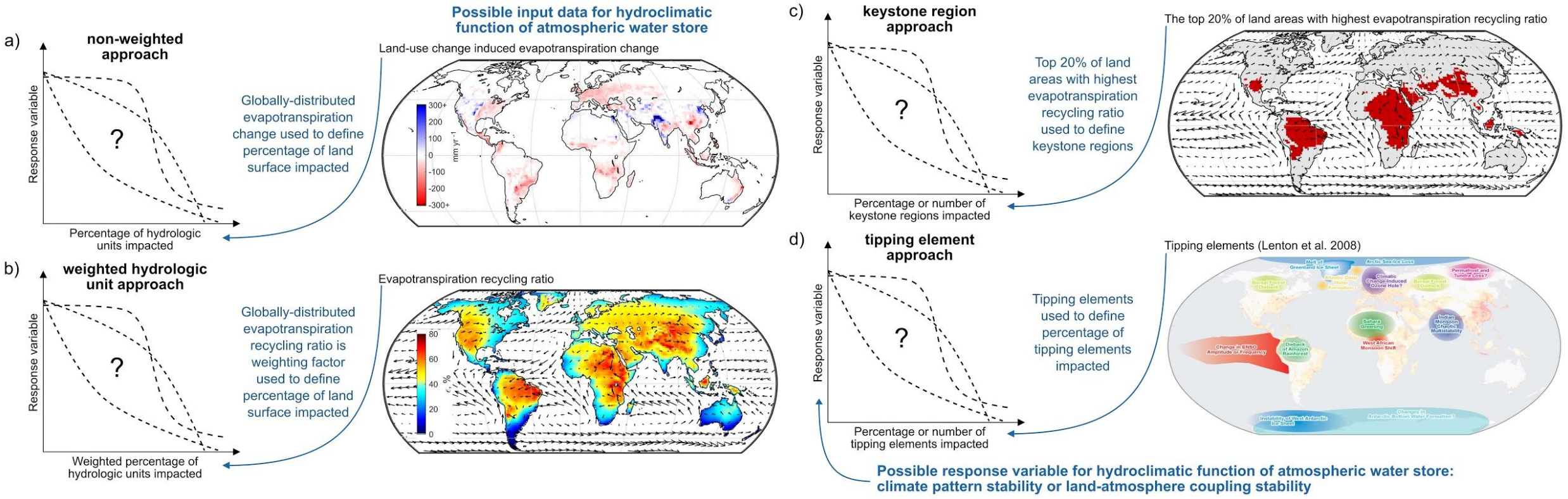
## Blue water PB

| | | |
|---|---|---|
| Basins within environmental flow limits | SURFACE WATER | Aquatic biosphere integrity |
| Basins with low flows | GROUNDWATER | Biosphere integrity or sea level rise |
| Volume of ice melt | FROZEN WATER | Sea level rise |

→ *Climate change PB*

Gleeson et al., (2020), WRR

# Example of aggregation approaches

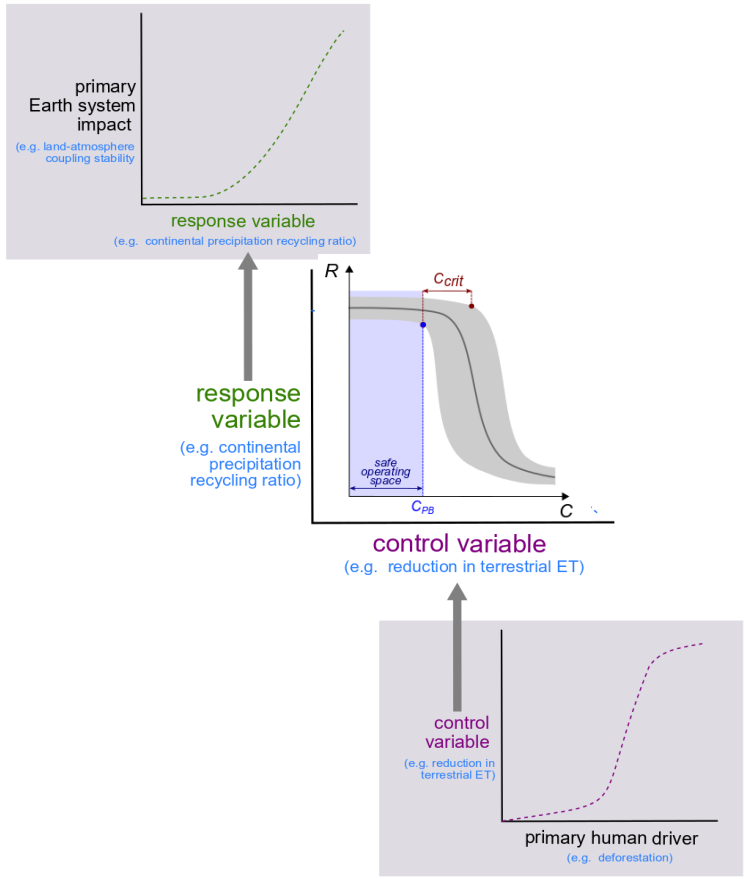


# Water PB variables to be determined

- Control variable
- Response variable(s)
- (Weighting factor for aggregation)

Values:

- Baseline (Holocene-like/pre-industrial)
- Uncertainty zone around critical value
- Safe boundary of the safe operating space



Adapted from Gleeson et al., (2020), One Earth and DuBois, T., Cornell, S, et al. in prep.

# What makes up a good water PB?

**Scientific criteria**

- ***Holocene-Anthropocene transition:*** Is the control variable a robust tracker of anthropogenic perturbation away from a Holocene-like baseline condition?
- ***Impacts on Earth system stability***: Does the water PB draws on the best available evidence of how water cycle modifications can impact Earth's stability?

**Scientific Representation Criteria**

- ***Measurability***: Can the status of the control variable be measured, tracked in time, and monitored?
- ***Actionability***: Does the water PB design maximize potential for active policy management?
- ***Parsimony***: Does the water PB design minimize overlaps and redundancy with other planetary boundaries?

Wang-Erlandsson, et al., in prep.

# Green water PB

- Control variable candidates based on literature review
  - Precipitation, evaporation/evapotranspiration, or soil moisture-related change
  - Annual mean, seasonality, measures of extremes, and/or vegetation stress
- Account for multiple response variables:
  - Long-term carbon uptake and ecosystem impacts.
- Weighting factor candidates:
  - moisture recycling ratio, land-atmosphere coupling feedback hotspots, biodiversity metrics, land carbon uptake hotspots.

Wang-Erlandsson, et al., in prep.

# Water availability in the unsaturated zone as control variable?

- ***Holocene exit characterization***: Need to develop rationale and approach for baseline selection in the absence of detailed knowledge.
- ***Earth system stability impacts***: Key determinant of the land carbon sink (Green et al., 2019), which constitutes a quarter of fossil fuel emissions (Ballantyne et al 2012). Also key determinant of the stability of the Amazon forest, a tipping element of the Earth system (Steffen et al., 2018).
- ***Measurability***: Current values through remote sensing (combined with modelling). Challenges to compare to Holocene or pre-industrial values.
- ***Actionability***: Can be integrated with land, water, and climate policies. Approaches and tools for atmospheric water management are currently being developed (if e.g., moisture recycling is used as weighting factor).
- ***Parsimony***: Often share the same drivers as climate change PB, biosphere integrity PB, and land system change PB. However, land management may influence outcomes not captured by other PBs.

*Work in progress to detail the PB variables and values. Discussion welcome!*

Wang-Erlandsson, et al., in prep.

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**Other**

- Ballantyne A et al, 2012, Increase in observed net carbon dioxide uptake by land and oceans during the past 50 years. Nature. 488 70–2
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