SIXTH ASSESSMENT REPORT
Working Group I – The Physical Science Basis

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# Recent and future water cycle changes Highlights from the AR6 WG1


Hervé Douville (Météo-France/CNRM)

Contact: herve.douville@meteo.fr


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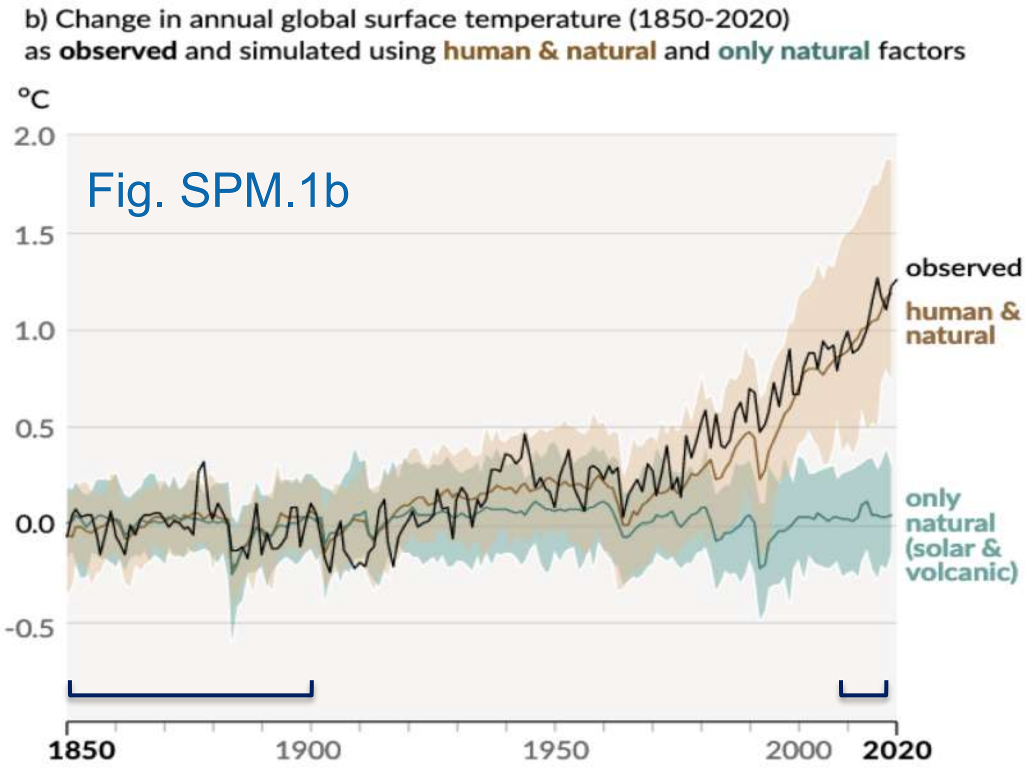
**Chapter 8 (Water cycle changes)**
**16 authors and 2 chapter scientists**
**1915 scientific publications assessed**
**4769 review comments addressed**

# Human influence has warmed the climate



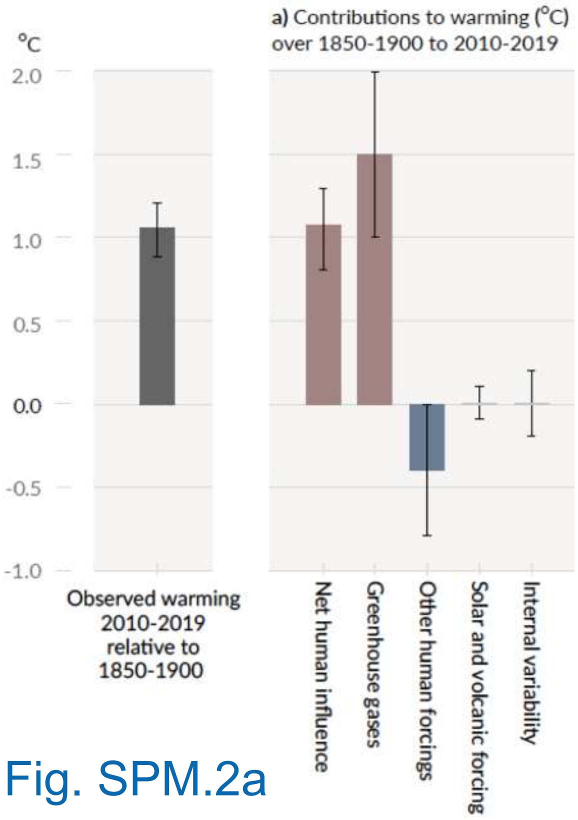
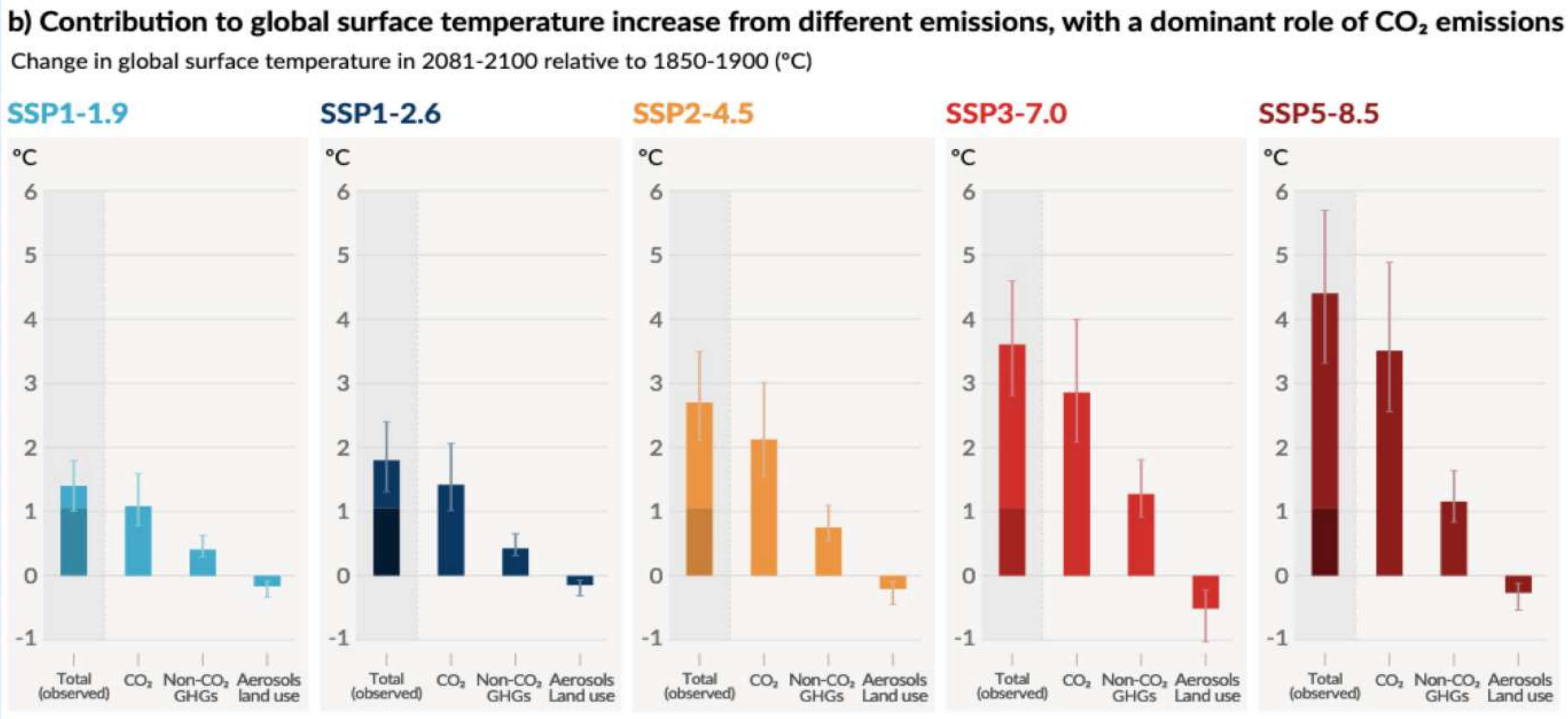
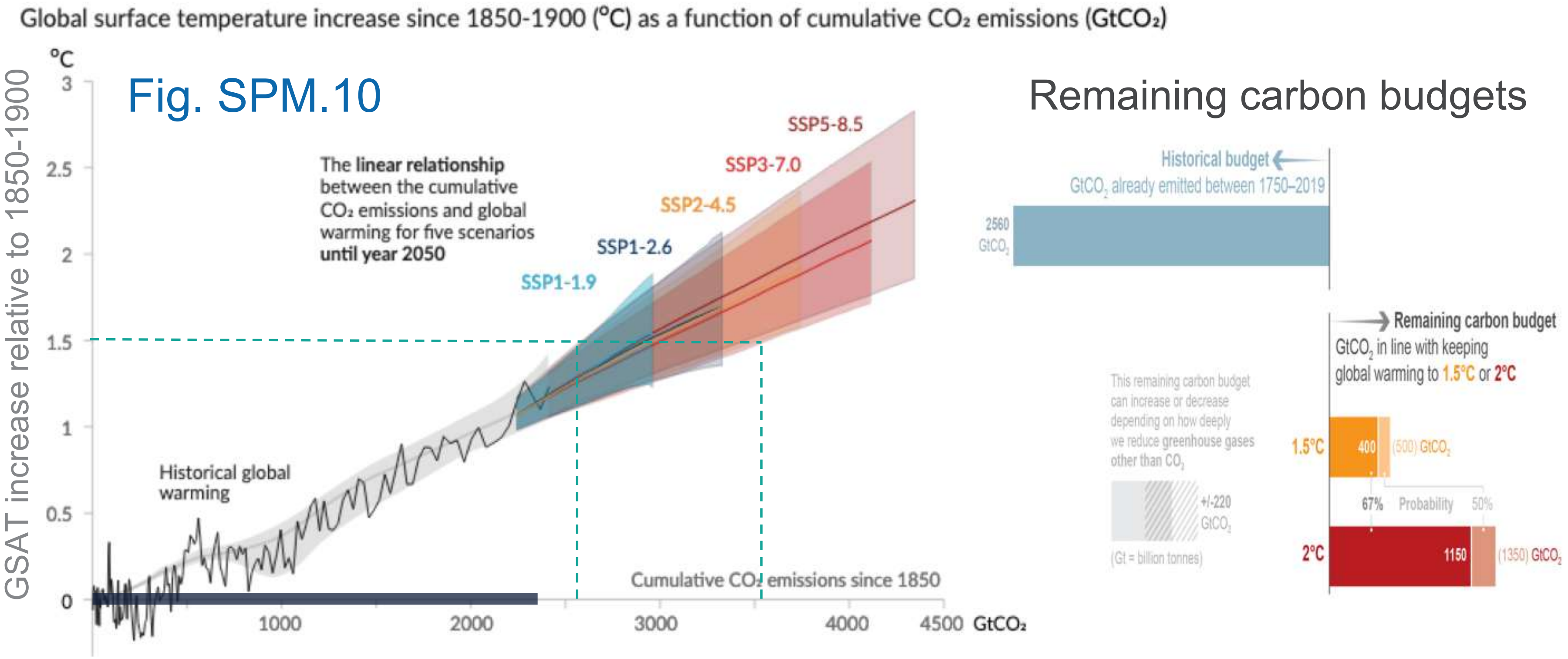




Fig. SPM.2a

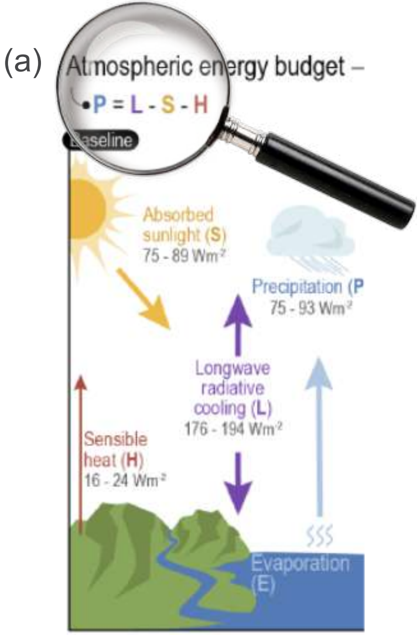
# Future emissions cause future additional warming (Fig. SPM.4b)



# Every tonne of CO2 emissions adds to global warming (Fig. SPM.10)




# “Why should we expect water cycle changes ?




GHG

AER

LULC

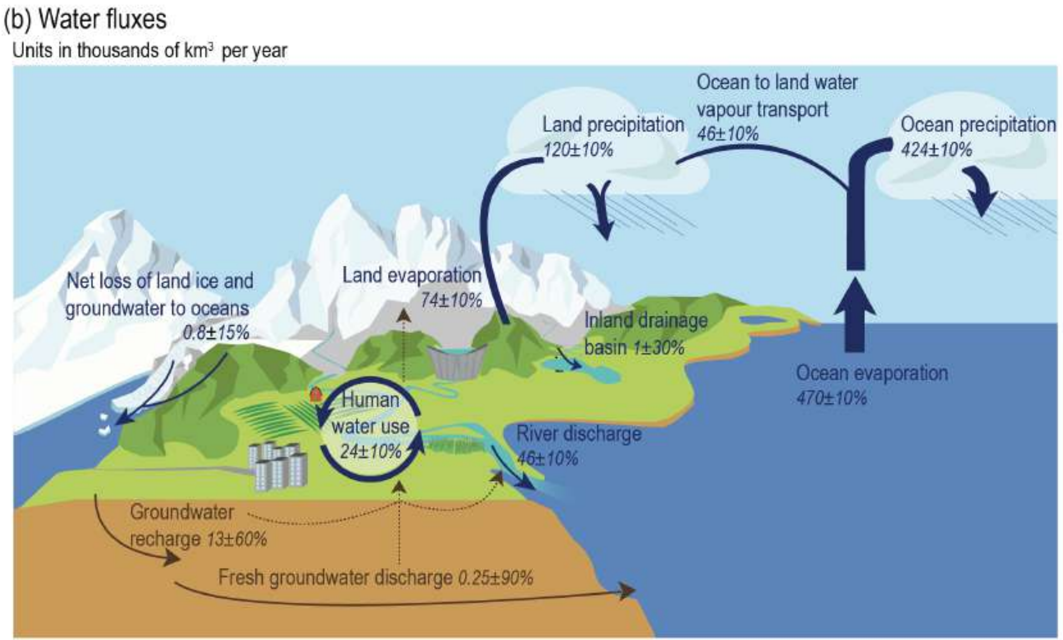



Fig.8.3: Coupling with the atmospheric **energy budget**.

Fig.8.2: Estimates of present-day global water fluxes with an **increasing human water use** (see also Abbott et al., 2018)

- Increase in near-surface atmospheric **water holding capacity** of about 7% per 1°C of warming (*high confidence*).
- Increase in **moisture transport** from evaporative to high precipitation regions over the ocean (*high confidence*).
- Greater warming over land than ocean drives an increase in **atmospheric evaporative demand** (*high confidence*).
- Global warming can also alter **atmospheric circulation patterns**: narrowing & strengthening of ITCZ core, weakening of tropical circulations, poleward shift in storm tracks, …

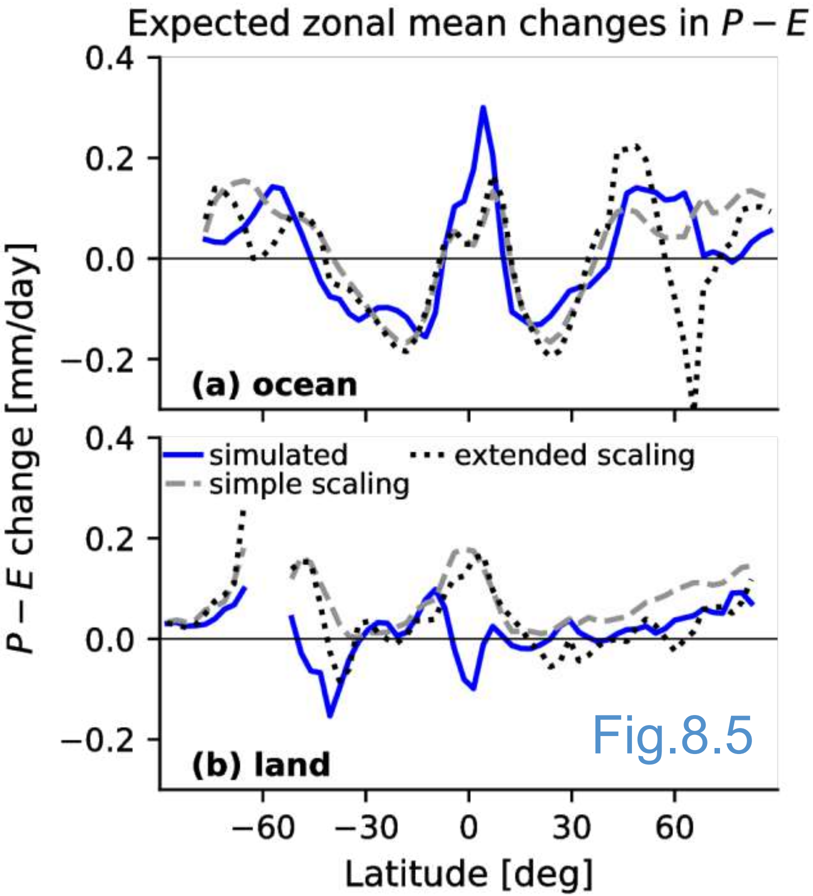



Fig.8.5


# "How is the water cycle changing, and why ?

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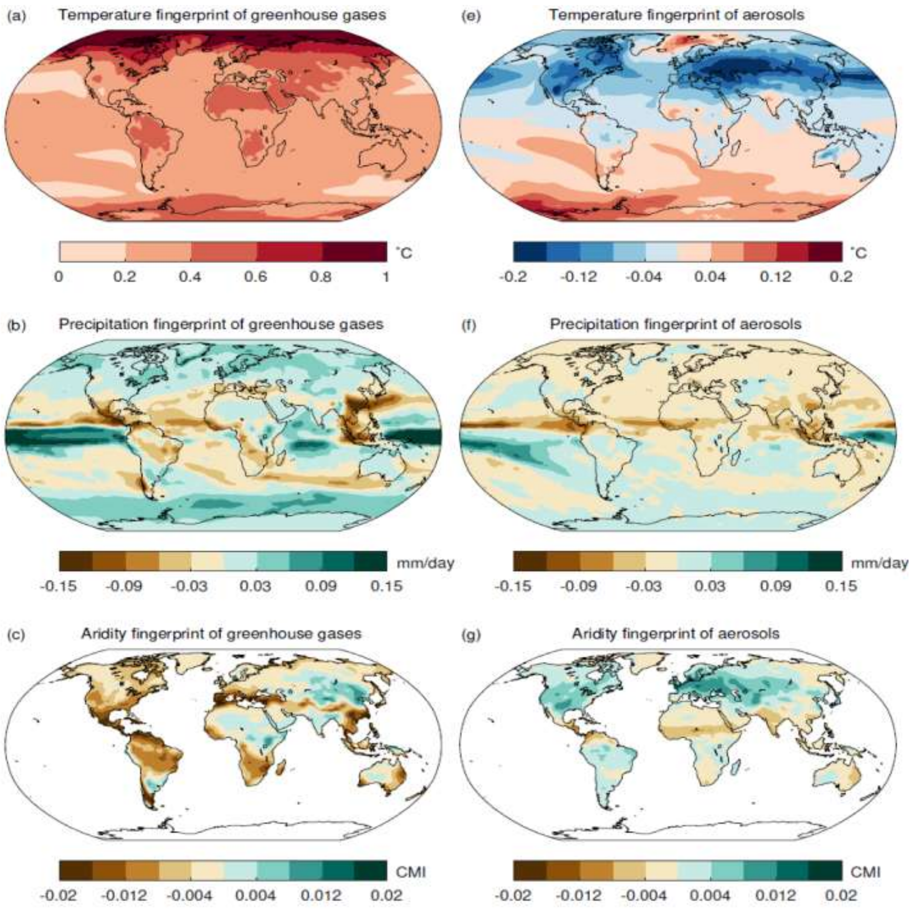



- **Left**: The ongoing warming influence of GHGs is associated with contrasted precipitation changes but drives an increase in atmospheric evaporative demand and aridity (*high confidence*).
- **Right**: Shifts in the tropical rain belt are associated with the inter-hemispheric temperature response to the time-evolving radiative influence of aerosols (*high confidence*).

Fig.8.9: Multivariate fingerprints (adapted from Bonfils et al., 2020)

- Evidence of observed changes in extremes has strengthened since AR5 in particular for extremes related to water cycle: precipitation, droughts, tropical cyclones and compound extremes (including dry/hot events and fire weather).
- Human-induced climate change is already affecting many weather and climate extremes in every region across the globe.
- Recent extreme events have been made more likely because of human-induced climate change (including Western Europe floods and Mediterranean fires in 2021).


Heavy precipitation


Floods


Droughts


Storms


Compound

# Heavy precipitation events have increased since the 1950s in almost all regions with observations, and human-induced climate change is *likely* the main driver.

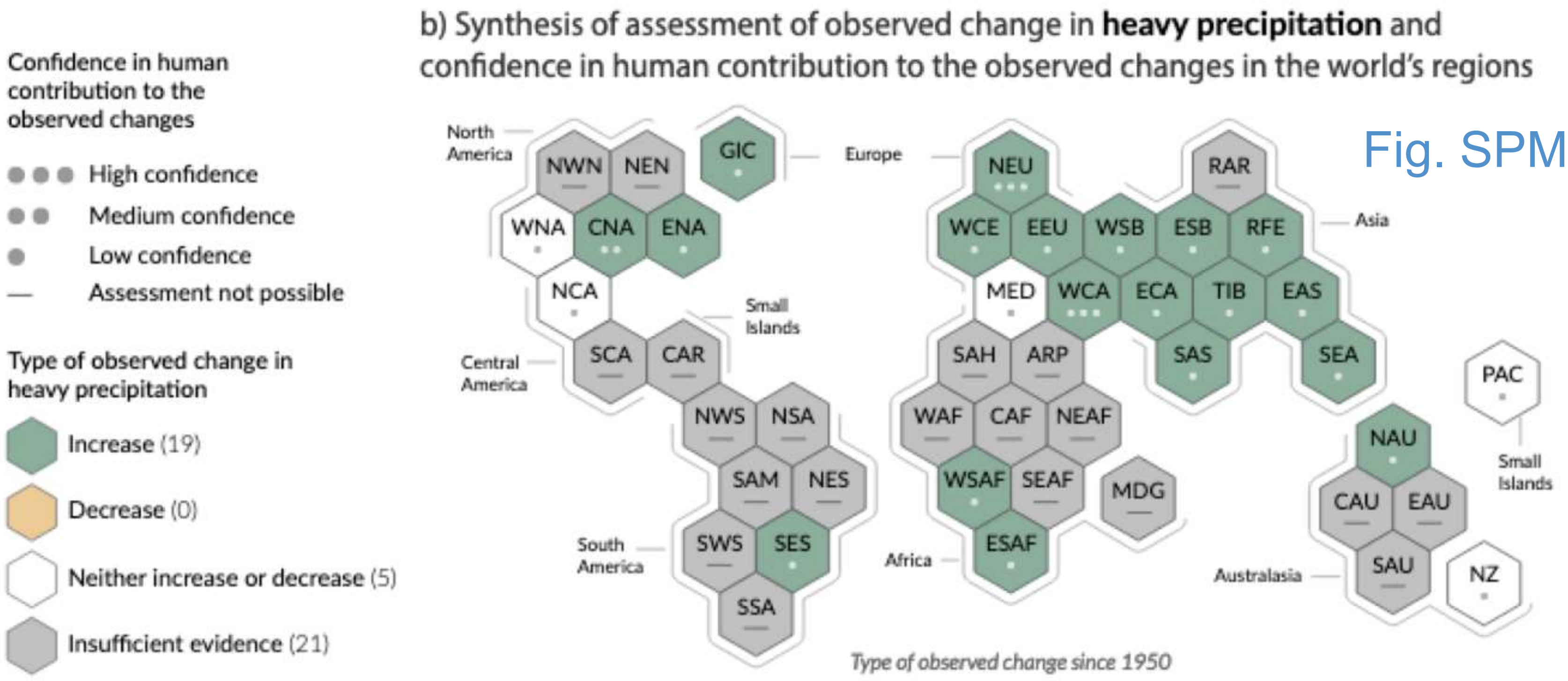
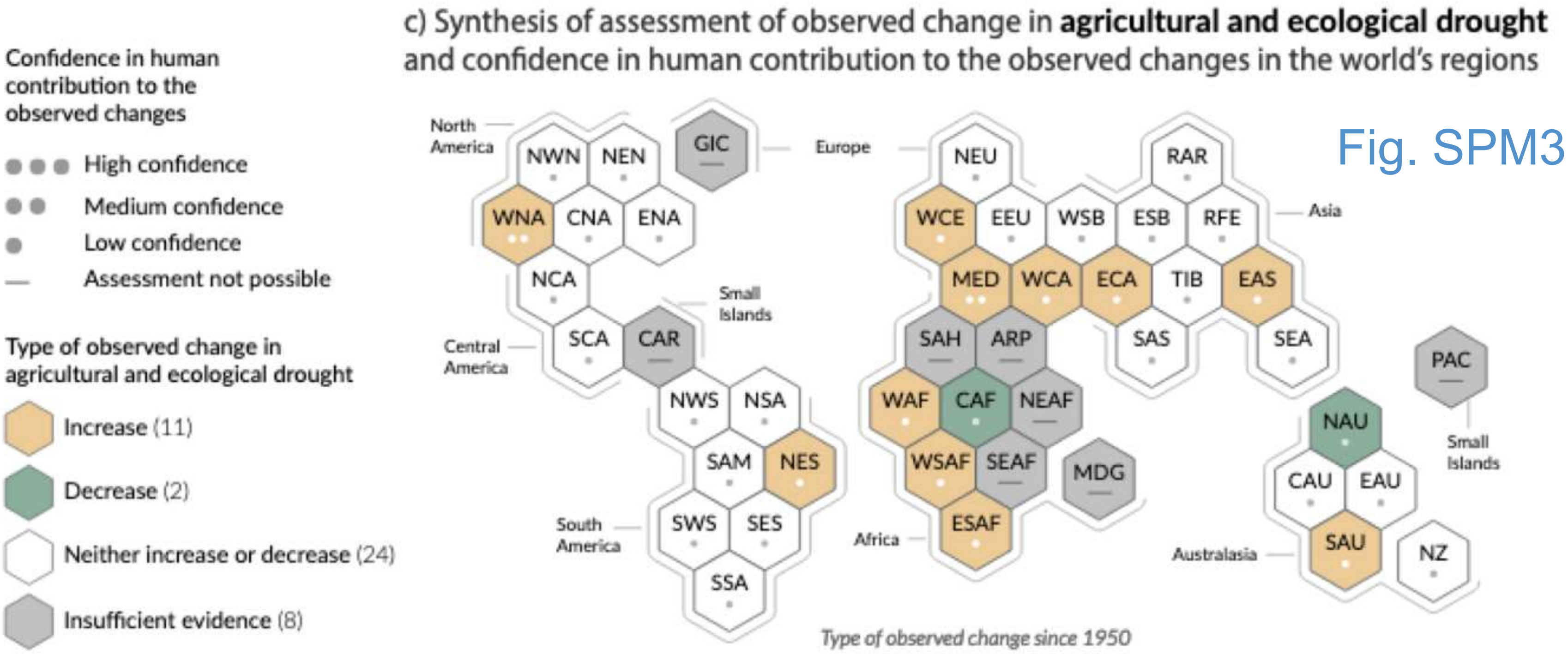



Fig. SPM3b

# Droughts have increased since the 1950s in some regions, mostly due to enhanced evapotranspiration.

Fig. SPM3c



**Land-use change and water extraction for irrigation** have influenced local and regional responses in the water cycle (*high confidence*).

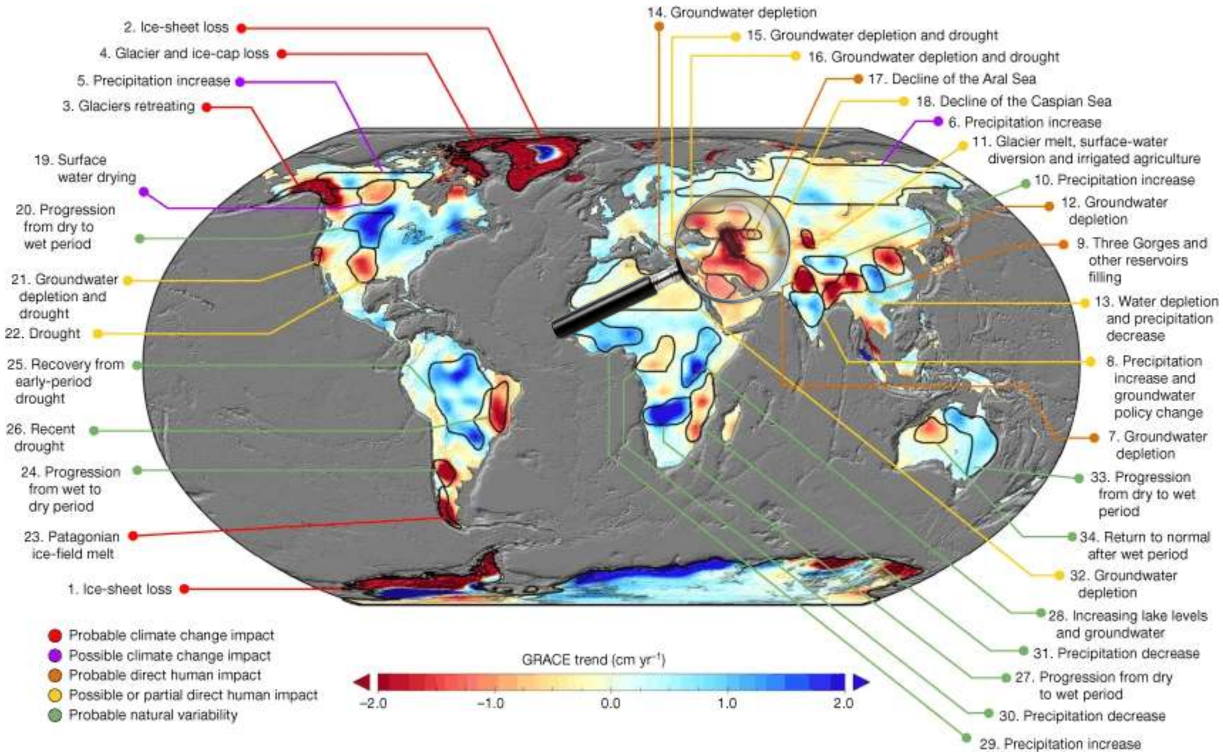



Fig.8.10: Trends in Terrestrial Water Storage (in cm per year) obtained on the basis of GRACE observations from April 2002 to March 2016.


# “What are the projected water cycle changes ?

# Many changes in the global water cycle become larger in direct relation to increasing global warming.

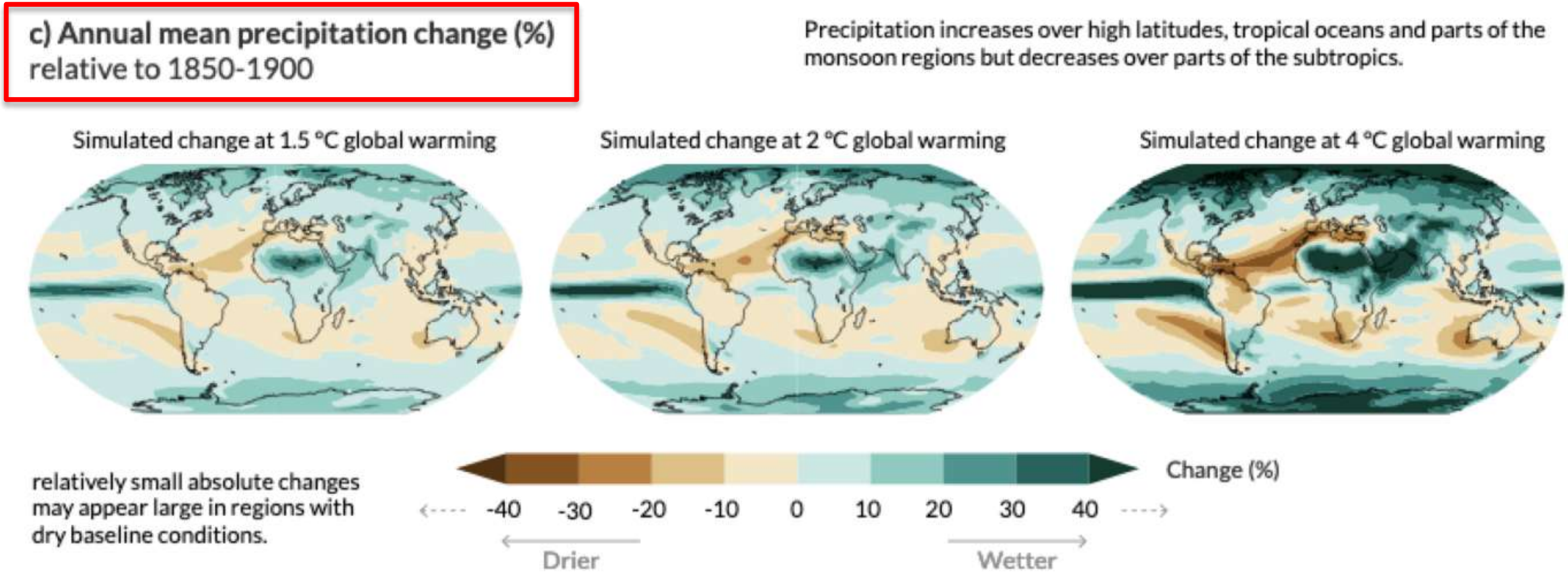



Fig. SPM.5c

# Projected changes in hydrological extremes are larger in frequency and intensity with every increment of global warming (even more for the most rare events)

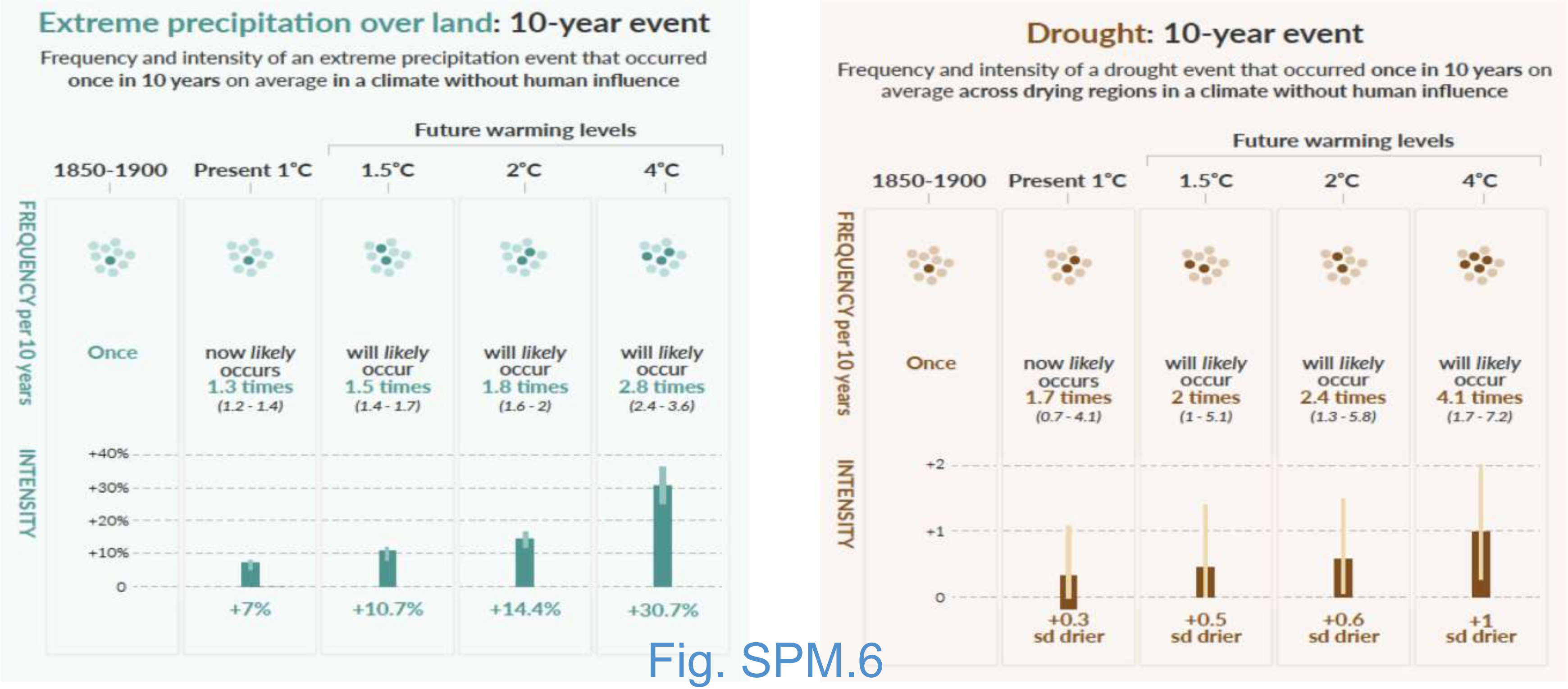
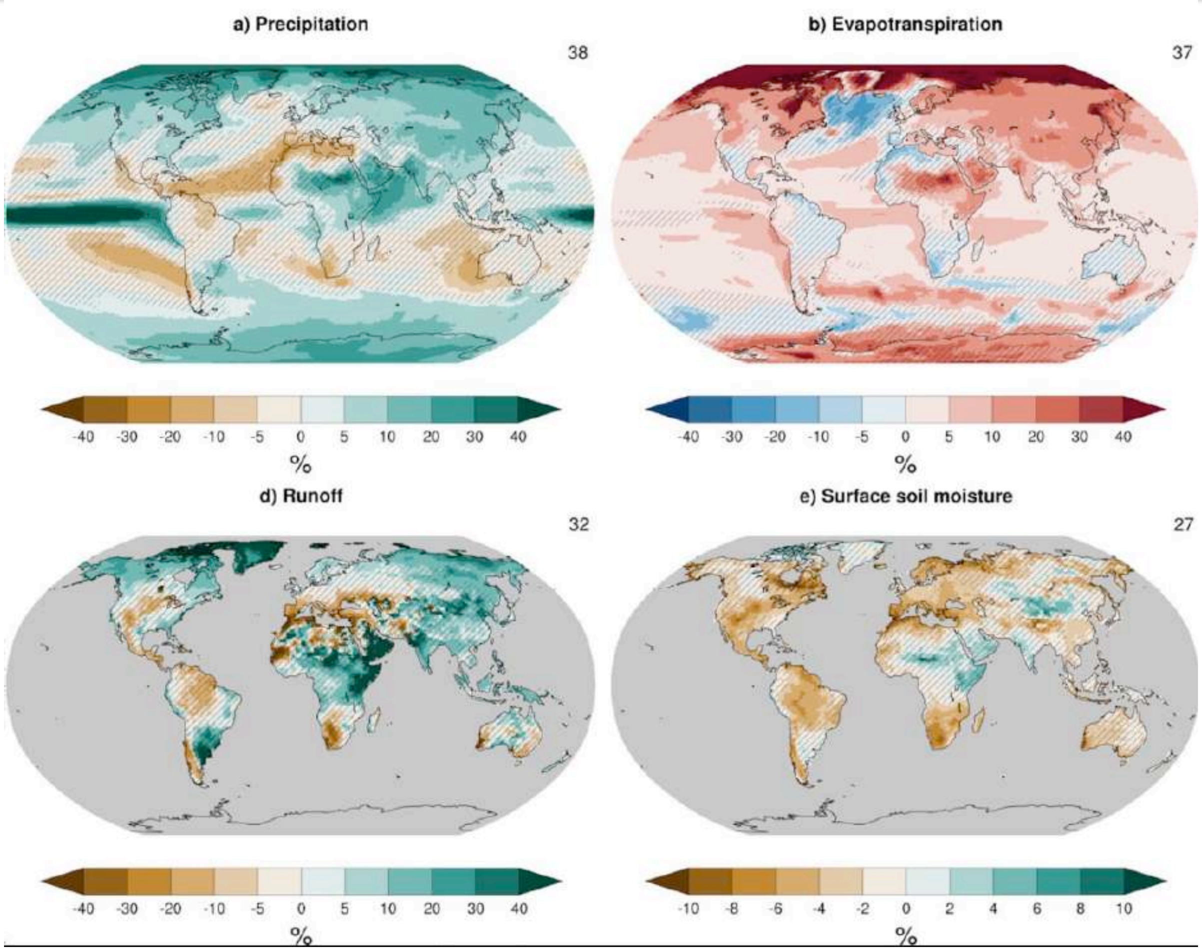



Fig. SPM.6

Beyond changes in precipitation (a) and runoff (d), increased evapotranspiration (b) will decrease soil moisture (e) in many areas (*high confidence*)

# Box TS.6 Fig. 1

Projected annual mean water cycle changes (%) in the SSP2-4.5 scenario (2081-2100 minus 1995-2014)



- The global water cycle will continue to intensify as global temperatures rise (*high confidence*)
- Precipitation and surface water flows are projected to become more variable over most land regions within seasons (*high confidence*) and from year to year (*medium confidence*), especially in the tropics.

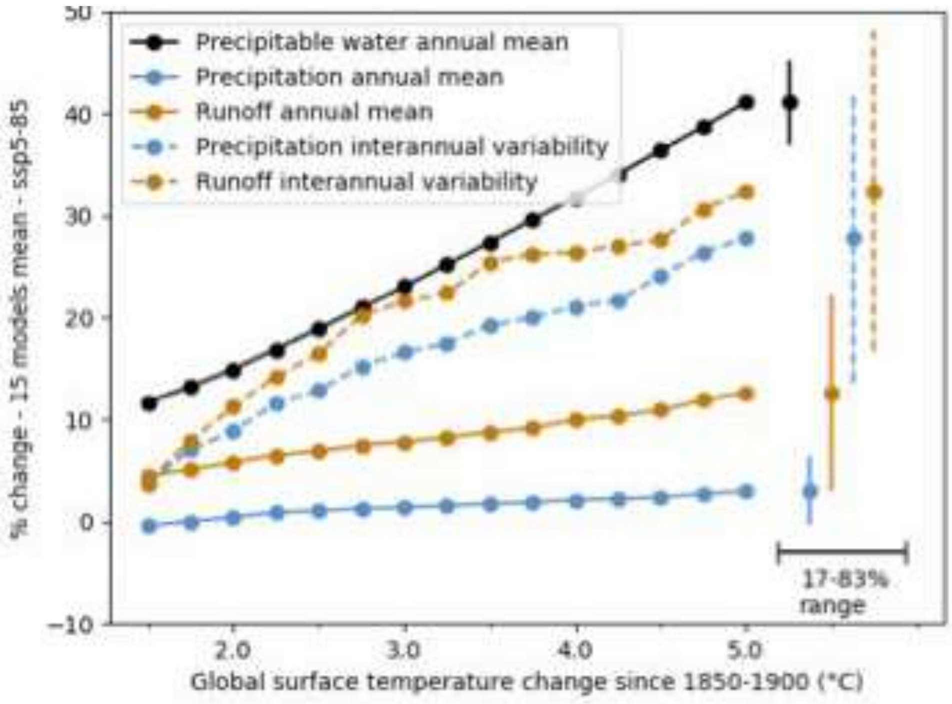



Figure TS.12e (for tropical land)

[Credit: UNESCO]

# “What are the limits for projecting water cycle changes, and what is the potential for abrupt change ?

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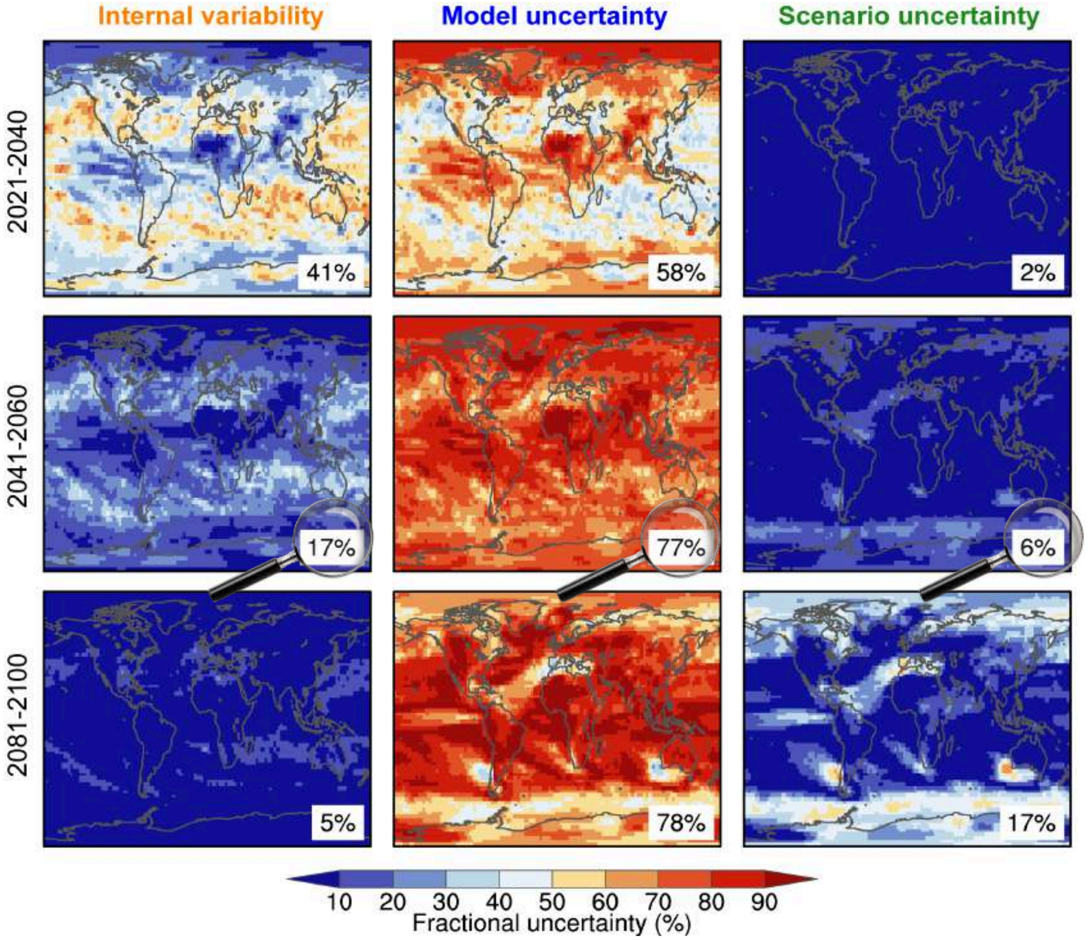
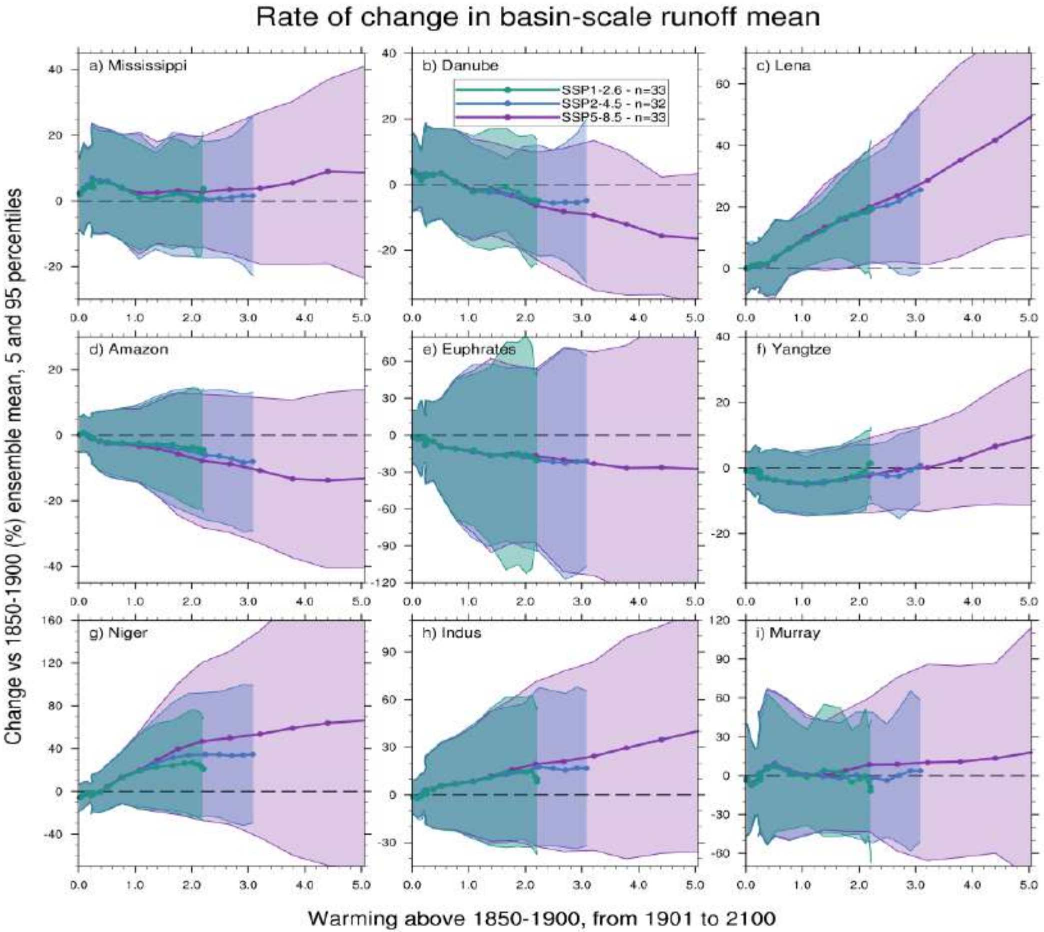
- GCMs are still **limited** in their ability to agree on future changes.
- Climate change studies benefit from sampling the **full distribution** of model outputs when considering future projections.
- **Natural climate variability** will continue to be a major source of uncertainty in the near-term (2021–2040).

Fig.8.23



- Rate of change (%) in **basin-scale annual mean runoff** with increasing global warming levels.
- **Lines** denote the multi-model ensemble median from a subset of CMIP6 models for three SSP scenarios.
- **Shading** indicates the 5-95% confidence interval.

Fig.8.26



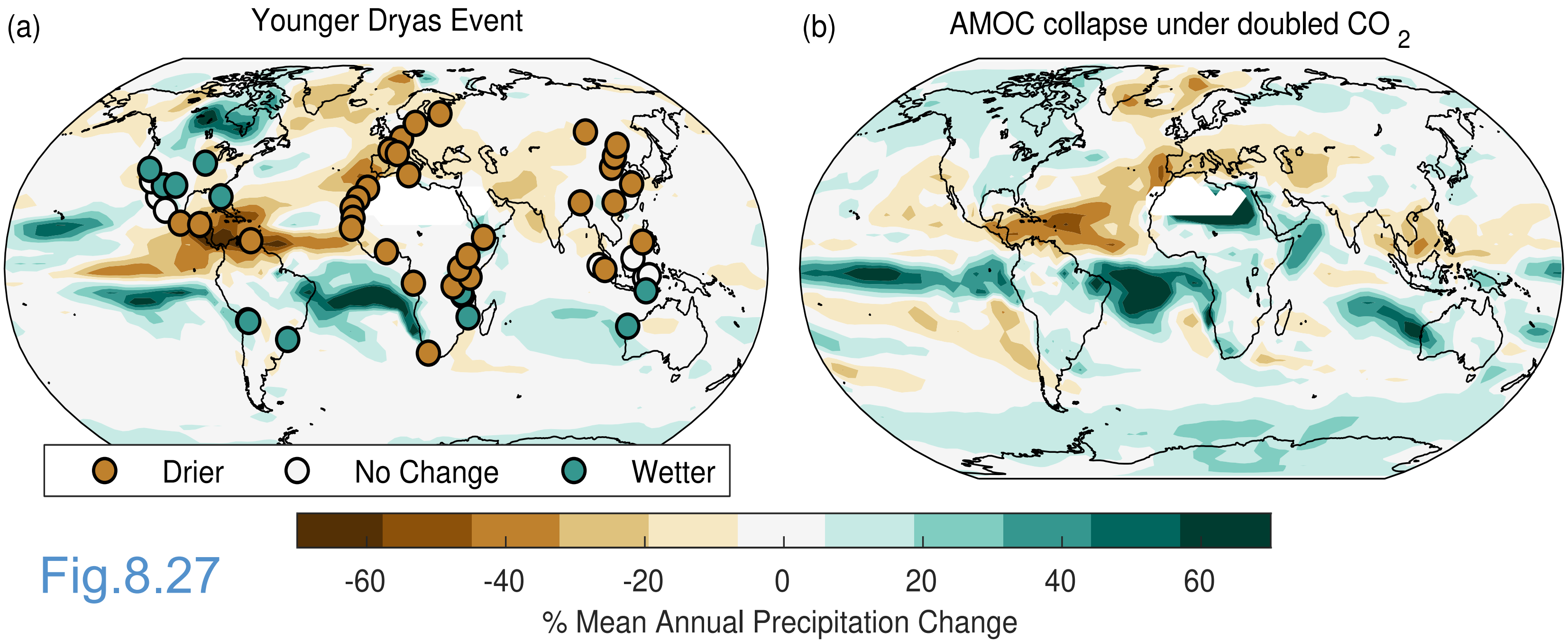
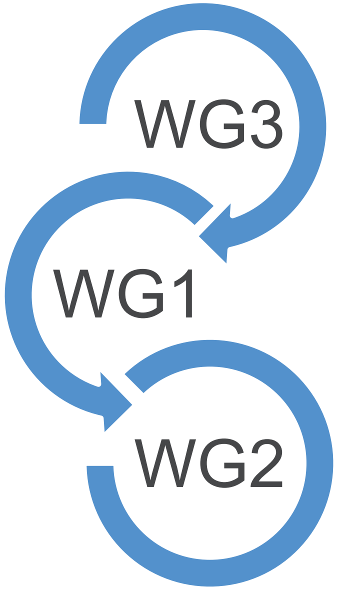



Fig.8.27

There is *medium confidence* that **AMOC** will not collapse before 2100, but should it collapse, it is *very likely* that there would be abrupt changes in the water cycle (as supported by paleoclimate records and simulations).

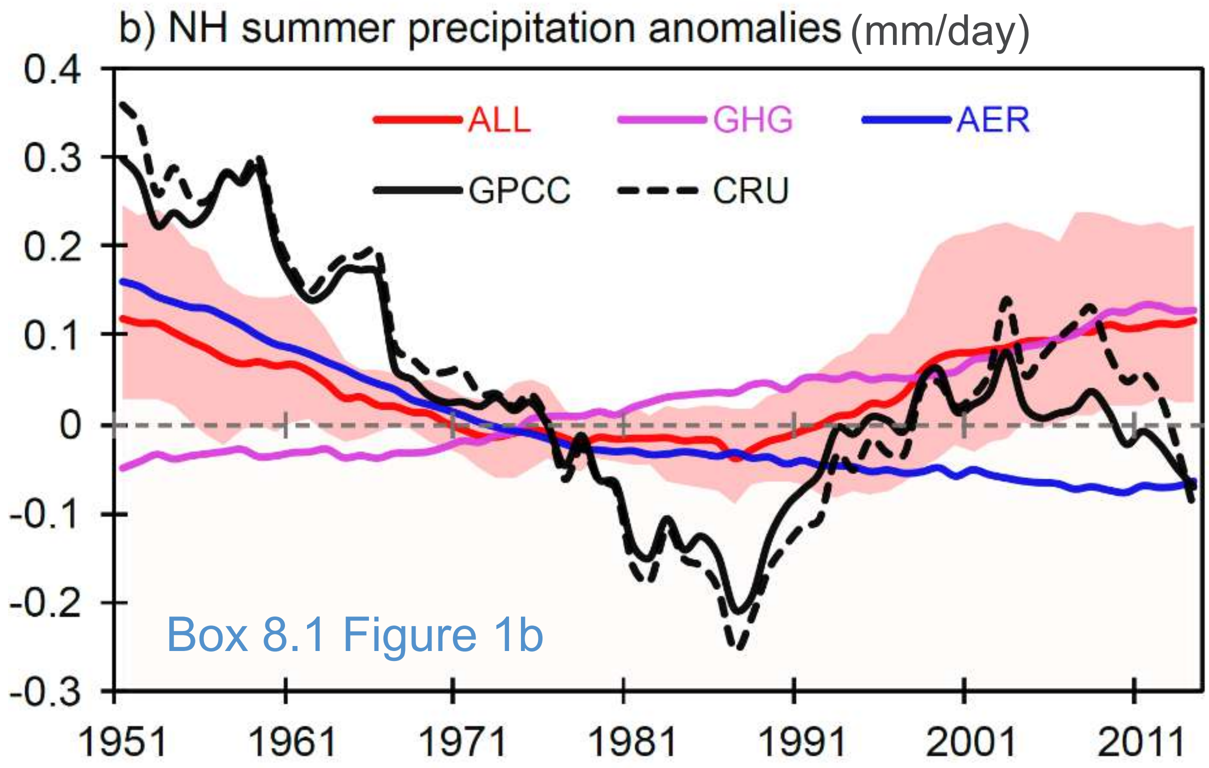

# “Some implications for adaptation & mitigation

- Half the world's population experience severe water scarcity for at least one month per year.
- Adaptation to water-related hazards represent about 60% of current adaptation responses.
- Such hazards will be exacerbated with further global warming, and thus stronger at warming above +1.5°C.
- Careful adaptation responses are needed to avoid maladaptation (*e.g.*, excessive irrigation) and the lack of co-benefits for mitigation (*e.g.*, hydroelectricity).
- Land-based mitigation options may have considerable water footprint (e.g. BECCS, af/reforestation) and also need to be managed carefully.





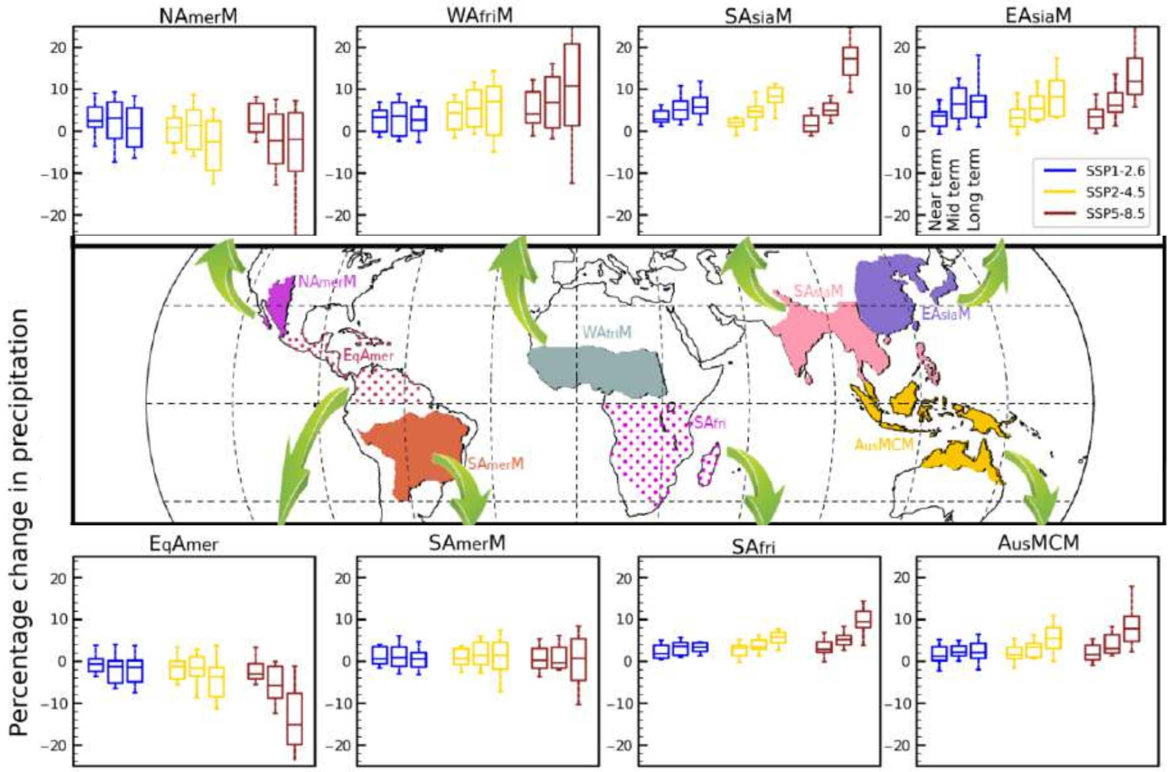
# Extra-slides




Observed and simulated rainfall anomalies due to ALL or individual radiative forcings

## Anthropogenic aerosols

- have driven detectable large-scale water cycle changes since at least the mid-20th century;
- have contributed to the Sahel drought from the 1970s to the 1980s;
- have counteracted GHG-induced changes in regional monsoon precipitation over much of the 20th century (*high confidence*).

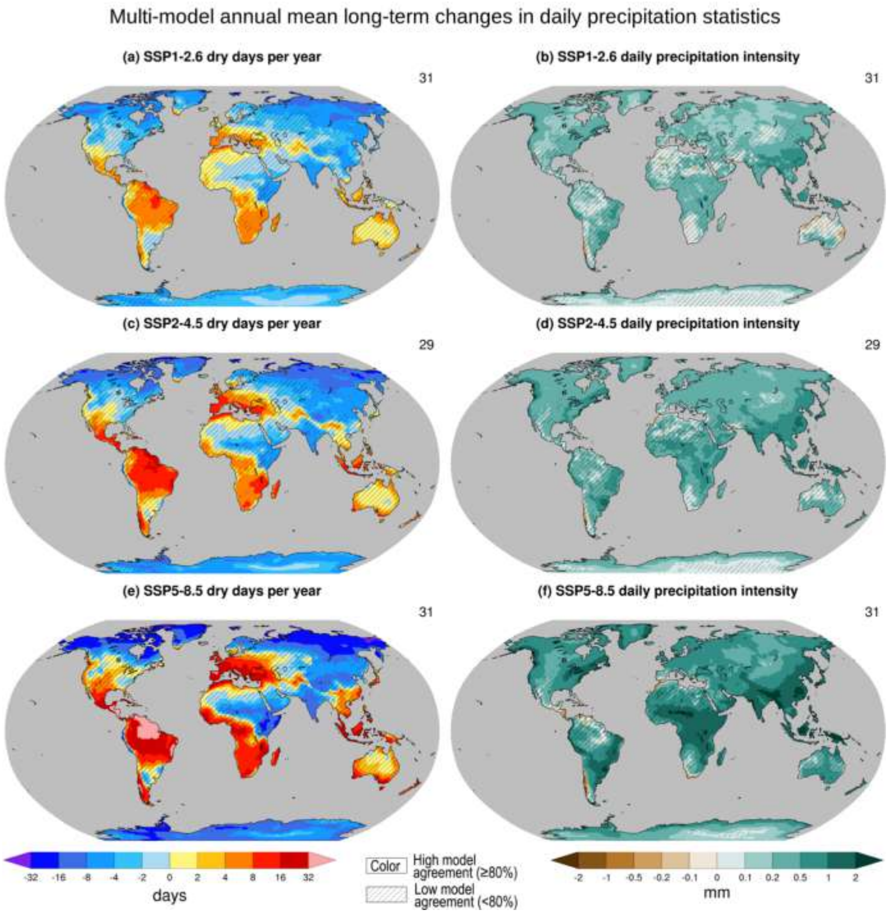



- **Monsoon precipitation** is projected to increase in the mid- to long term at the global scale, particularly over South and Southeast Asia, East Asia and West Africa apart from the far west Sahel (*high confidence*).
- The **monsoon season** is projected to have a delayed onset over North and South America and West Africa (*high confidence*) and a delayed retreat over West Africa (*medium confidence*).

Fig.8.22: Projected changes in seasonal monsoon rainfall.

**Projected long-term relative changes in daily precipitation statistics.** Global maps of projected seasonal mean relative changes (%) in the number of dry days (i.e. days with less than 1 mm of rain) and daily precipitation intensity (in mm/day, estimated as the mean daily precipitation amount at wet days) averaged across CMIP6 models in 3 SSPs.

Fig.8.15



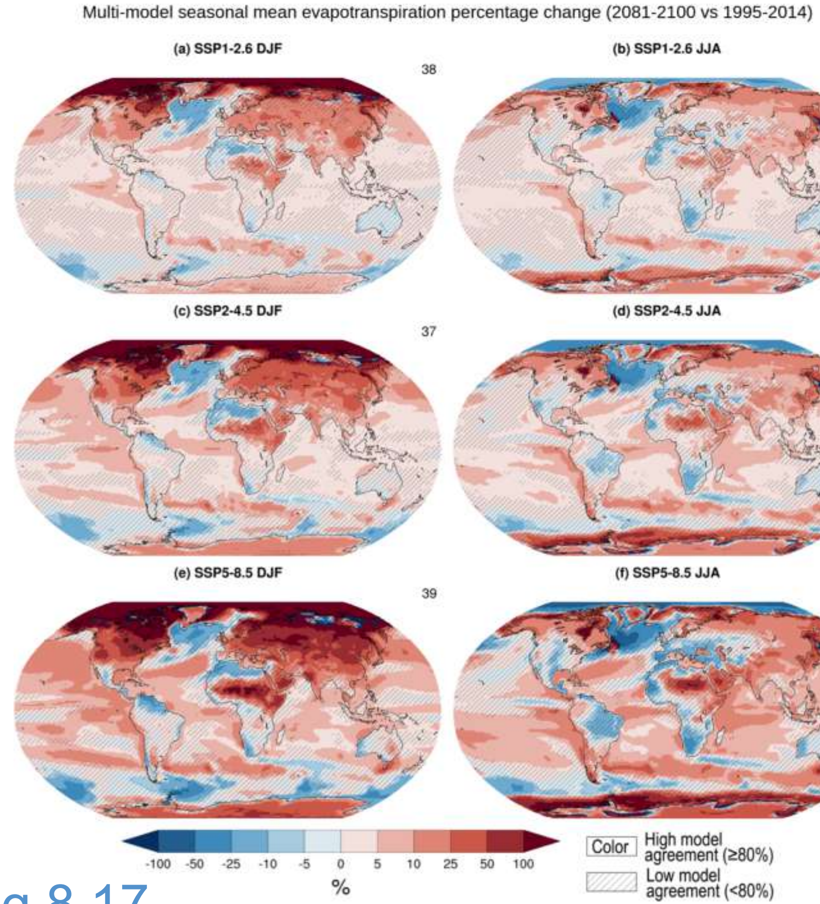



Fig.8.17

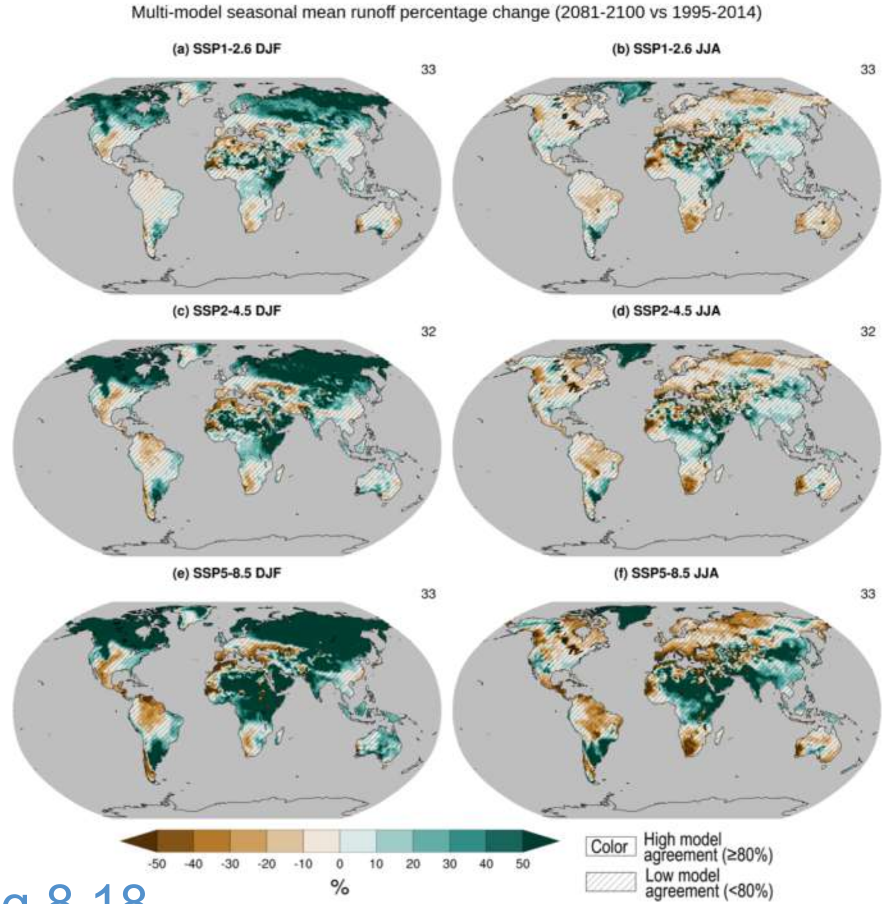



Fig.8.18

Projected long-term relative (%) changes in annual mean **soil moisture and vapor pressure deficit.**

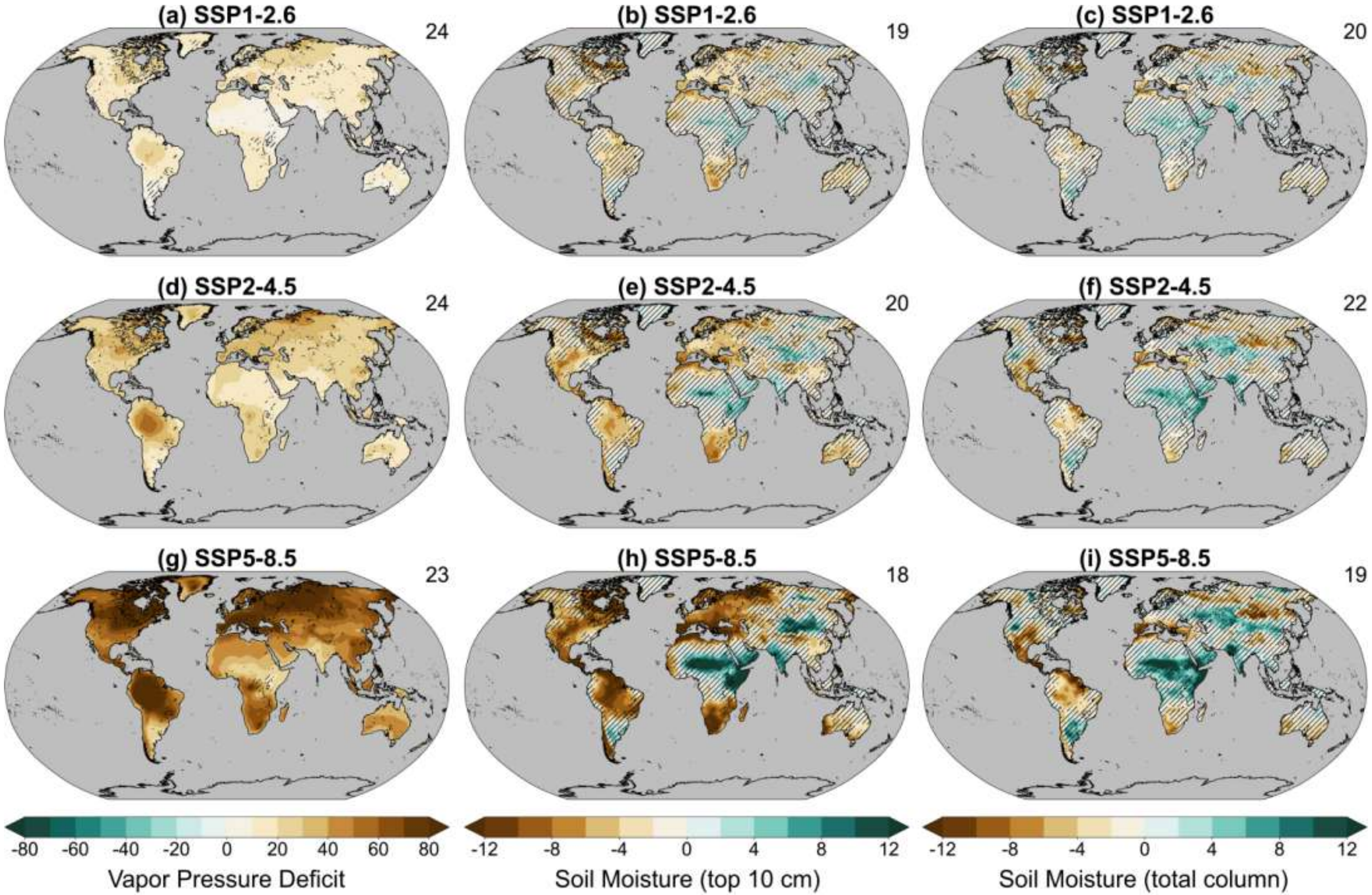



Fig.8.19

- Natural climate variability will continue to be a major source of uncertainty in near-term (2021–2040) water cycle projections (*high confidence*).

- Decadal predictions of water cycle changes should be considered with *low confidence* in most land areas because the internal variability of precipitation is difficult to predict.

Fig.8.24