Evaluation des changements climatiques sur les fonctions hydrologiques à l'échelle régionale

M. Vanclooster

Lérins, France, 11 Juin 2025

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- The multidimensional aspects of water
- The different water pressures
- Impact assessments of CC on hydrological functions at the regional scale
- Some epistemological thoughts about uncertainty.
- Take ahome messages.

The multi-dimensional aspects of water

- Water is blue, green & grey.
- Water is salt, fresh & virtual.
- Water is esssential for the economy and for jobs.
- Water is holy.
- Water is a cross-cutting theme in the development agenda (food – energy – health -…)

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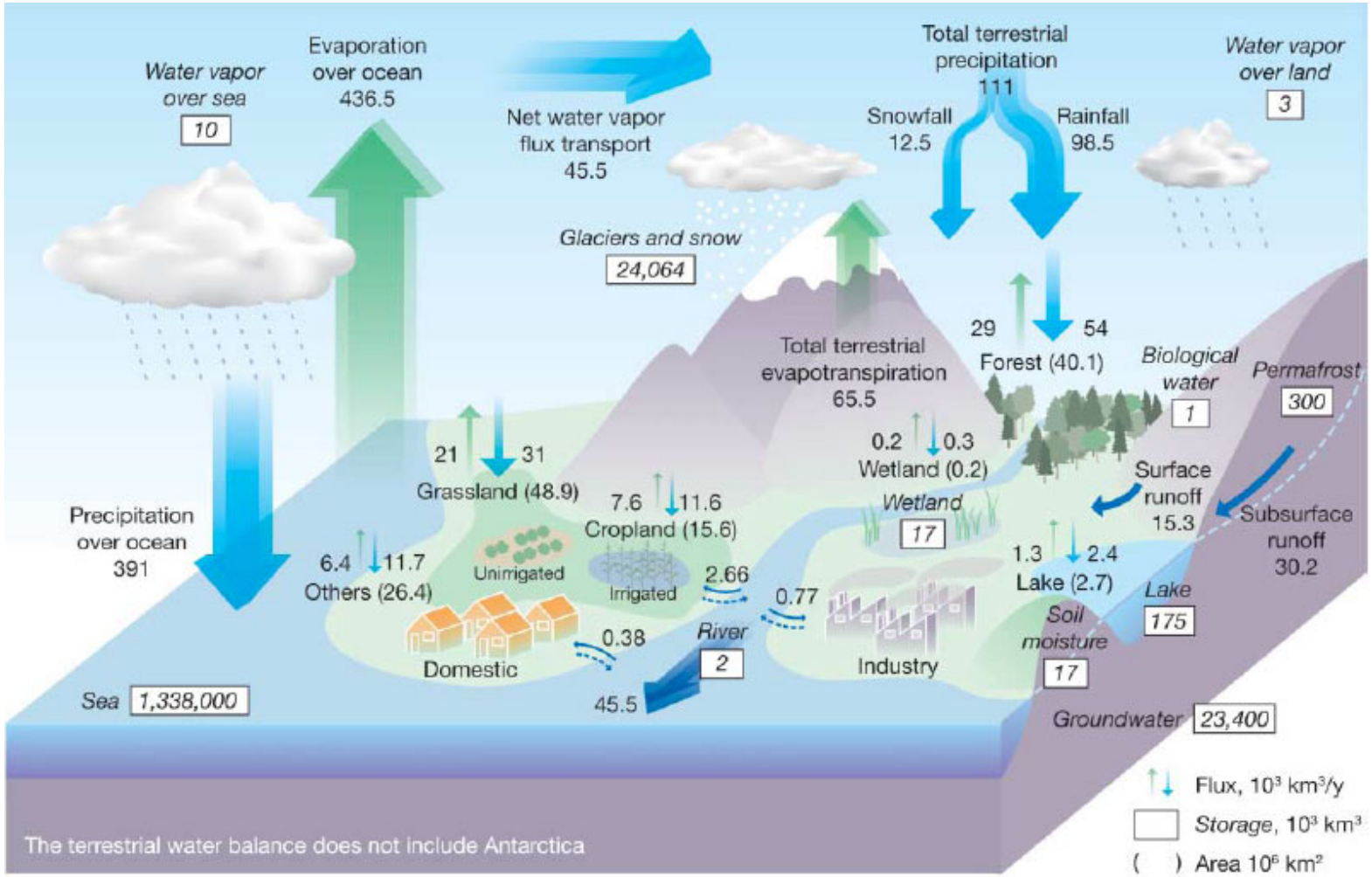
LOUVAIN Water

The water problem is not a total stock problem: We are still living on a blue planet!



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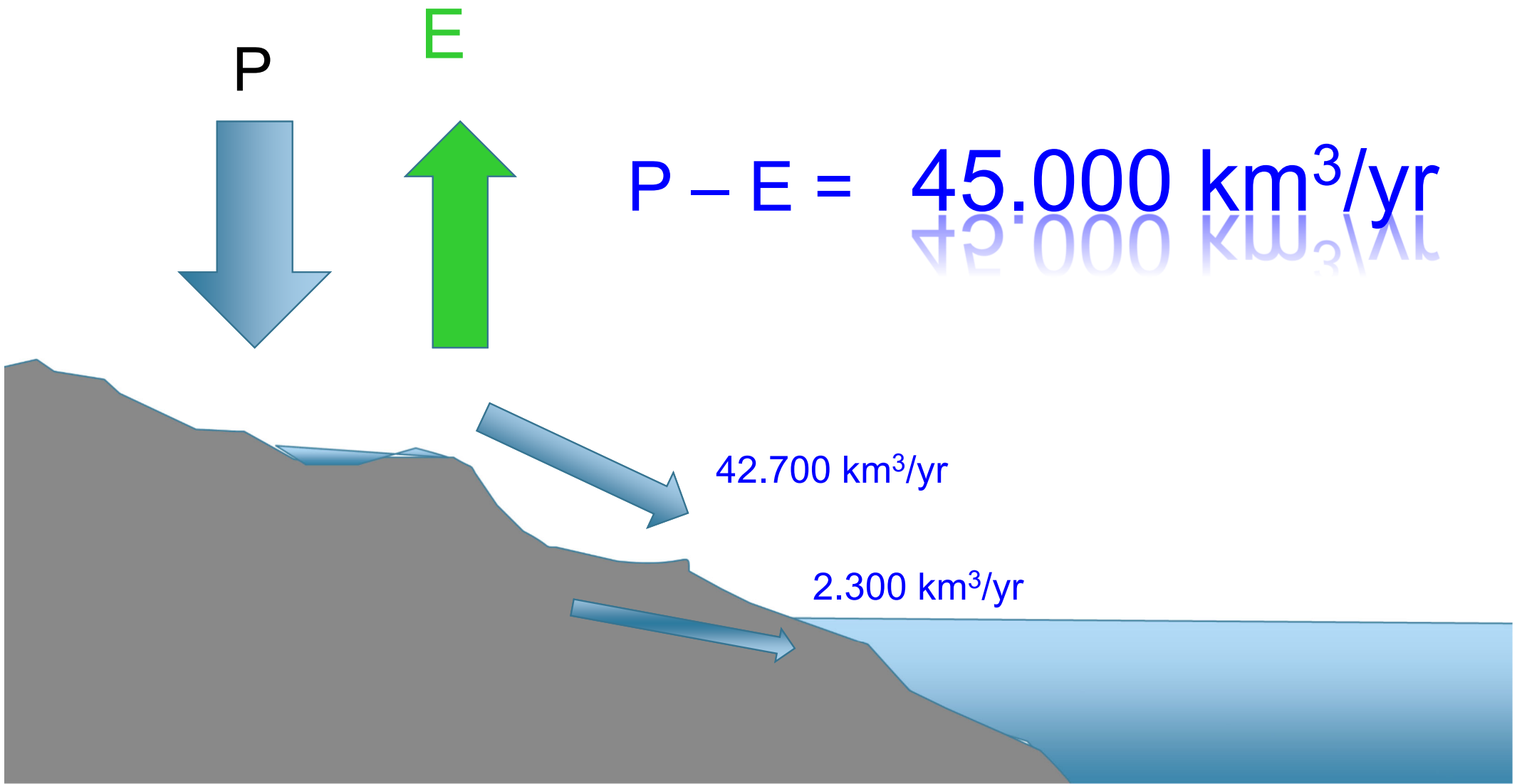
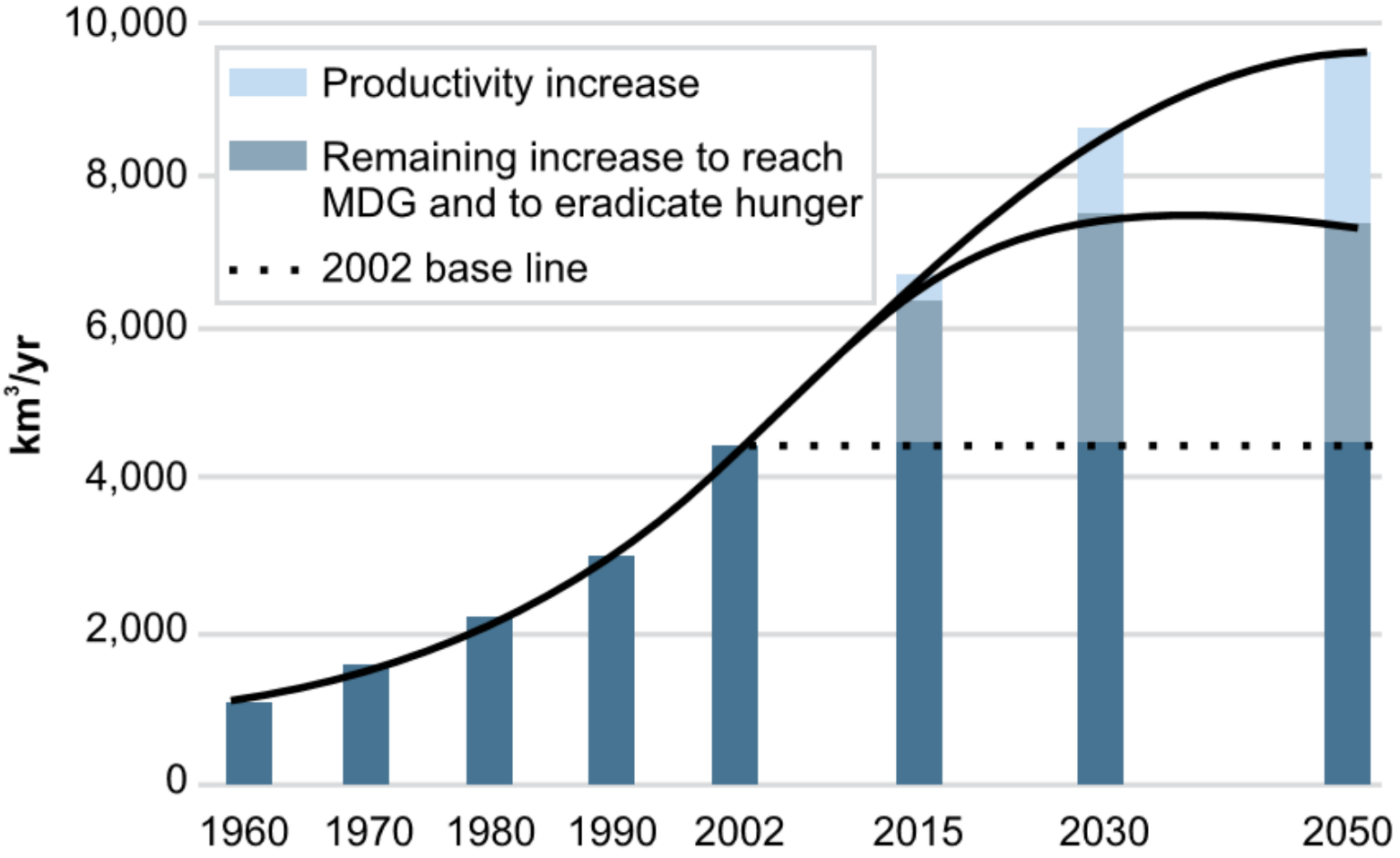
LOUVAIN Water

Oki and Kanae, Science, 2006

The water problem is not a total stock problem: We are still living on a blue planet!



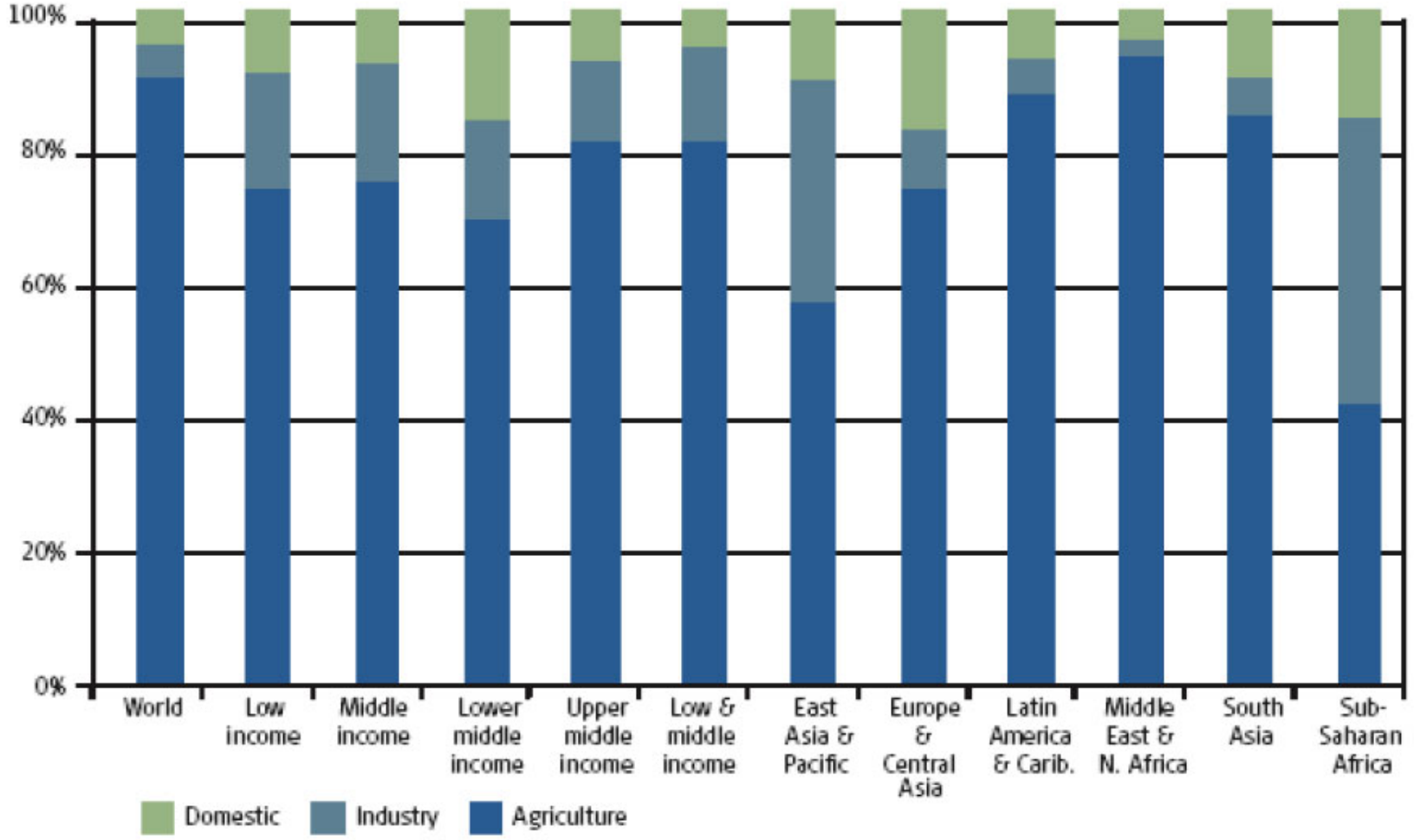
The water problem is not a total stock problem: We are still living on a blue planet!



SEI, 2005

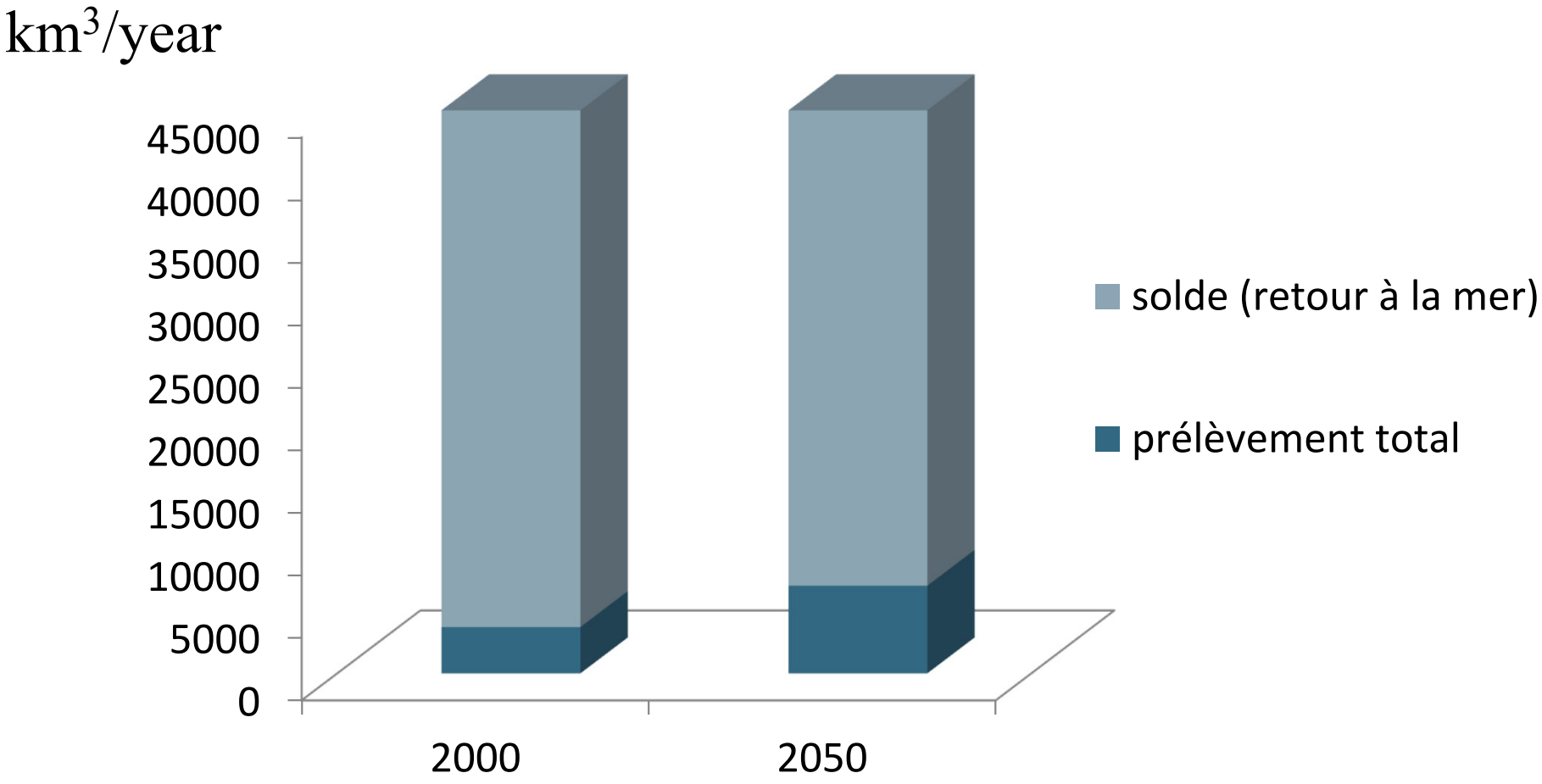
The water problem is not a total stock problem: We are still living on a blue planet!

Figure 8.3: Water use by industry vs. domestic use and agriculture



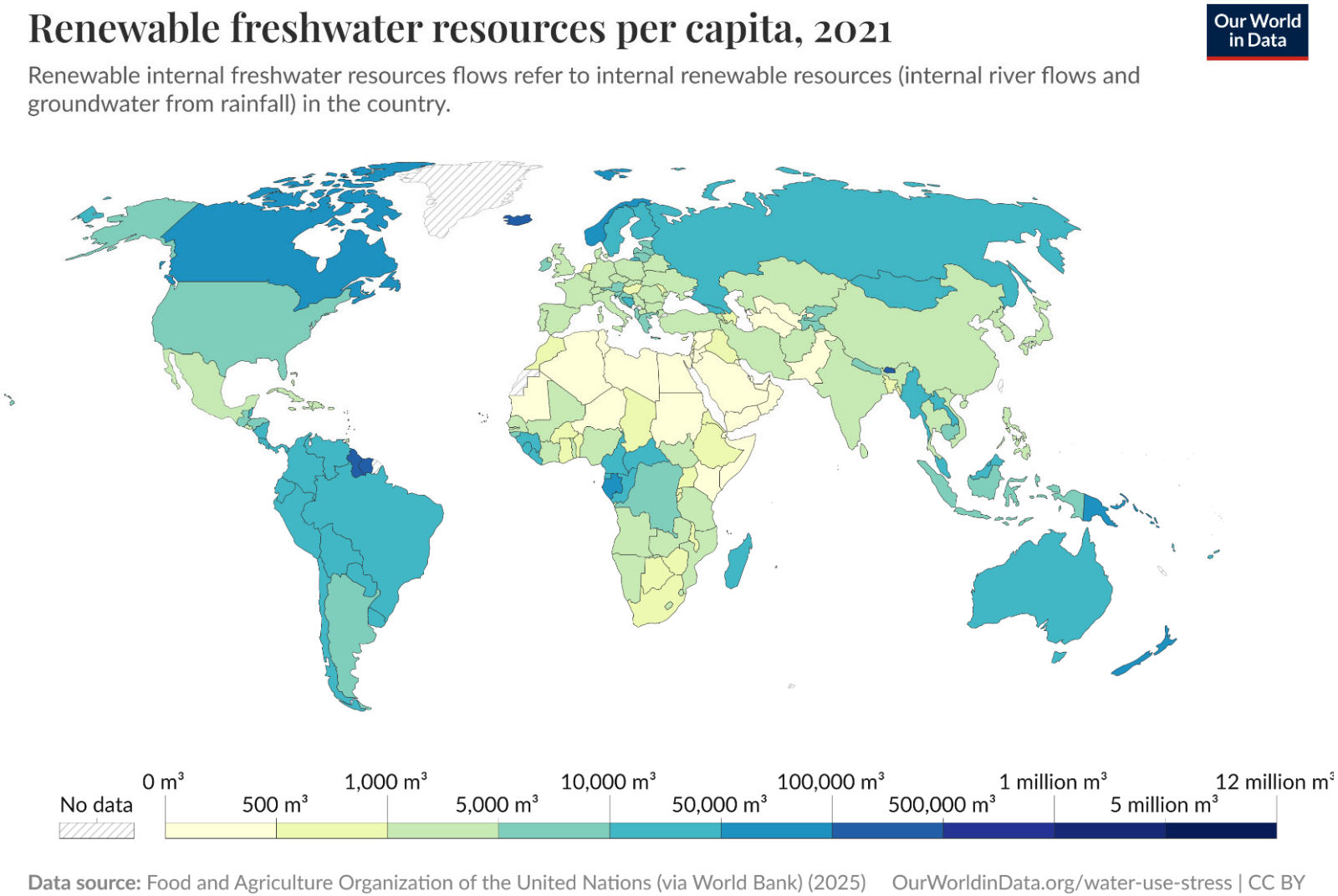
Water consumption by sector , WWDR, 2014

The water problem is not a total stock problem: We are still living on a blue planet!



SEI, 2005

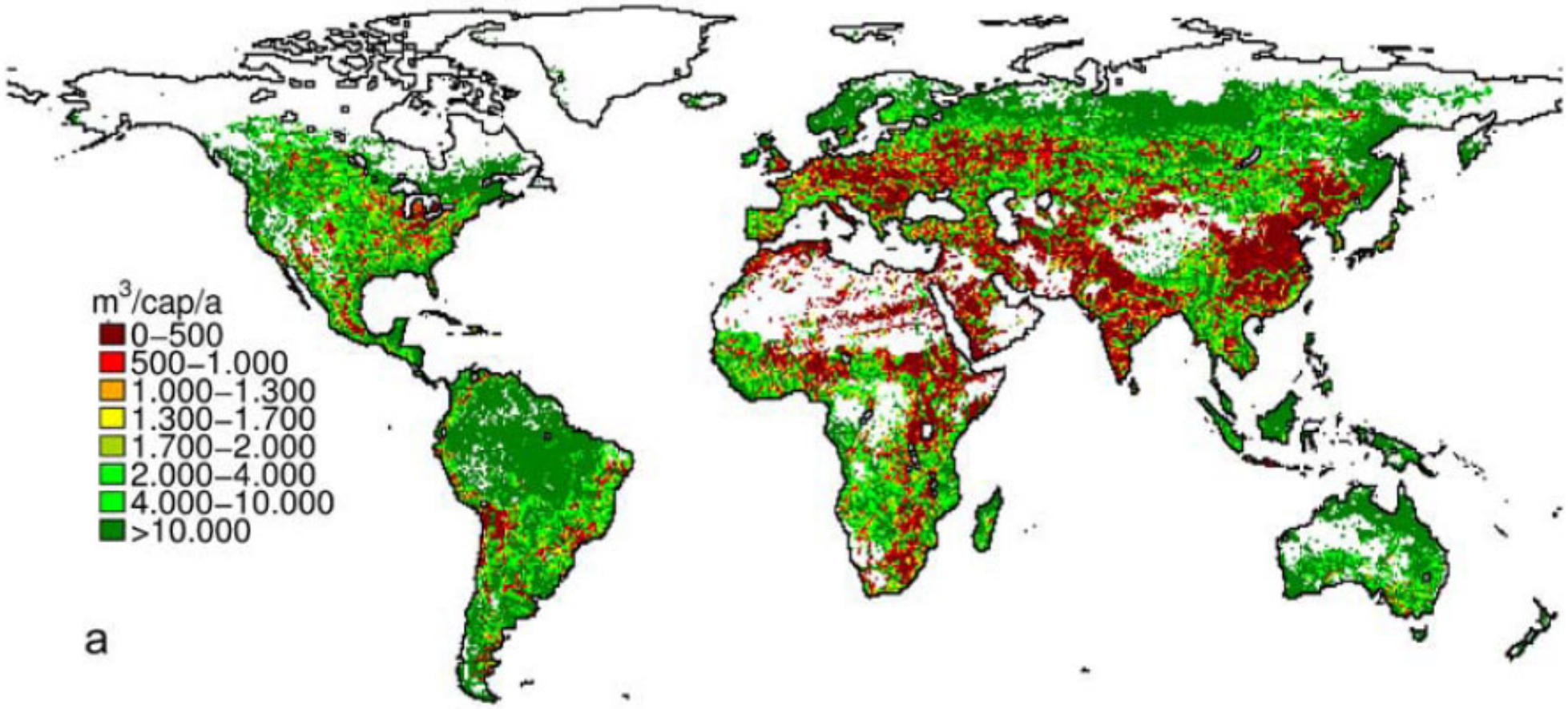
It is a spatial and temporal distribution problem !



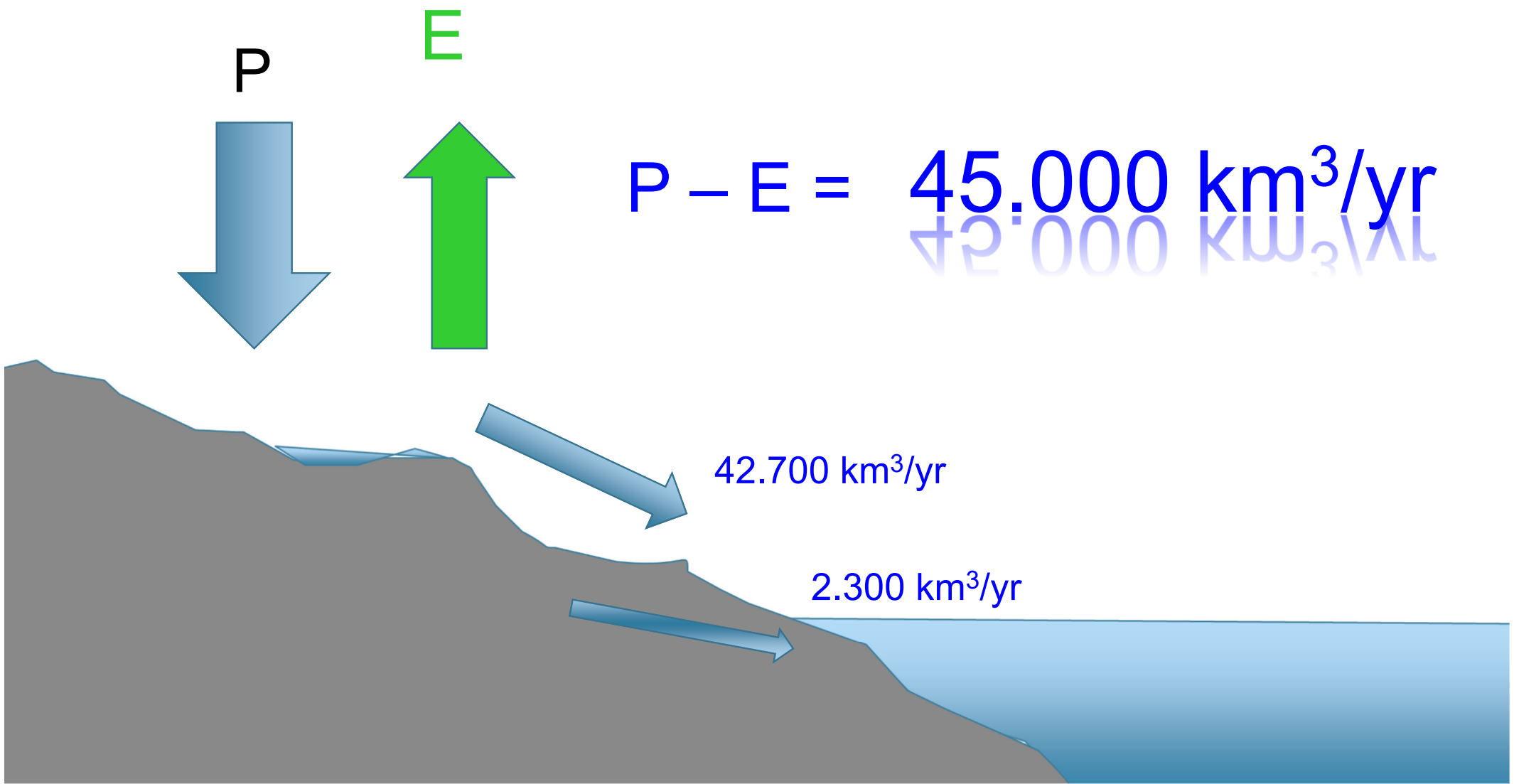
Source: https://ourworldindata.org/, 28/2/2025

Newsweek , 1 May 2015

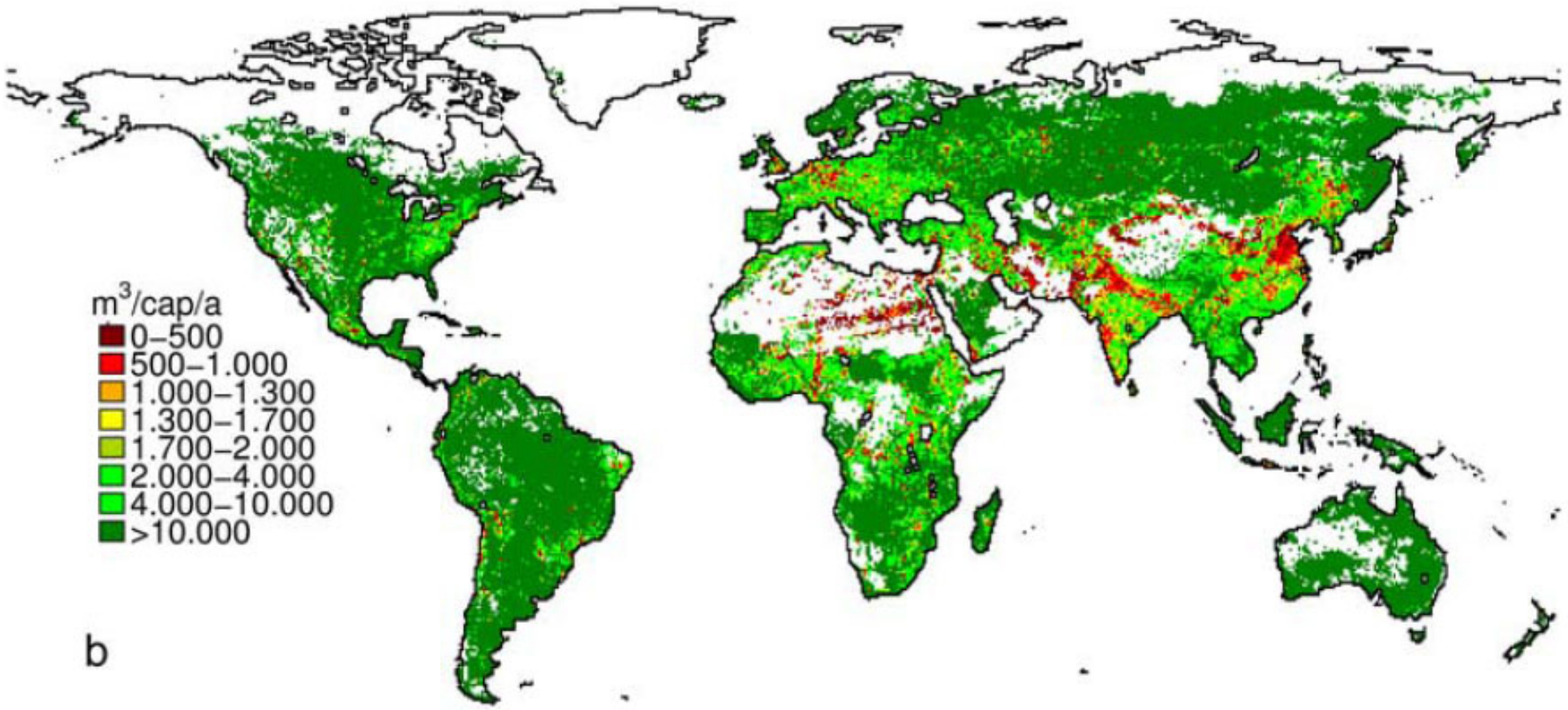
It is a spatial and temporal distribution problem of blue water…



Blue water distribution in 2000, Rockström et al., 2009, WRR

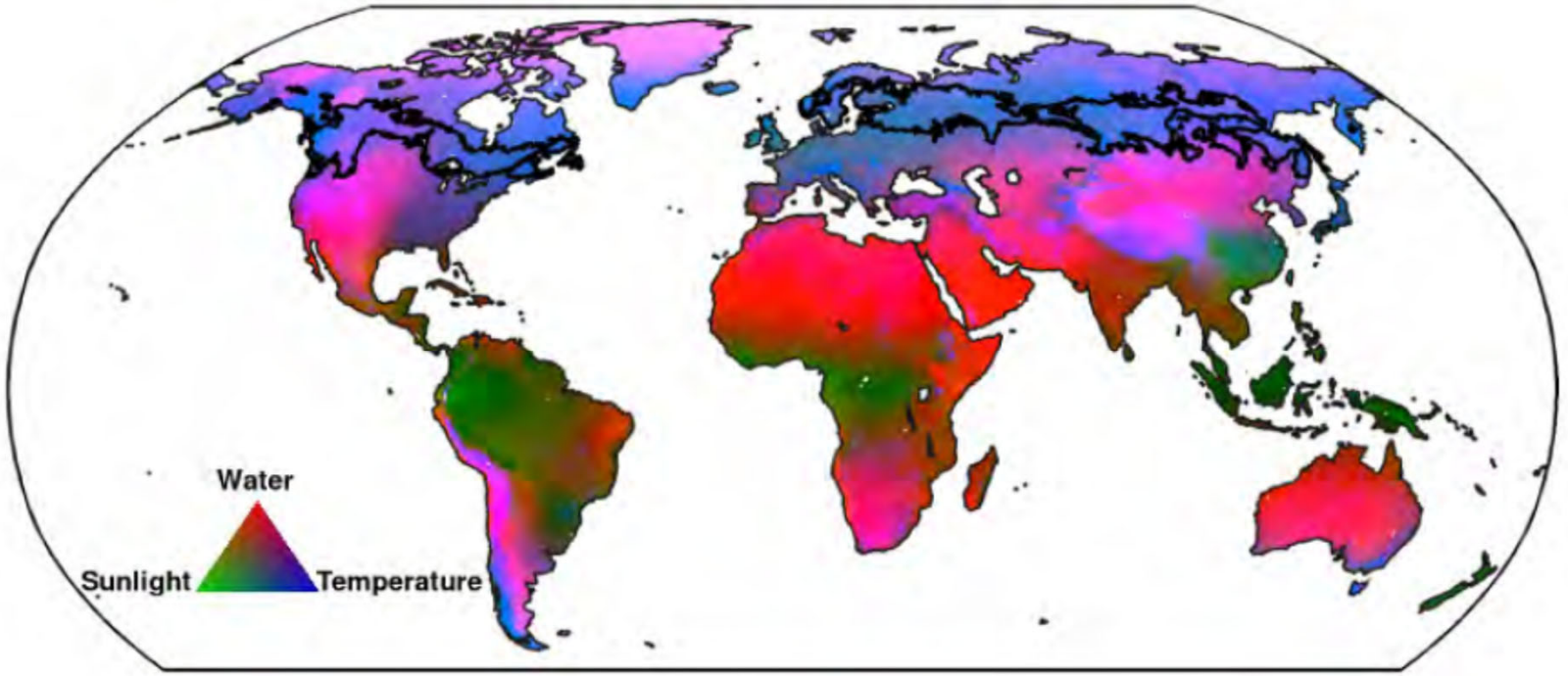

P
E
P – E = 45.000 km³/yr
42.700 km³/yr
2.300 km³/yr

…but not yet for green water.



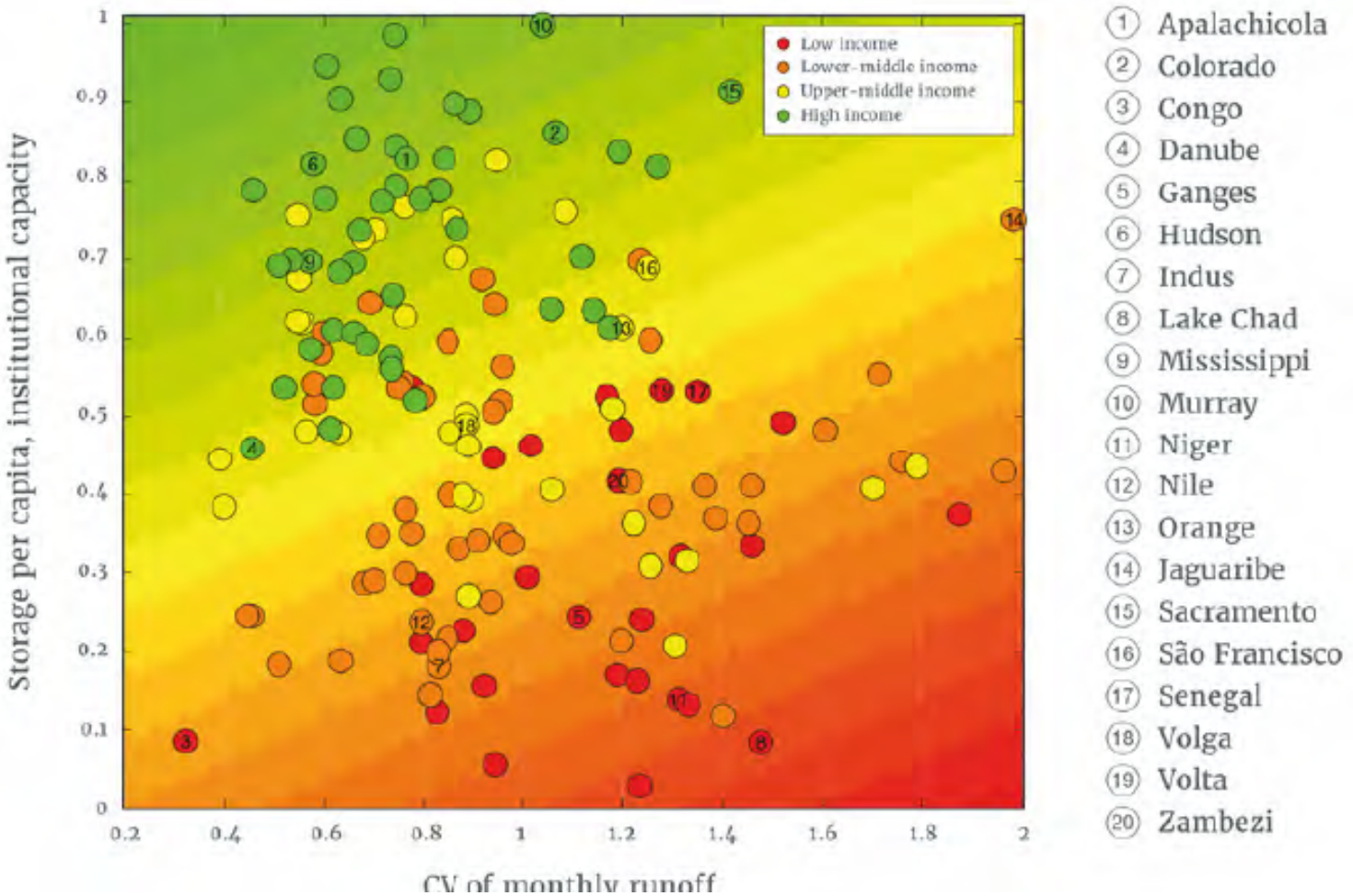
Green water availability in 2000, Rockström et al., 2009, WRR

It creates considerable constraints on food production.



Potential constraints on crop productivity, Nemani et al., 2003

It strongly influences the economic system.



Hall et al, Science, 2014

It strongly influences the economic system and supports many jobs.

- WWAP, 22/3/2016: Water and jobs.

  "3 out of 4 jobs of the global workforce (3.2 billion people) are moderately or highly dependent upon access to water and water-related services"

- VKW

  "1 op 6 jobs in Vlaanderen is sterk gerelateerd aan water en water services…

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It endangers spirituality and mental health

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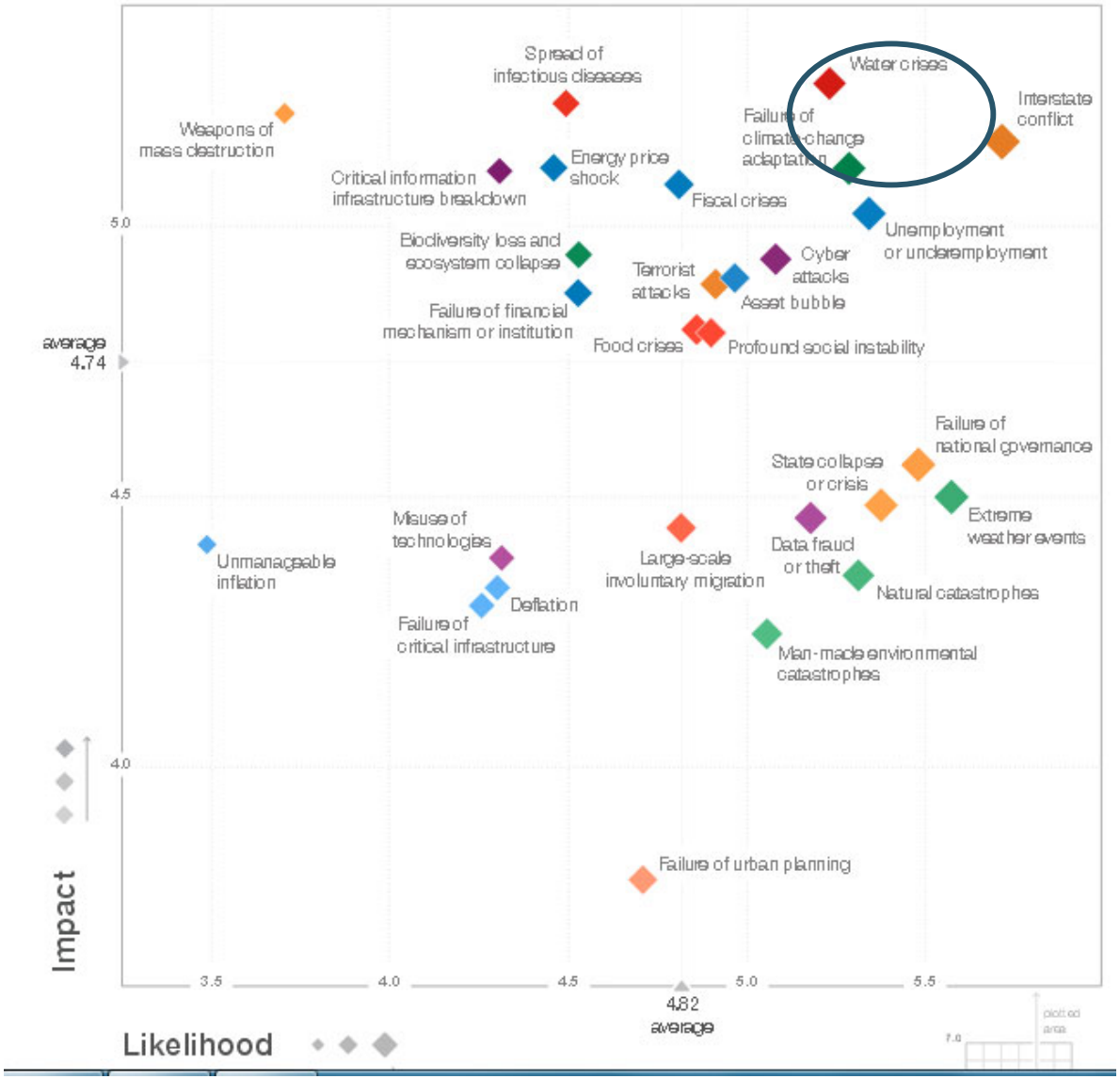
It creates global risks



Global risk map,
World Economic Forum, 2015

It creates global risks

FIGURE C **Global risks ranked by severity over the short and long term**

"Please estimate the likely impact (severity) of the following risks over a 2-year and 10-year period."

Source

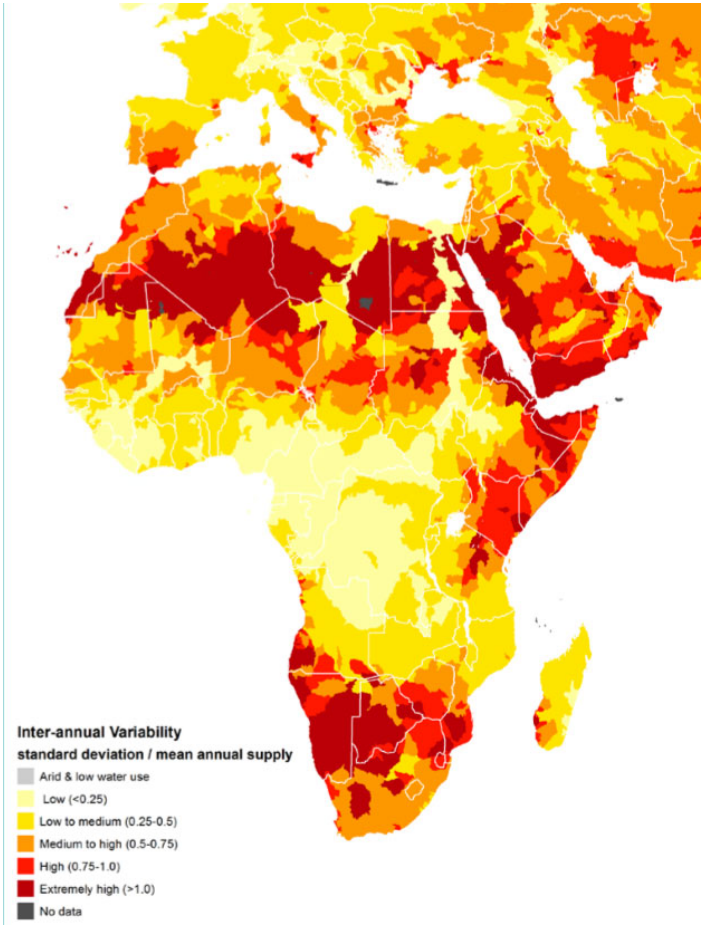
World Economic Forum Global Risks Perception Survey 2024-2025.

Source: https://www.weforum.org/publications/global-risks-report-2025/digest/ ; Consulted 9/6/25

… and global conflicts,

Newsweek , 1 May 2015

… and it induces migration.



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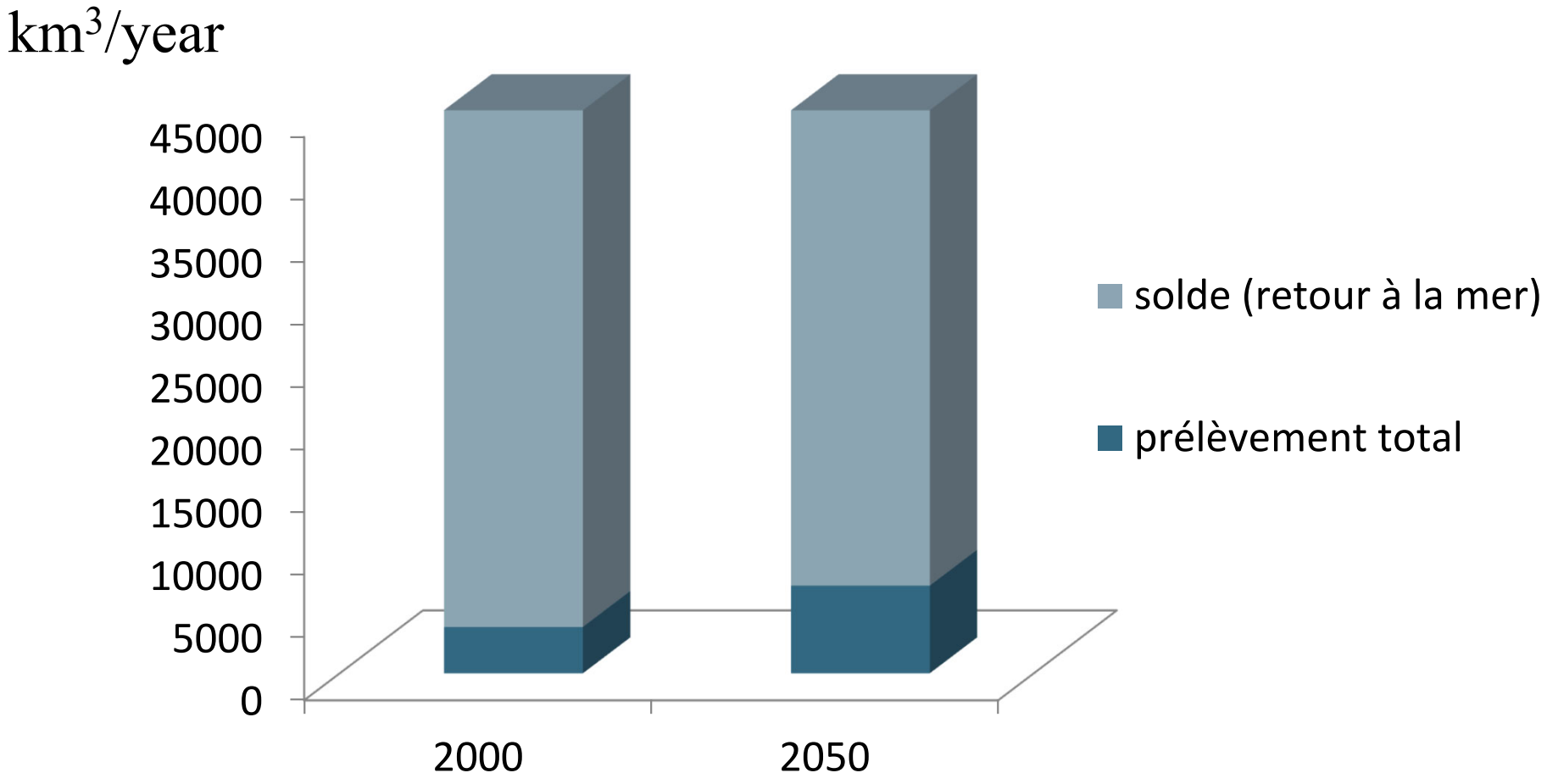
LOUVAIN Water

The water problem is not a total stock problem: We are still living on a blue planet! The positive narrative



SEI, 2005

Overview effect

"An astronaut who spent 178 days in space reveals a "big lie" he realized when he saw the Earth.

Ron Garan, a former NASA astronaut, has spent 178 days in space and accumulated more than 114 million kilometers traveling in 2,842 orbits around Earth. His journey, however, hasn't been just about impressive numbers. During one of those trips, he experienced something that few humans have ever experienced: the so-called Overview Effect, a phenomenon that transforms the way we see our planet.

The solution, according to Garan, is a radical change of priorities. Instead of thinking about "economy, society, planet", we should reverse the order: "planet, society, economy". This simple exchange reflects the need to place environmental health as the basis for all other decisions. "This is the only way we will really evolve," he argued...."

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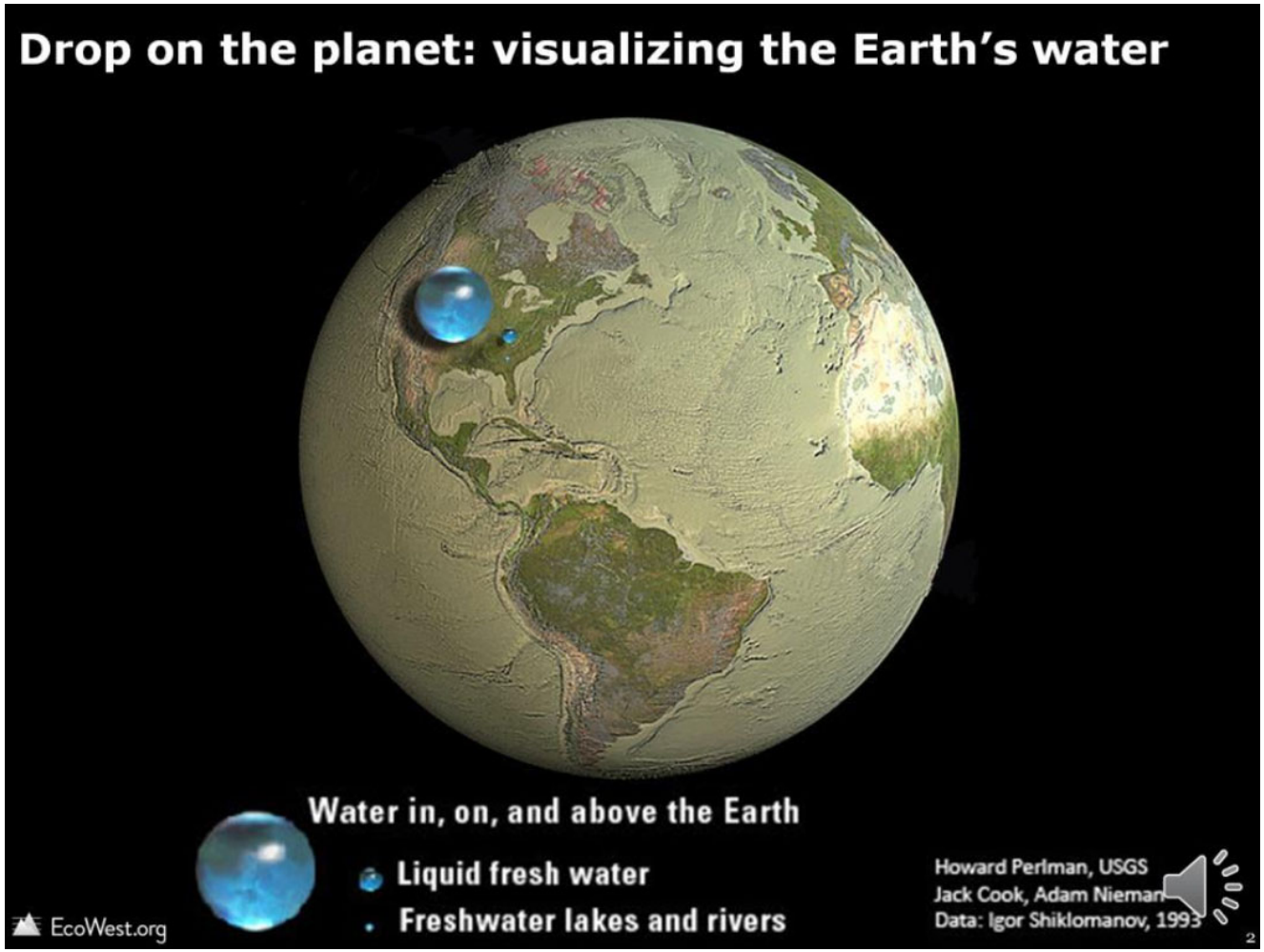
Earth and Life Institute (ELI)

The water problem considering the «overview effect ».
The less positive narrative: A brown planet.



Humanity started realizing that climate change affects natural systems considerably.

Radiative forcing

~ 3W/m²

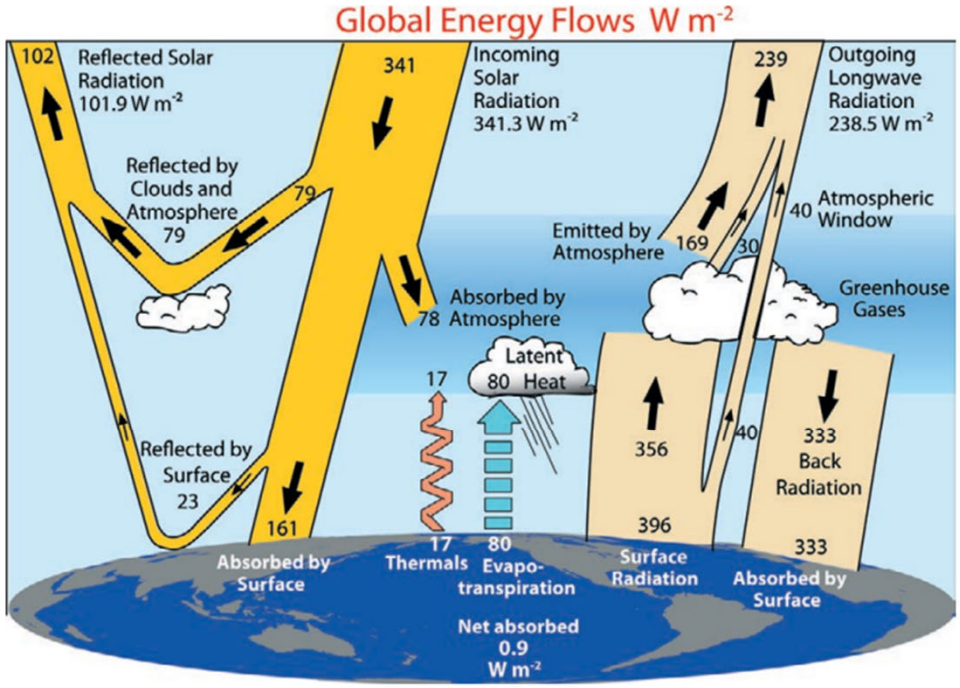
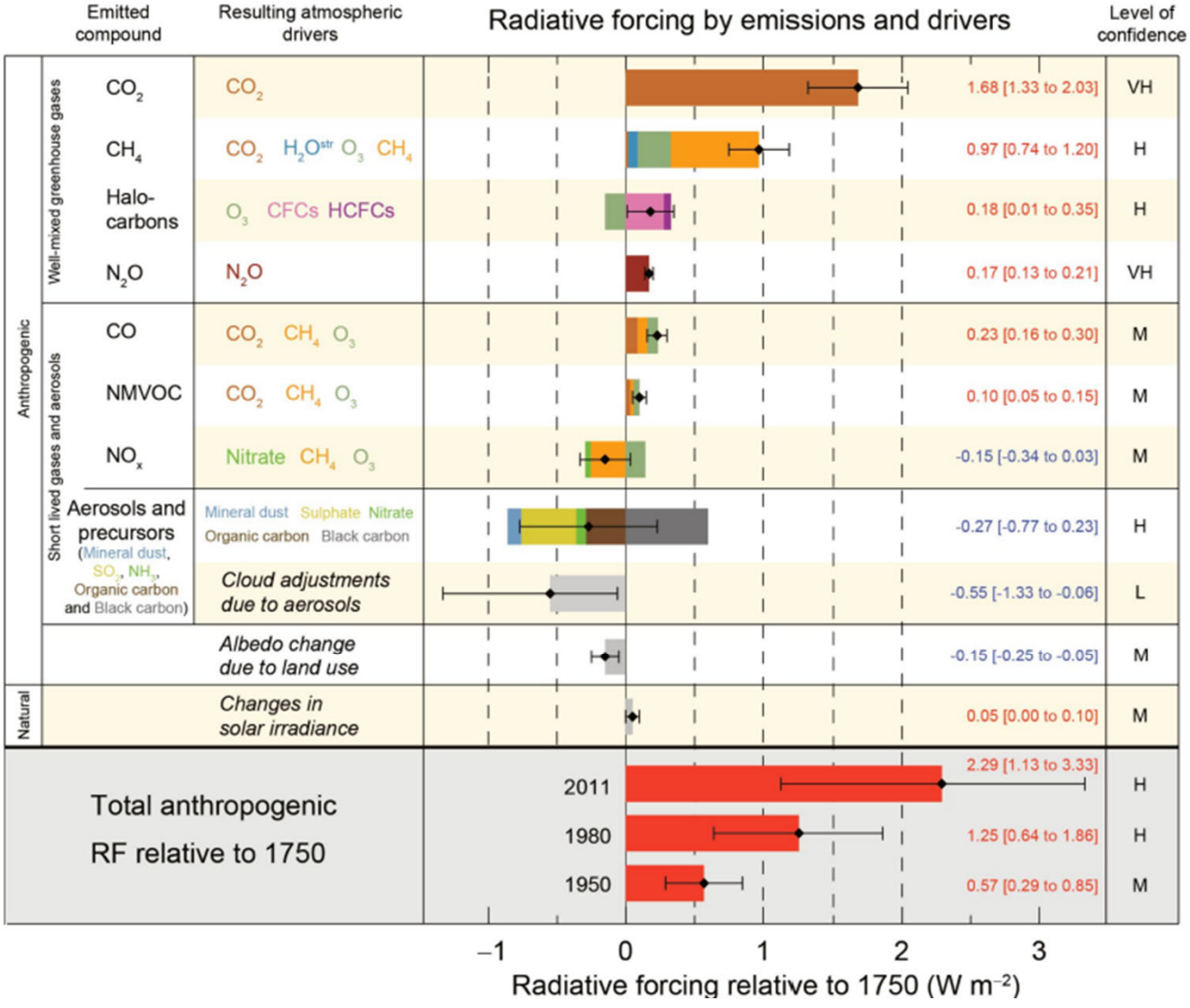


FIG. 1. The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period (W m⁻²). The broad arrows indicate the schematic flow of energy in proportion to their importance.

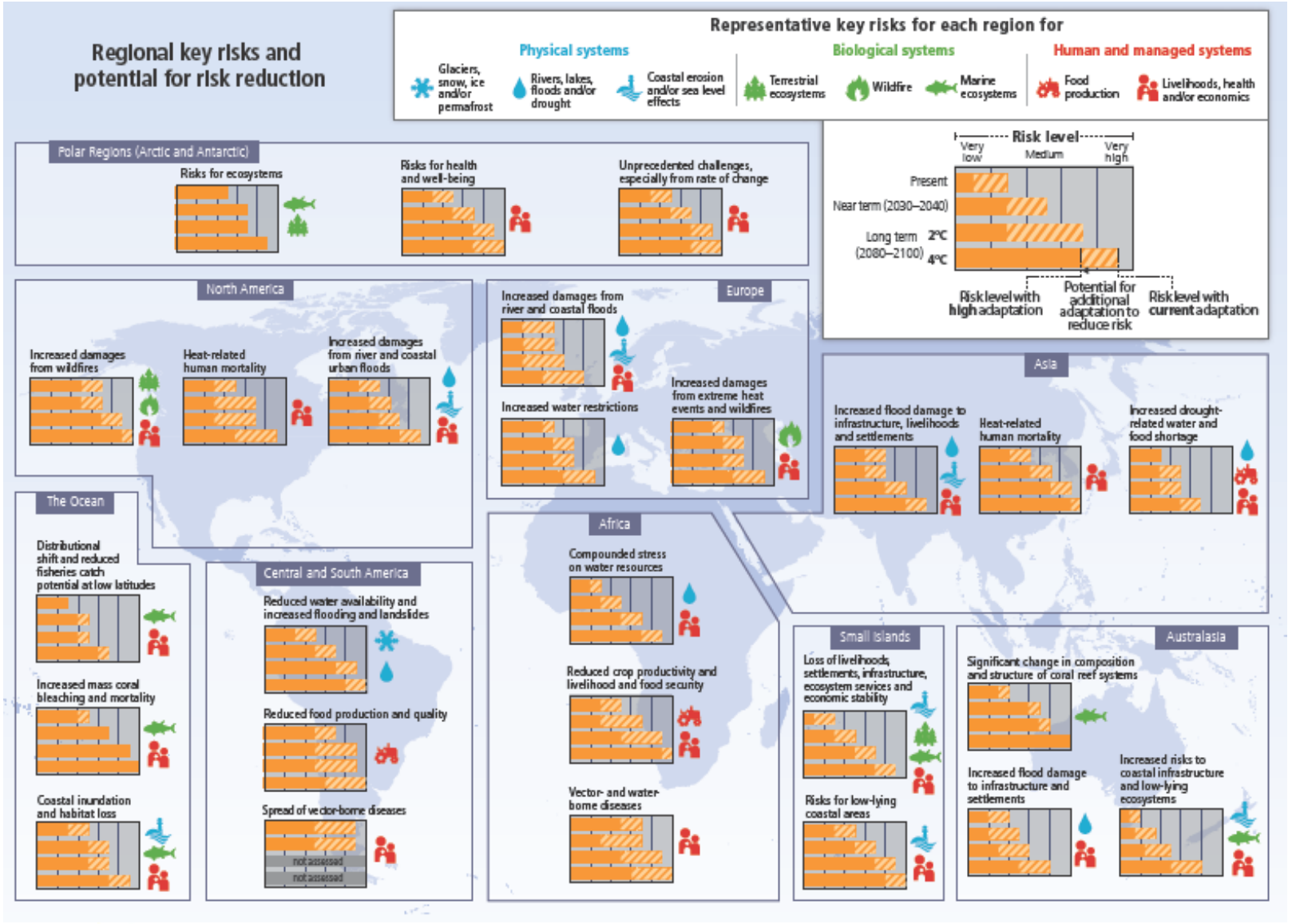
Source: Trenberth, Fasullo, and Kiehl, 2009

Humanity started realizing that climate change affects natural systems considerably.



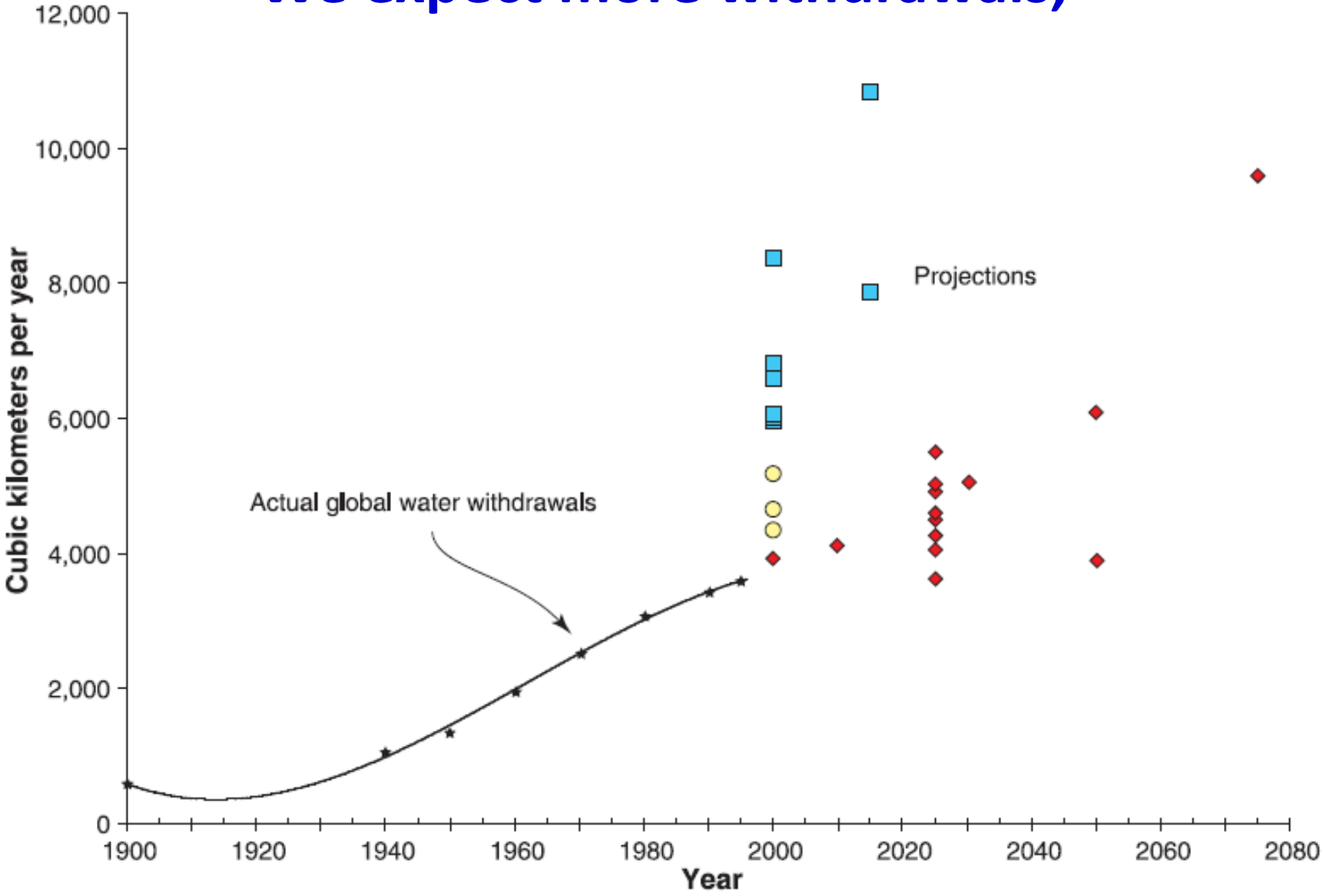
Source: IPCC SMP 5

The future is not blue!



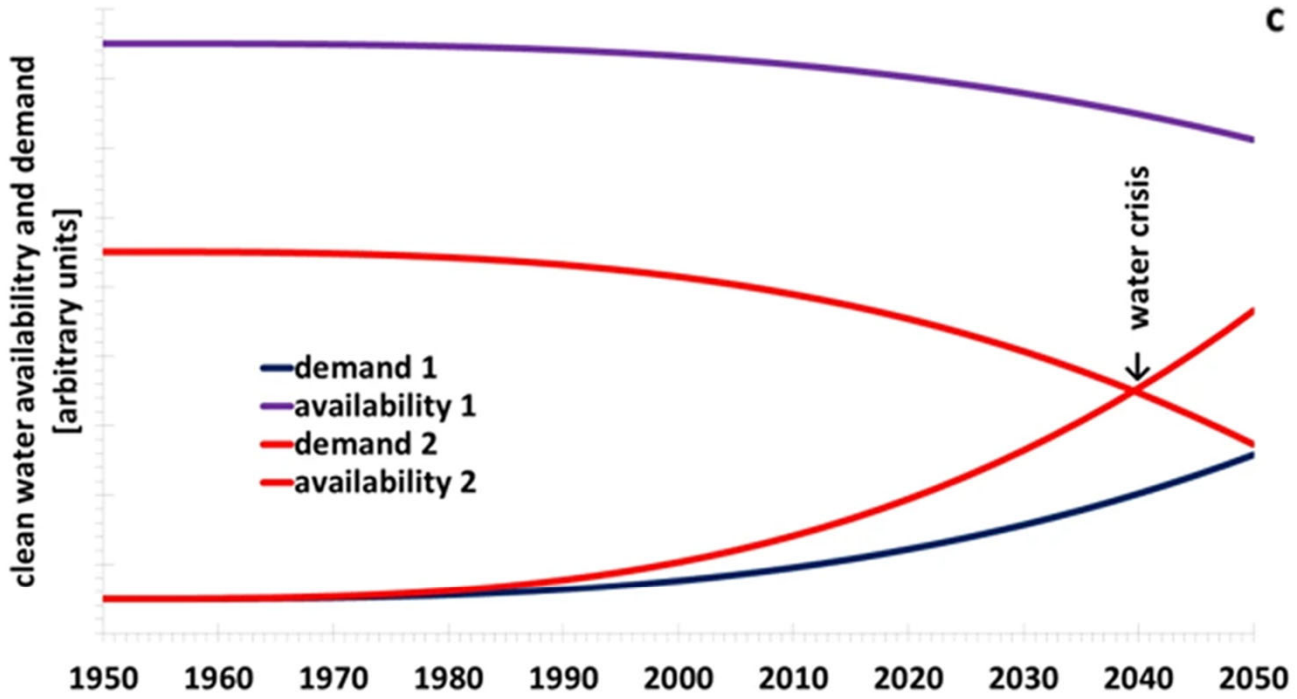
Overall risks associated with CC.
IPCC, AR5

We expect more withdrawals,



Estimated global withdrawals.
Gleick, P., 2003, Science

We expect more withdrawals,



a Water withdrawal, GDP pro-capita, and world population. The water withdrawal data to 2014 is from.[71] The GPD pro-capita data to 2016 is from.[73] The population data to 2018 is from.[72] **b** The population of the world and selected countries of Asia and Africa. The data to 2018 is from ref. [72] The values for 2050 are obtained by linear extrapolations from recent years. **c** Graphical concept of water scarcity, resulting from a more than linear growing demand and a similarly more than a linear reduction of clean water availability

Source: Boretti, A., Rosa, L. Reassessing the projections of the World Water Development Report.
npj Clean Water **2**, 15 (2019). https://doi.org/10.1038/s41545-019-0039-9

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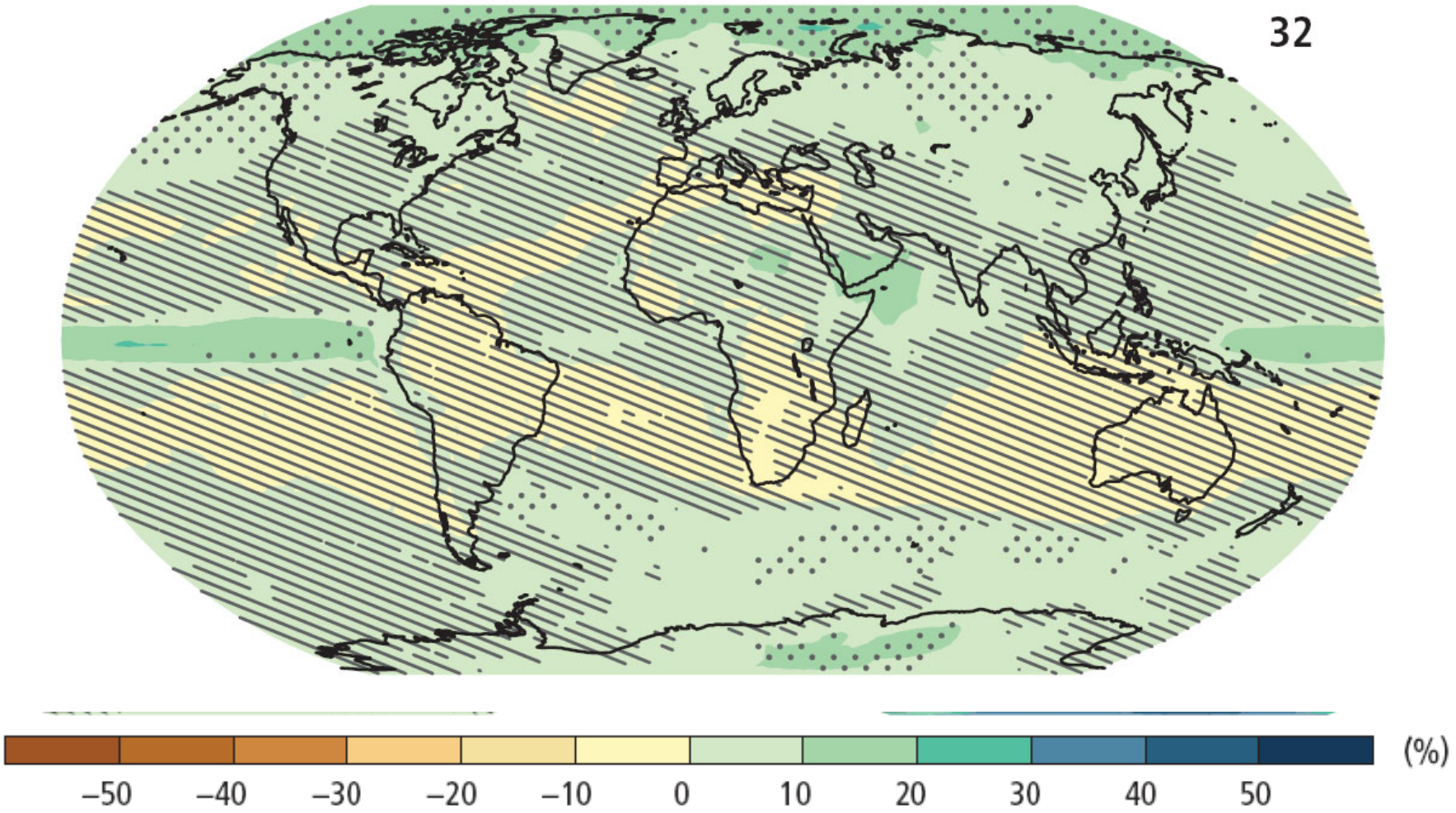
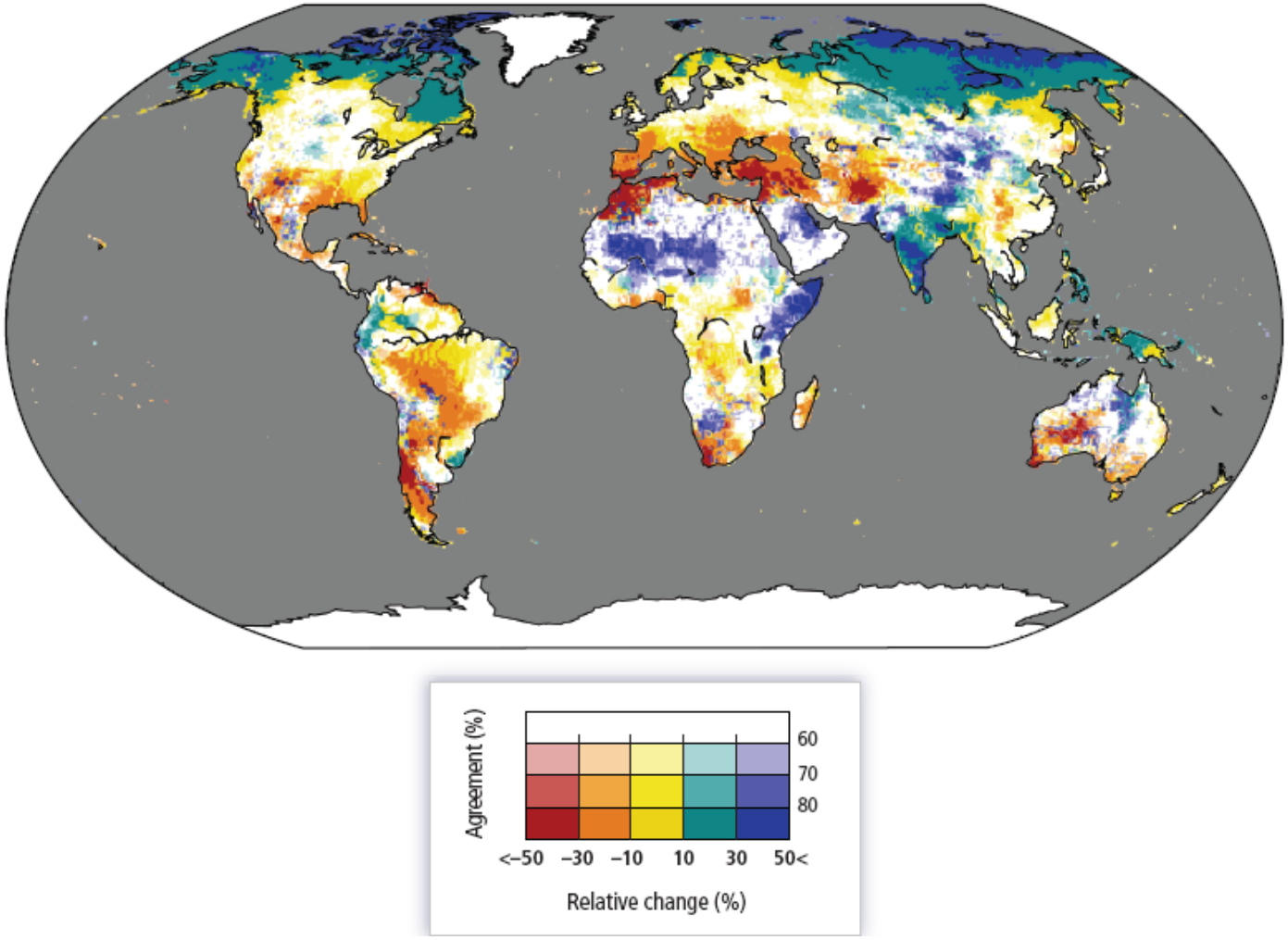
…modified climate patterns,



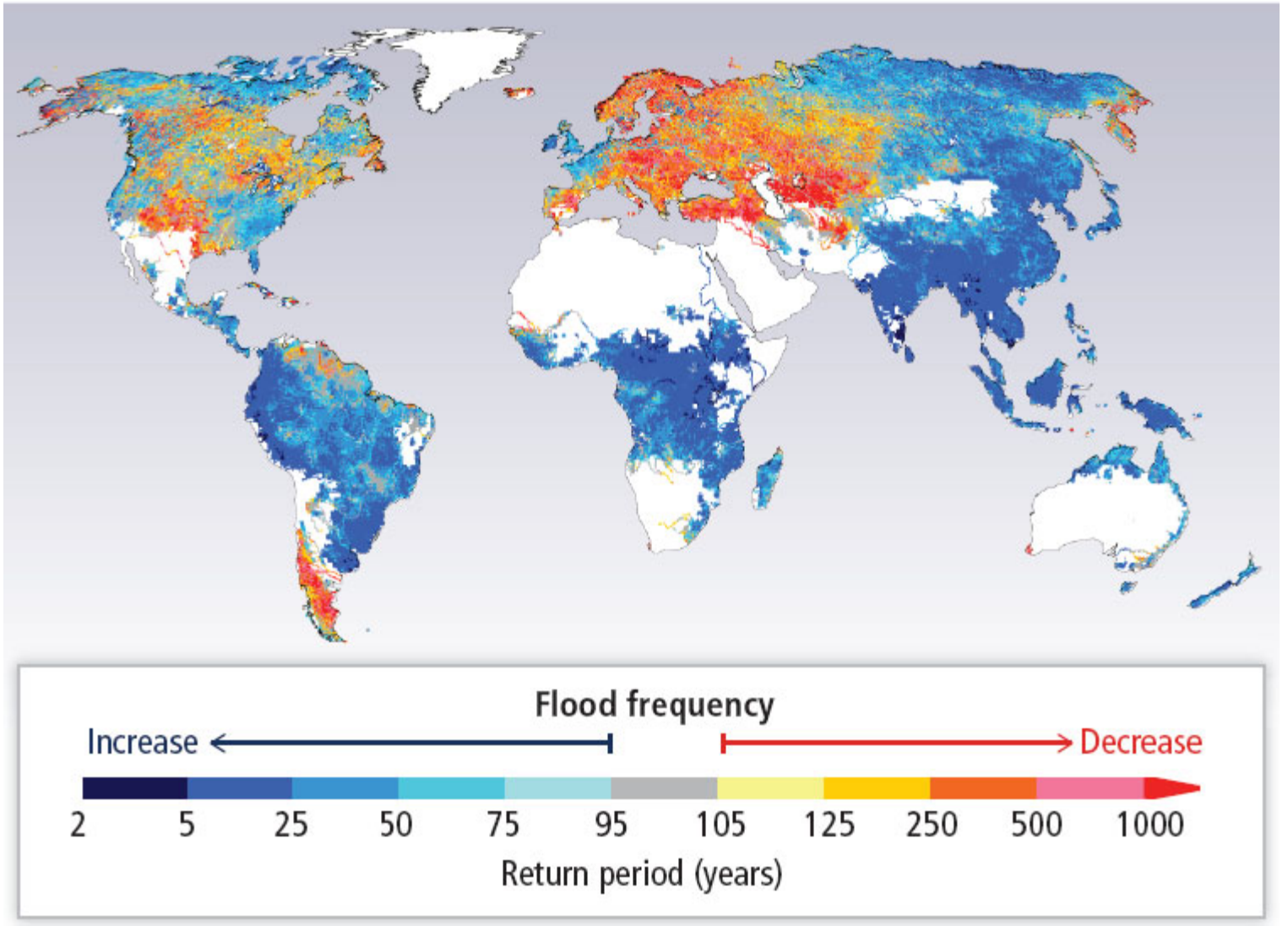
Changed precipitations,
RCP 2,6 (2081-2100 vs 1986-2005)
IPCC, AR5

…modified runoff patterns,



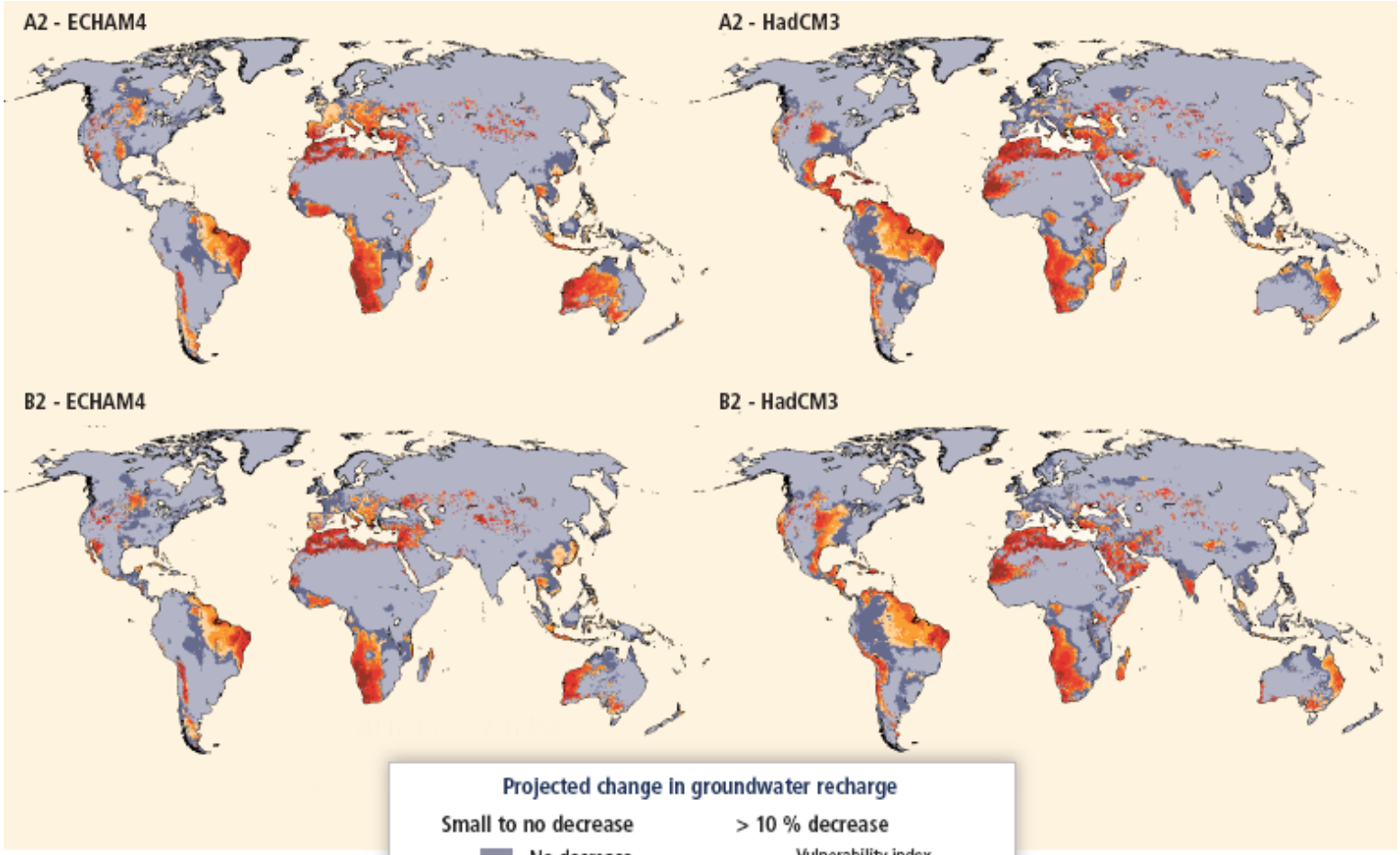
Change of annnual streamflow, IPCC, AR5

…modified runoff patterns,



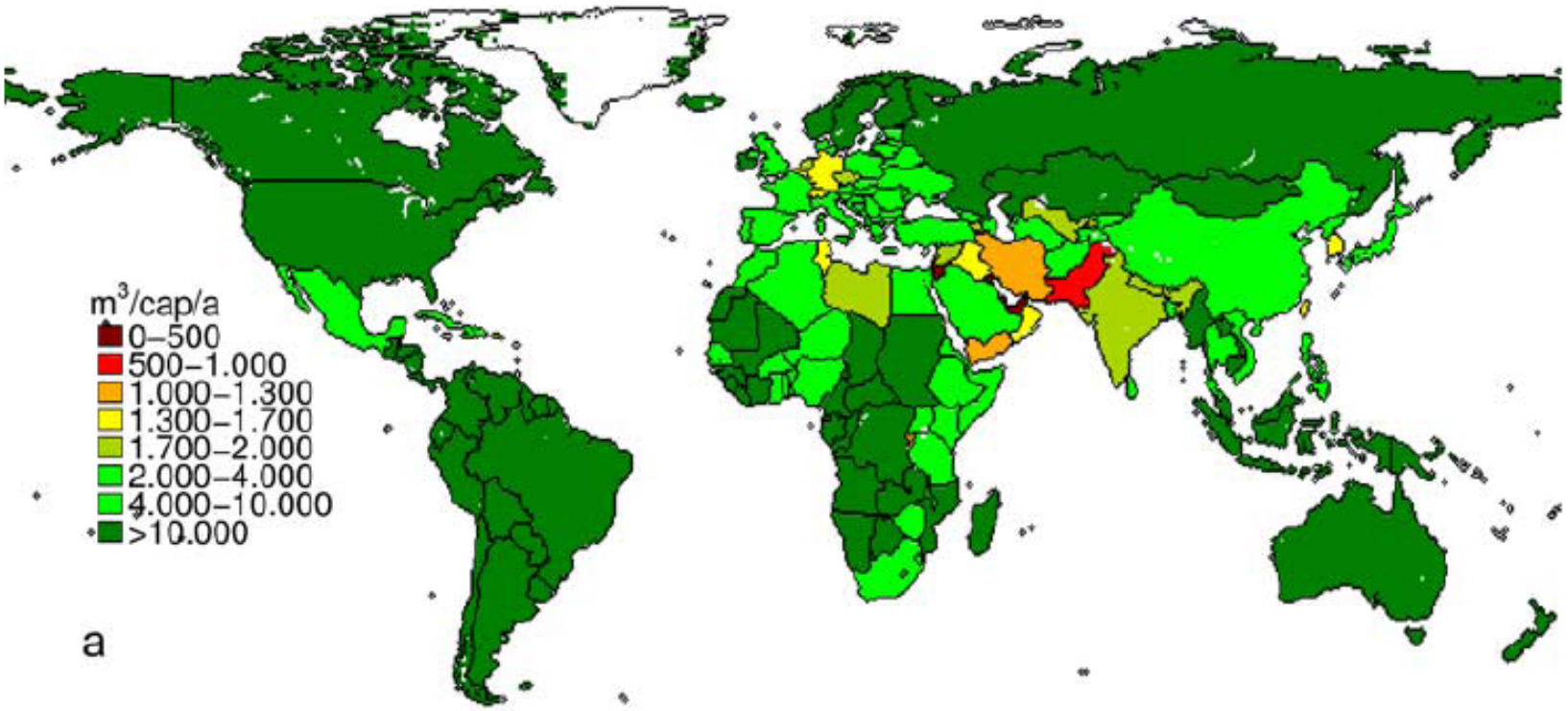
Change of return period in 2080 of the 20th century 100 year flood
IPCC, AR5

…modified recharge patterns,



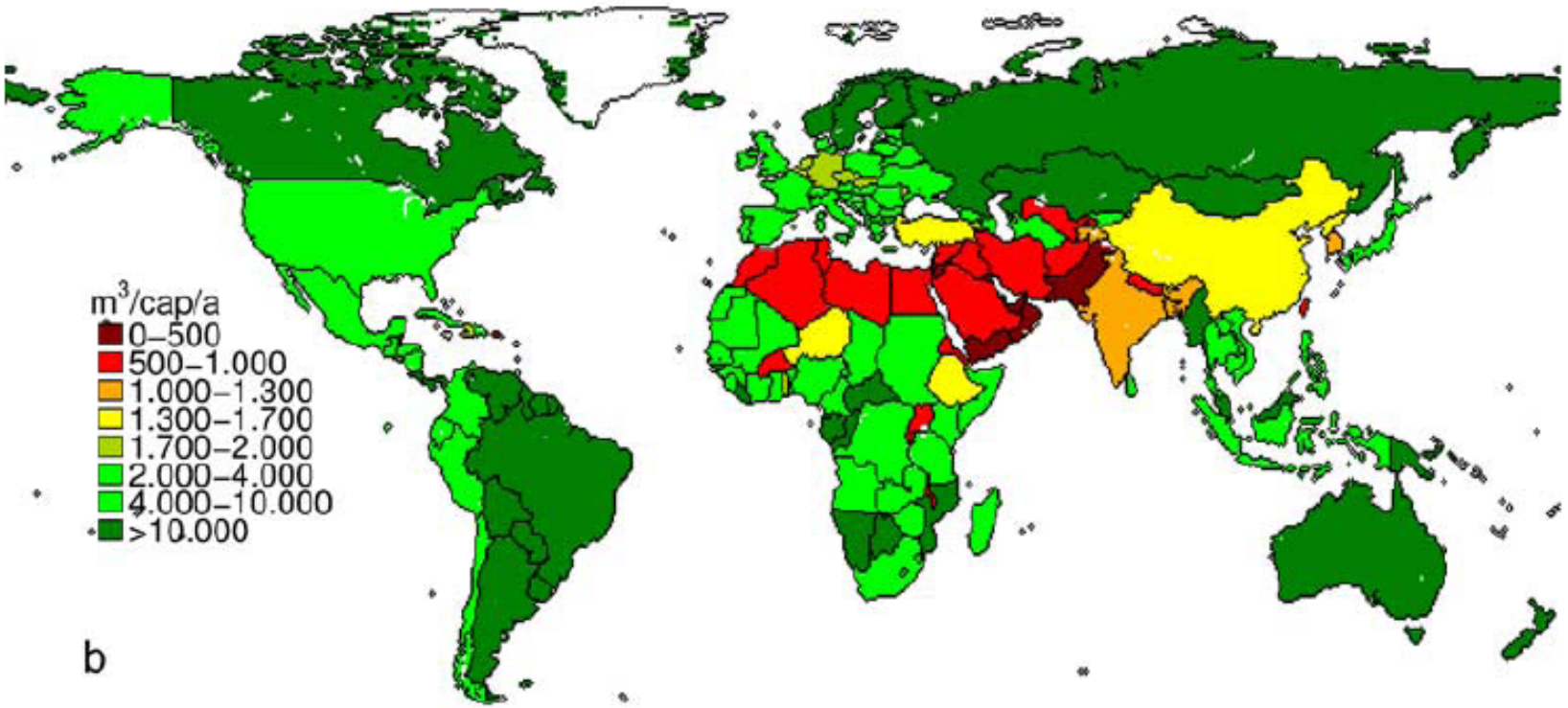
Change of recharge, IPCC, AR5

… modified blue and green water availability,



Blue and green water availability 2000
Rockström et al., 2009, WRR

…modified blue and green water availability,



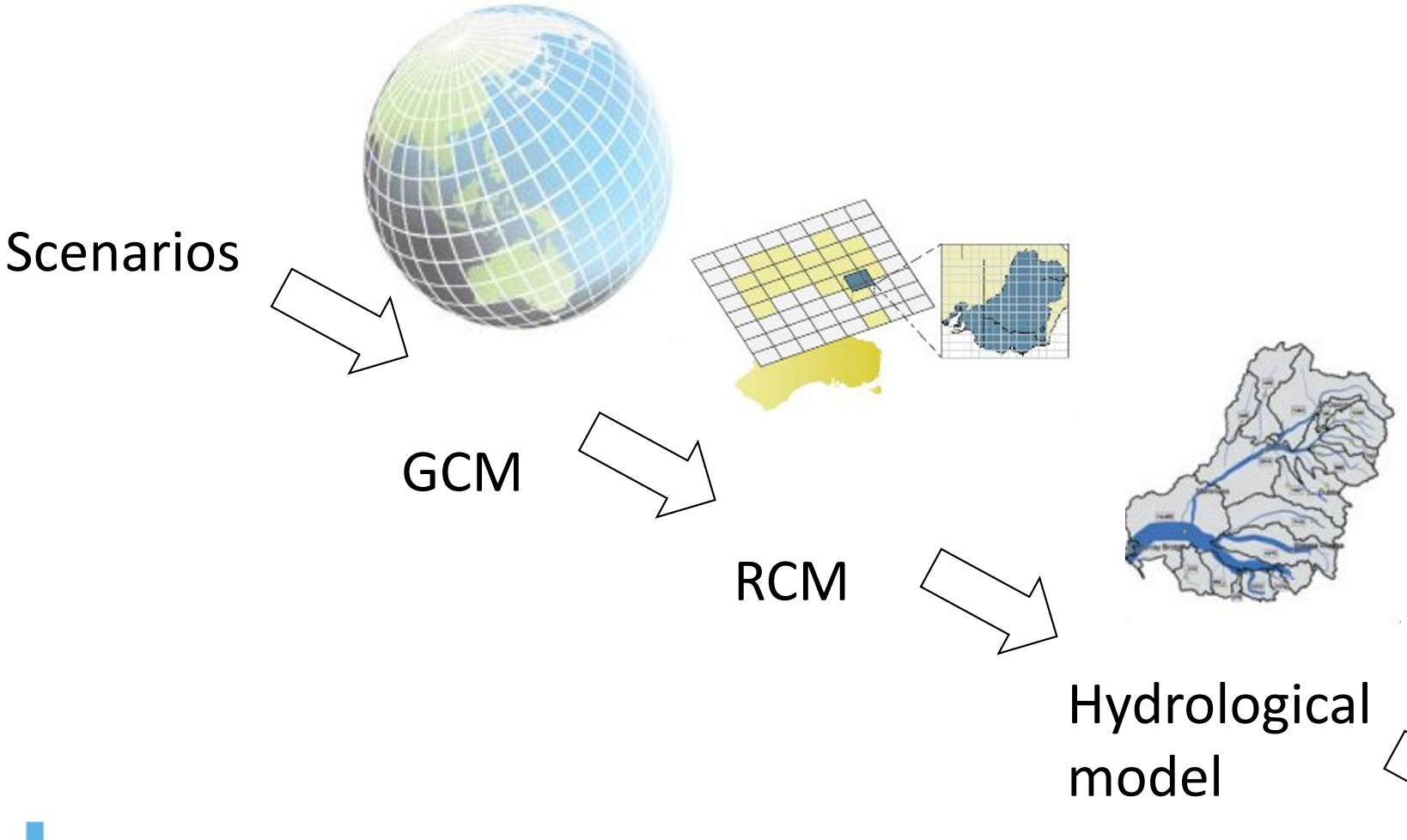
Blue and green water availability 2050
Rockström et al., 2009, WRR

… modified blue and green water availability,

	Blue water shortage (10^9 inhabitants)	Blue and green water shortage (10^9 inhabitants)
Europe	0,16	0,00081
North America	0,05	0,0052
South America	0	0
Asia	5,46	3,35
Africa	0,83	0,57
Oceania	0	0
World shortage	6,50	3,93
World	10,95	10,95

Blue and green water shortage, 2050.
Rockström et al., 2009, WRR

The modelling chain for assessing hydrological impacts of climate change at the regional scale



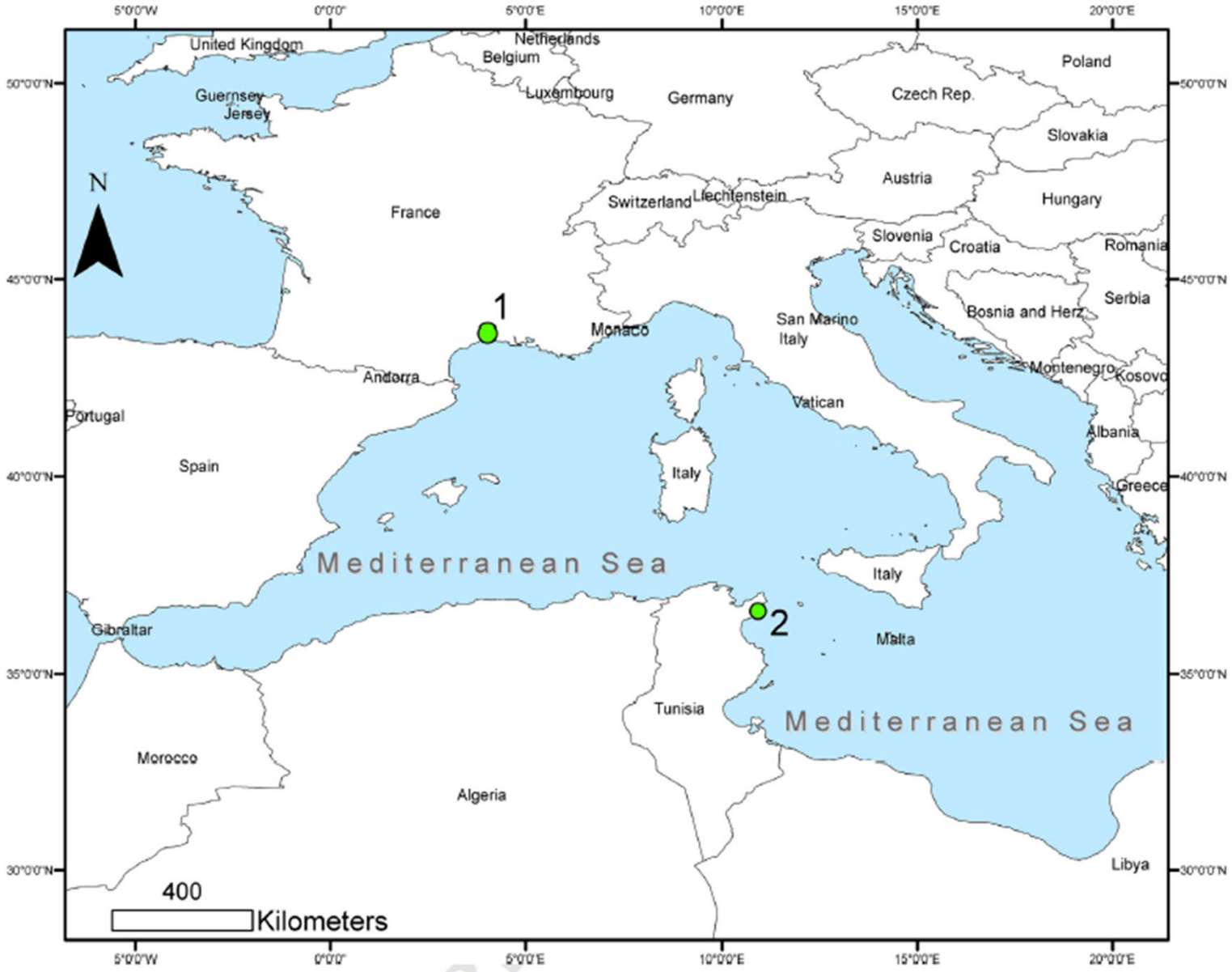
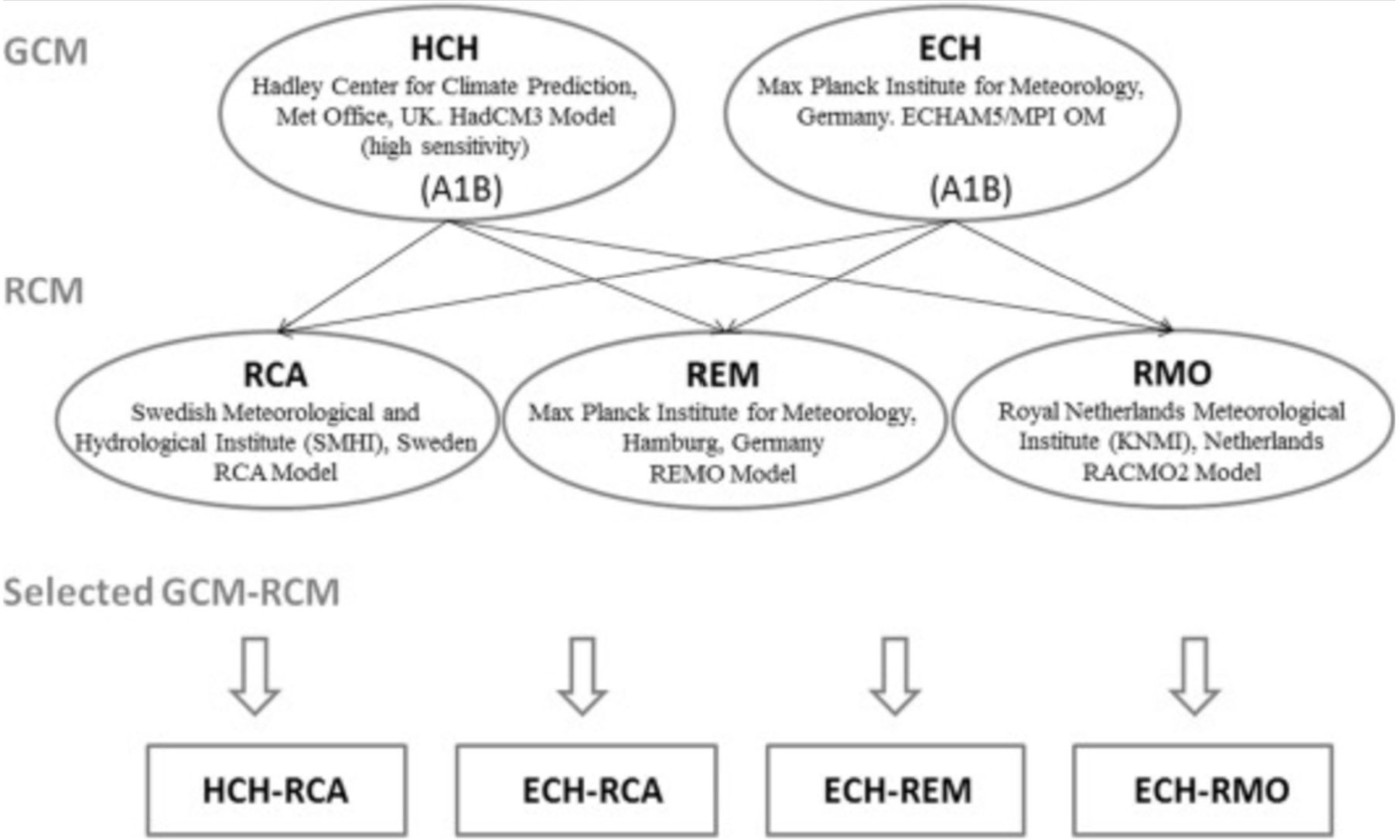
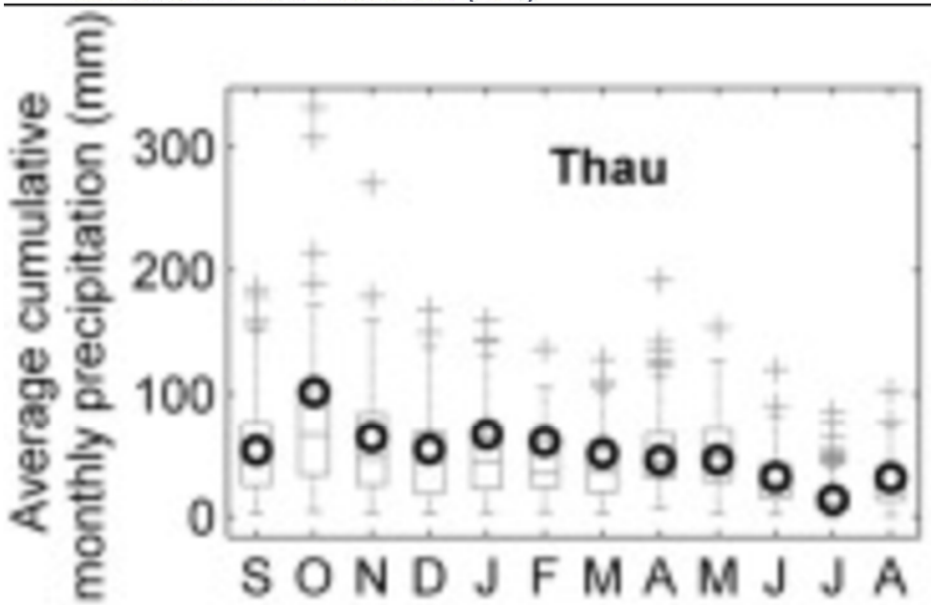
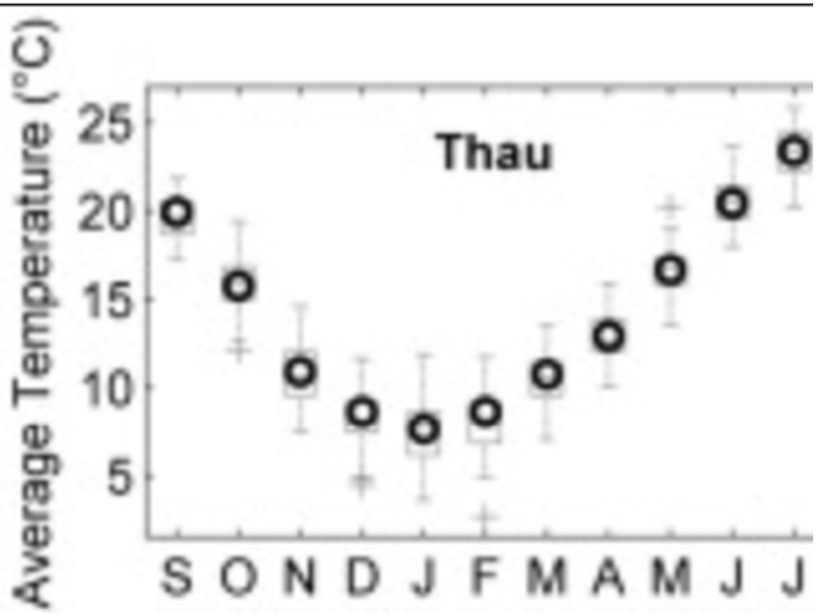
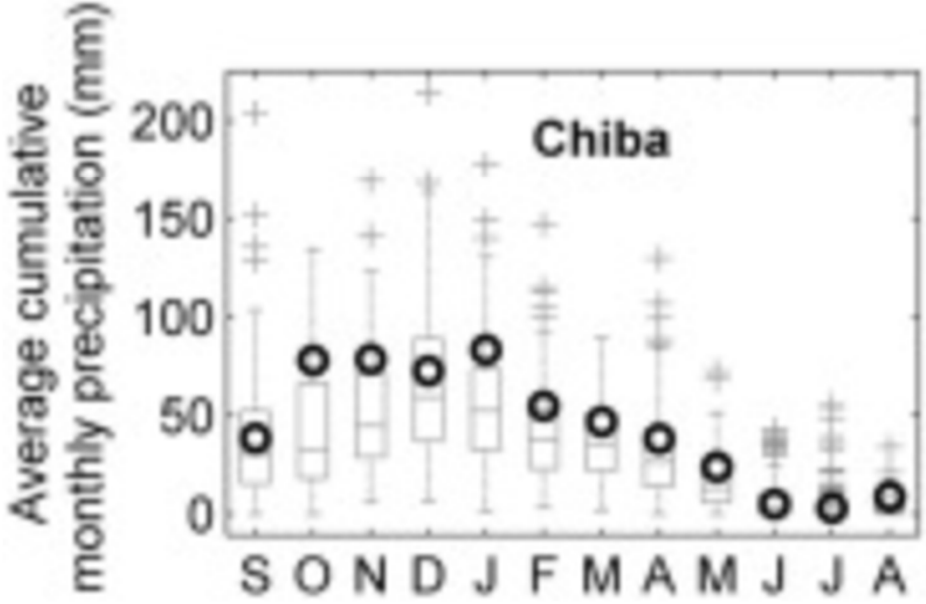


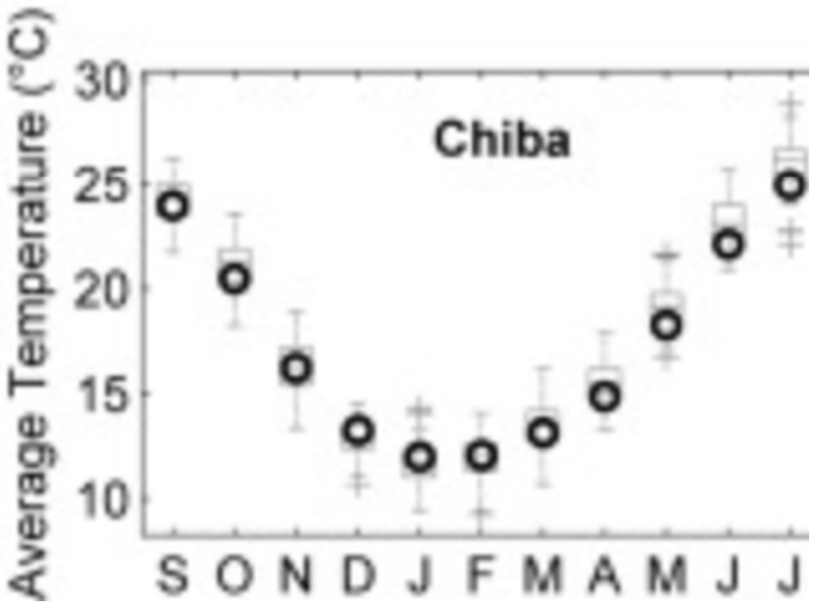
Fig. 1. Location of the study sites: (1) the Thau catchment and (2) the Chiba catchment.

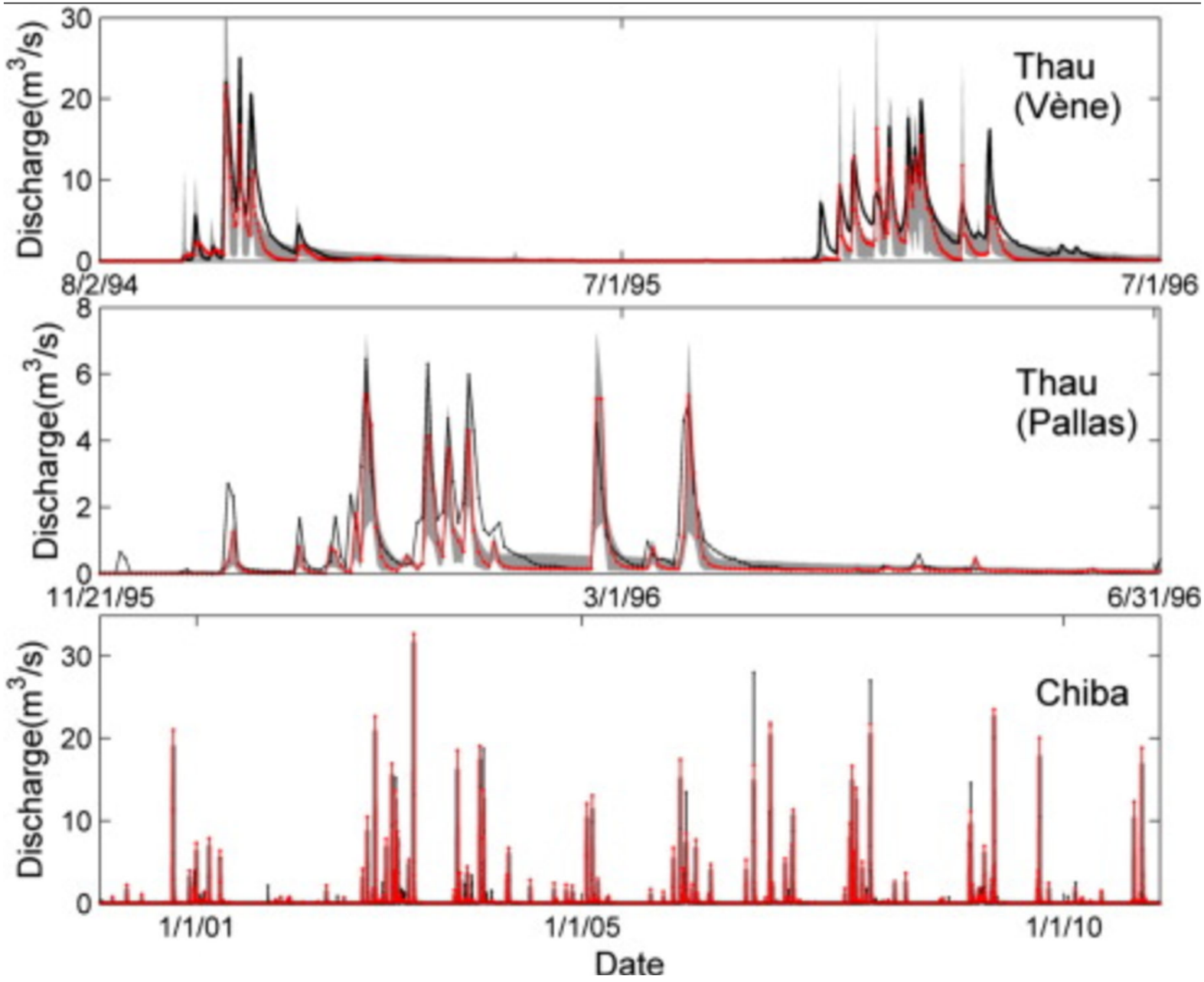

GCM
HCH
Hadley Center for Climate Prediction, Met Office, UK. HadCM3 Model (high sensitivity)
(A1B)
ECH
Max Planck Institute for Meteorology, Germany. ECHAM5/MPI OM
(A1B)
RCM
RCA
Swedish Meteorological and Hydrological Institute (SMHI), Sweden
RCA Model
REM
Max Planck Institute for Meteorology, Hamburg, Germany
REMO Model
RMO
Royal Netherlands Meteorological Institute (KNMI), Netherlands
RACMO2 Model
Selected GCM-RCM
HCH-RCA
ECH-RCA
ECH-REM
ECH-RMO


Thau
Average cumulative monthly precipitation (mm)
300
200
100
0
S O N D J F M A M J J A

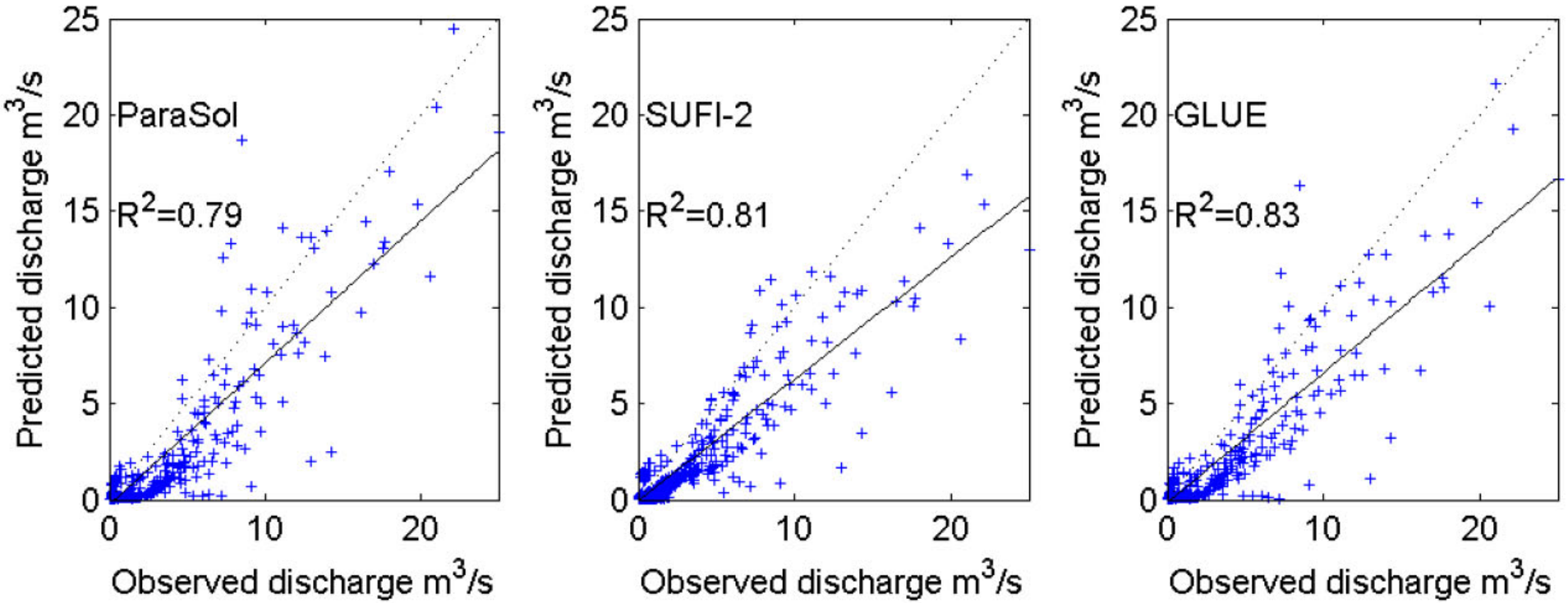

Thau
Average Temperature (°C)
25
20
15
10
5
S O N D J F M A M J J


Chiba
Average cumulative monthly precipitation (mm)
200
150
100
50
0
S O N D J F M A M J J A

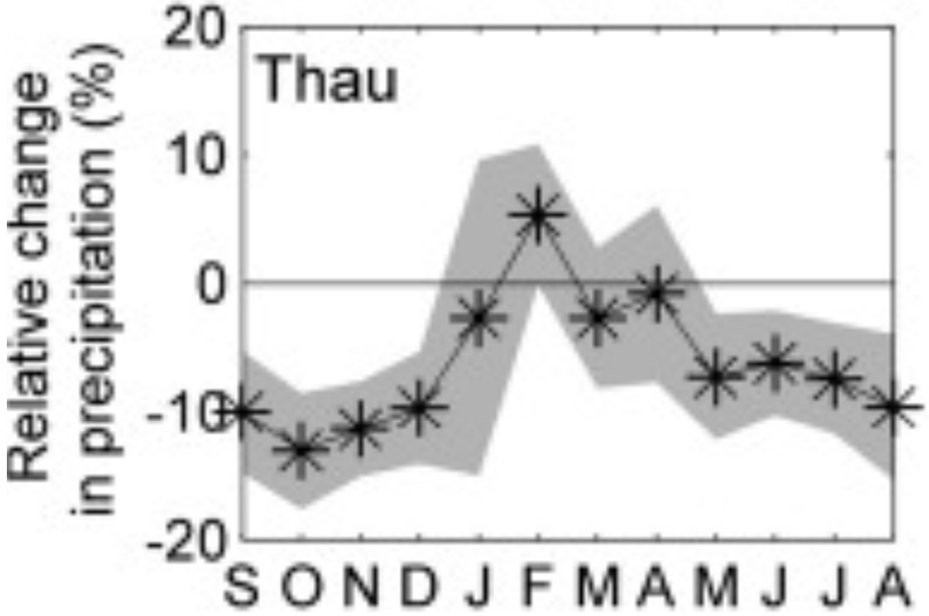

Chiba
Average Temperature (°C)
30
25
20
15
10
S O N D J F M A M J J

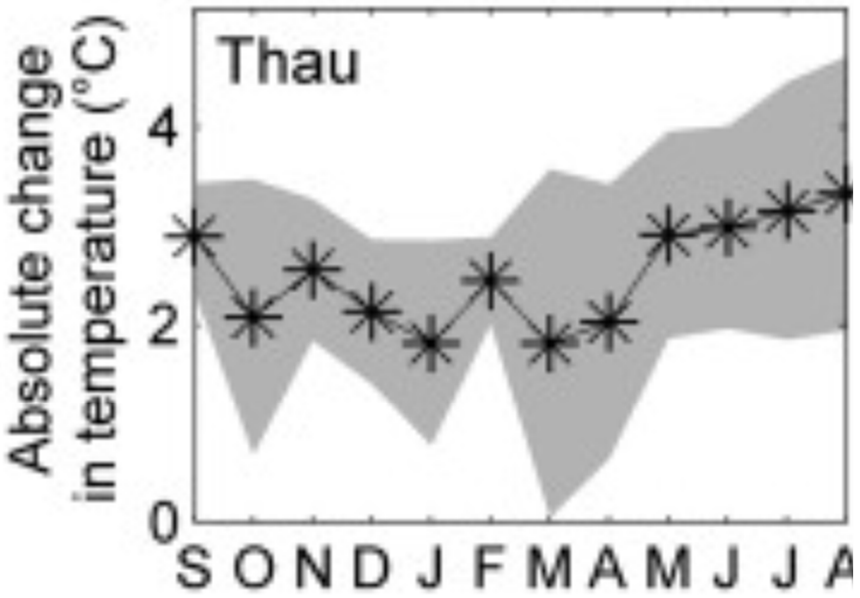

Discharge(m3/s)
30
20
10
0
8/2/94
7/1/95
7/1/96
Thau
(Vène)
Discharge(m3/s)
8
6
4
2
0
11/21/95
3/1/96
6/31/96
Thau
(Pallas)
Discharge(m3/s)
30
20
10
0
1/1/01
1/1/05
1/1/10
Date
Chiba

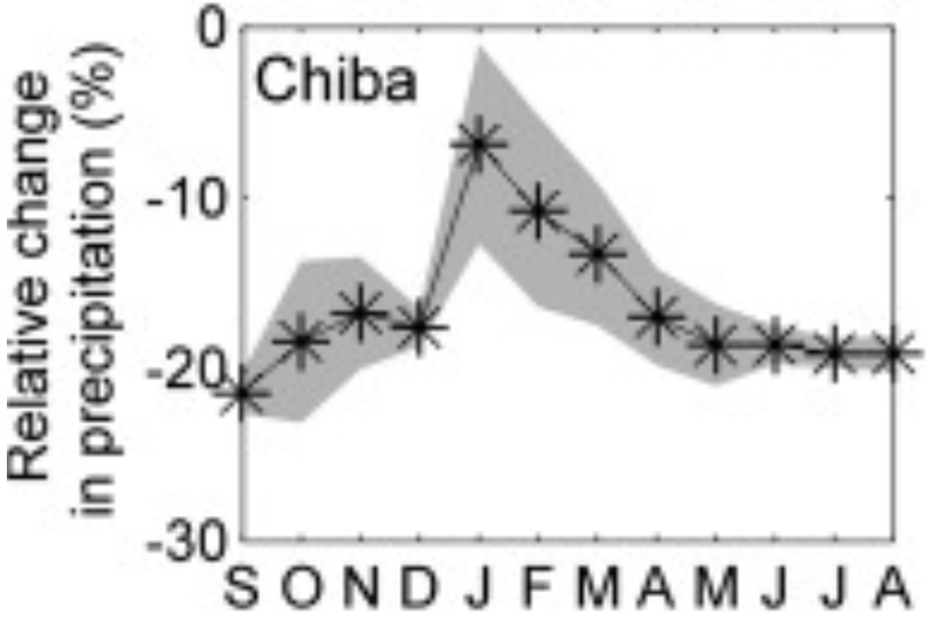
(a)

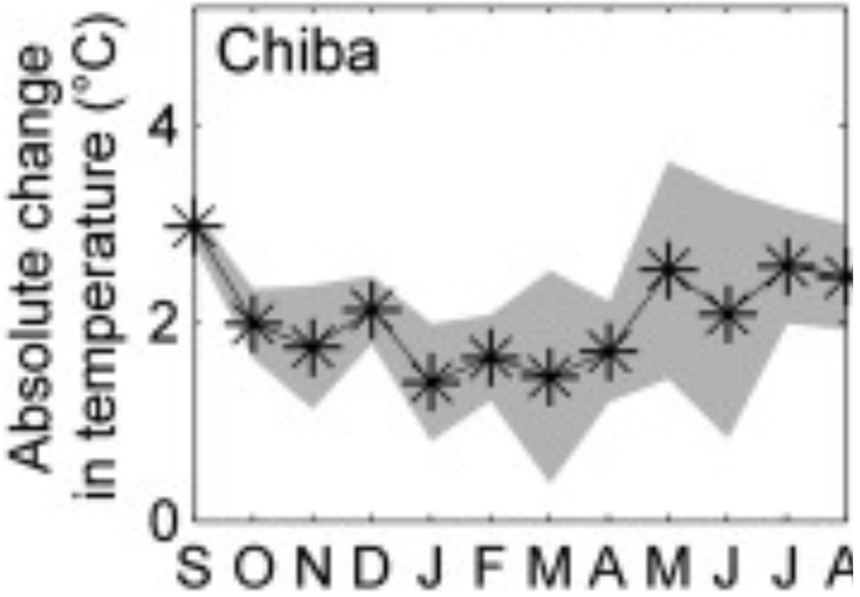


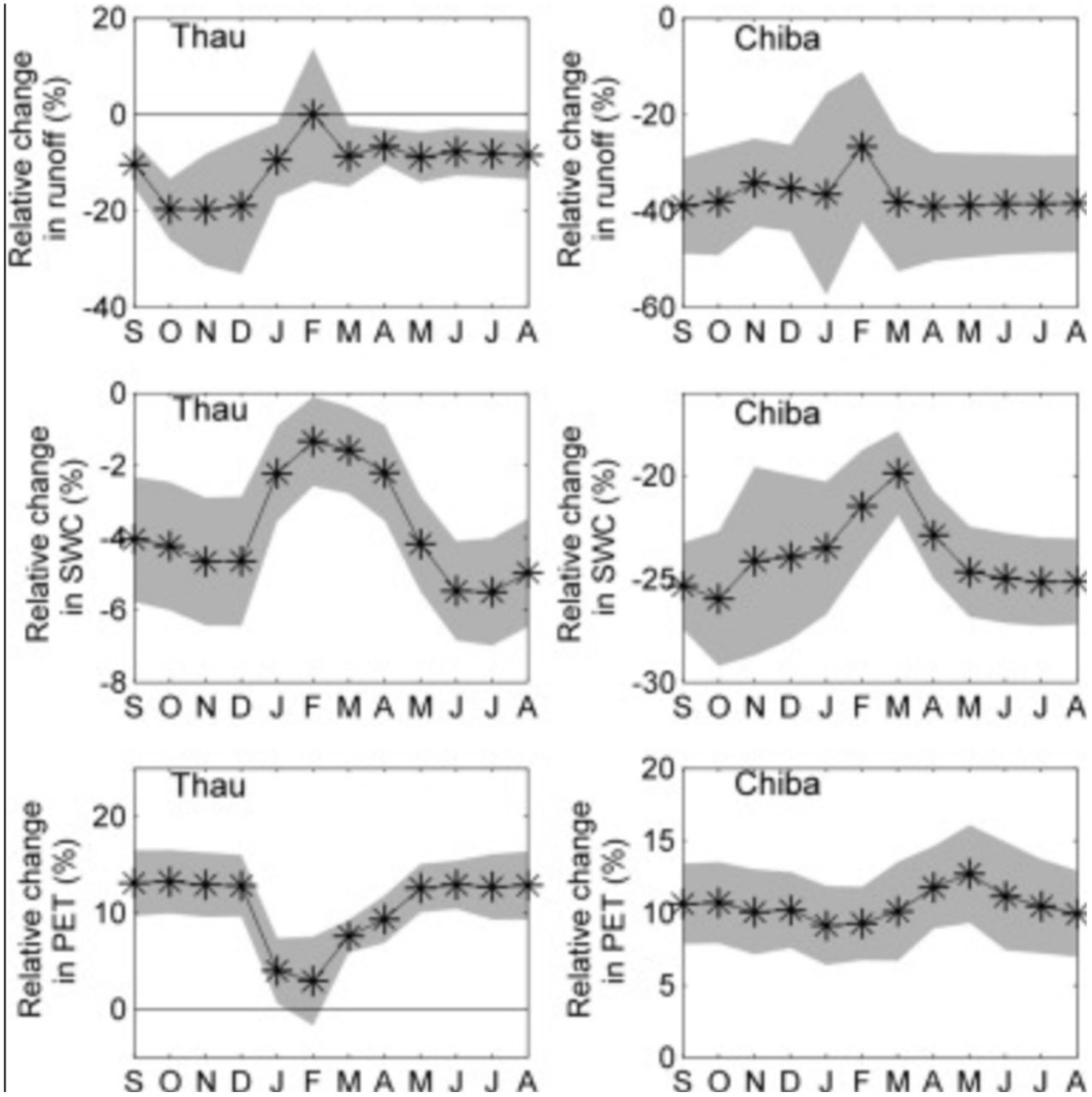
Source: Sellami et al., 2012

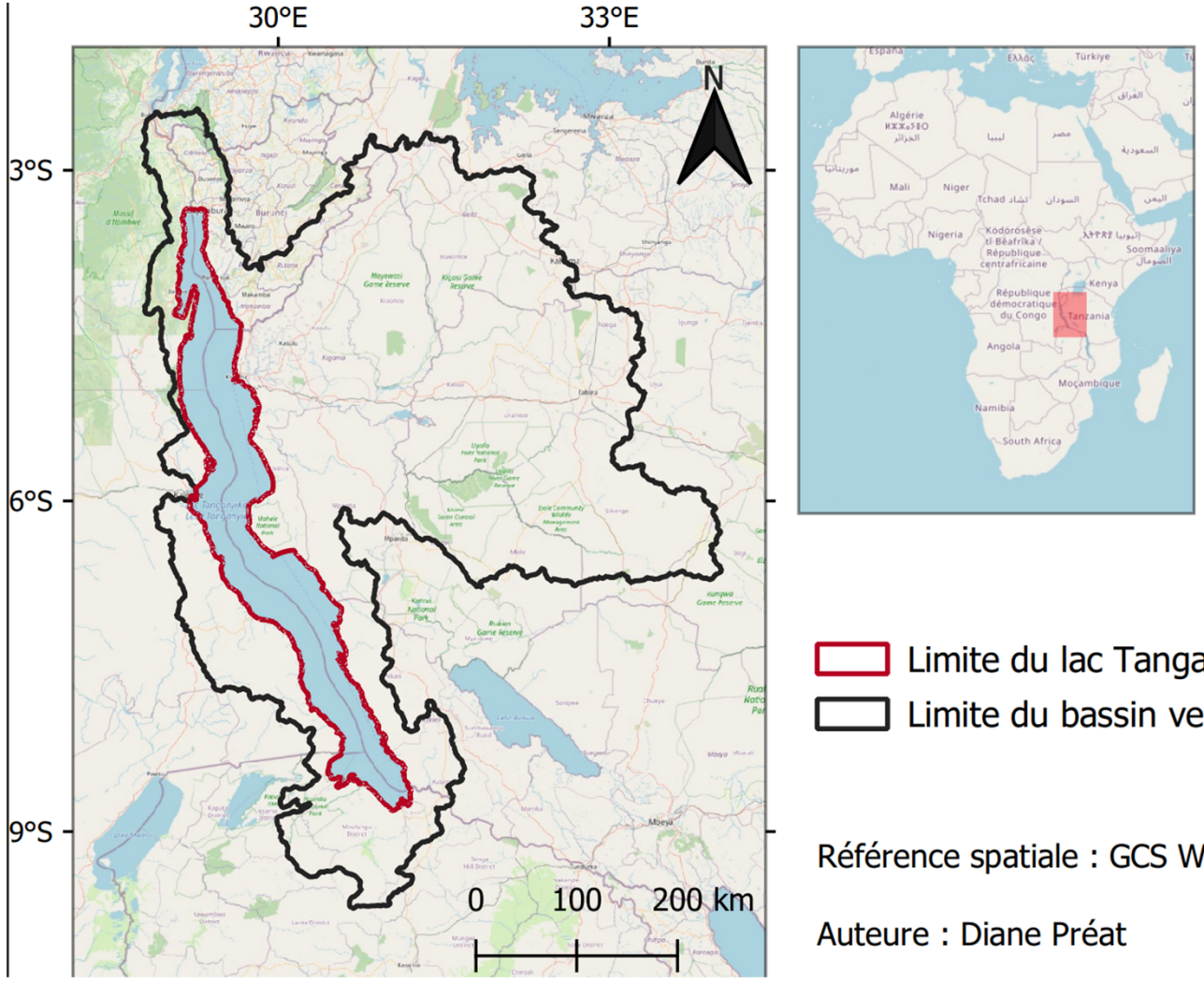

Thau
Relative change in precipitation (%)
20
10
0
-10
-20
S O N D J F M A M J J A

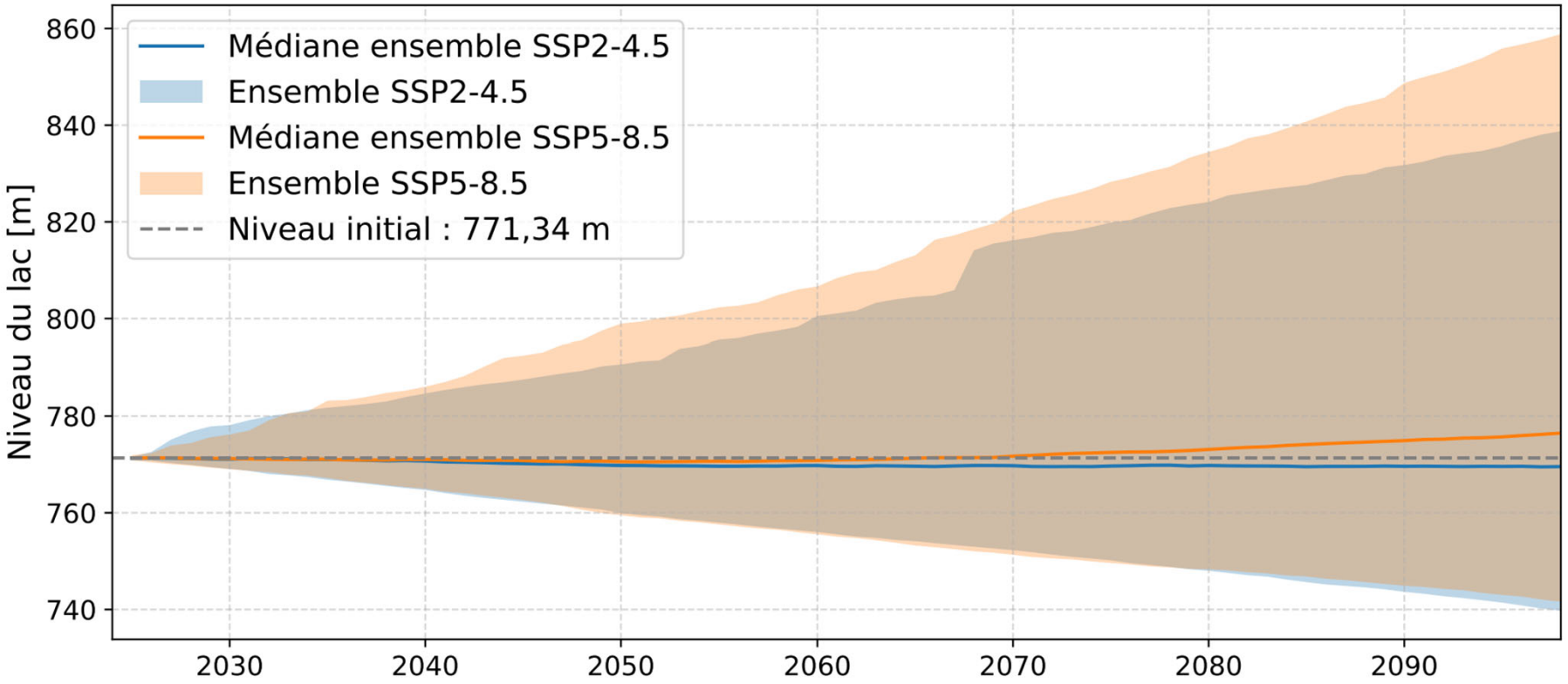

Thau
Absolute change in temperature (°C)
4
2
0
S O N D J F M A M J J A


Chiba
Relative change in precipitation (%)
0
-10
-20
-30
S O N D J F M A M J J A

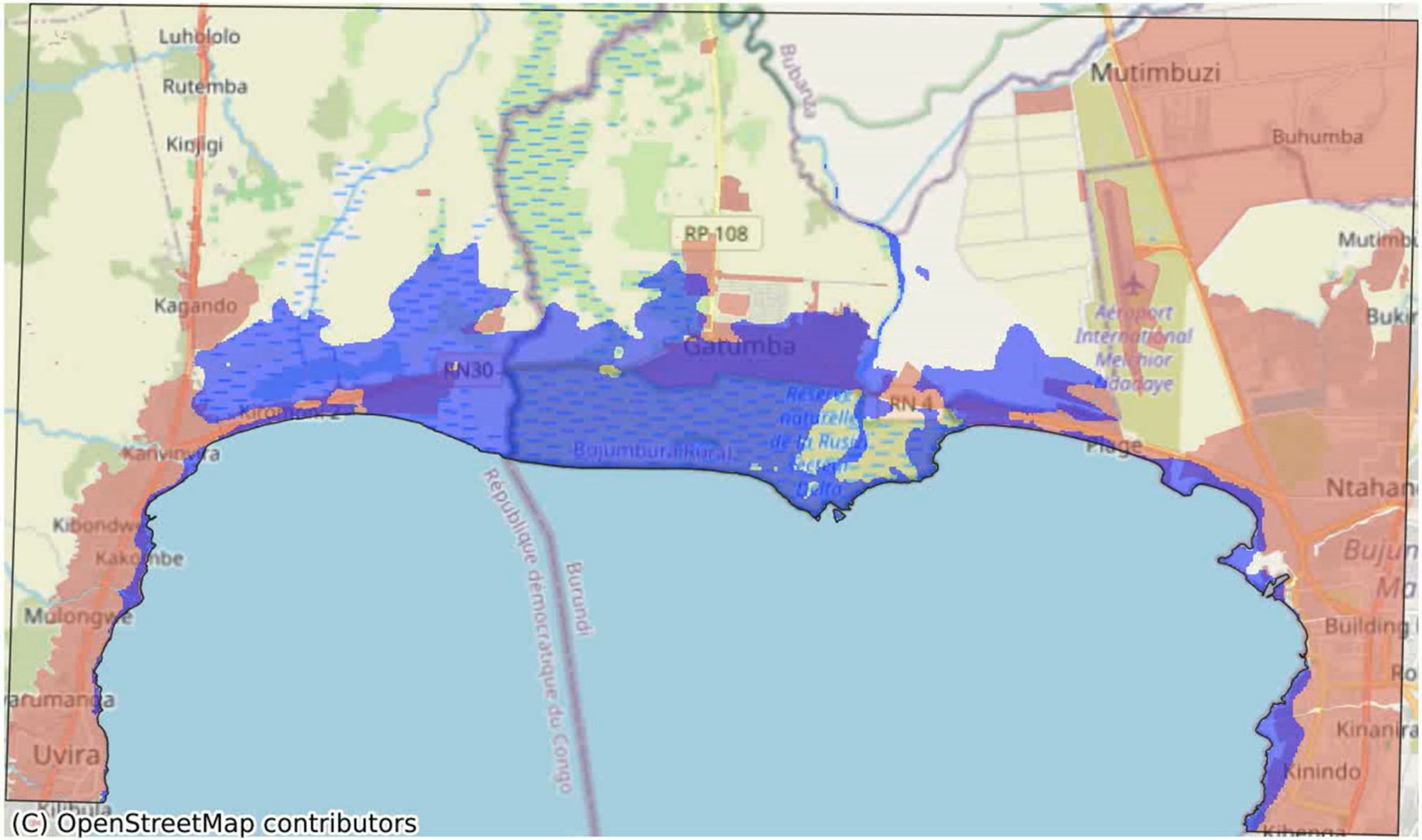

Chiba
Absolute change in temperature (°C)
4
2
0
S O N D J F M A M J J A

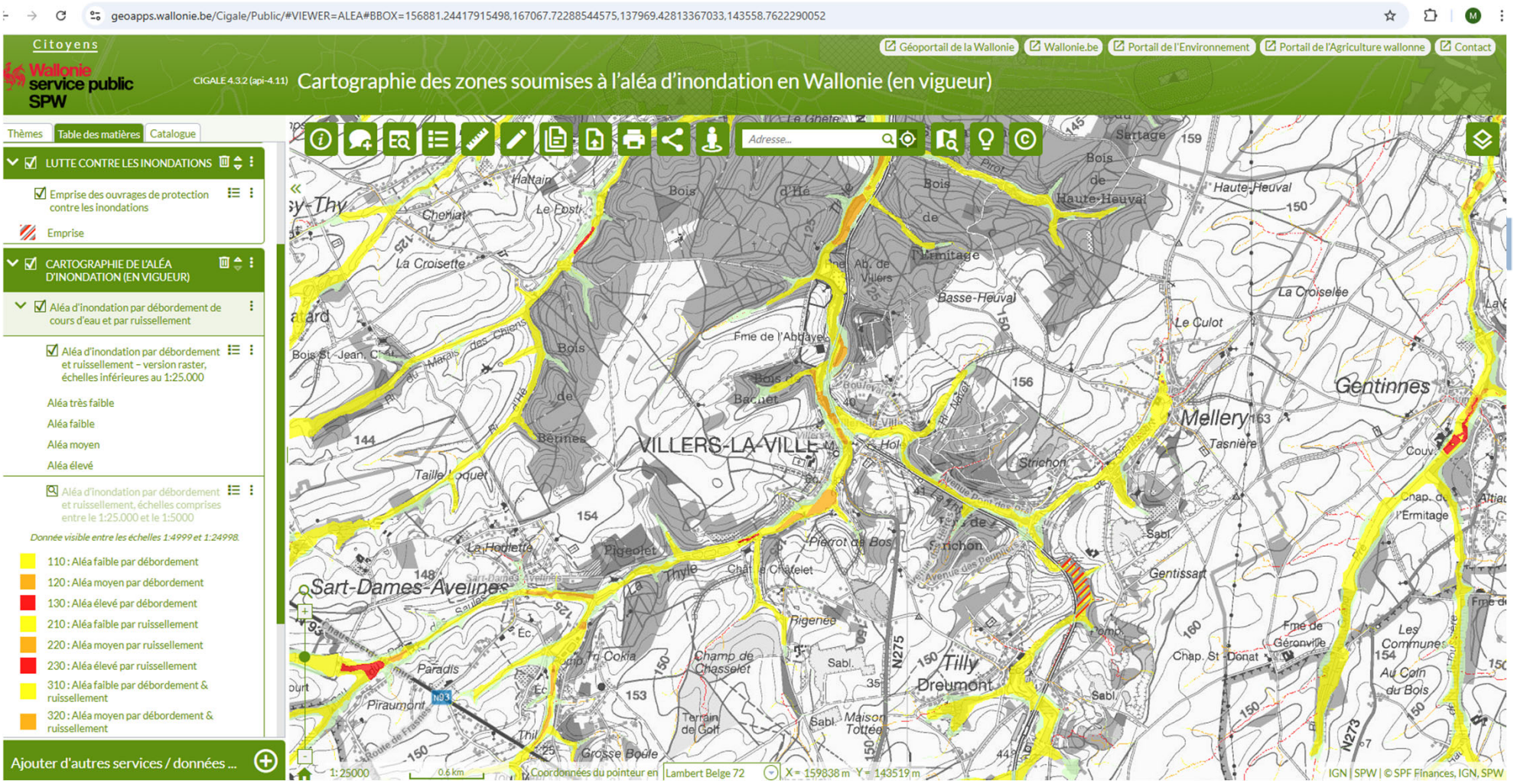

Thau
Chiba
Relative change in runoff (%)
Relative change in SWC (%)
Relative change in PET (%)
S O N D J F M A M J J A


30°E
33°E
3°S
6°S
9°S
N
0
100
200 km
Limite du lac Tanganyika
Limite du bassin versant
Référence spatiale : GCS WGS 1984
Auteure : Diane Préat


Médiane ensemble SSP2-4.5
Ensemble SSP2-4.5
Médiane ensemble SSP5-8.5
Ensemble SSP5-8.5
Niveau initial : 771,34 m
Niveau du lac [m]
860
840
820
800
780
760
740
2030
2040
2050
2060
2070
2080
2090

Zones inondées - 01/01/2024




geoapps.wallonie.be/Cigale/Public/#VIEWER=ALEA#BBOX=156881.24417915498,167067.72288544575,137969.42813367033,143558.7622290052
Citoyens
Wallonie service public SPW
CIGALE 4.3.2 (api-4.11)
Cartographie des zones soumises à l'aléa d'inondation en Wallonie (en vigueur)
Géoportail de la Wallonie
Wallonie.be
Portail de l'Environnement
Portail de l'Agriculture wallonne
Contact
Thèmes
Table des matières
Catalogue
LUTTE CONTRE LES INONDATIONS
Emprise des ouvrages de protection contre les inondations
Emprise
CARTOGRAPHIE DE L'ALÉA D'INONDATION (EN VIGUEUR)
Aléa d'inondation par débordement de cours d'eau et par ruissellement
Aléa d'inondation par débordement et ruissellement – version raster, échelles inférieures au 1:25.000
Aléa très faible
Aléa faible
Aléa moyen
Aléa élevé
Aléa d'inondation par débordement et ruissellement, échelles comprises entre le 1:25.000 et le 1:5000
Donnée visible entre les échelles 1:4999 et 1:24998.
110 : Aléa faible par débordement
120 : Aléa moyen par débordement
130 : Aléa élevé par débordement
210 : Aléa faible par ruissellement
220 : Aléa moyen par ruissellement
230 : Aléa élevé par ruissellement
310 : Aléa faible par débordement & ruissellement
320 : Aléa moyen par débordement & ruissellement
Ajouter d'autres services / données ...
Adresse...
VILLERS-LA-VILLE
Sart-Dames-Avelines
Tilly
Gentinnes
Mellery
Haute-Heuval
Basse-Heuval
Gentissart
Dreumont
1:25000
0.5 km
Coordonnées du pointeur en Lambert Belge 72
X = 159838 m Y = 143519 m
IGN | SPW | © SPF Finances, IGN, SPW

Modelling uncertainty sources

- Model input uncertainty and model parameter uncertainty
- Observational uncertainty
- Scenario uncertainty
- Structural model uncertainty

Modelling uncertainty sources

- Model input uncertainty and parameter uncertainty
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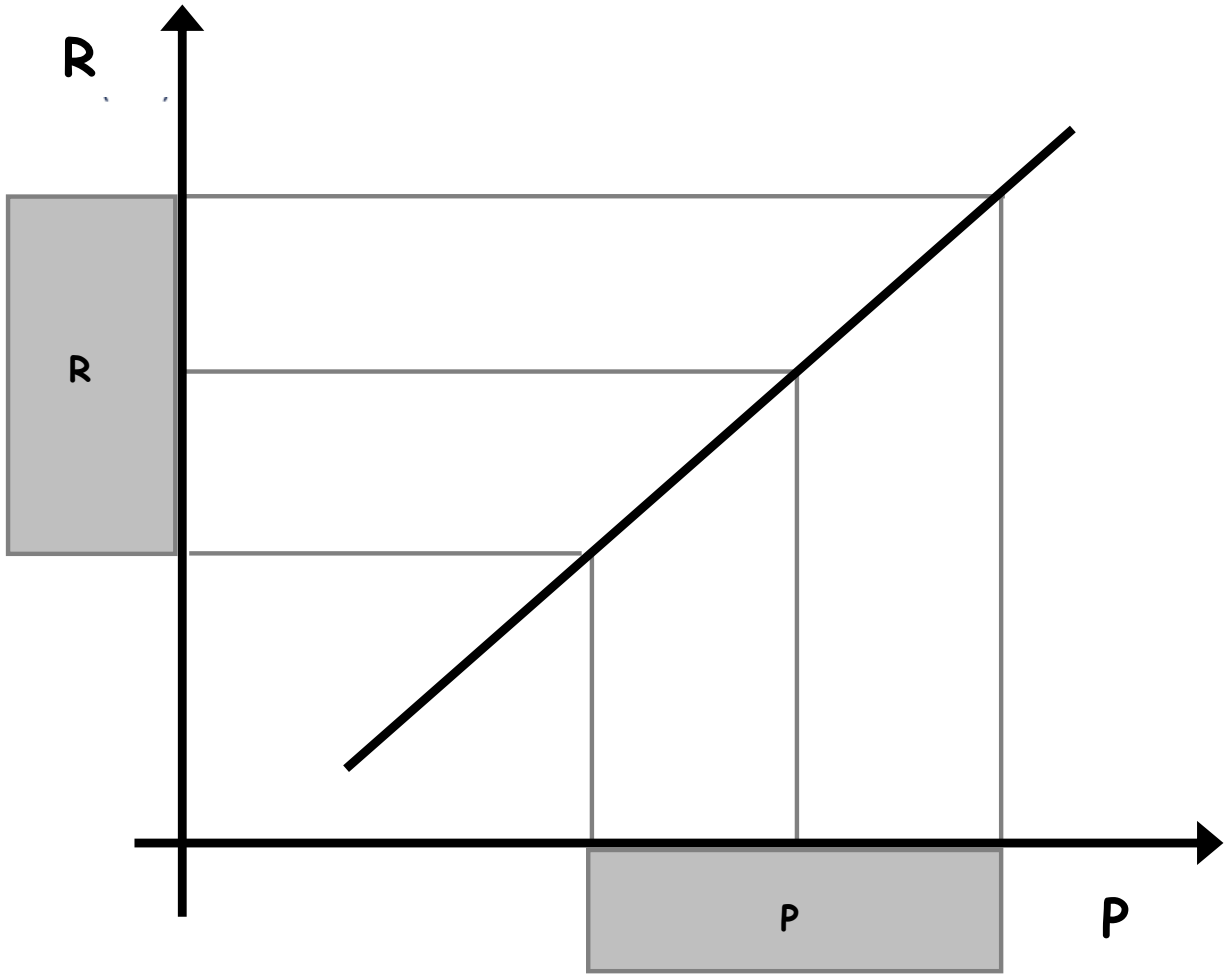
Propagating uncertainty

$$E(R) = F(E(P))$$

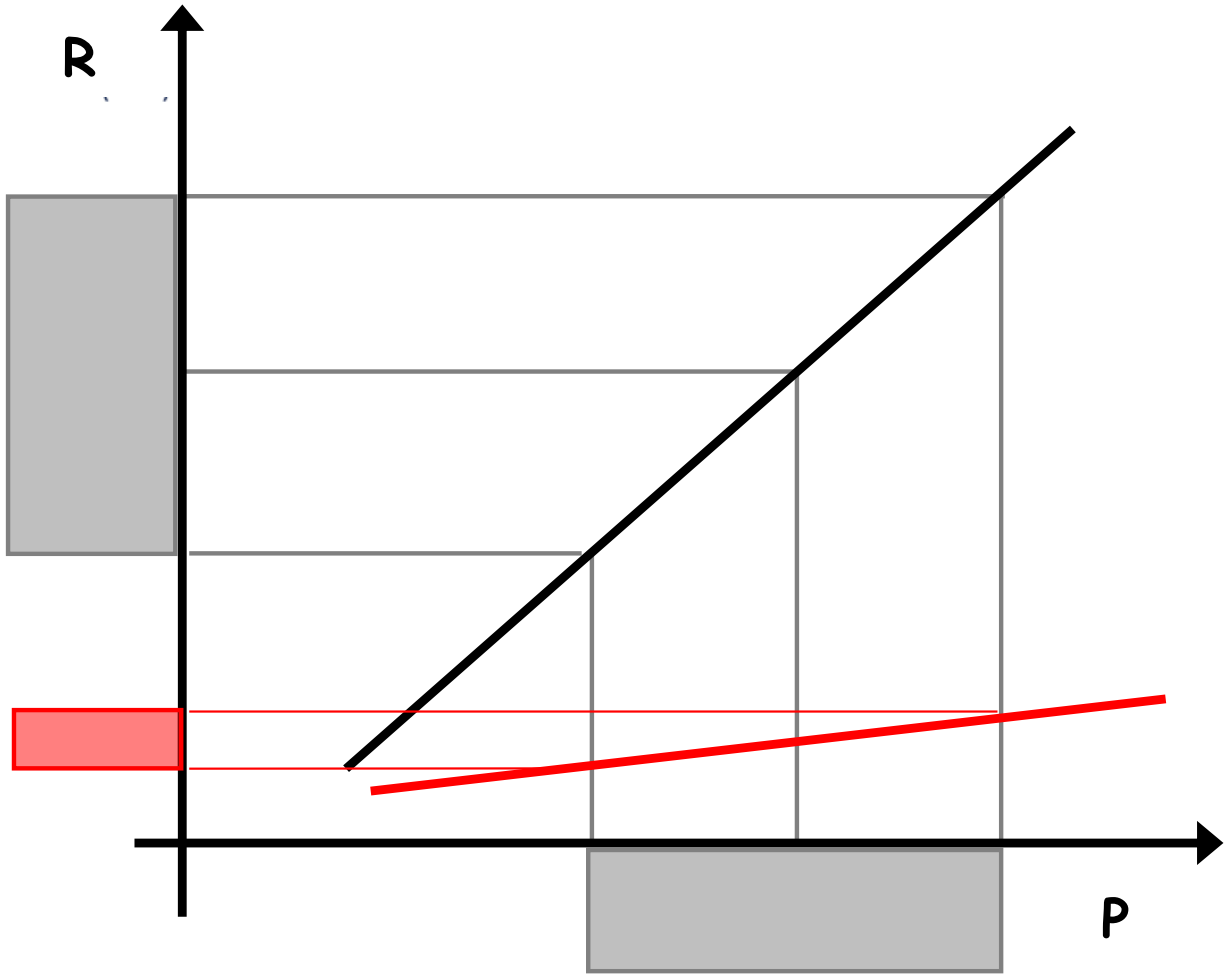
$$\text{var}(R) = \sum_i \left(\frac{\partial F}{\partial P_i}\right)^2 \text{var}(P_i)$$



Propagating uncertainty: Effect of sensitivity

$$E(R) = F(E(P))$$

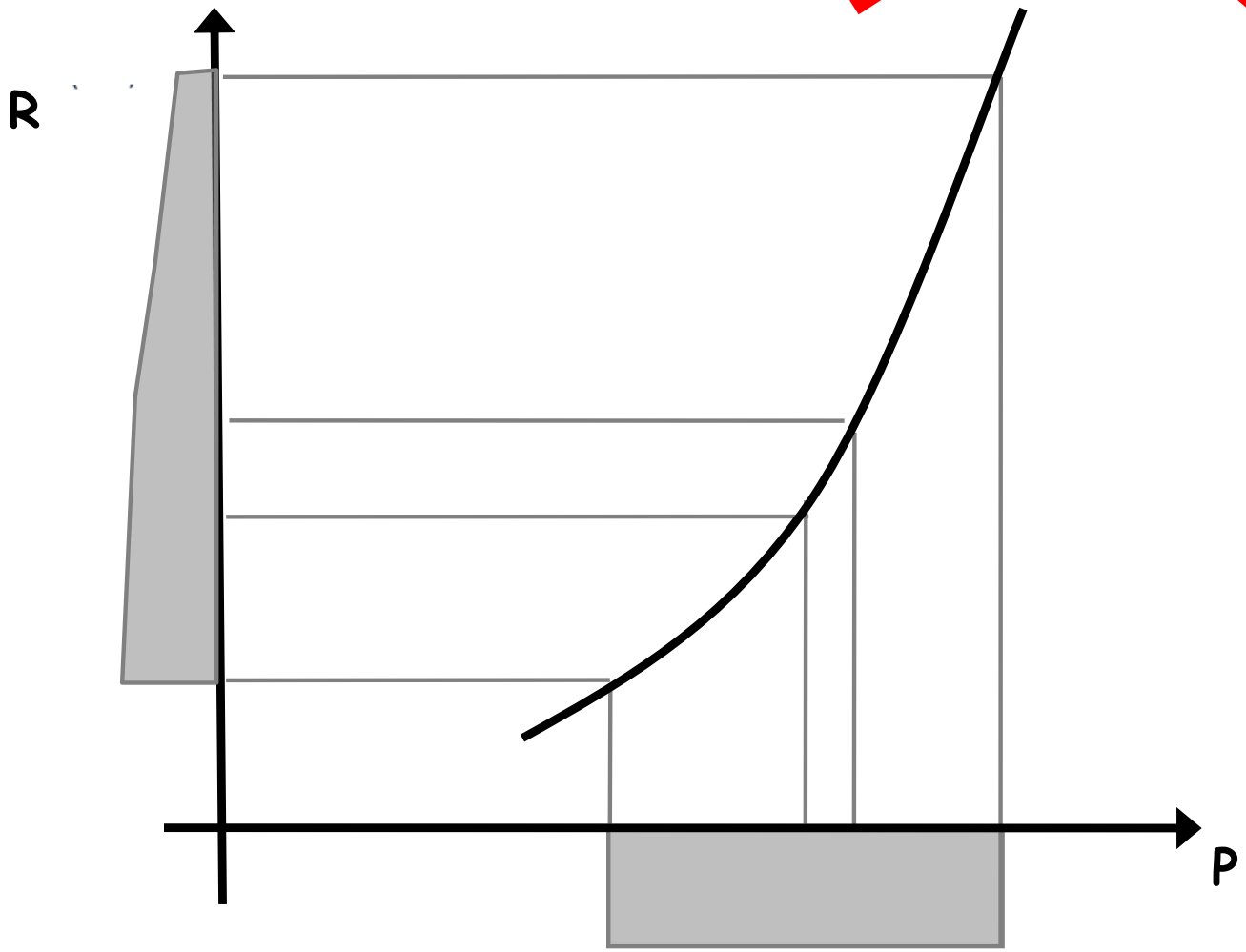
$$\mathrm{var}(R) = \sum_i \left(\frac{\partial F}{\partial P_i}\right)^2 \mathrm{var}(P_i)$$



Propagating uncertainty: Effect of non linearity

$$E(R) = F(E(P))$$

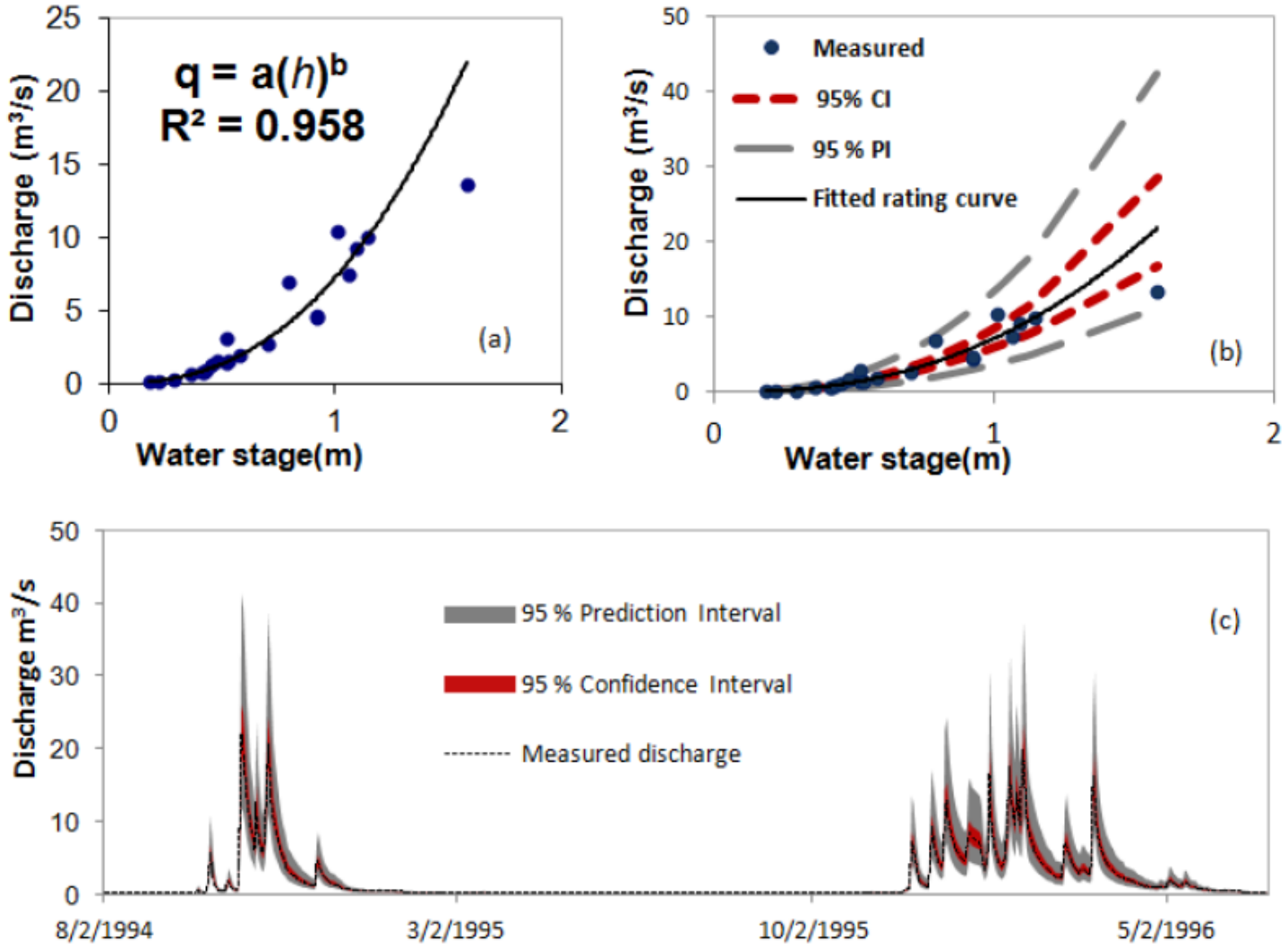
$$\mathrm{var}(R) = \sum_i \left(\frac{\partial F}{\partial P_i}\right)^2 \mathrm{var}(P_i)$$



Modelling uncertainty sources

- Model input uncertainty
- Model parameter uncertainty
- Observational uncertainty
- Scenario uncertainty
- Structural model uncertainty

Observational uncertainty



Source: Sellami et al., 2012

Statistical criteria	Deterministic rating curve		Uncertain rating curve	
	Method	Catchment		
		Vène	Pallas	Vène	Pallas
NS*	SUFI-2	0.69	0.73	---	---
	GLUE	0.71	0.76	---	---
	ParaSol	0.58	0.67	---	---
R^{2*}	SUFI-2	0.81	0.78	---	---
	GLUE	0.83	0.81	---	---
	ParaSol	0.79	0.69	---	---
p-factor (%)	SUFI-2	38	48	47	54
	GLUE	50	61	67	75
	ParaSol	19	28	21	29
R-factor	SUFI-2	0.38	0.36	0.44	0.41
	GLUE	0.46	0.44	0.67	0.59
	ParaSol	0.13	0.10	0.20	0.18

Source: Sellami et al., 2012

Modelling uncertainty sources

- Model input uncertainties
- Model parameter uncertainty
- Observation uncertainty
- Scenario uncertainty
- Structural uncertainty

Scenario validation

The quality of a scenario is defined as the adequacy for a given use.

Components of scenario validation:

- Representativeness
- Theoretical and logical consistency
- Juridical conformity
- Political conformity

Modelling uncertainty sources

- Model input uncertainties
- Model parameter uncertainty
- Observation uncertainty
- Scenario uncertainty
- Structural model uncertainty

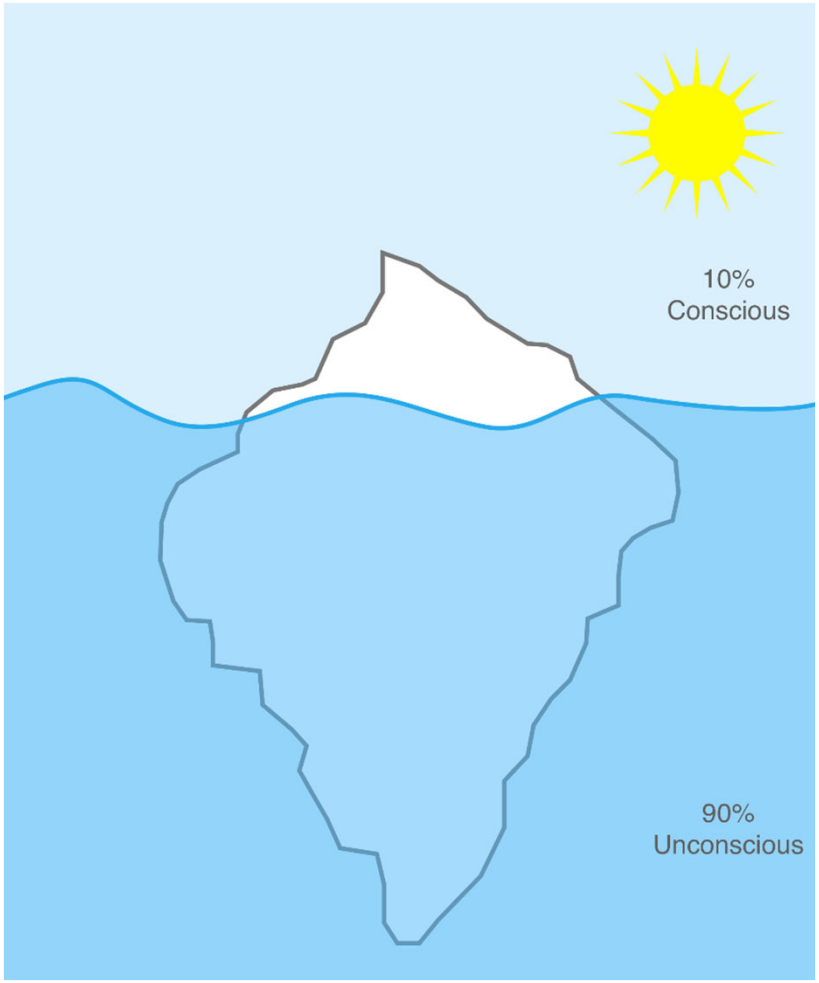
About certain and uncertain uncertainty

"Reports that say that something hasn't happened are always interesting to me, because as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns—the ones we don't know we don't know. And if one looks throughout the history of our country and other free countries, it is the latter category that tends to be the difficult ones"

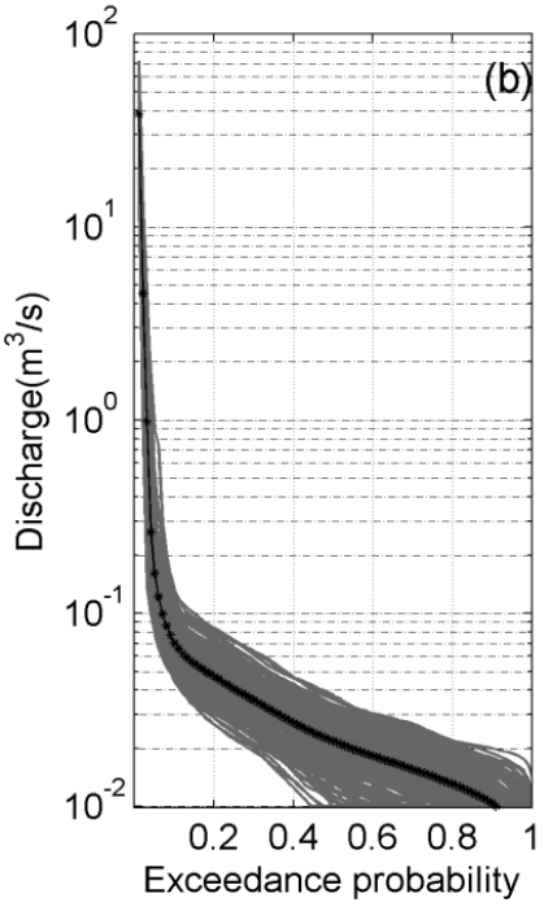
Source: Donald Rumsfeld, 2002

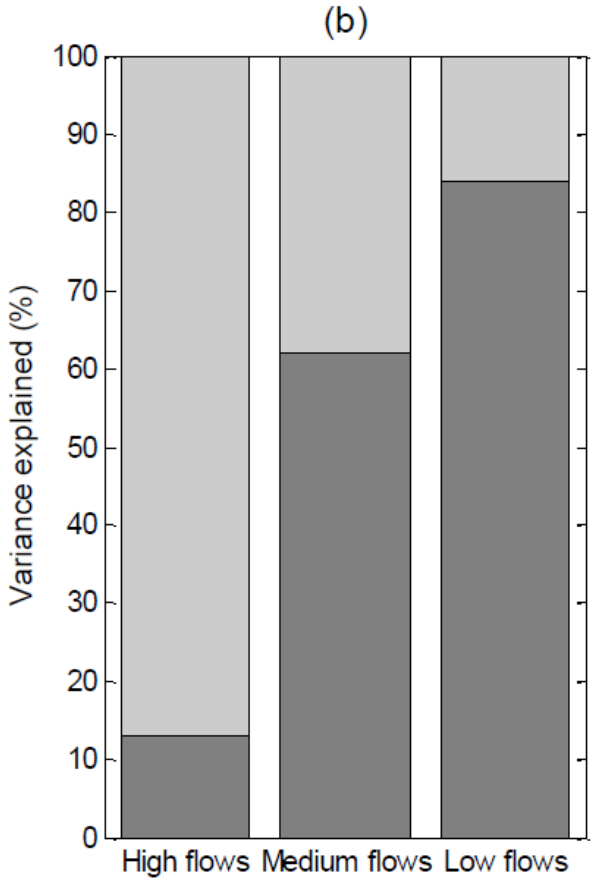
https://www.youtube.com/watch?v=GiPe1OiKQuk

About certain and uncertain uncertainty



What dominates? Climate model uncertainty or hydrological model uncertainty





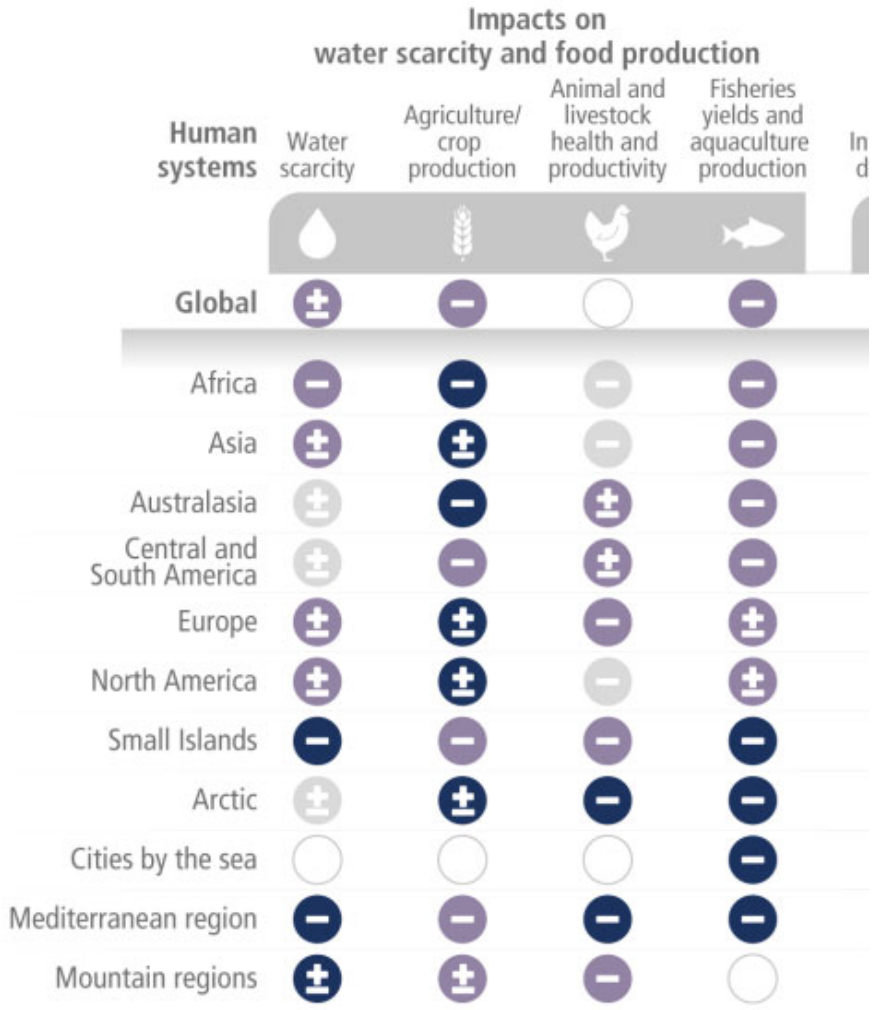
Climate

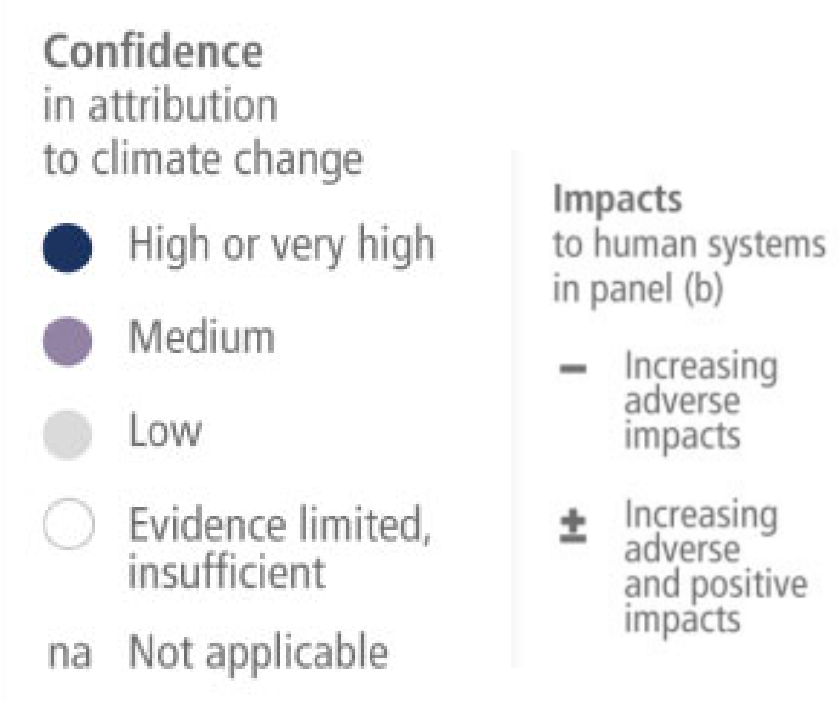
Hydrology

Source: Sellami et al., 2021

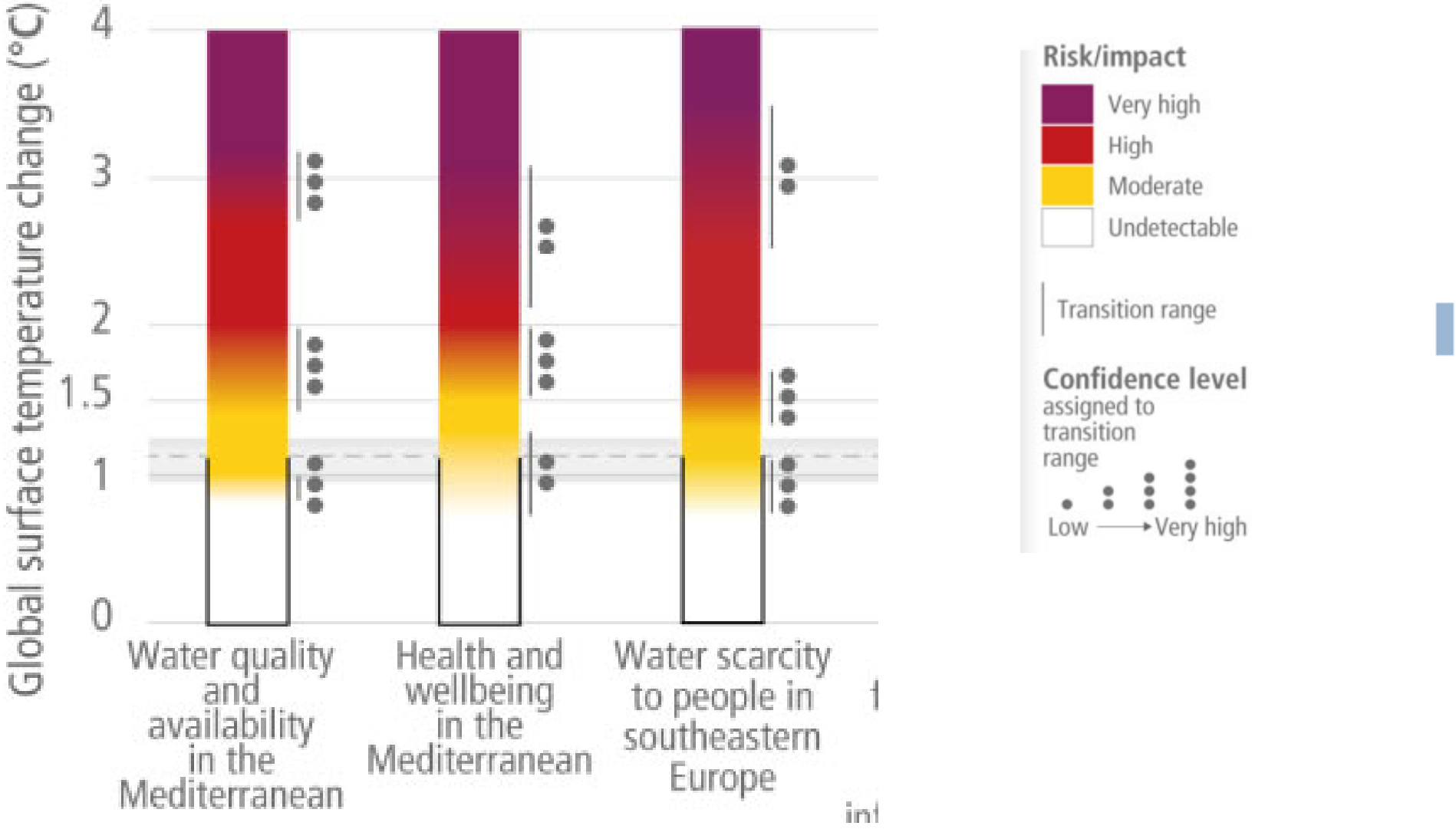
About communicating uncertainty

(b) Observed impacts of climate change on human systems





Source: https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_SummaryForPolicymakers.pdf



Source: https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_SummaryForPolicymakers.pdf

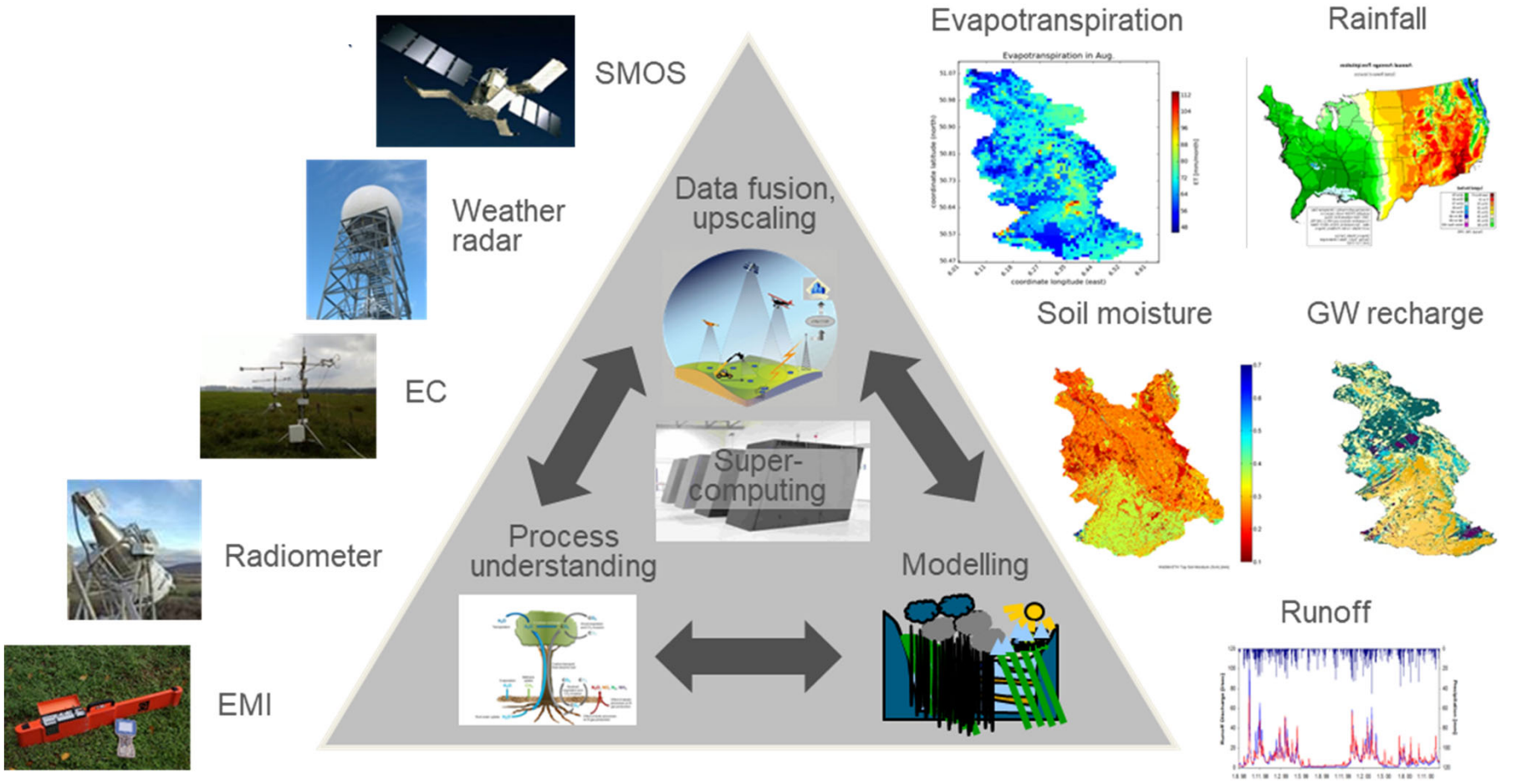
About communicating uncertainty

"Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, e.g., medium confidence. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99-100% probability, very likely 90-100%, likely 66-100%, as likely as not 33-66%, unlikely 0-33%, very unlikely 0-10%, exceptionally unlikely 0-1%."

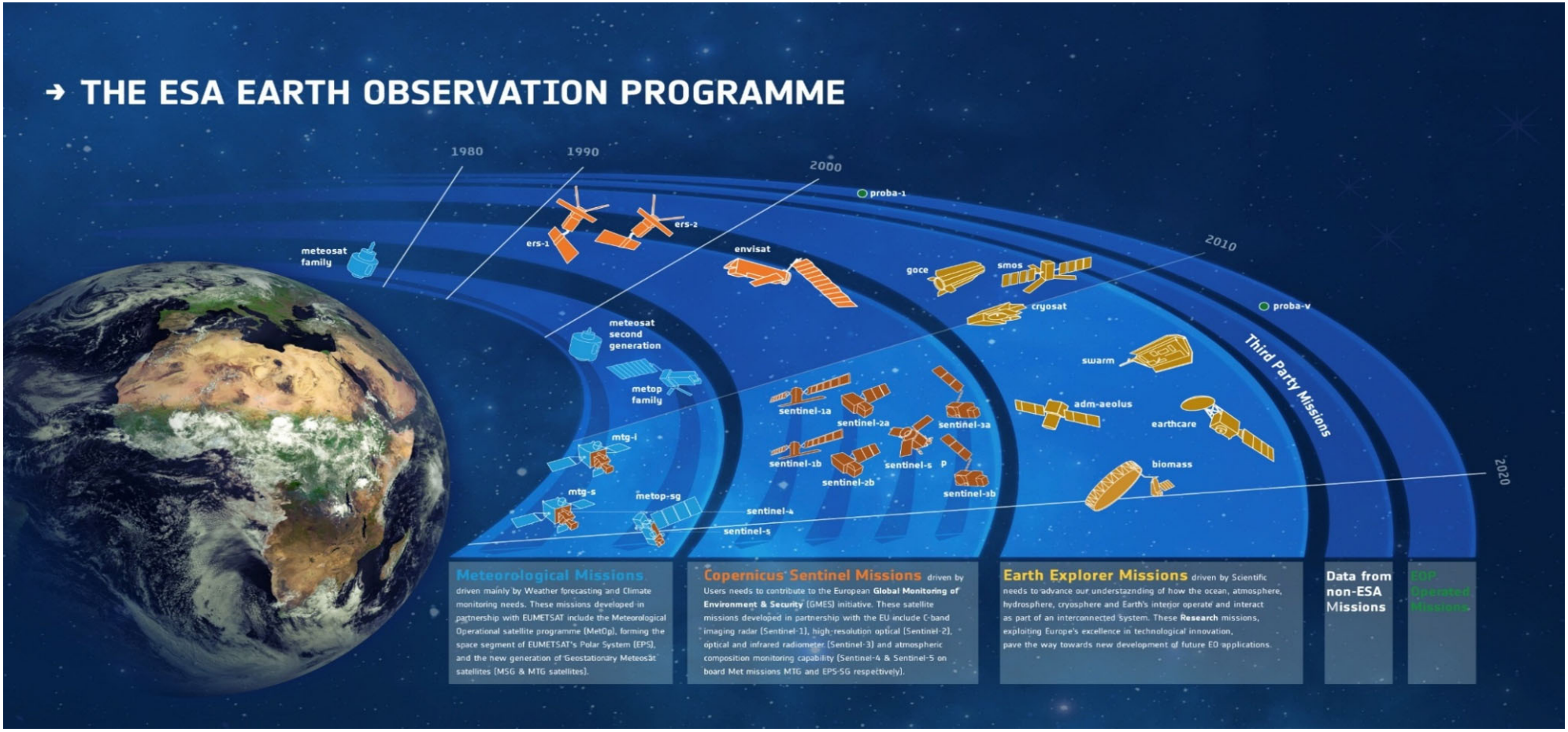
Source: https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_SummaryForPolicymakers.pdf

How to handle uncertainty

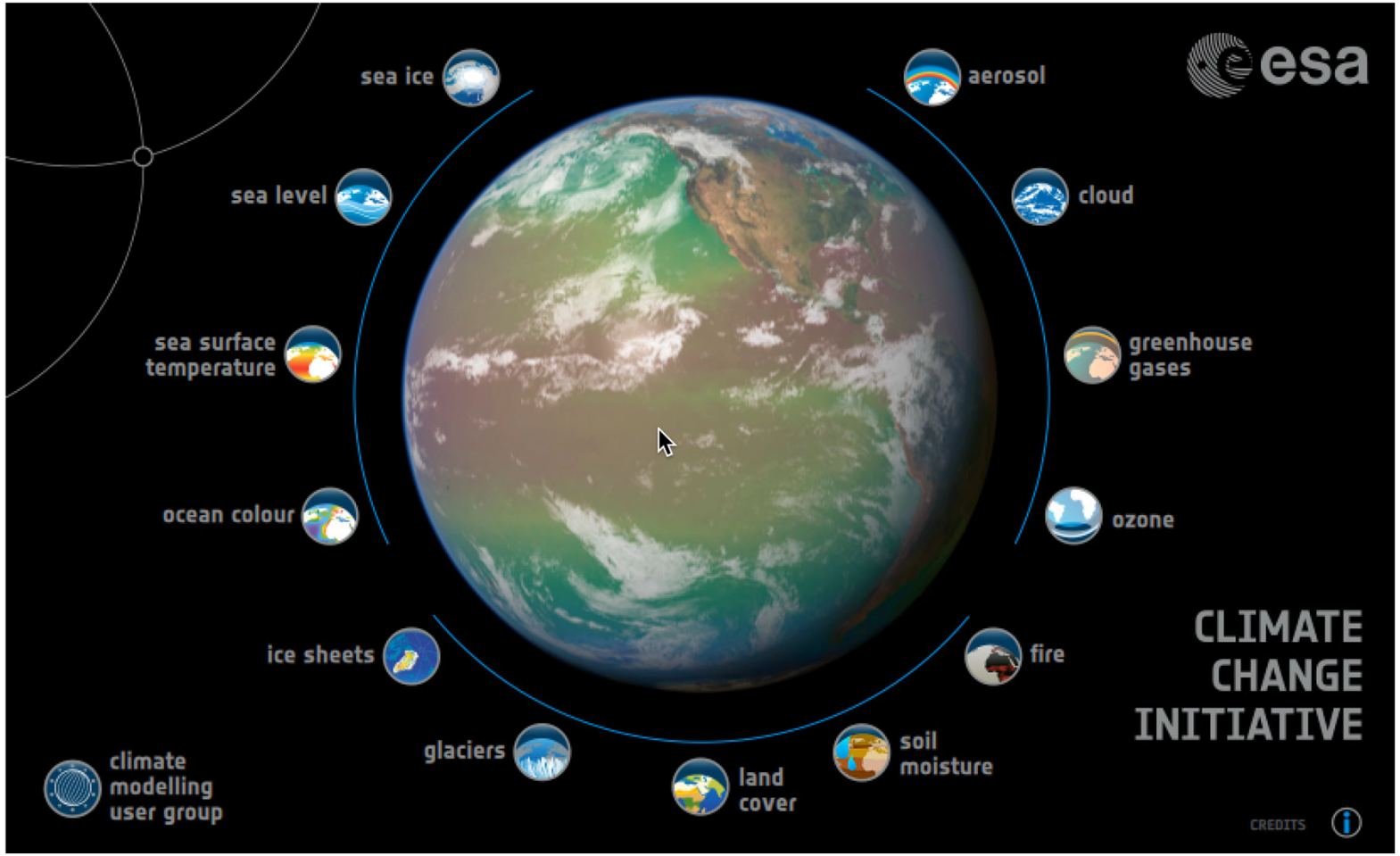
How to handle uncertainty



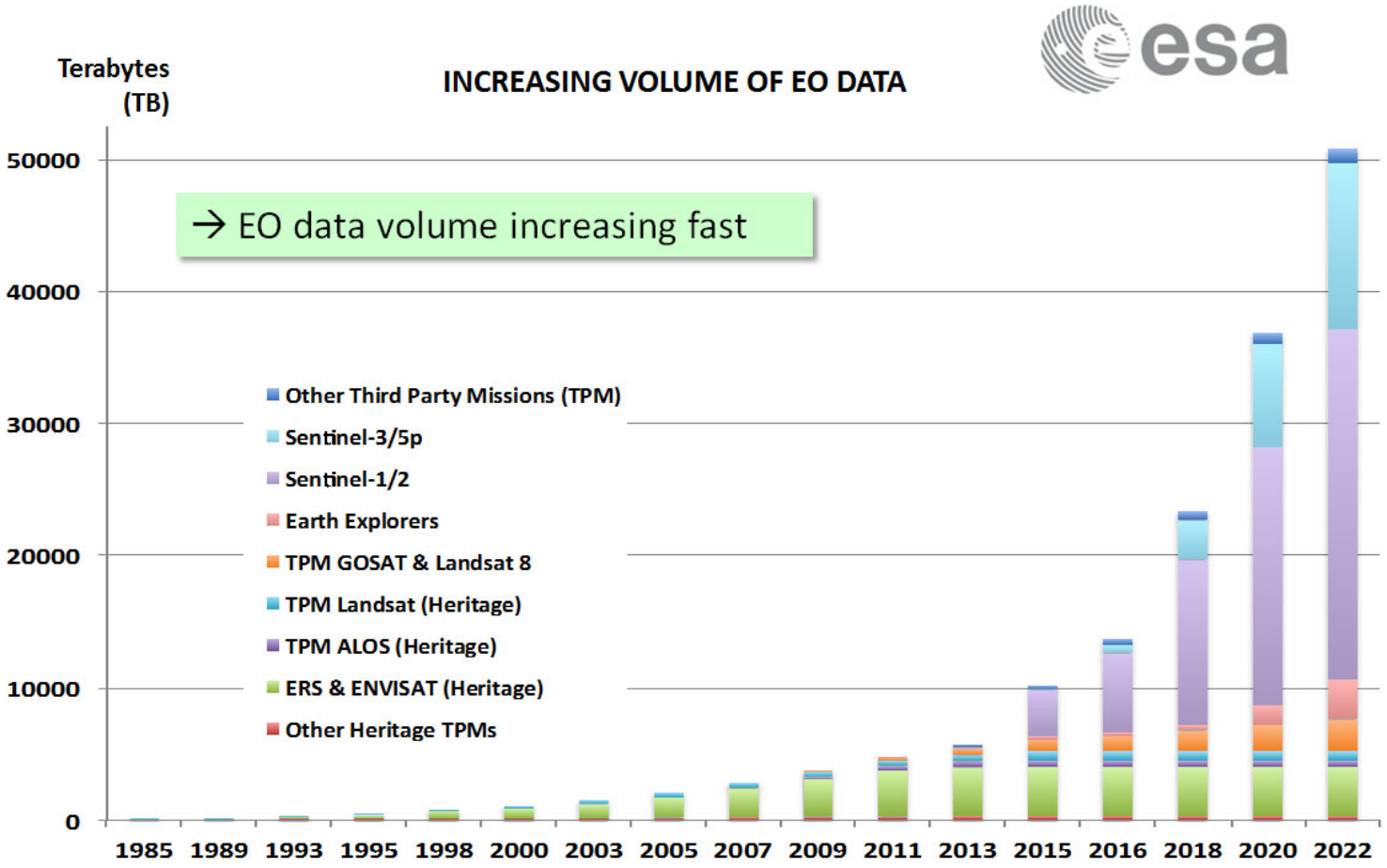
How to handle uncertainty



How to handle uncertainty

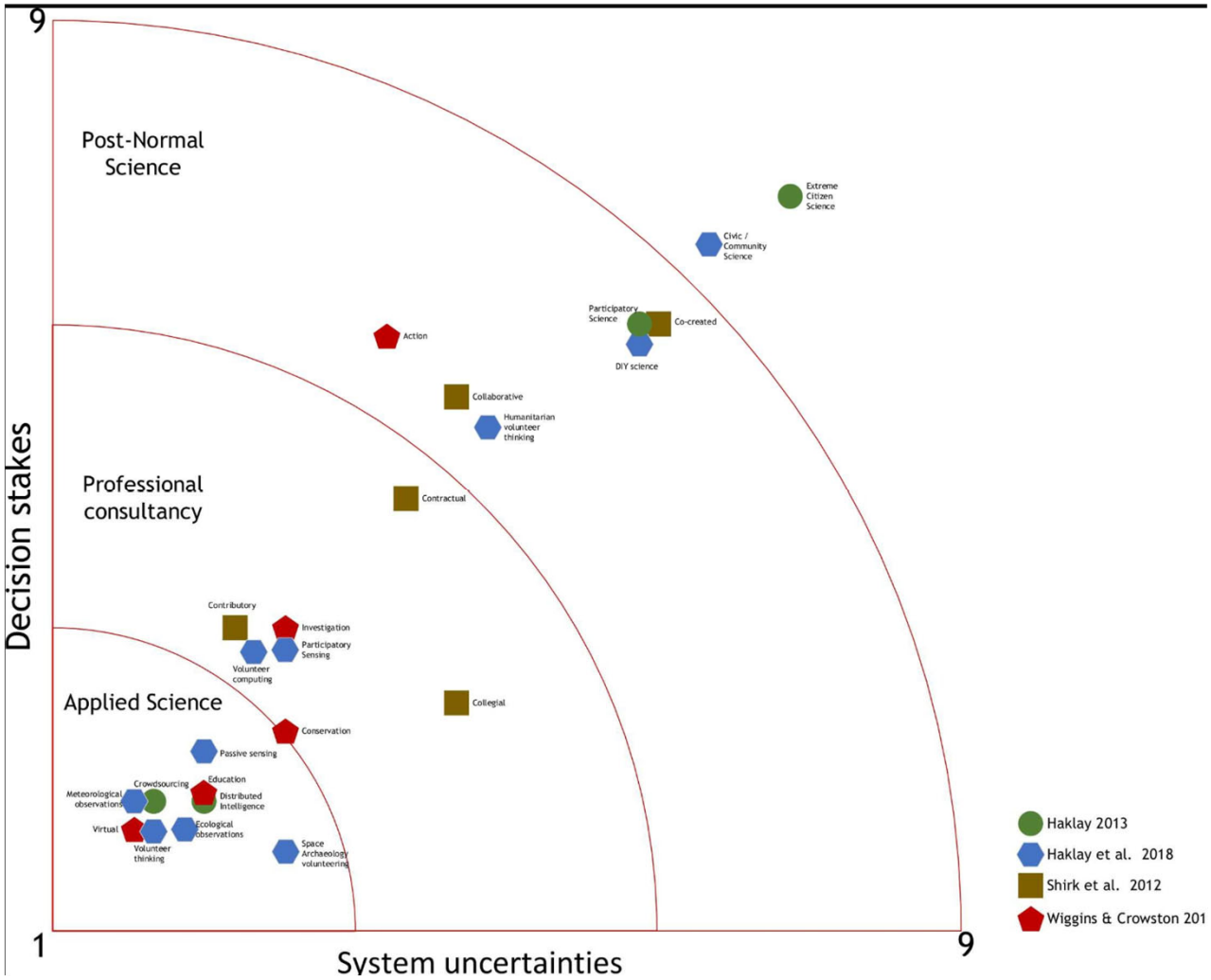


How to handle uncertainty



How to handle uncertainty

How to handle uncertainty



Take ahome messages

- Our planet is still blue, however…
- Climate change is expected to affect the water system considerably, in particular in the mediterranean area.
- Sure, there is much uncertainty in the climate change hydrological impact modelling chain.
- The science community very often propagate the certain uncertainties, much less effort is devoted to deep uncertain uncertainty.
- Take care of good uncertainty communication.
- Uncertainty on predicted impacts is very often determined by case study specific conditions.
- Impact of certain uncertainty can be reduced by increasing observational quality, improving model and modelling validation.
- Save a seat for the deep uncertain uncertainty and post-normal science.

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