Global change and ecosystem response: cross-scale interactions and the chain of uncertainties

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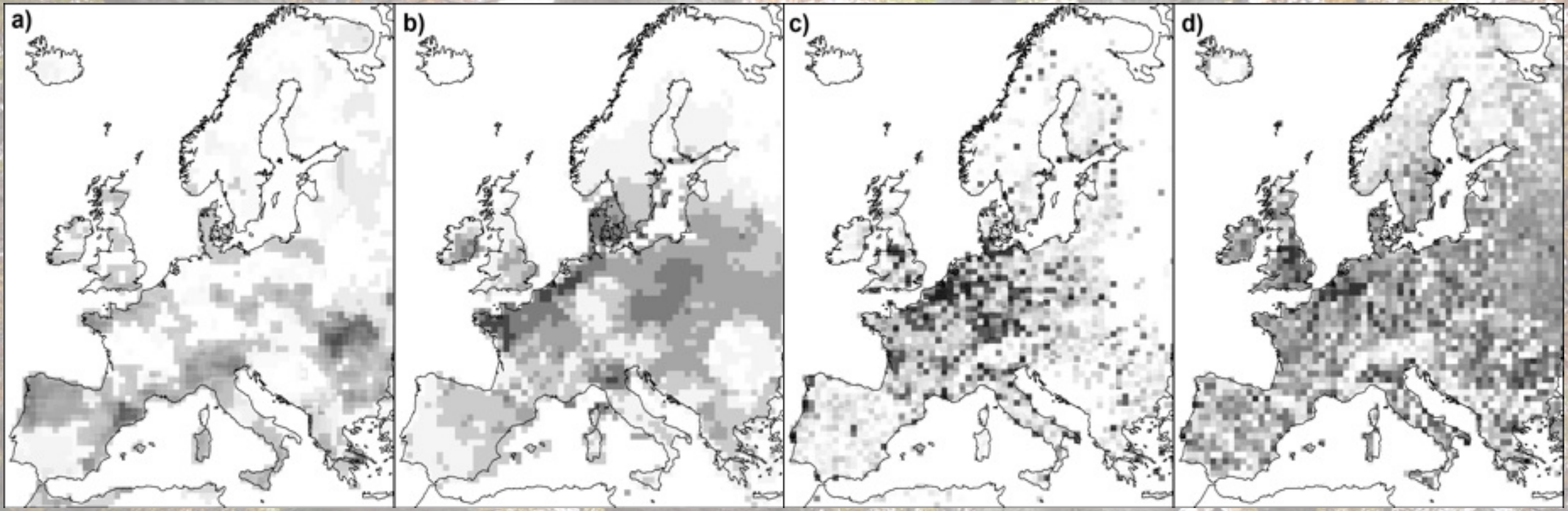
ECOLOGY AT THE INTERFACE
SCIENCE – BASED SOLUTIONS FOR HUMAN WELL-BEING

Global and local threats
(climate change, pollution, land-use change,
alien species, habitat fragmentation) **are changing ecosystem structure, functions, processes and services**

Loss of ecosystem services (clean air and water, slope stability, water regulation, raw materials, sustainable tourism,religious and aesthetic values) **is a major issue of the Anthropocene**

Loss of ecosystem services: a problem at continental scale with local modulation

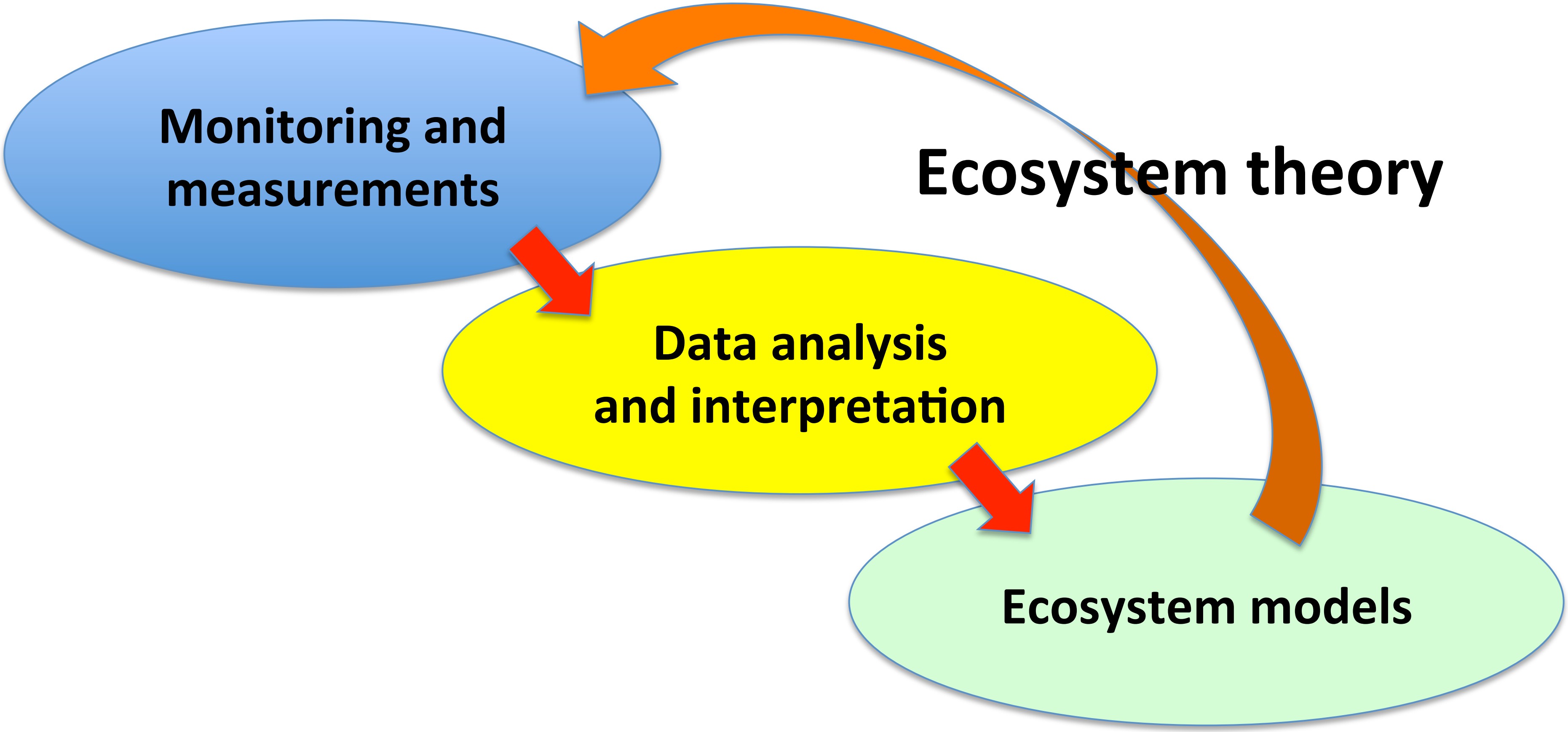
Drivers and Responses



Climate Change Pollution Land Cover Change Biodiversity Response

- Continental-scale and local drivers of the loss of ecosystem services
- Rapid and large-scale responses are problematic for monitoring and policy
- Priority areas must be defined
- Need for future projections on ecosystem state and services

Beierkuhnlein, Jaeschke, Provenzale in prep.



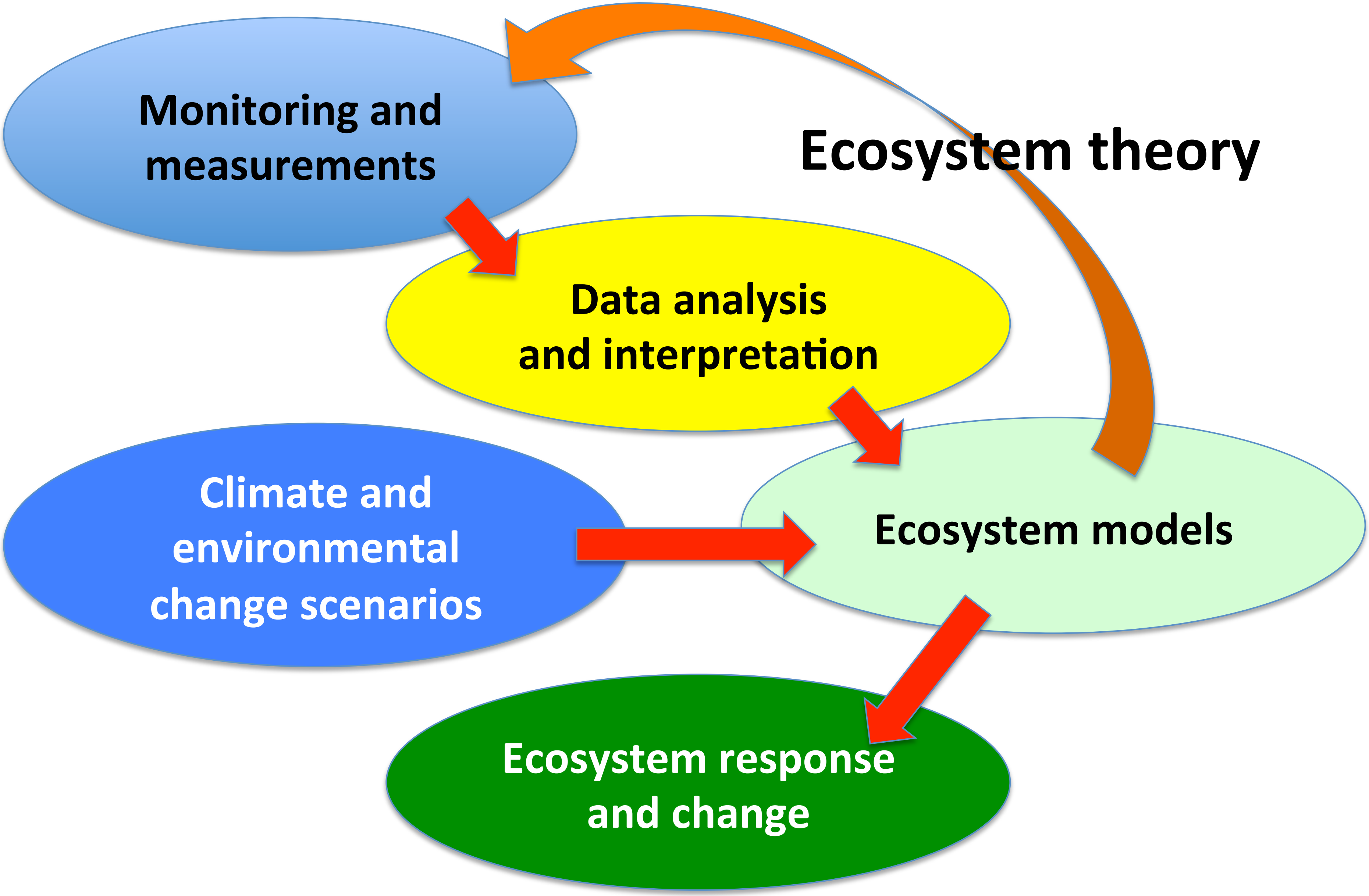
Monitoring and measurements

Data analysis and interpretation

Ecosystem models

Ecosystem theory

How do we address prediction of ecosystem response to global change?



Monitoring and measurements

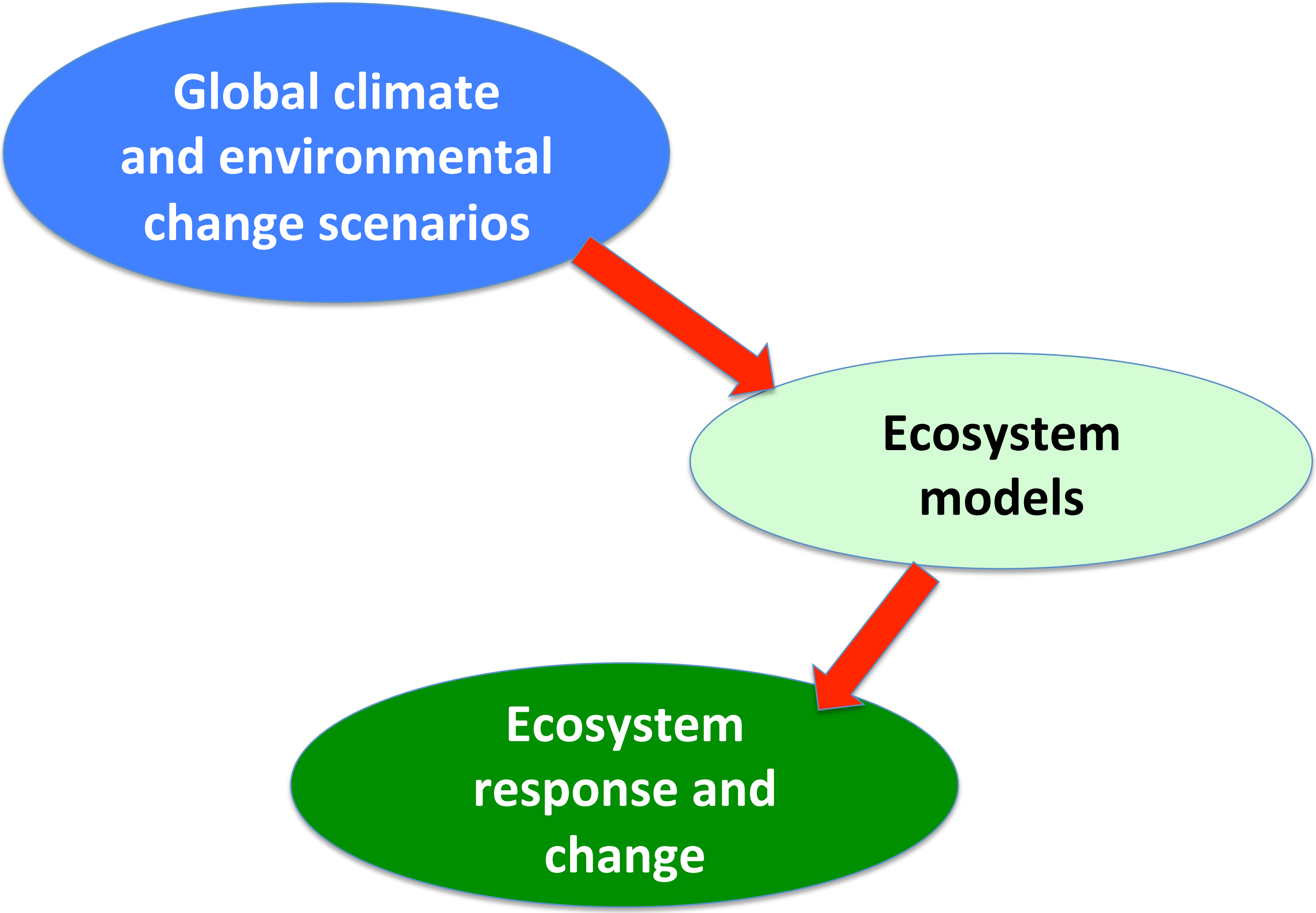
Data analysis and interpretation

Ecosystem theory

Climate and environmental change scenarios

Ecosystem models

Ecosystem response and change

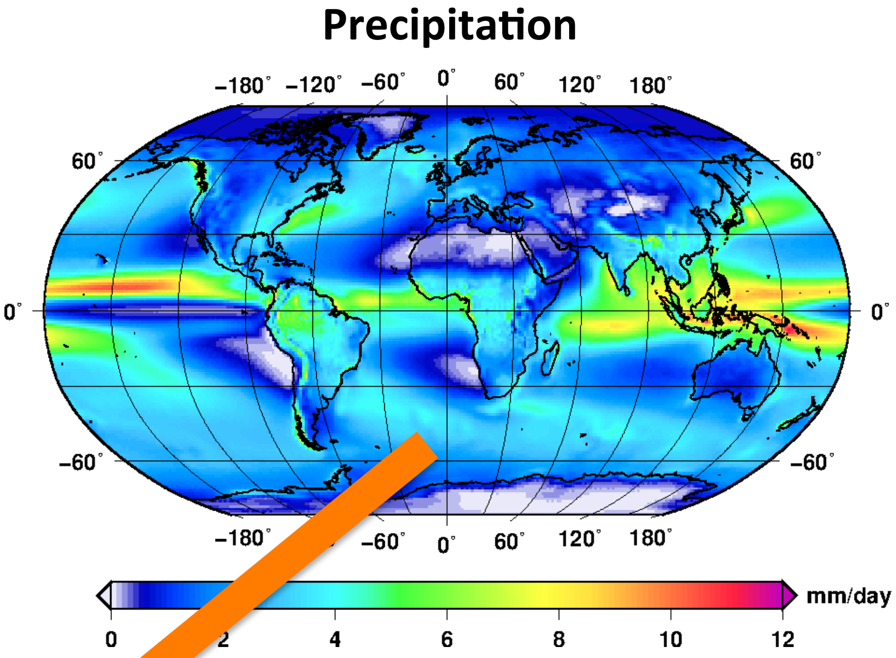


Global climate
and environmental
change scenarios

Ecosystem
models

Ecosystem
response and
change

Global Climate Models: The most advanced tools that are currently available for simulating the global climate system and its response to anthropogenic and natural forcings.

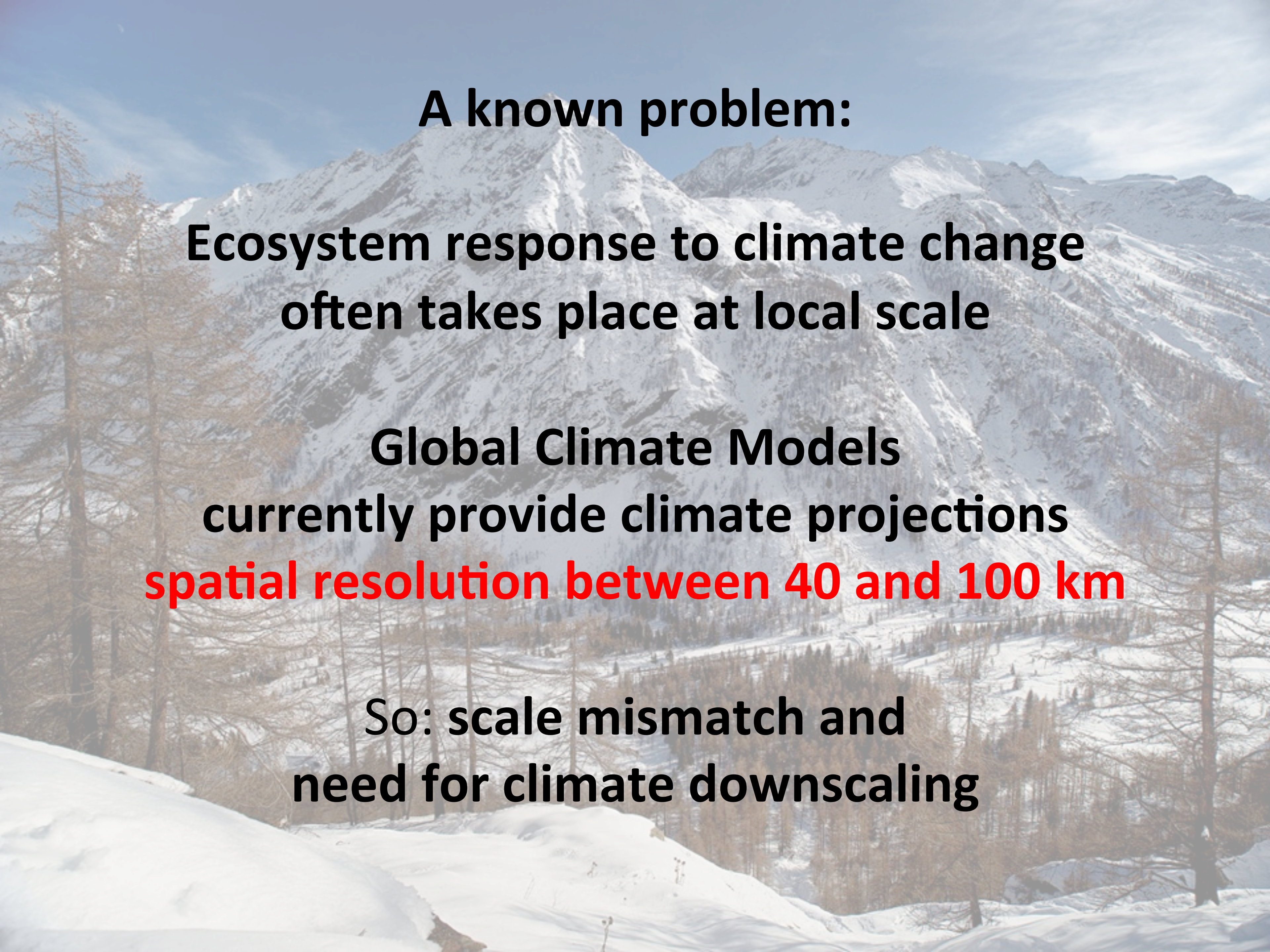


Precipitation

Ecosystem models

(deterministic, empirical)

Biodiversity estimates/models



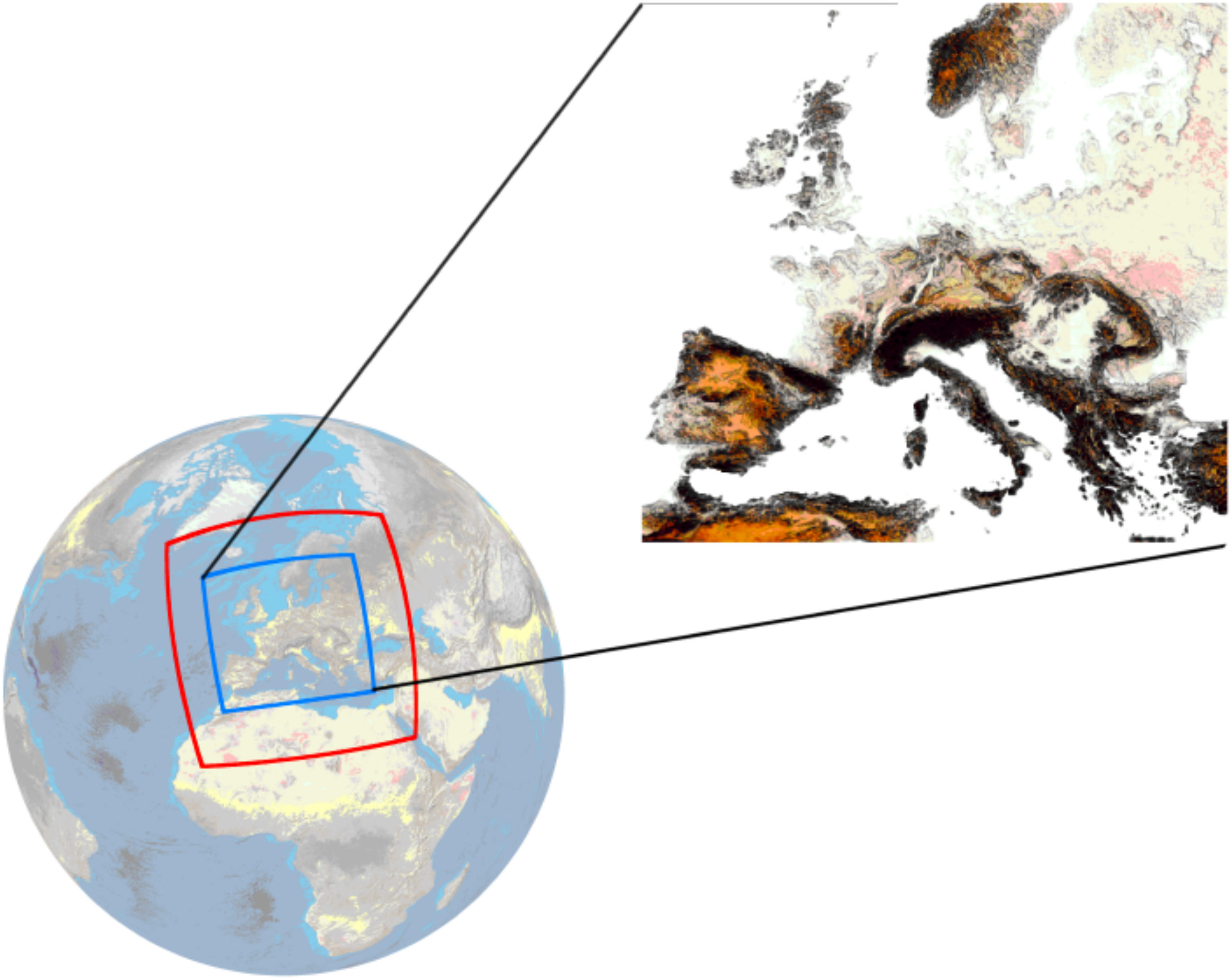
A known problem:

Ecosystem response to climate change often takes place at local scale

Global Climate Models currently provide climate projections spatial resolution between 40 and 100 km

So: **scale mismatch and need for climate downscaling**

Dynamical downscaling

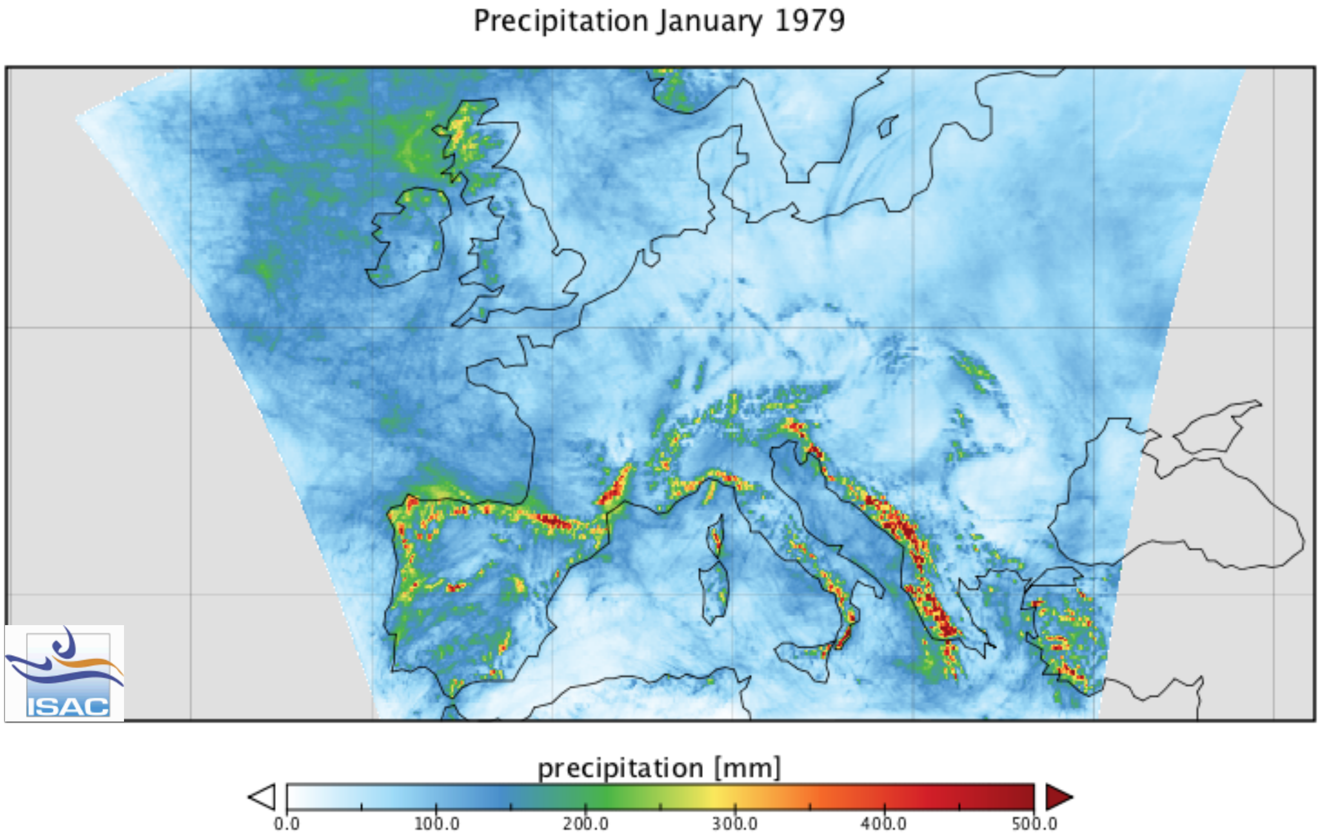


Non-hydrostatic RCMs: simulations with WRF

WRF - Weather Research & Forecasting Model

http://www.wrf-model.org/index.php

Climate simulations (30 years) with WRF at high spatial resolution (0.11° and 0.04°) nested into reanalyses (to be nested also into the EC-Earth GCM)



Total precipitation

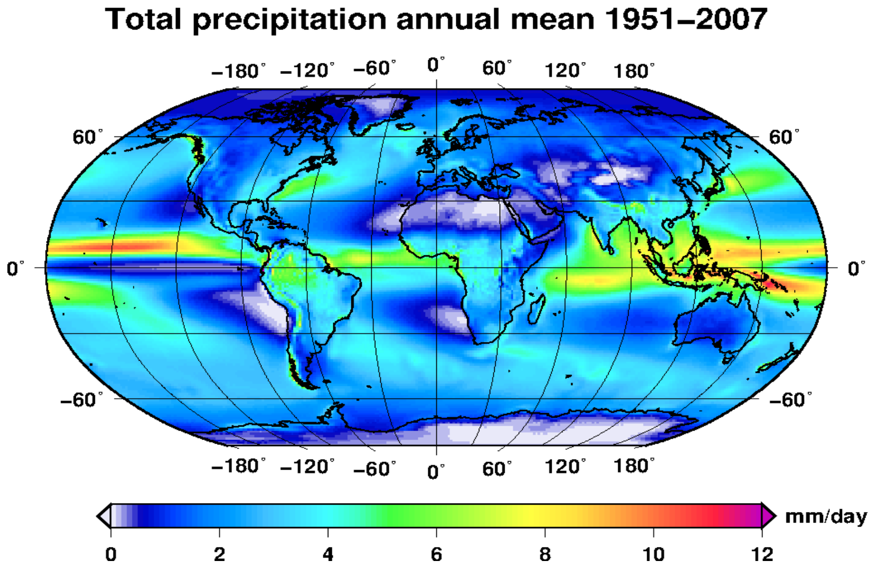
from WRF climate simulations at 4 km January 1979

Simulations @ Leibniz-Rechenzentrum (LRZ)/ SuperMUC, Munich

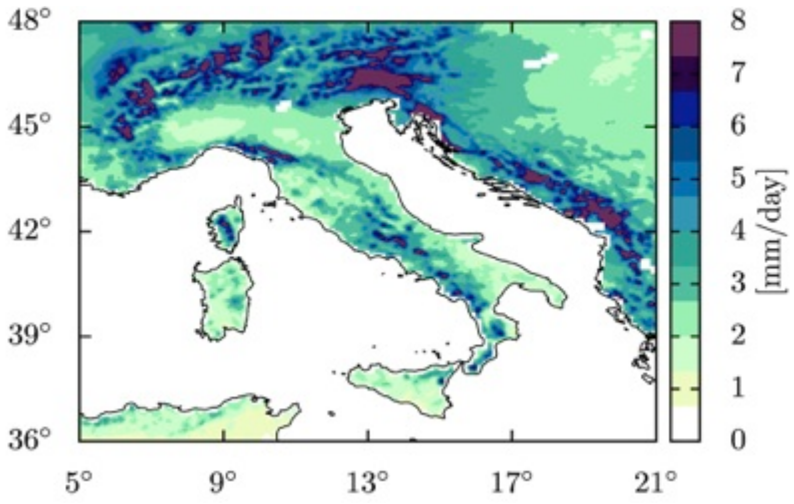
Alexandre Pieri et al,
J. Hydrometeorology 2015

The downscaling-impact chain

Global climate model


Total precipitation annual mean 1951–2007

Regional climate model



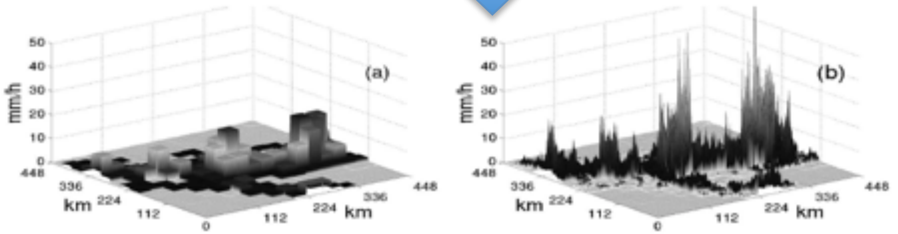


FIG. 10. (a) A snapshot of the forecasted rain field obtained from the LAM forecast and (b) one example of a downscaled field obtained by application of the RainFARM. The vertical scale indicates precipitation intensity (mm h^{-1}) and it is the same for the two fields.

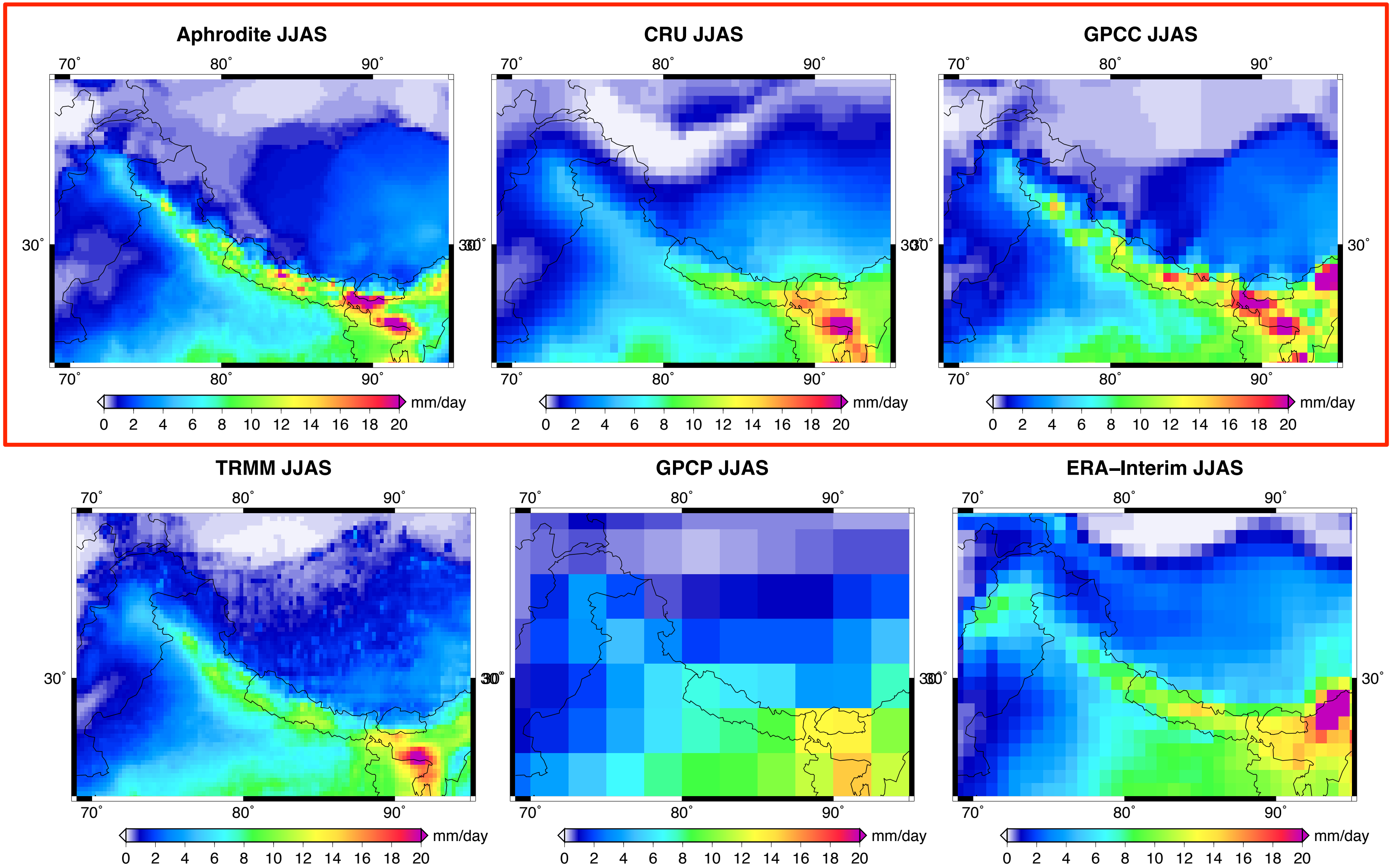
Statistical/stochastic downscaling

Impact on eco-hydrological processes

Troubles, oh troubles

The chain of uncertainties: data for model validation

Summer precipitation (JJAS), Multiannual average 1998-2007



Aphrodite JJAS

CRU JJAS

GPCC JJAS

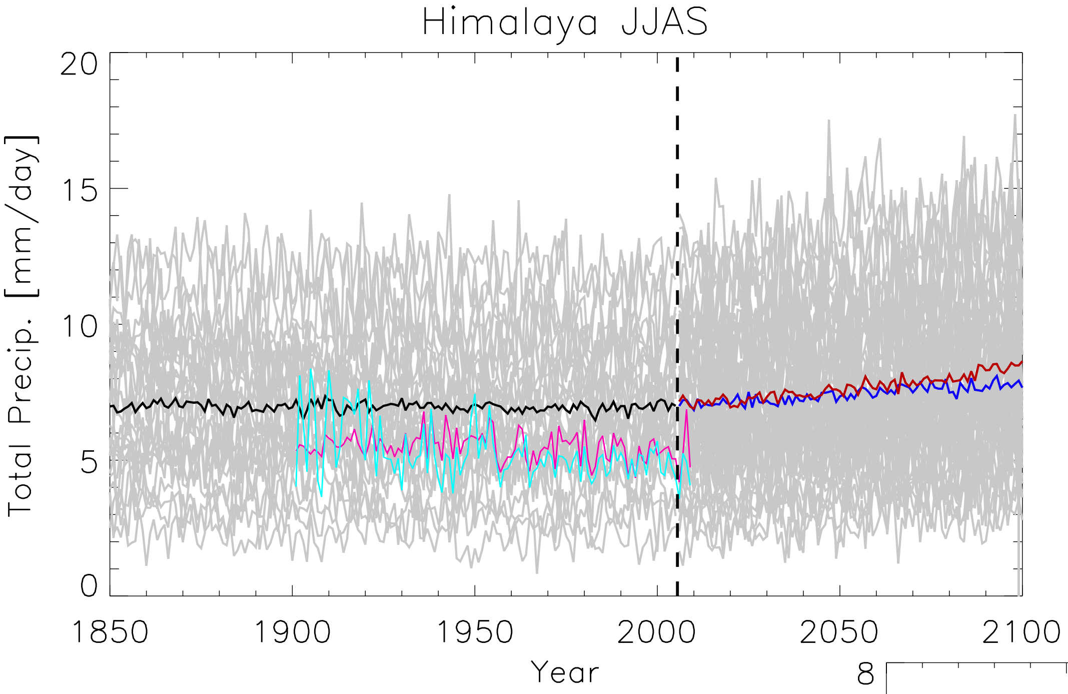
TRMM JJAS

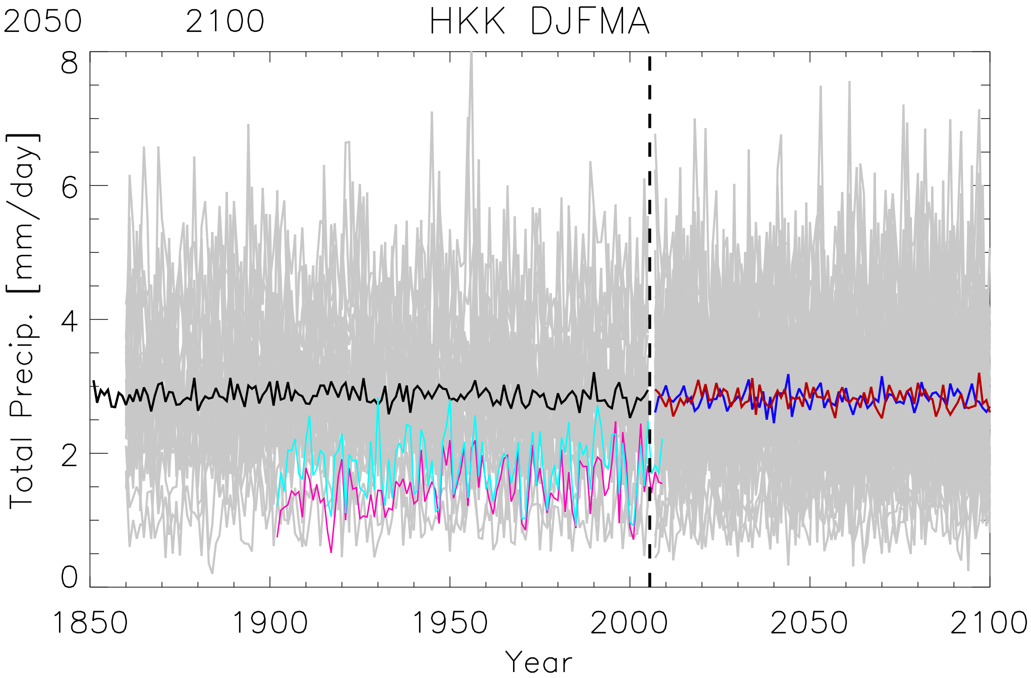
GPCP JJAS

ERA–Interim JJAS

Palazzi E., von Hardenberg J., Provenzale A.: Precipitation in the Hindu-Kush Karakoram Himalaya: Observations and future scenarios, JGR 2013

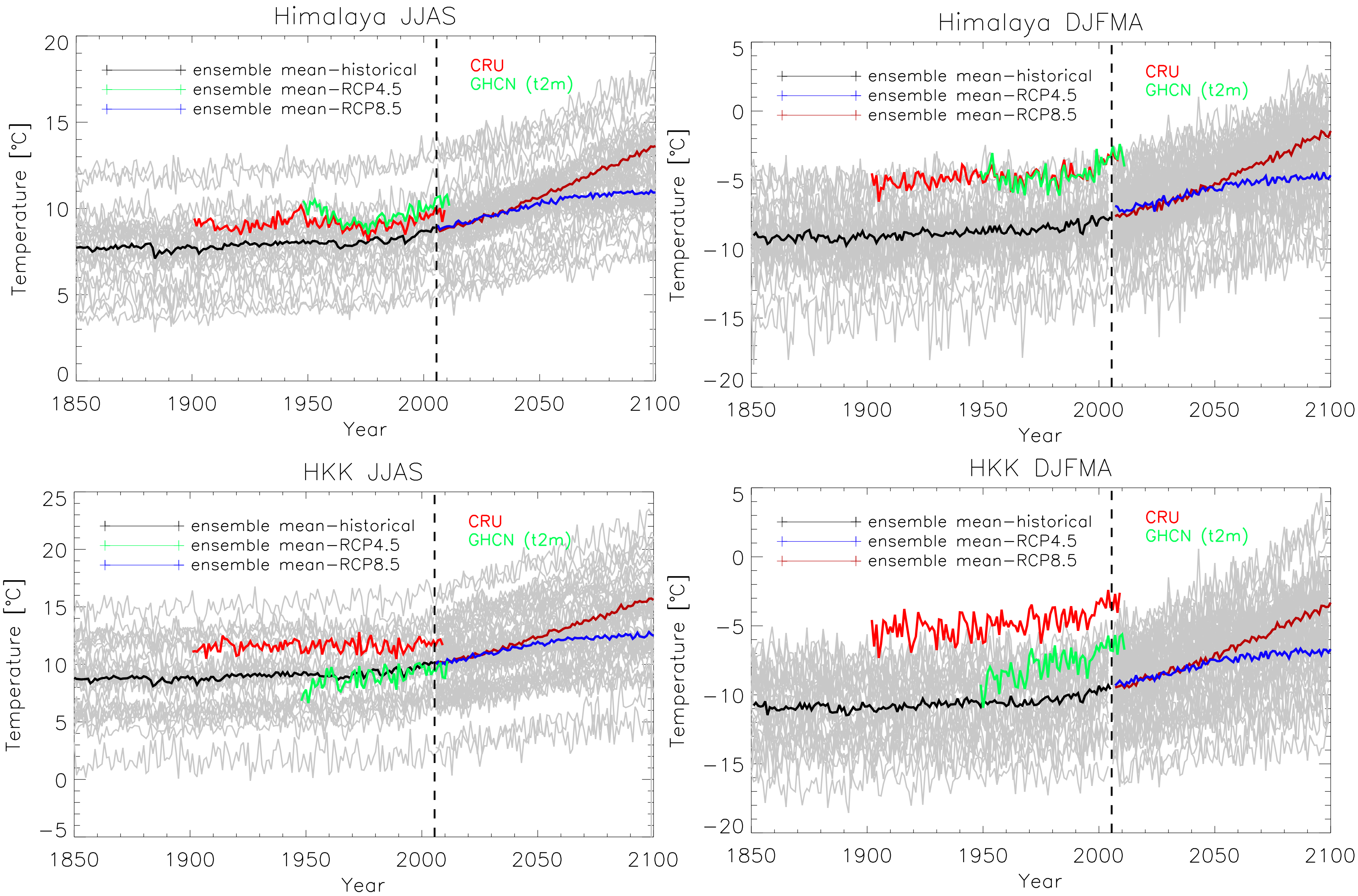
The chain of uncertainties: spread between CMIP5 models



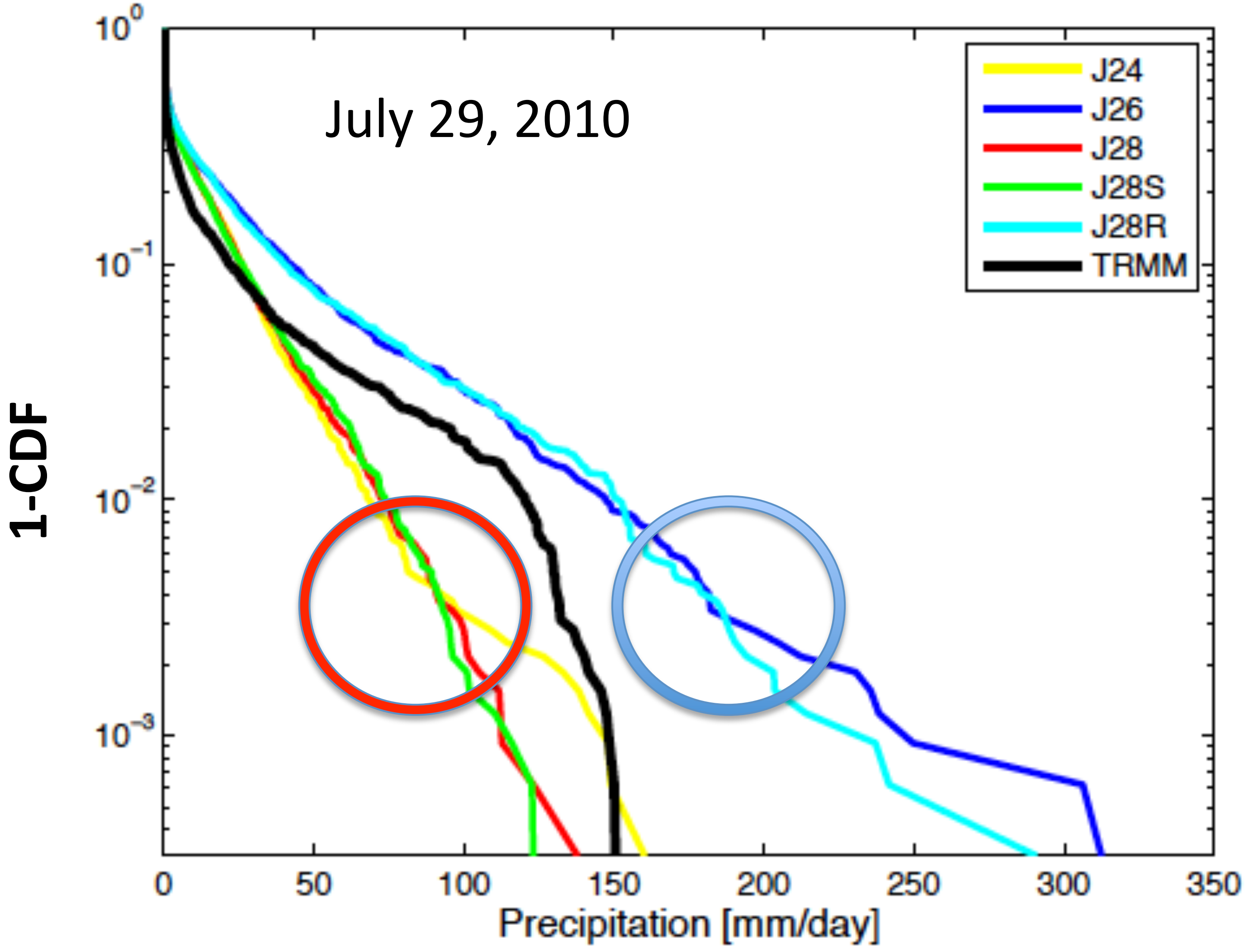


Palazzi E., von Hardenberg J.,
Terzago S., Provenzale A.:
Precipitation in the Karakoram-Himalaya:
A CMIP5 view, Climate Dynamics, 2015

and the spread of CMIP5 temperatures

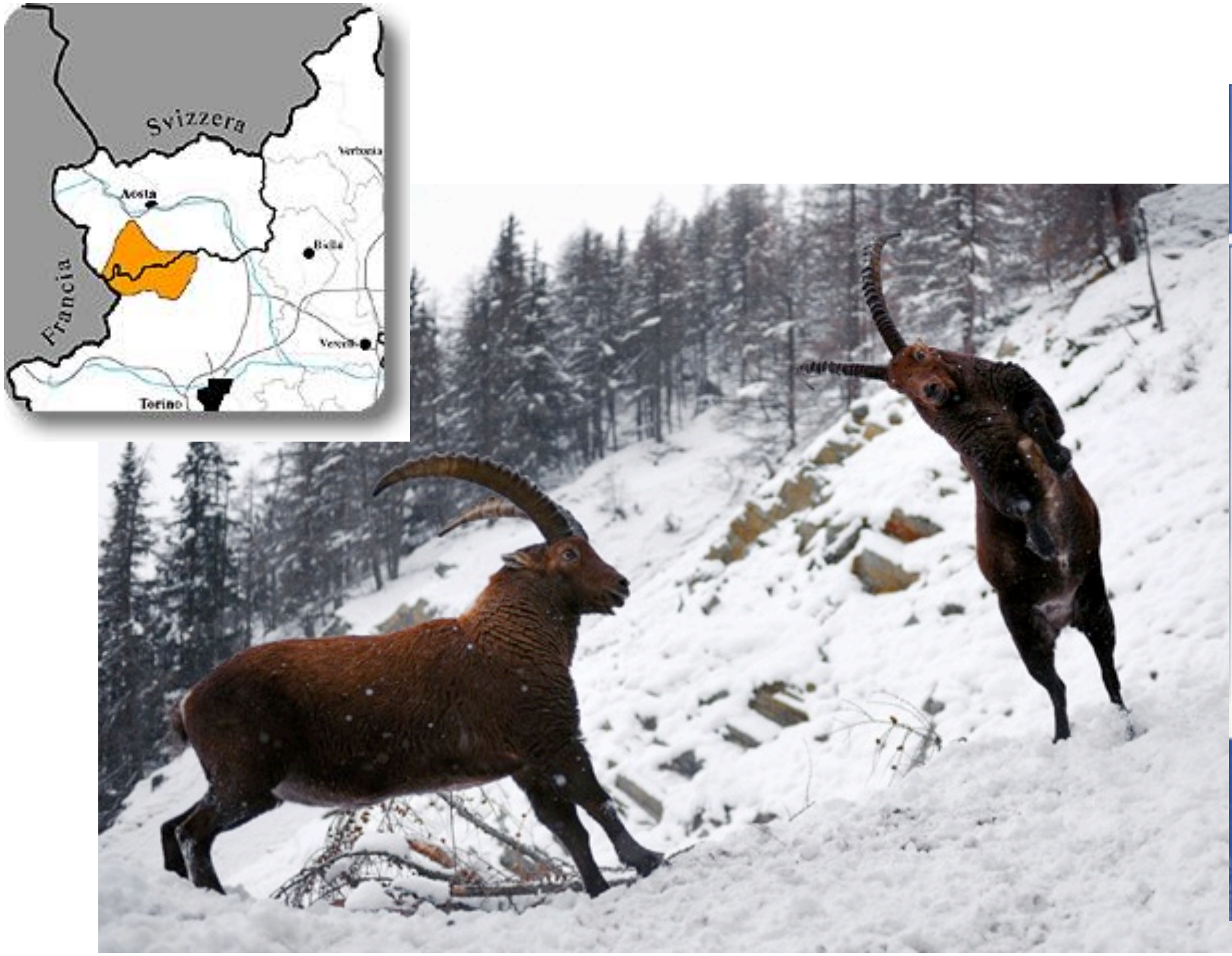


Precipitation statistics from WRF (Pakistan Flood 2010)



Francesca Viterbo et al., *sub judice* (2015)

Missing processes in ecological models



June 2004

esa

Volume 85 No. 6

ECOLOGY

A PUBLICATION OF THE ECOLOGICAL SOCIETY OF AMERICA

Special Feature

Community and Evolutionary Ecology of Nectar

Reports

Functional redundancy supports biodiversity and ecosystem function in a closed and constant environment

Exotic weed invasion increases the susceptibility of native plants to attack by a biocontrol herbivore

Articles

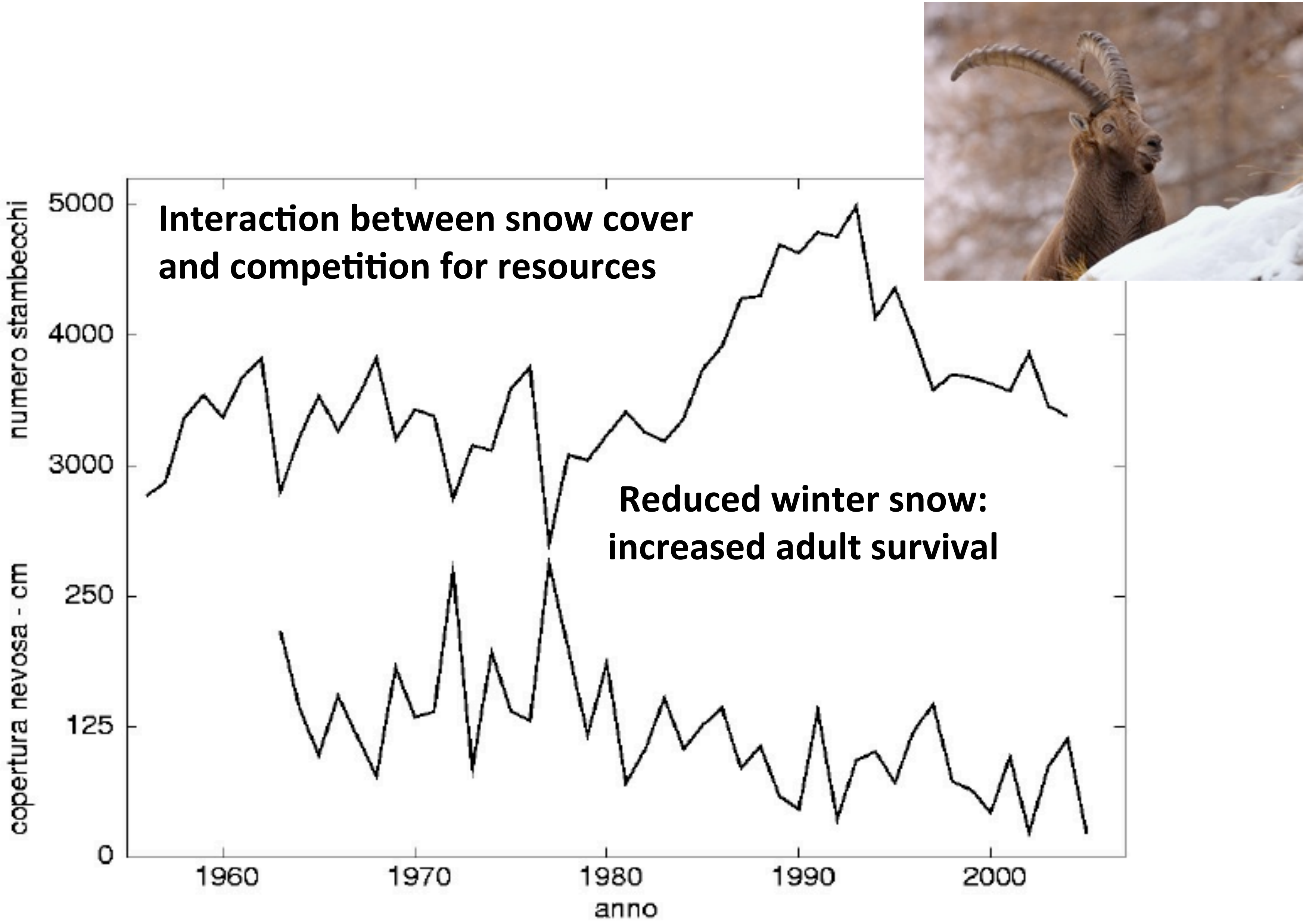
Climate forcing and density dependence in a mountain ungulate population

Density regulation in tadpoles of *Rana temporaria*: a full pond field experiment

Climate change, snow and mountain ecosystems: Alpine ibex at the Gran Paradiso National Park

Jacobson, Provenzale, Bassano, von Hardenberg, Festa-Bianchet, *Ecology,* 2004

Mignatti, Casagrandi, Provenzale, von Hardenberg, Gatto, *Wildlife Biology*, 2012

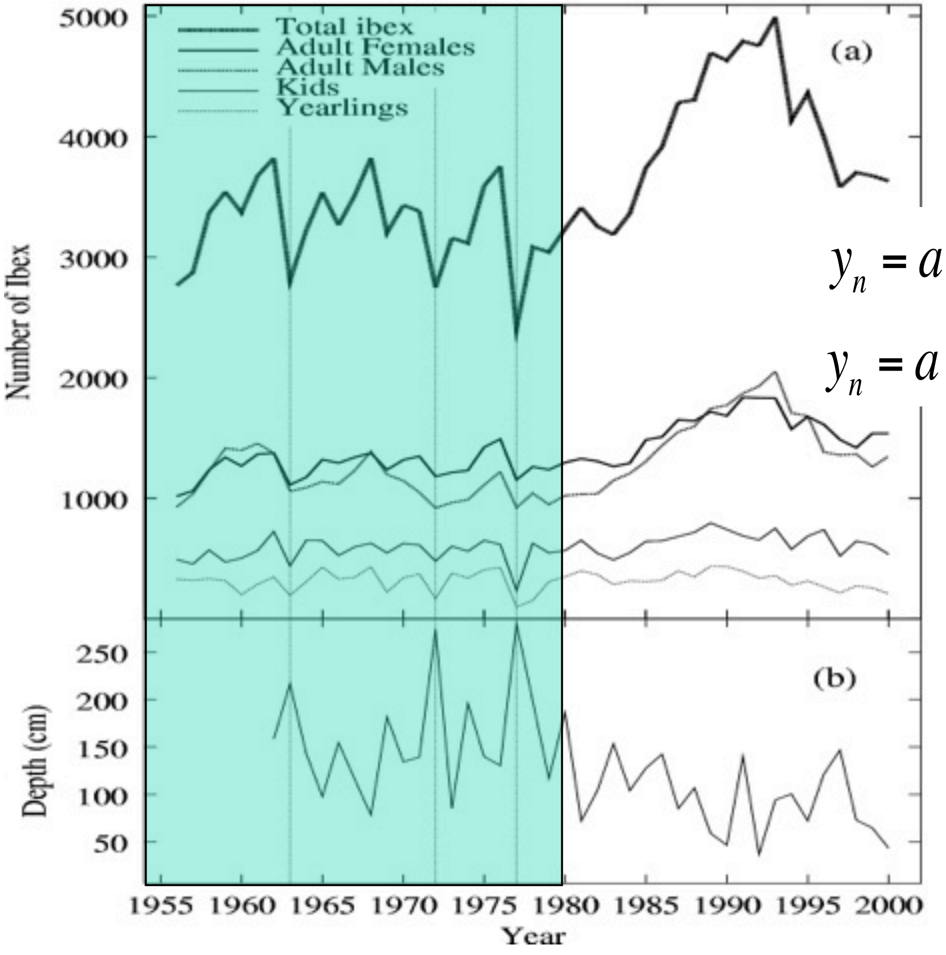


Interaction between snow cover and competition for resources

Reduced winter snow: increased adult survival

"Out-of-sample" predictions

Train the model on the first portion of the data and use it to predict the following behavior of the system

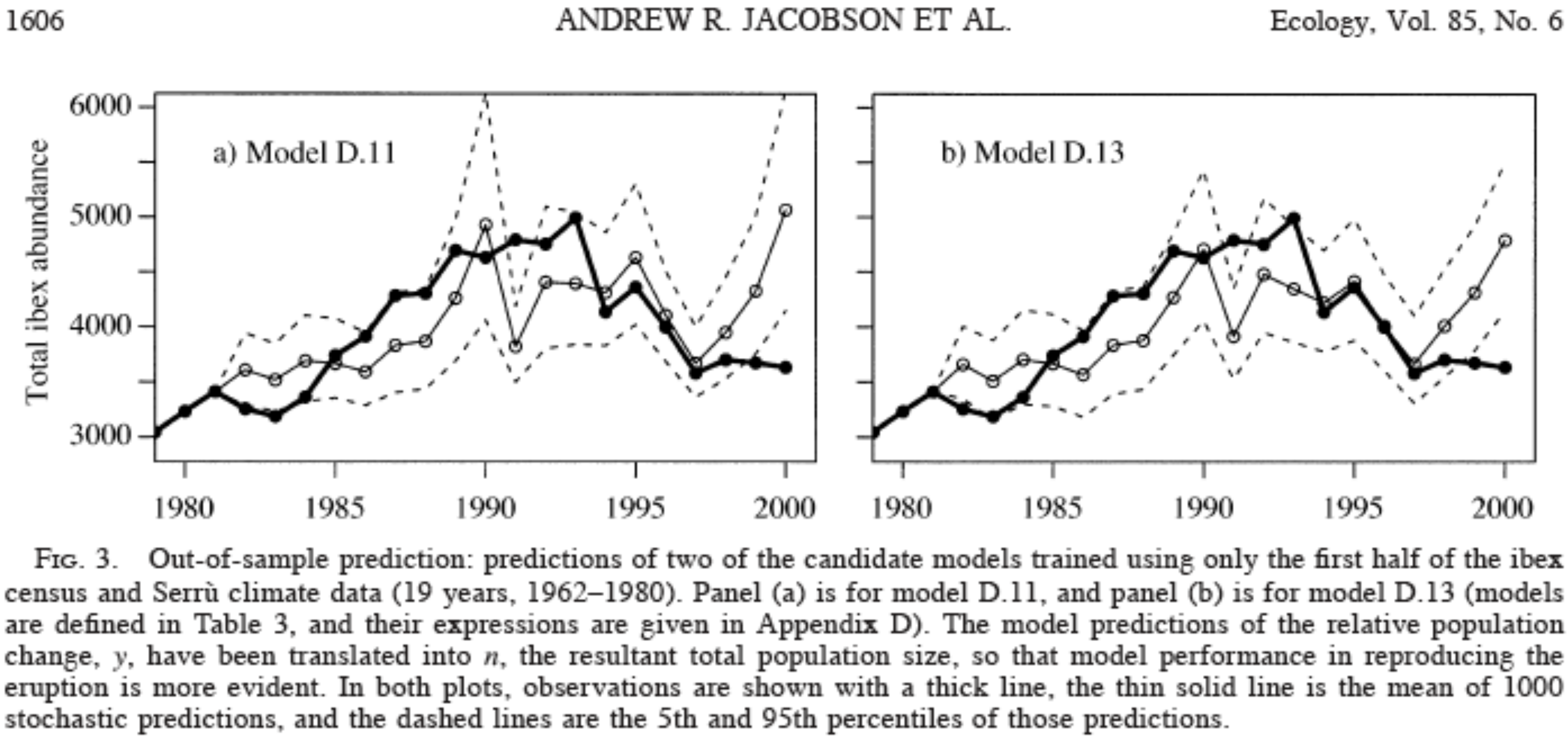


$$y_n = a + b^{\pm} X_n + c^{\pm} S_n + e^{\pm} X_n S_n + \sigma^{\pm} W_n$$

$$y_n = a + b^{\pm} N_n + c^{\pm} S_n + e^{\pm} N_n S_n + \sigma^{\pm} W_n$$

“Out-of-sample” predictions

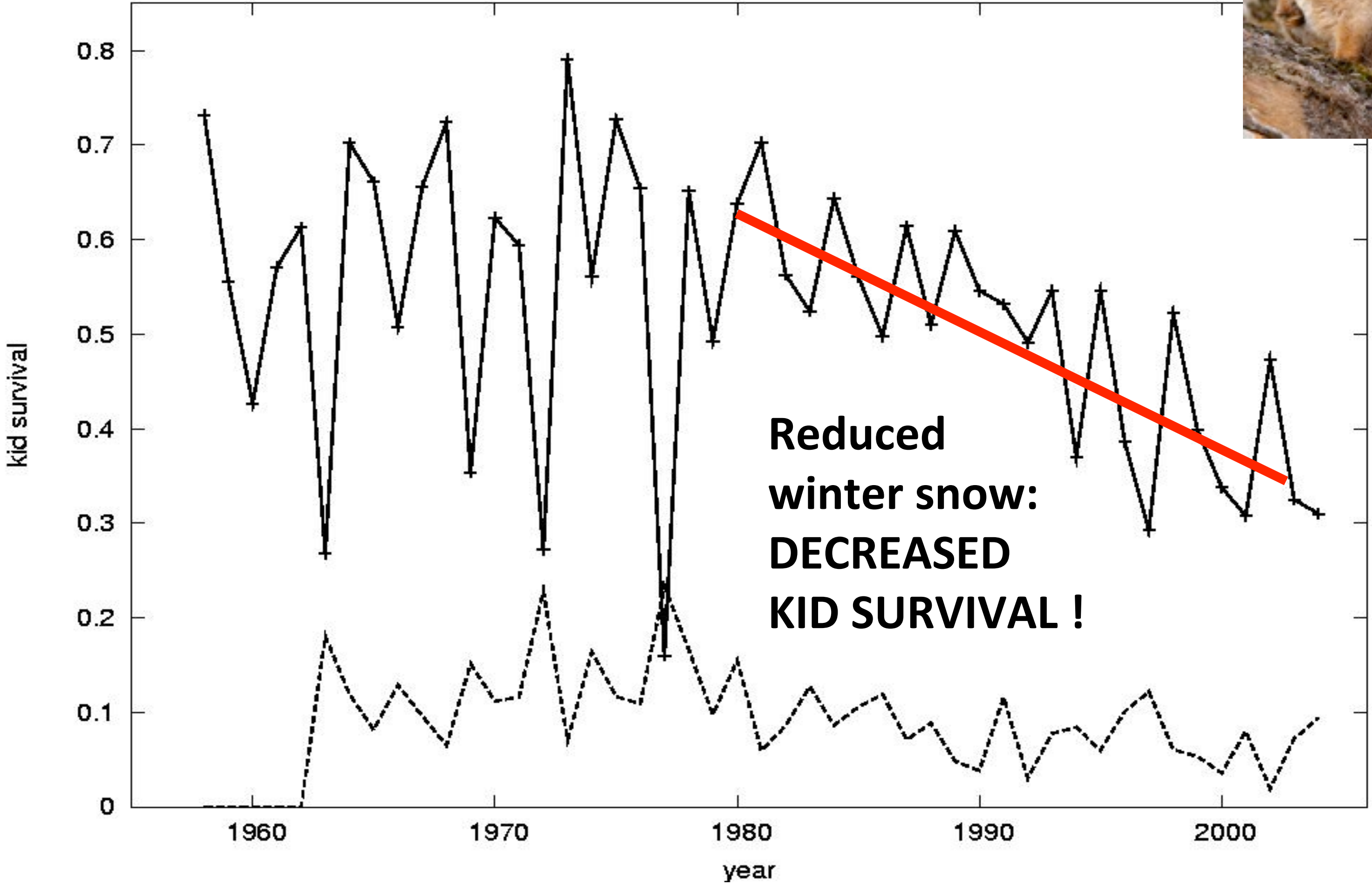
Train the model on the first portion of the data and use it to predict the following behavior of the system



1606 ANDREW R. JACOBSON ET AL. Ecology, Vol. 85, No. 6

FIG. 3. Out-of-sample prediction: predictions of two of the candidate models trained using only the first half of the ibex census and Serrù climate data (19 years, 1962–1980). Panel (a) is for model D.11, and panel (b) is for model D.13 (models are defined in Table 3, and their expressions are given in Appendix D). The model predictions of the relative population change, *y*, have been translated into *n*, the resultant total population size, so that model performance in reproducing the eruption is more evident. In both plots, observations are shown with a thick line, the thin solid line is the mean of 1000 stochastic predictions, and the dashed lines are the 5th and 95th percentiles of those predictions.

An even more complex interaction between snow cover and population dynamics

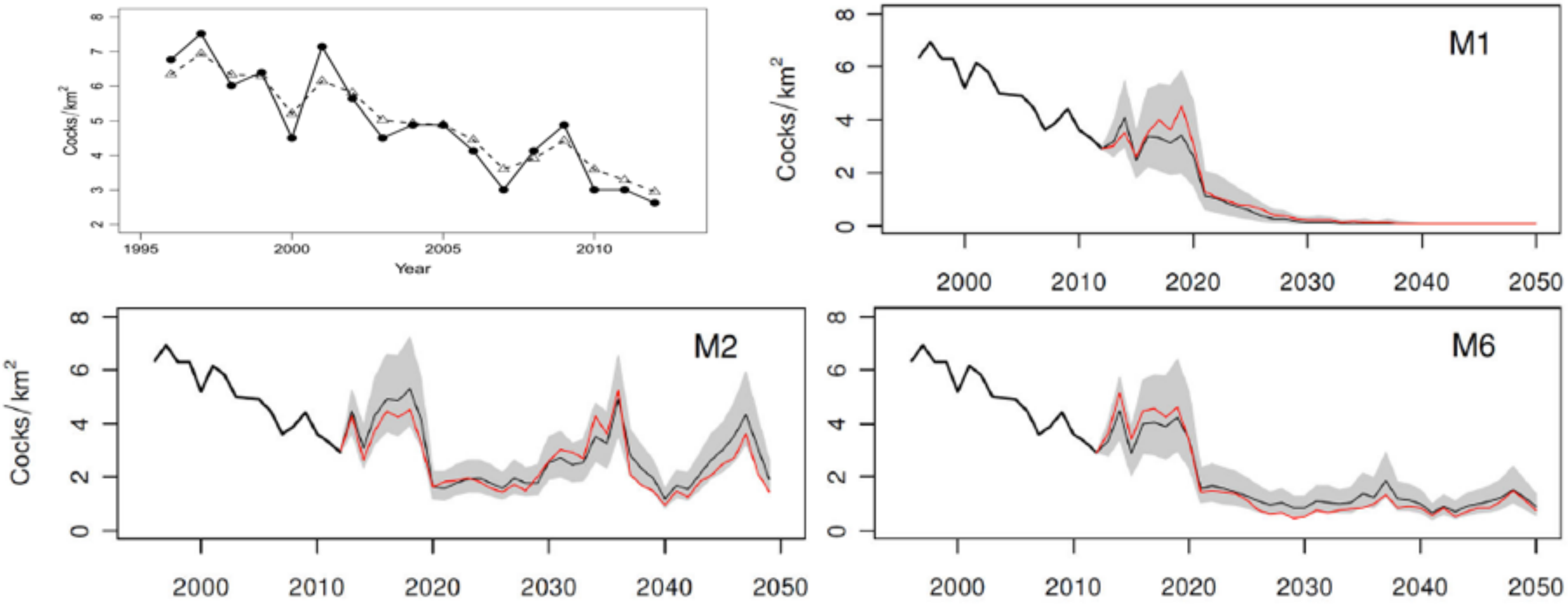


Reduced winter snow: DECREASED KID SURVIVAL !

Snow can have a double and contrasting effect

Possible mismatch between plant blooming and ibex birth date

Statistical uncertainties in ecological models



Model	Intercept	lnN$_{t-1}$	lnN$_{t-2}$	SE$_{t-1}$	SS$_{t-1}$	SP$_t$	T(July)$_{t-1}$	P(July)$_{t-1}$	T(Jan-Mar)$_t$	T(Apr-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

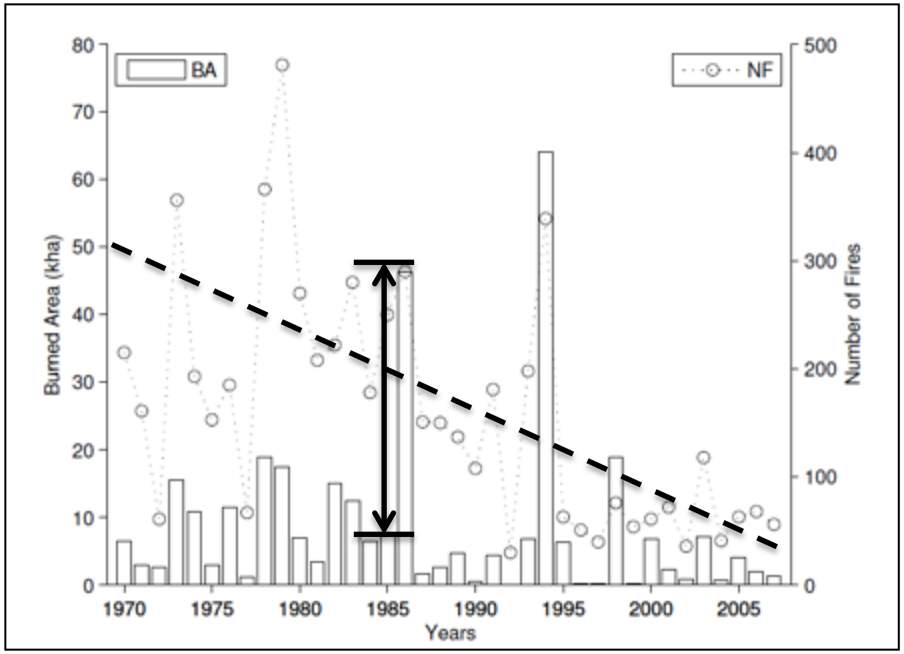
Missing drivers in response models

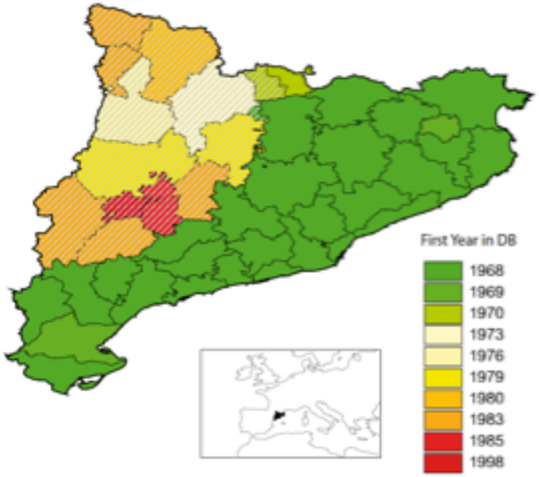
Climate change and forest fires

Drivers → climate variability and trends, prevention and management strategies

Year-to-year changes in NF and BA are related mainly to **climate variability**.

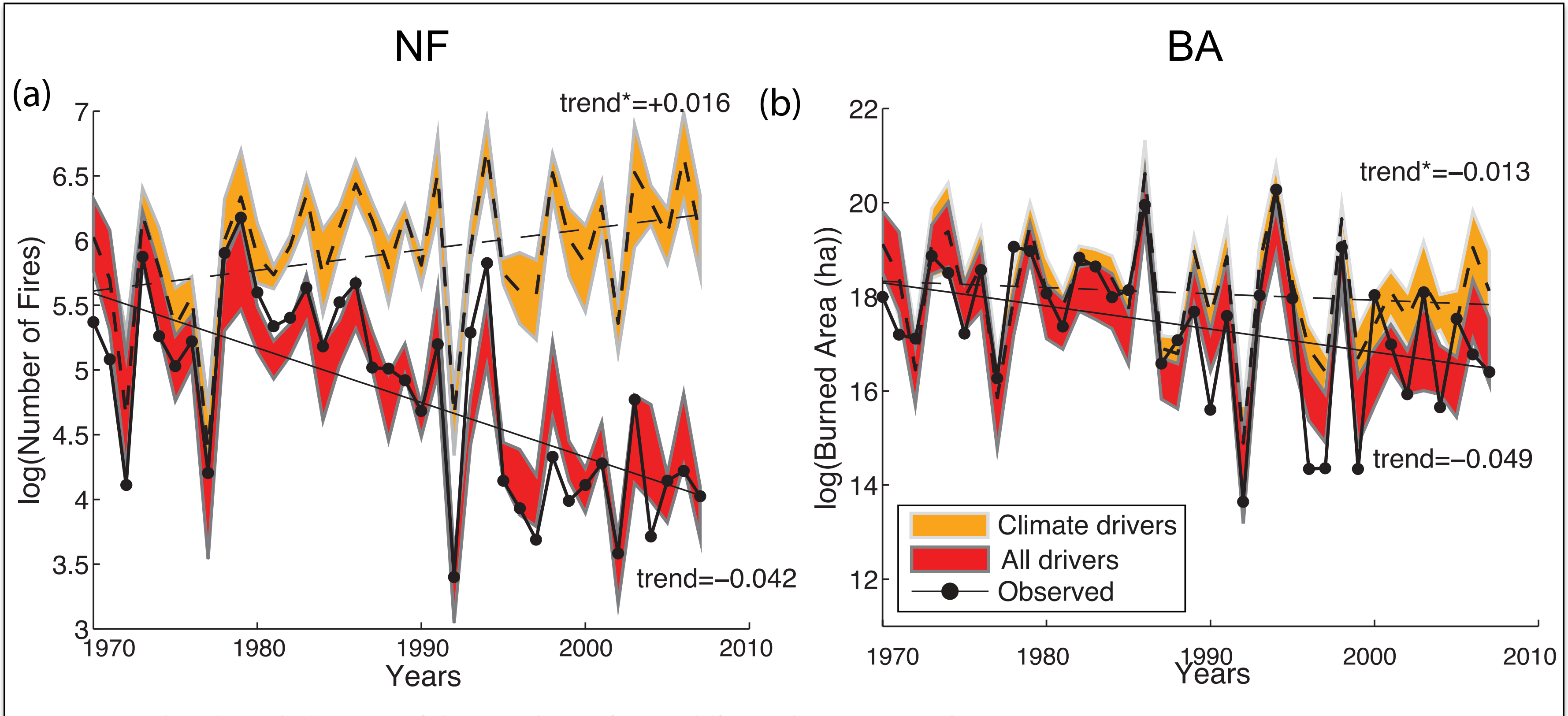
Climate acts on two aspects:
antecedent climate → fuel availability
current climate → fuel flammability





Turco et al. Climatic Change 2013, 2014, NHESS 2013

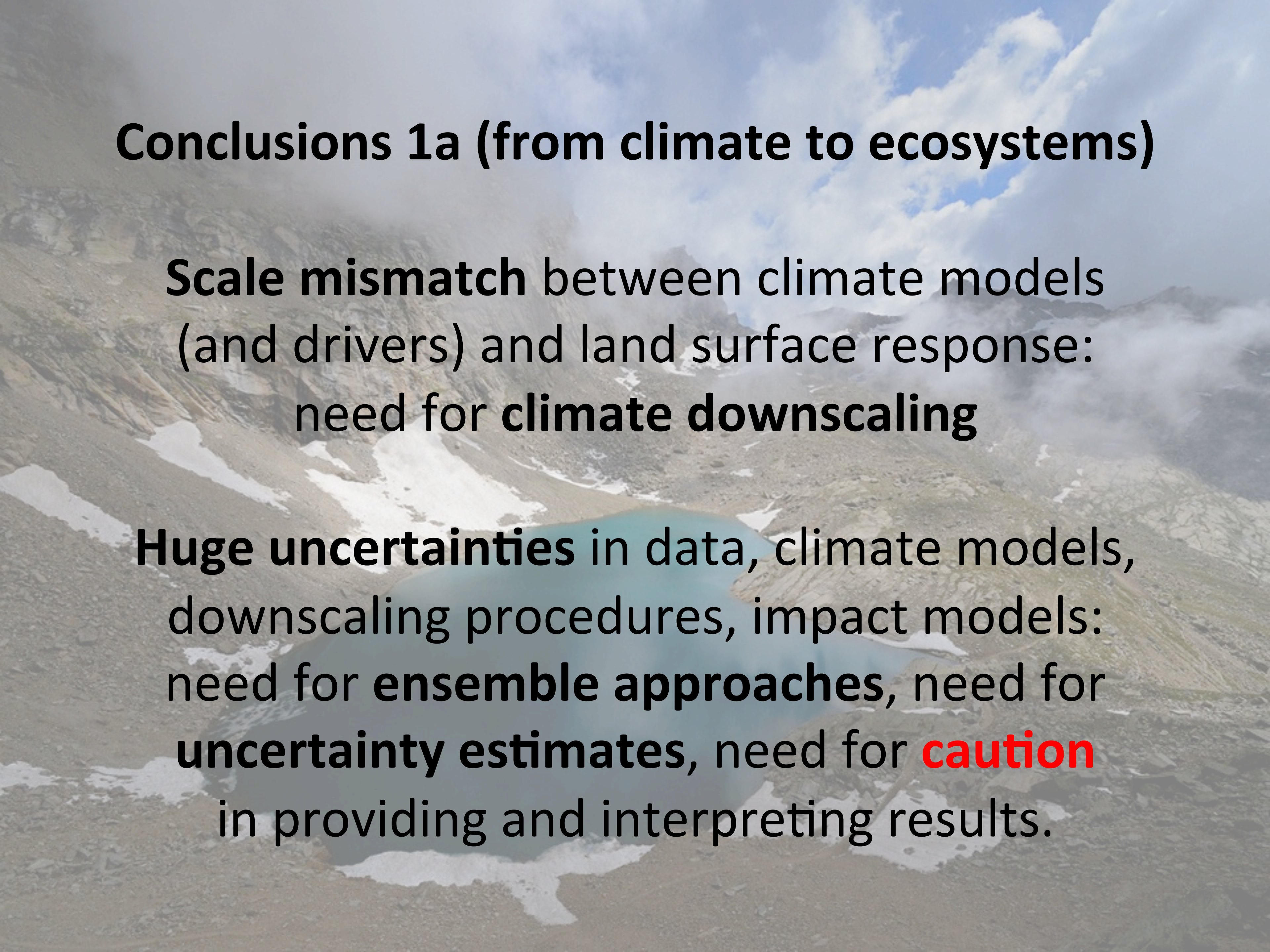
Fire response to climate trends



Uncertainty bands: includes 90% of the members of 1000 different bootstrap replicates

Climate drivers = both interannual variability and trends are driven only by climate
All drivers = includes the trend of prevention measures

Consideration of the trends of management strategies is crucial for a correct forecast



Conclusions 1a (from climate to ecosystems)

Scale mismatch between climate models (and drivers) and land surface response: need for **climate downscaling**

Huge uncertainties in data, climate models, downscaling procedures, impact models: need for **ensemble approaches**, need for **uncertainty estimates**, need for **caution** in providing and interpreting results.

Conclusions 1b (from climate to ecosystems)

From climate change hotspots
to ecosystem response hotspots

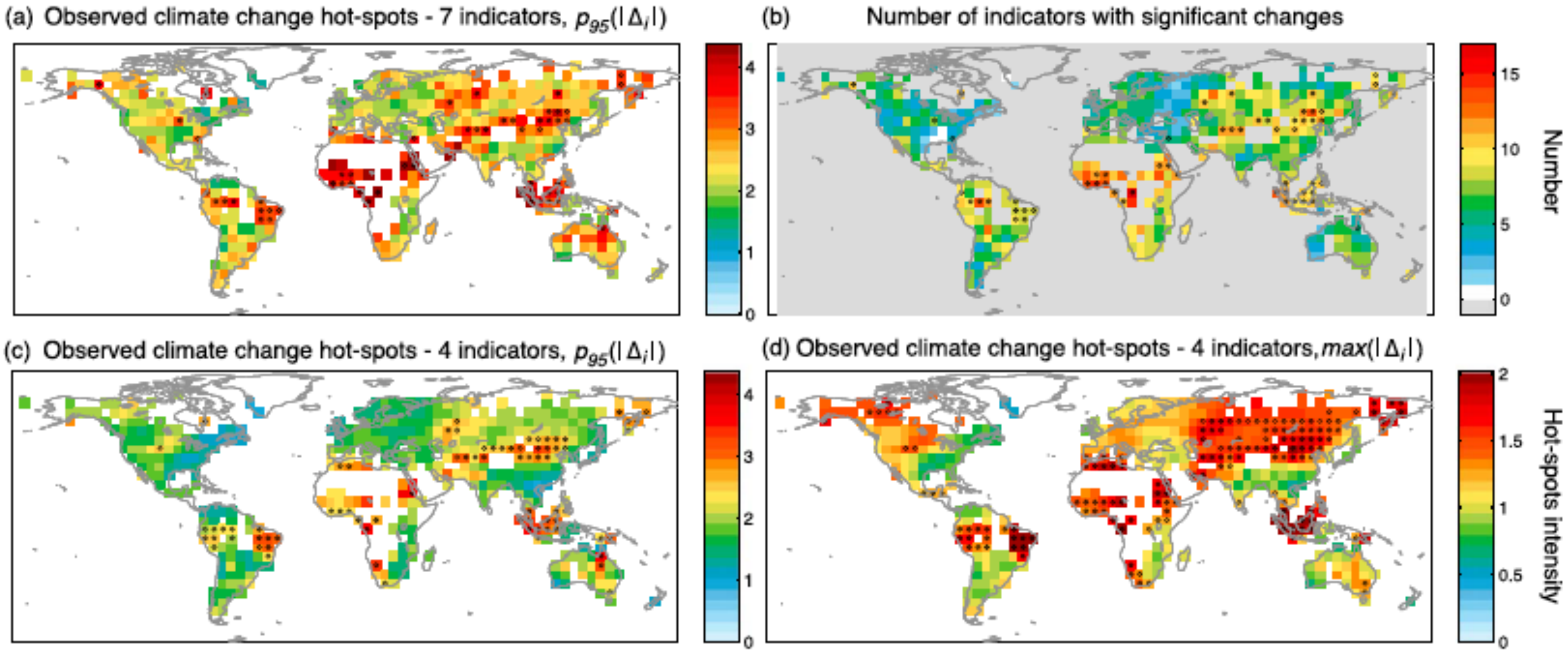
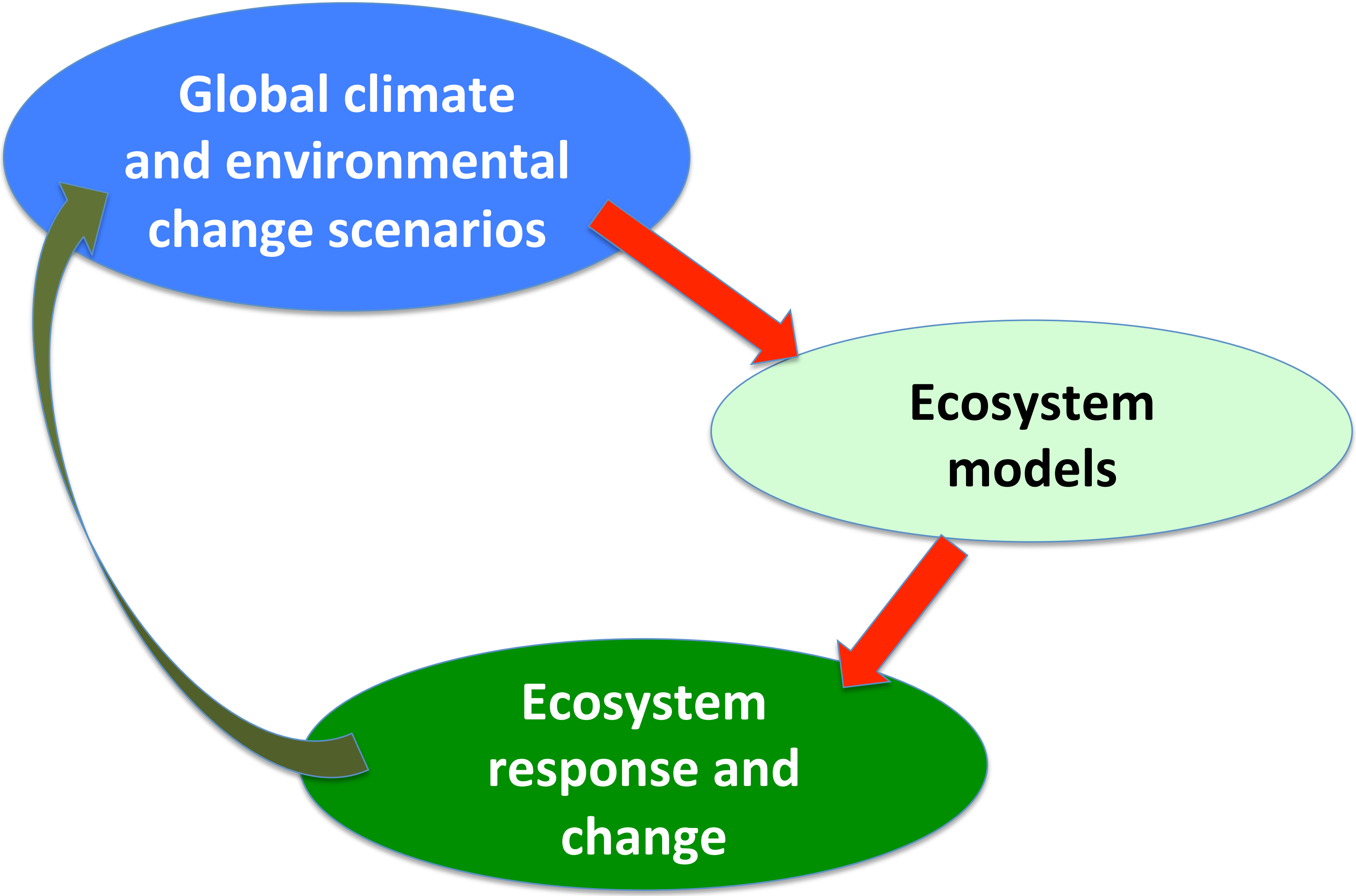


Figure 3. (a) Observed climate change hotspots at grid point scale using the seven indicators and the normalization factor $p_{95}(|\Delta_i|)$; (b) number of individual climate indicators that show significant change; (c) hotspots considering only four indicators (ΔT, ΔT_{var}, f_{hot}, and ΔP) and the normalization factor $p_{95}(|\Delta_i|)$; and (d) the same as Figure 3c but with the normalization factor $\max(|\Delta_i|)$ (the global maximum of the field). The data sets employed are GISTEMP$_{1200}$ and GPCC. Black points (empty circles) indicate significant hotspots at 95% (90%) level.

Turco, Palazzi, von Hardenberg, Provenzale, *GRL*, 2015

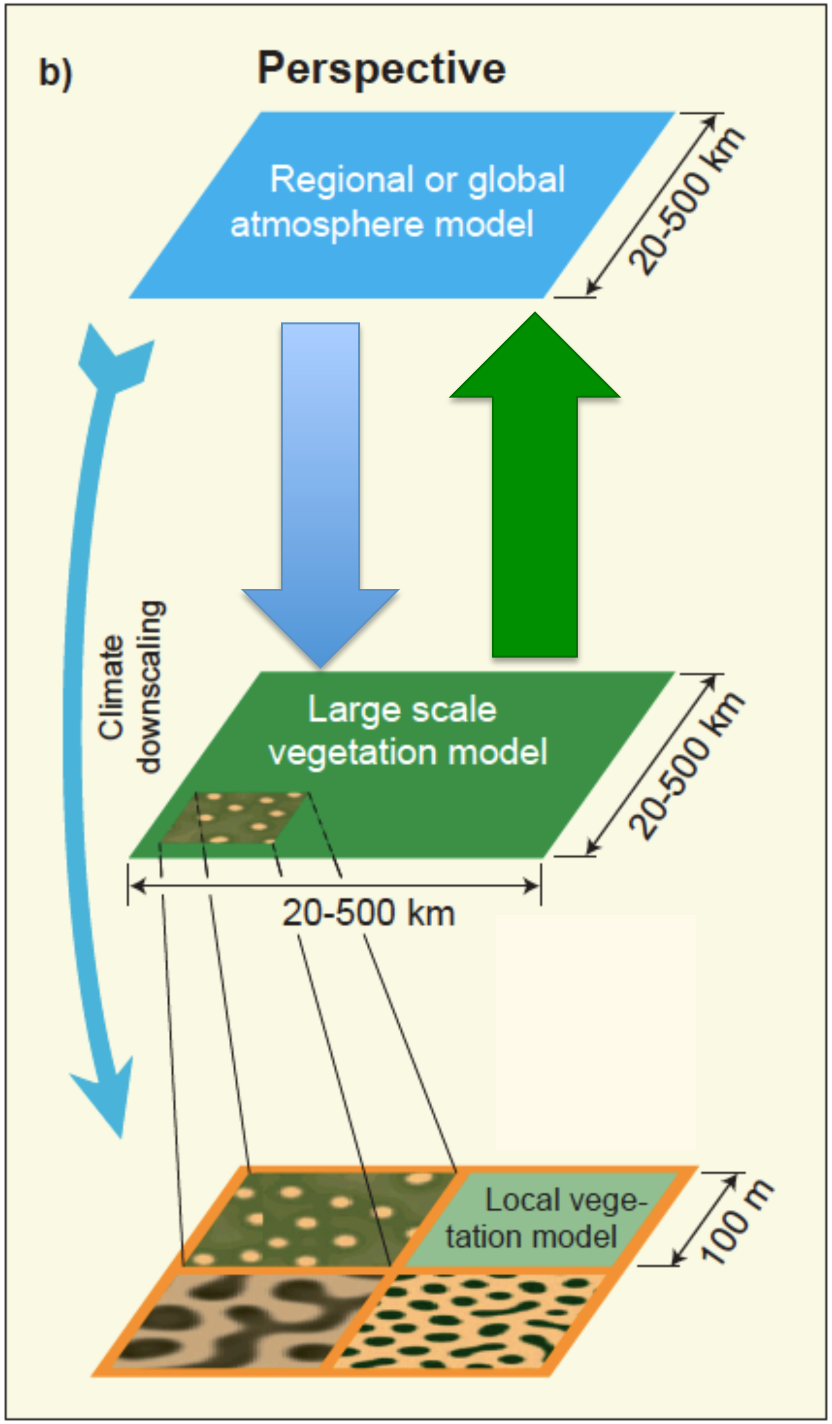
Ecosystem feedbacks on climate



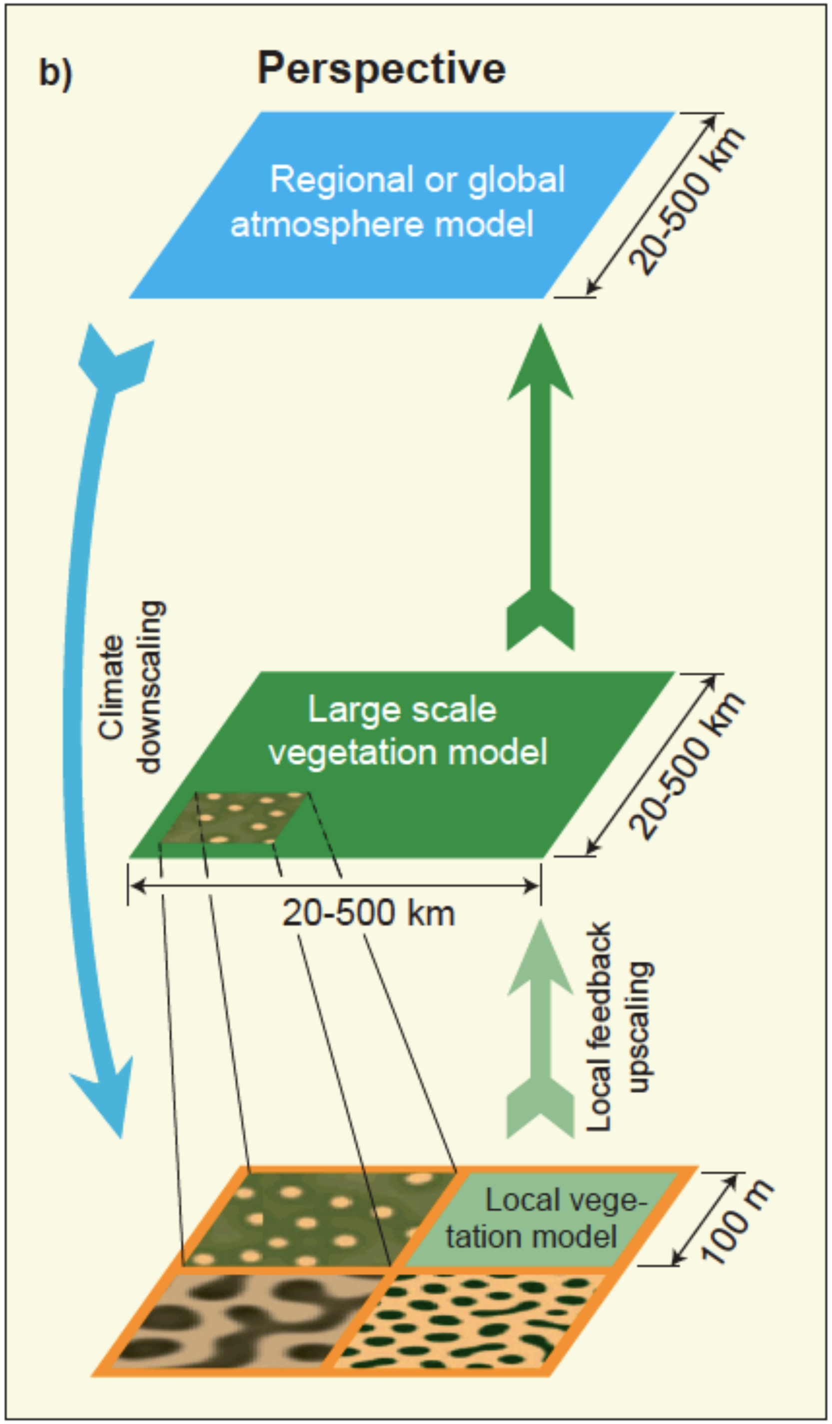
Global climate and environmental change scenarios

Ecosystem models

Ecosystem response and change



Climate downscaling

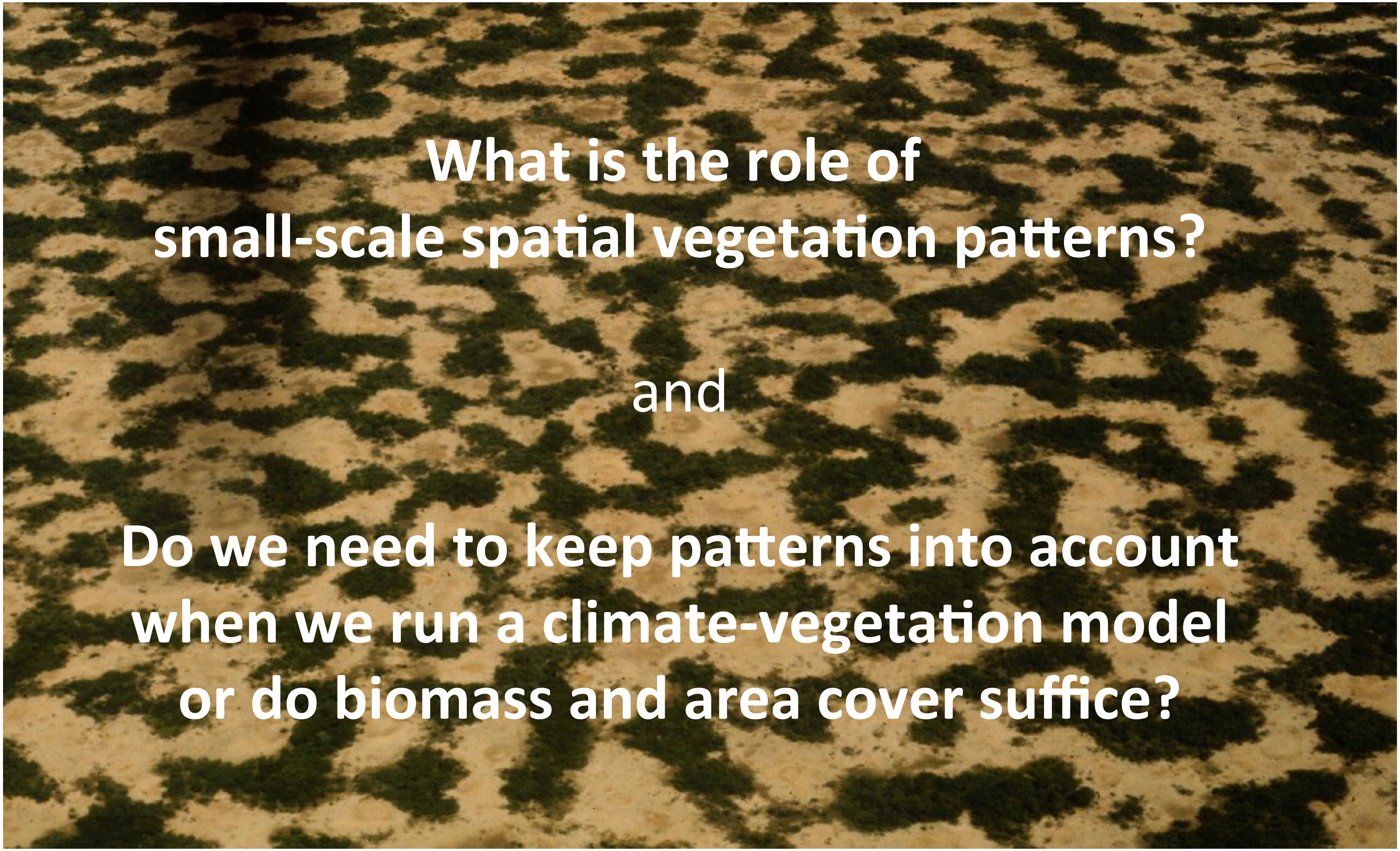


Upscaling of ecosystem feedbacks

Rietkerk et al.
Ecological complexity 2011

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

Vegetation patterns in arid and semi-arid regions



What is the role of small-scale spatial vegetation patterns?

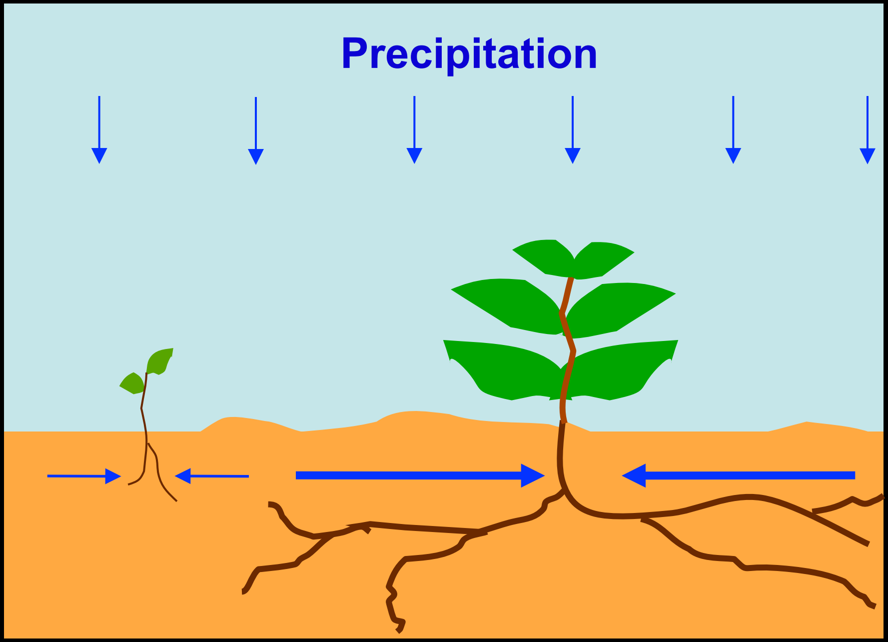
and

Do we need to keep patterns into account when we run a climate-vegetation model or do biomass and area cover suffice?

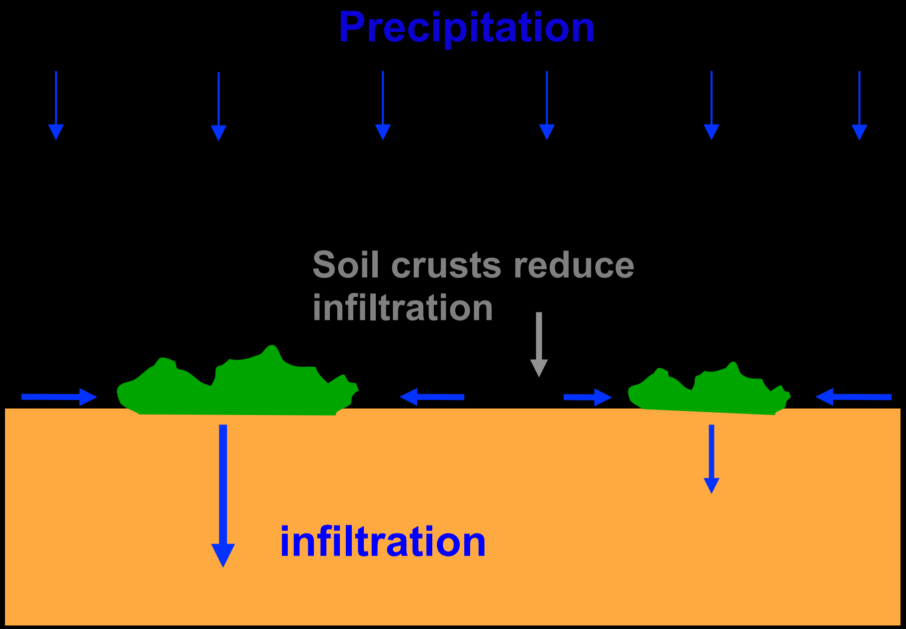
Mechanisms of vegetation patterning

Positive feedbacks between biomass and water + competition

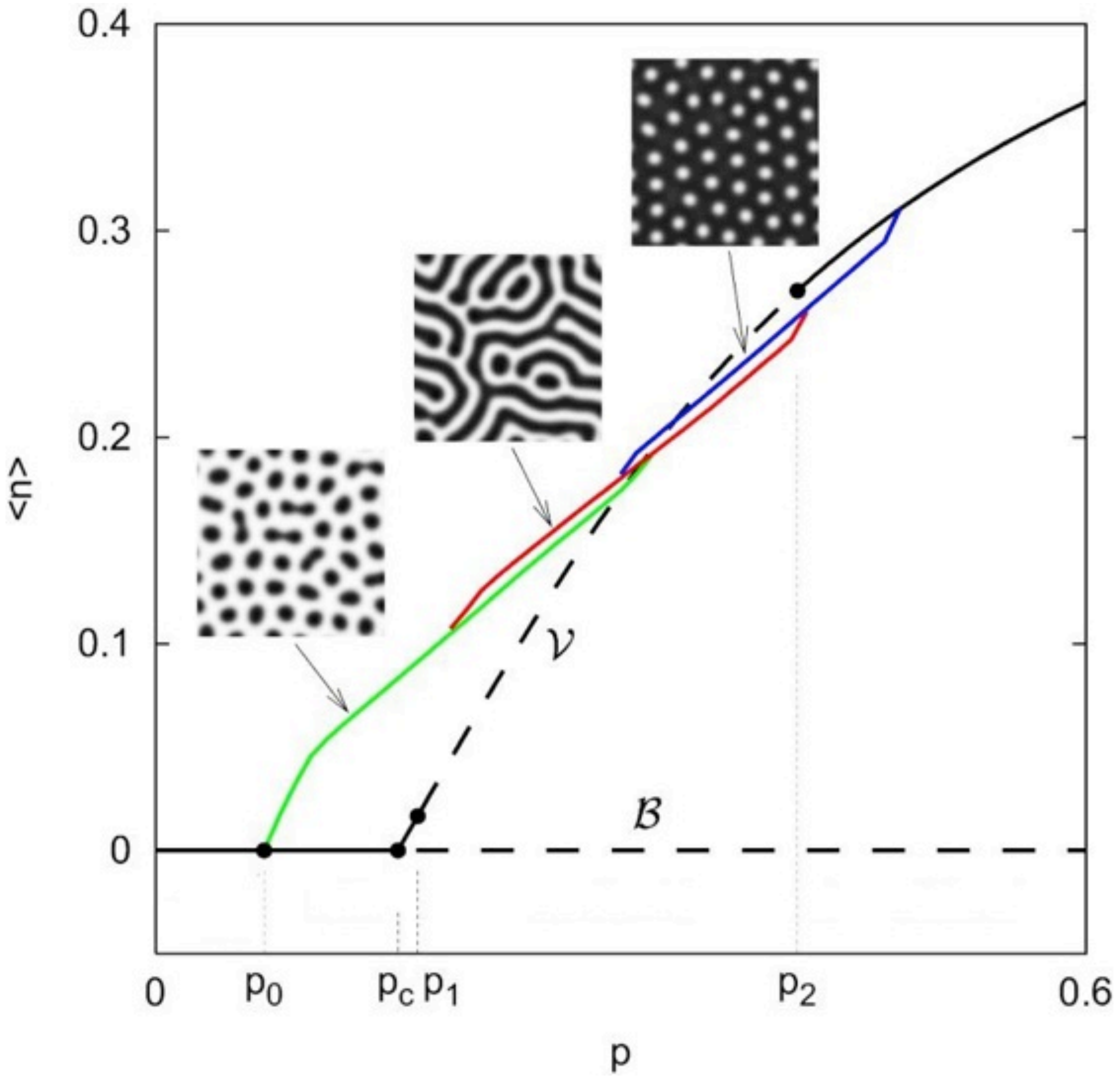
Water uptake by roots



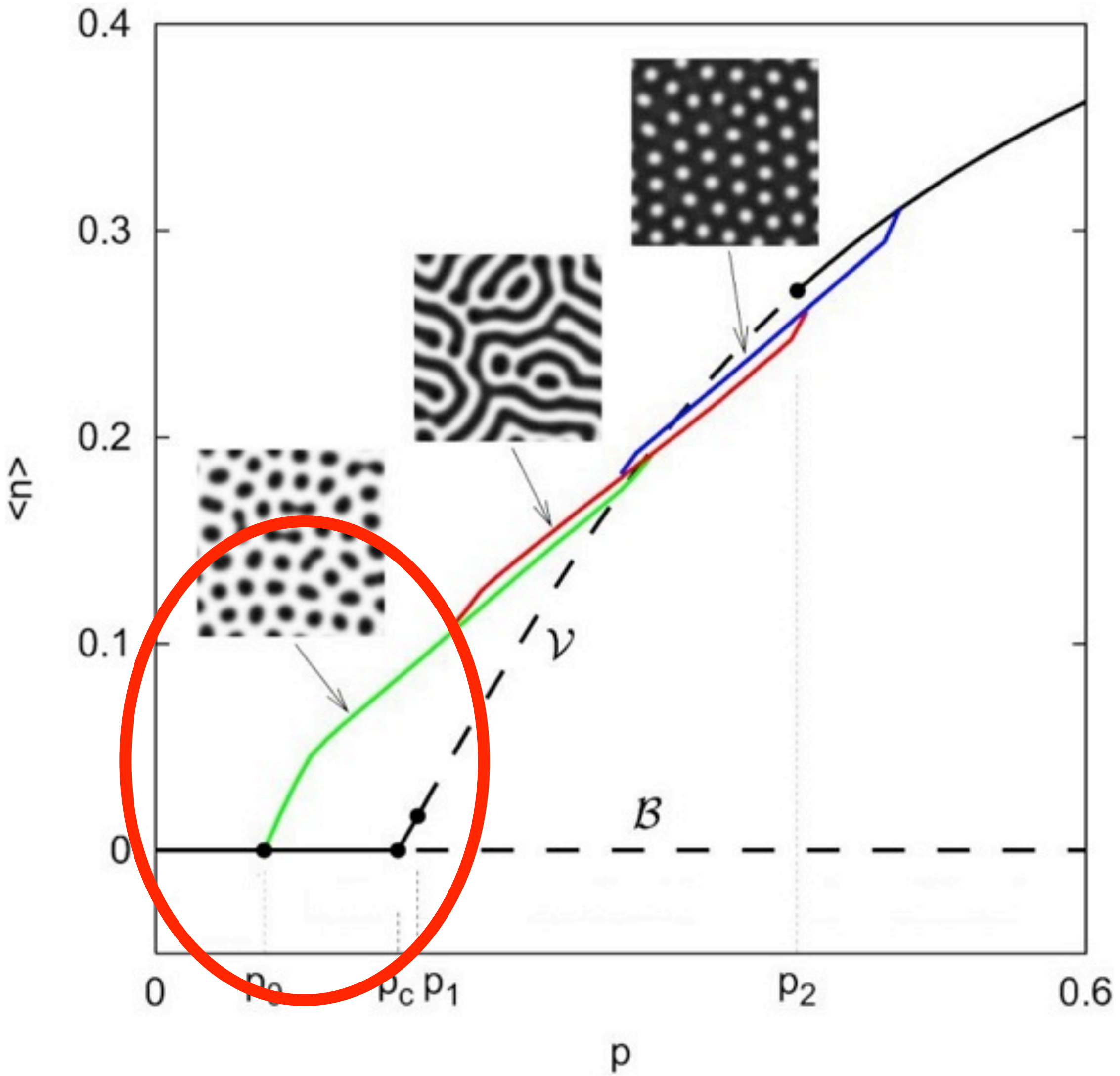
Increased infiltration



Von Hardenberg et al, PRL 2001, Gilad et al PRL 2004, JTB 2007,
Kletter et al JTB 2009, Baudena et al AWR 2013

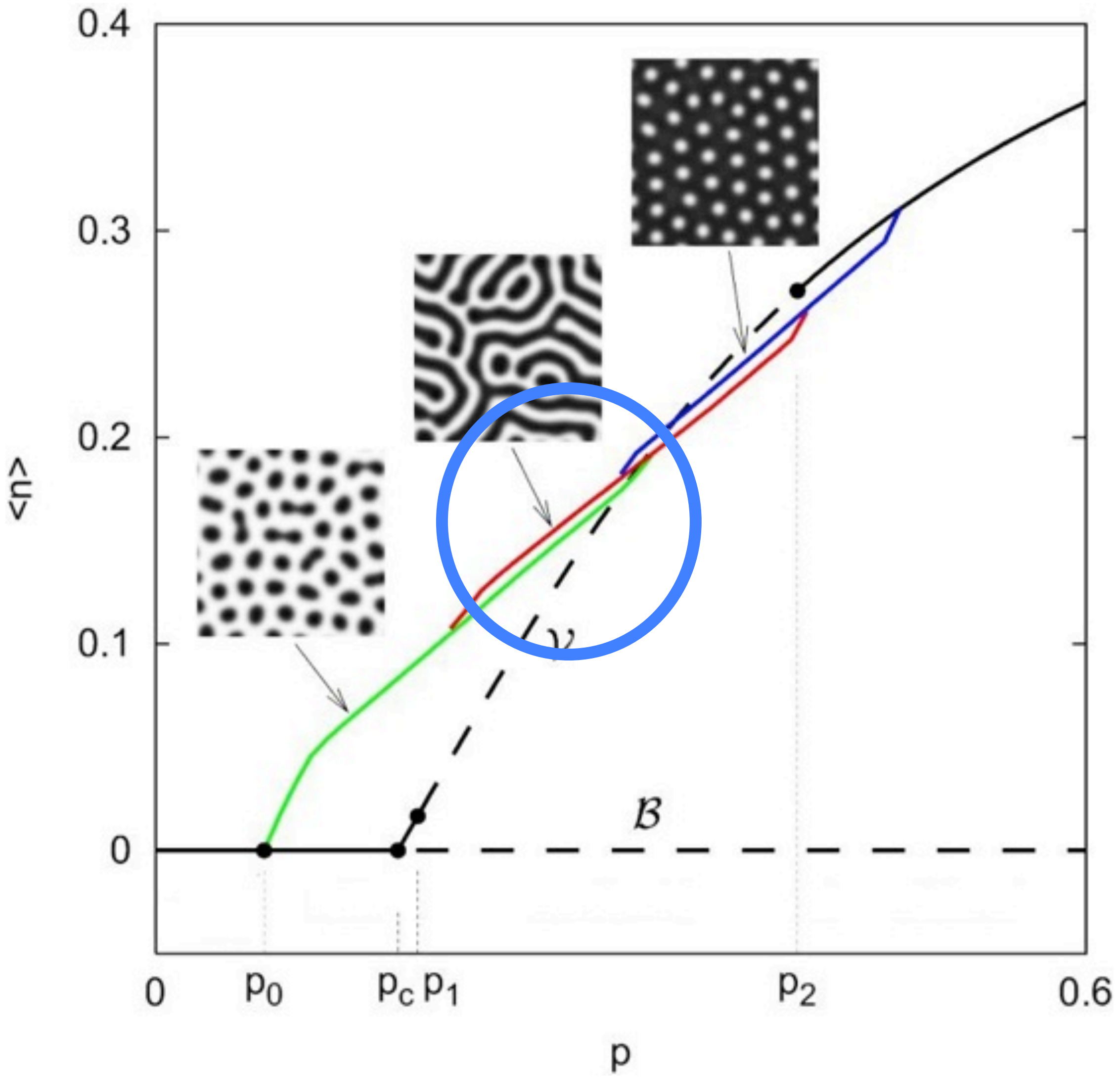


Multiple steady states
with non-homogeneous vegetation distributions



The extension of the desert

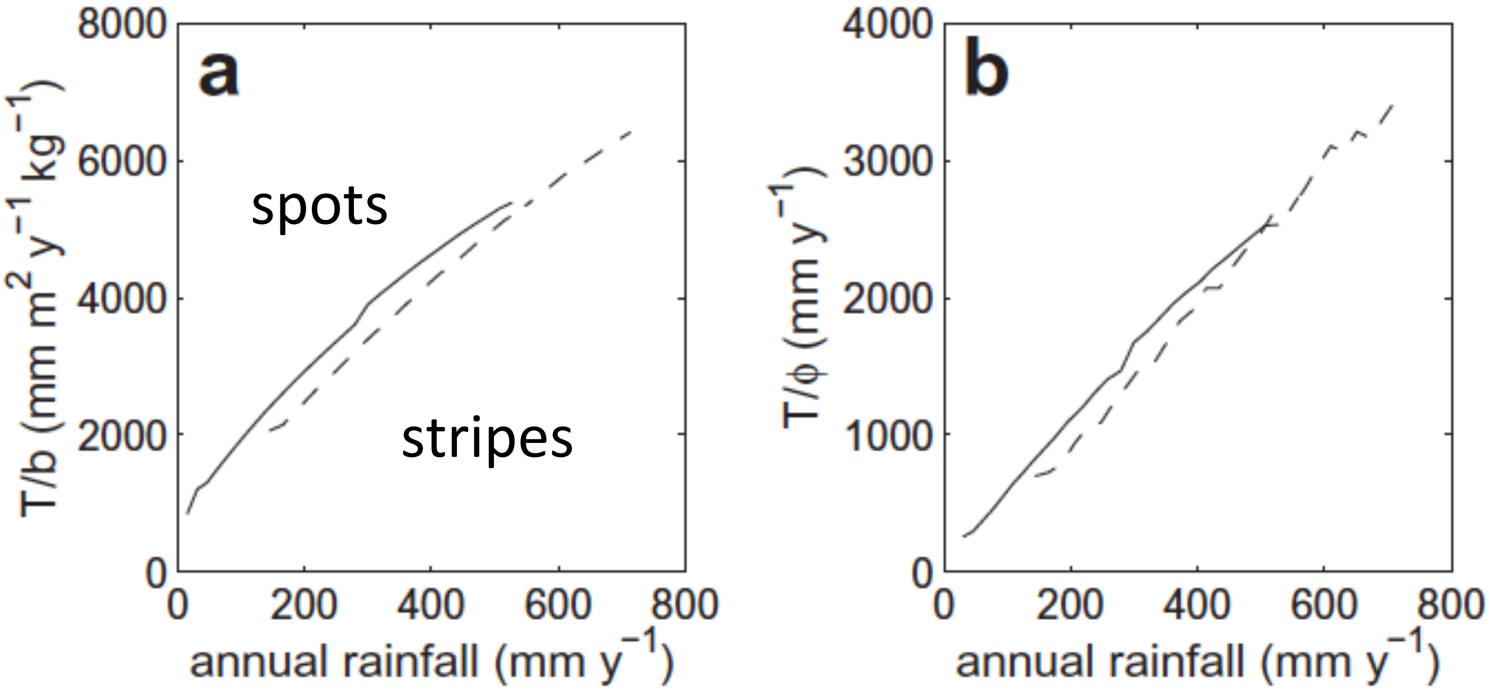
Dekker et al, Global Change Biology 2007, Biogeosciences 2010



Evapotranspiration differences between different patterns

Baudena et al, Advances Water Resources 2013

Effects on transpiration fluxes



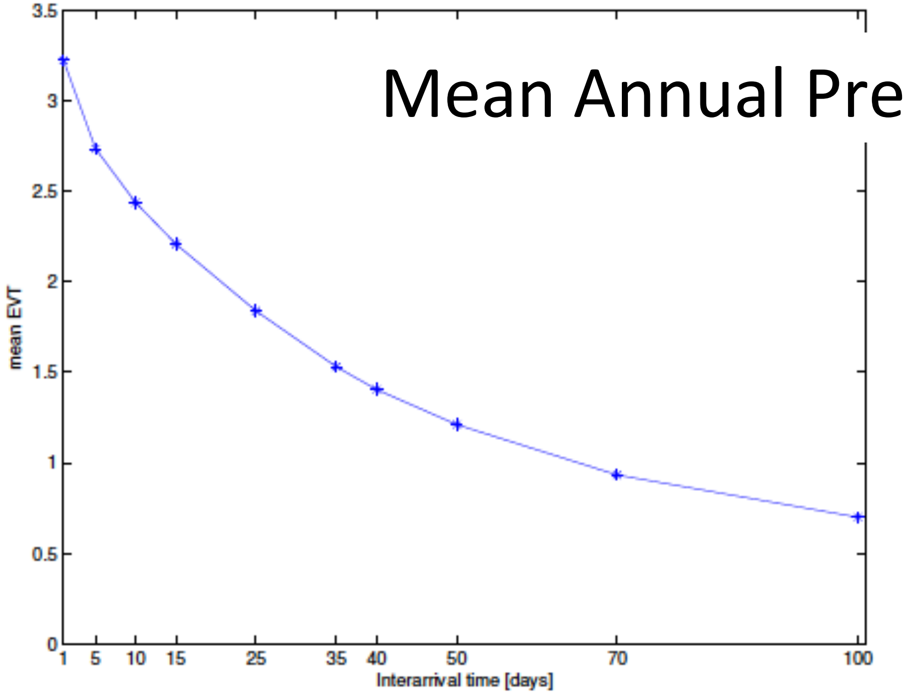
Transpiration and evaporation
per unit biomass or unit vegetation cover
in the five days after a rainfall event

Baudena et al., *Advances Water Resources* 2013

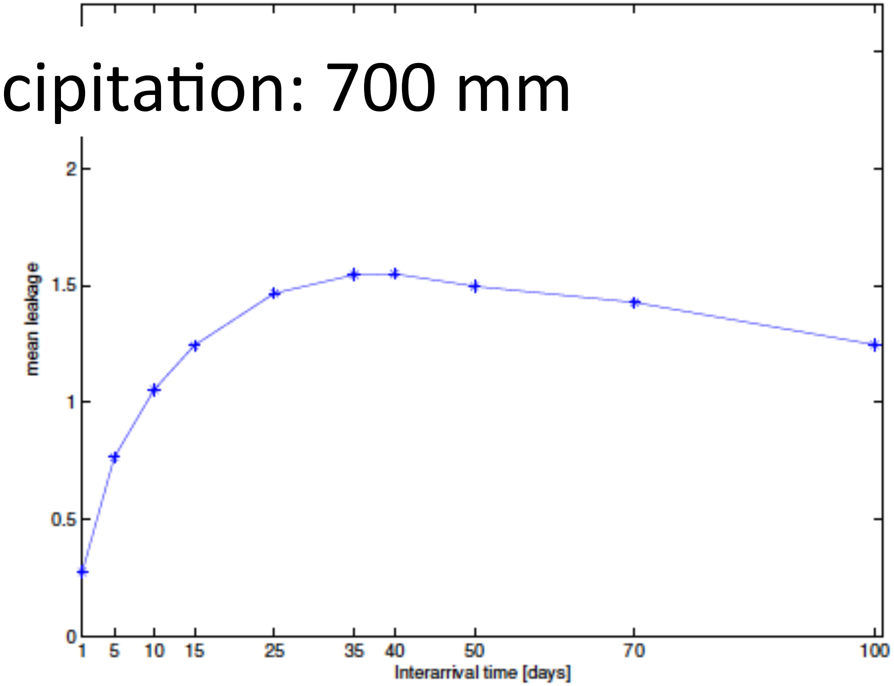
Effects of temporal rainfall intermittency

D’Onofrio et al., in preparation 2015

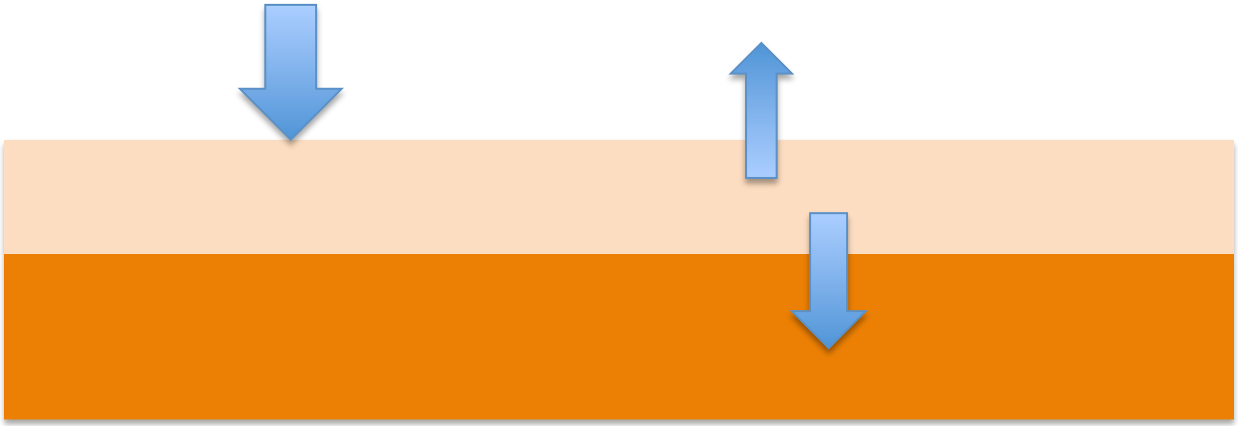
Mean Annual Precipitation: 700 mm

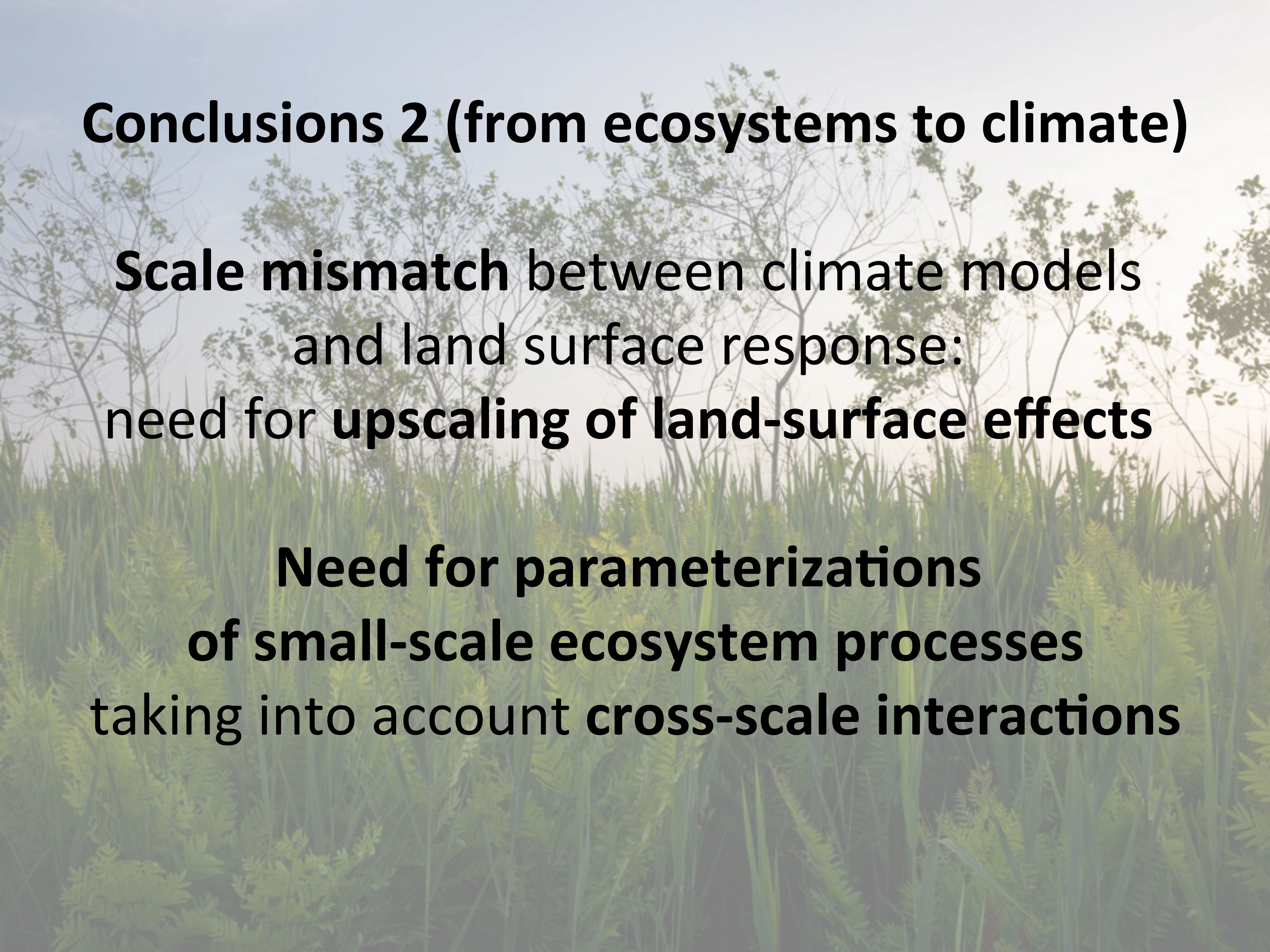


(e) average evapotranspiration mm/day



(g) average leakage mm/day



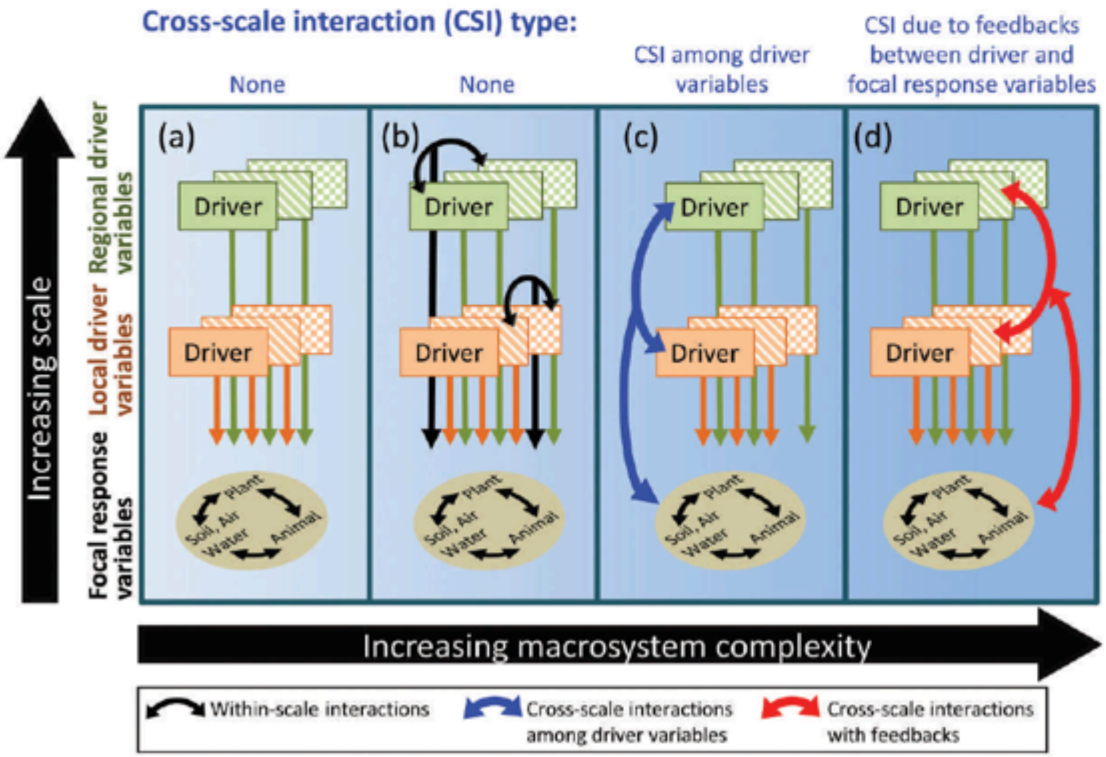


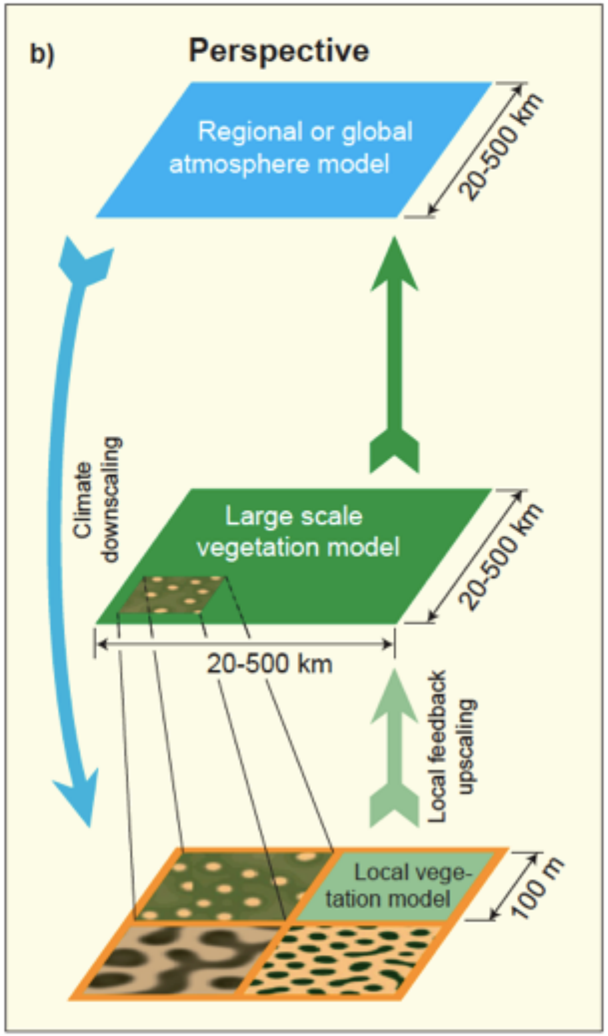
Conclusions 2 (from ecosystems to climate)

Scale mismatch between climate models
and land surface response:
need for **upscaling of land-surface effects**

Need for parameterizations
of small-scale ecosystem processes
taking into account **cross-scale interactions**

A European way to Macrosystems Ecology and cross-scale interactions





Cross-scale interactions

Soranno et al. Frontiers Ecol. Env. 2014

Rietkerk et al., Ecological Complexity 2011

ECOPOTENTIAL: Improving future ecosystem benefits through Earth Observations

Starting date: 1st of June 2015, Duration: 4 years

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

ECOPOTENTIAL:

- Focus on ecosystem services
- Use EO data (satellite and in situ)
- Build products and make them widely available
- Build models capable of including EO data
- Assess the current state and estimate the future evolution of ecosystem services
- Define policy options and the requirements of future protected areas
- Develop capacity building strategies
- Make all results available to the community, contributing to GEO and GEOSS

European
Commission

ECOPOTENTIAL Participants

ecp

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exploitation & conservation

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InBIO RESEARCH NETWORK
Biodiversity and Evolutionary Biology

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FORTH
Foundation for Research & Technology - Hellas

EPFL
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

אוניברסיטת בן-גוריון בנגב
Ben-Gurion University of the Negev

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ISPRA

POLITECNICO
DI MILANO

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Starlab
Living Science

Earth and Environmental Science

museum für
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berlin

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Biodiversity Research (iDiv)
Halle-Jena-Leipzig

CESBIO

UNESCO

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THE LONDON SCHOOL
OF ECONOMICS AND
POLITICAL SCIENCE

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| Science

ETH zürich

Environmental and Water Agency of Andalusia
REGIONAL MINISTRY OF ENVIRONMENT AND SPATIAL PLANNING

ueb
UBO
université de bretagne
occidentale

Focus on Protected Areas

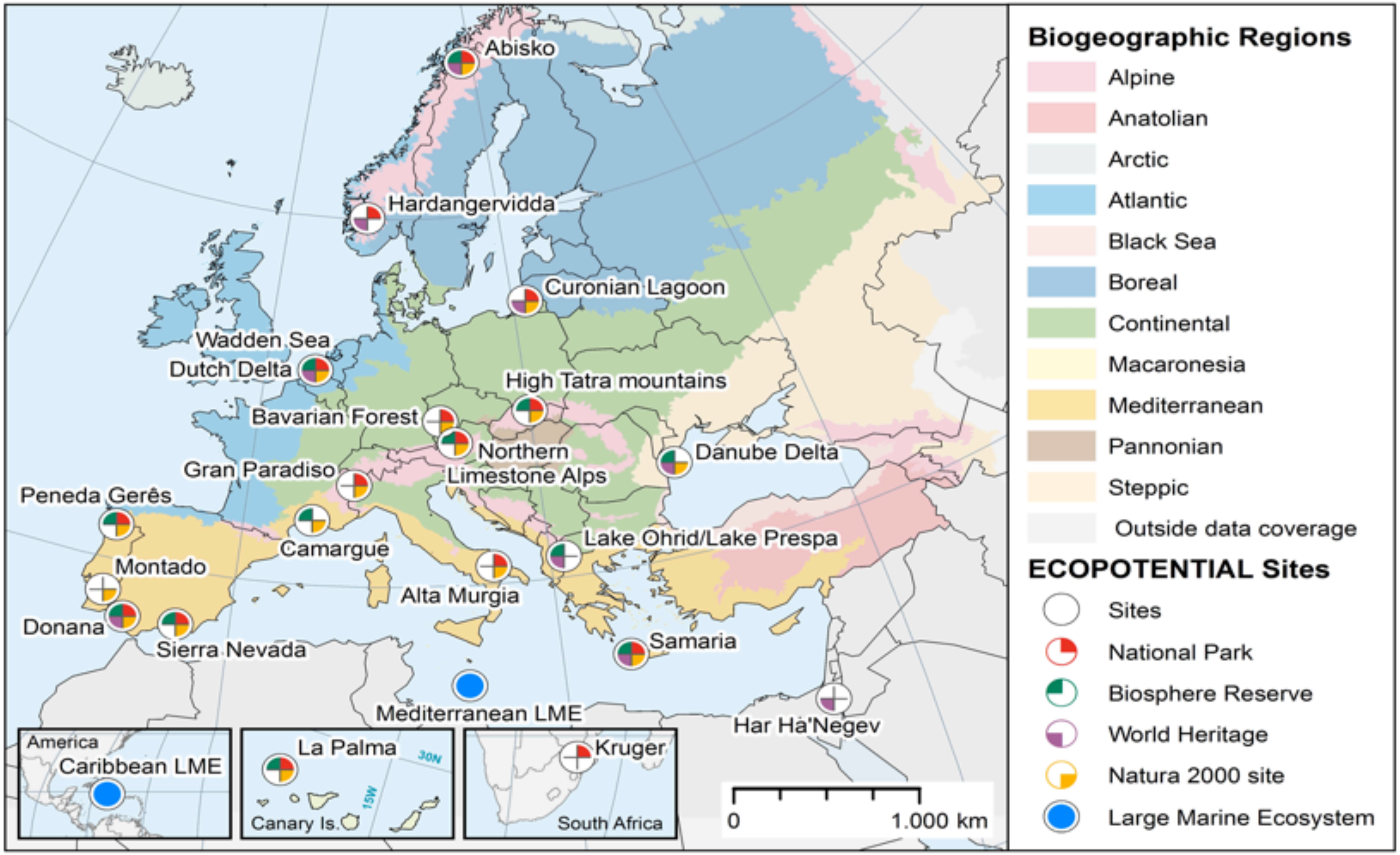
ECOPOTENTIAL sites cover terrestrial **protected areas** over:

- spatial gradients in Europe
- climatic gradients in Europe
- biogeographical regions in Europe
- major ecosystem types
- and one outlayer ecosystems of iconic importance (Kruger NP, SA) for cross-continental implementation

In addition **two Large Marine Ecosystems** are included:

- Mediterranean Sea
- Carribean Sea

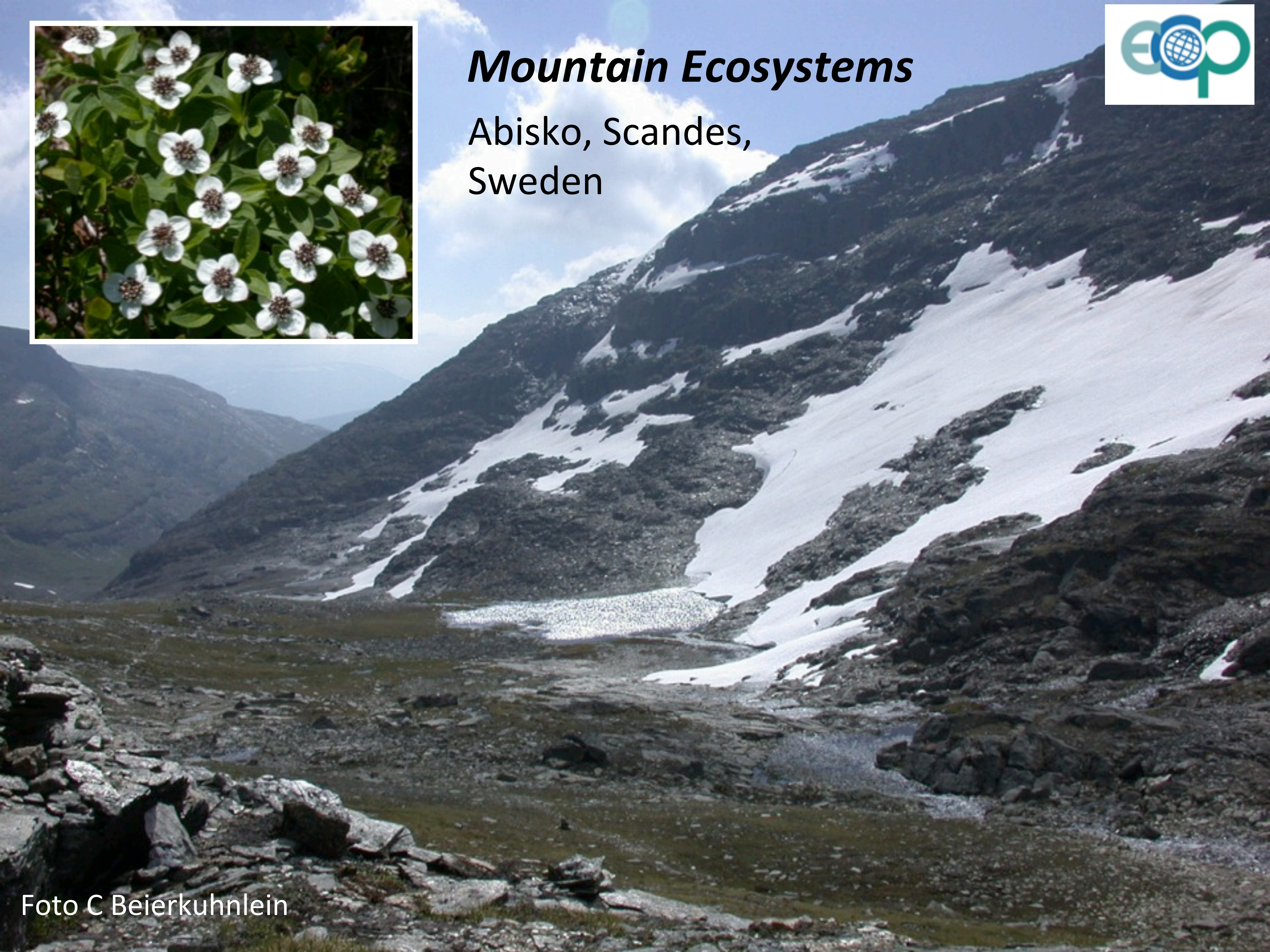
Location and protection status of the Protected Areas in ECOPOTENTIAL and European biogeographic regions



Mountain Ecosystems

Gran Paradiso,
Italian Alps

Foto C Beierkuhnlein



Mountain Ecosystems

Abisko, Scandes,
Sweden

Foto C Beierkuhnlein

Arid / Semiarid Ecosystems

Negev Desert,
Israel

Foto C Beierkuhnlein

Arid / Semiarid Ecosystems

Kruger,
South Africa

Foto Hansm auf wikivoyage shared

Coastal Ecosystems

Danube Delta,
Romania

Foto Elena Pleskevich Wikimedia Commons

Coastal Ecosystems

Camargue,
France

bruno monginoux / www.photo-paysage.com

UNESCO
United Nations
Educational, Scientific and
Cultural Organization

Intergovernmental
Oceanographic
Commission

Large Marine Ecosystems: Mediterranean

Cinque Terre - Vernazza,
Mediterranean Sea

Foto n-tv.de
picture-alliance/dpa-tmn

United Nations
Educational, Scientific and
Cultural Organization

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Large Marine Ecosystems: Caribbean

ECOPOTENTIAL: Ecosystem Services

Gran Paradiso (CNR)	Land use changes; climate change; natural system modifications; human disturbance.	Nutrition; materials from plants; water; mediation of flows and flood protection; maintenance of physical and biological conditions; gene pool protection; climate regulation; scientific, educational, heritage, cultural, aesthetic values.
Sierra Nevada (UGR)	Climate change; biogeochemical cycle changes; land use changes.	Water; feeding; landscape; geological materials; genetic pool; recreational activities; traditional knowledge; dampening of perturbations; water cycle regulation.
High Tatra (UNEP)	Mass tourism and tourism and sports infrastructure; human settlements (private housing); air pollution; environmental damages caused by historic mismanagement of land.	Surface water; water flow maintenance; flood protection; genetic materials from all biota; wood fuel; mass stabilisation and control of erosion rates; pollination and seed dispersal; soil formation and composition; climate regulation; wild plants and animals; scientific, educational, heritage, cultural, aesthetic values.
Samaria (FORTH)	Overgrazing and uncontrolled fires; poaching and uncontrolled abstraction of endemic species of flora; massive touristic flow.	Water; cultivated crops; reared animals; wild animals; mass stabilisation and control of erosion rates; pollination and seed dispersal; nursery populations and habitats; decomposition and fixing processes; experiential use of plants, animals and land-/seascapes; cultural benefits.
Danube Delta (UBC)	Fisheries; hunting; tourism; eutrophication; water transport.	Local climate and water flow regulation; water purification; nutrient and erosion regulation; pollination; energy (biomass); fodder; livestock; fibre; timber; wood; fisheries; aquaculture; wild foods; biochemicals/ medicine; freshwater; tourism; knowledge systems; religious and spiritual services; cultural/natural heritage.

ECOPOTENTIAL: Best use of EO and field data
Essential Variables for Ecosystems

Essential Biodiversity Variables	Essential Climate Variables	Essential Ocean Variables	Essential Water Variables	Essential Social and Environmental Variables
Species Composition	Precipitation	Sea Surface Temperature	Runoff/streamflow/ river discharge	Population density
Functional groups traits	Temperature	Ocean acidification	Lakes/ reservoir levels	Resource use and management
Ecosystem extent & structure	Irradiance	Zooplankton composition	Glaciers front	Natural-areas accessibility

ECOPOTENTIAL thus aims to **develop widely applicable monitoring indicators for ecosystem status and trends, biodiversity change and ecosystem services** (including their socio-economic demand), creating a unified EV framework. This necessitates extending the already developed concepts of EBVs, ECVs etc. and include indicators that capture the major dimensions of ecosystem services supply and demand. Such indicators include,

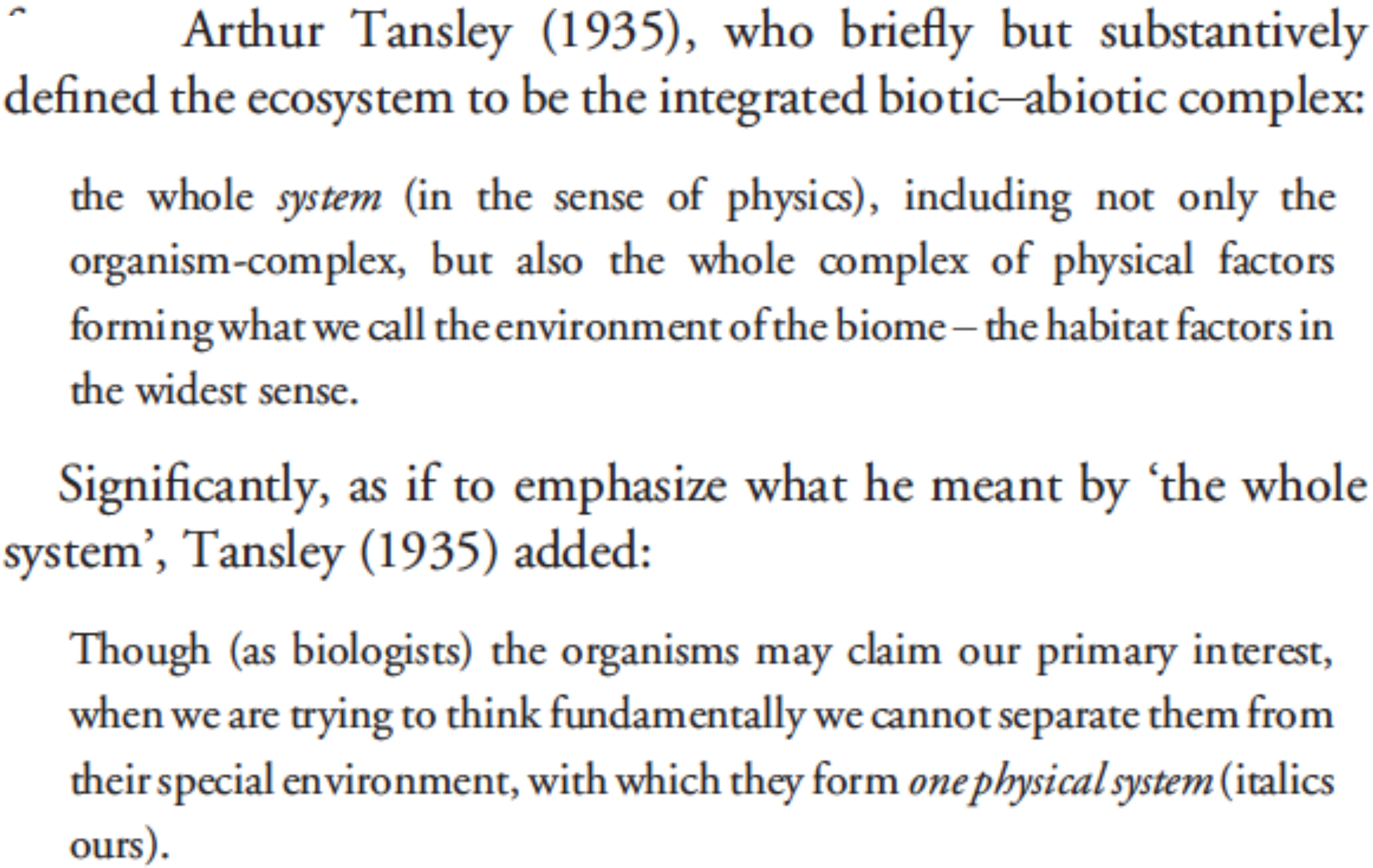
A suite of remote-sensing and *in-situ* observation data will also be used to develop and define Essential Ecological and Environmental Protection Descriptors (EEPD) and the indicators of the current quality status in the PAs to be studied. To these indicators belong requirements such as: level of (bio)diversity (as being relevant for e.g. the description of the Good Environmental Status (GES) as used in the Marine Strategy Framework Directive (MSFD)), level of protection of key-species, improvement in numbers of (certain) species, habitat diversity, (minimal) size of the area, connectivity with other (protected) areas, and habitat quality. In particular, the parameters "habitat diversity", "size of the area" and "connectivity with other areas" will be mainly determined through EO data.

ECOPOTENTIAL will develop models using Essential Variables and able to incorporate Remote Sensing and field information

Data will be assimilated into widely used process-based ecosystem modelling tools

Future projections (including uncertainty)

ECOPOTENTIAL Conceptual aspects: back to the future

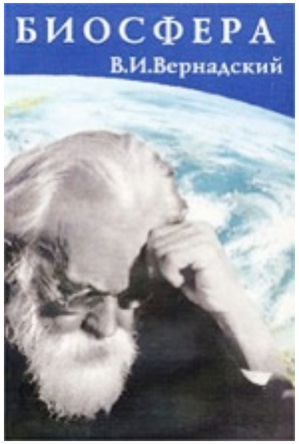


Arthur Tansley (1935), who briefly but substantively defined the ecosystem to be the integrated biotic–abiotic complex:

> the whole *system* (in the sense of physics), including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment of the biome – the habitat factors in the widest sense.

Significantly, as if to emphasize what he meant by ‘the whole system’, Tansley (1935) added:

> Though (as biologists) the organisms may claim our primary interest, when we are trying to think fundamentally we cannot separate them from their special environment, with which they form *one physical system* (italics ours).



Ecosystems as complex adaptive systems actively interacting with the physical environment

Thank you for your attention