

Agronomie Globale & Climat

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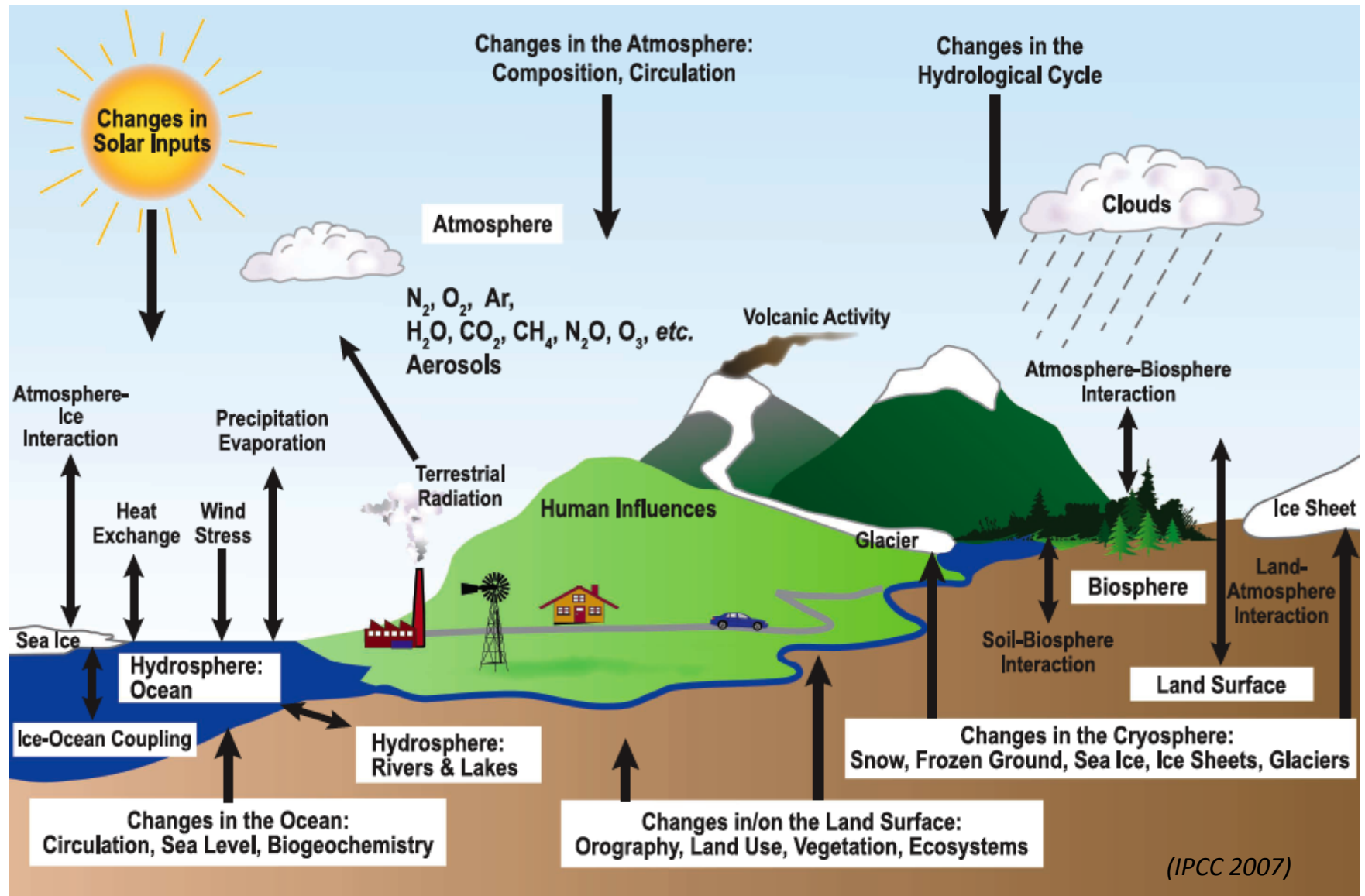
Pourquoi les climatologues s'intéressent-ils à l'Agronomie?

Quelles sont les méthodes pour évaluer les impacts du changement climatique sur l'agriculture, à grande échelle ? Comment peut-on progresser?

Partie I

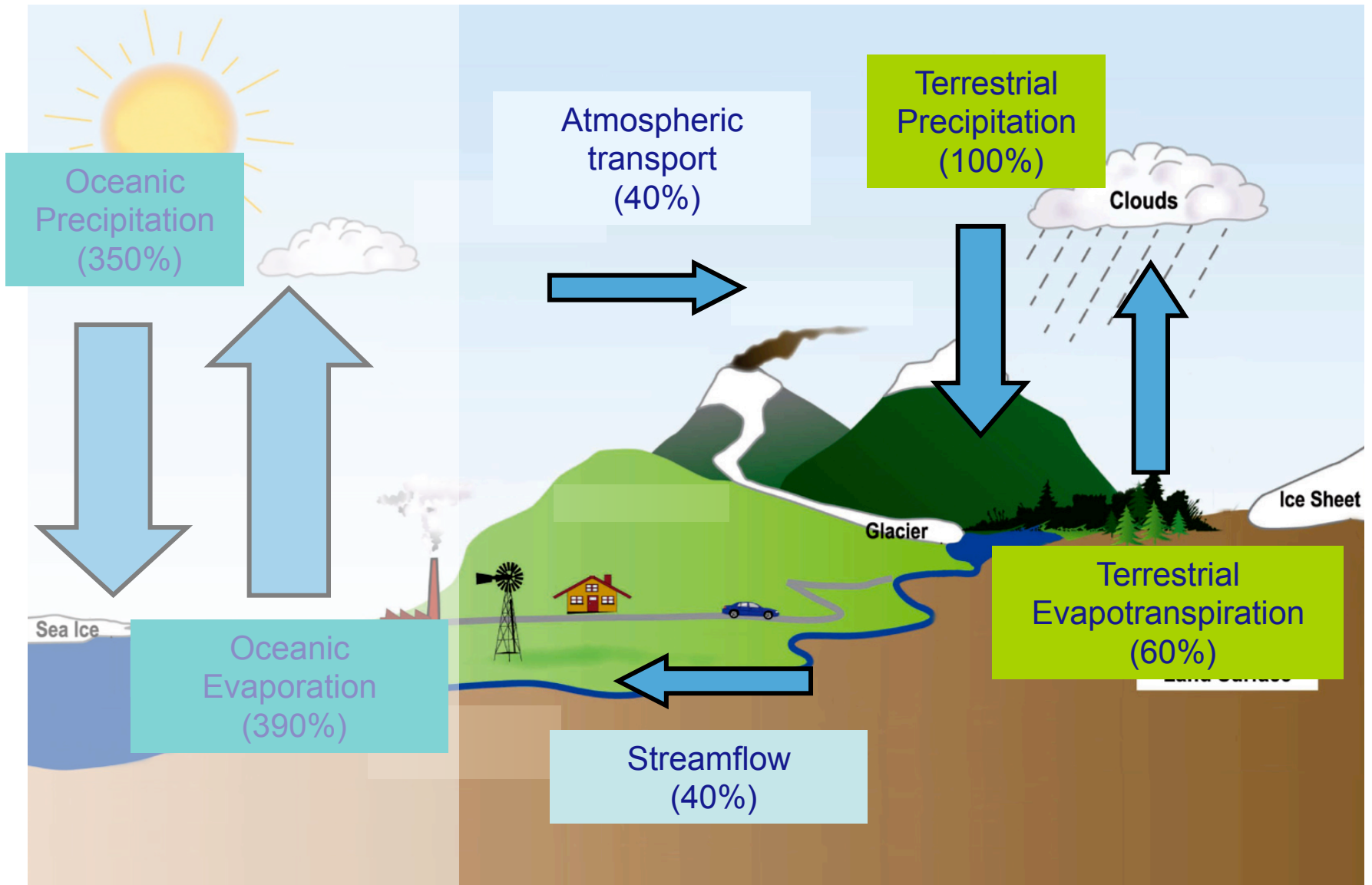
Pourquoi les climatologues
s'intéressent-ils à l'Agronomie ?

Le système climatique: des composantes et des interactions complexes à mettre en équation



La Biosphère dans le système
climatique en quelques chiffres
et quelques mécanismes

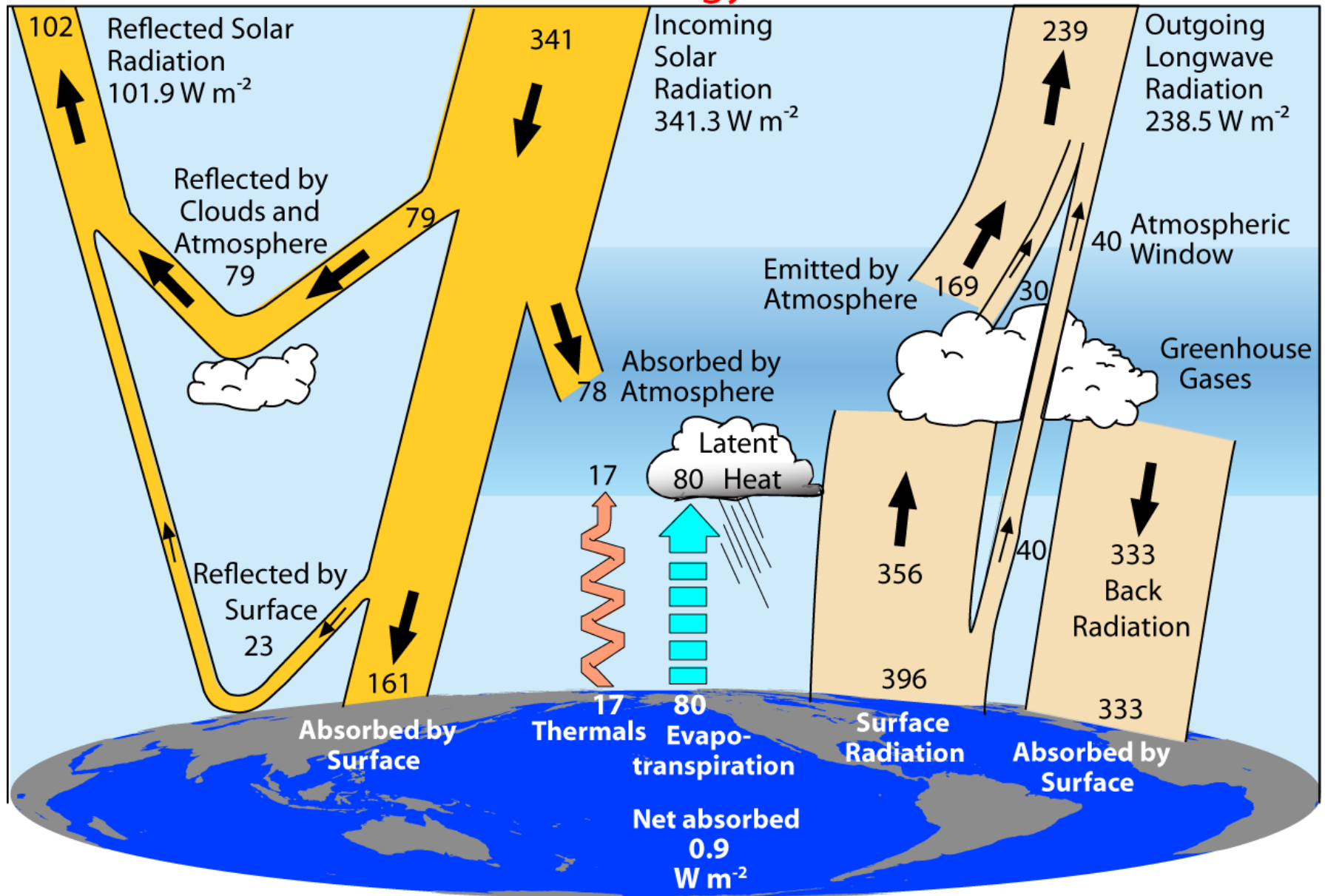
Une participation importante au cycle de l'eau

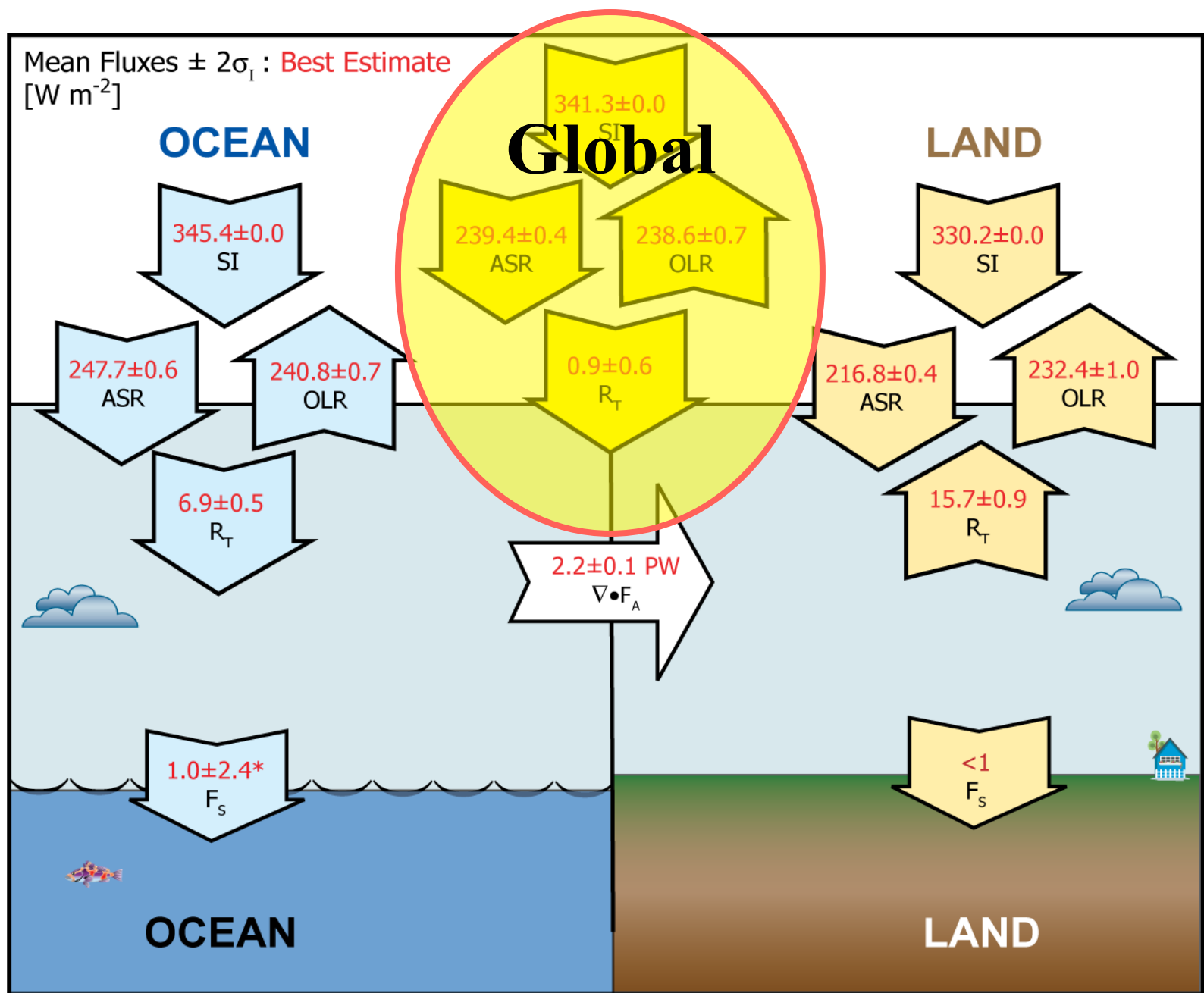


(Flux estimates: Oki and Kanae, Science 2006)

2000-2005 (CERES Period)

Global Energy Flows W m^{-2}

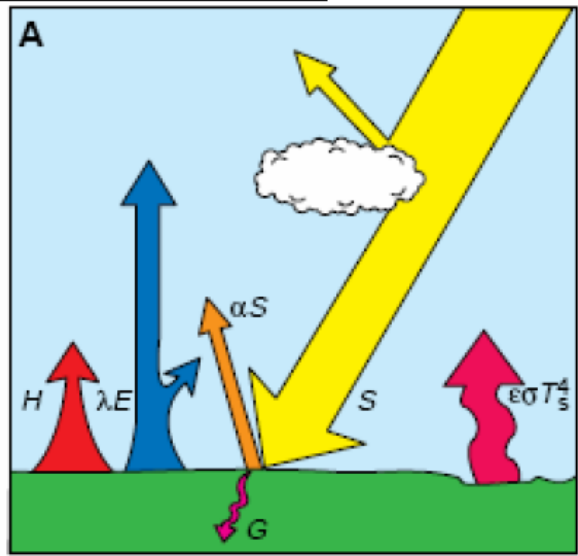




* Values for the net flux into ocean are based on 1996-2003 values from Willis et al. (2004).

CERES period March 2000 to May 2004

A/ Bilan d'énergie à la surface



$$R_n = \underbrace{S(1 - \alpha)}_{\text{courtes } \lambda} + \underbrace{L_w - \varepsilon \sigma T_s^4}_{\text{grandes } \lambda}$$

Energie radiative absorbée par la surface et disponible pour un transfert en d'autres formes d'énergie

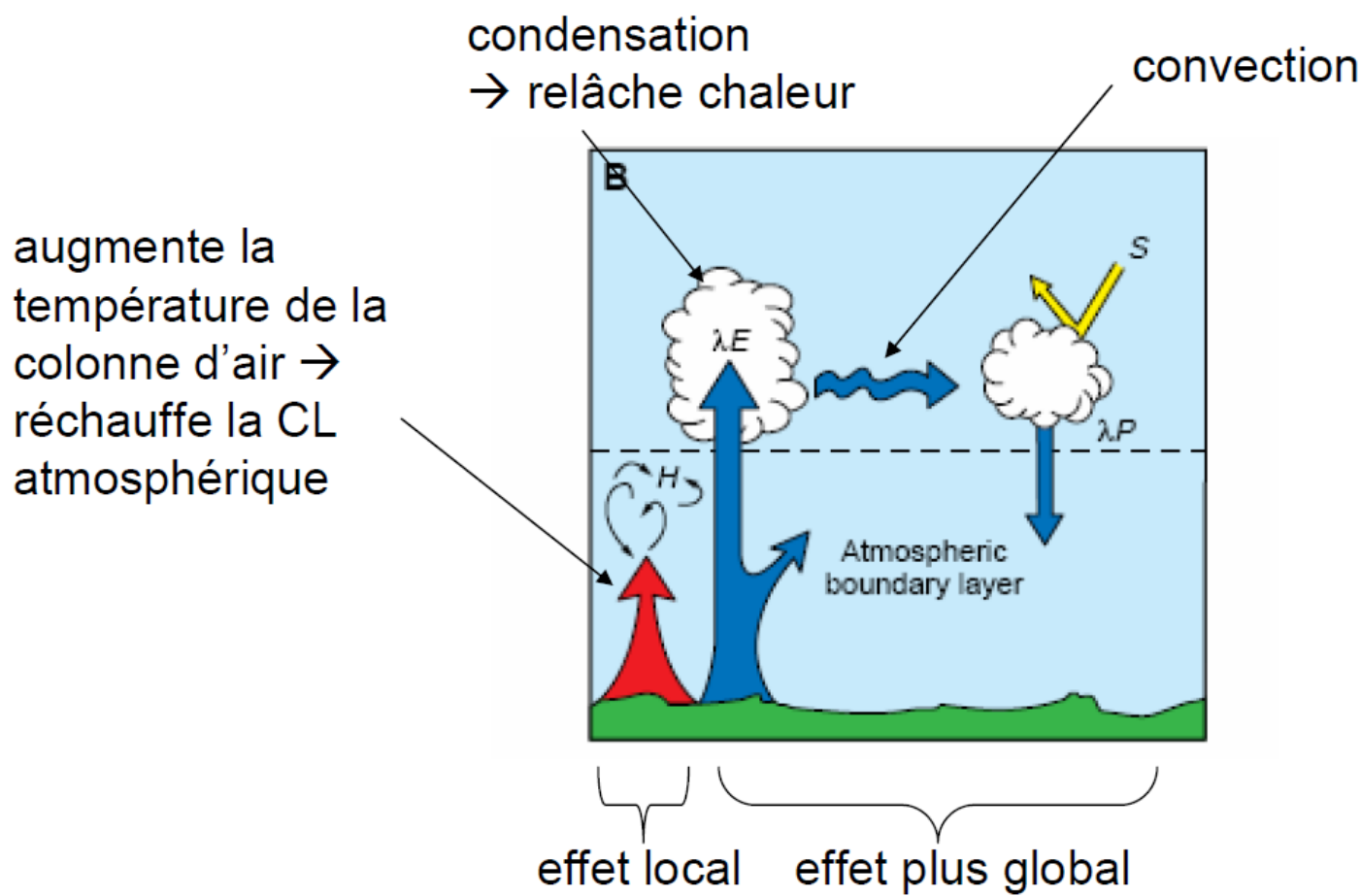
↓

$$R_n = \underbrace{G + H + \lambda E}_{\text{flux non radiatifs}}$$

- R_n = rayonnement net
- S = rayonnement incident
- α = albedo
- ε = émissivité
- σ = constante de S-B
- $T_s = T_{\text{surface}}$

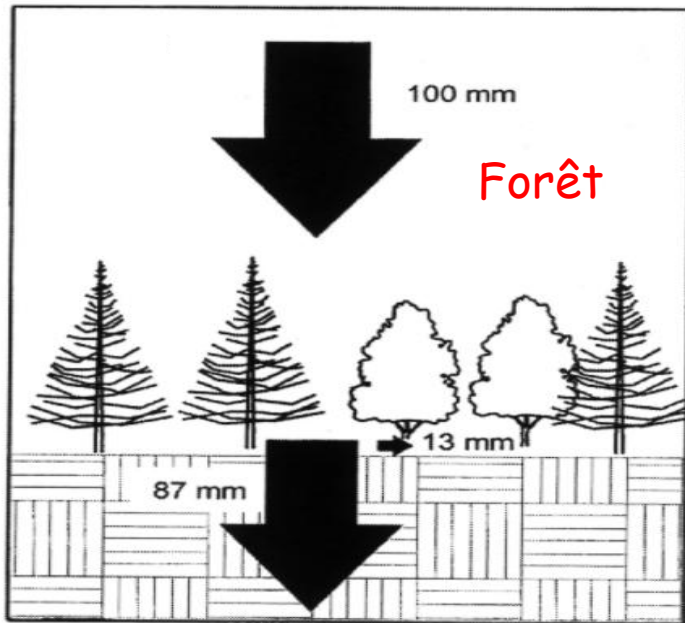
- G = flux de conduction
- H = flux de chaleur sensible
- E = évapotranspiration
- λ = chaleur latente de vaporisation

B/ Effet des flux de chaleur sur la circulation atmosphérique

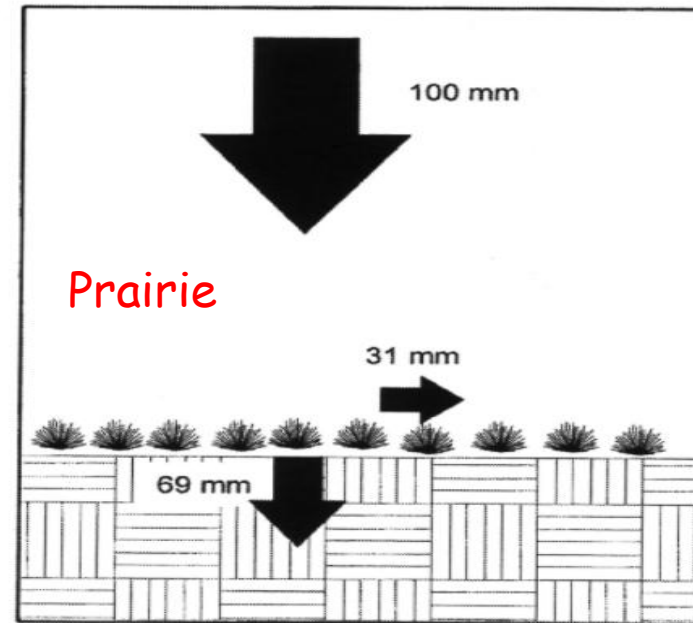


λE = énergie équivalente à l'évaporation + transpiration

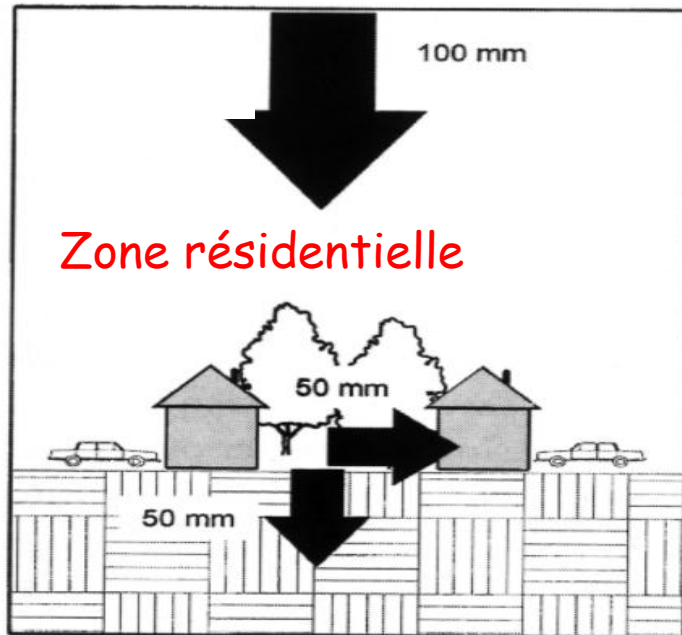
Forest



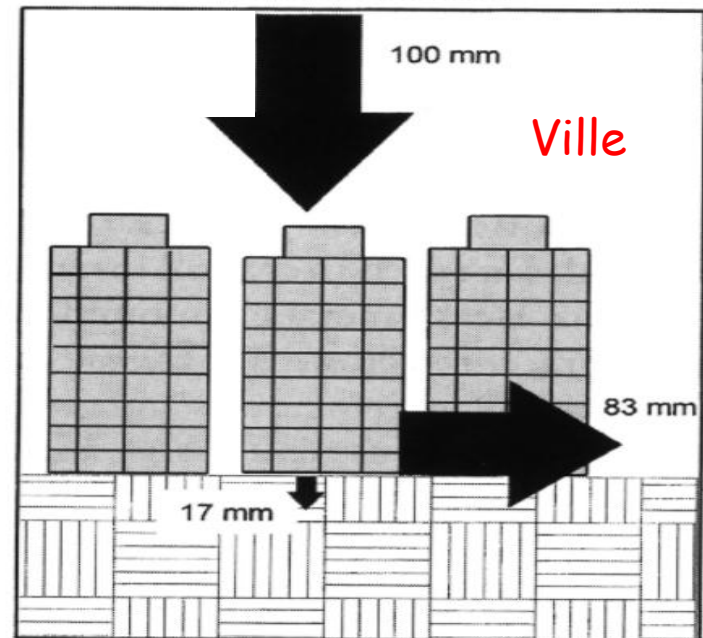
Pasture



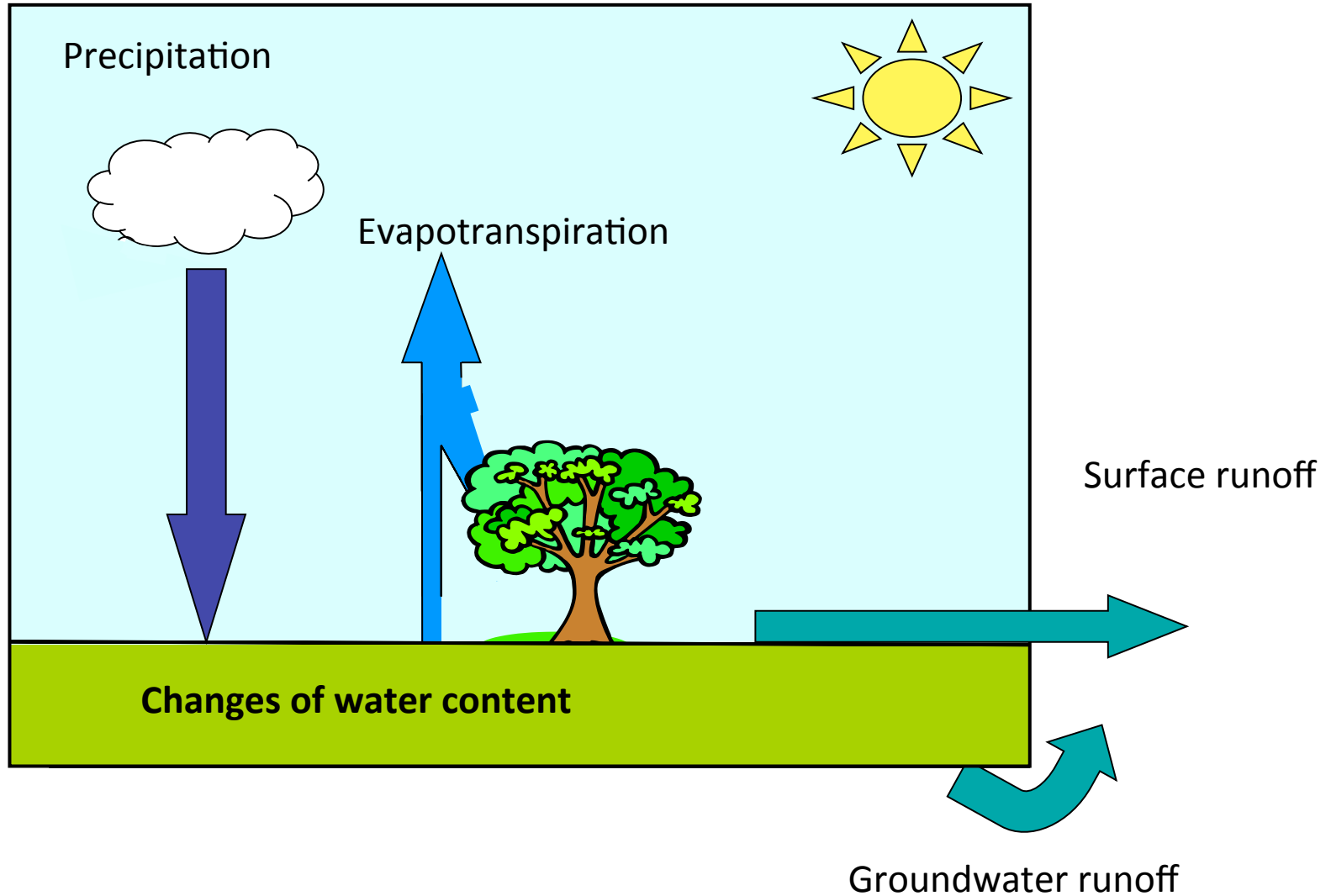
Residential



Business District



Land water balance



Une variabilité spatiale importante des caractéristiques de la biosphère



Une variabilité temporelle importante des caractéristiques de la biosphère

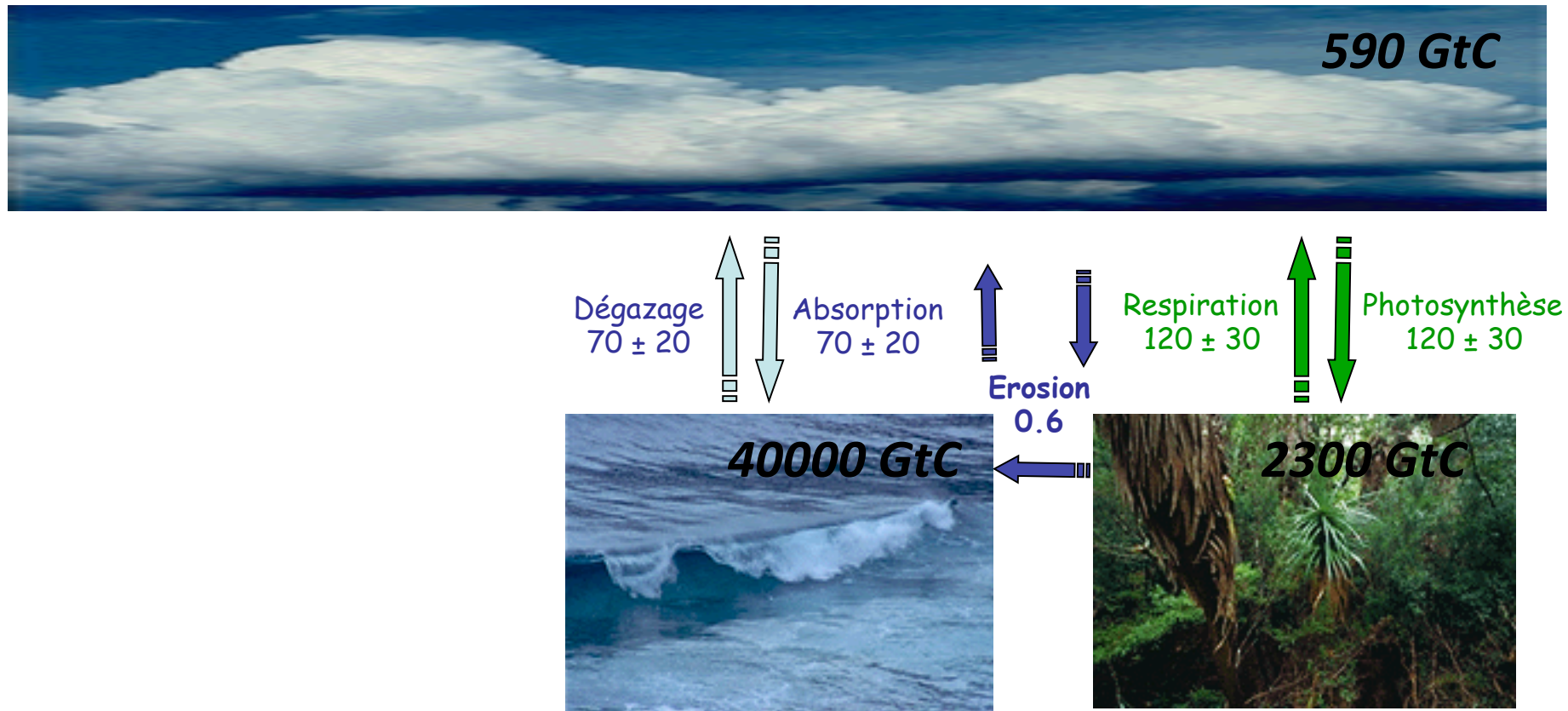
Albédo ~ 12 à 20%



Albédo > 60%



Le bilan global «naturel» du CO_2 en GtC an^{-1} ($1 \text{ GtC} = 10^{15} \text{ gC}$)

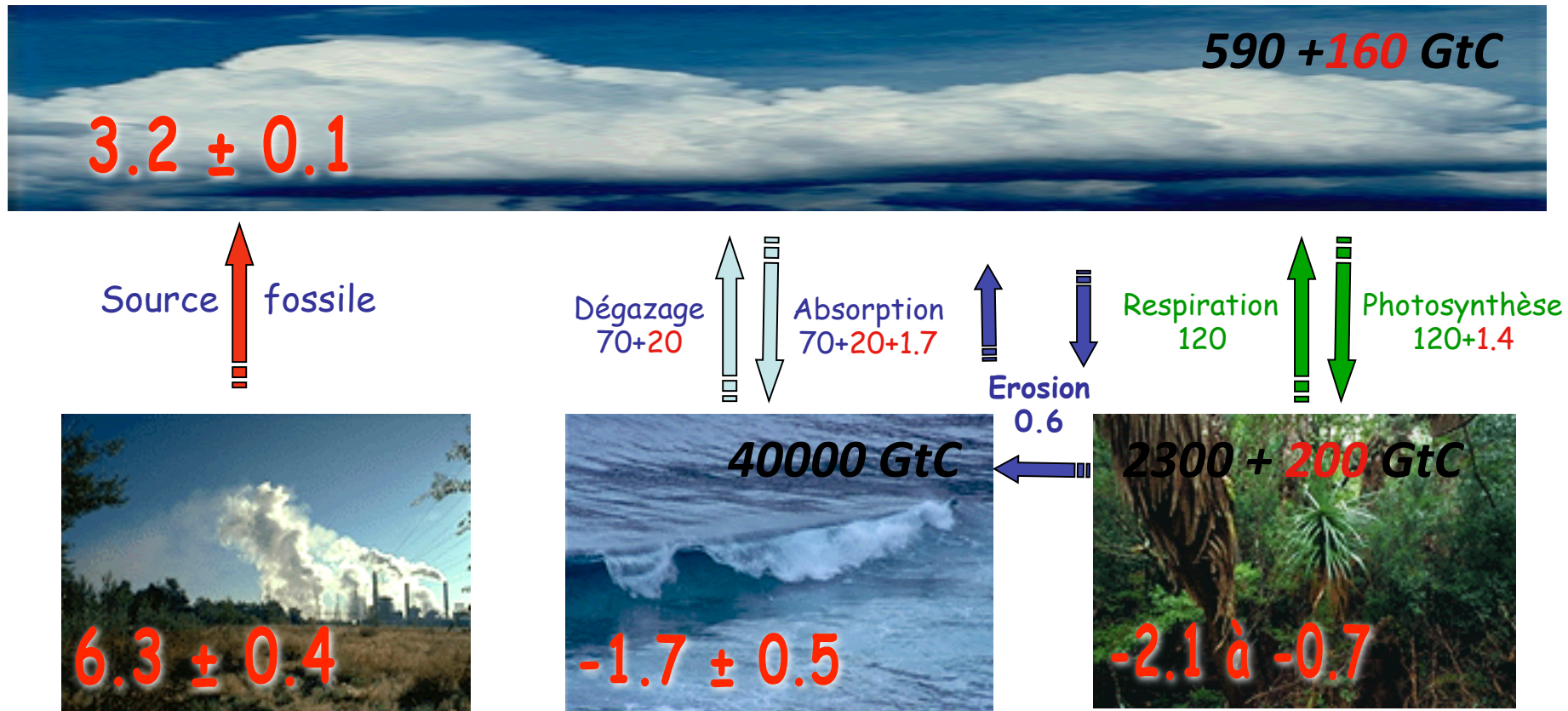


Flux annuels pré-industriels

Stocks moyens réservoirs

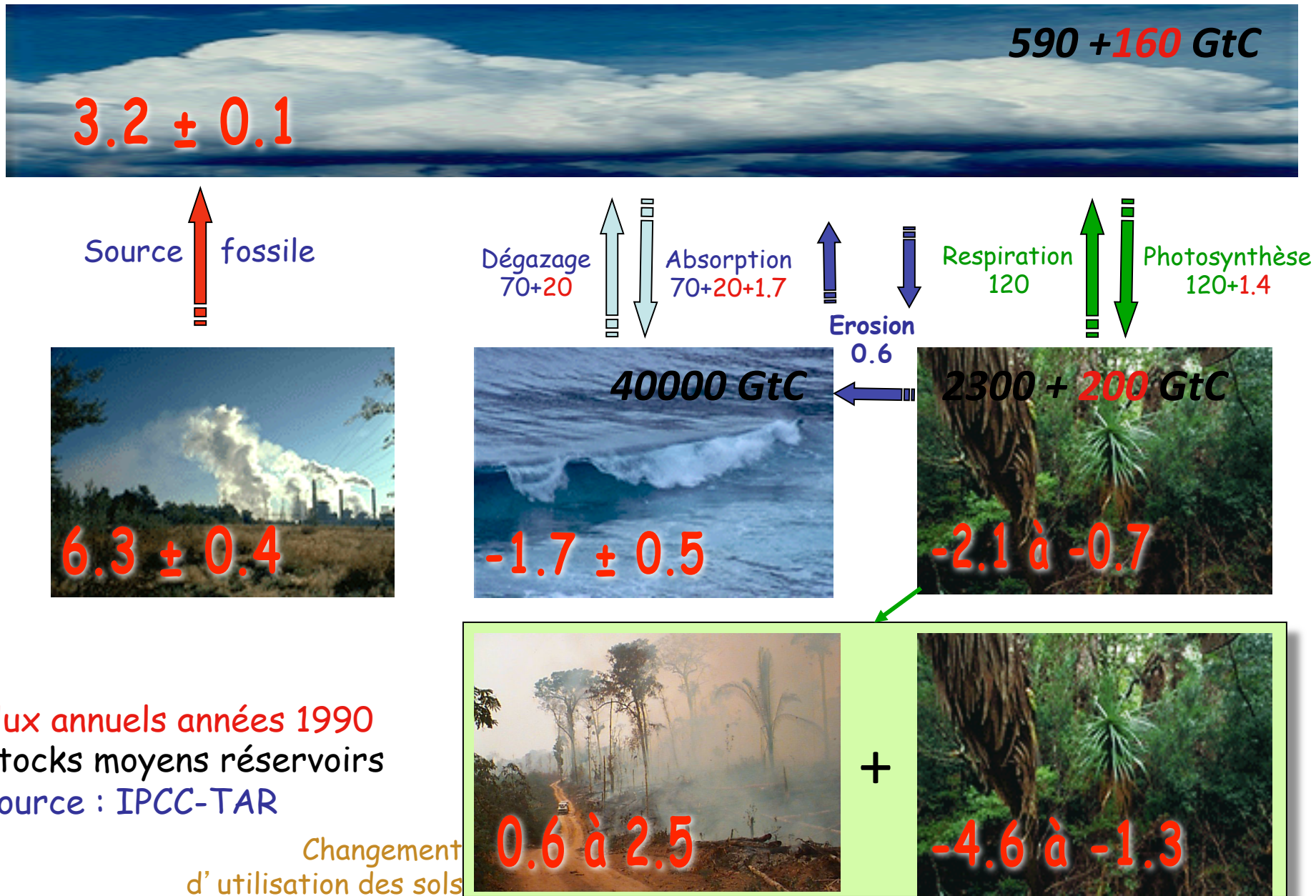
Source : IPCC-TAR

Le bilan global actuel du CO_2 en GtC an^{-1} ($1 \text{ GtC} = 10^{15} \text{gC}$)



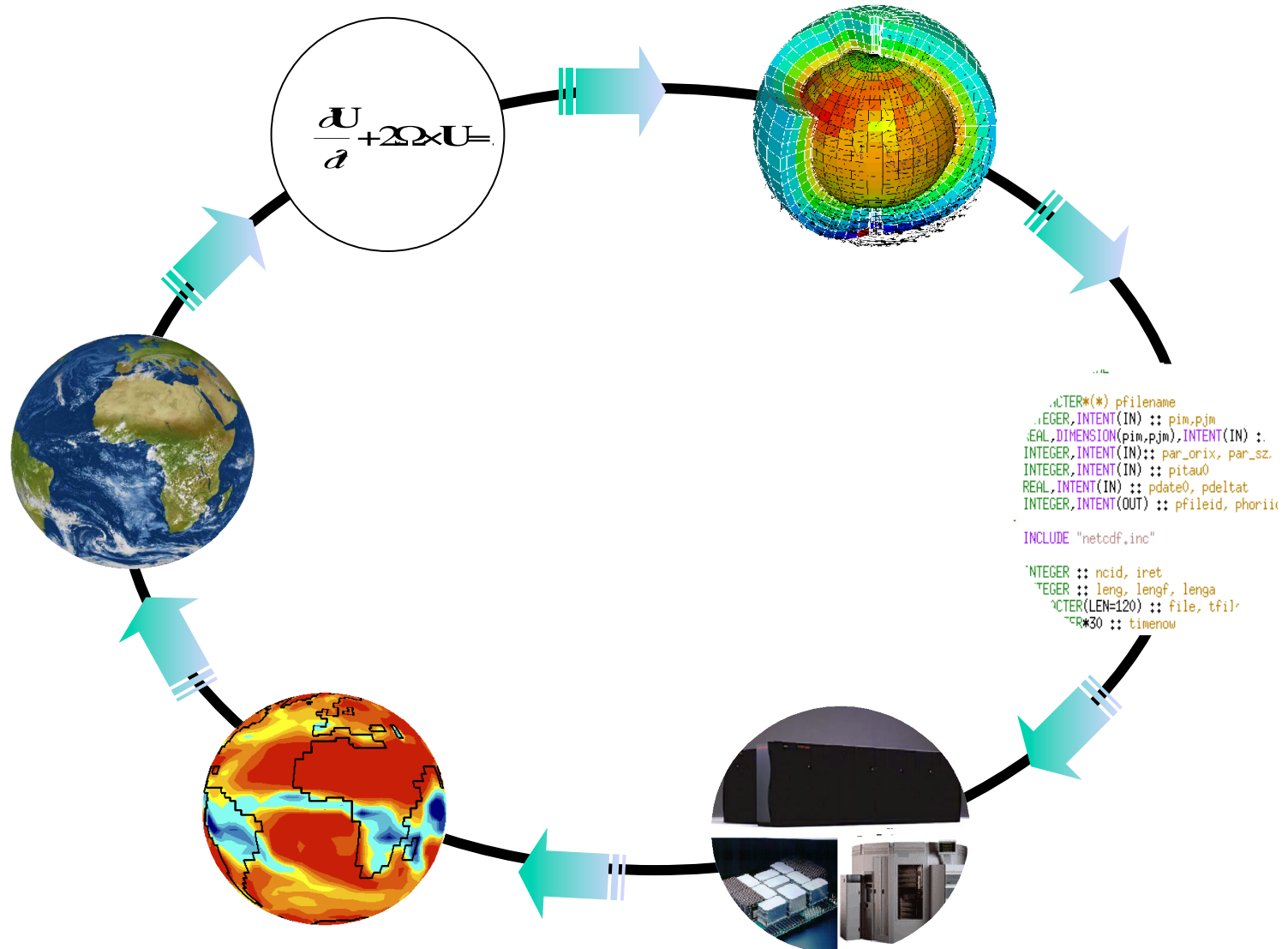
Flux annuels années 1990
Stocks moyens réservoirs
Source : IPCC-TAR

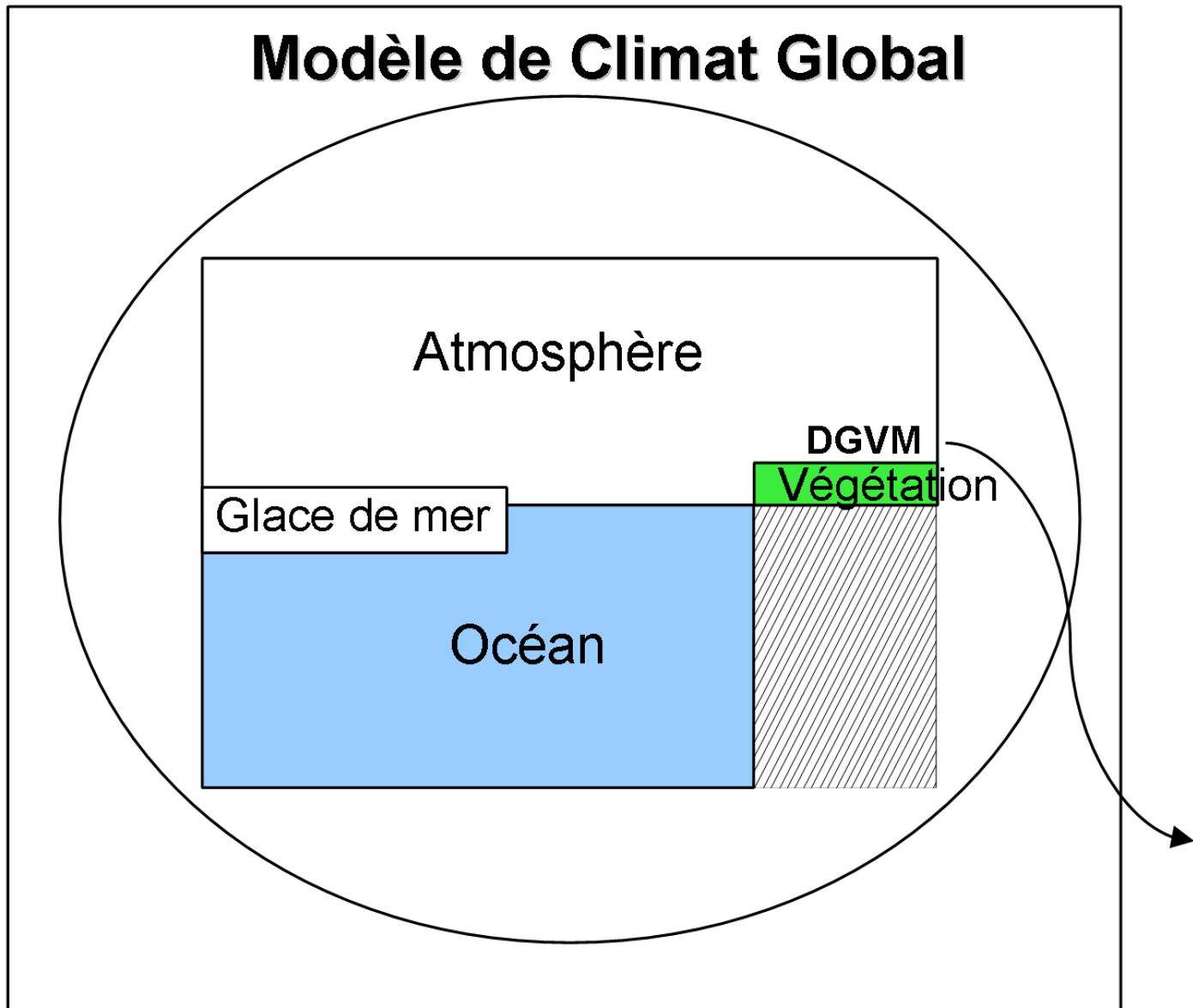
Le bilan global actuel du CO₂ en GtC an⁻¹ (1 GtC = 10¹⁵gC)



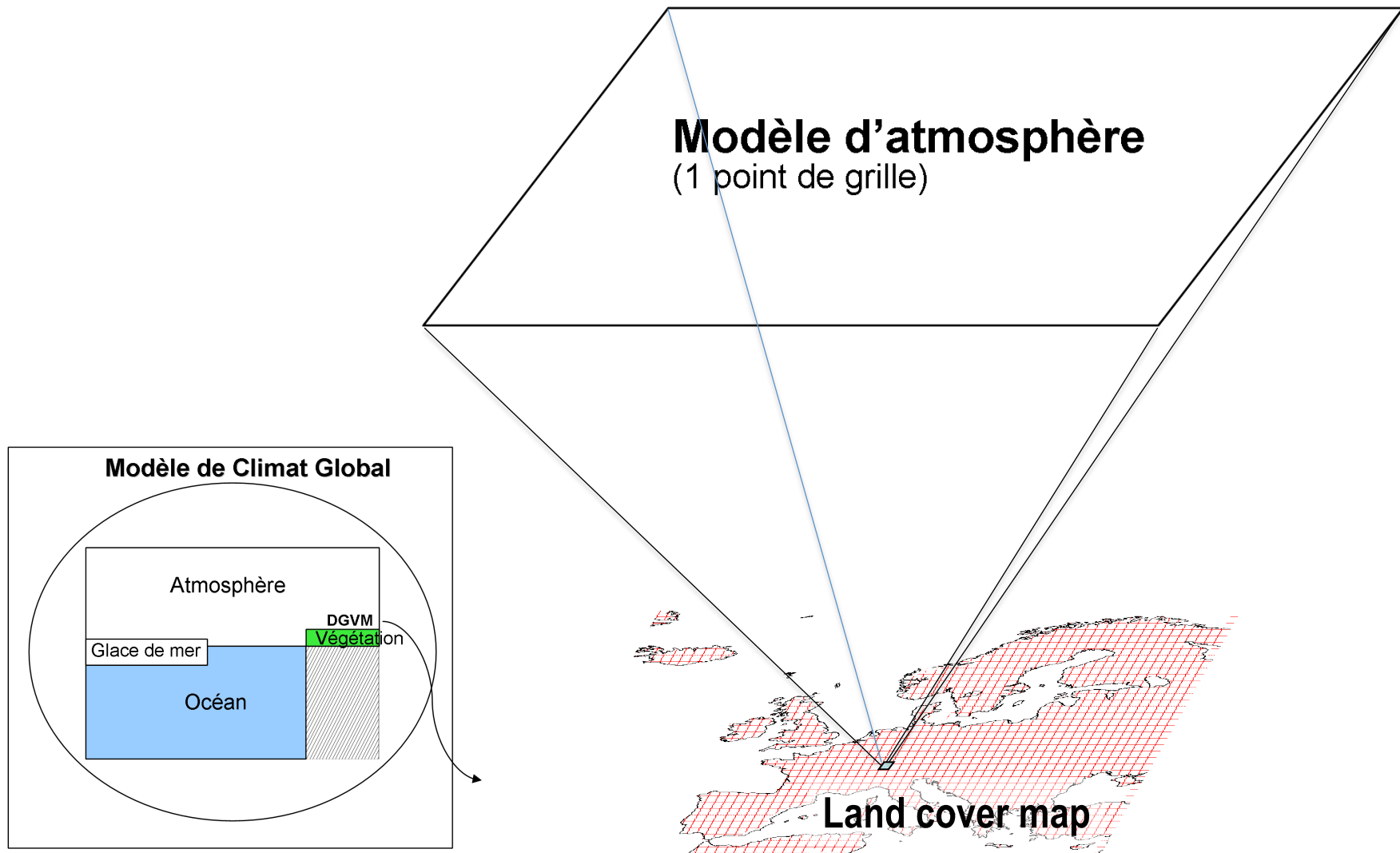
La Modélisation

Comment construit-on un modèle ?

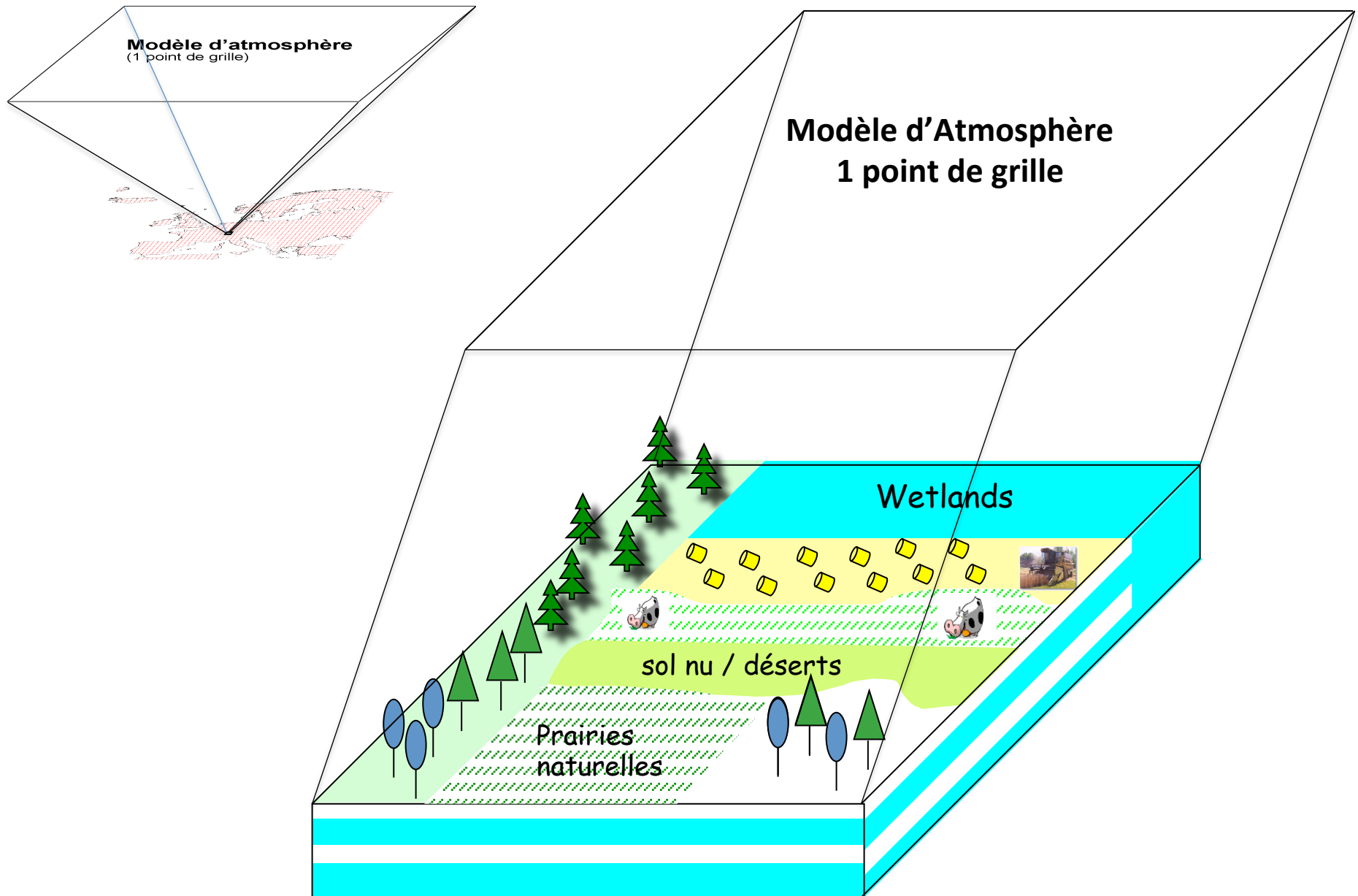




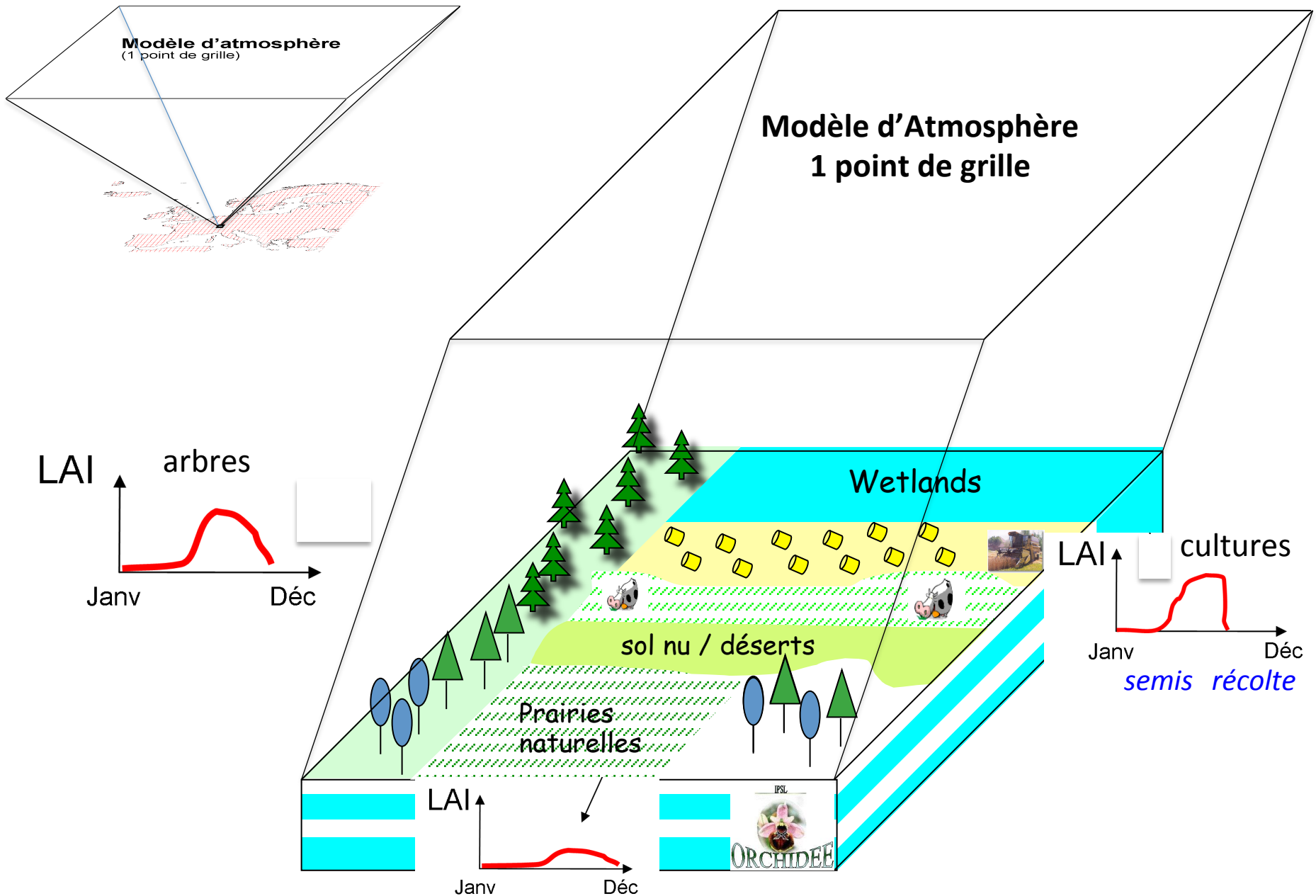
... la surface vue par l'atmosphère en un point de grille ...



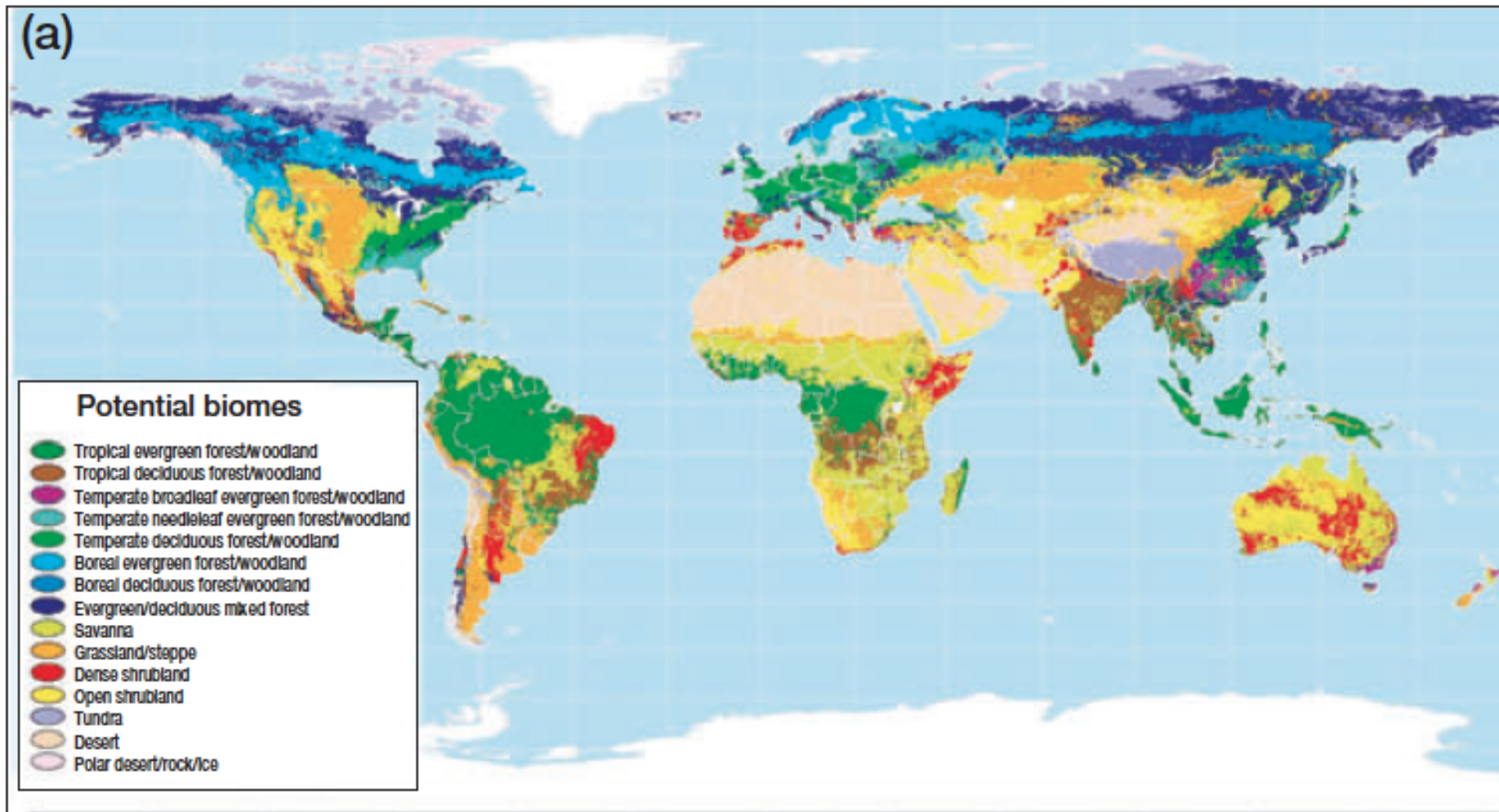
... regroupe une mosaïque d'écosystèmes représentés de façon simplifiée ...



... l'une des variables les plus importantes à bien représenter étant ... **le LAI**



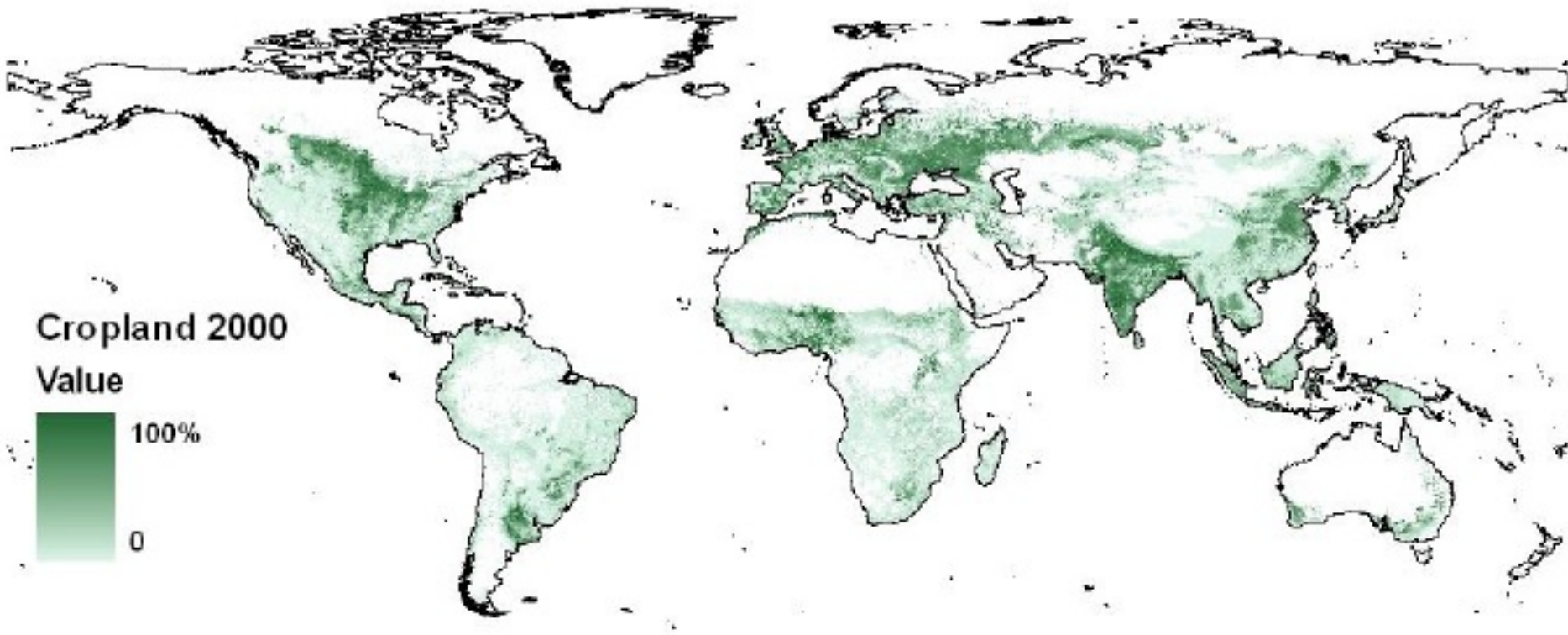
Végétation Potentielle



MAIS

**~47 millions de km² sont aujourd'hui occupés par l'Homme
soit ~40% des terres émergées**

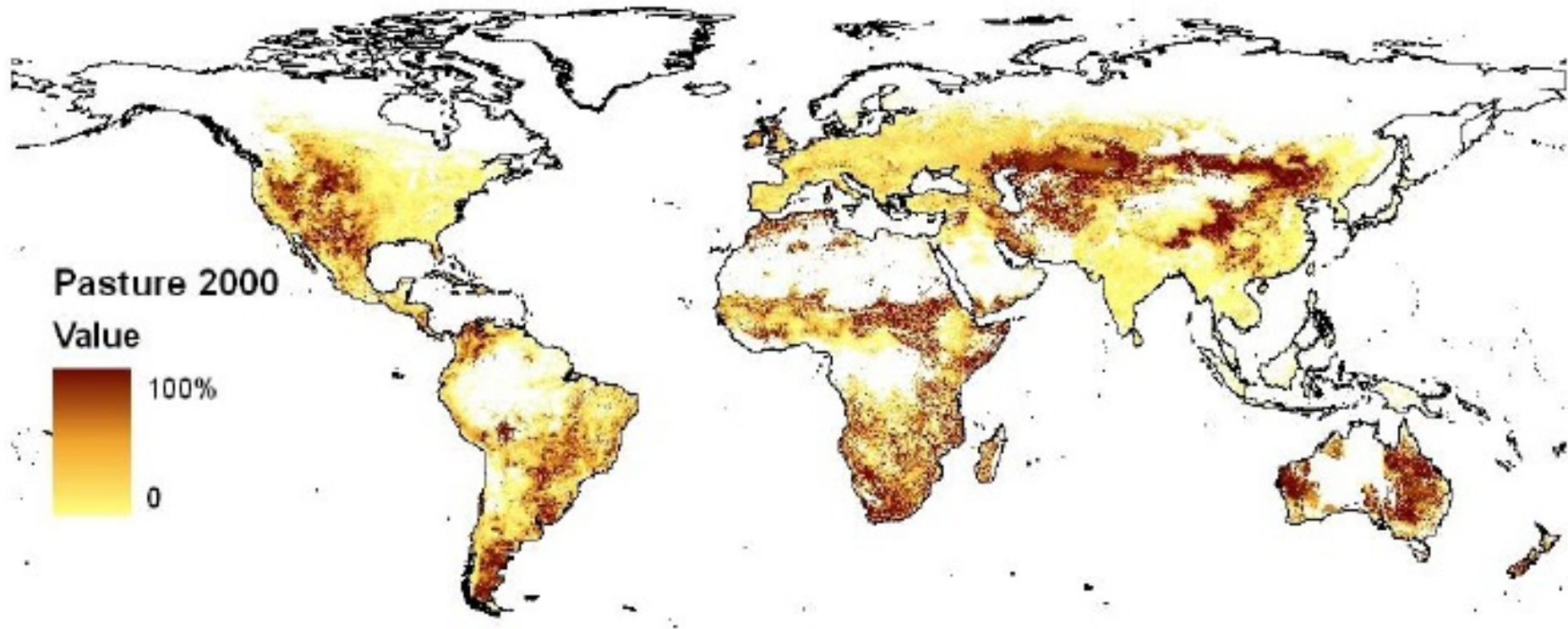
Extension actuelle des zones cultivées (pourcentage de chaque point de grille)



~15 millions de km²

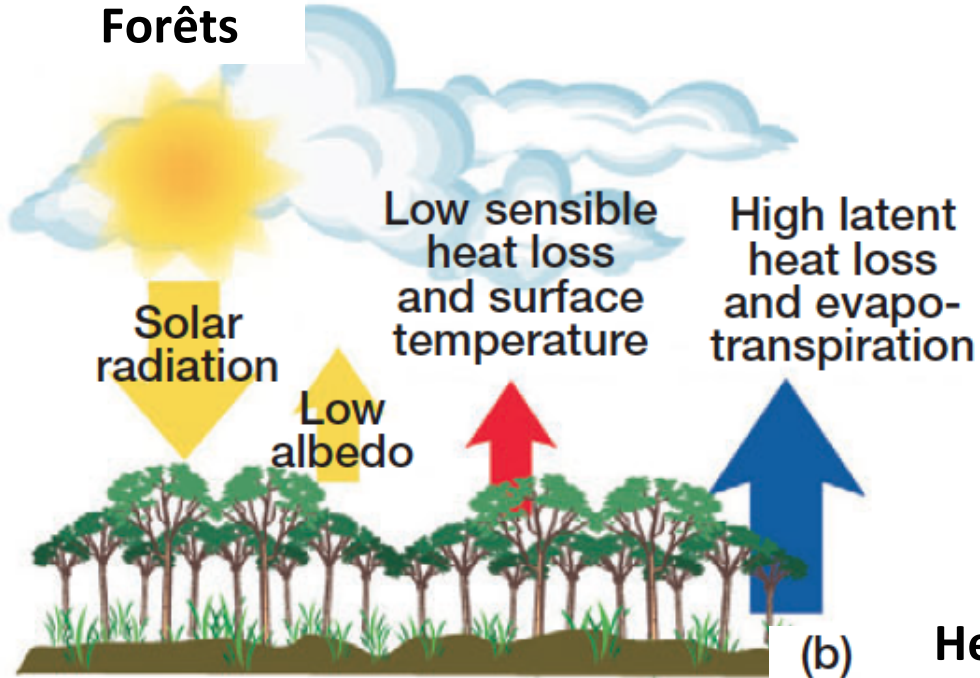
Ramankutty *et al.*, 2002

Extension actuelle des zones de pâturage (pourcentage de chaque point de grille)



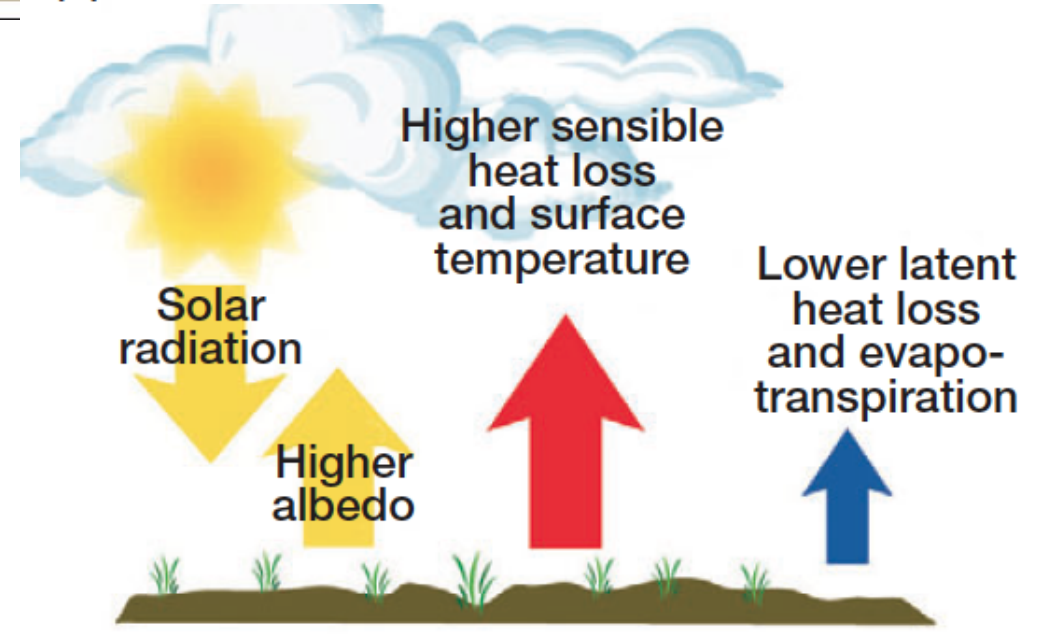
(a)

Forêts



(b)

Herbacées



Usage des Terres et formations nuageuses

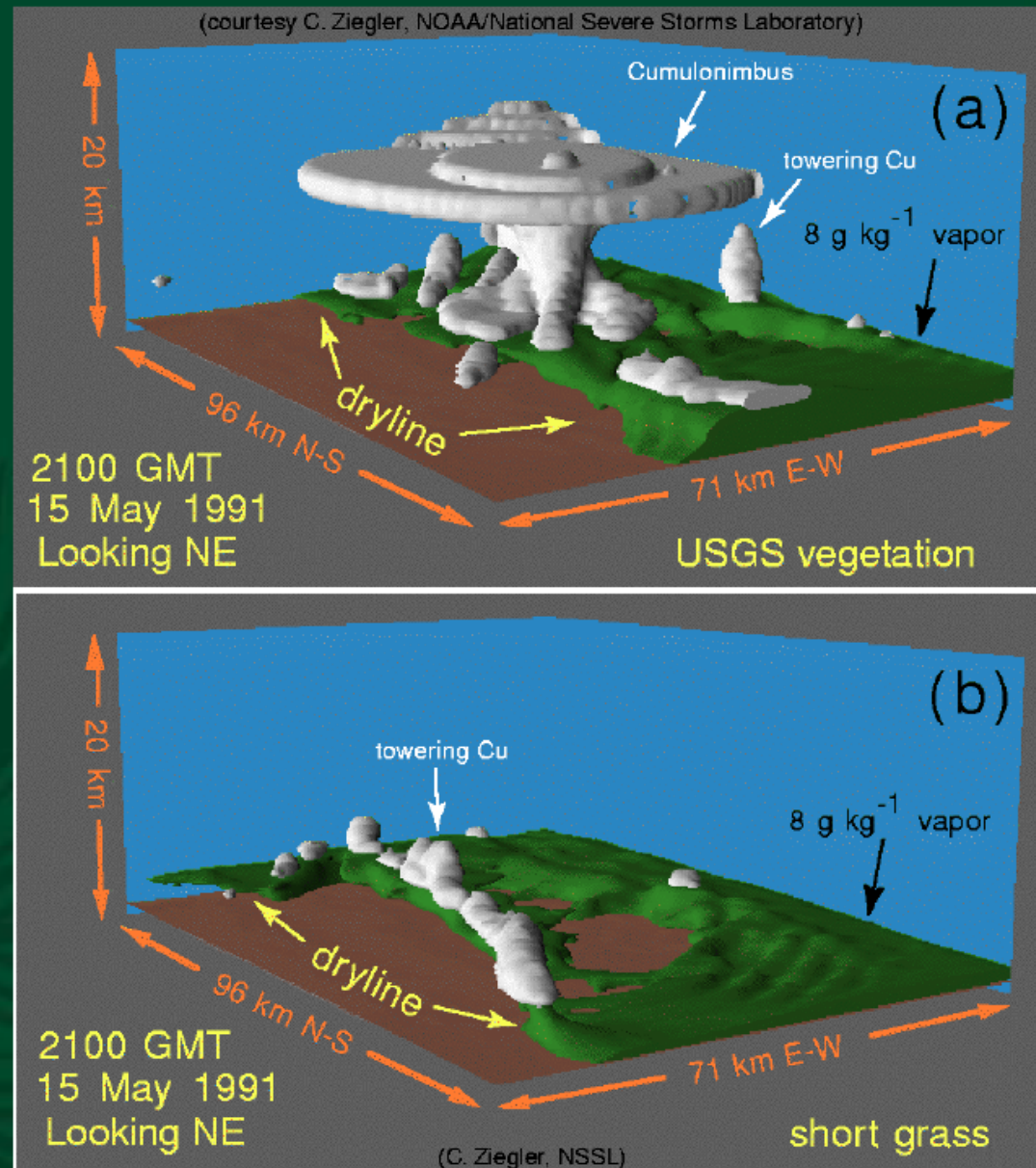
Effect of Land-Use Change on Deep Cumulonimbus Convection

Present-day vegetation :
irrigated crops, shrubs,
and short grass

Natural Landscape

From Pielke Sr., R.A., 2001: Influence of the spatial distribution of vegetation and soils on the prediction of cumulus convective rainfall. *Rev. Geophys.*, 39,151-177.

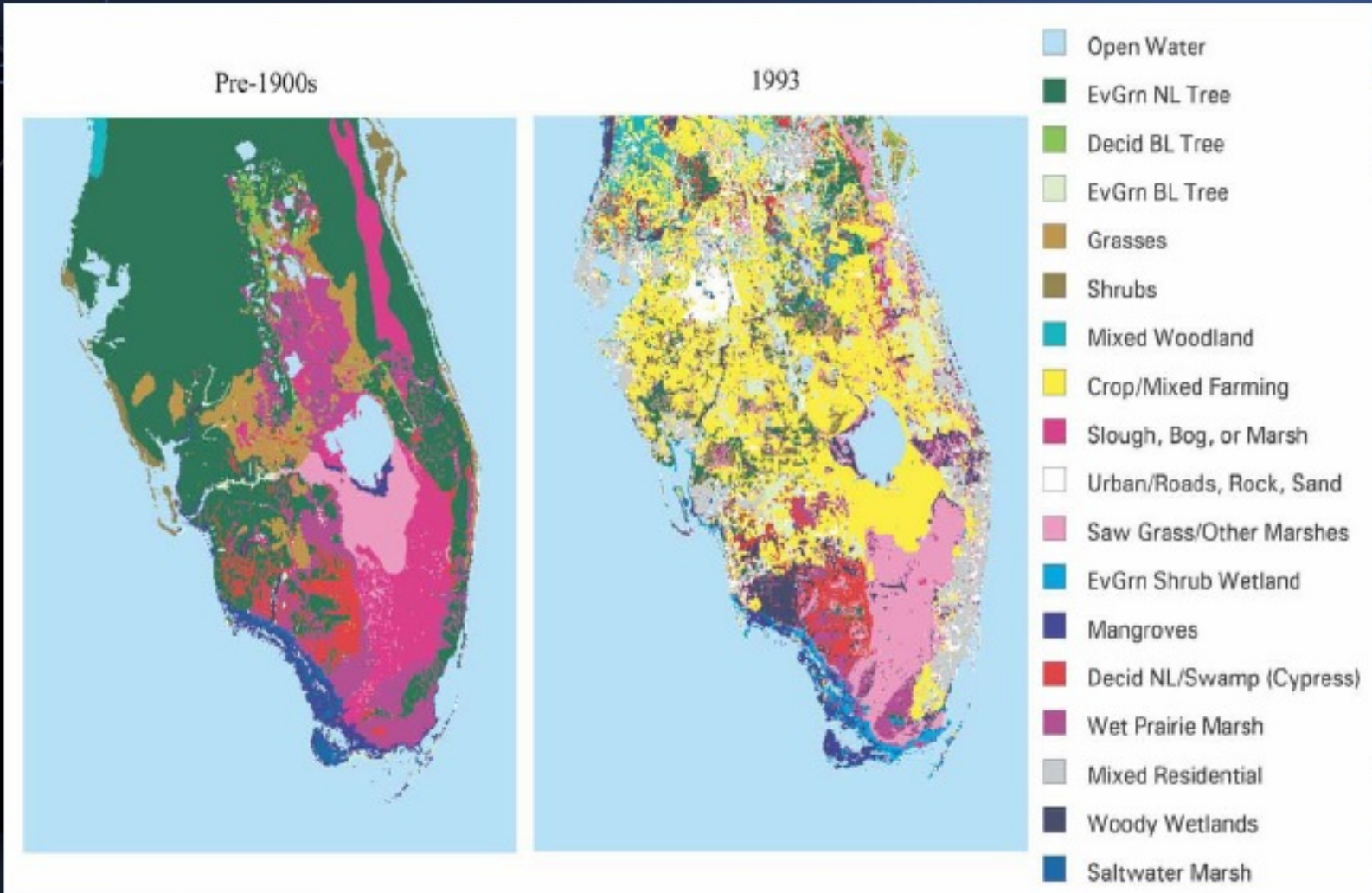
<http://blue.atmos.colostate.edu/publications/pdf/R-231.pdf>



**Effet d'un déplacement vers le Sud de la Floride
de zones agricoles (céréales d'hiver, citronniers,
canne à sucre) – en 1993 – pour éviter les gelées
dévastatrices du Nord de la Floride.**

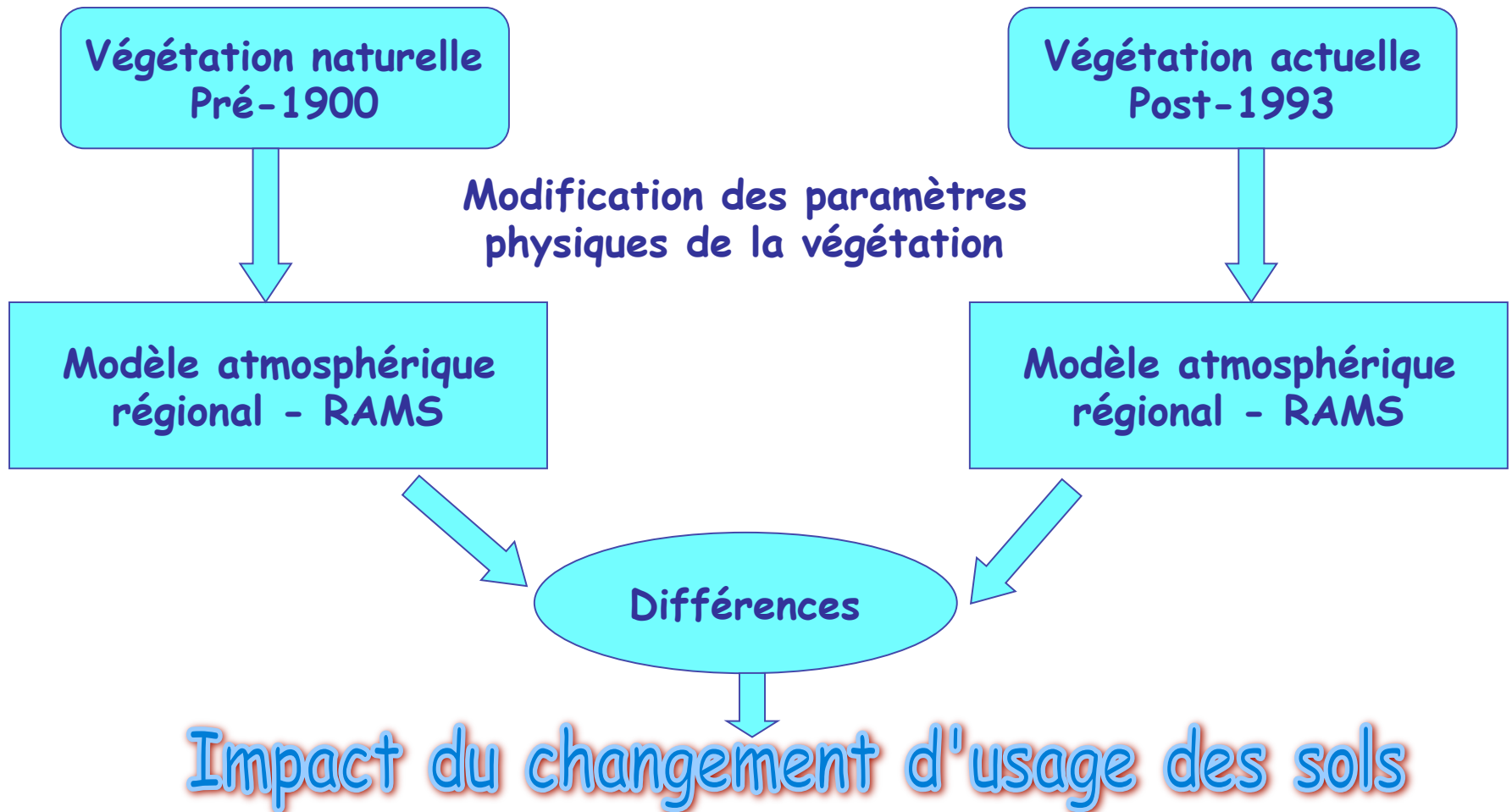
*Marshall et al. (Nature 2003),
Marshall et al. (Monthly Weather Review 2004)*

en 1993, des cultures remplacent les marécages naturels

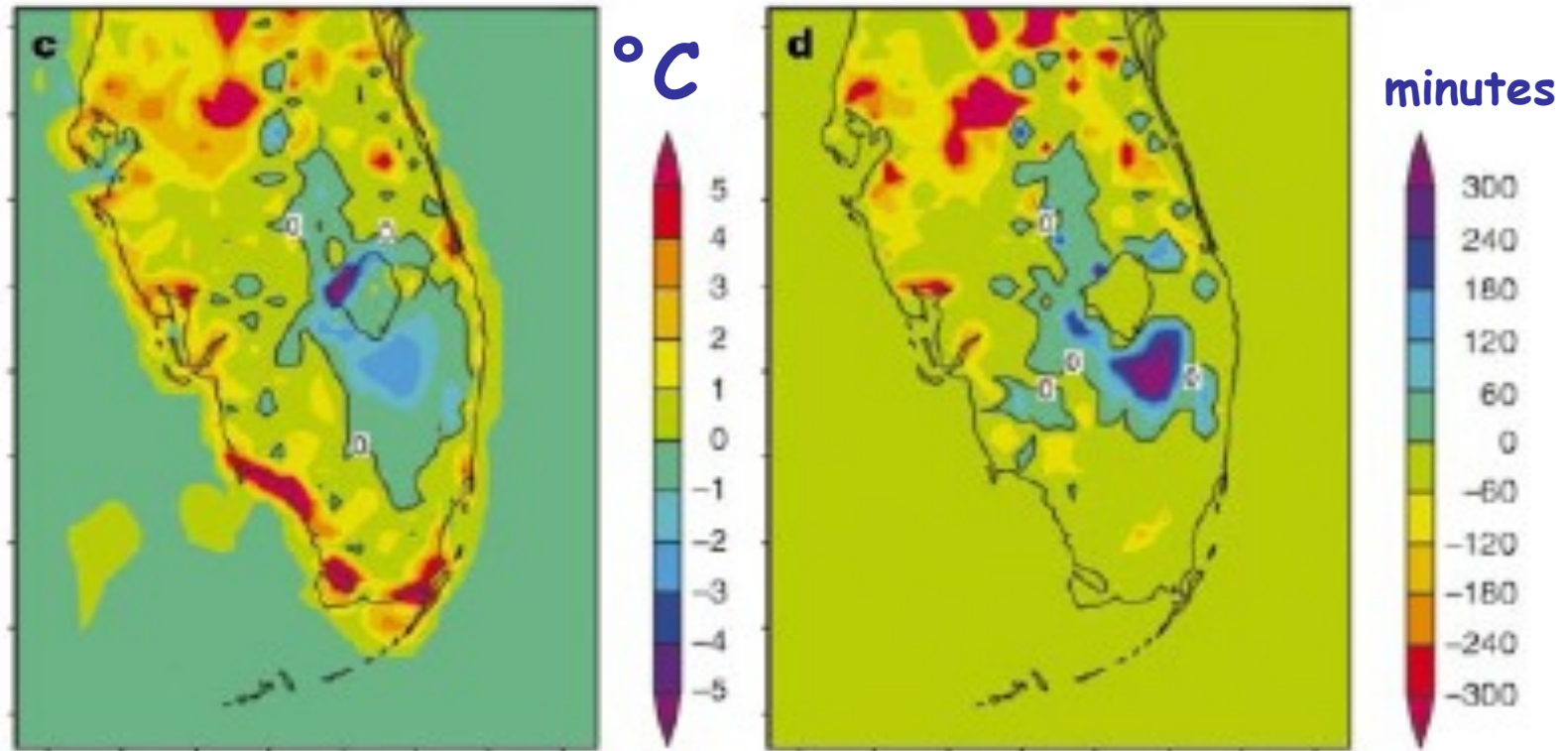


en 1997, des jours de gel intenses détruisent les récoltes

Ces jours de gel auraient-ils été aussi intenses si les
marécages avaient été maintenus?



Effets du changement d'usage des sols sur la température et la durée des jours de gel



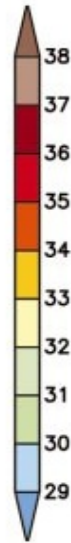
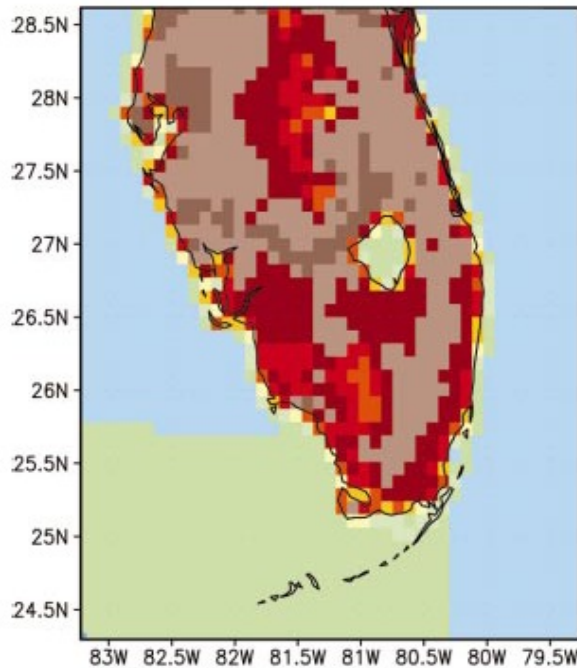
Températures plus froides
après avoir drainé
les marécages

Durée plus longue des gelées

Marshall et al., Nature 2003

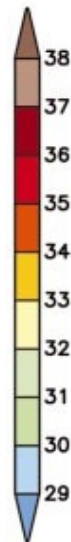
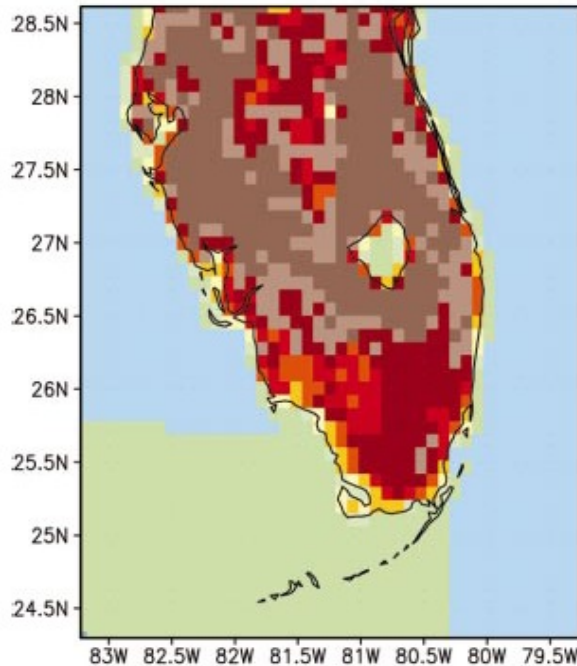
Les effets de ce drainage de marécages se voient également en été

Température maximale sous abri en Juillet-Août (°C)

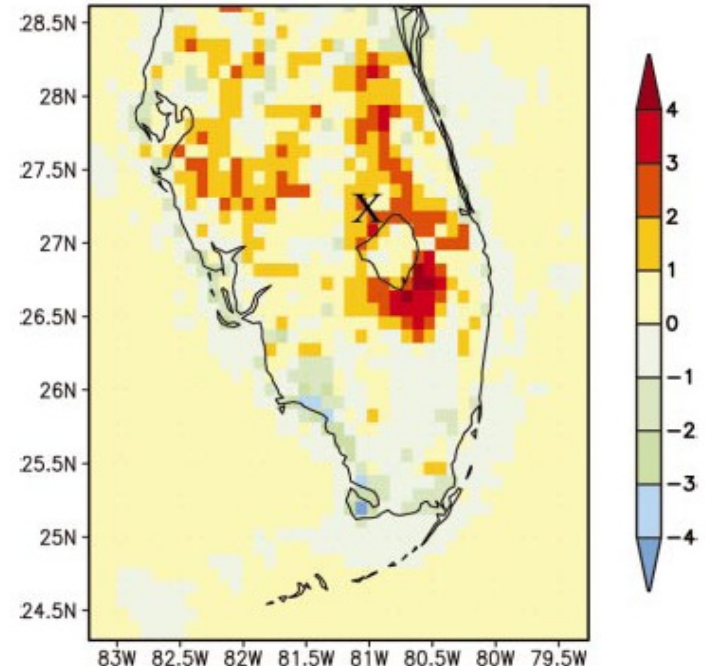


avant 1993

cultivé - marécages



après 1993



Impacts comparés

- a) du changement d'usage des terres global, passé
- b) de l'augmentation combinée
des GES dans l'atmosphère
et des changements de température des océans

Projet international d'intercomparaison de modèles
LUCID (Land-Use and Climate :
Identification of robust impacts)

Pitman, de Noblet-Ducoudré et al. *GRL* 2009
de Noblet-Ducoudré et al. *Journal of Climate* 2011

■ Ensemble simulations (with & without land-use changes).

Exp. design		veg. cover	
		1870	1992
SST & GHG	1870	PI	PIv
	1992	PDv	PD

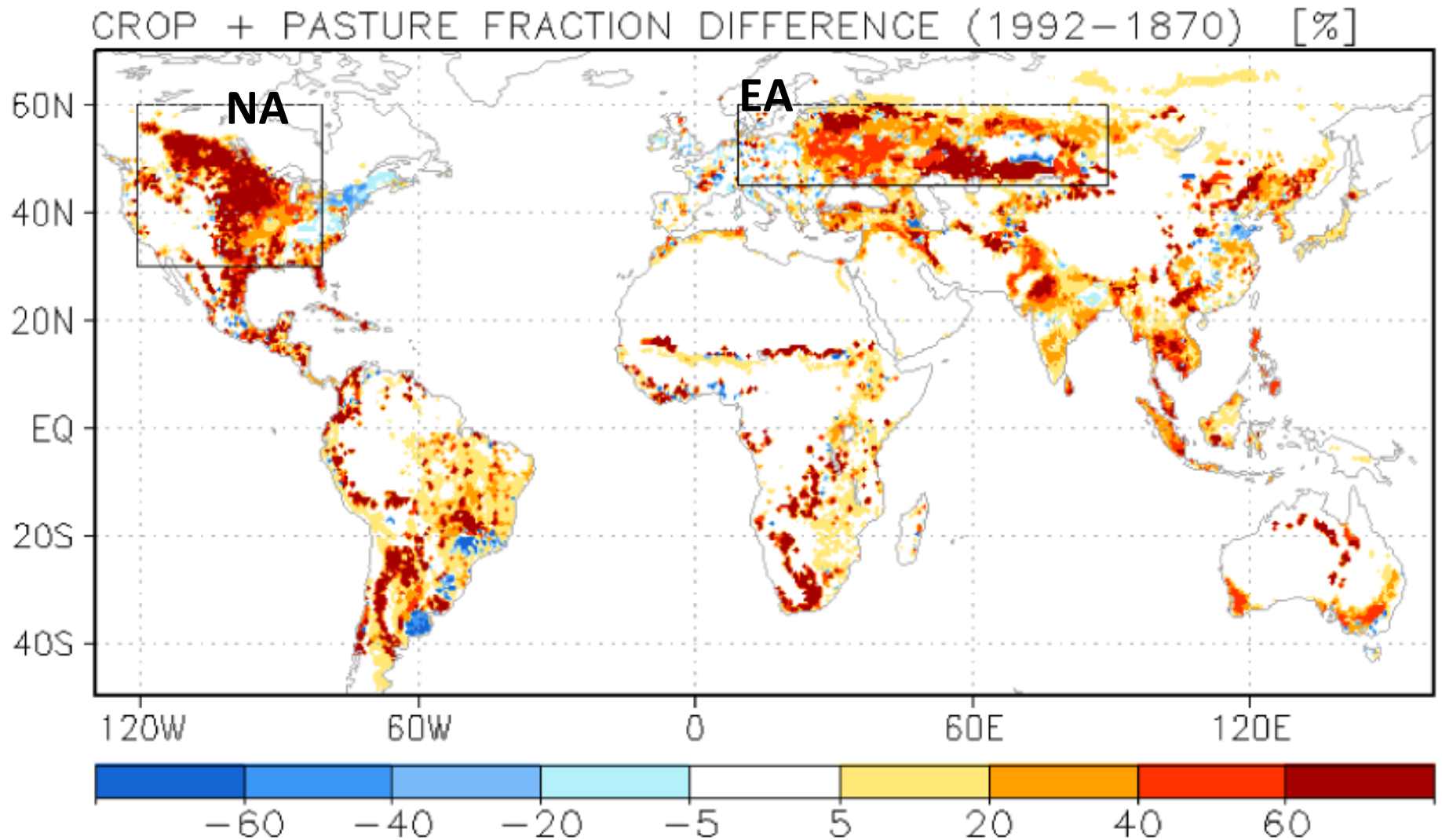
> LCC-induced changes : {PD-PDv, PIV-PI}

- 7 groups have run the snap-shot experiments(5 members per ensemble) :

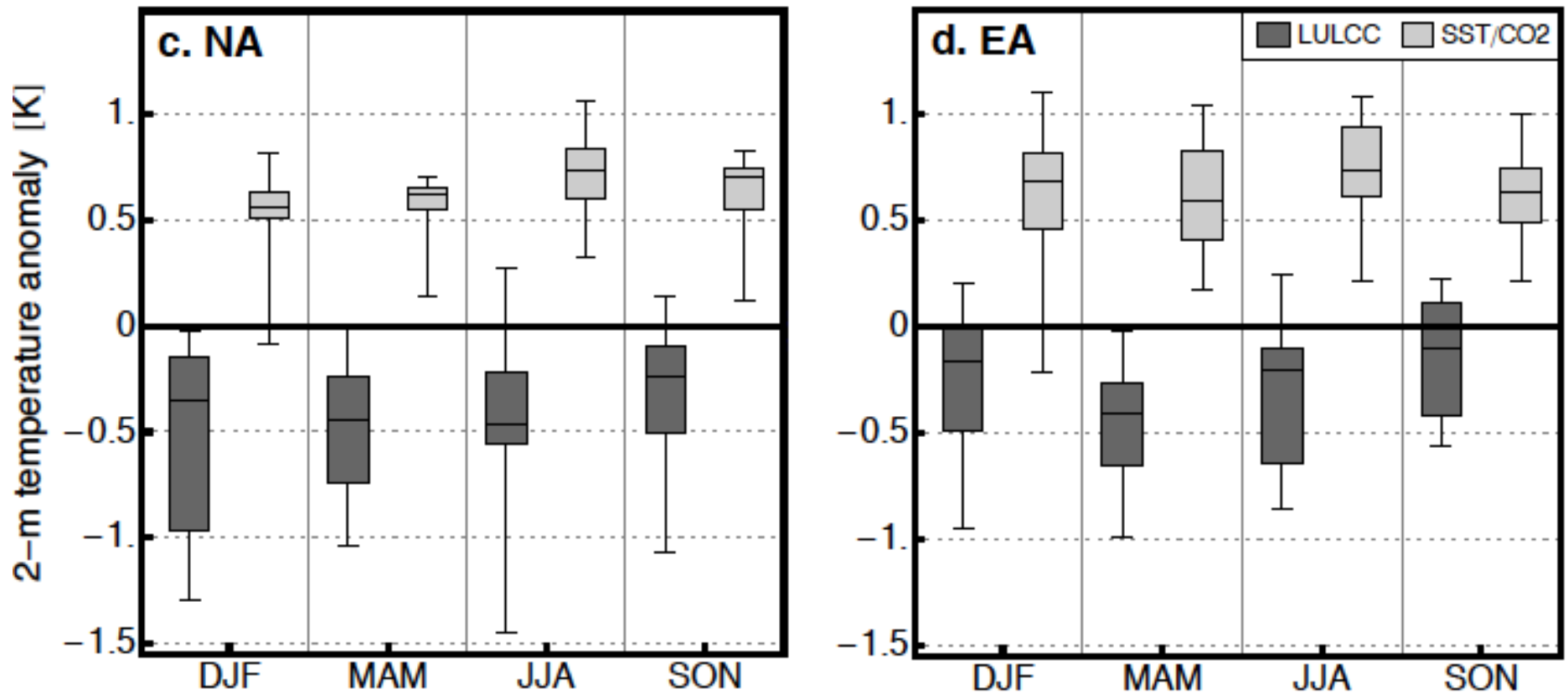
Name of Climate Model	Name of Land-surface Model
ARPEGE	ISBA
CCAM	CABLE
CCSM	CLM
ECearth	TESSEL
IPSL	ORCHIDEE
SPEEDY	LPJmL
ECHAM5	JSBACH

Same crop and pasture maps provided to each group for pre-industrial and present-day time periods ($0.5^{\circ} \times 0.5^{\circ}$; fractions of grid-cells)

Changes in crop+pasture fractions from 1870 to 1992



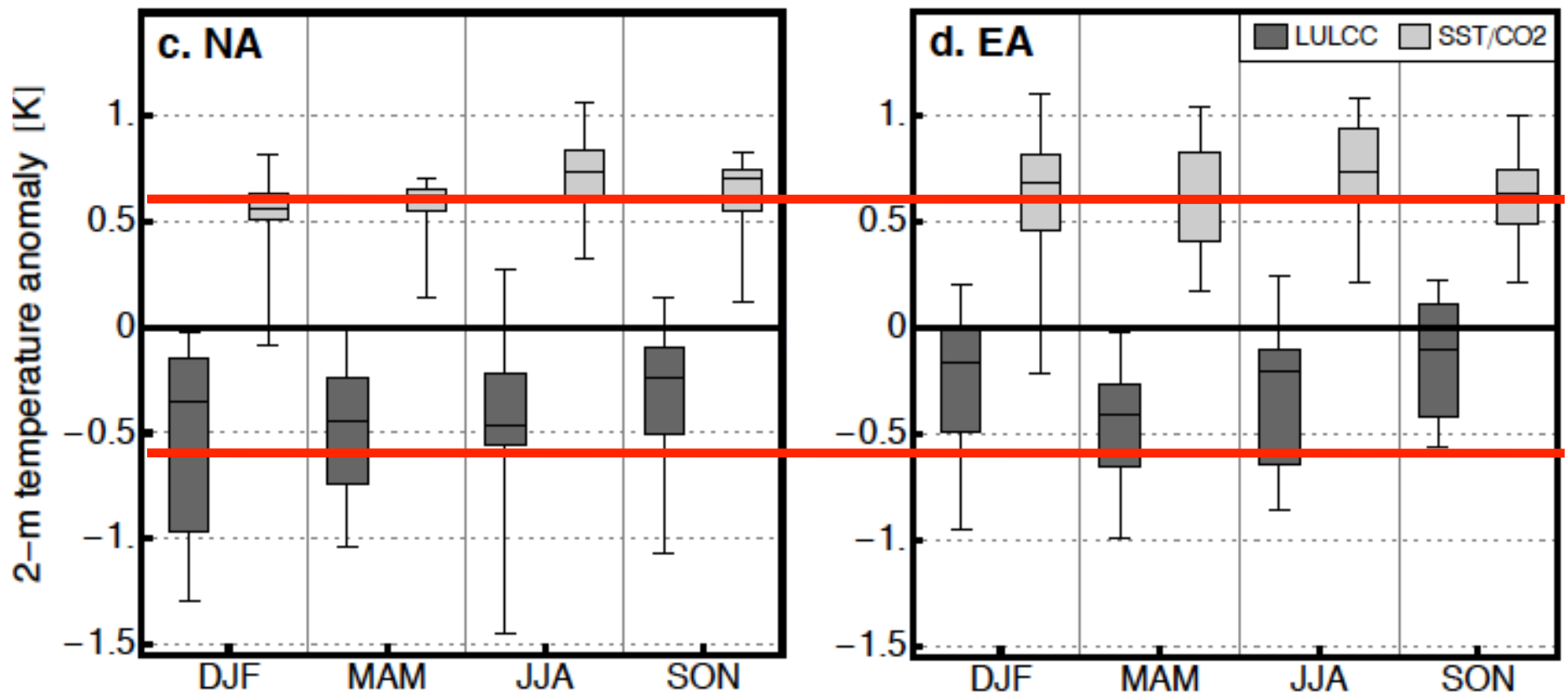
Impacts on the simulated 2m air temperature



Impact of LCC

Impact of SSTs+SiC+CO₂

Impacts on the simulated 2m air temperature

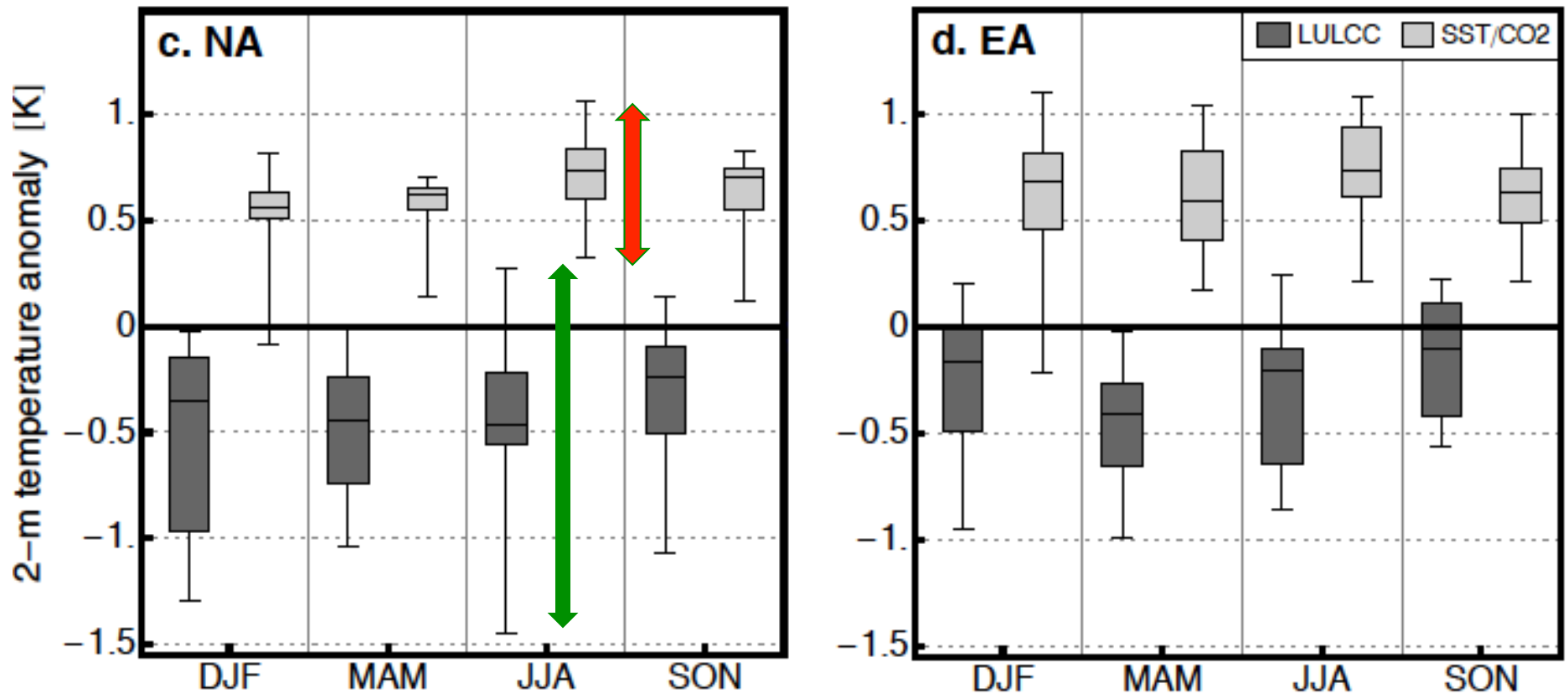


Impact of LCC

Impact of SSTs+SiC+CO₂

Magnitude of LULCC impacts
as large as
CO₂-SST impacts

Impacts on the simulated 2m air temperature



Impact of LCC

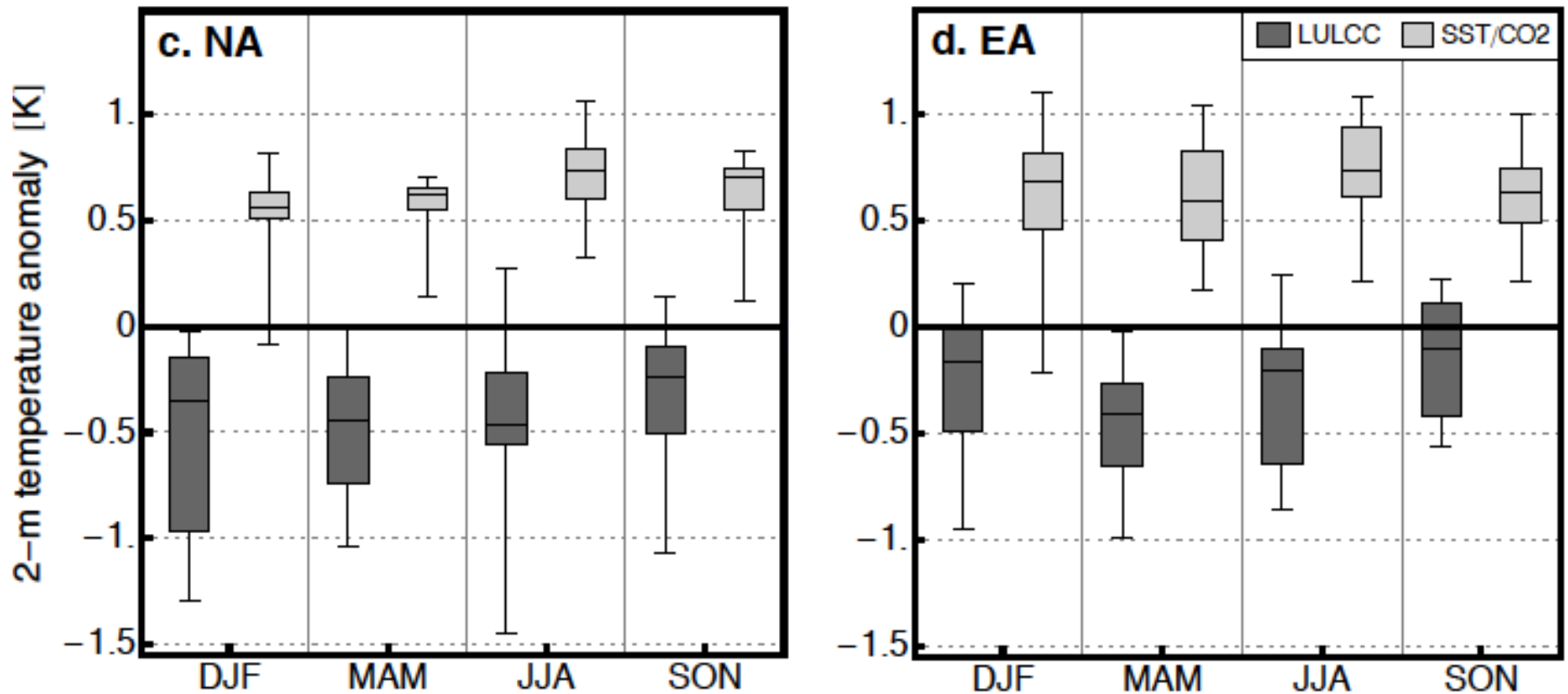
Impact of SSTs+SiC+CO₂

LULCC impacts

→ larger inter-model variations

Impacts on the simulated 2m air temperature

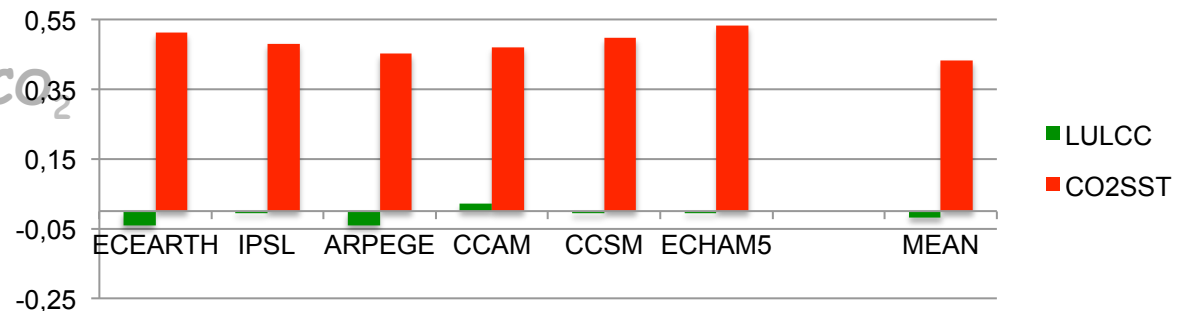
Large and Significant Regional Changes. No Global changes



Mean Global Annual Change

Impact of LCC

Impact of SSTs+SiC+CO₂



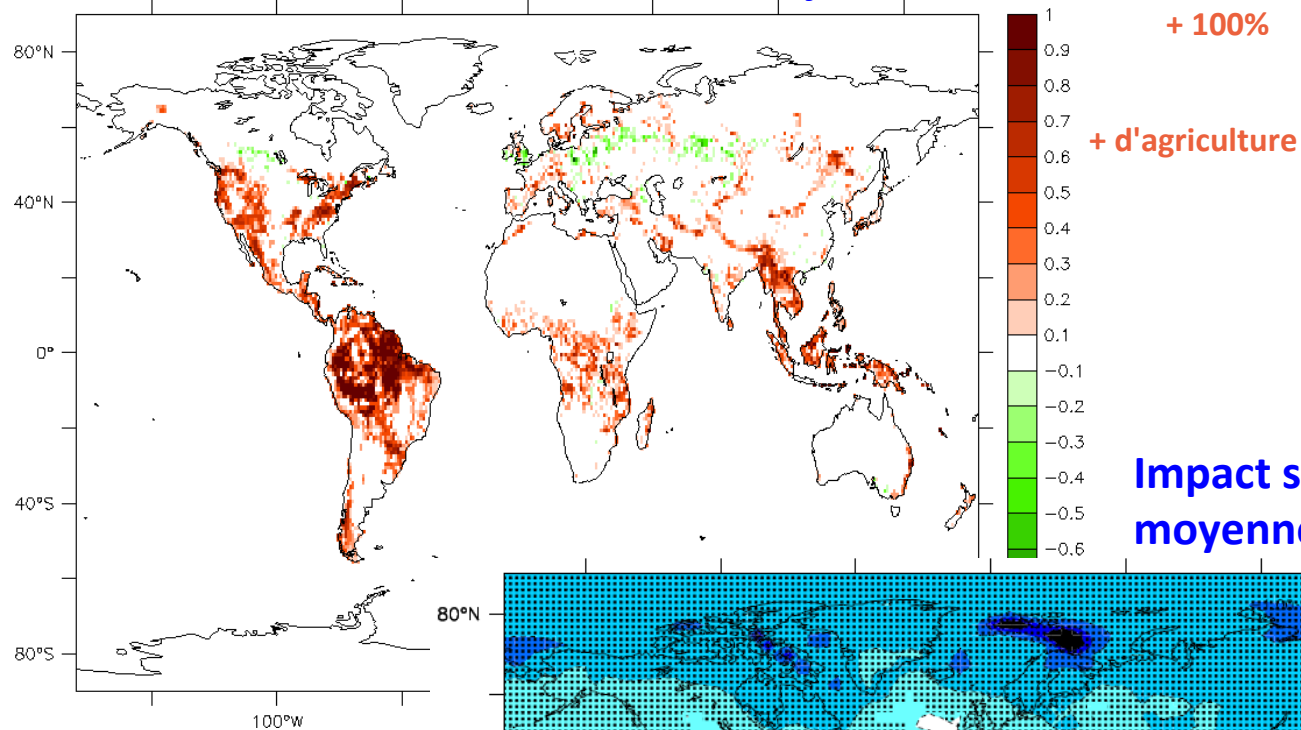
**Et si l'Amazonie était en grande partie
mise en cultures dans le futur ?**

(Scénario SRES-A2 du modèle intégré IMAGE 2.2)

Davin, thèse 2007

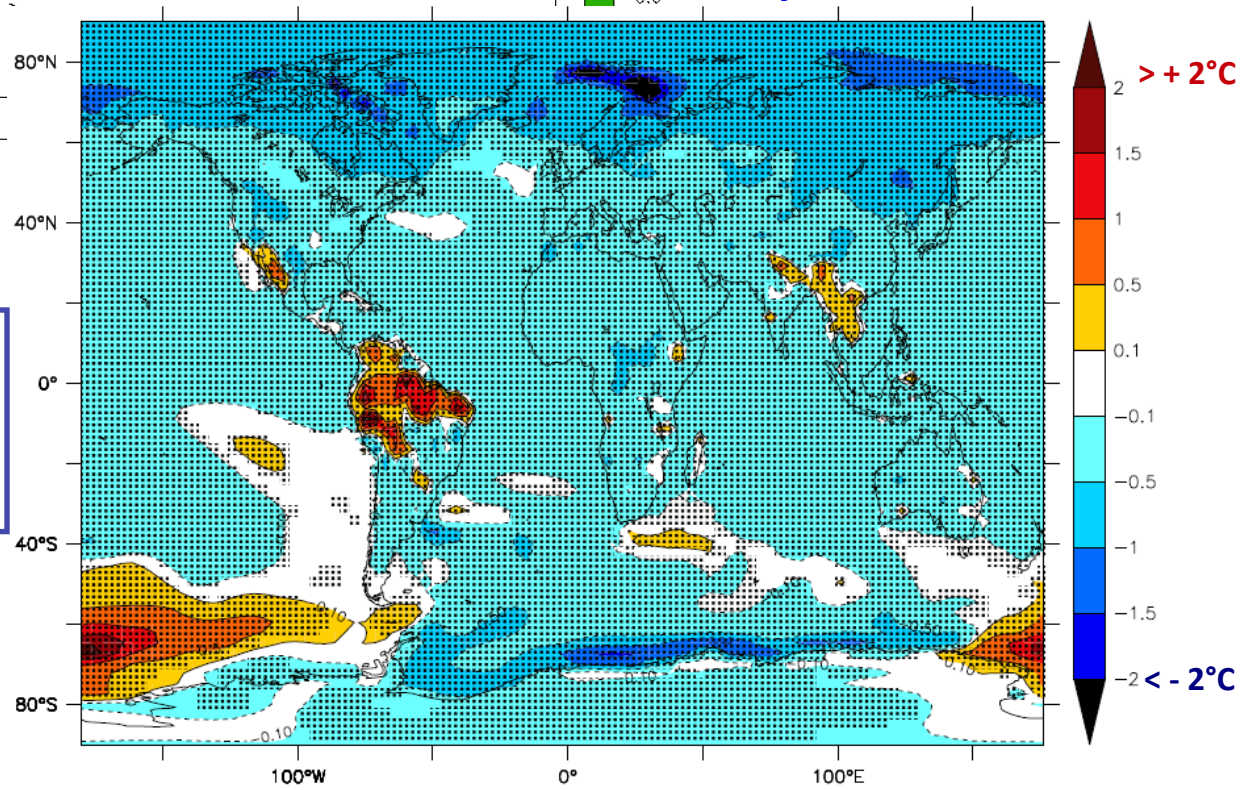
Davin, de Noblet-Ducoudré et al. (en préparation)

Evolution des zones cultivées entre aujourd'hui et 2100



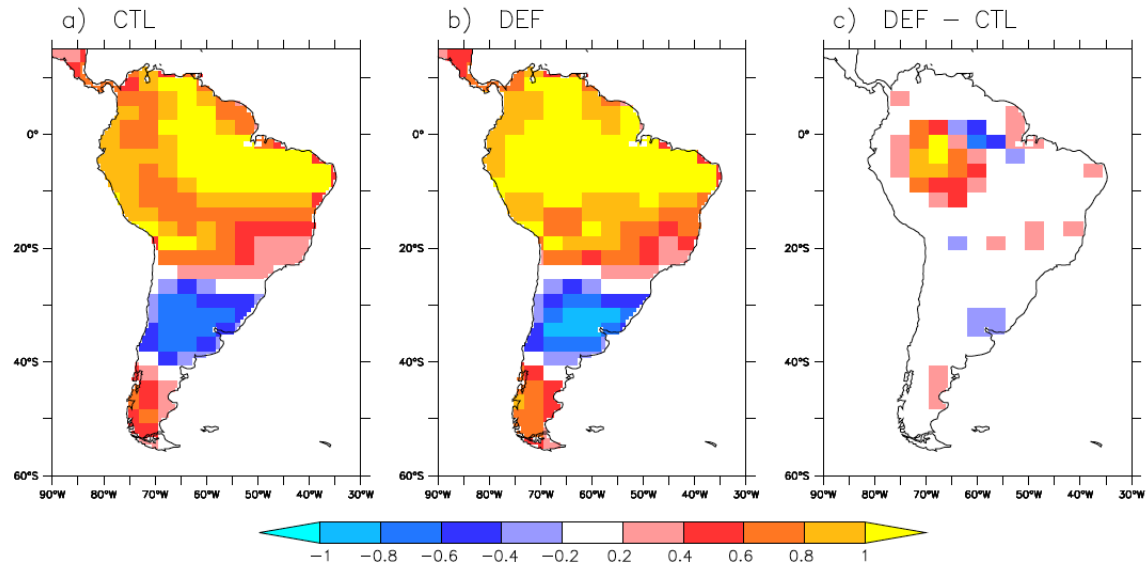
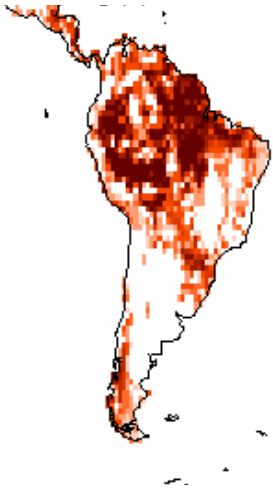
Impact sur la température moyenne annuelle de l'air

un refroidissement global faible mais significatif
 $\Delta T_s = -0.24^\circ\text{C}$



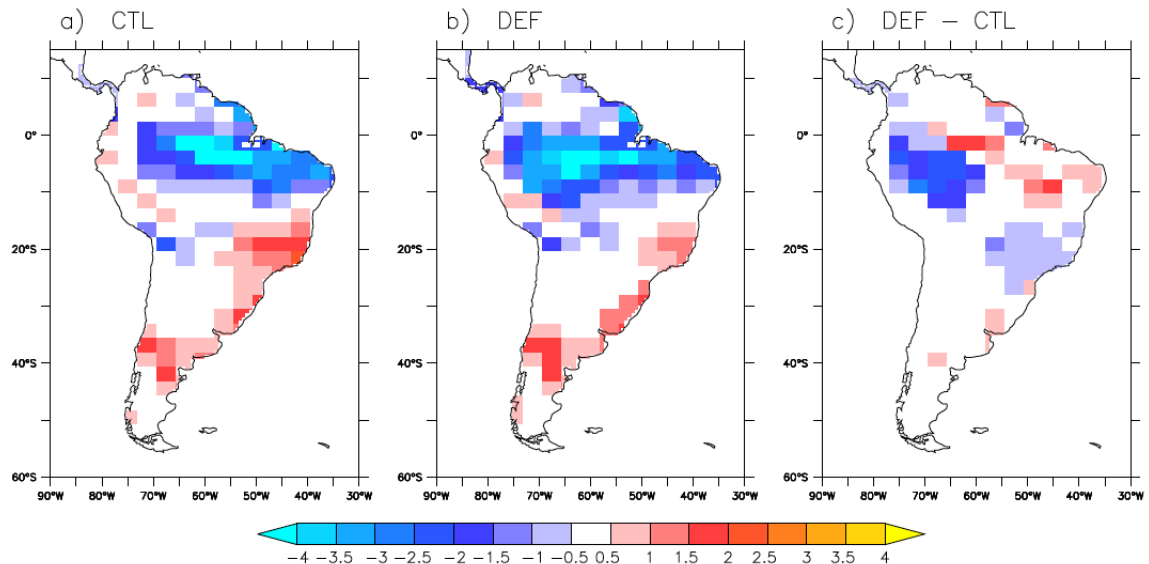
Impact d'un événement El Nino

sur la température à la surface



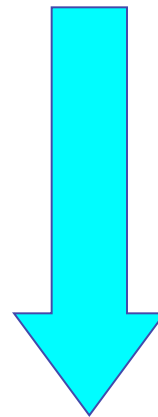
sur la productivité

la chute de productivité est 1,5 fois plus importante en présence d'agriculture



Faut-il tenir compte des impacts de l'usage des terres sur le 'climat' avant de prendre une décision sur l'usage que l'on fait des sols ?

Stratégies d'usage des sols



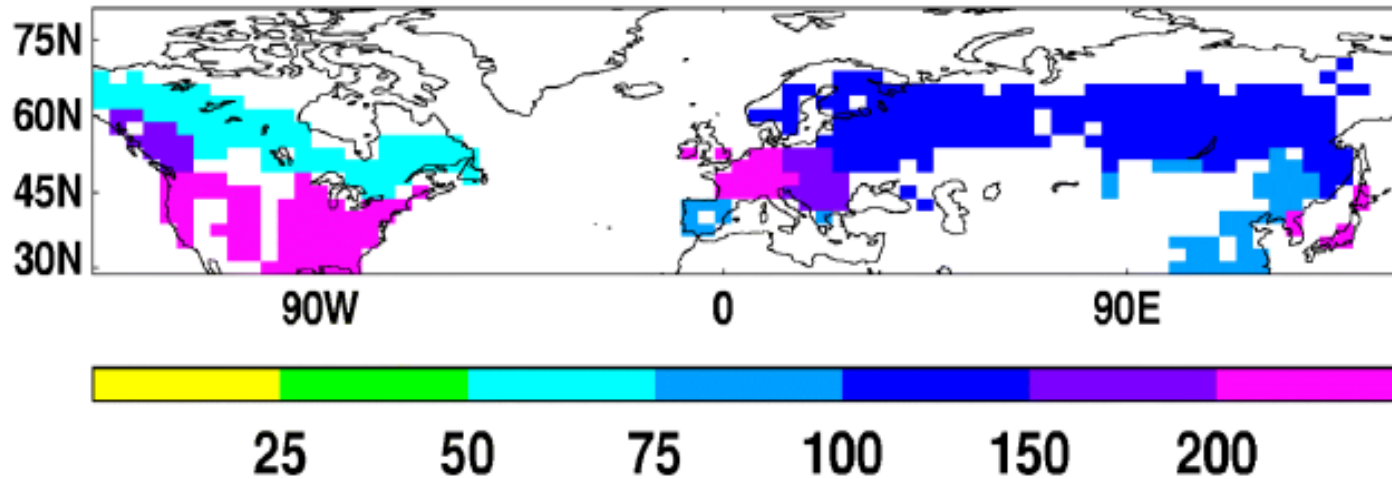
Effets sur le climat

Planter des forêts dans les hautes latitudes Nord ?

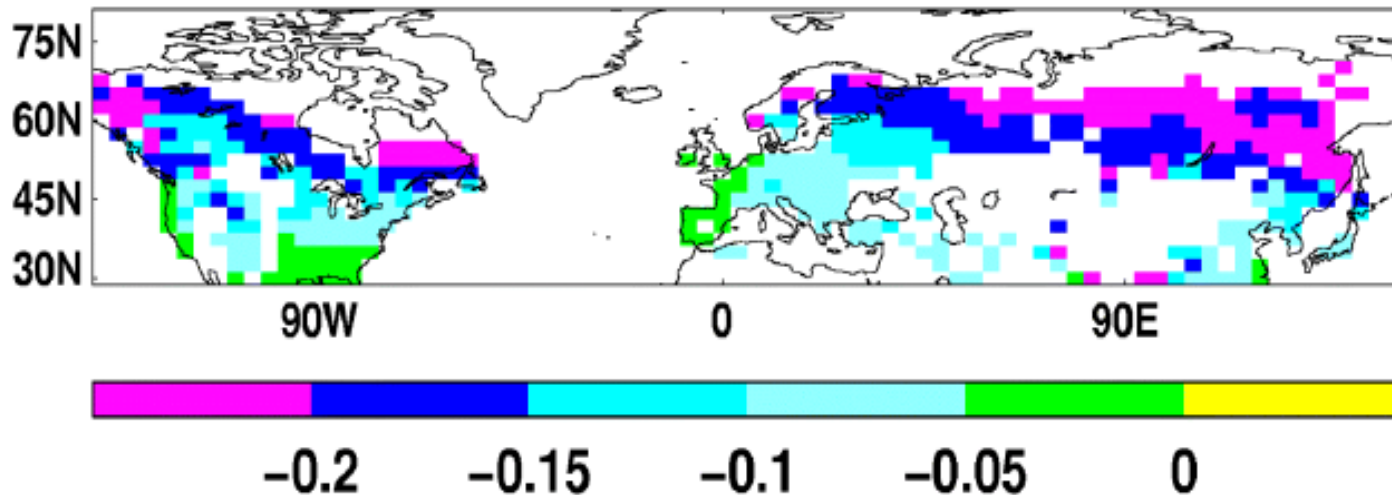
Betts (Nature 2000)

Sensitivity study: compare carbon sequestration and albedo change in a 1ha plantation in different locations

Carbon uptake (above+below ground, tC ha^{-1}), 1 harvest rotation period

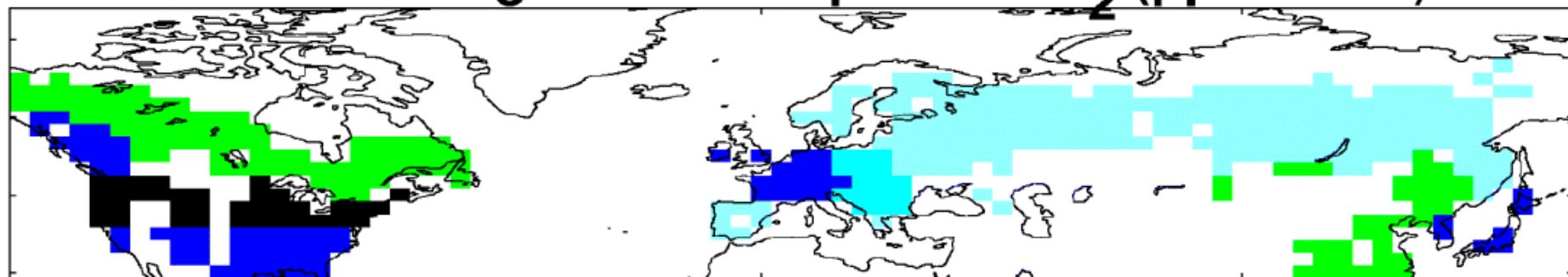


Albedo difference, dense coniferous forest - open land

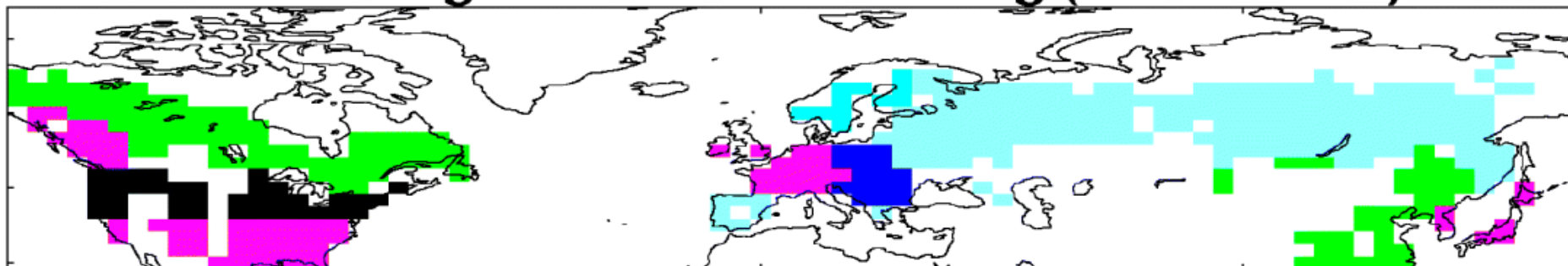


Radiative forcing due to carbon sequestration in a 1 ha plantation in different locations

Reduction in global atmospheric CO₂ (ppmv ha⁻¹)



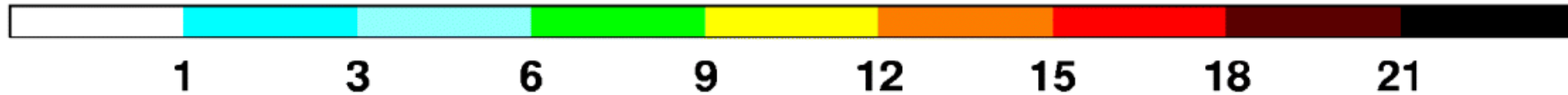
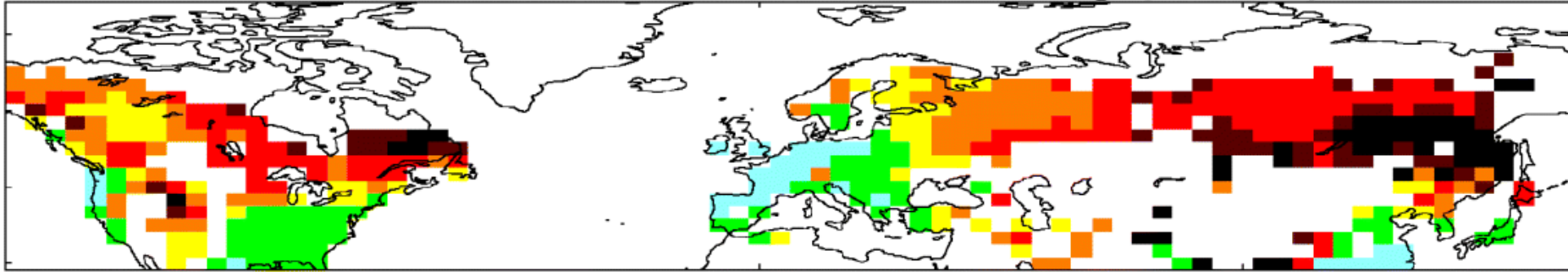
Global longwave radiative forcing (nW m⁻² ha⁻¹)



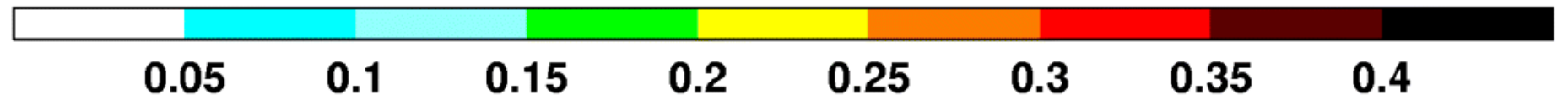
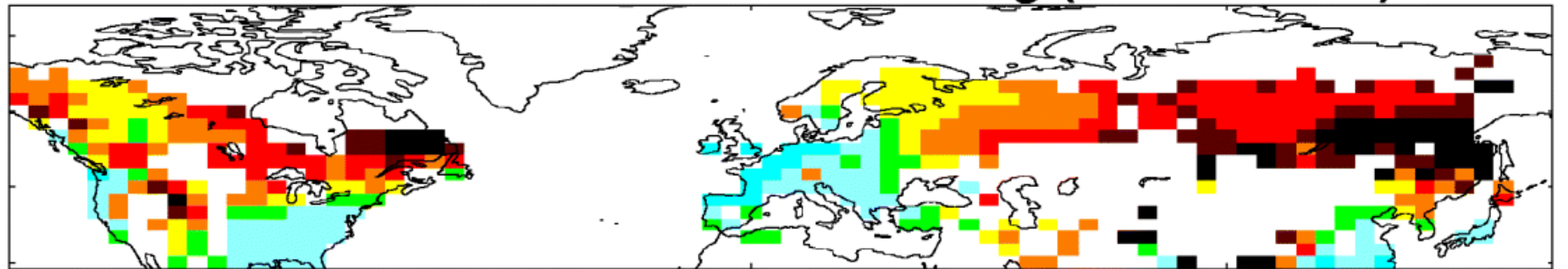
-0.8 -0.6 -0.5 -0.4 -0.3 -0.2

Radiative forcing due to surface albedo change in 1 ha
plantation in different locations

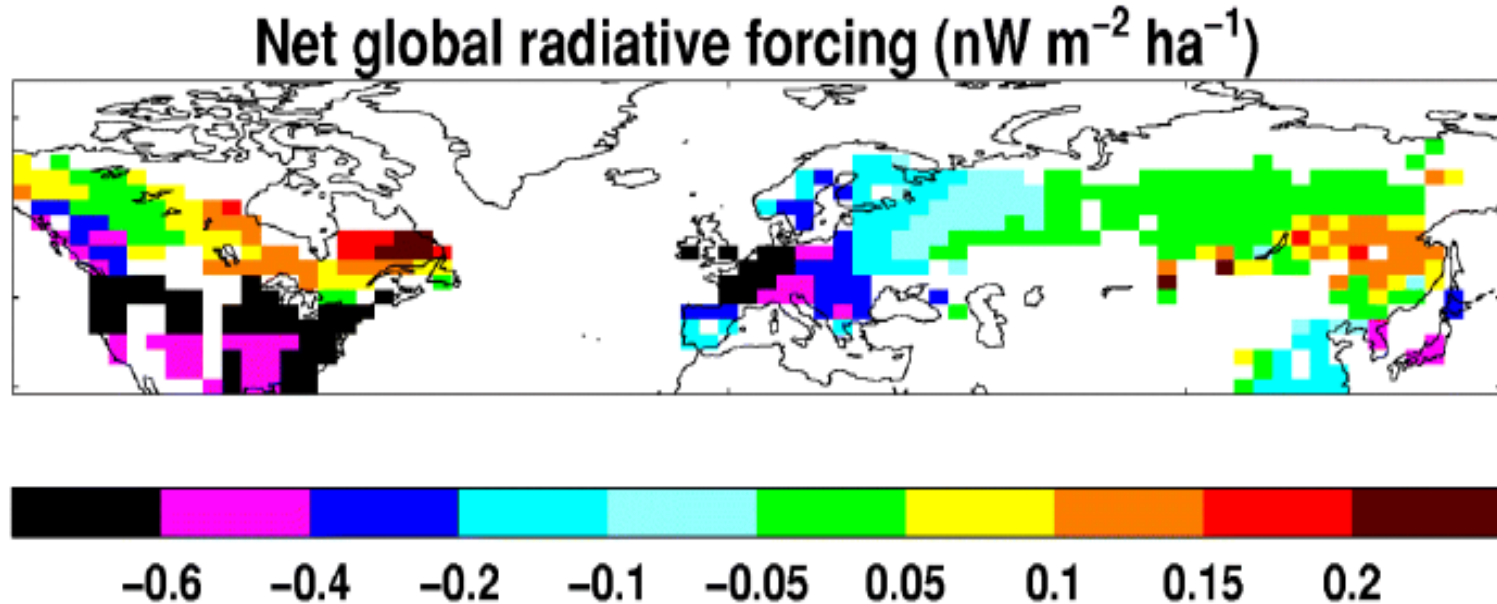
Local shortwave radiative forcing (W m^{-2})



Global shortwave radiative forcing ($\text{nW m}^{-2} \text{ ha}^{-1}$)



Net radiative forcing due to a 1 ha “carbon sink” plantation in different locations

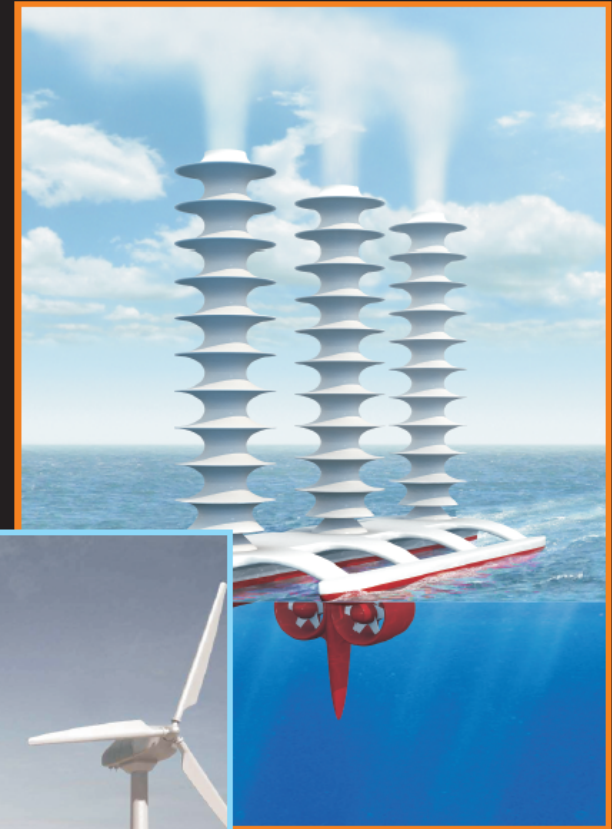
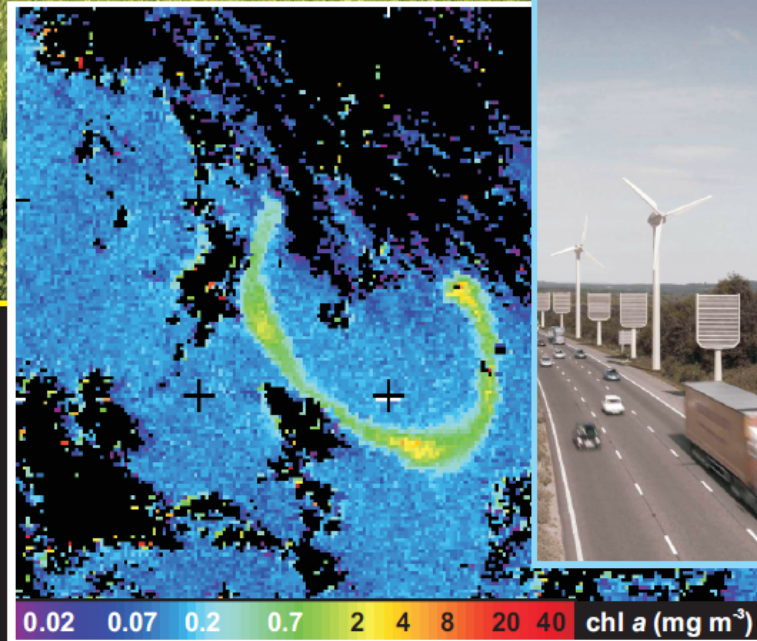
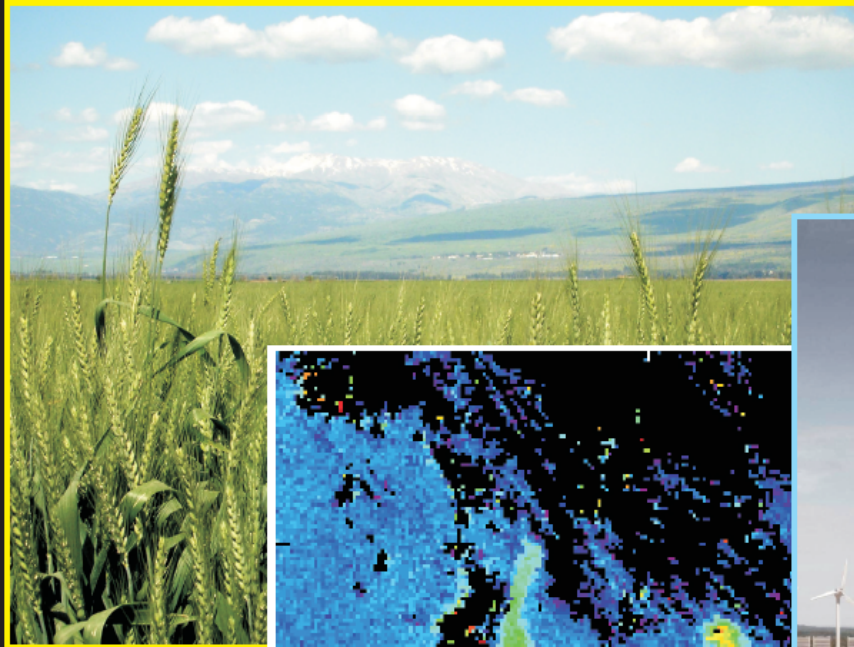


Positive net forcing implies afforestation causes net warming

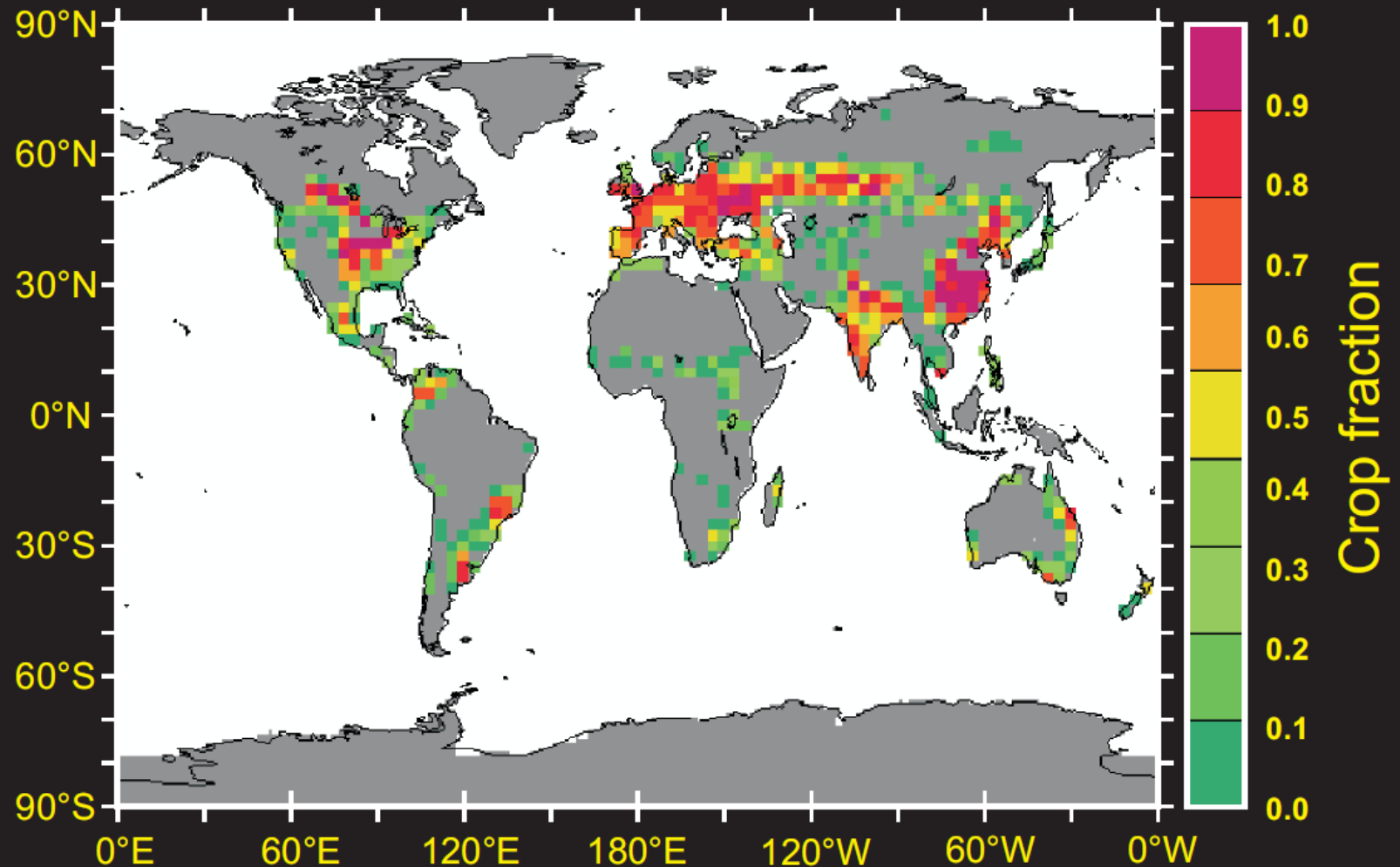
Some regions see neutral effect of afforestation

Some regions still see net negative forcing (cooling) - but smaller than that expected from carbon sequestration alone

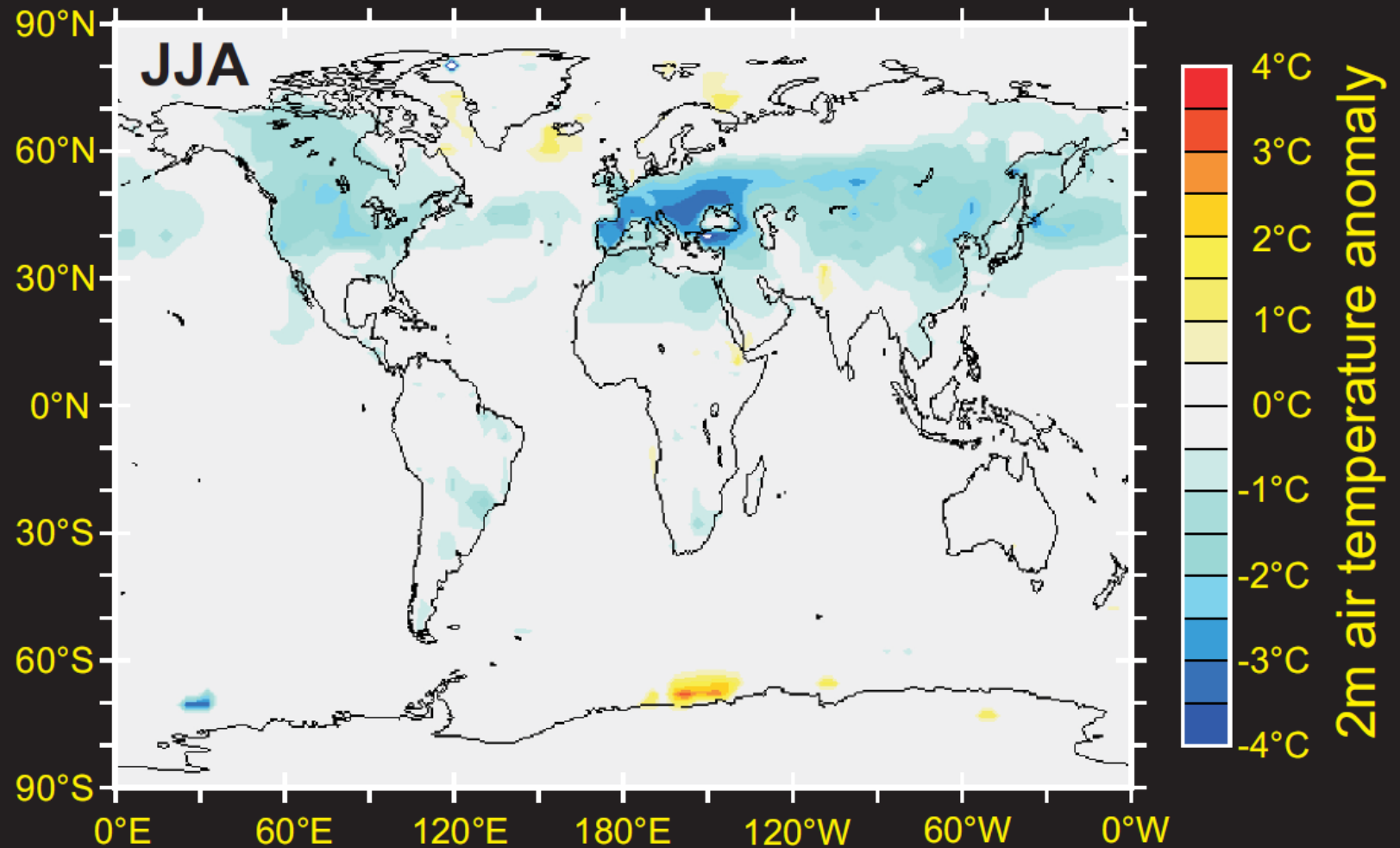
Geoengineering: A test of our understanding of the Earth system(?)



Increasing the reflectiveness of crops



Increasing the reflectiveness of crops



Productivity impacts?



Partie II

Quelles sont les méthodes pour évaluer les impacts du changement climatique sur l'agriculture, à grande échelle ?

Comment sont évalués les impacts du changement climatique à l'échelle mondiale?

Méthodes	Stratégies	Variables principales présentées dans les publications	Références
Statistiques			
Modèles globaux de Biosphère			

Evaluation des impacts potentiels à l'échelle mondiale

Méthodes	Stratégies	Variables principales présentées dans les publications	Références
Statistiques	<u>Corrélations</u> Variable = F(climat)	Rendement	<i>Schlenker & Roberts (2009)</i>
	<u>Méta-analyses</u> Analyse biblio → variable=F(climat)	Rendement	<i>Wilcox et Makowski (soumis)</i>
	<u>Analogues</u> Définition de niches spécifiques pour chaque espèce = enveloppes climatiques	Apparition / disparition d'espèces en un lieu	<i>Williams et al. (2007)</i>
	<u>Extrapolation Globale de modèles spécifiques</u>	Rendement Production	<i>Parry et al. (1999)</i>
	<u>Global Agro-Ecological Assessments</u> Combinaison de modèles empiriques et de cartographies	Surfaces potentiellement cultivables / variétés Rendement / Production	<i>Fischer et al. (2002)</i>

Evaluation des impacts potentiels à l'échelle mondiale

Méthode	Stratégie	Variables principales présentées dans les publications	Références
Modèles globaux de Biosphère	<u>Basés sur les Processus</u> Cultures représentées par des Crop Functional Types Végétation naturelle : Types fonctionnelles de plantes	Rendement <i>(mais potentiel de sortir d'autres variables)</i>	<i>Müller et al. (2010)</i> <i>Challinor et al. (2004)</i> <i>Berg et al. (2011)</i>
	<u>Empiriques</u> ne considèrent que les écosystèmes agricoles	Dates de semis/fauche Rendement Zones potentielles pour les cultures en questions	<i>Deryng et al. (2011)</i>

Corrélations Statistiques

Schlenker & Roberts (2009)

Des statistiques qui essaient de tenir compte des non-linéarités entre variables atmosphériques & rendements

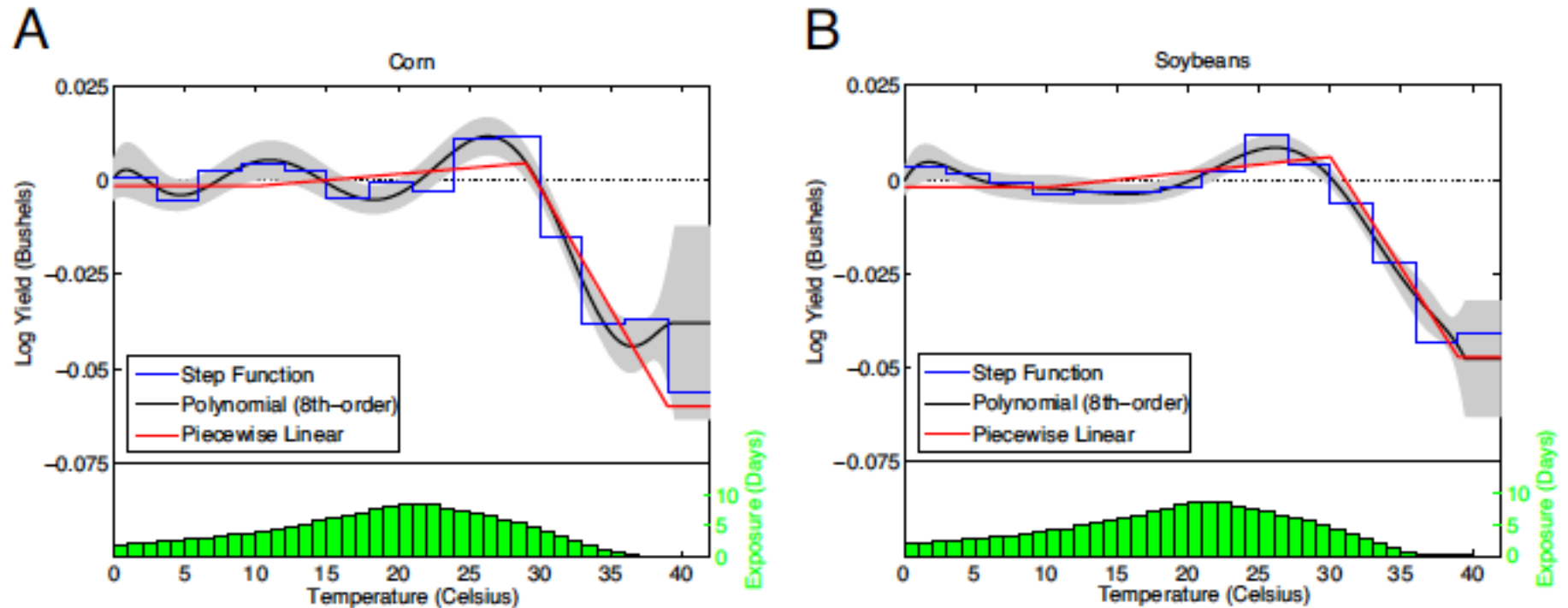


Fig. 1. Nonlinear relation between temperature and yields. Graphs at the top of each frame display changes in log yield if the crop is exposed for one day to a particular 1° C temperature interval where we sum the fraction of a day during which temperatures fall within each interval. The 95% confidence band, after adjusting for spatial correlation, is added as gray area for the polynomial regression. Curves are centered so that the exposure-weighted impact is zero. Histograms at the bottom of each frame display the average temperature exposure among all counties in the data.

$$y_{it} = \int_{\underline{h}}^{\overline{h}} g(h) \phi_{it}(h) dh + \mathbf{z}_{it} \boldsymbol{\delta} + c_i + \epsilon_{it}$$

Une fonction qui
exprime la
distribution de la
chaleur dans le
temps

Une fonction de
croissance

À l'horizon de la fin du 21^{ème} siècle

B

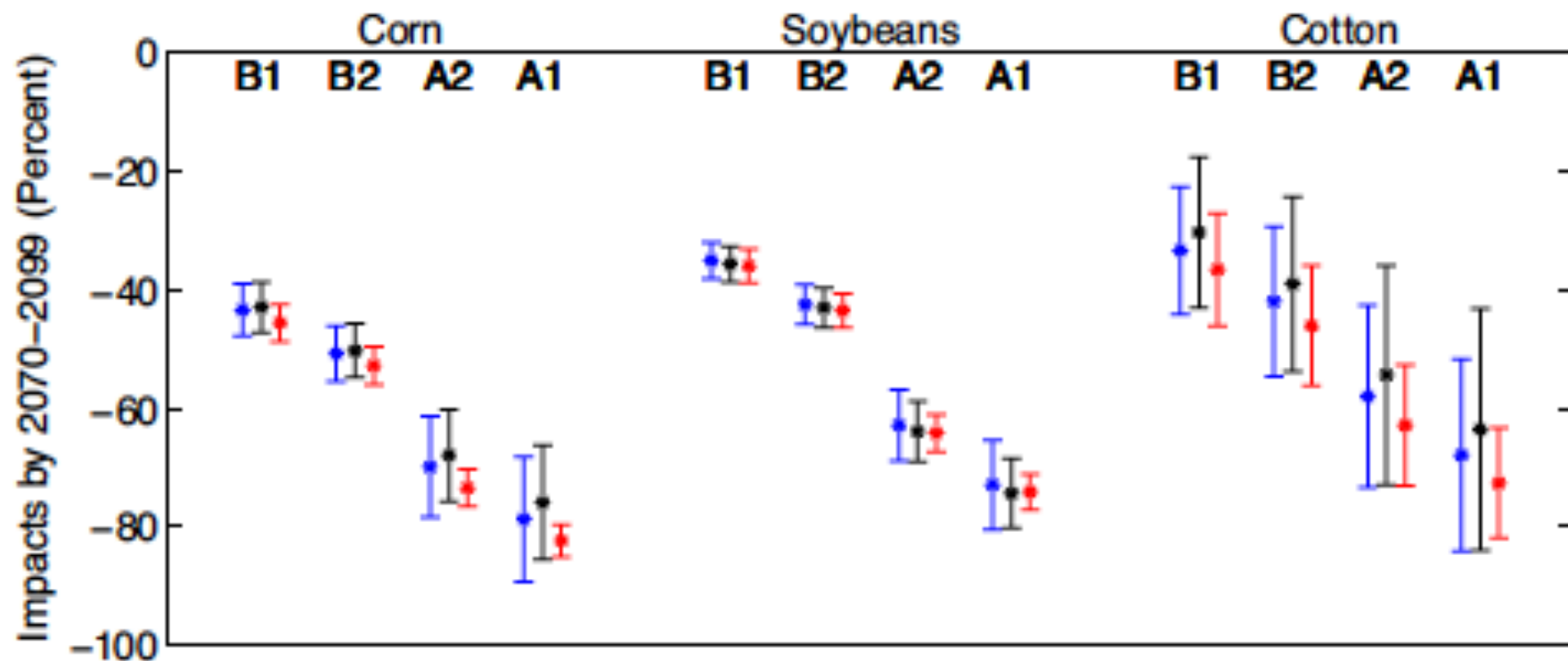


Fig. 2. Predicted climate-change impacts on crop yields under the Hadley III climate model. Graphs display predicted percentage changes in crop yields under four emissions scenarios. Frame A displays predicted impacts in the medium term (2020–2049) and frame B shows the long term (2070–2099). A star indicates the point estimates, and whiskers show the 95% confidence interval after adjusting for spatial correlation. The color corresponds to the regression models in Fig. 1.

Méta-Analyses

Wilcox & Makowski (soumis)

Meta-analysis

Predicted effects of climate change on wheat yields using simulation studies

ISI Web of Knowledge: Web of Science

TS=((yield OR ((water OR nitrogen) AND use AND efficiency) OR disease OR grain)
AND ((climat* AND change) OR (global AND warming))
AND ((triticum AND aestivum) OR wheat)
AND model*)



639 references found in Web of Science on 22/05/2012

Criteria for selecting articles using titles and abstracts

The articles must have information on:

- at least one climate variable (CO₂, temperature, precipitation);
- at least one response variable (wheat yield, grain number, grain weight, grain protein, disease, water use efficiency, nitrogen use efficiency, growing period)
- The study had to compare the effects of current and future climate on the response variable

639 references initially found using search equations

485 articles did not meet the above criteria

154 useful articles

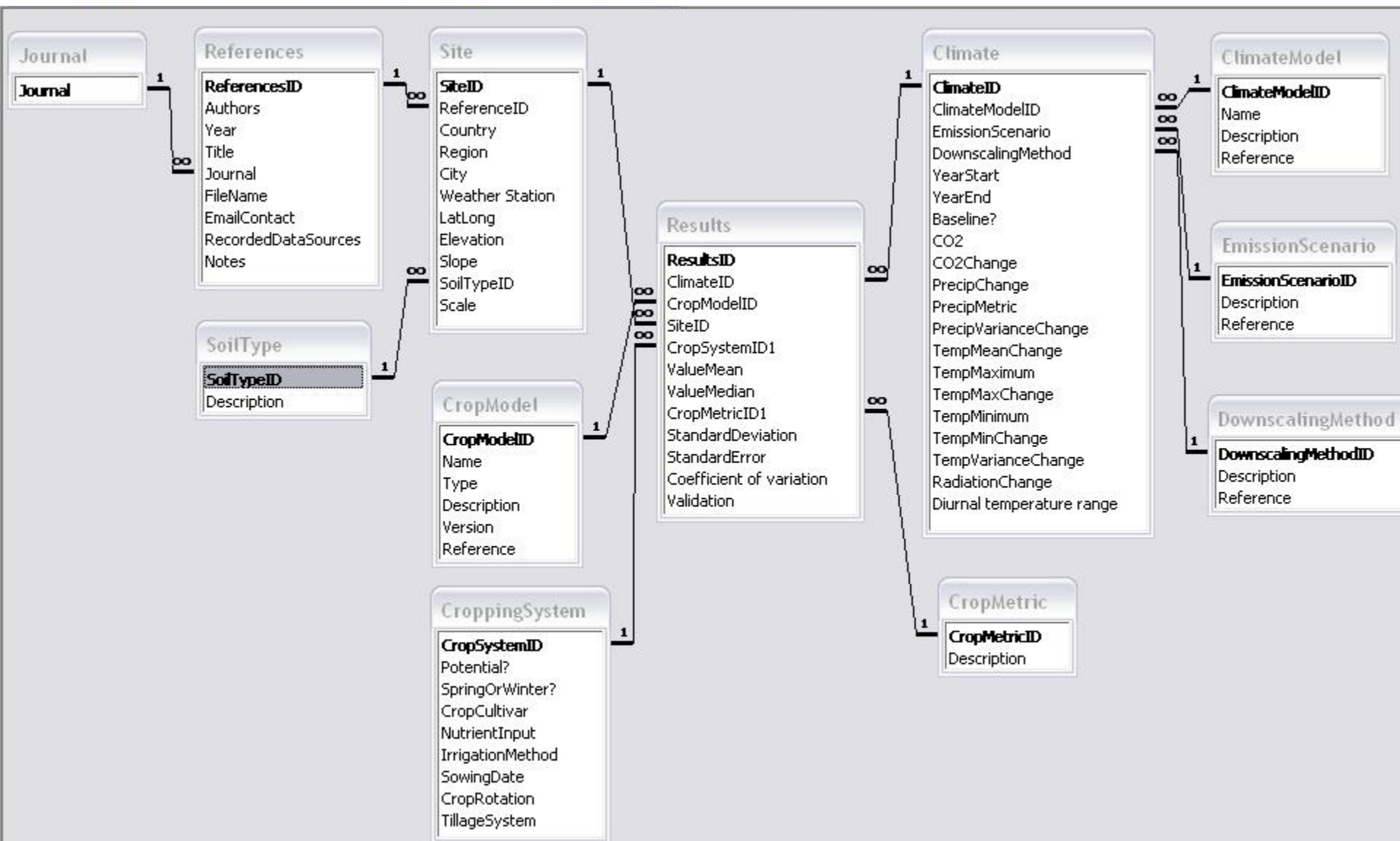
Criteria for selecting articles using the text

- 154 articles classified as potentially useful
- 19 articles did not have the full text available
- 135 articles to read
- 45 articles did not meet the data criteria
- 90 articles with useful data

Criteria for selecting articles using the text

Microsoft Excel - WheatModel.xls																
Fichier Edition Affichage Insertion Format Outils Données Fenêtre ?																
P119 fx Data in Table 3.																
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1		rating	climate variable					response variable							Comments	
2	article	(1-4)	CO2	temper ature	precip itation	radia tion	ozone	Yield	Grain #	Grain weight	Grain protein	Disease	WUE	NUE	Growing period	
3	Abbaspour et al., 2009	1		x	x											Paragraph 41 mentions wheat yield, but no data are given
4	Al-Bakri et al., 2011	2		x	x											Studied durum wheat
5	Alexandrov and Hoogenboom, 2000a (AlexandrovHoogenbo om2000)	4	x	x	x	x		x							x	Good data in Figure 9, Figure 8
6	Alexandrov and Hoogenboom, 2000b (Alexandrovetal 2000)	3	x	x	x	x		x								Percent changes in yield given in Table 2, 3, and 4
7	Alexandrov et al., 2002	3	x	x	x	x		x							x	Data in figures 5 and 6 looks okay- percent yield changes.
8	Alexandrov, 1997	2	x	x	x			x								Possible data from Figure 6 on yields, but I'm not sure what year these data represent. Questionable data Figure 5 and Table 1

Database structure



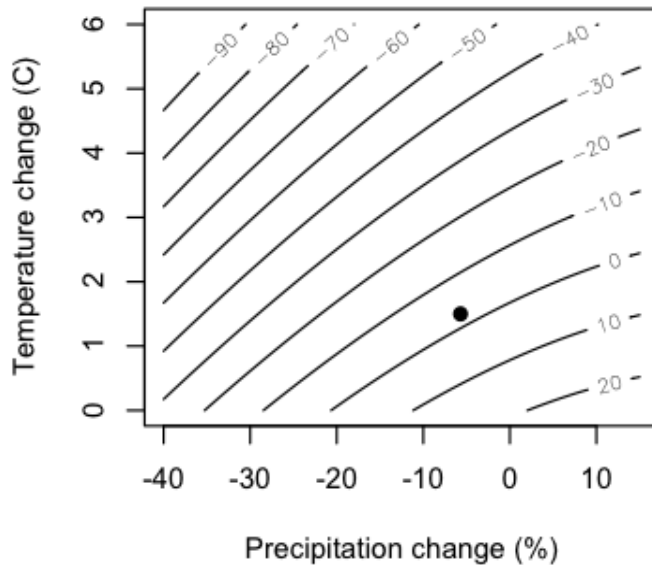
Model selection

Yield ~ (Mean temperature change) +
(CO2 level) +
(percent change in precipitation) +
(percent change in precipitation)^2
interaction(temperature*precipitation)

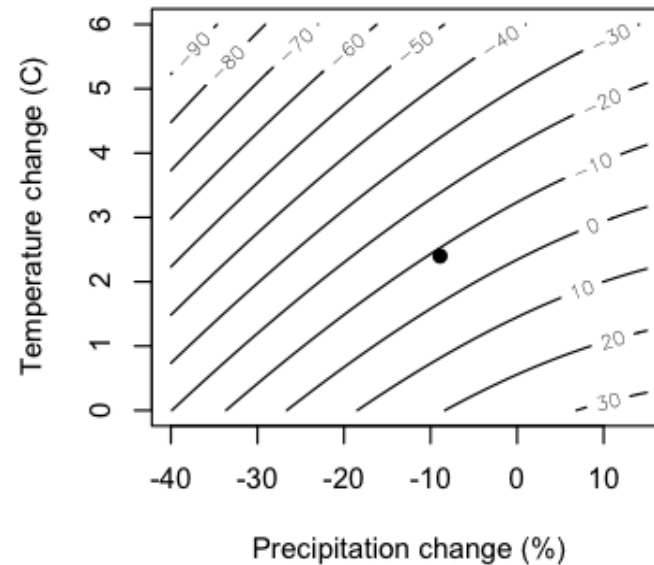
Random Effects of Site:

Intercept + slope of temperature + slope of
precipitation

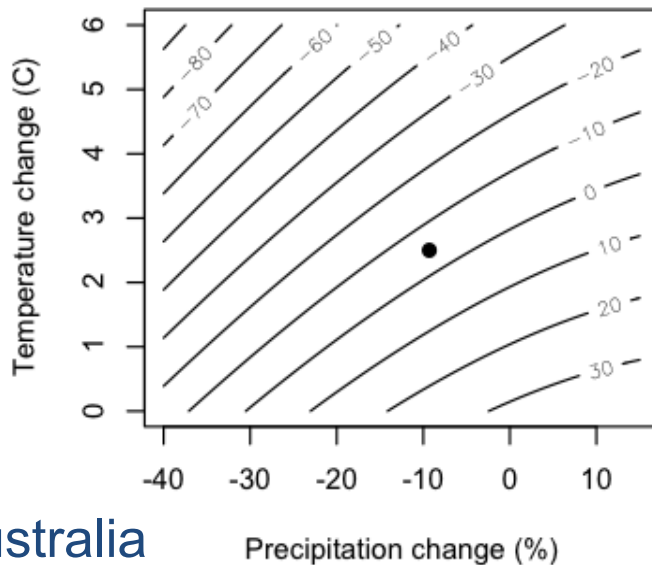
A. CO2 concentration= 477



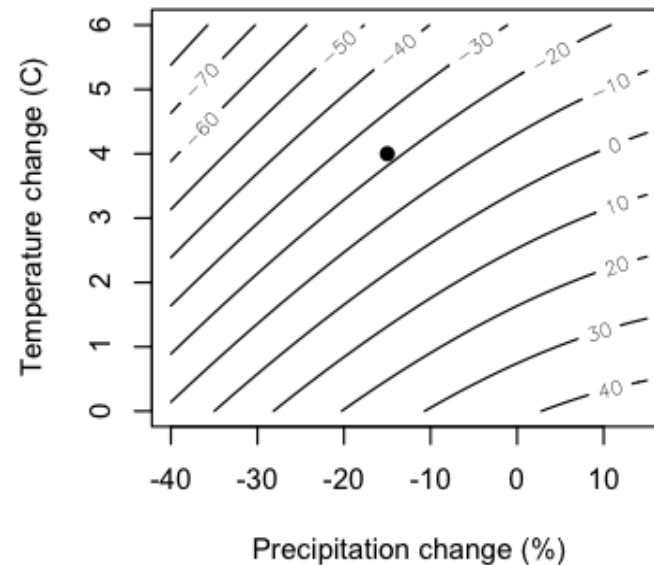
B. CO2 concentration= 570



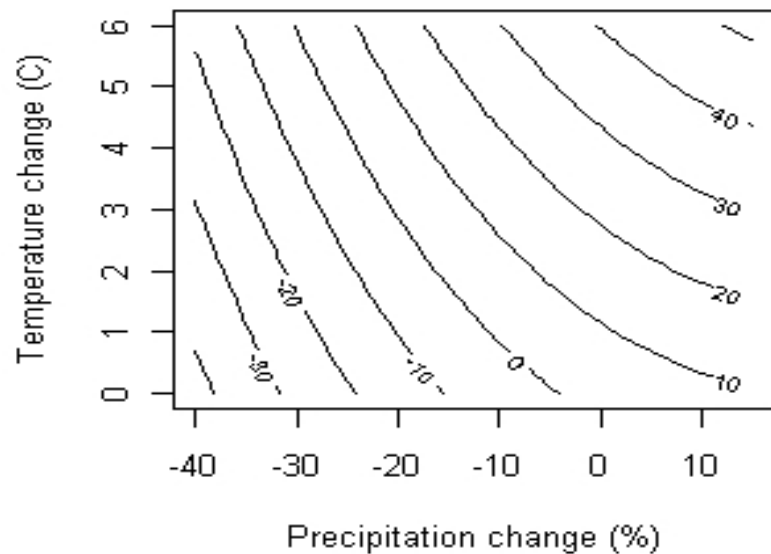
C. CO2 concentration= 637



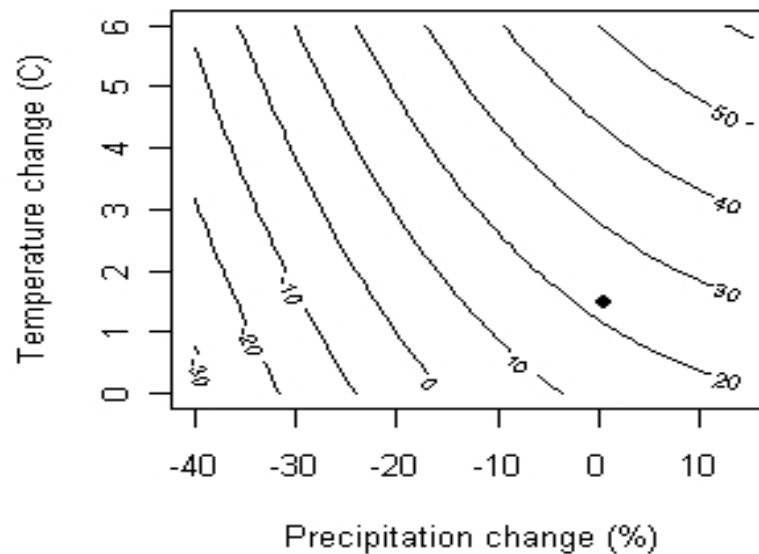
D. CO2 concentration= 720



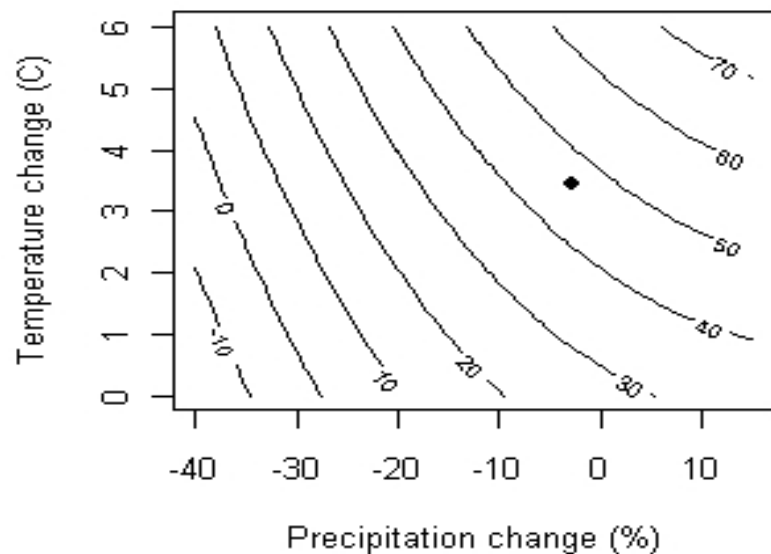
A. CO₂ concentration= 344



B. CO₂ concentration= 465



C. CO₂ concentration= 645



Modèles de Niches ou Analogues

Williams et al. (2007)

... mais pas appliqué aux agro-systèmes.

Principe 'classique' des forestiers

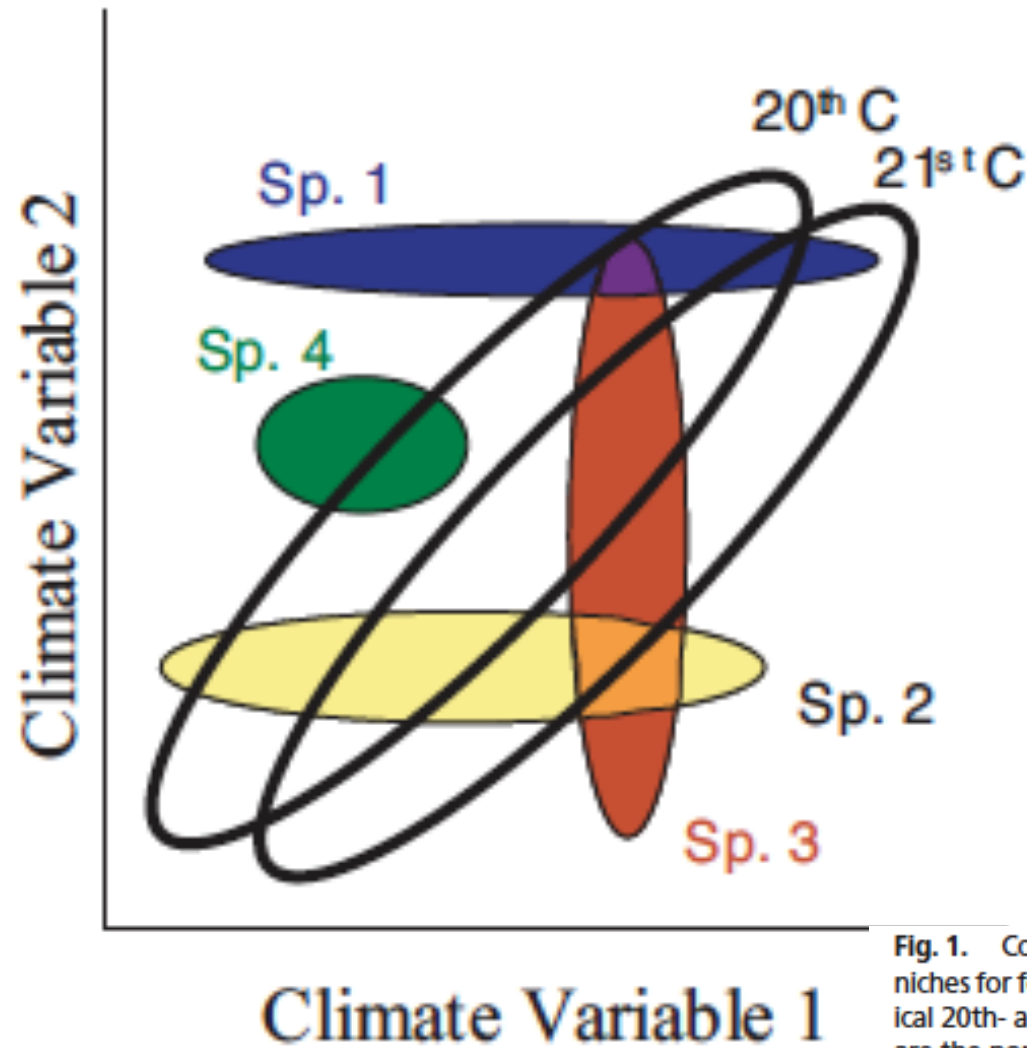
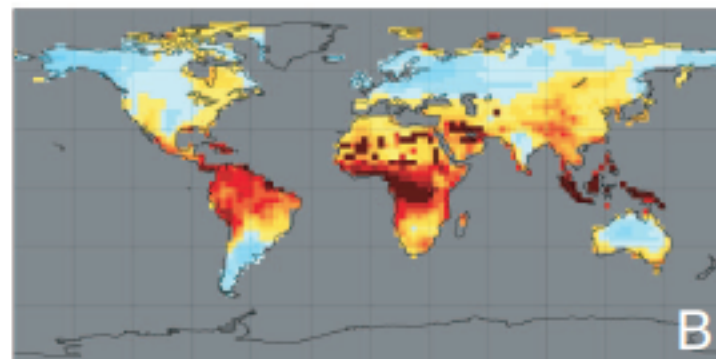
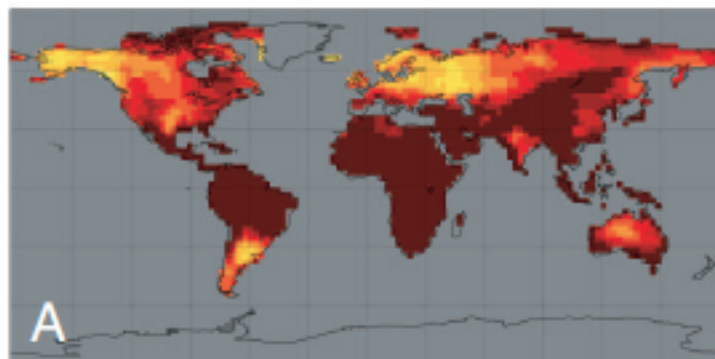
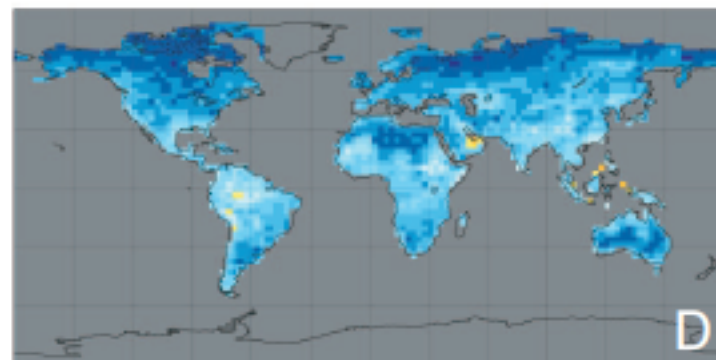
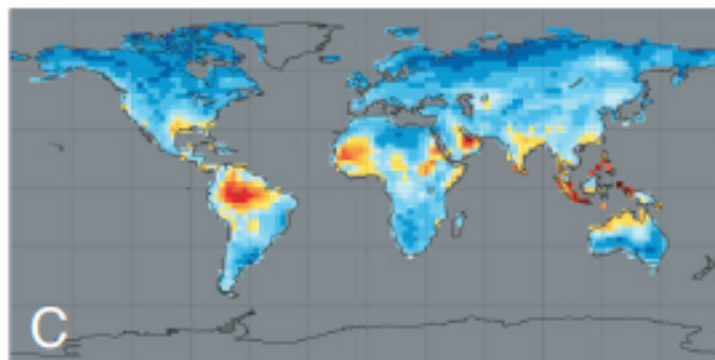
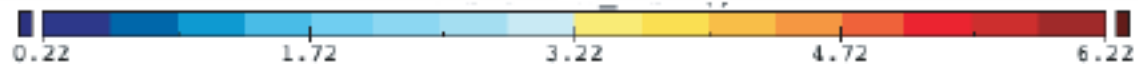
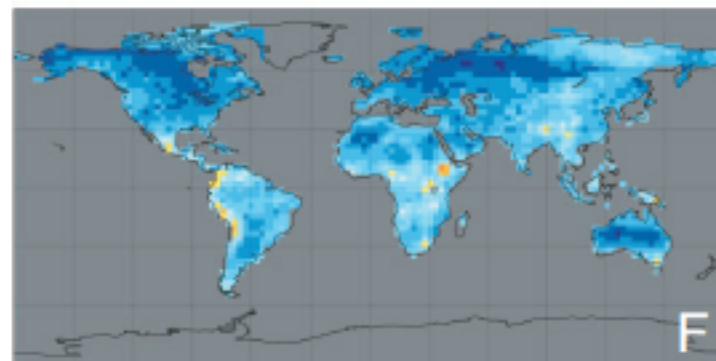
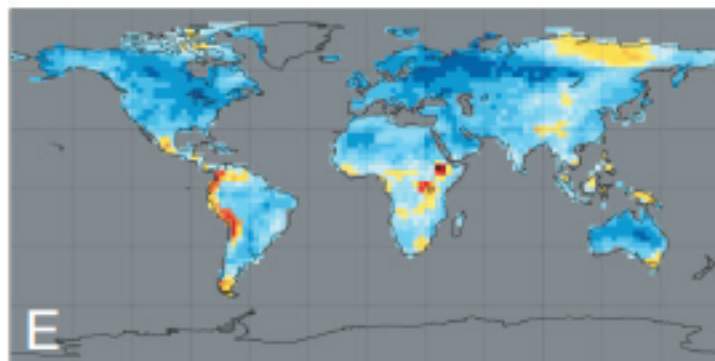


Fig. 1. Conceptual diagram showing the intersection among the fundamental niches for four species (Sp.; colored ellipses) and climatic envelopes for hypothetical 20th- and 21st-century climates (black-bordered ellipses) (8). Novel climates are the portions of the 21st-century envelope that do not overlap 20th-century climates, and disappearing climates are the portions of the 20th-century envelope that do not overlap 21st-century climates. Species cooccur only if their fundamental niches simultaneously intersect with each other and the current climatic space. Future climate change may cause a variety of ecological responses, including shifts in species distributions (species 1–3), community disaggregation (species 1 and 3), new communities forming (species 2 and 3), and extinction (species 4). This conceptual model assumes fixed niches, i.e., that climate change will outpace evolutionary adaptation (8).

A2**Local Change****B1****Novel Climates****Disappearing Climates**

Extrapolation Globale de modèles spécifiques

Parry et al. (1999)

**Crop yield by site
and scenario
ET, irrigation,
season length**



**Aggregation of site results
Agroecological zone analysis**



**Yield functions by region
Yield = $f(T, P, CO_2)$**



**Yield change estimates
Commodity group and
country/region**

STEP-1: Plusieurs simulations
sur plusieurs sites (ici 124)

- Climat actuel
- Études de sensibilité
- Avec une conduite de culture 'actuelle'

Position des 124 sites utilisés pour cette étude

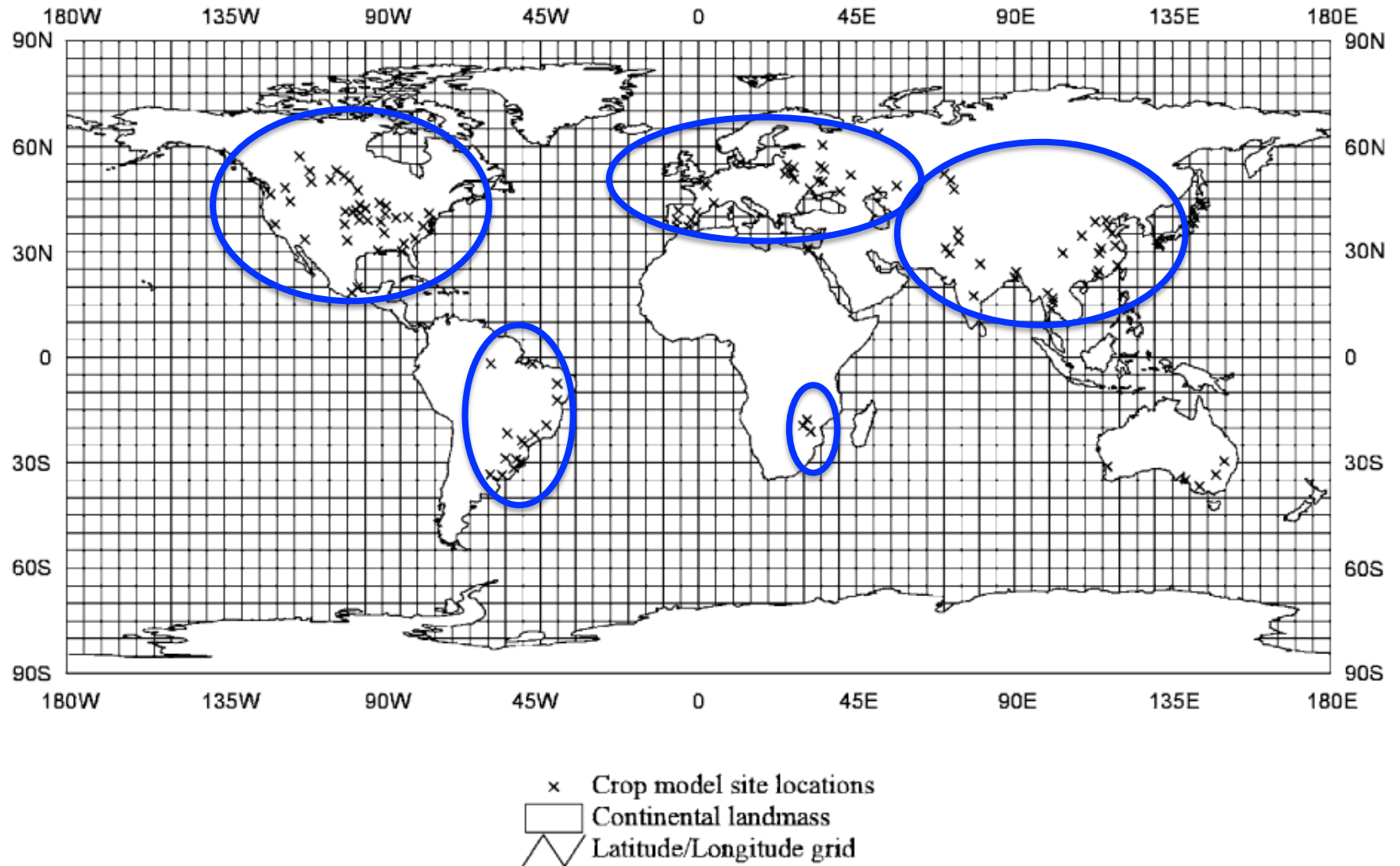


Fig. 3. The locations of the IBSNAT crop model sites.

**Crop yield by site
and scenario
ET, irrigation,
season length**

STEP-1: Plusieurs simulations
sur plusieurs sites (ici 124)

***MAIS uniquement pour
le blé, le riz, le maïs et le soja.***

**Aggregation of site results
Agroecological zone analysis**

STEP-2: aggrégation des résultats de modèles
par région agroclimatique

***MAIS pas d'information dans le papier de la
définition des zones agro-climatiques***

**Yield functions by region
 $\text{Yield} = f(T, P, \text{CO}_2)$**

**Yield change estimates
Commodity group and
country/region**

**Crop yield by site
and scenario
ET, irrigation,
season length**

STEP-1: Plusieurs simulations
sur plusieurs sites (ici 124)

***MAIS uniquement pour
le blé, le riz, le maïs et le soja.***

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***MAIS pas d'information dans le papier de la
définition des zones agro-climatiques***

**Yield functions by region
 $\text{Yield} = f(T, P, \text{CO}_2)$**

STEP-3: dérivation de fonctions liant le
rendement à des variables 'climat' pour
chaque zone agroclimatique

**Yield change estimates
Commodity group and
country/region**

**Crop yield by site
and scenario
ET, irrigation,
season length**

STEP-1: Plusieurs simulations
sur plusieurs sites (ici 124)

***MAIS uniquement pour
le blé, le riz, le maïs et le soja.***

**Aggregation of site results
Agroecological zone analysis**

STEP-2: aggrégation des résultats de modèles
par région agroclimatique

***MAIS pas d'information dans le papier de la
définition des zones agro-climatiques***

**Yield functions by region
 $\text{Yield} = f(T, P, \text{CO}_2)$**

STEP-3: dérivation de fonctions liant le
rendement à des variables 'climat' pour
chaque zone agroclimatique

**Yield change estimates
Commodity group and
country/region**

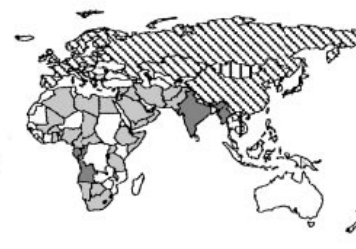
STEP-4: les fonctions définies dans l'étape 3
sont utilisées pour projeter les évolutions de
rendement

HadCM2 Ensemble Experiments- 2080s

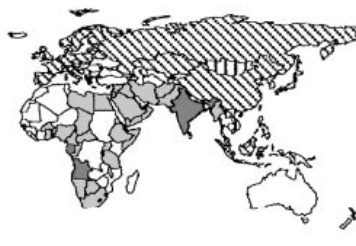
GGa1



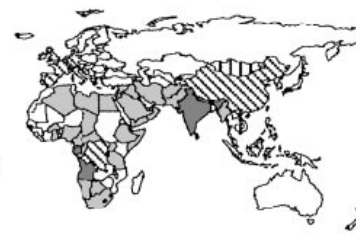
GGa3



GGa2

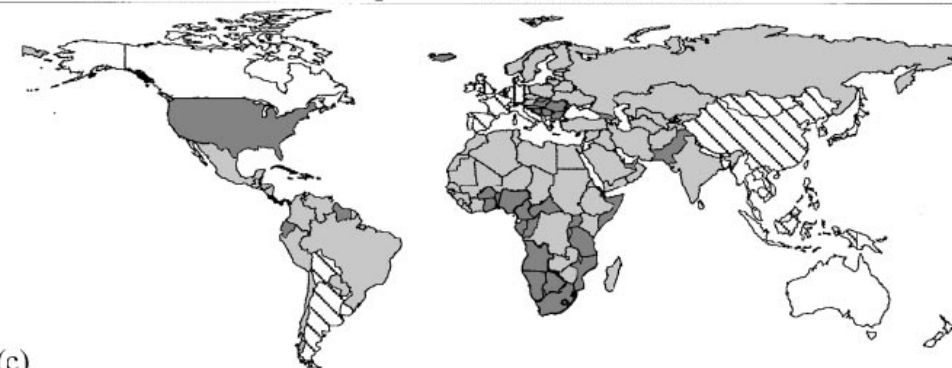


GGa4

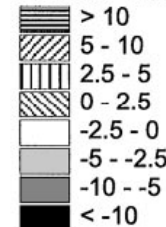


4 réalisations
du climat par un
même modèle

HadCM3GGa1 Experiment - 2080s



Potential Yield Change (%)



1 réalisation
du climat par un
autre modèle

the area most adversely affected under HadCM2 is the Indian subcontinent, under HadCM3 it is western Africa and the USA. In summary the negative effects of climate change are far more evident under the HadCM3 climate change scenario than under the HadCM2 scenarios. The primary causes of decreases in simulated yields are:

primary causes of decreases in simulated yields are:

- *Shortening of the growing period.* Higher temperatures during the growing season speed annual crops through their development (especially grain-filling stage), allowing less grain to be produced. This occurs at all sites except those with the coolest growing-season temperatures in Canada and Russia.
- *Decrease in water availability.* This is due to a combination of increases in evapotranspiration rates in the warmer climate, enhanced losses of soil moisture and, in some cases, a projected decrease in precipitation in the climate change scenarios.
- *Poor vernalization.* Vernalization is the requirement of some temperate cereal crops, e.g. winter wheat, for a period of low winter temperatures to initiate or accelerate the flowering process. Low vernalization results in low flower bud initiation and ultimately reduced yields. Decreases in winter wheat yields at some sites in Canada and the former USSR are due to lack of vernalization.

Global Agro-Ecological Assessment

Fischer et al. (2002)

<http://gaez.fao.org/Main.html#>

First, AEZ provides a standardized framework for the characterization of climate, soil, and terrain conditions relevant to agricultural production. In this con-

**Sélection de
systèmes de
production: F**
(intrants, ITK,
besoins envirt, ..)

**Procédures pour
calculer les
rendements**

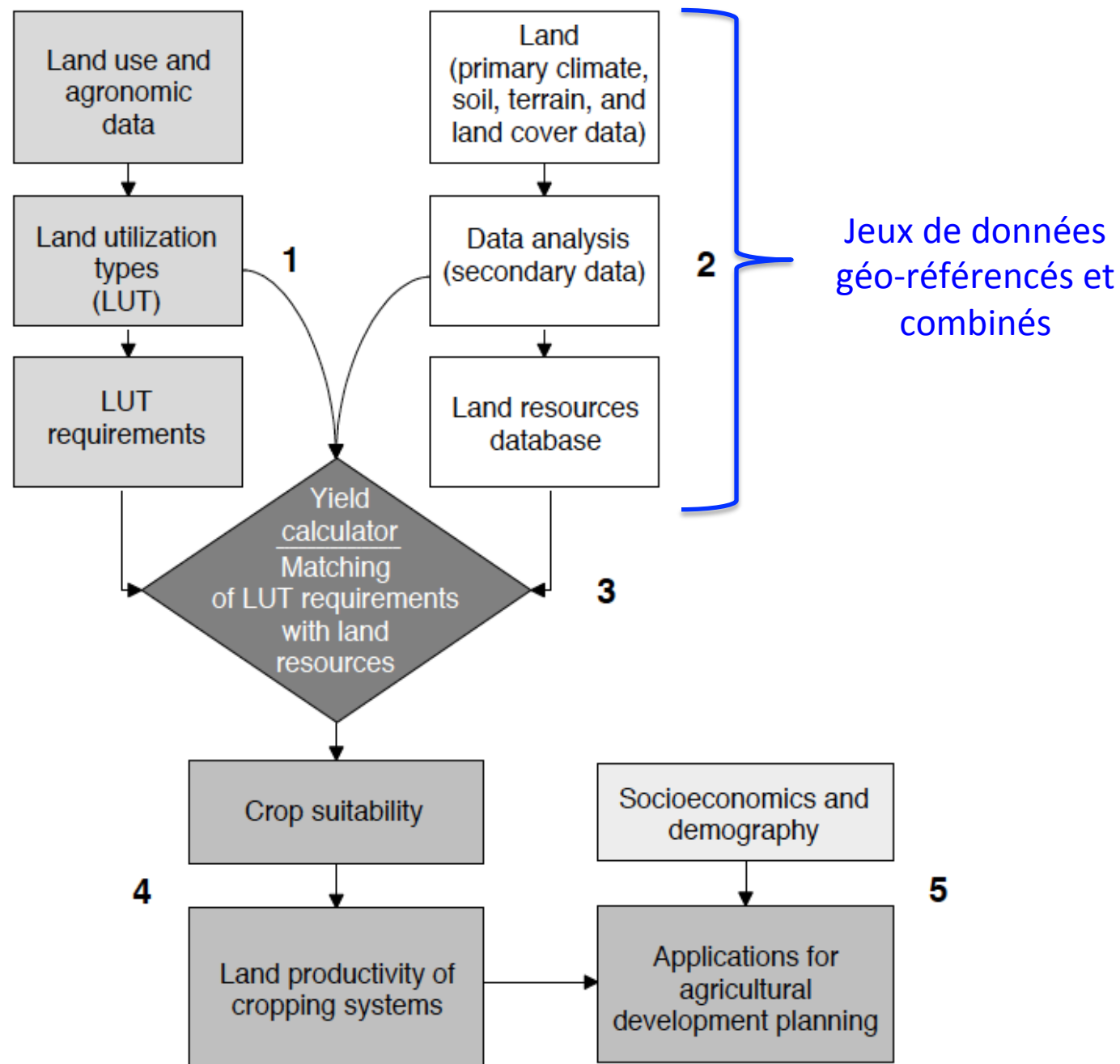


Figure 2.1. Conceptual framework of agro-ecological zones methodology.

Table 4.1. Crop types included in the GAEZ study.

Crops	Crop types	Climate zones
<i>Cereals</i>	(83)	
Wheat (hibernating)	4	Boreal, temperate, and subtropics
Wheat (non-hibernating)	12	Boreal, temperate, subtropics, and tropics
Rice, japonica (wetland)	4	Tropics, subtropics, and temperate
Rice, indica (wetland)	4	Tropics and subtropics
Rice (dryland)	3	Tropics
Maize (grain)	13	Tropics, subtropics, and temperate
Maize (silage)	6	Subtropics and temperate
Barley (hibernating)	4	Boreal, temperate, and subtropics
Barley (non-hibernating)	12	Boreal, temperate, subtropics, and tropics
Sorghum	7	Tropics, subtropics, and temperate
Pearl millet	2	Tropics
Foxtail millet (<i>Setaria</i>)	4	Subtropics and temperate
Rye (hibernating)	4	Temperate and subtropics
Rye (non-hibernating)	4	Boreal, temperate, and subtropics
<i>Roots and tubers</i>	(8)	
White potato	4	Boreal, temperate, subtropics, and tropics
Cassava	1	Tropics
Sweet potato	3	Subtropics and tropics
<i>Pulses</i>	(17)	
Phaseolus bean	9	Tropics, subtropics, and temperate
Chickpea	5	Subtropics and tropics
Cowpea	3	Tropics
<i>Oil crops</i>	(25)	
Soybean	6	Tropics, subtropics, and temperate
Rape (hibernating)	2	Temperate and subtropics
Rape (non-hibernating)	6	Temperate, subtropics, and tropics
Groundnut	3	Tropics, subtropics, and temperate
Sunflower	6	Temperate, subtropics, and tropics
Oil palm	1	Tropics and subtropics
Olive	1	Subtropics and temperate
<i>Fiber crops</i>	(7)	
Cotton	7	Tropics, subtropics, and temperate
<i>Sugar crops</i>	(6)	
Sugarcane	1	Tropics and subtropics
Sugar beet	5	Temperate and subtropics
<i>Fruit crops</i>	(1)	
Banana/plantain	1	Tropics and subtropics
<i>Forage/fodder</i>	(7)	
Forage legume (alfalfa)	1	Temperate and subtropics
Pasture grasses	4	Boreal, temperate, subtropics, and tropics
Pasture legumes	2	Boreal, temperate, subtropics, and tropics
Total	154	

**Land Utilization Types: 154 types
(cultures, fourrages, prairies),
chacun à 3 niveaux d'intrants
(haut, intermédiaire, bas)**

Table 2.1. An example of crop parameterization in GAEZ: Winter wheat, high level of inputs.

Crop characteristics		
Adaptability group		C3/1
Growth cycle		110–130 days
Pre-dormancy period		30 days
Post-dormancy period		90 days
Maximum leaf area index		4.5
Crop stages (%)	Initial	10
	Crop development	30
	Mid-season	35
	Late season	25
Crop water requirement	Initial	0.4
(K_c -factor)	Crop development	0.4–1.1
	Mid-season	1.1
	Late season	1.1–0.4
Moisture-stress-related yield	Initial	0.2
reduction (K_y -factor)	Crop development	0.6
	Mid-season	0.75
	Late season	0.50
Crop requirements		
Thermal climates	Boreal, temperate, subtropics	
Temperature profile	See Chapter 4	
Growing period	See Chapter 4	
Dormancy	Required	
Post-dormancy accumulated temperature (optimal)	> 1300	
Post-dormancy accumulated temperature (suboptimal)	> 1200	
Sensitivity to soil moisture depletion	Class 3	
Soil and terrain conditions	See Chapter 4	
Crop conversion factors		
Harvest index	0.45	
Cereal equivalent ratio	1.0	
Extraction rate	75%	
Energy contents (Kcal/1,000 g)	3,640	
Protein contents (g/1,000 g)	110	
Crop residue factor (kg dry matter/kg yield)	1.0	
Crop residue utilization rate	40%	
Crop by-product factor (kg dry matter/kg yield)	0.20	
Crop by-product utilization rate	90%	

ICI:
un exemple de caractéristiques
pour un LUT, permettant de
calculer le rendement potentiel

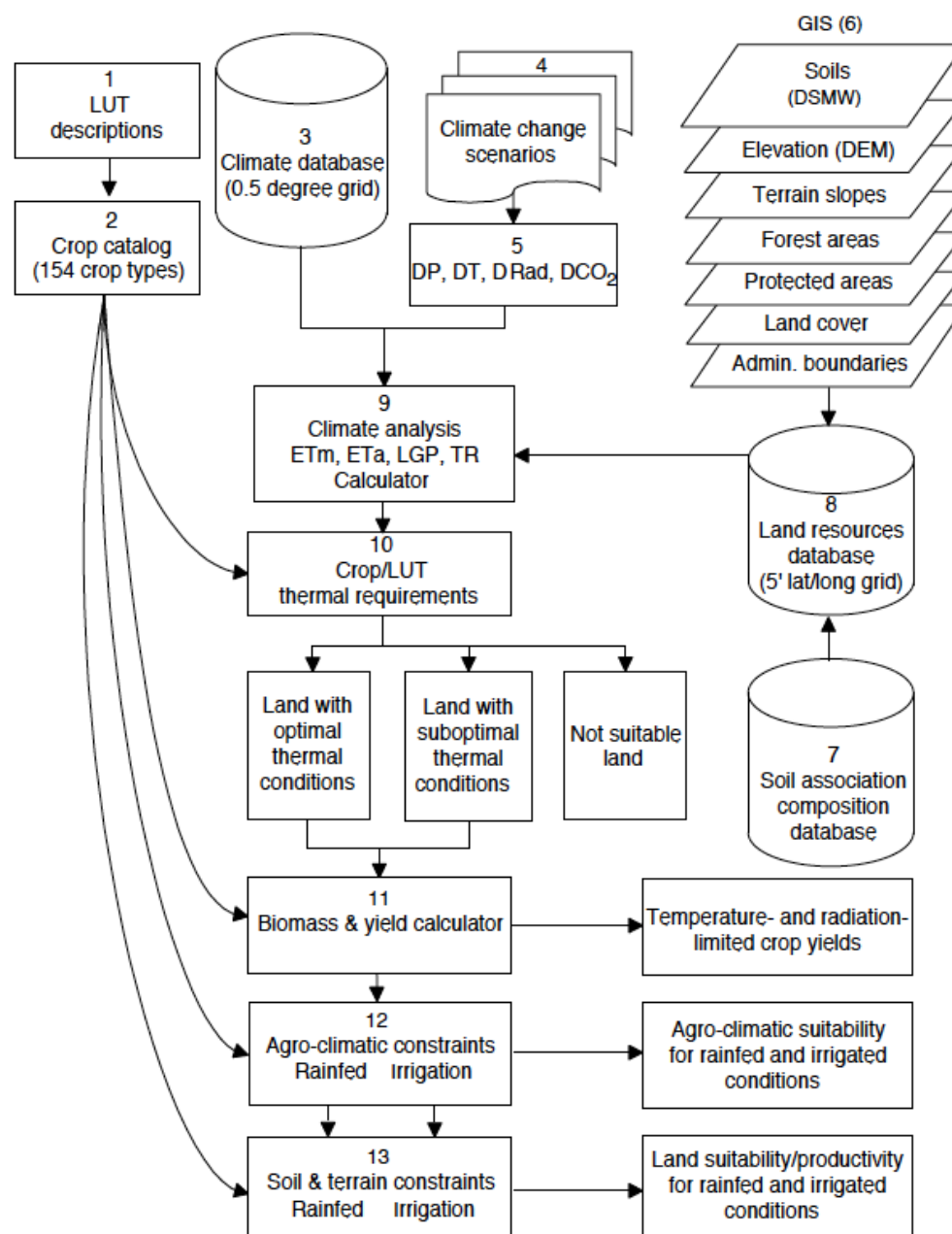


Figure 2.2. Global agro-ecological zones methodology.

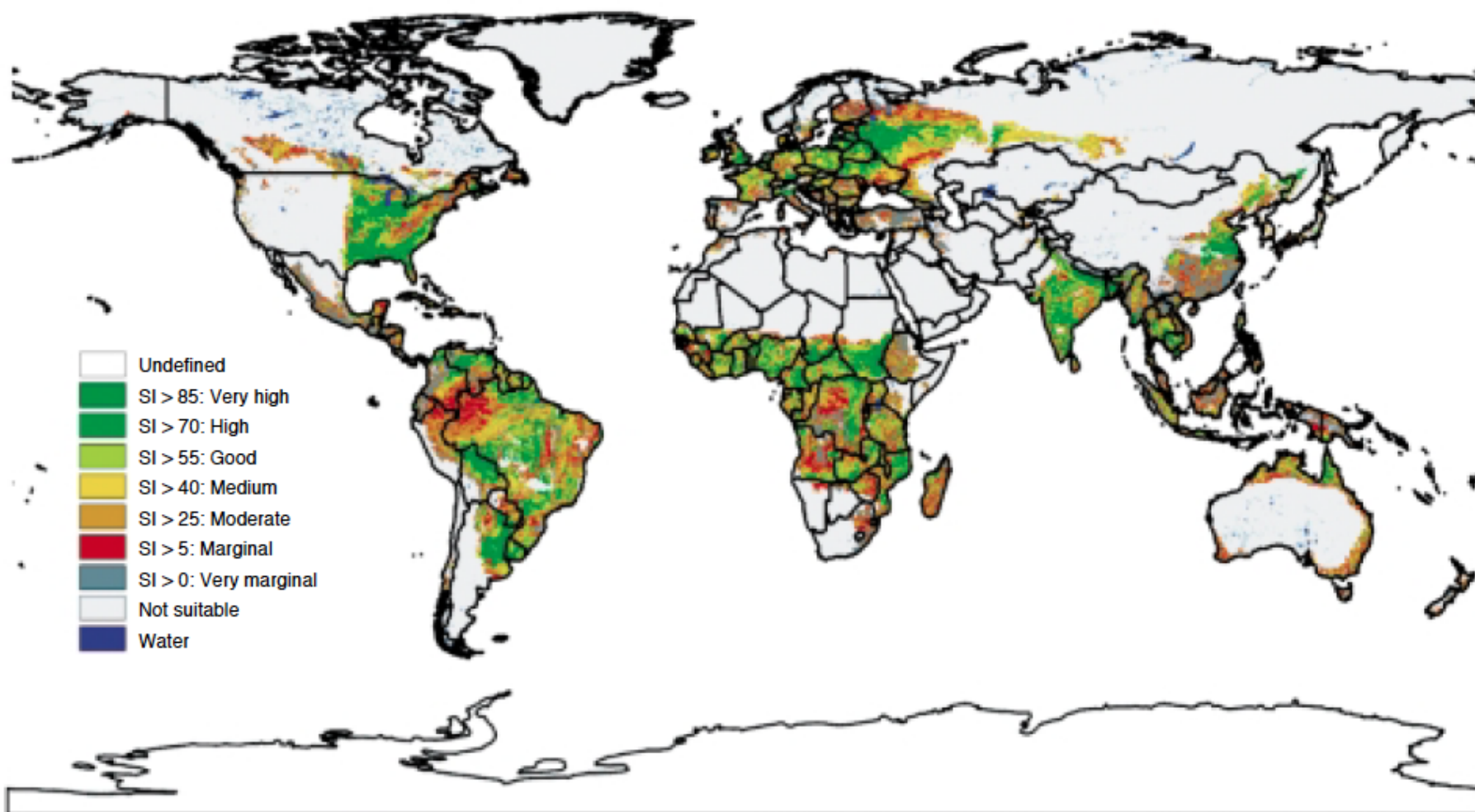


Plate G. Suitability for rain-fed cereals (high level of inputs).

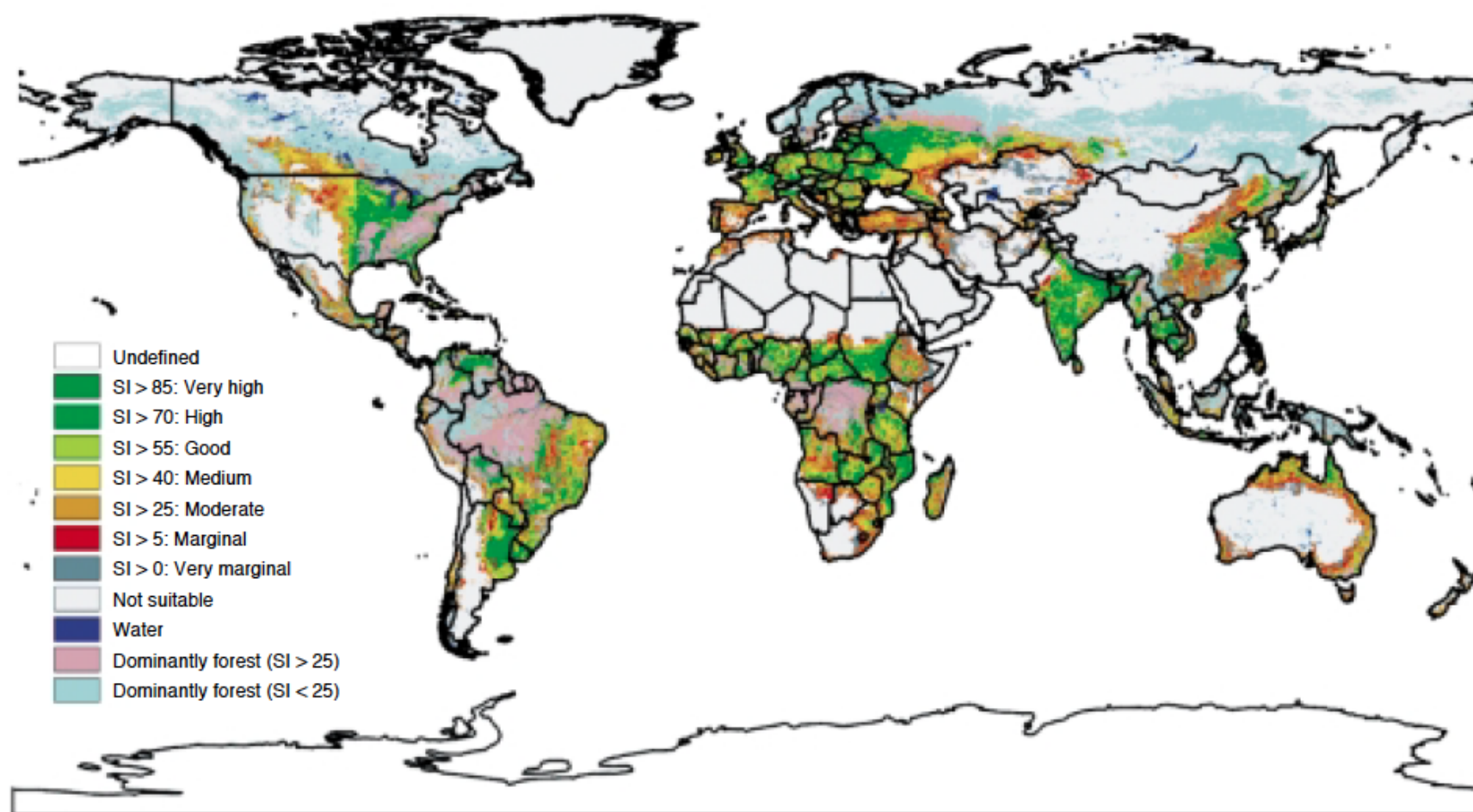


Plate H. Suitability for rain-fed crops (maximizing technology mix).

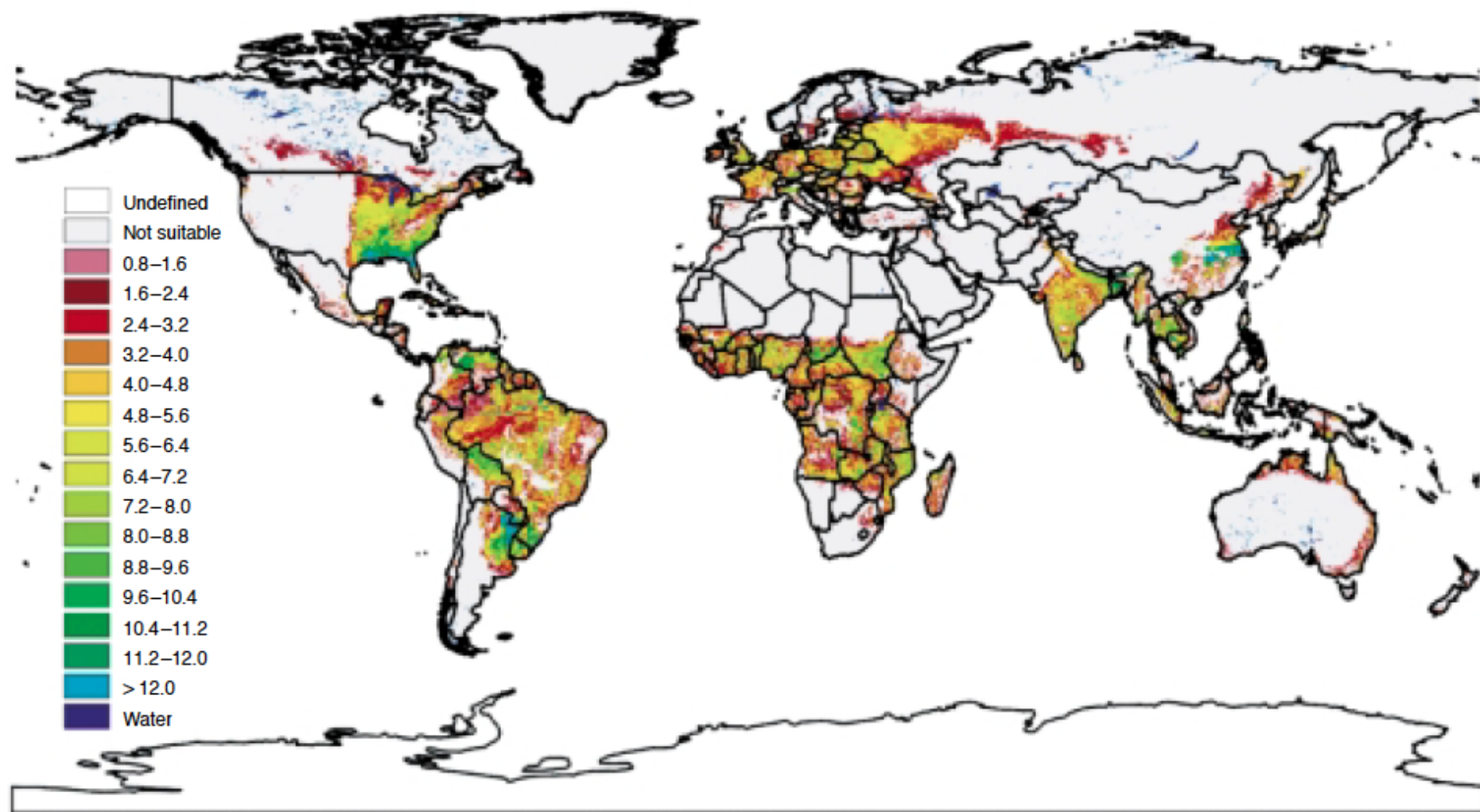


Plate J. Expected grid-cell output^a per hectare for multiple cropping of rain-fed cereals (high level of inputs).

^aGrid-cell output differs from yields; it accounts for per hectare production of total land of individual grid-cells, including not suitable areas.

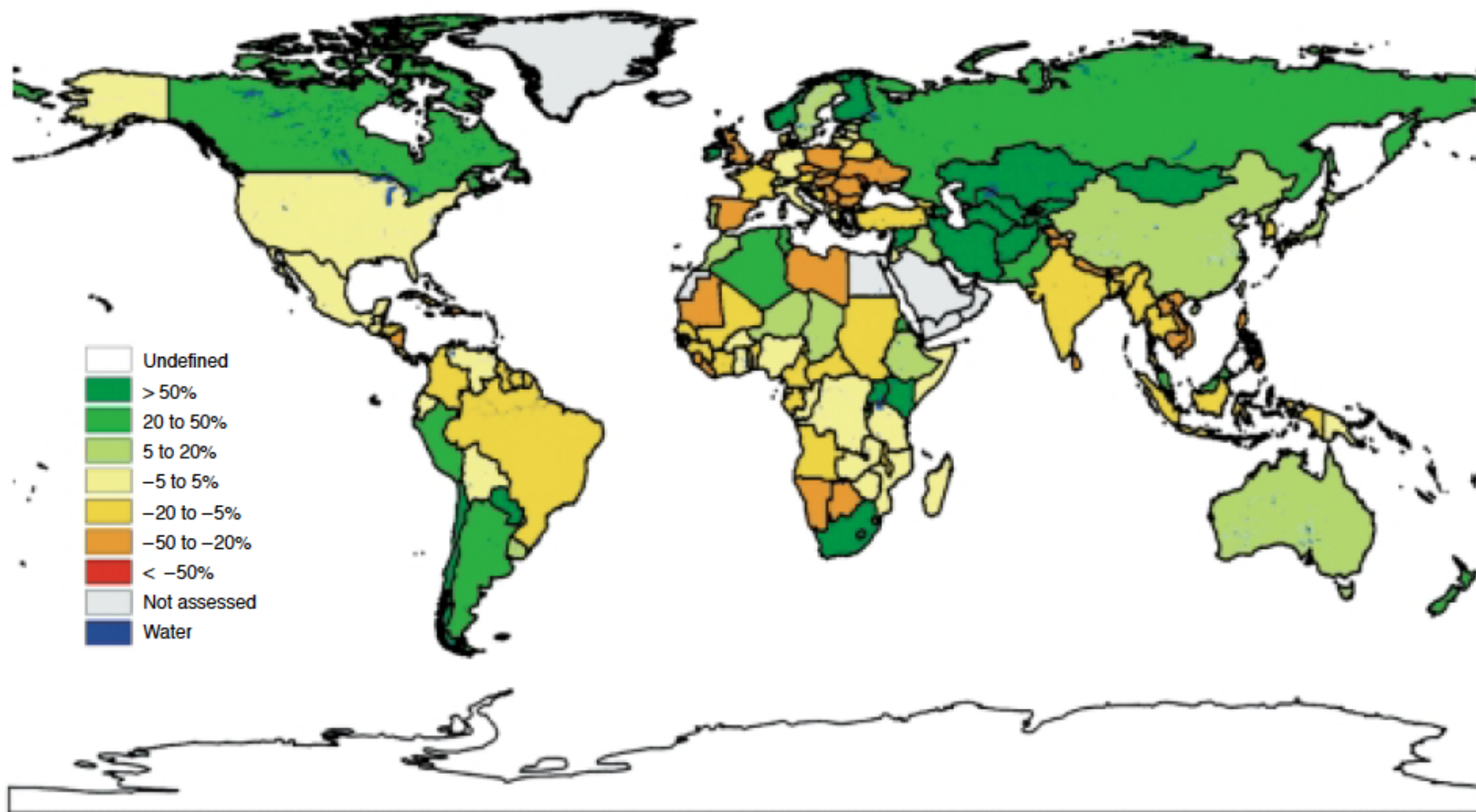


Plate K. Max-Planck Institute of Meteorology/ECHAM4 2080: Country-level climate change impacts on rain-fed cereal production potential on currently cultivated land.

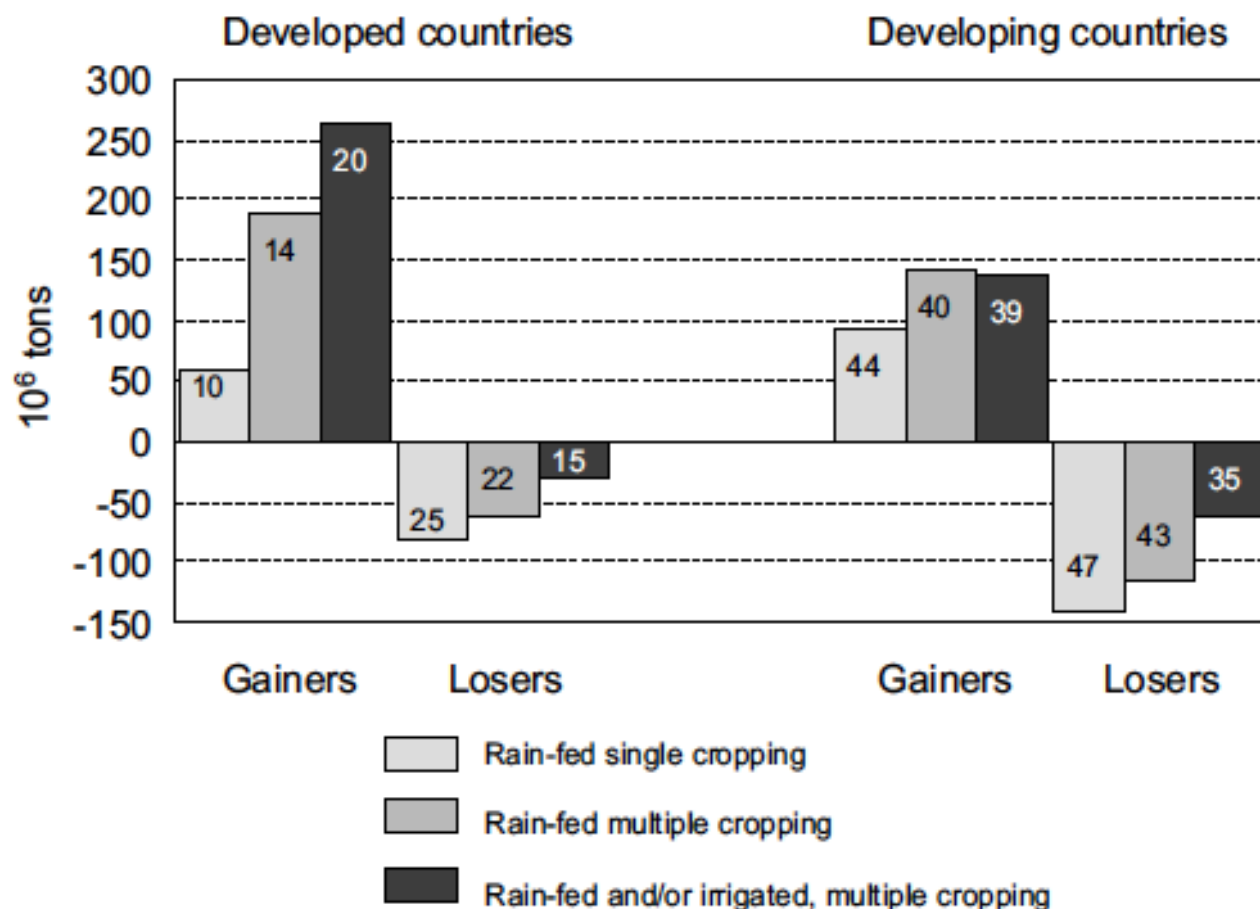


Figure 5.3. Impact of climate change on rain-fed (RF) single cropping, rain-fed multiple cropping (RF_MC), and rain-fed and/or irrigated multiple cropping (RF+IR_MC) cereal production potential on currently cultivated land. Number of countries affected is shown in bars. Gains refer to production increases larger than 5%, losses refer to decreases of 5% or more. The total number of countries is 158, of which 117 are developing and 41 developed. Countries in the range of -5% to +5% are not shown.

Modèles Globaux empiriques

Deryng et al. (2011)

Modèle PEGASUS

Base de données

Table 1. Minimum Data Requirements to Run PEGASUS and Description of the Specific Data Sets Used in This Study

Data Set	Variable Name	Spatial Reference	Temporal Reference	Source
Climate data (CRU)	temperature, precipitation, fraction of sunshine hours	10' lat × 10' lon	monthly average 1961–1990	<i>New et al.</i> [2002]
Soil data (ISRIC-WISE)	Available water capacity (top 50 cm, top 20 cm, 50–150 cm soil columns)	10' lat × 10' lon (original is 5' lat × 5' lon)	-	<i>Batjes</i> [2006]
Irrigation data (MIRCA 2000)	Annual irrigated harvested area	10' lat × 10' lon (original is 5' lat × 5' lon)	2000	<i>Portmann et al.</i> [2010]
Fertilizer data	total chemical fertilizer application	national average	mid-1990s	<i>IFA</i> [2002]
M3-crops data	Yield, Harvested area	' lat × 10' lon (original is 5' lat × 5' lon)	average for 1998–2002	<i>Monfreda et al.</i> [2008]
Global crop calendar	planting dates, harvesting dates	10' lat × 10' lon	1990s and early 2000s	<i>Sacks et al.</i> [2010]

Modèle PEGASUS

Des règles allométriques

Une étape d'évaluation du modèle À suivre

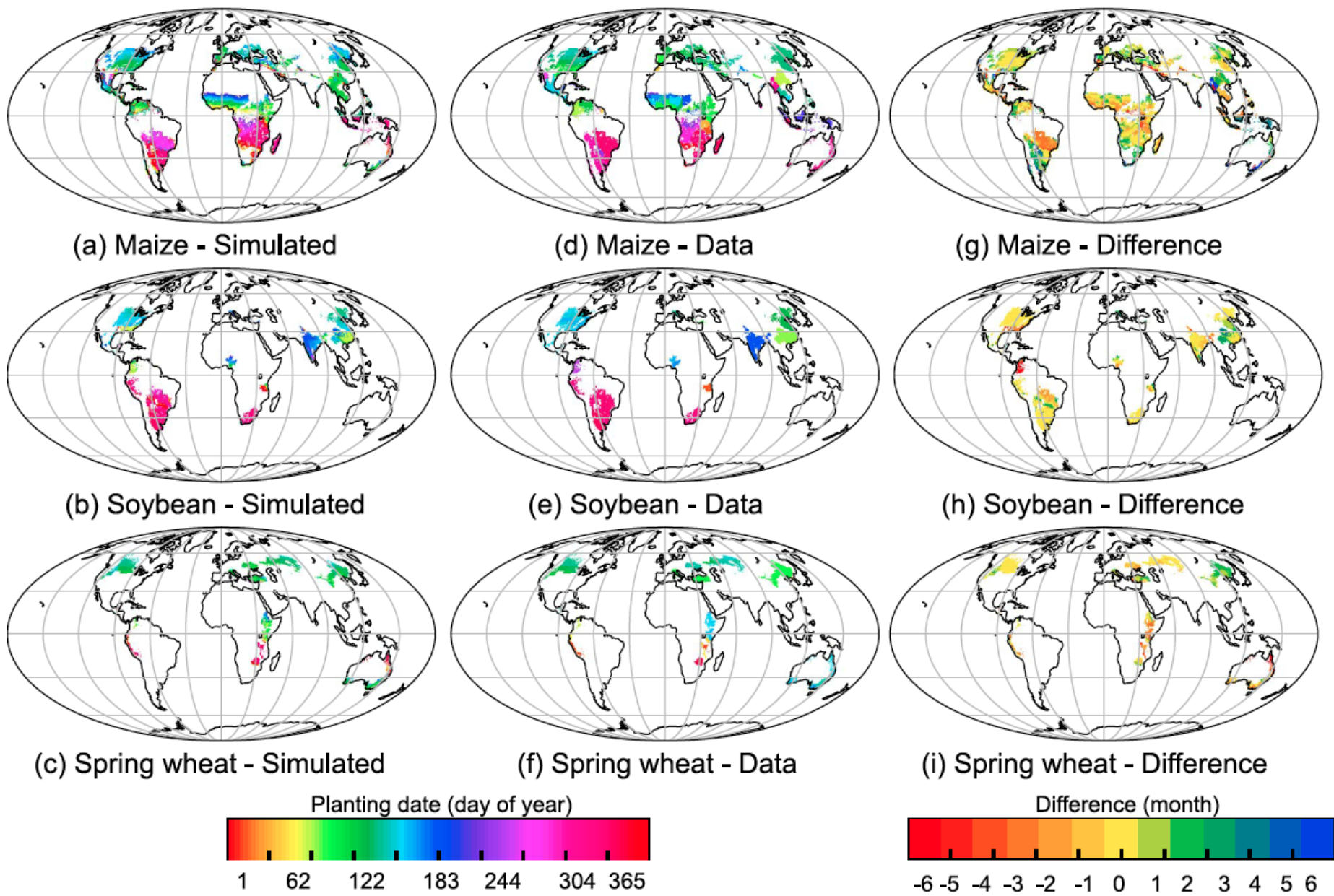


Figure 6. (a–c) Global planting dates simulated by PEGASUS and (d–f) corresponding planting date observations [Sacks *et al.*, 2010] for each crop. (g–i) The difference in months between simulated and observed planting dates.

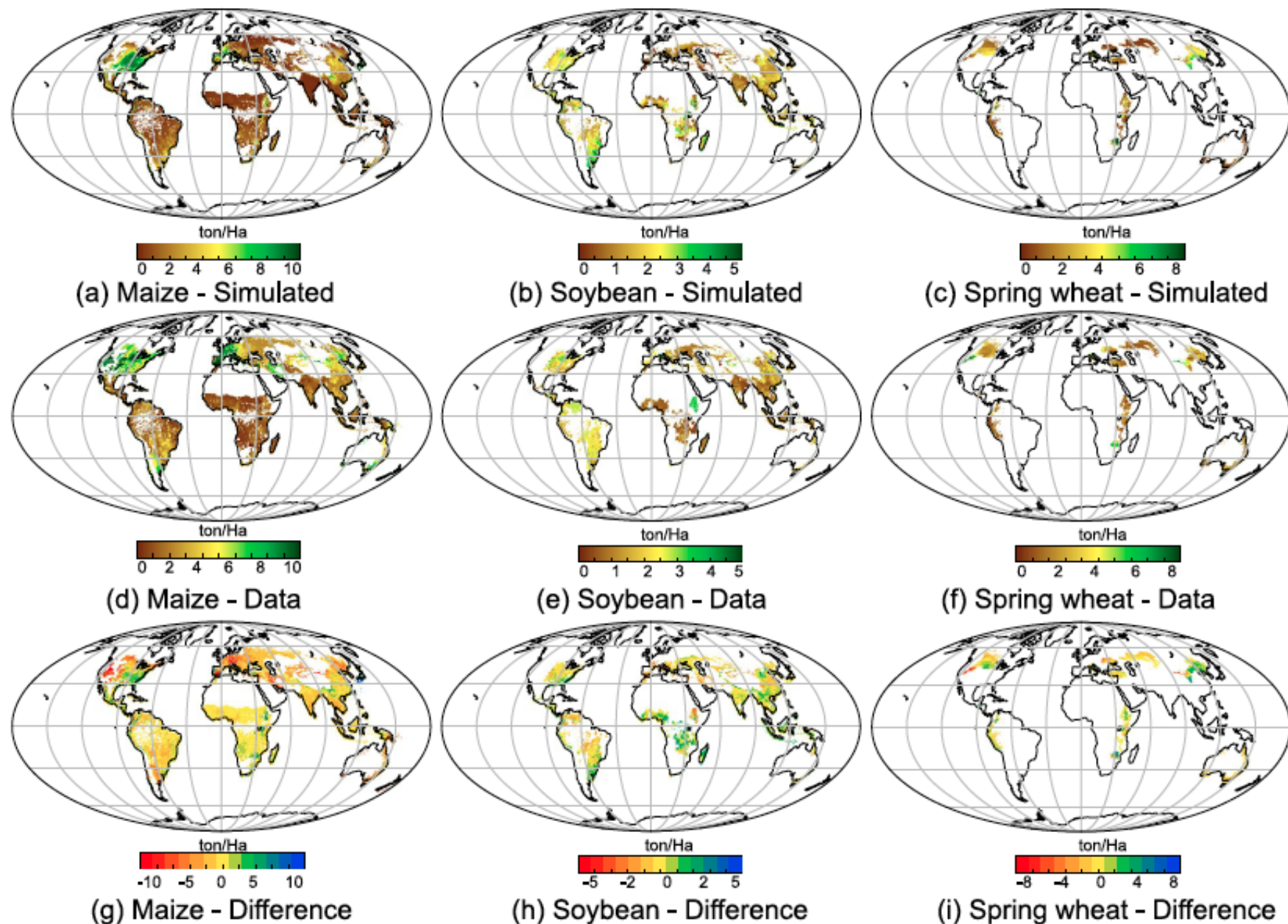


Figure 8. Global crop yields simulated by PEGASUS for (a) maize, (b) soybean, and (c) spring wheat and (d–f) corresponding crop yield observations [Monfreda *et al.*, 2008]. (g–i) The spatial differences in ton/ha between simulated and observed crop yields for each corresponding crop type.

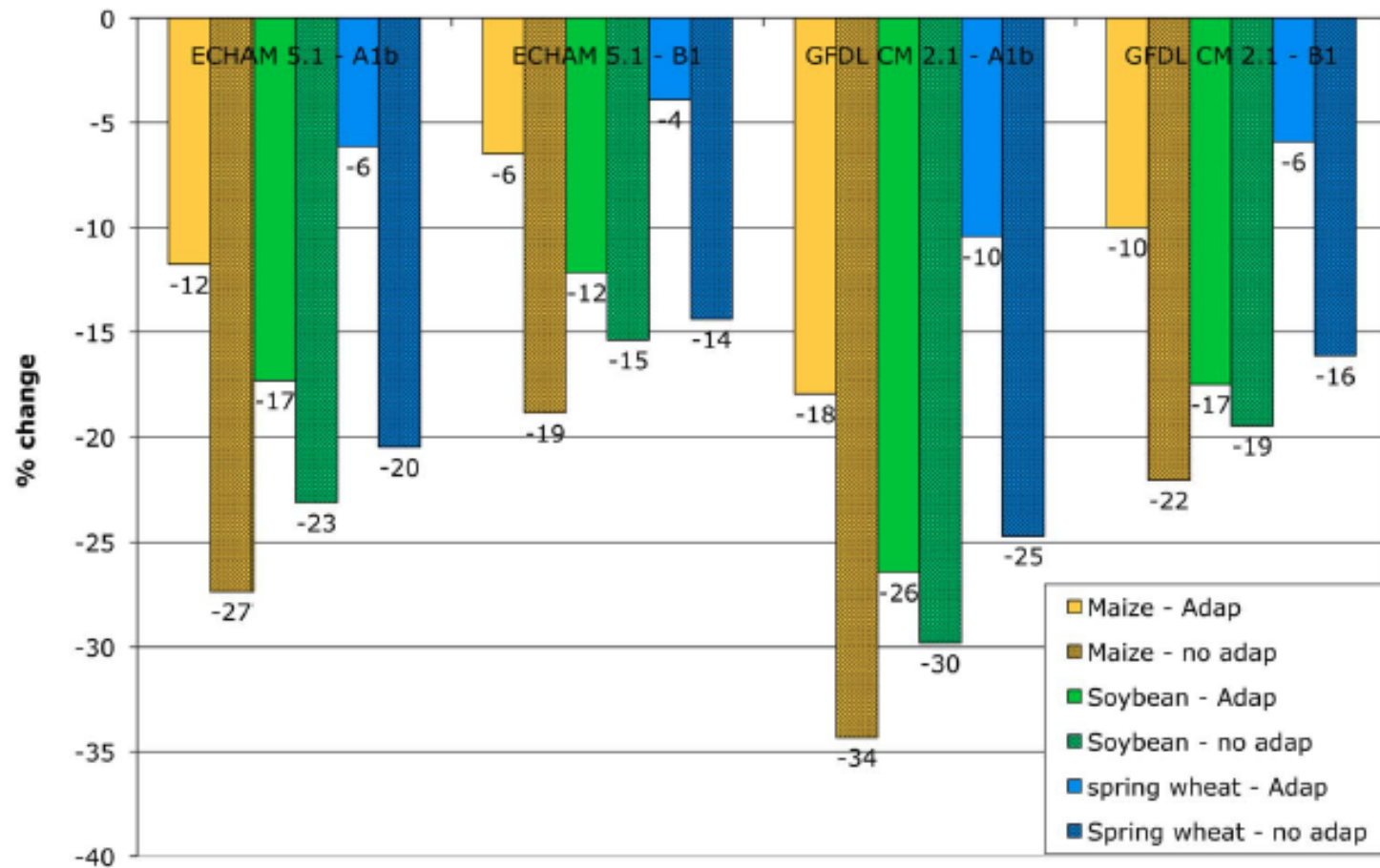


Figure 10. Estimated changes in global average crop yield by 2050 using temperature and precipitation simulations from two GCMs (ECHAM 5.1 and GFDL CM 2.1), two emissions scenarios (A1b and B1), and for the two scenarios of planting and harvesting decisions.

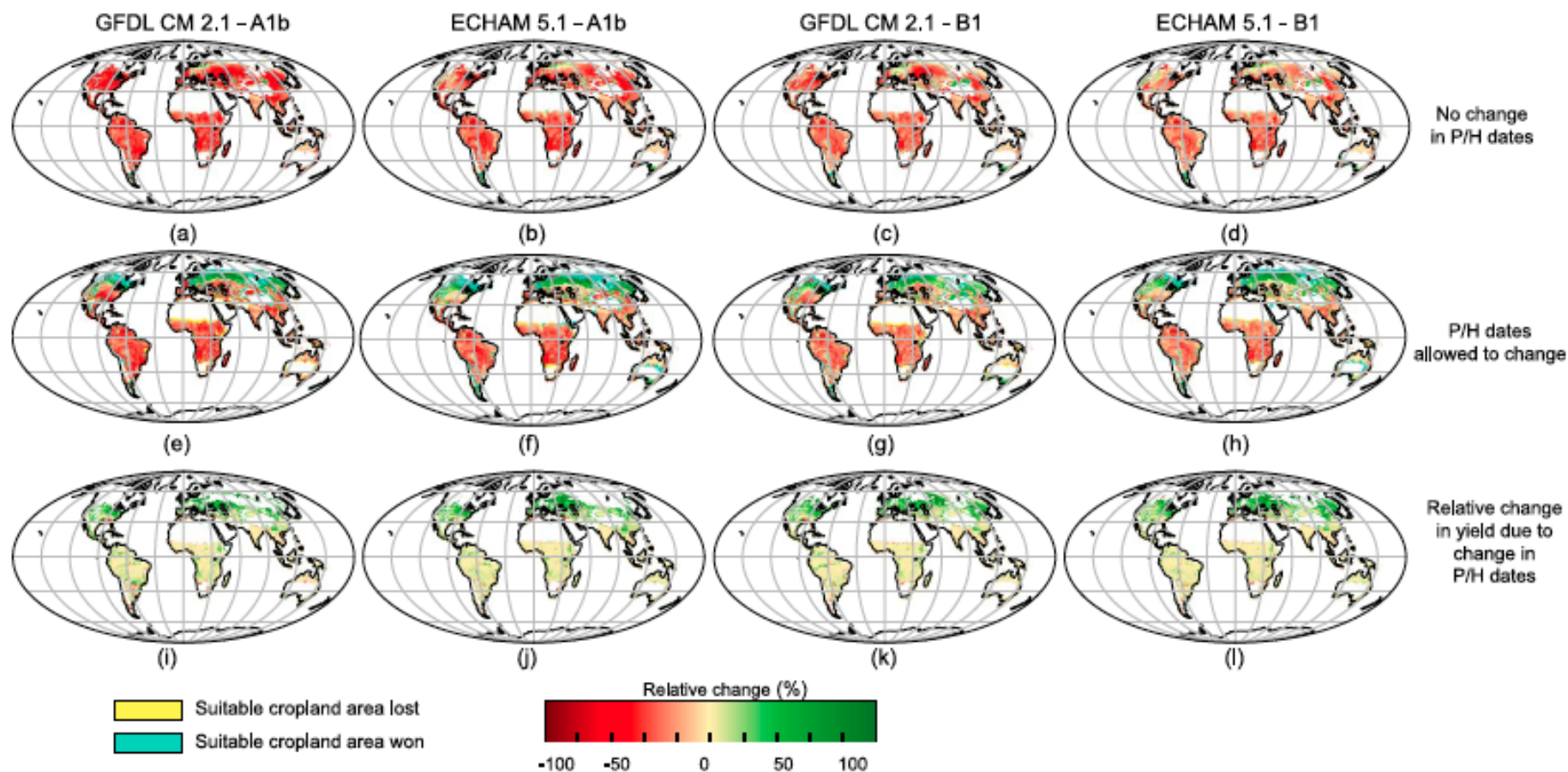


Figure 11. Estimated change (%) in maize yield by 2050, relative to the control simulation, with four different future climate simulations (a–d) for present-day planting (P) and harvesting (H) dates and (e–h) for planting and harvesting dates adapted to higher temperature. (i–l) The relative difference (%) between Figures 11a–11d and the corresponding Figures 11e–11h. White areas indicate unsuitable regions for growing crops.

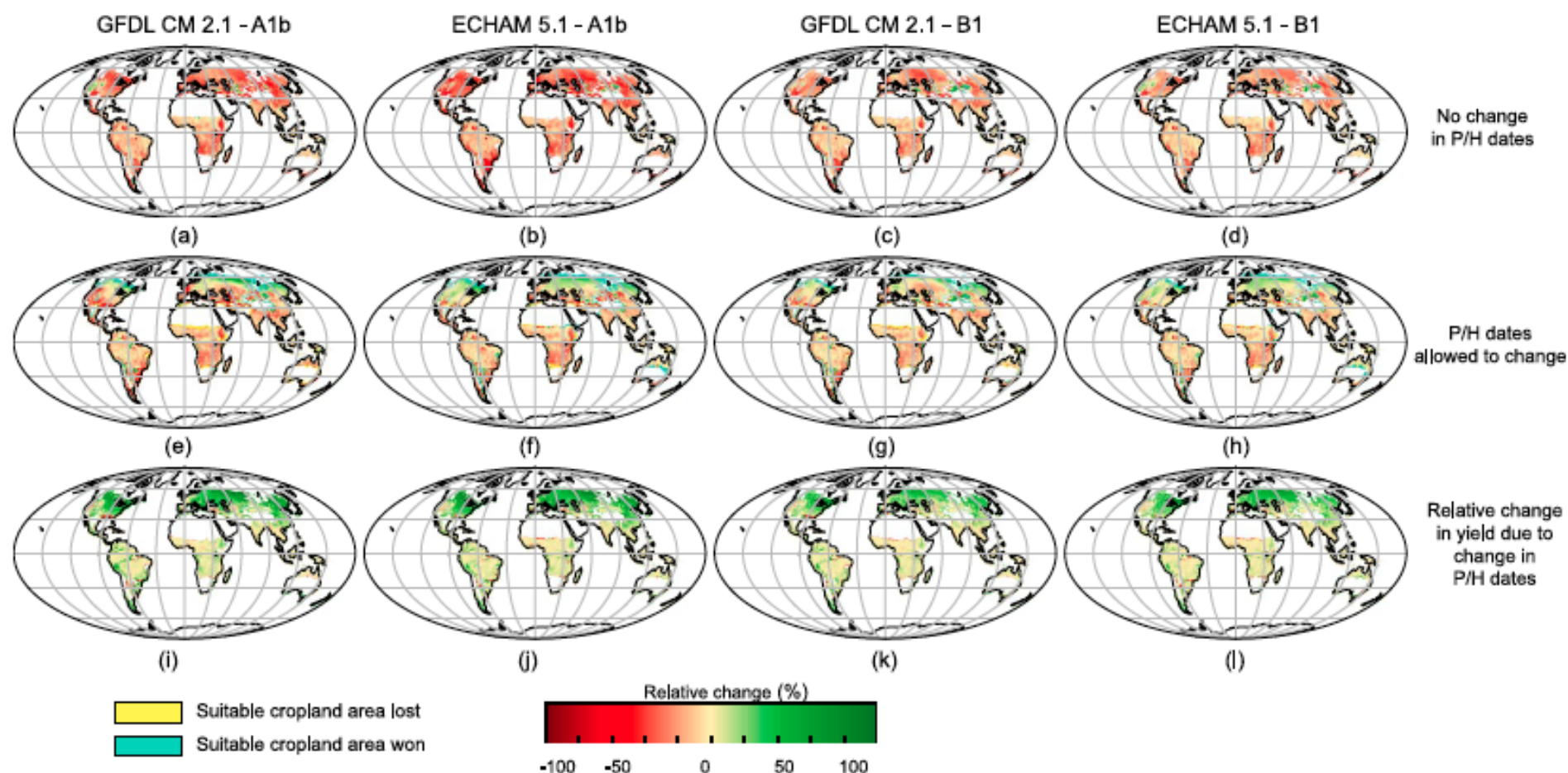


Figure 13. Estimated change (%) in spring wheat yield by 2050, relative to the control simulation, with four different future climate simulations (a–d) for present-day planting (P) and harvesting dates (H) and (e–h) for planting and harvesting dates adapted to higher temperature. (i–l) The relative difference (%) between Figures 13a–13d and the corresponding Figures 13e–13h. White areas correspond to unsuitable regions for growing crops.

Modèles Globaux basés sur les processus

**les résultats de tels modèles peuvent être utilisés
pour des projections d'analyse de 'faim dans le monde'!**

**Christoph Müller, Alberte Bondeau, Alexander Popp, Katharina Waha,
and Marianela Fader**

Potsdam Institute for Climate Impact Research (PIK), Germany

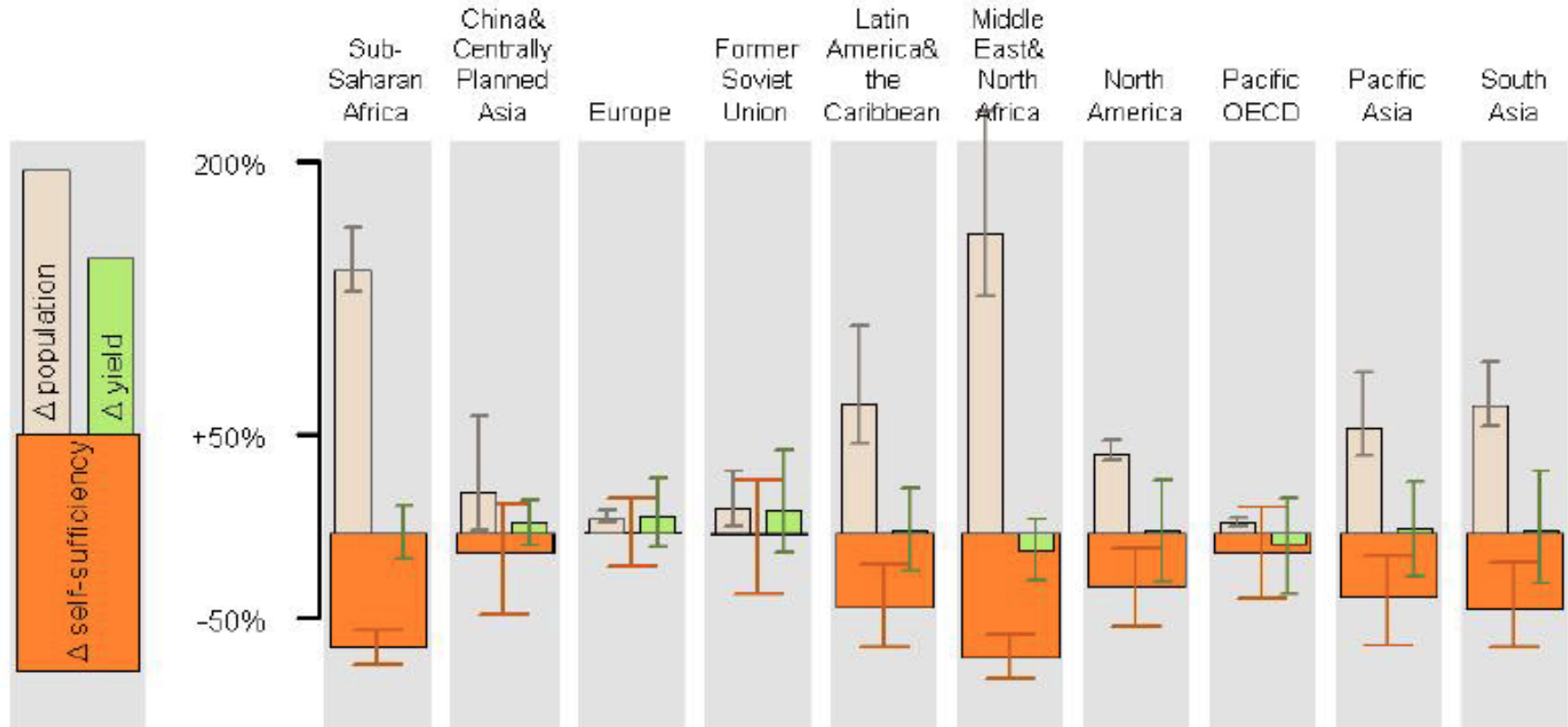


Figure 2.2.1: Mean change in crop yields (green bars) from 1996-2005 to 2046-2055 in all 30 scenarios considered here. Whiskers indicate the range of impacts, which is mainly determined by the effectiveness of CO₂ fertilization. Tan-coloured bars indicated projected changes in population (Nakicenovic and Swart, 2000). Most regions are likely to experience significant decreases in self-sufficiency, because population growth often offsets even increasing crop yields.

- La plupart de ces approches globales se focalisent sur les rendements / la production

→ Or certaines pourraient produire d'autres diagnostics

→ Difficile d'aborder l'ensemble des variétés existantes de part le monde (la plus à même de le faire = GAEZ)

→ NOTRE proposition dans le cadre du projet

ANR-ORACLE : « Opportunités et Risques pour les Agro-écosystèmes et les forêts dans le cadre du Changement climatique, socio-économiques et politiques en France) »

<https://oracle.lsce.ipsl.fr/>

INRA: Agroclim, UREP, EPHYSE, Agronomie, EcoPub
SISYPHE; LSCE; CNRM; CERFACS; LEF-LERFoB

From a thorough selection of sites

Run

DGVMs



specific models

Compare
DGVMs' outputs to
specific models' outputs

Develop Transfer Functions
to translate
DGVMs' outputs into
specific indicators

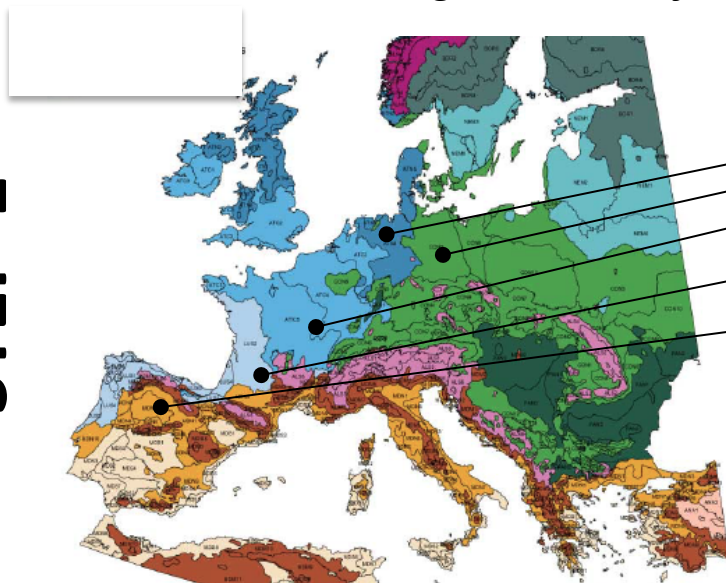
STEP-1

STEP-2

STEP-3

STEP-1

From a thorough selection of sites



Run

DGVMs



specific models

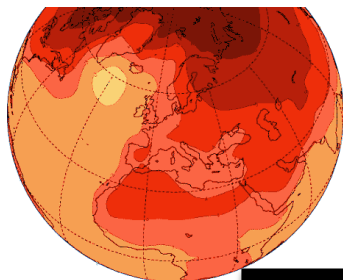
Compare
DGVMs' outputs to
specific models' outputs



Develop Transfer Functions
to translate
DGVMs' outputs into
specific indicators

STEP-2

Climate Scenario



DGVMs

Developed Transfer Functions

Calculate climatic and agro-climatic indices

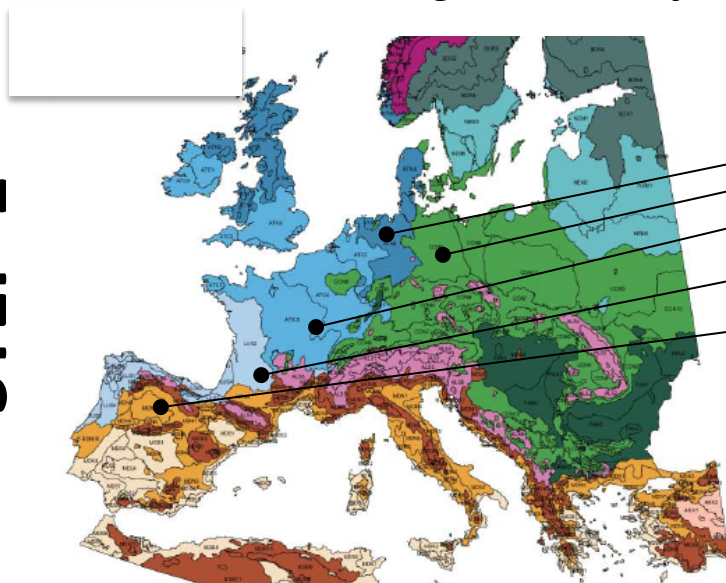
Derive specific indicators

STEP-3

Risk / Opportunity analysis → identify hot-spot areas

STEP-1

From a thorough selection of sites



Run

DGVMs



specific models

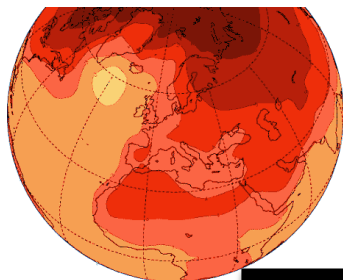
Compare
DGVMs' outputs to
specific models' outputs



Develop Transfer Functions
to translate
DGVMs' outputs into
specific indicators

STEP-2

Climate Scenario



DGVMs

Developed Transfer Functions

Calculate climatic and agro-climatic indices

Derive specific indicators

STEP-3

**Impacts
on hot spots
Proposed
Adaptations**



specific models

Risk / Opportunity analysis → identify hot-spot areas

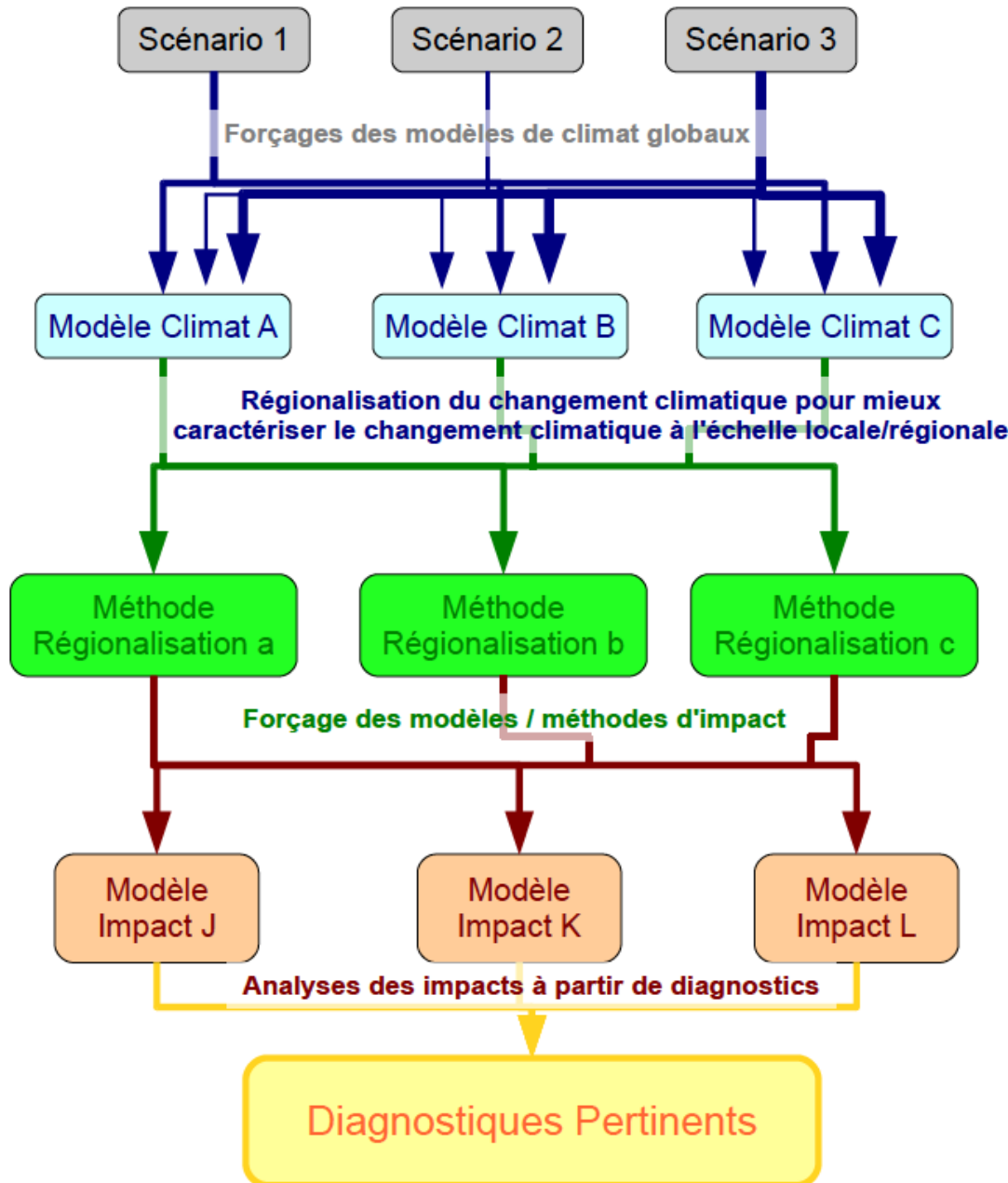
run on hot spots only

Quelle que soit la méthode utilisée,

Il y a de nombreuses incertitudes

Cascade d'incertitudes

Définitions de plusieurs scénarios socio-économiques (futurs potentiels)



■ ■ ■ ■ **incertitudes sur le futur**
3 scénarios

■ ■ ■ ■ **incertitudes épistémiques**
9 simulations-1 :
3 scén. * 3 mod.

■ ■ ■ ■ **incertitudes épistémiques**
27 simulations-2 :
9 sim-1 * 3 reg.

■ ■ ■ ■ **incertitudes épistémiques**
81 simulations-3 :
27 sim-2 * 3 imp.
à analyser

Quelques éléments de réflexion pour terminer

- Comment instaurer le dialogue avec les acteurs du territoire pour évaluer, avec eux, si les impacts de l'occupation des sols sur la météorologie et les extrêmes, sont susceptibles d'influencer les stratégies d'aménagement du territoire (e.g. reboisement, extensions urbaines, rotations agricoles, ...)
 - ➔ choix de diagnostics pertinents pour calculer les impacts
 - ➔ comparaison de ces impacts à d'autres, issus d'autres 'forçages'
- ➔ hiérarchisation
 - ➔ tests de scénarios (dans quels cas les risques sont-ils grands?)

MERCI