Geosphere-biosphere-hydrosphere interactions in the Earth Critical Zone

lessons from European Protected Areas and the H2020 ECOPOTENTIAL project

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Institute of Geosciences and Earth Resources, Pisa
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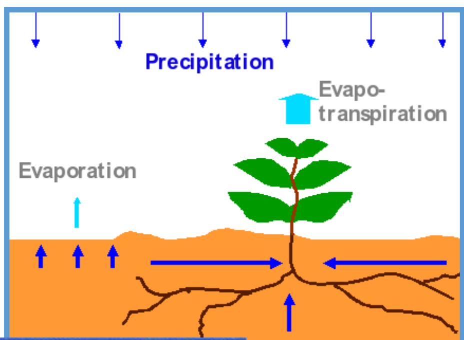
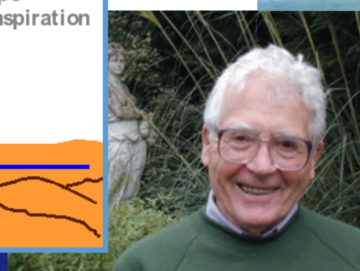
This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 641762

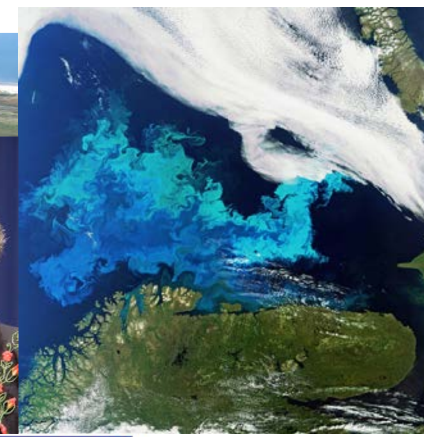
ECRA General Assembly,
7-8 March 2017, Bruxelles, Belgium

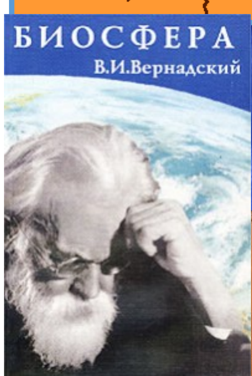
Geo-bio-hydro : “back to the future”

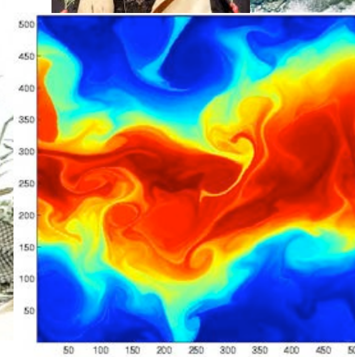
Ecosystems are seen as “one physical system” with their environment, with cross-scale geosphere-biosphere-hydrosphere interactions



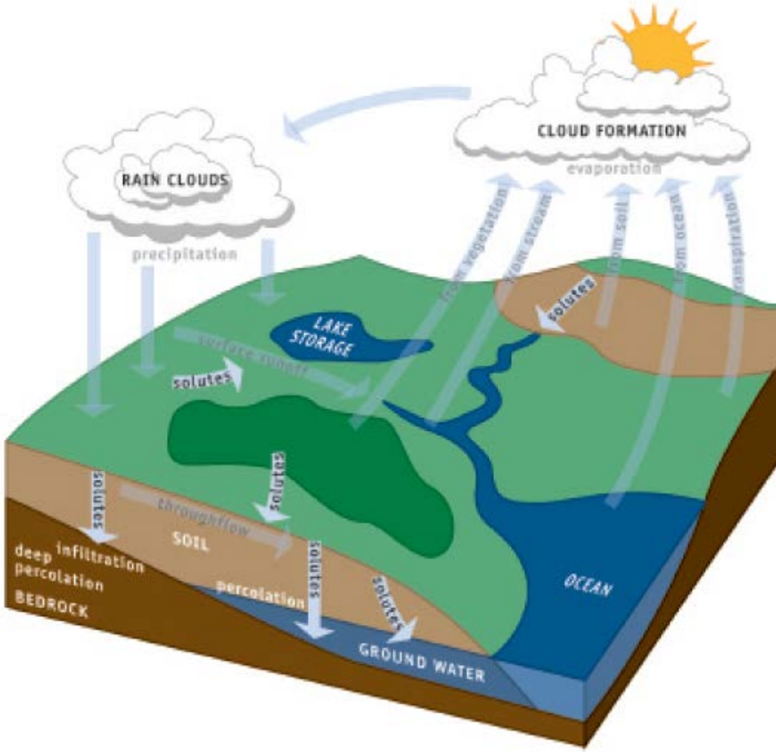


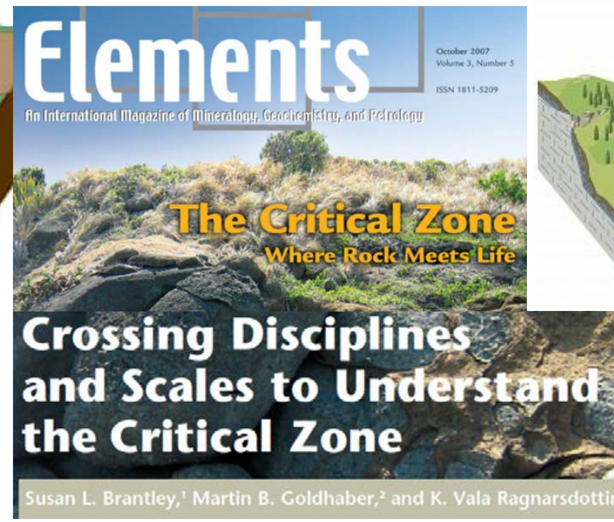


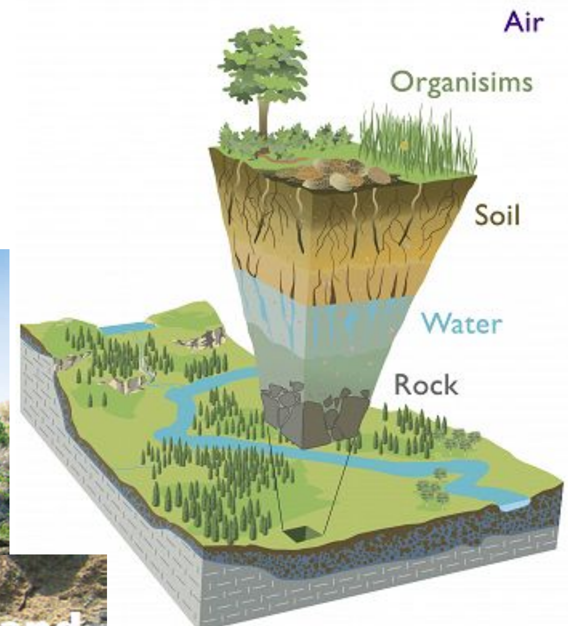




The Earth Living Skin (aka the Earth Critical Zone)



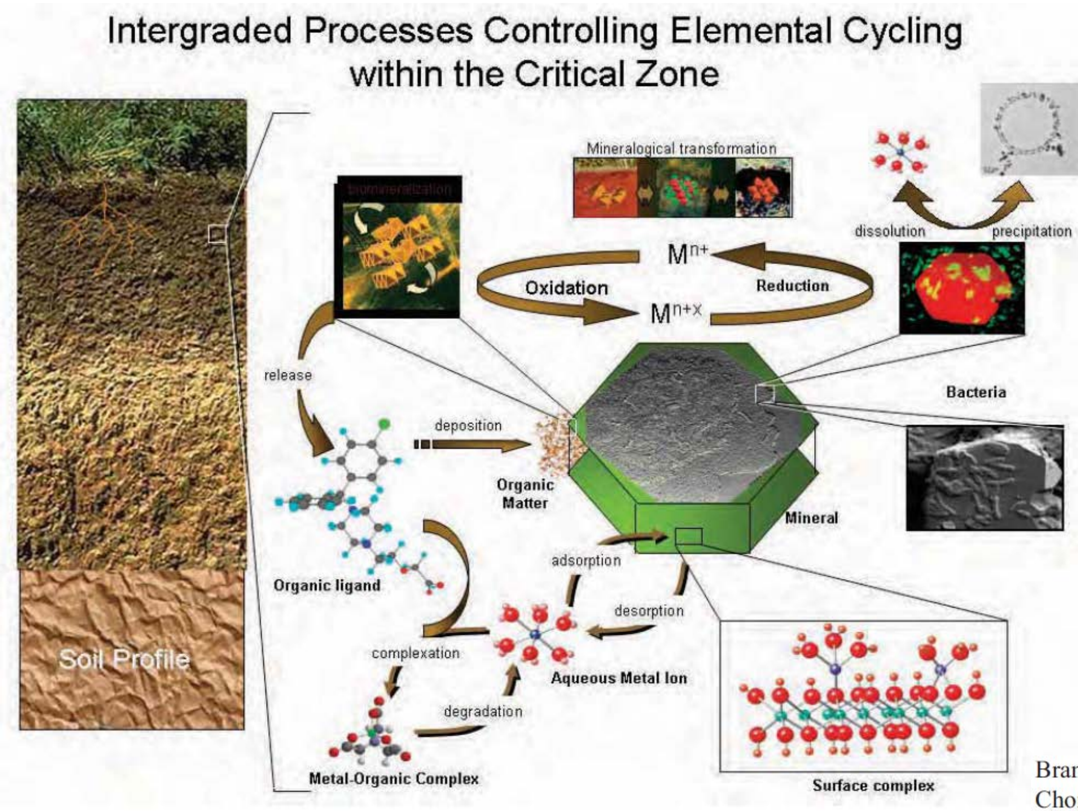




www.czen.org , http://criticalzone.org/national/

The layer between the top of vegetation canopy and the "rocky matrix", where physics, chemistry, hydrology, eco-hydrology, geology and biology closely interact

The Earth Living Skin (aka the Earth Critical Zone)



Text Box 1. The economic goods and services of Earth's Critical Zone.

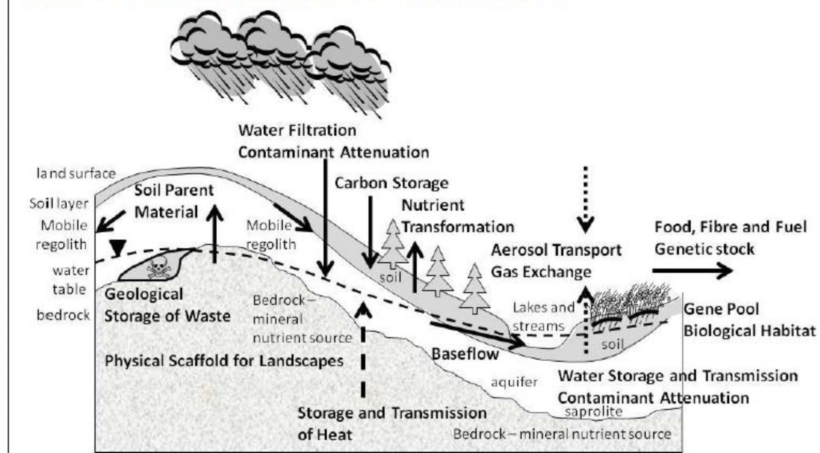


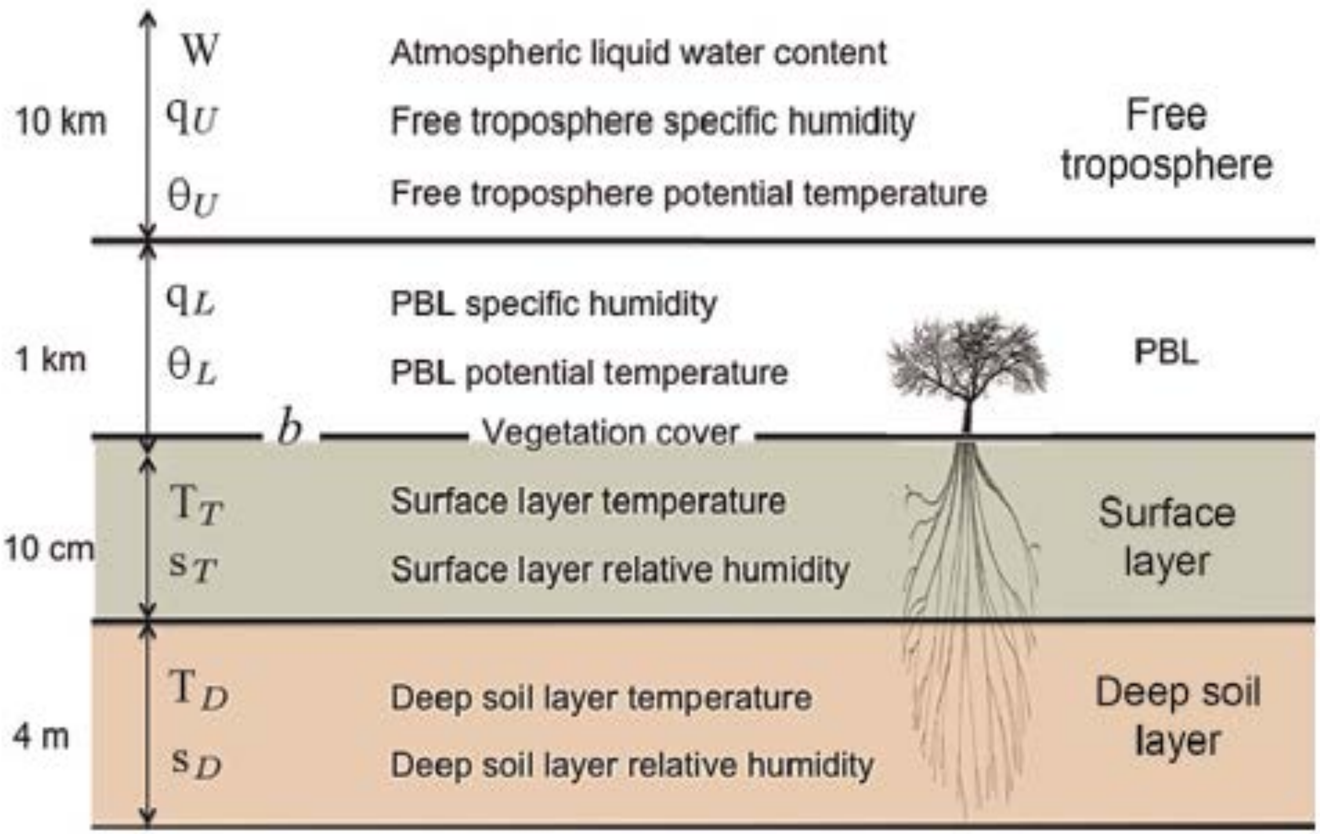
Figure 1. Flows of material and energy in Earth's Critical Zone.

Sustaining Earth's Critical Zone

Brantley, S.L., White, T.S. , White, A.F., Sparks, D., Richter, D., Pregitzer, K., Derry, L., Chorover, J., Chadwick, O., April, R., Anderson, S., Amundson, R., 2006, Frontiers in Exploration of the Critical Zone: Report of a workshop sponsored by the National Science Foundation (NSF), October 24-26, 2005, Newark, DE, 30p.

Biogeochemical cycling
Hydrological cycle
Weathering

Find your way into the ECZ!
here: simple soil-vegetation-atmosphere models



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ECRA General Assembly,
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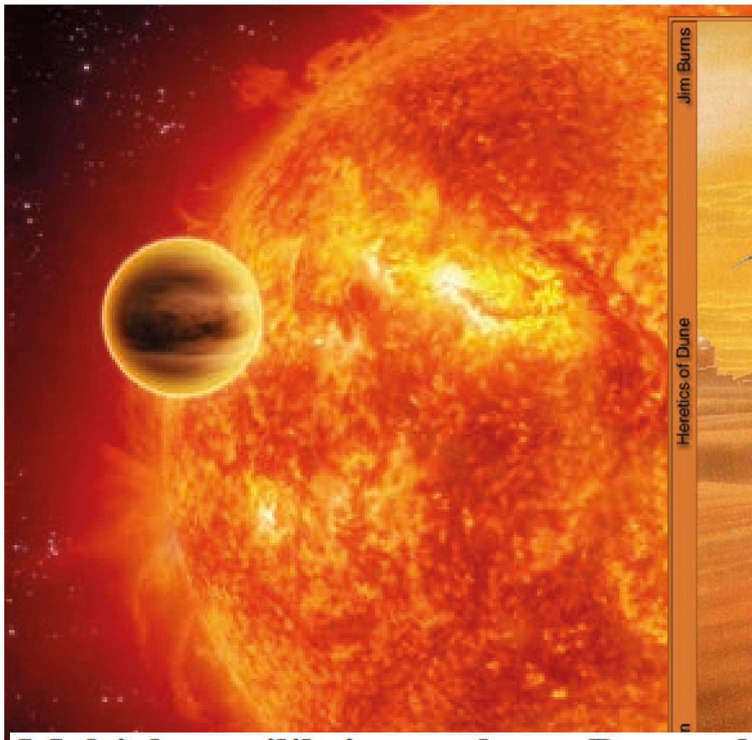
First challenge – can vegetation trigger a hydrological cycle?

Imagine a sandy planet with no ocean; water is in the sand

No vegetation: only evaporation



Multiple equilibria on planet Dune: climate–vegetation dynamics on a sandy planet

Cresto Aleina, Baudena, D'Andrea, Provenzale

Tellus SERIES B CHEMICAL AND PHYSICAL METEOROLOGY

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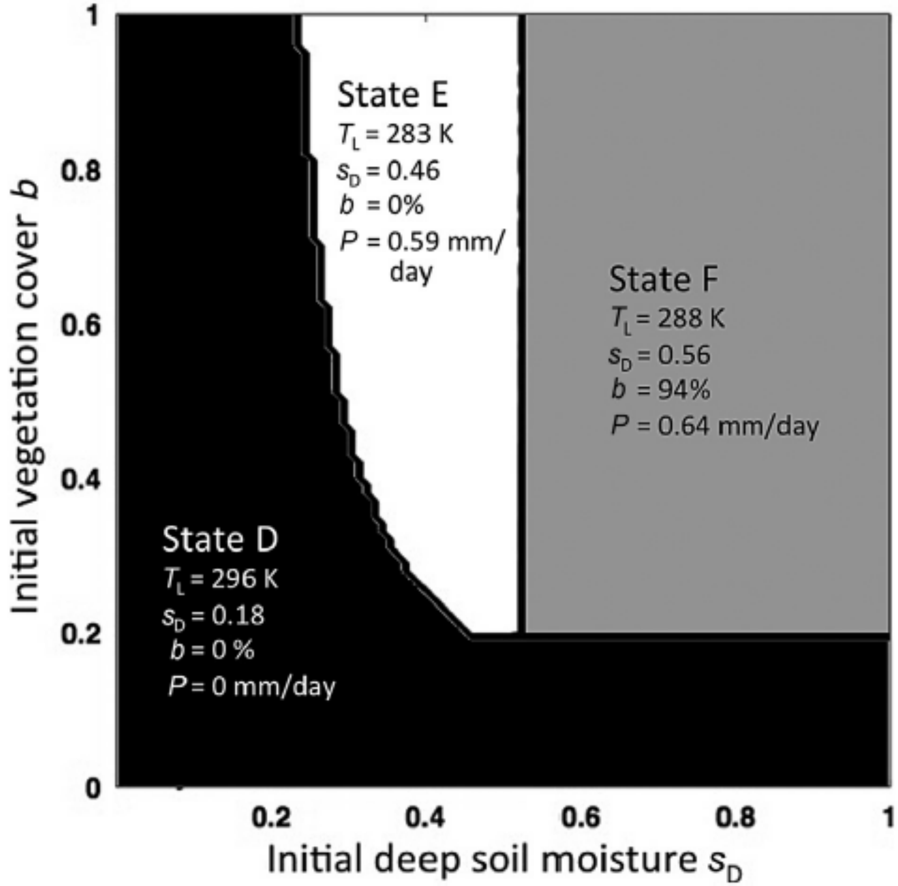
First challenge – can vegetation trigger a hydrological cycle?



Multiple equilibria on planet Dune: climate–vegetation dynamics on a sandy planet

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Tellus SERIES B CHEMICAL AND PHYSICAL METEOROLOGY

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Second challenge: driver intermittency
The example of savanna ecosystems

$$\frac{dG}{dt} = c_G(s)G(1-T-G) - \mu_G G \quad (1)$$

$$\frac{dS}{dt} = c_T(s)T(1-T-G-S) - gS - c_G(s)GS - \mu_S S \quad (2)$$

$$\frac{dT}{dt} = gS - \mu_T T \quad (3)$$

$$\frac{ds}{dt} = \frac{1}{nZ_r}[I(s,r) - (1-T-S-G)E_0(s) - TE_T(s) - SE_S(s) - GE_G(s) - L(s)] \quad (4)$$

Effects of rainfall intermittency on model savanna dynamics

Tree-grass competition for soil water in arid and semiarid savannas: The role of rainfall intermittency

Donatella D'Onofrio[1,2], Mara Baudena[3], Fabio D'Andrea[4], Max Rietkerk[3], and Antonello Provenzale[2]

Water Resources Research

10.1002/2014WR015515

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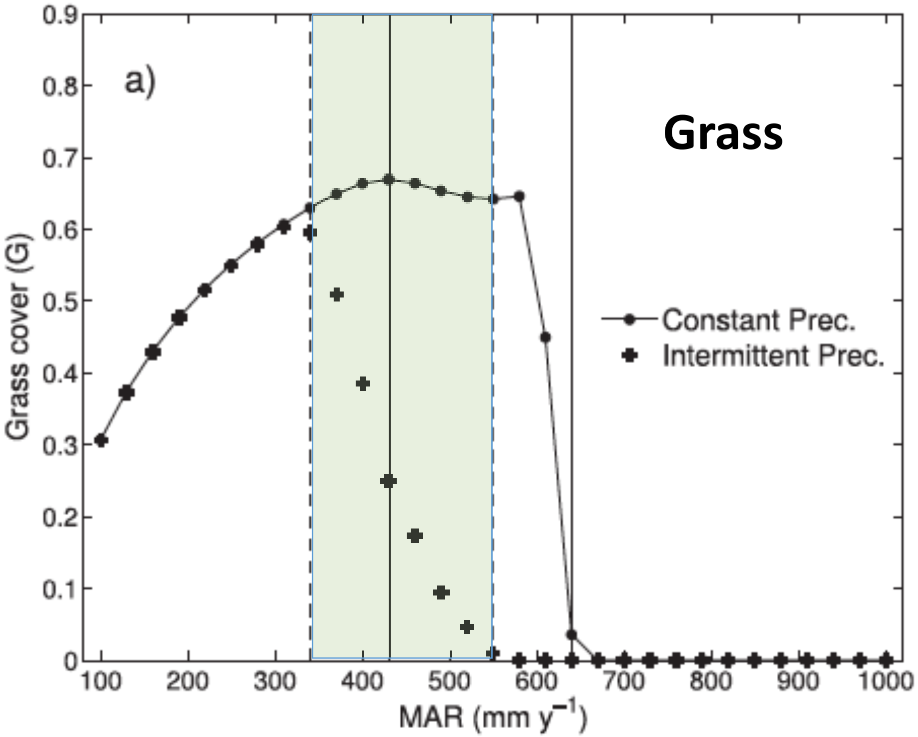
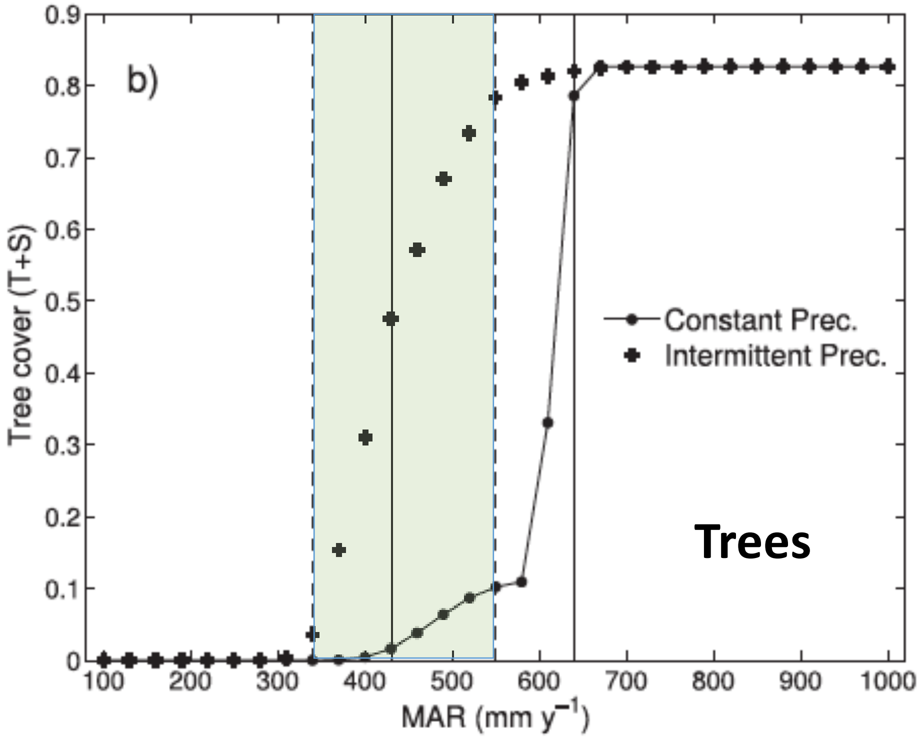
Second challenge: driver intermittency
The example of savanna ecosystems





In the model, rainfall intermittency favors tree survival at lower MAR

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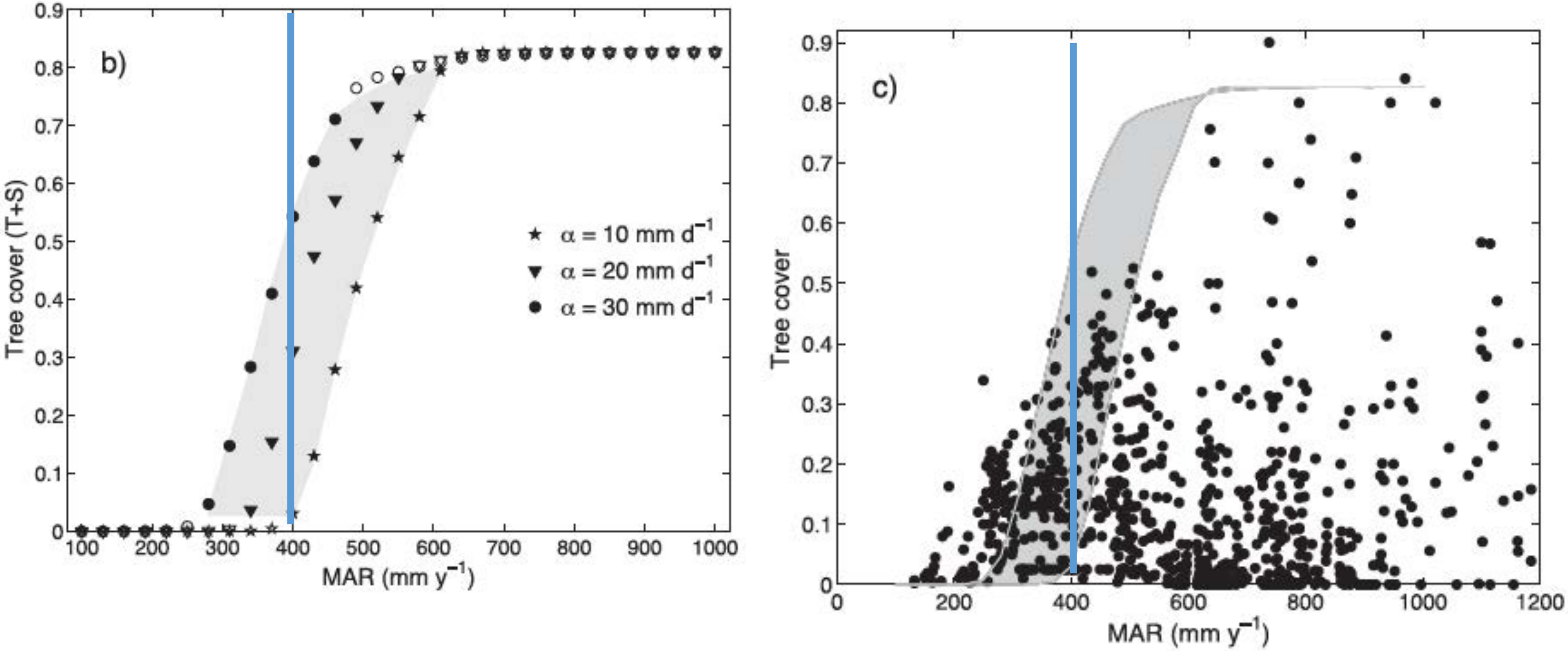
Second challenge: driver intermittency
The example of savanna ecosystems



General issue: the effect of driver (rainfall) intermittency on ecosystem dynamics and long-memory ecosystem response

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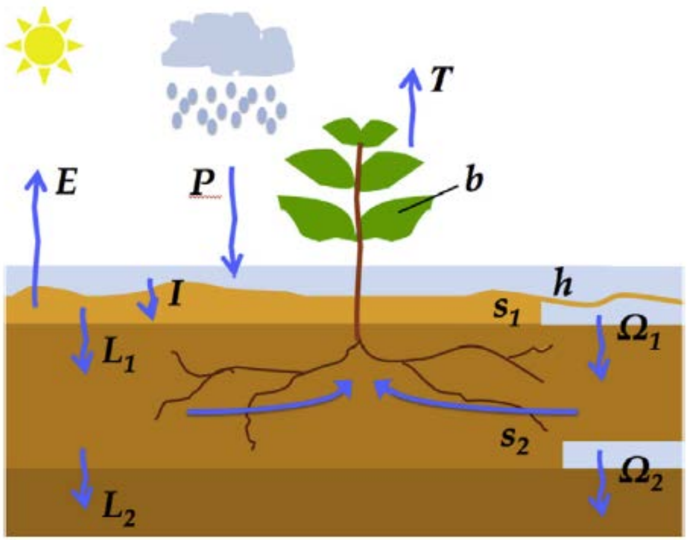
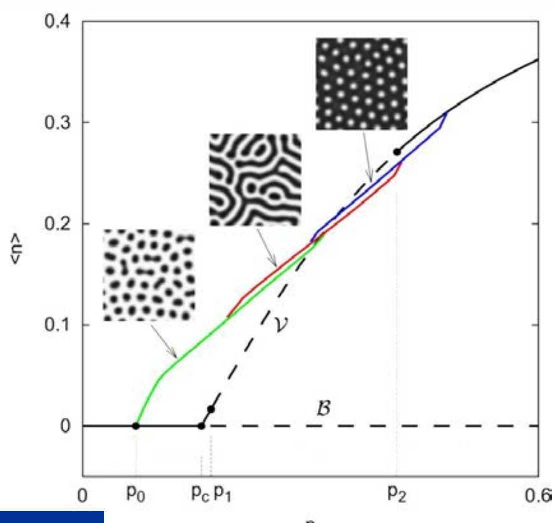
Third challenge
cross-scale interactions






Rietkerk et al., *The American Naturalist* **160** (4), 2002

Gilad et al PRL 2004, JTB 2007, Kletter et al JTB 2009

Vegetation patterns and soil–atmosphere water fluxes in drylands

Mara Baudena[a,b,c,*], Jost von Hardenberg[b], Antonello Provenzale[b]

Advances in Water Resources 53 (2013) 131–138

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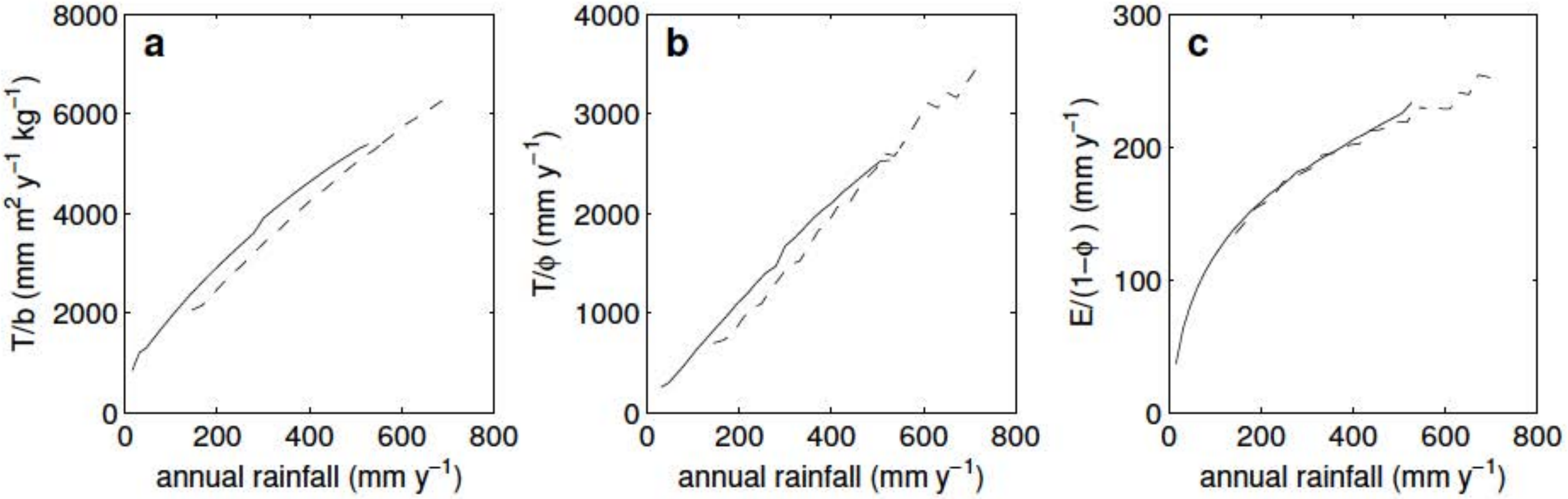

Figure 3: Evapotranspiration fluxes variation along a rainfall gradient. a. Transpiration flux T per unit biomass density *b*; b. transpiration flux T per unit vegetated area ϕ; c. evaporation flux E per unit bare soil $(1-\phi)$. Continuous line, spots; dashed line: stripes. Evaporation and transpiration fluxes are averaged in the five days after rainfall events, during the last 100 year of each run, and above the whole plot.

Vegetation patterns and soil–atmosphere water fluxes in drylands

Mara Baudena[a,b,c,*], Jost von Hardenberg[b], Antonello Provenzale[b]

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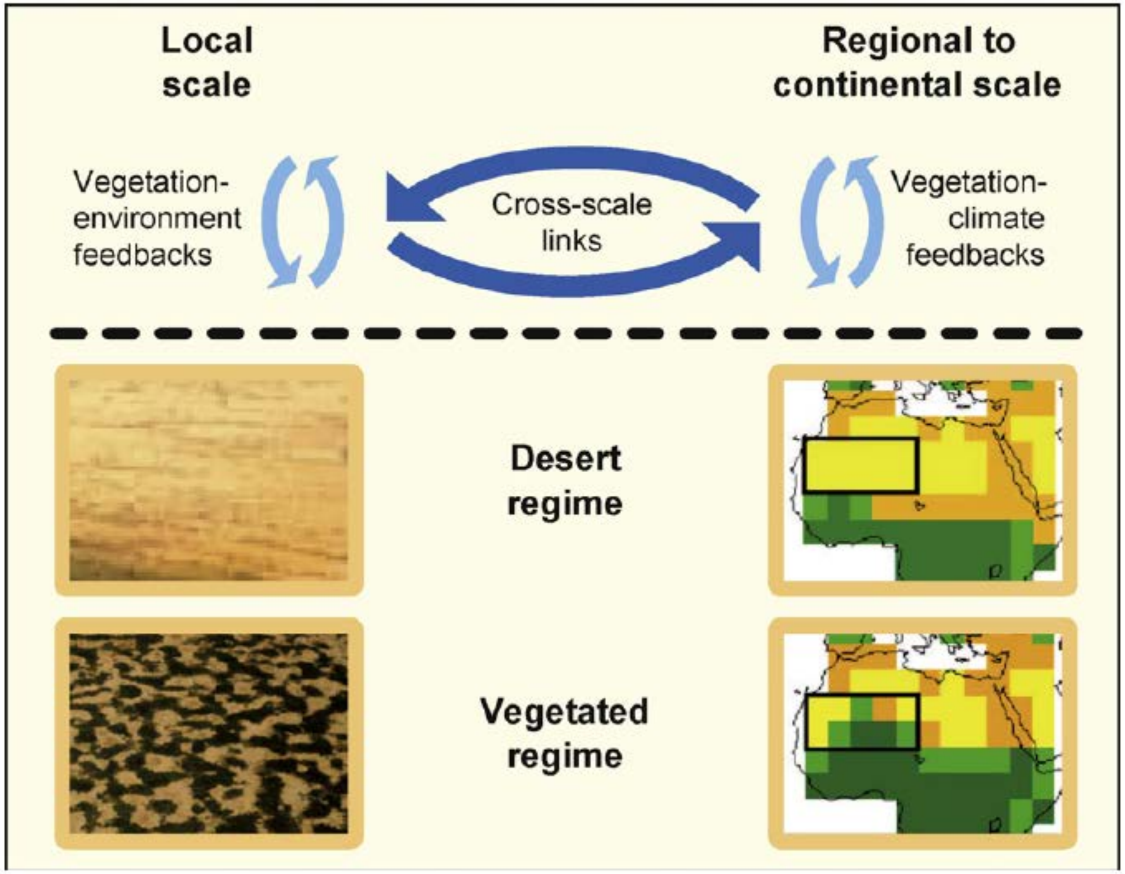
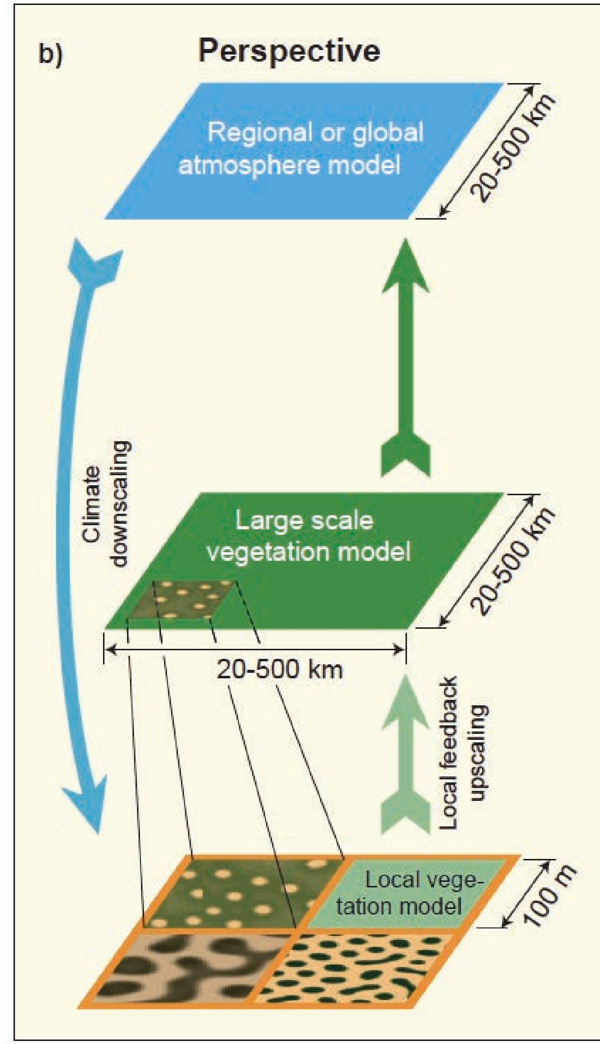


Local ecosystem feedbacks and critical transitions in the climate

Max Rietkerk[a,*], Victor Brovkin[b], Peter M. van Bodegom[c], Martin Claussen[b], Stefan C. Dekker[a], Henk A. Dijkstra[d], Sergey V. Goryachkin[e], Pavel Kabat[f], Egbert H. van Nes[g], Anje-Margriet Neutel[h], Sharon E. Nicholson[i], Carlos Nobre[j], Vladimir Petoukhov[k], Antonello Provenzale[l], Marten Scheffer[g], Sonia I. Seneviratne[m]



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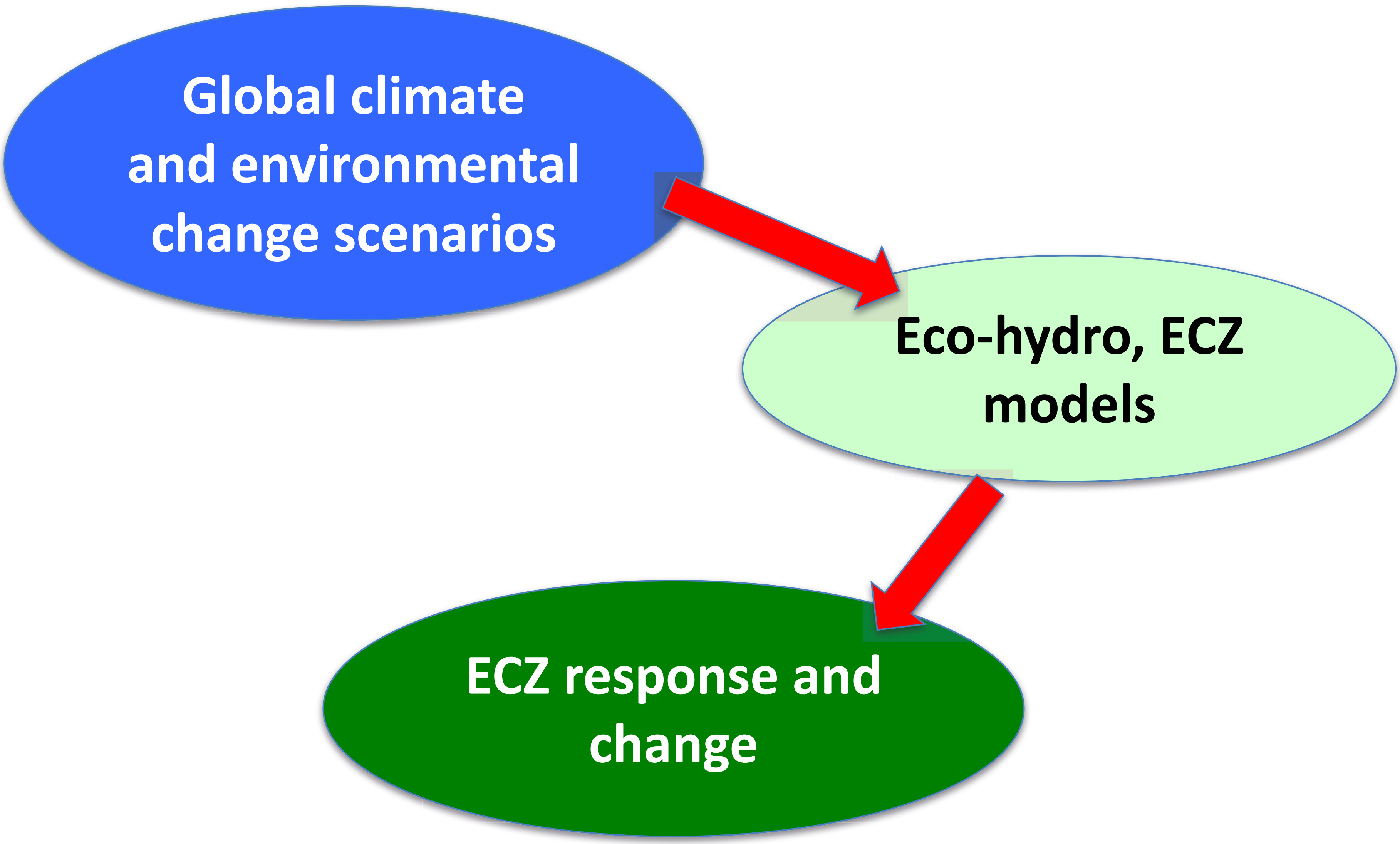
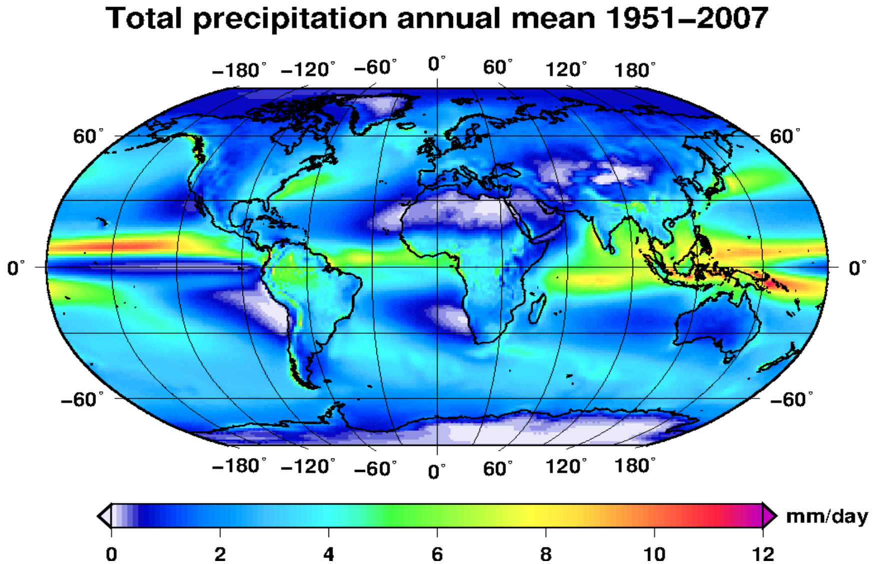
Fourth challenge:
Effects of climate change on the ECZ

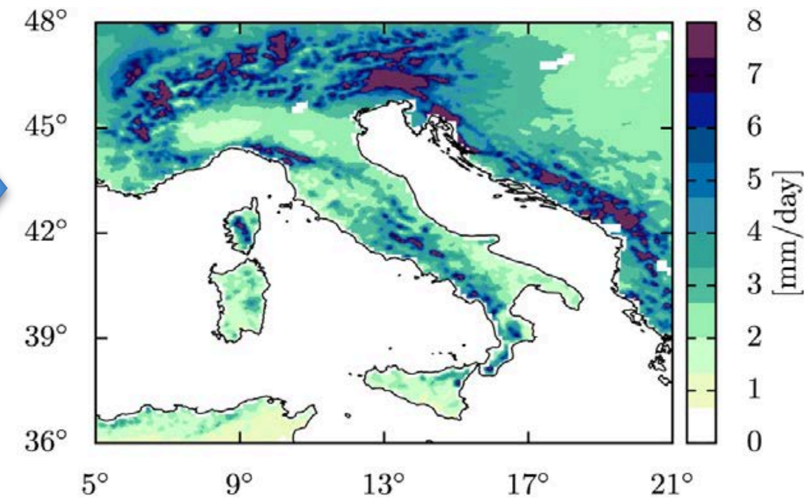


Scale mismatch: the downscaling-impact chain

GLOBAL CLIMATE MODEL



REGIONAL CLIMATE MODELS



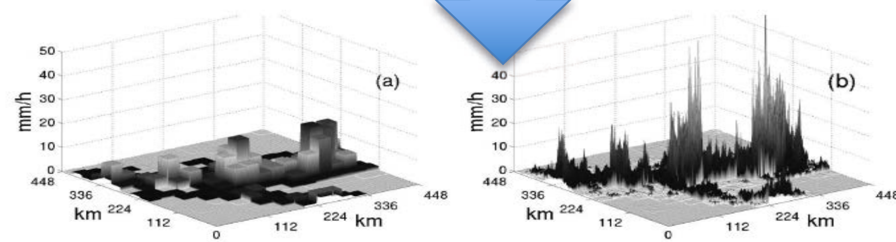
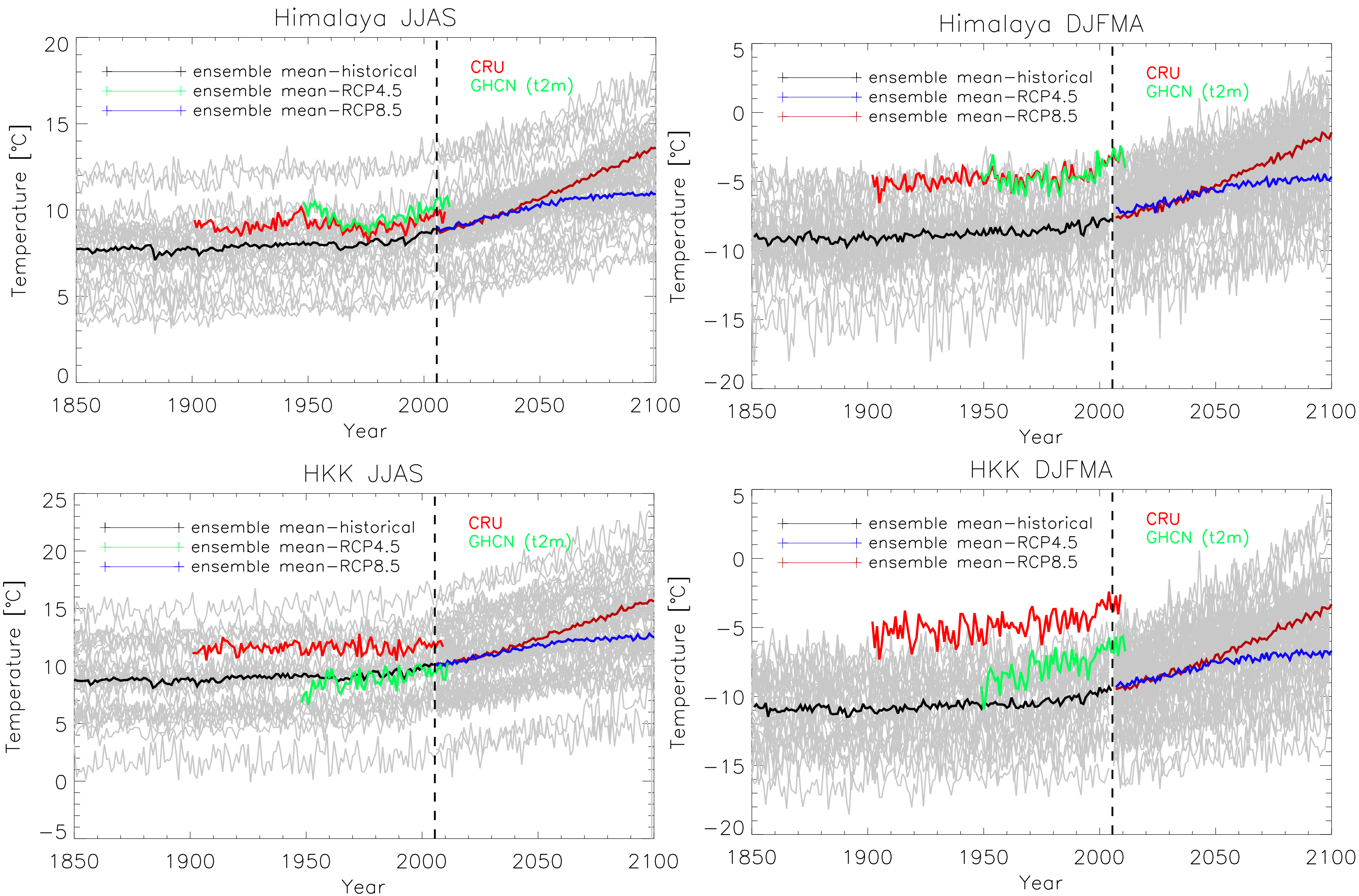


FIG. 10. (a) A snapshot of the forecasted rain field obtained from the LAM forecast and (b) one example of a downscaled field obtained by application of the RainFARM. The vertical scale indicates precipitation intensity (mm h^{-1}) and it is the same for the two fields.

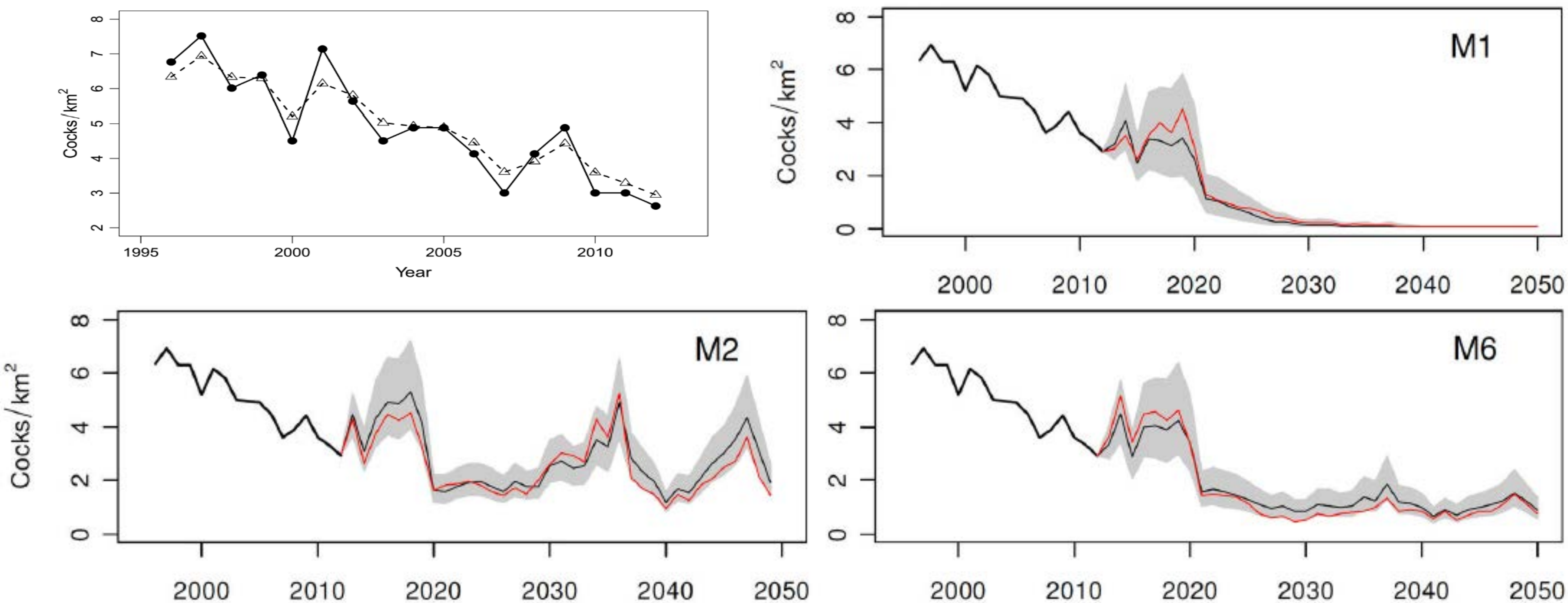
ECO-HYDROLOGICAL MODELS

STOCHASTIC / STATISTICAL DOWNSCALING

Troubled waters: the spread of CMIP5 temperatures



Even more troubles: Statistical uncertainties in eco(hydro)logical models

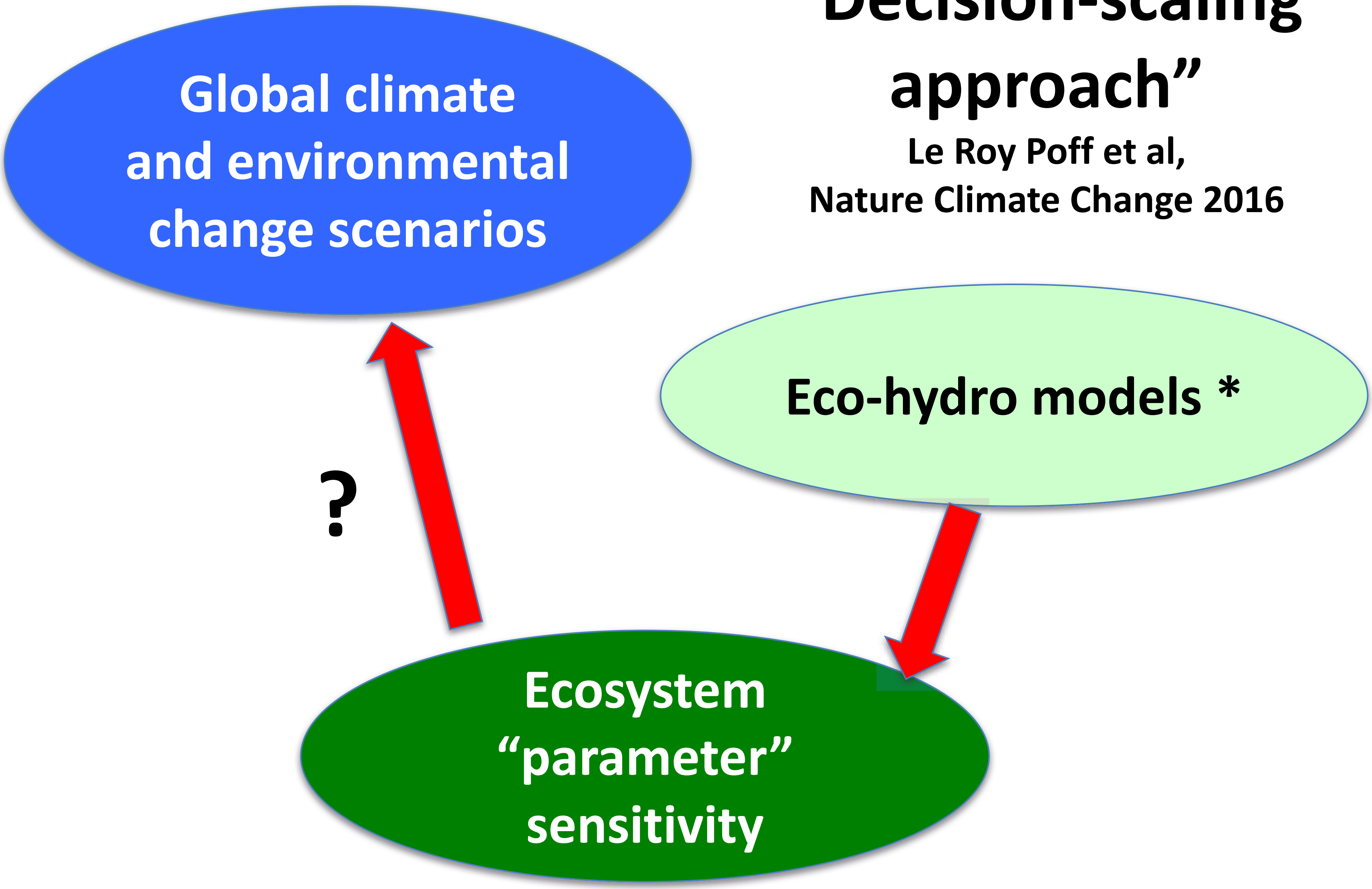


Model	Intercept	$\ln N_{t-1}$	$\ln N_{t-2}$	SE_{t-1}	SS_{t-1}	SP_t	$T(July)_{t-1}$	$P(July)_{t-1}$	$T(Jan\text{-}Mar)_t$	$T(Apr\text{-}May)_t$	var.	R^2	AICc
M1	-0.07±0.04			**-0.19±0.04**	**-0.18±0.04**						2	0.78	-50.53
M2	0.34±0.24		-0.25±0.14	**-0.19±0.04**	**-0.19±0.04**						3	0.83	-50.20
M3	-0.07±0.04			**-0.19±0.04**	**-0.18±0.04**			0.05±0.03			3	0.82	-49.28
M4	-0.07±0.04			**-0.19±0.04**	**-0.17±0.04**		-0.05±0.04				3	0.81	-48.51
M5	-0.07±0.04			**-0.20±0.04**	**-0.18±0.04**				-0.03±0.04		3	0.79	-47.28
M6	0.08±0.26	-0.10±0.16		**-0.18±0.04**	**-0.17±0.04**						3	0.78	-46.98

Simona Imperio, Radames Bionda, Ramona Viterbi, Antonello Provenzale,
Alpine Rock Ptarmigan, PLOS One, 2013

"Decision-scaling approach"

Le Roy Poff et al,
Nature Climate Change 2016



* Once tested!...

ECOPOTENTIAL:
Improving future ecosystem benefits through Earth Observations

Starting date: 1st June 2015, Duration: 4 years, 47 partners

Coordinator: **Antonello Provenzale**

Institute of Geosciences and Earth Resources, National Research Council of Italy

Co-Coordinator: **Carl Beierkuhnlein**

Biogeography, BayCEER, University of Bayreuth, Germany

Project Manager: **Carmela Marangi**

Institute of Applied Mathematics, National Research Council of Italy

External Communication Officer: **Mariasilvia Giamberini**

Institute of Geosciences and Earth Resources, National Research Council of Italy

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7-8 March 2017, Bruxelles, Belgium

ECOPOTENTIAL

This project is funded by the European Union

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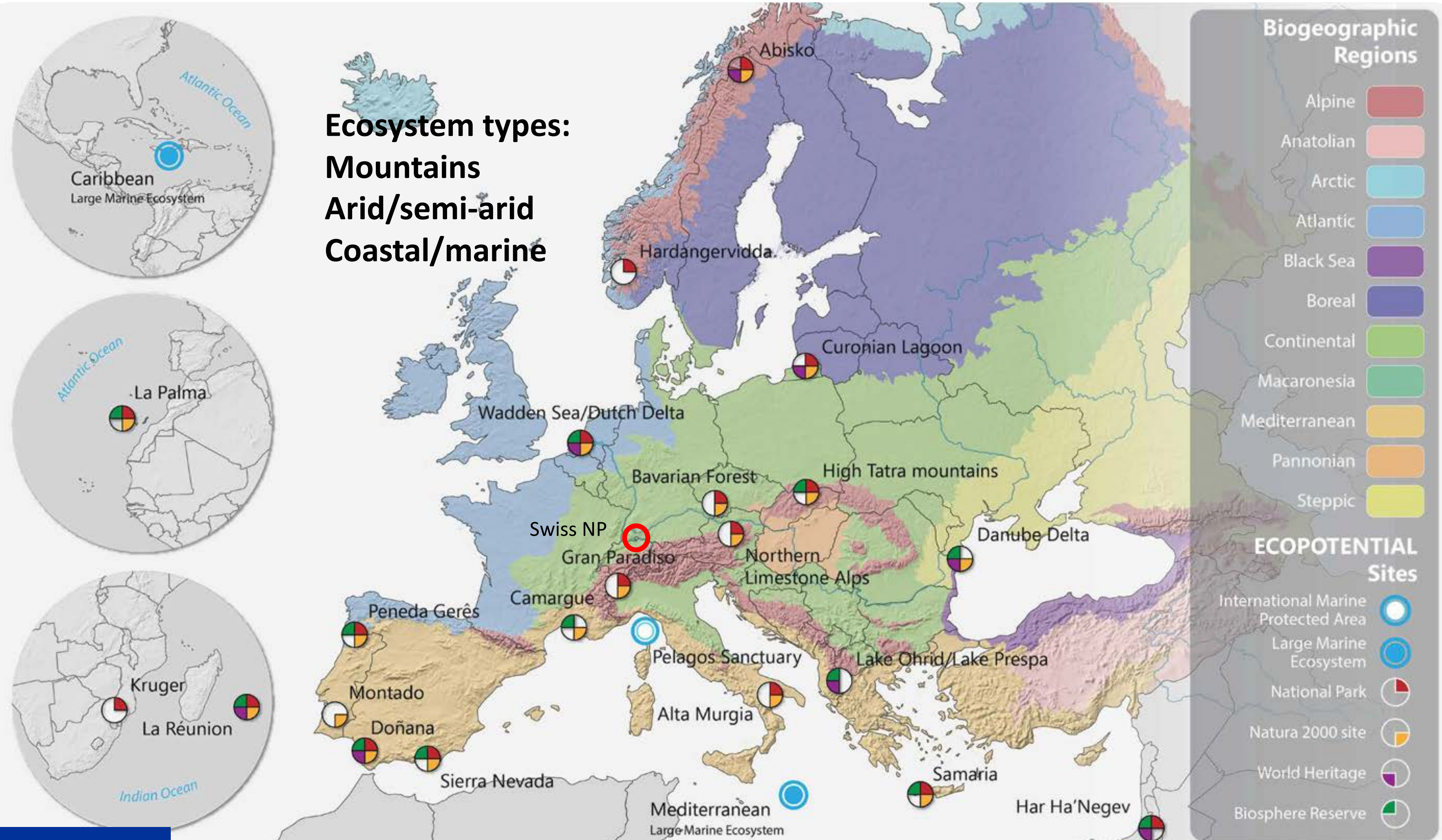
Working in partnership with 23 Protected Areas in Europe and beyond

Ecosystem types:
Mountains
Arid/semi-arid
Coastal/marine



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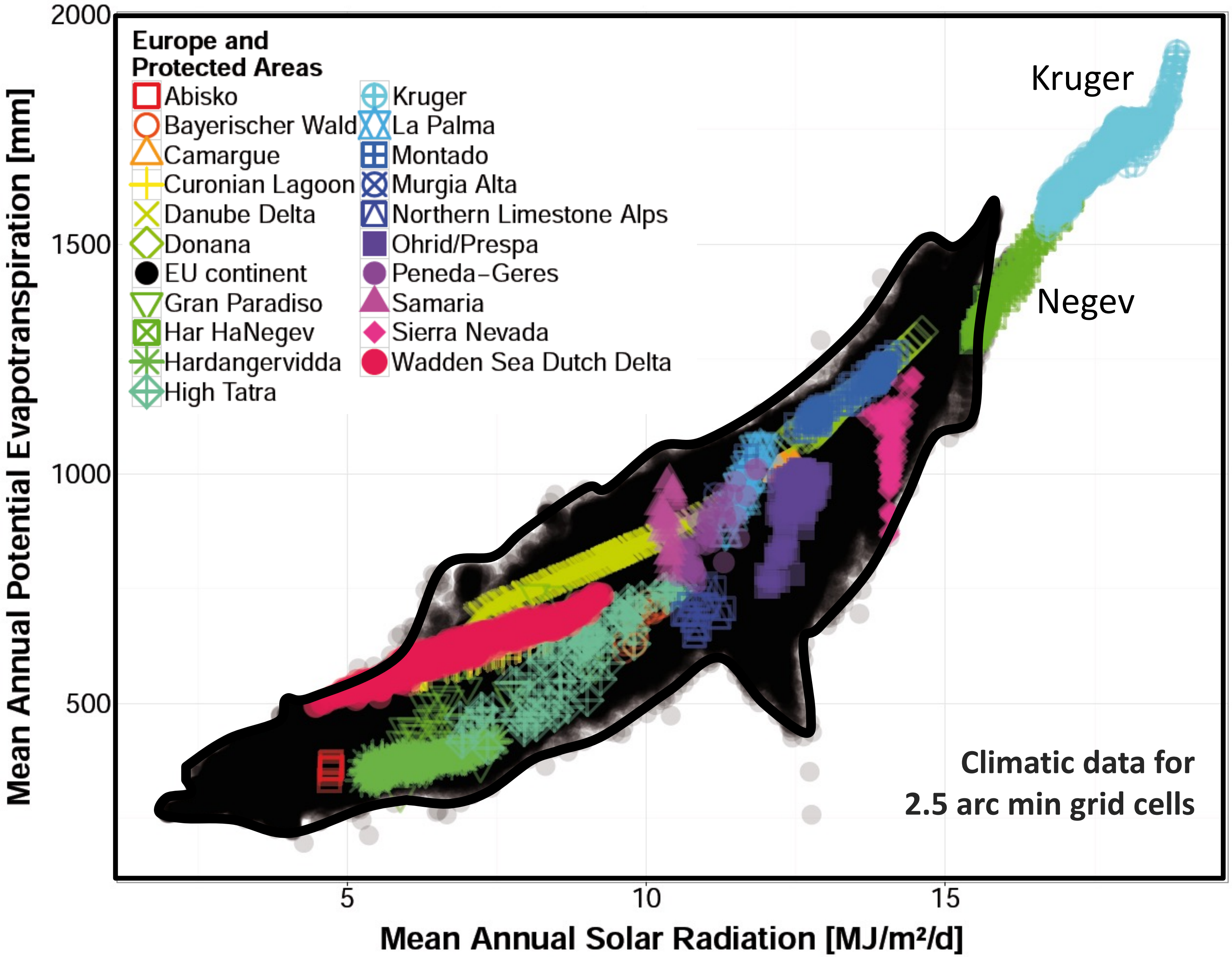
ECOPOTENTIAL and climate



What do we study in the Protected Areas:

Current state of Protected Areas from Remote Sensing

Ongoing changes in the ecosystems and environment of the ECOPOTENTIAL Protected Areas

Future projections on the state of the ecosystem in the ECOPOTENTIAL Protected Areas

Narratives related to stakeholder needs: The Storylines

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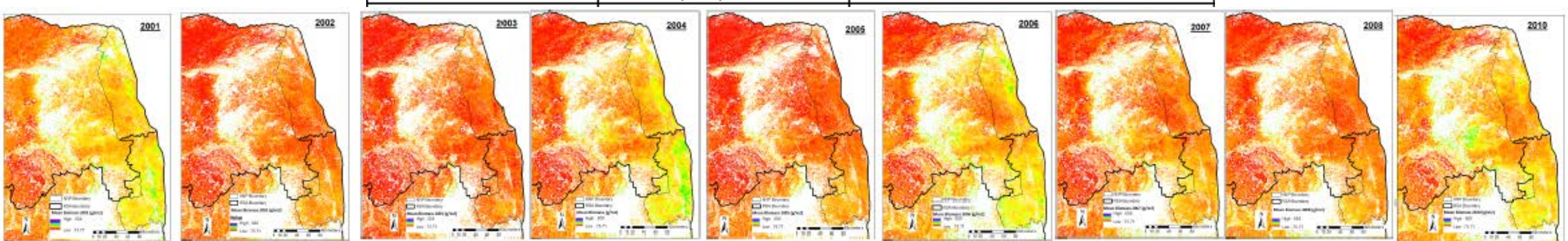
Spatial-temporal dynamics of savanna ecosystems a life support system to wildlife and livestock production in and around Kruger National Park (A. Ramoelo, CSIR)

SoE	Indicator	Method [reference] (type)*
Distribution of grazing and browsing resources in the semi-arid environments	amount of grass per unit area (biomass)	empirical techniques [Ramoelo et al. 2015] (M)
	percentage of nutrients in dry matter (leaf N (%))	empirical techniques [Ramoelo et al. 2012; 2015] (M)
	percentage of tree cover per unit area (%)	field, LiDAR and SAR empirical techniques [Mathieu et al. 2013, Naidoo et al. 2014, Urbazaev et al. 2015] (M)
	above ground woody biomass per unit area (ha) & woody volume as biomass proxy	field, LiDAR and SAR empirical techniques [Mathieu et al. 2013, Naidoo et al. 2014] (M)



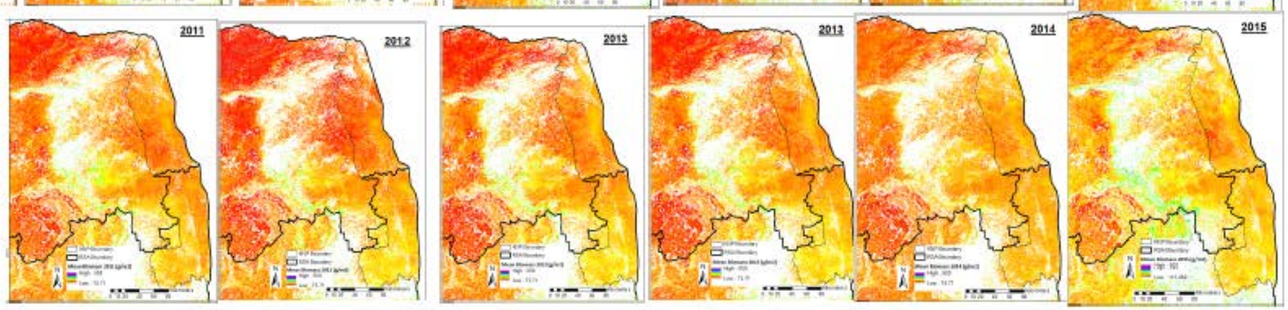


Figure 2: Time series of mean annual biomass data based on 500m spatial resolution MODIS data (2001 – 2015).

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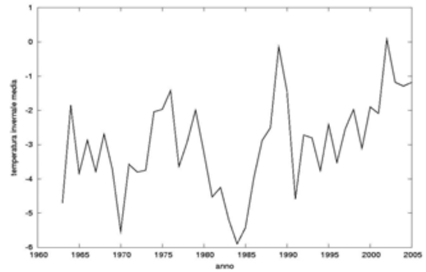
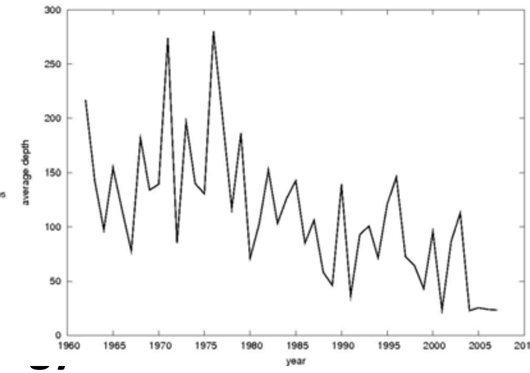
Example of PA changes: the Gran Paradiso National Park

Local meteo-climatic datasets





Gridded meteo-climatic datasets

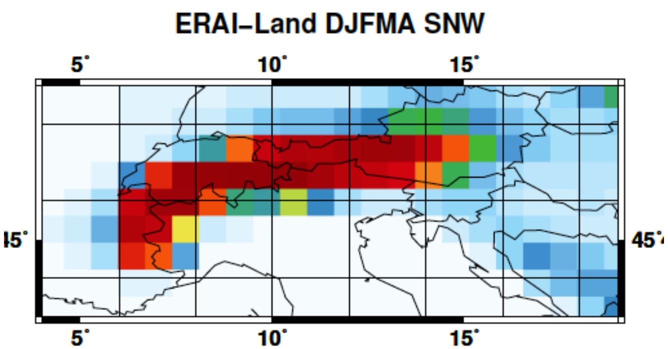
E-OBS: 0.25°, EURO4M: 0.05° (only prec)

HISTALP, OI (Piedmont): 0125°

Model outputs and reanalyses

CMIP5, EURO-CORDEX,

ERA-Interim/Land and 20CRv2, MERRA, NCEP



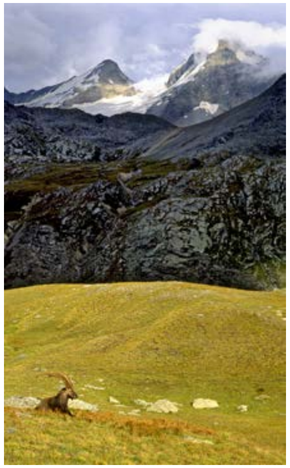
Water/carbon fluxes and phenc

eddy covariance

flux chambers

Ecosystem and population dynamics

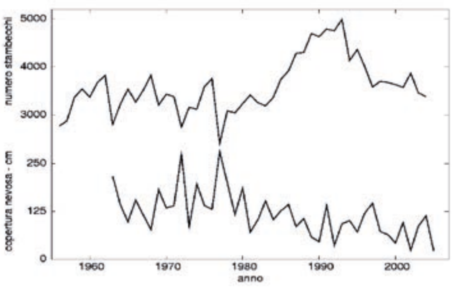
ibex, chamois, vegetation, biodiversity

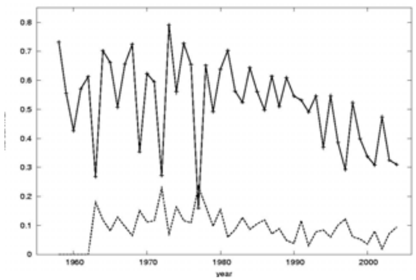


Satellite products

e.g. snow: Global SWE, AMSR-E

vegetation, NDVI, LC/LU





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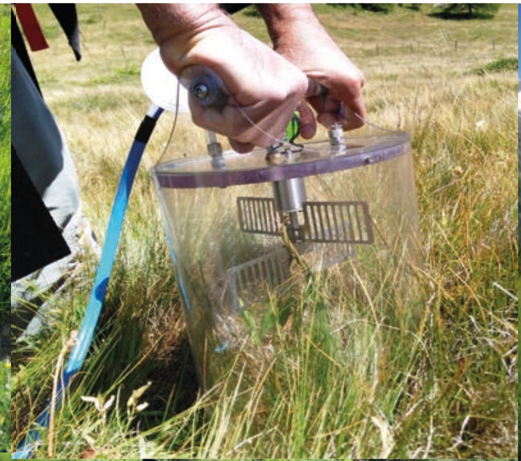
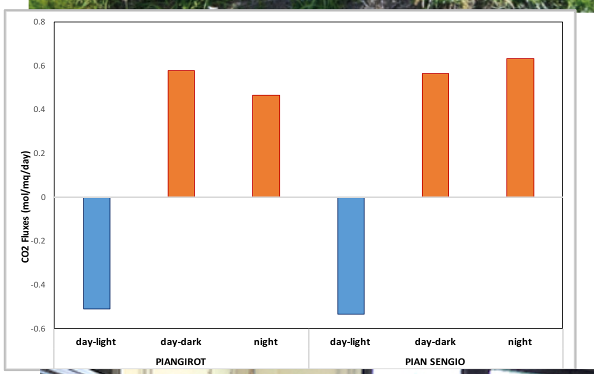
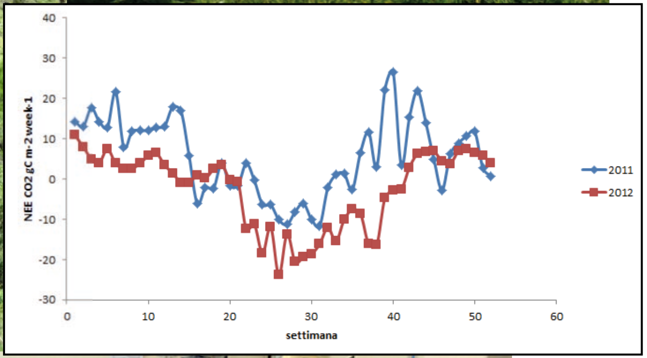
Studies of the ECZ at GPNP







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Studies of the critical zone

The Earth Critical Zone is the meeting point of geology, geomorphology, geochemistry, hydrology, soil science, ecology and biology

Need for sites where to study the whole range of processes and mechanisms and how ECZ responds to climate change
In Europe, such sites are part of LTER

Ned for models including different aspects of ECZ dynamics across scales

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Thank you for your attention