

Interactions entre stratégies d'usage des sols & climat

Nathalie de Noblet

nathalie.de-noblet@lsce.ipsl.fr

Définition du terme 'usage des sols'

Le terme usage des sols regroupe au moins 2 éléments importants :

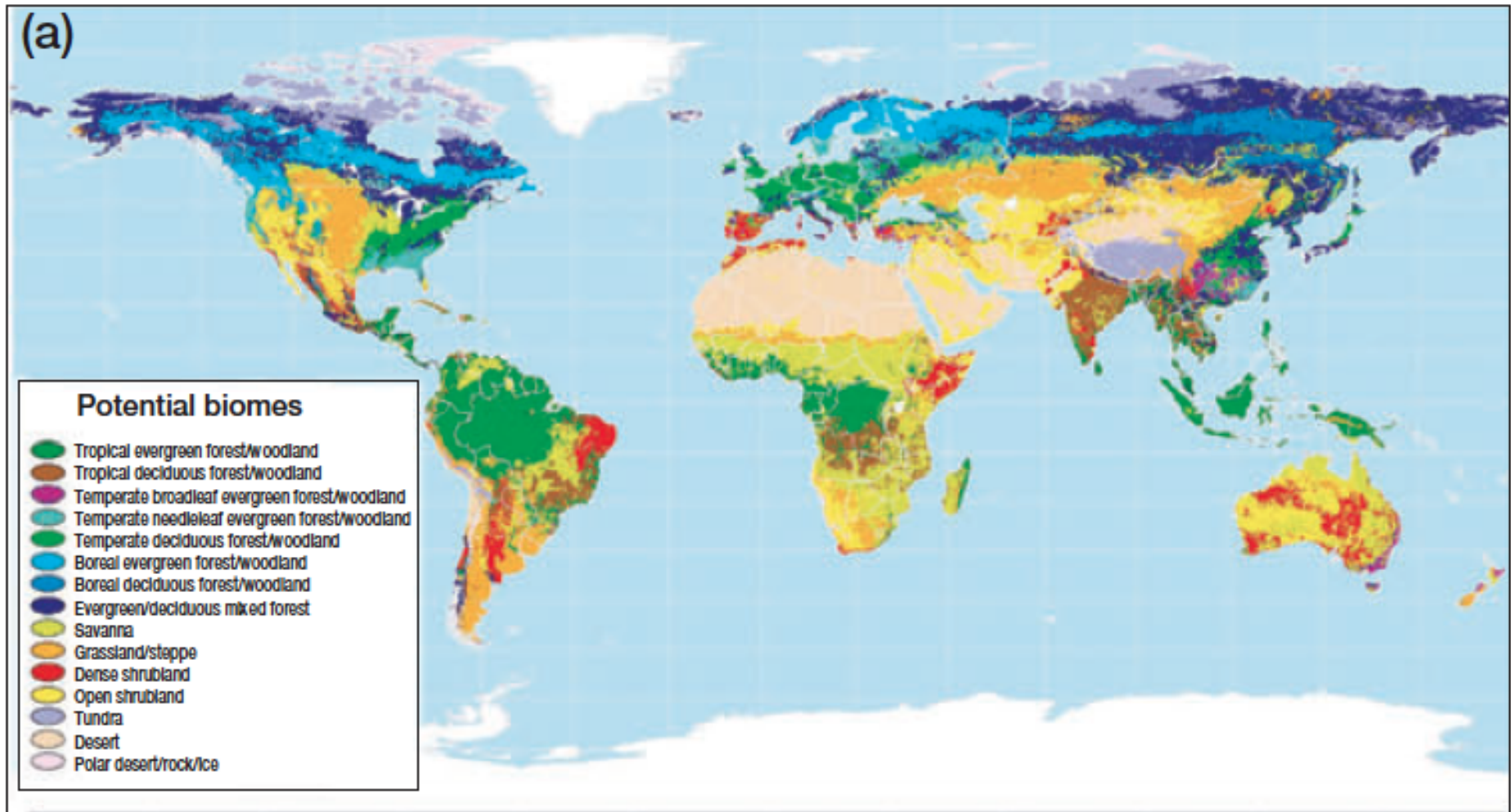
1) Une modification du type de surface

- Déforestation, afforestation-reforestation
- Drainage de marécages
- Mise en culture ou en prairies gérées
- Urbanisation
-

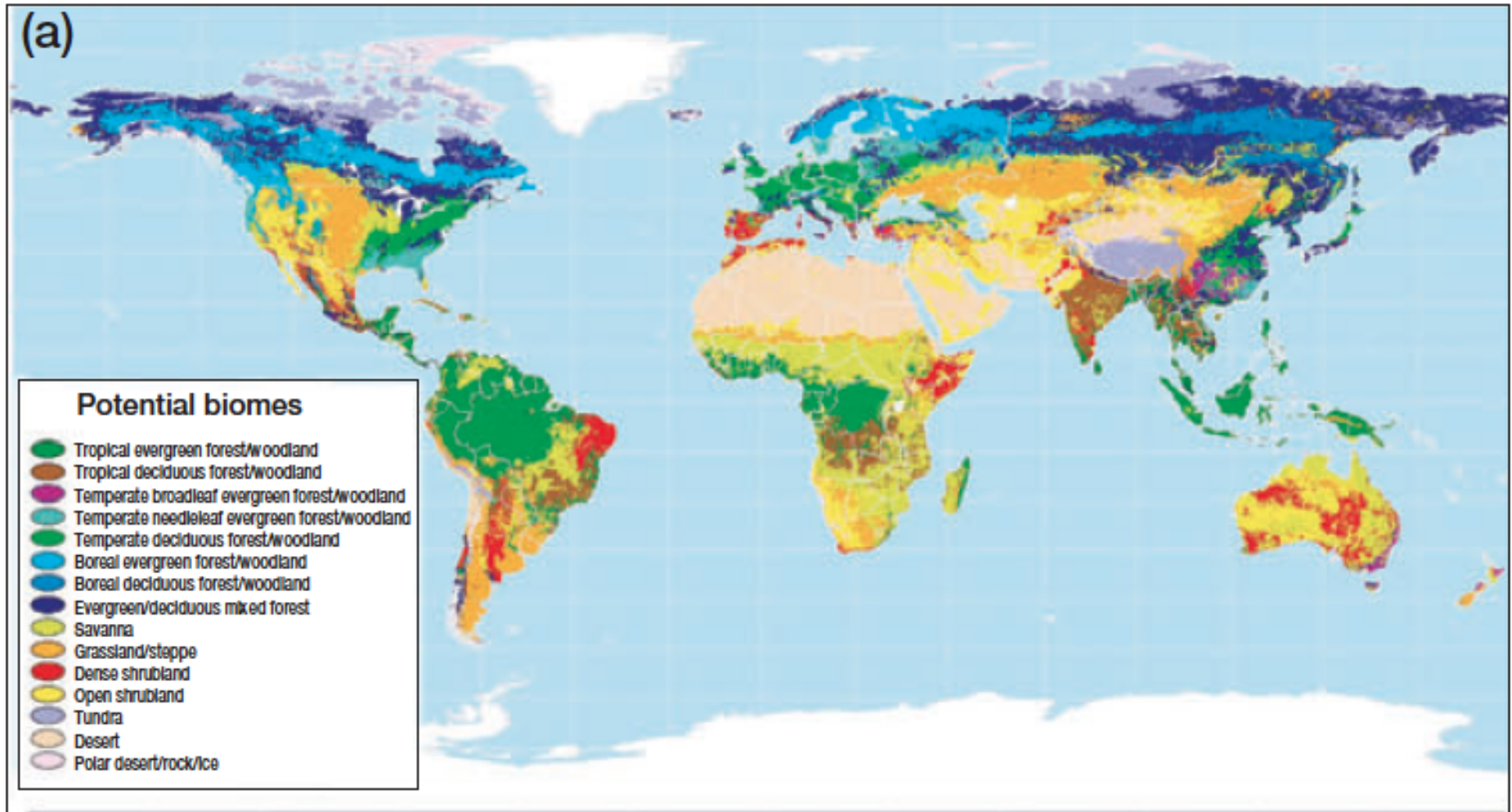
2) Une modification de la gestion du couvert végétal

- Prélèvements par coupes dans une forêt
- Irrigation ou non d'un champ
- Fertilisation ou non d'une culture
- ... autres conduites de culture

Végétation Potentielle



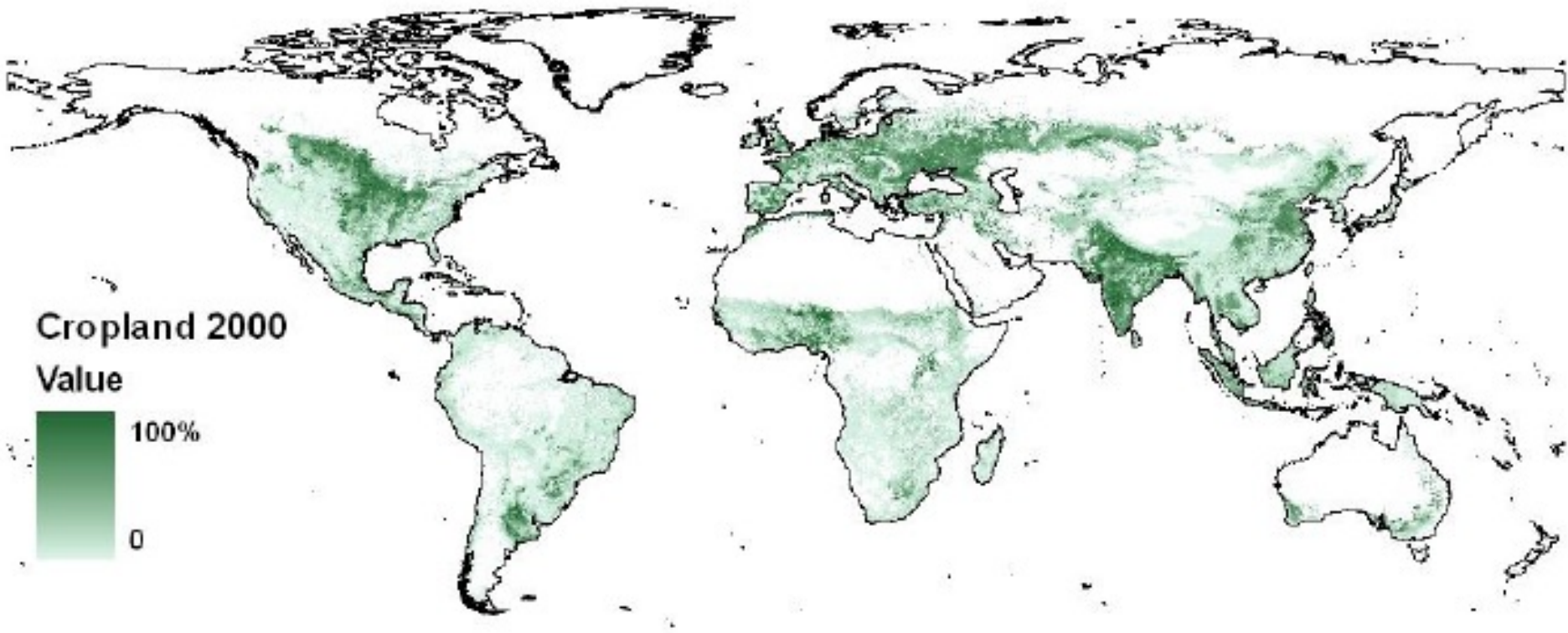
Végétation Potentielle



MAIS

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

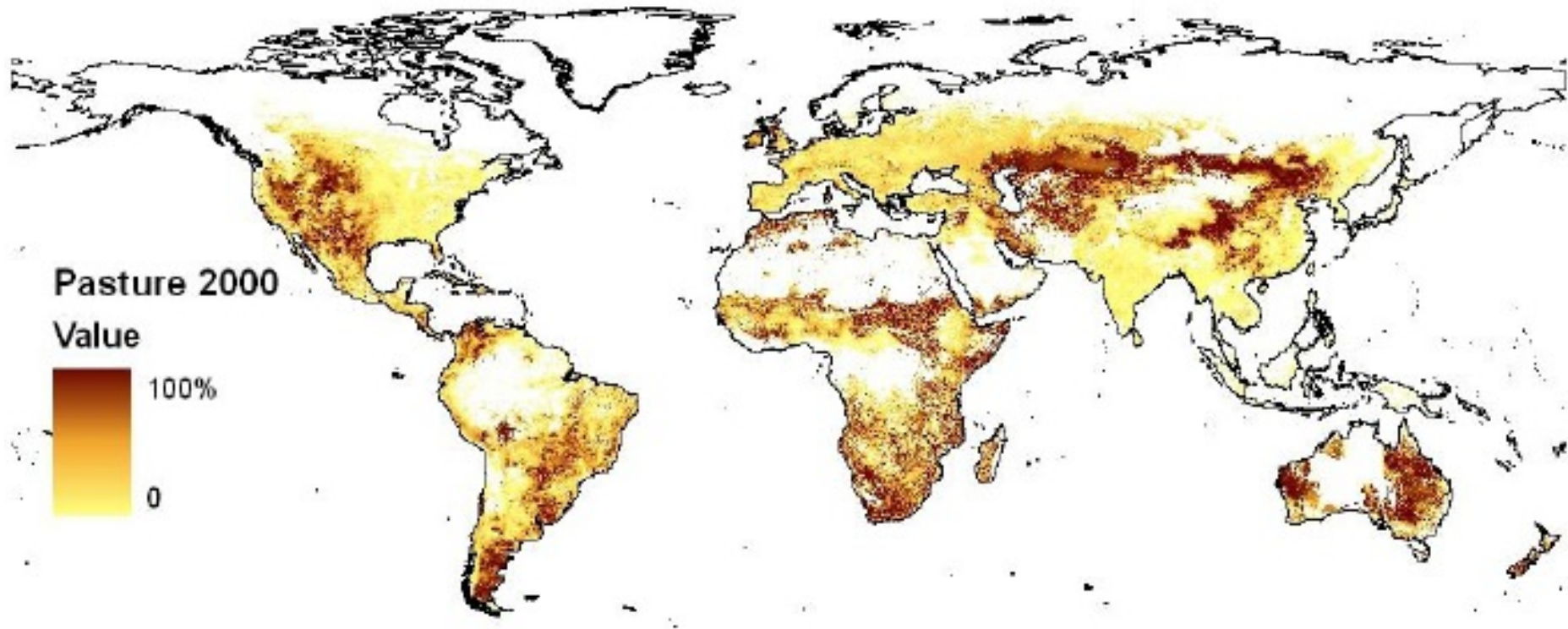
Extension actuelle des zones cultivées (pourcentage de chaque point de grille)



~15 millions de km²

Ramankutty *et al.*, 2002

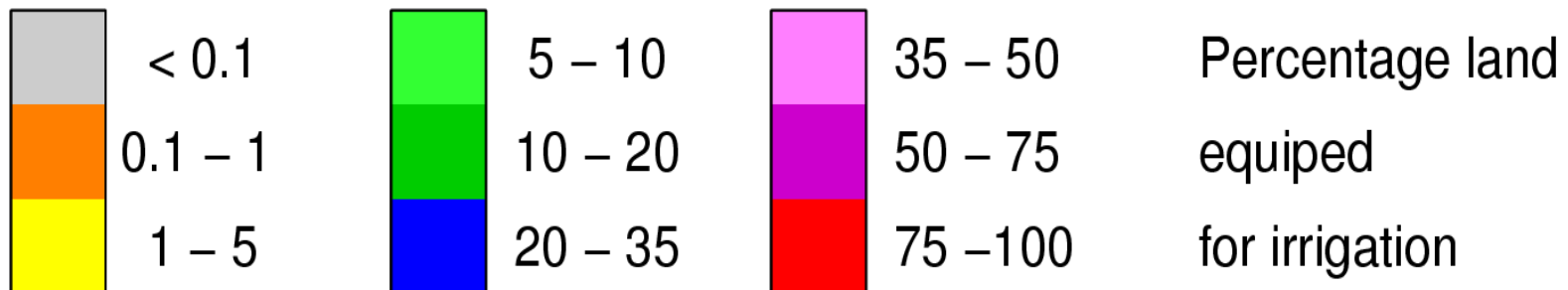
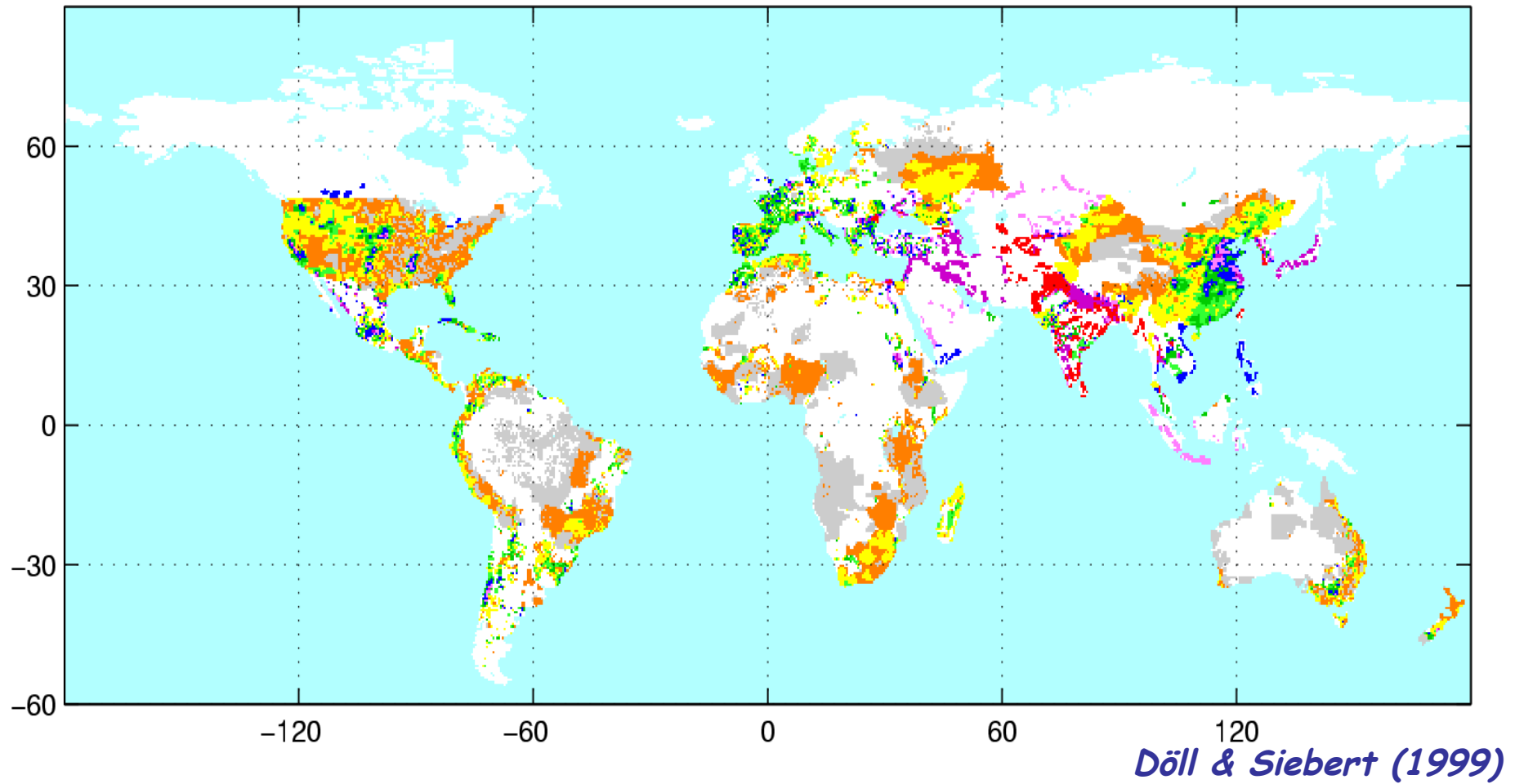
Extension actuelle des zones de pâturage (pourcentage de chaque point de grille)

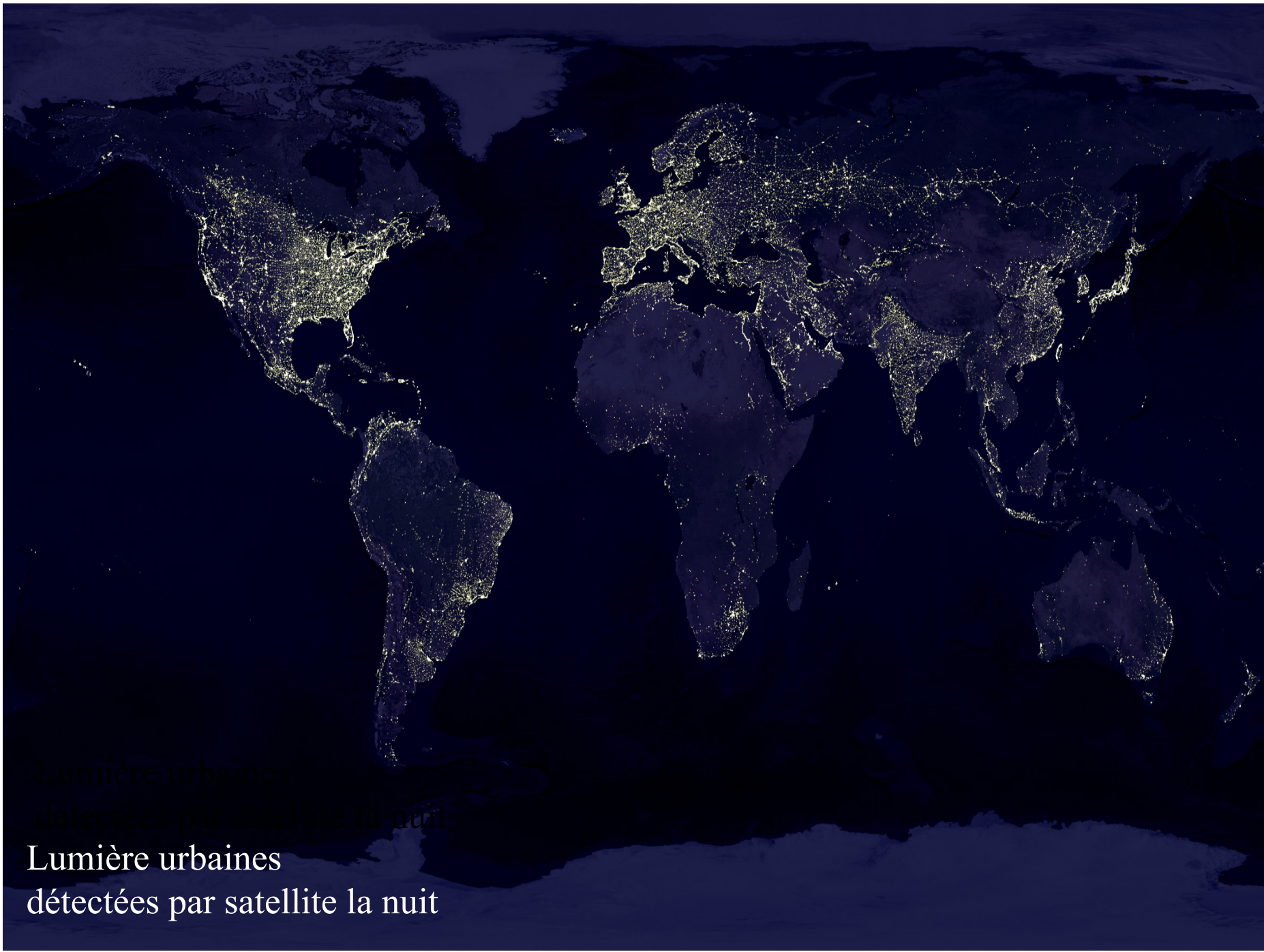


~32 millions de km²

Ramankutty *et al.*, 2002

Extension actuelle des zones pouvant être irriguées





Lumière urbaines
détectées par satellite la nuit

Lumière urbaines
détectées par satellite la nuit

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

Plan de cet exposé

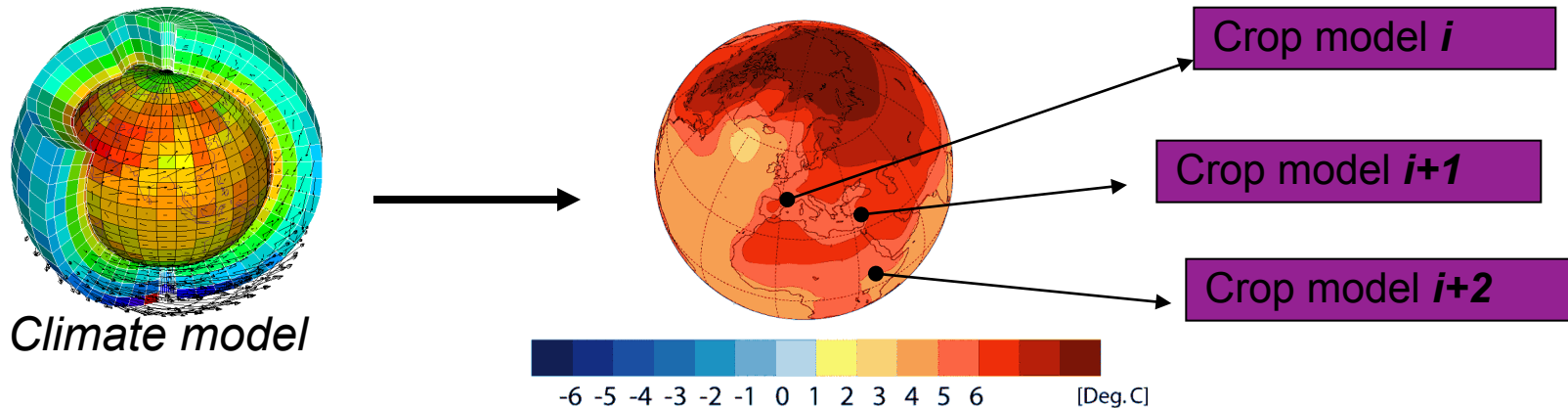
- *Études d'impact des changements climatiques sur la productivité*
 - Comment réconcilier les approches locales & globales?
- Les impacts des changements d'occupation des sols sur le climat
- Travailler sur l'usage des terres pour lutter contre le changement climatique (ou global ?)
- Quelques éléments de réflexion sur une science en marche

PARTIE-1

Comment évaluer les impacts du
changement global
sur la productivité ?

Approche multilocale – GIEC AR4

- Linking crop models and climate models = crop yields projections



- scale mismatch
- local assessments / spatially heterogeneous impacts / different climate and crops models

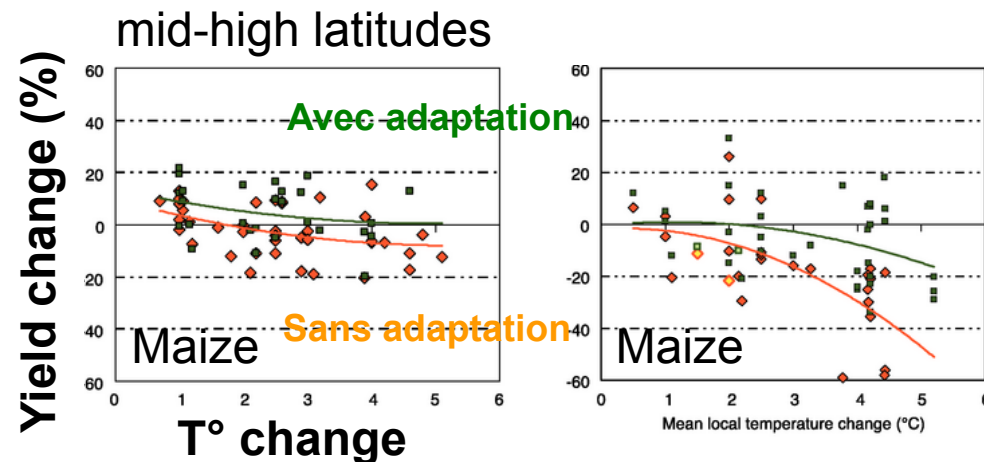
IPCC 2007 - Cereal yield change with global warming:

69 studies at multiple simulation sites

Inconsistent / qualitative assessment:

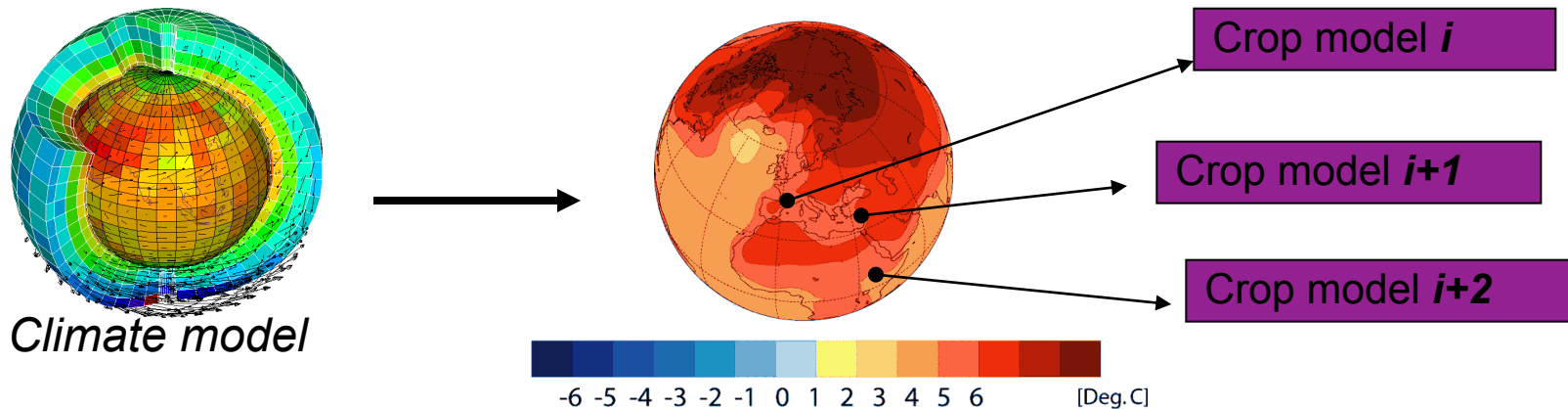
“Temperate: 1-3 K threshold”

“Tropics: 1-2 K threshold”



Approche multilocale – GIEC AR4

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IPCC 2007 - Cereal yield change with global warming:

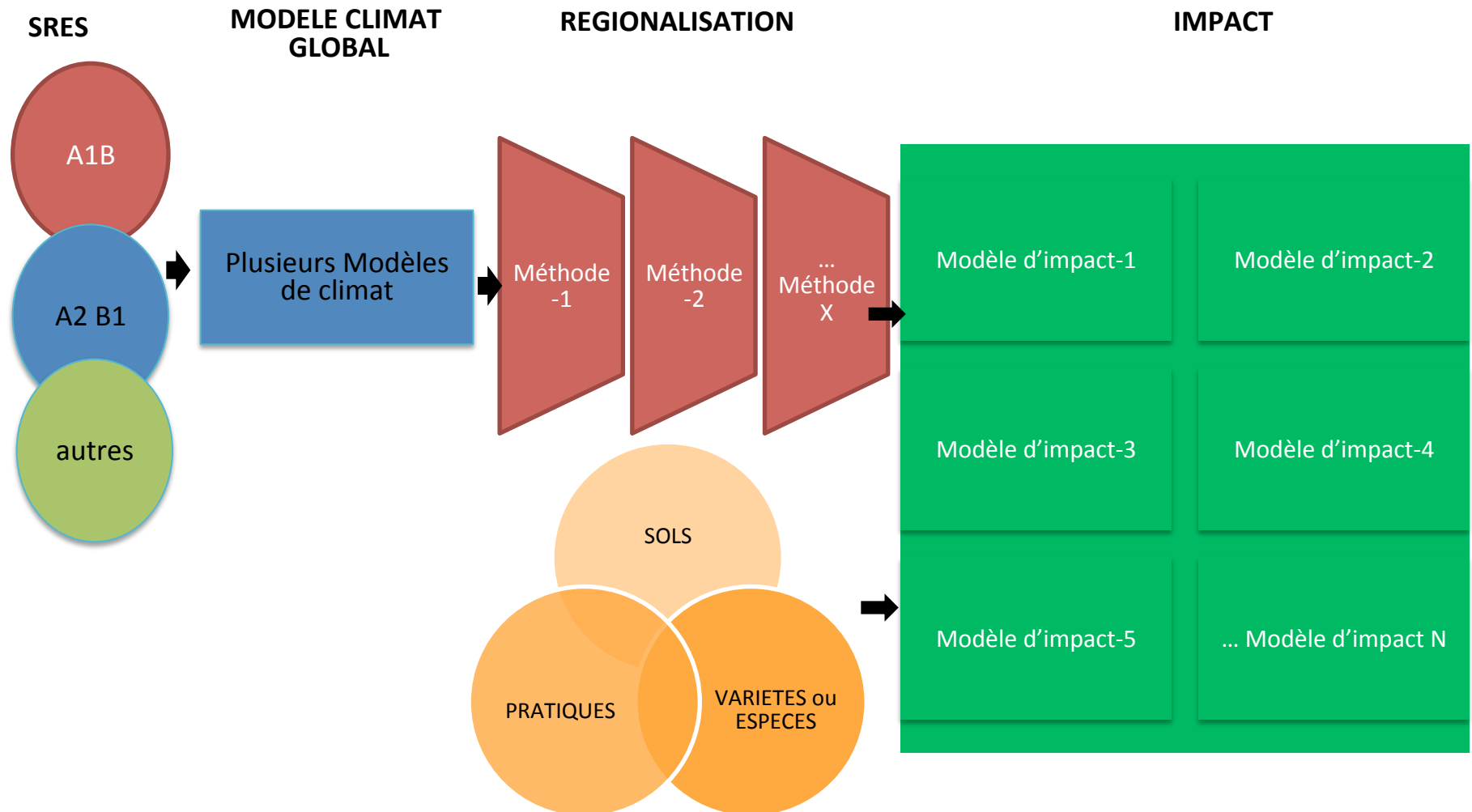
69 studies at multiple simulation sites



Need for more consistent, large-scale, spatially distributed and quantitative climate change impact studies

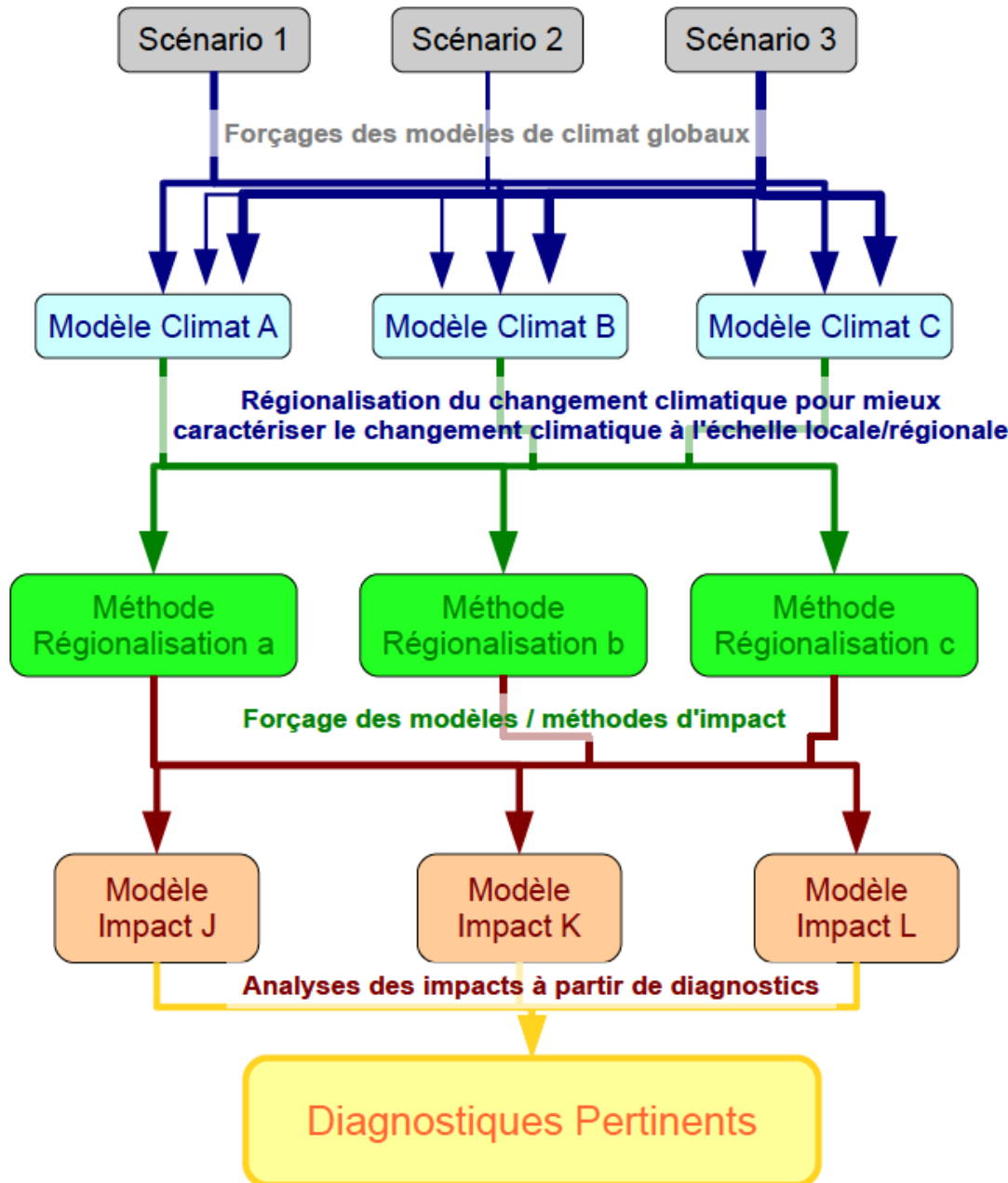
 **Inconsistent / qualitative assessment:**
“Temperate: 1-3 K threshold”
“Tropics: 1-2 K threshold”

Méthodologie – Approches multilocales



Cascade d'incertitudes

Définitions de plusieurs scénarios socio-économiques (futurs potentiels)



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

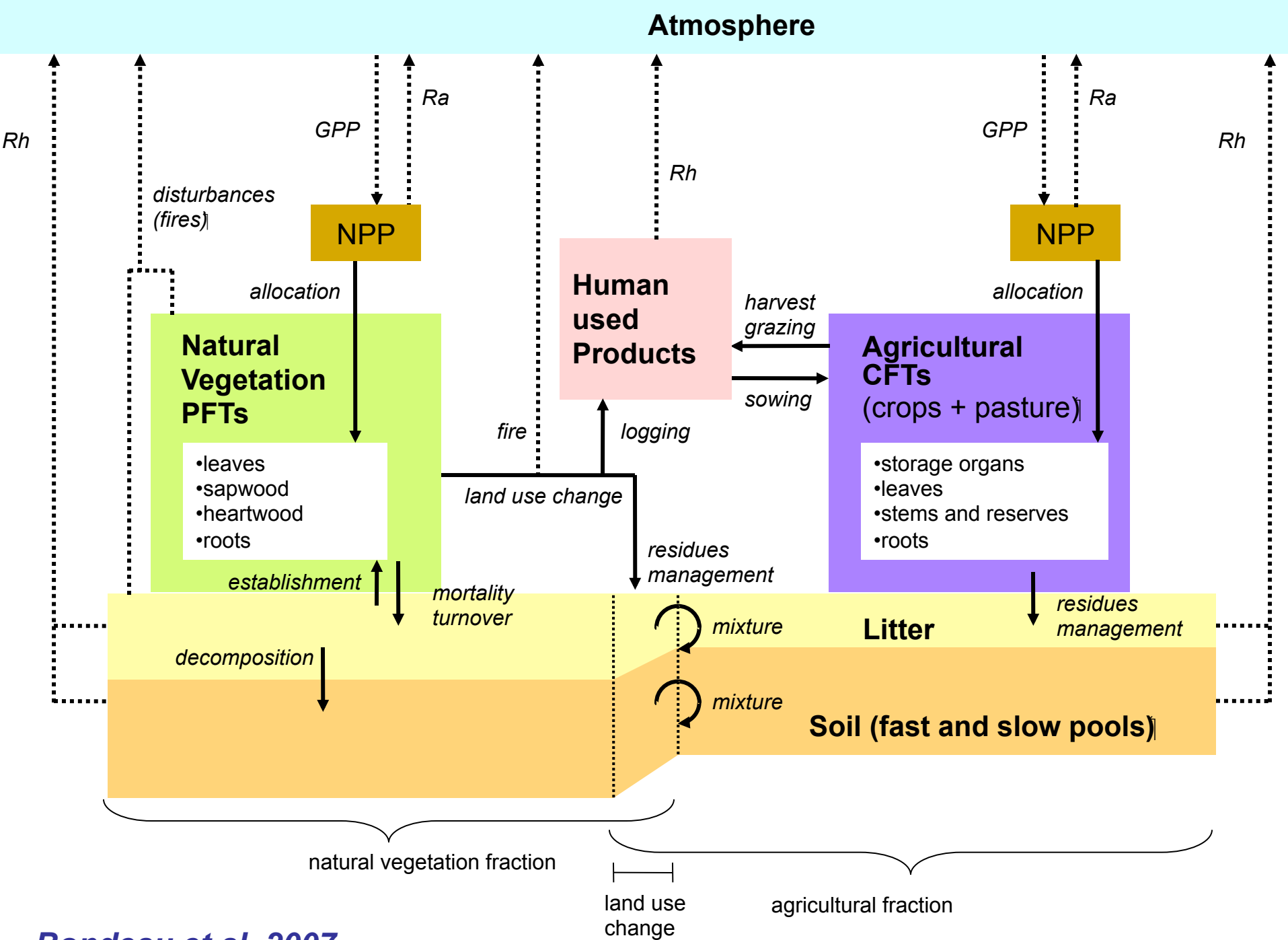
■ ■ ■ ■ **incertitudes épistémiques**
9 simulations-1 :
3 scén. * 3 mod.

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

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

En parallèle d'une approche multi-
locale, on assiste au
développement d'approches
globales:

évolutions de la modélisation
de la Biosphère Terrestre
à Grande Echelle

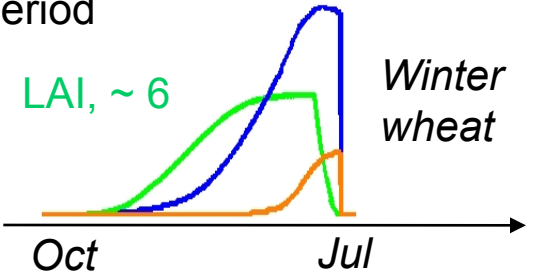


2 stratégies pour inclure les
agrosystèmes dans les modèles de
Biosphère Terrestre
à Grande Echelle

Stratégie-1: des nouveaux écosystèmes + leurs paramétrisations sont incluse dans le DGVM

Sowing date estimation:
for 4 temperate CFTs = $f(T)$,
for 4 tropical CFTs = $f(P)$
Adaptation of heat sum and
vernalization requirement

Daily coupled growth and
development simulation:
Phenology, LAI change,
carbon allocation to leaves,
roots, storage organs, ...
Estimation of the harvesting
period



Total biomass, ~ 15 tDM/ha
Grain harvested, ~ 6 tDM/ha

For grasses, several
cuts ($f(LAI)$), or
regular grazing

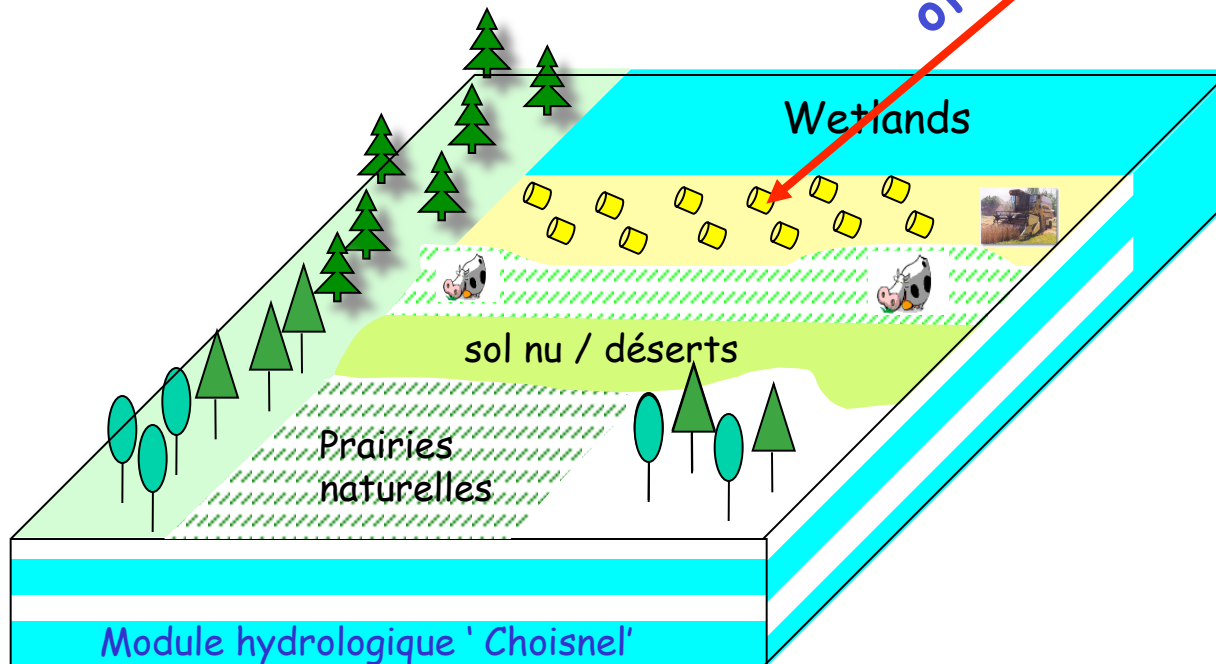
Deforestation
Afforestation

Multiple
cropping
(e.g. rice)
Grass as
intercrop

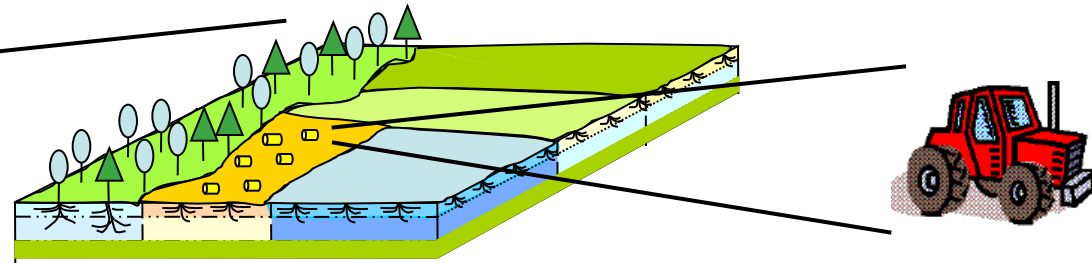
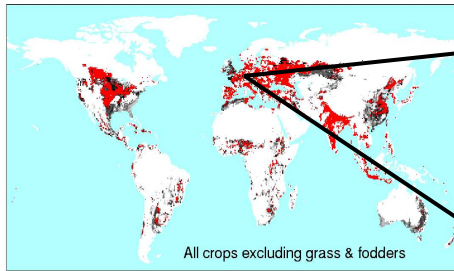
Harvested biomass
removed, residues
added to the litter
pool or removed
(fodder, biofuel, ...)

No water stress for
irrigated crops,
computation of the
water requirement
and of irrigation

Stratégie-2: Le DGVM est couplé à un modèle agronomique



Model complementarity => new coupling scheme



Vegetation map
Krinner et al. (2004)

Gridded climate/soil forcing

Agricultural practices
Brisson et al. (2002)

Terrestrial Biosphere Model



Natural ecosystem functioning
+ disturbances

scale : local => regional => global
1 year => 1000 years



ORCHIDEE

Generic Crop Model

LUE growth

Biomass allocation and yield
Water and Nitrogen balance

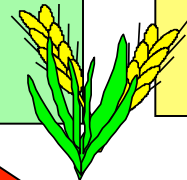
No soil C balance

scale : field / seasonal cycle

stics

wheat
maize
soybean

daily



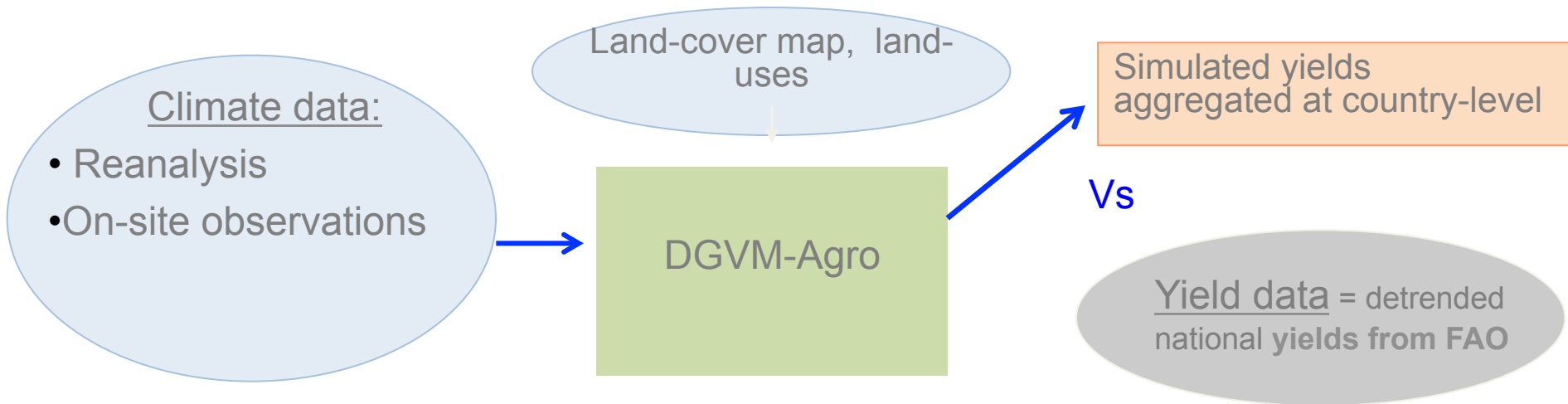
Irrigation

Nitrogen stress index

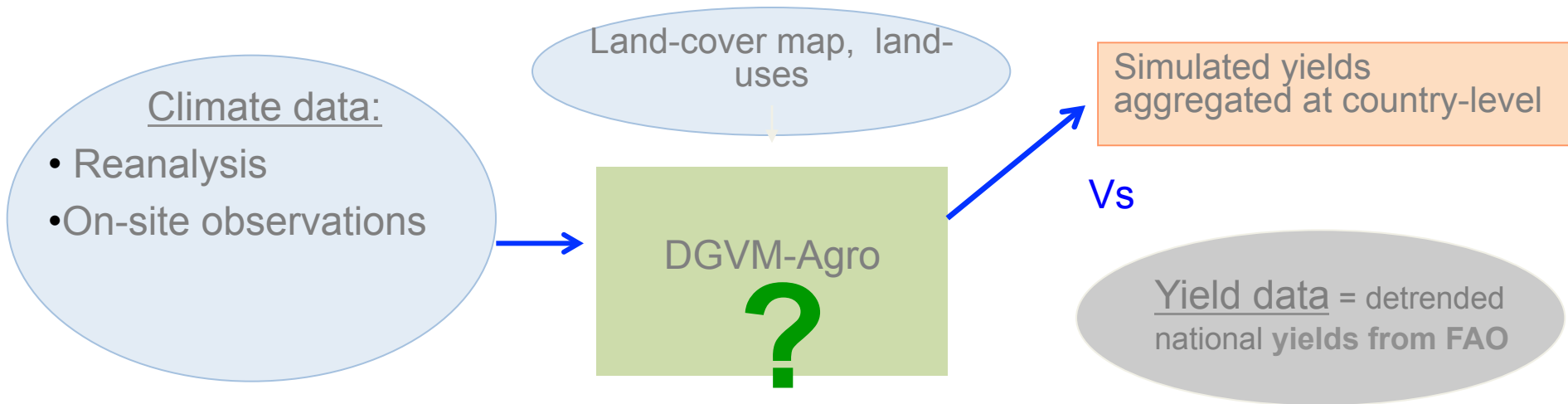
LAI

Vegetation height

Le problème de l'évaluation de ces modèles aux échelles régionales et supérieures

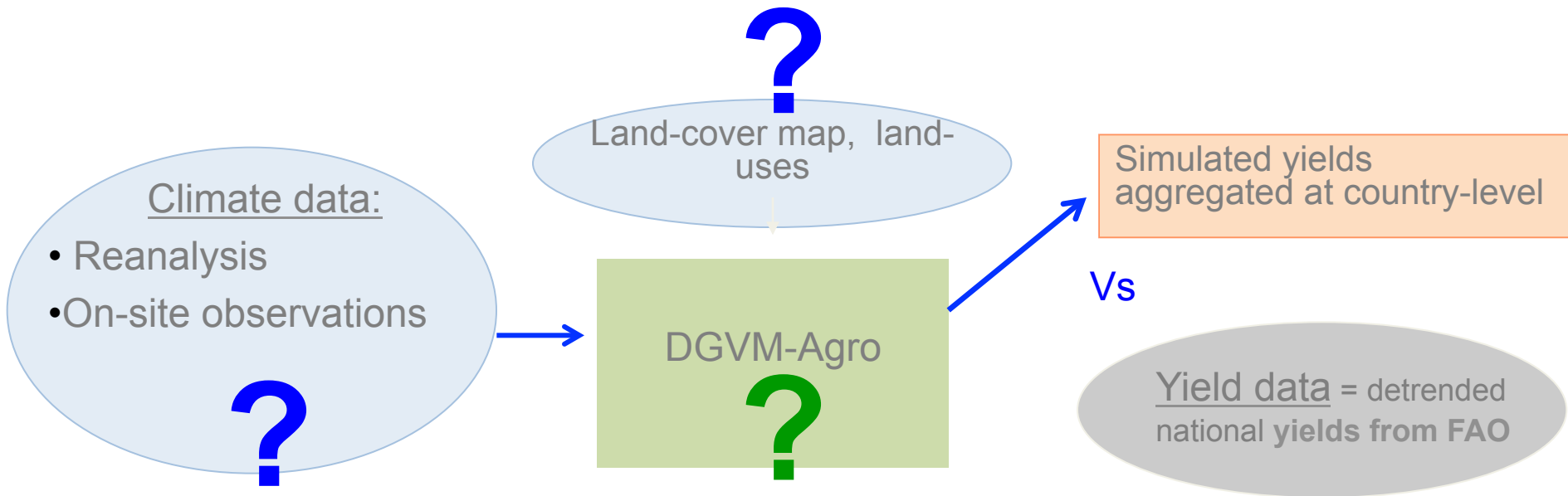


Le problème de l'évaluation de ces modèles aux échelles régionales et supérieures



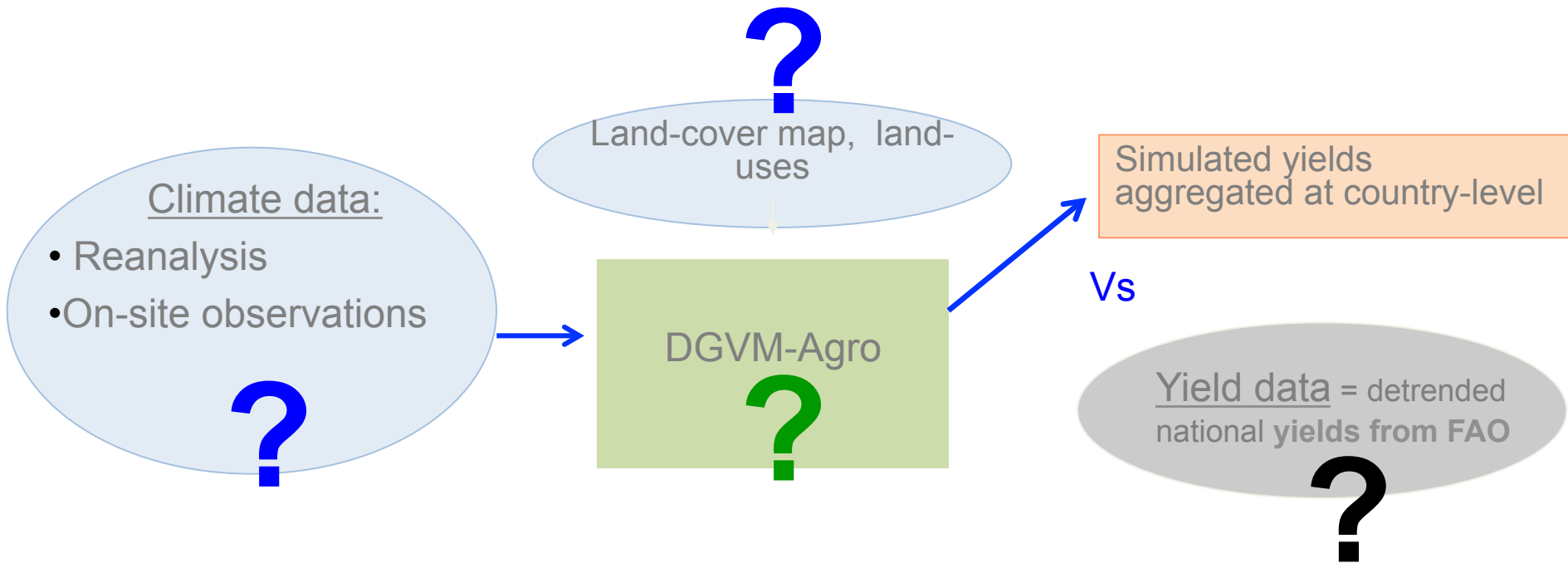
- Uncertainties in model accuracy

Le problème de l'évaluation de ces modèles aux échelles régionales et supérieures



- **Uncertainties in model accuracy**
- **Uncertainties in input data**

Le problème de l'évaluation de ces modèles aux échelles régionales et supérieures



- **Uncertainties in model accuracy**

- **Uncertainties in input data**

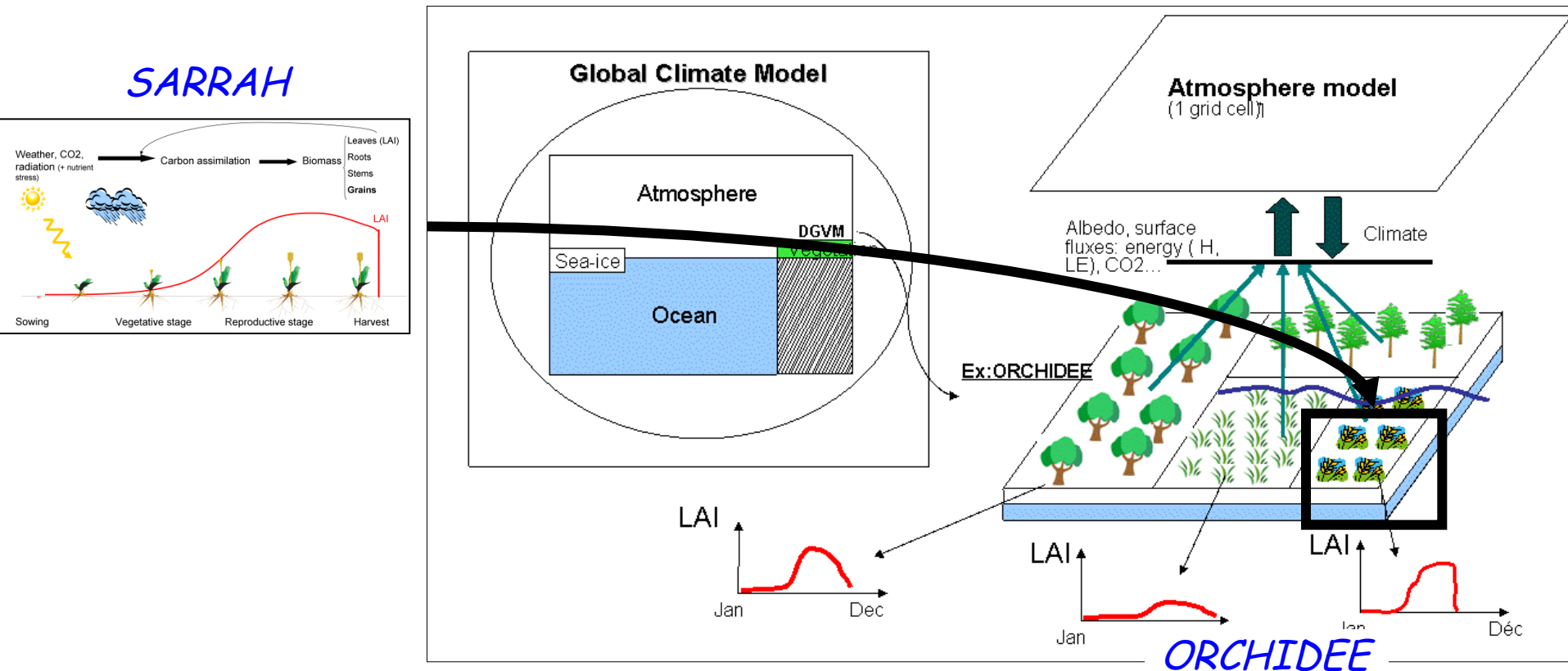
- **Uncertainties in observations: how much 'climate' do they really contain?**

Des DGVMs + « agro »

**→ les climatologues se mêlent
des impacts agronomiques**

Quels Risques pour la production de Millet dans le futur, en Afrique?

ORCHIDEE incluant une paramétrisation du millet dérivée du modèle agronomique SARRAH



Projections of climate change impacts on potential C4 crop productivity over Africa and India

• Experiment:

Climate data:

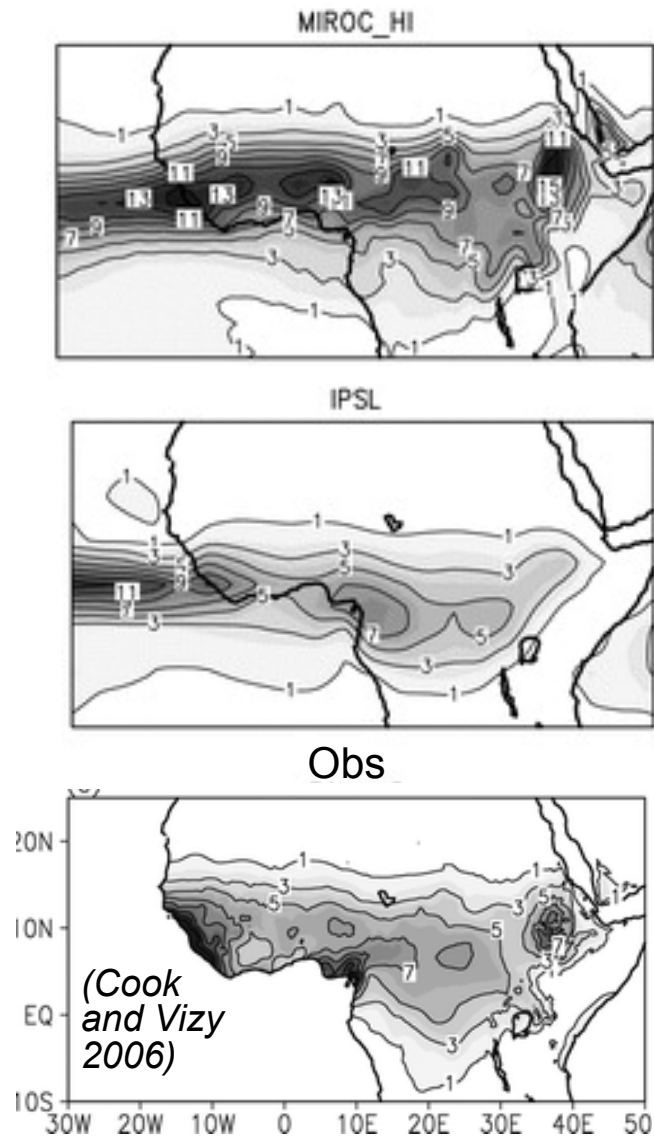
- IPCC climate projections
- 2 scenarios (A1B, A2):
7 and 5 models
- 1961-2100
- 2.5°x2.5°

ORCHIDEE-mil

Potential yield
change

No land-use
map: crops
everywhere

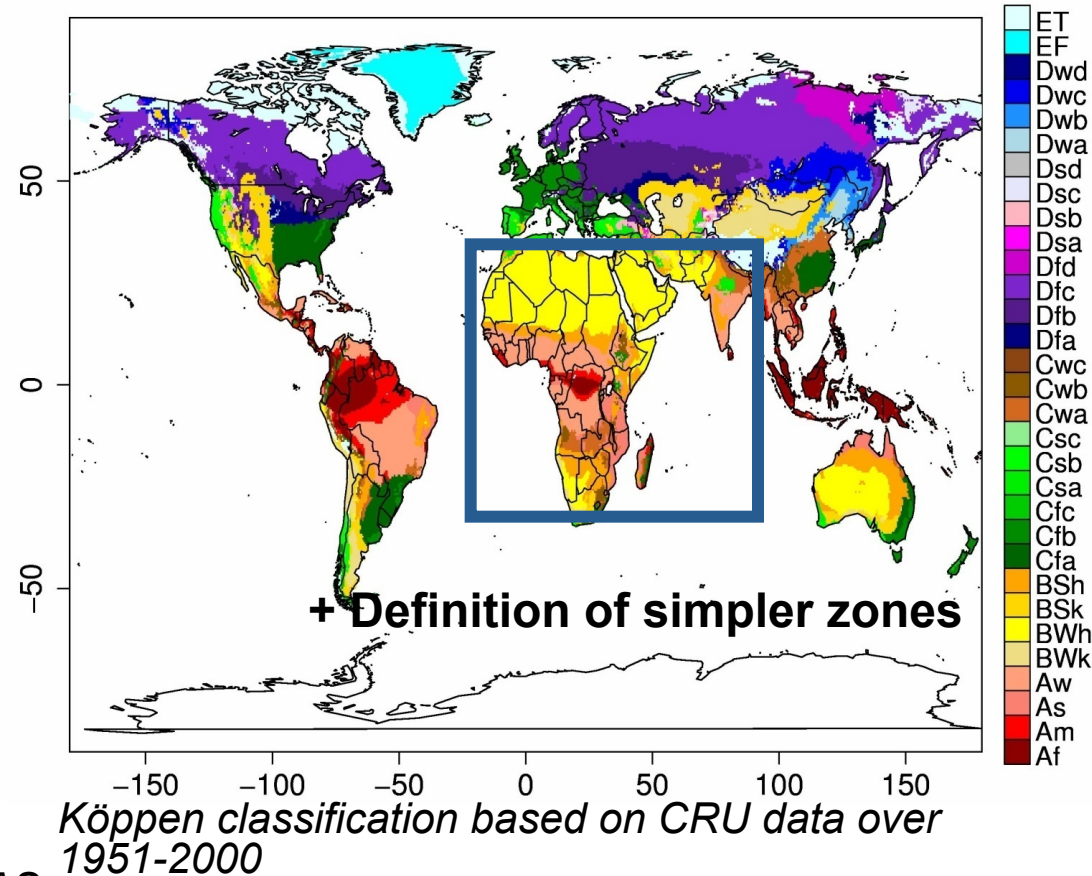
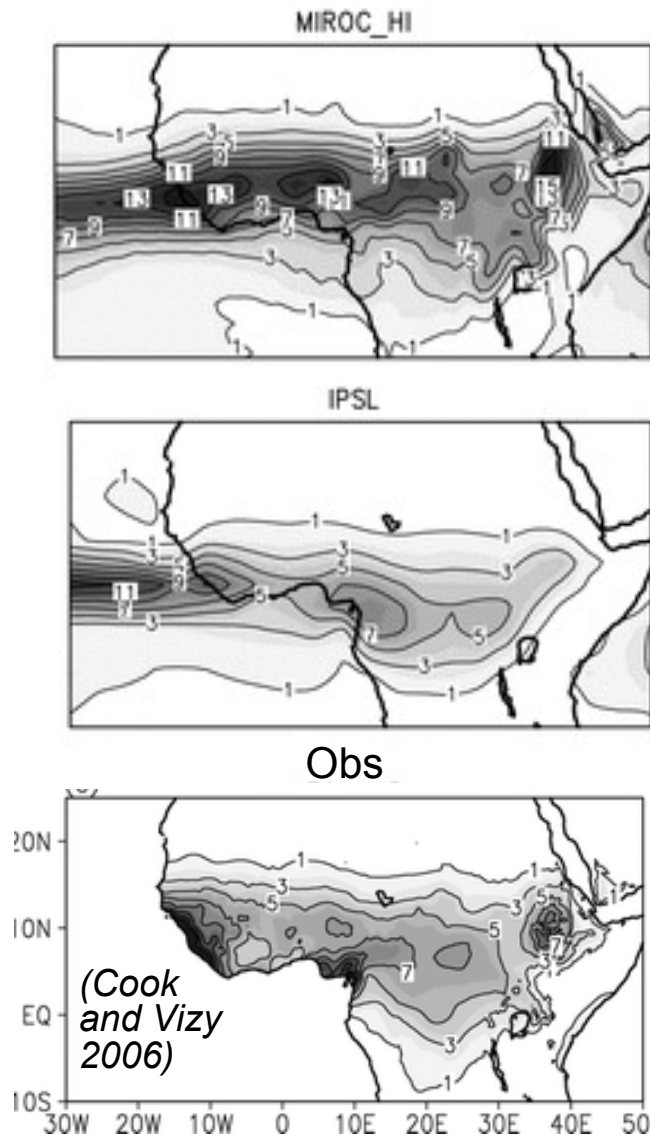
- Regional biases in climate models...



Observed and simulated 1949–2000 JJAS precipitation rates (mm/day) in 2 IPCC models

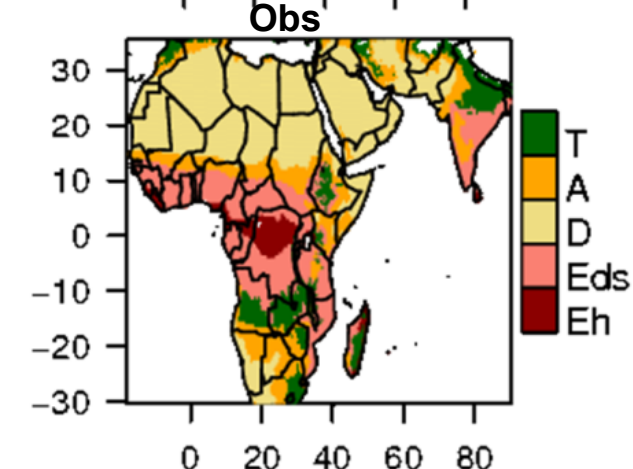
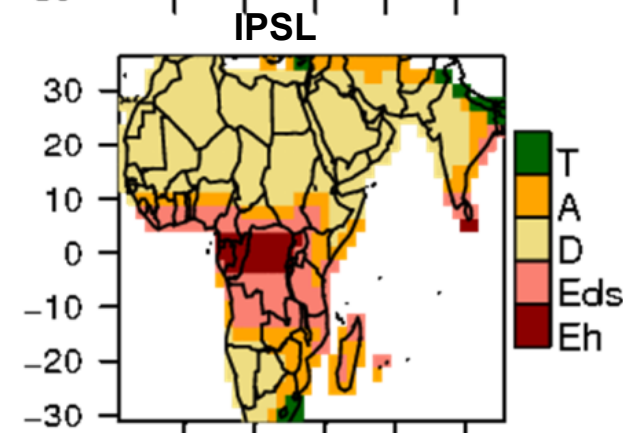
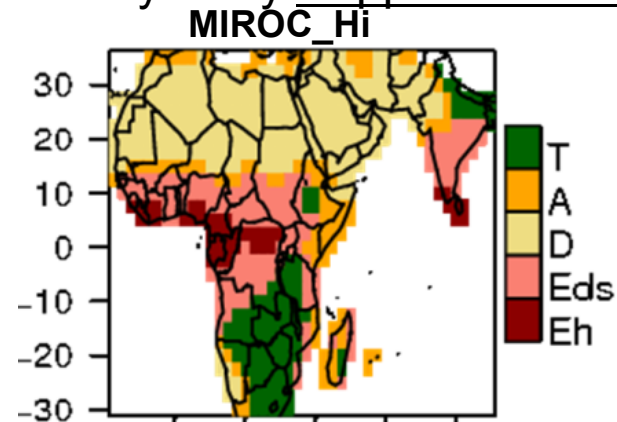
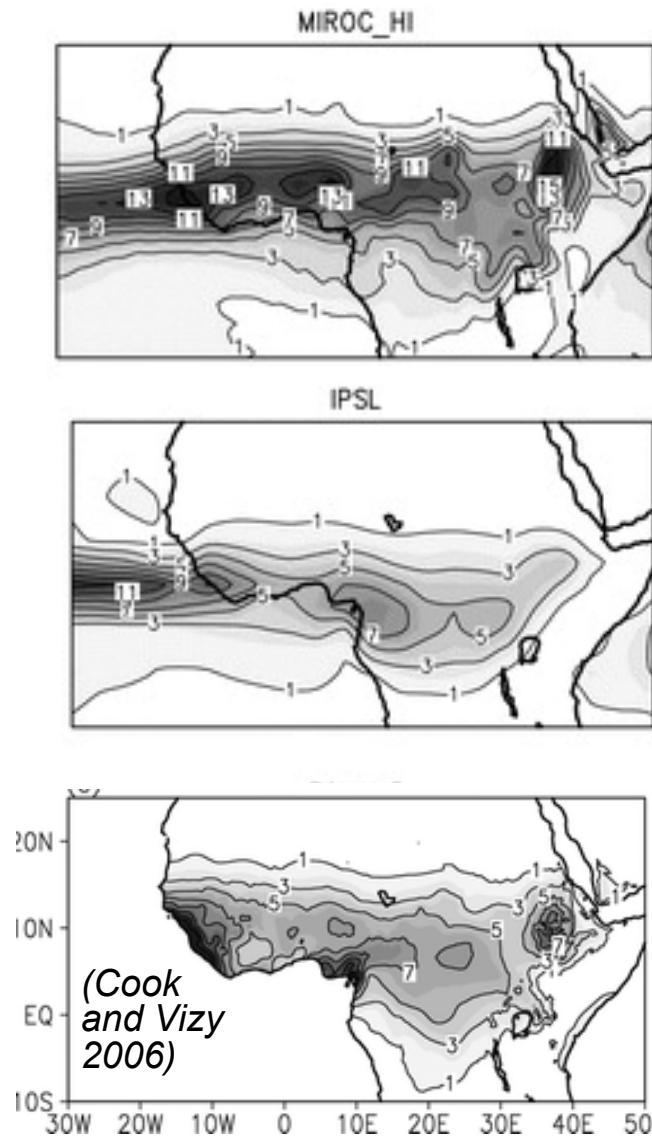
- Regional biases in climate models... ➔ analysis by Köppen bioclimatic zones

- based on T and P
- based on threshold values and seasonality
- broadly correspond to biomes



Observed and simulated 1949–2000 JJAS precipitation rates (mm/day) in 2 IPCC models

- Regional biases in climate models... ➔ analysis by Köppen bioclimatic zones



Temperate

Arid

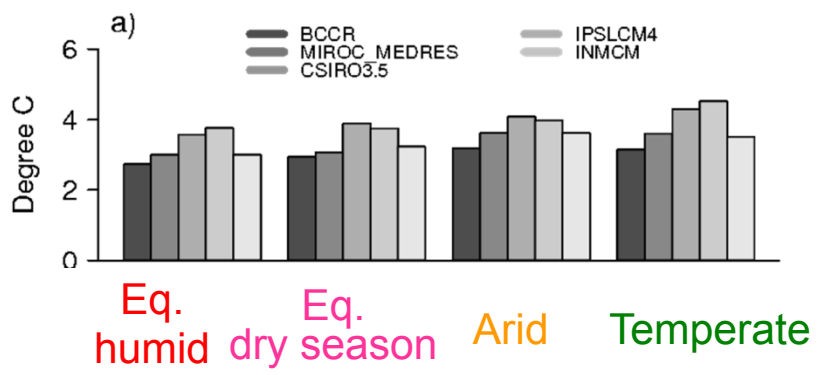
Desert

Eq. dry season

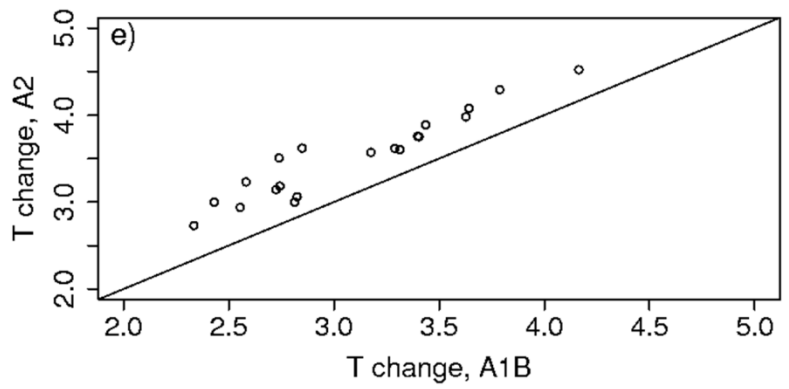
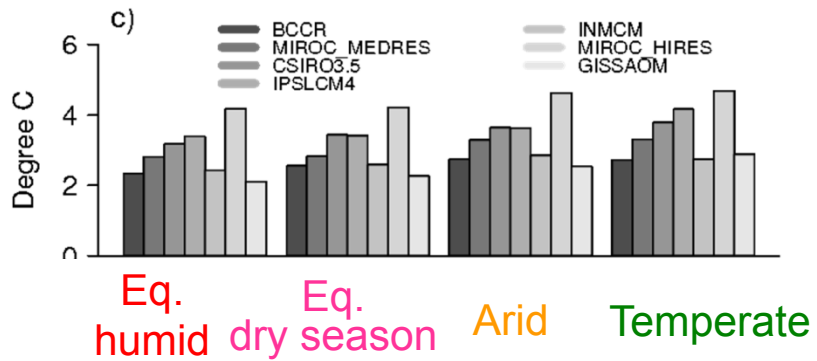
Eq. humid

T change by (2070-2100)

A2



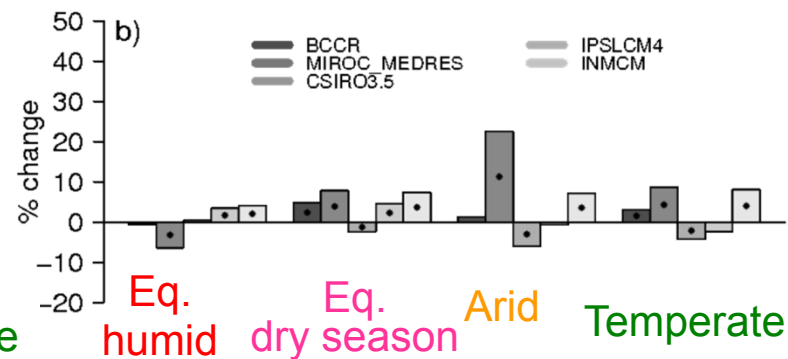
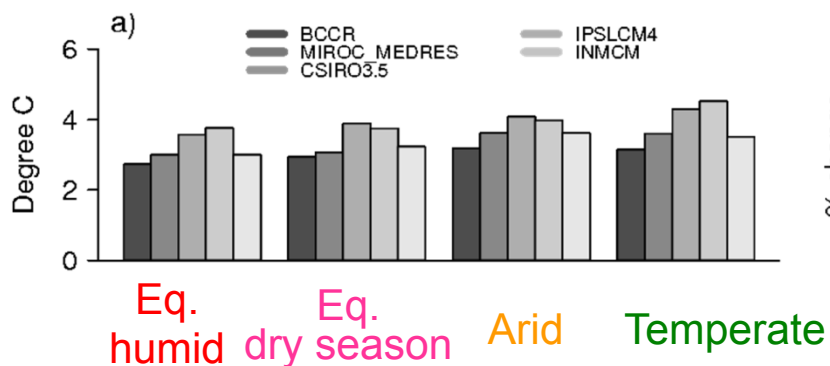
A1B



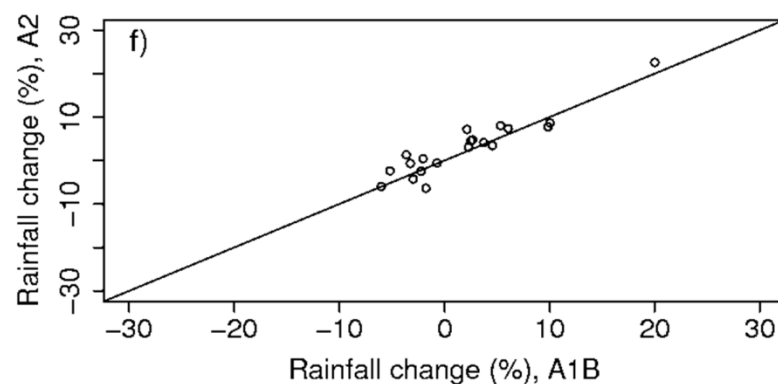
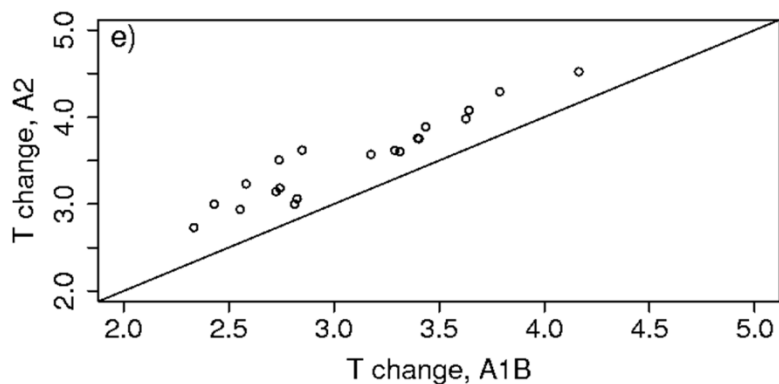
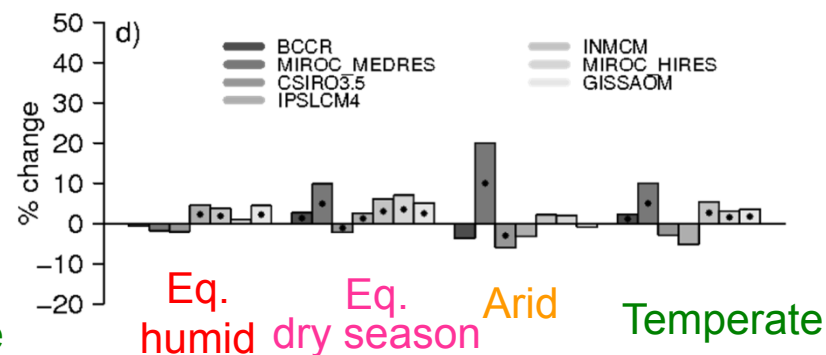
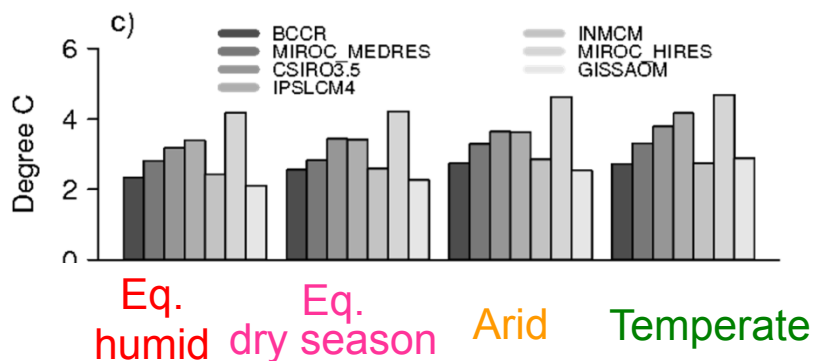
T change by (2070-2100)

P change by (2070-2100)

A2



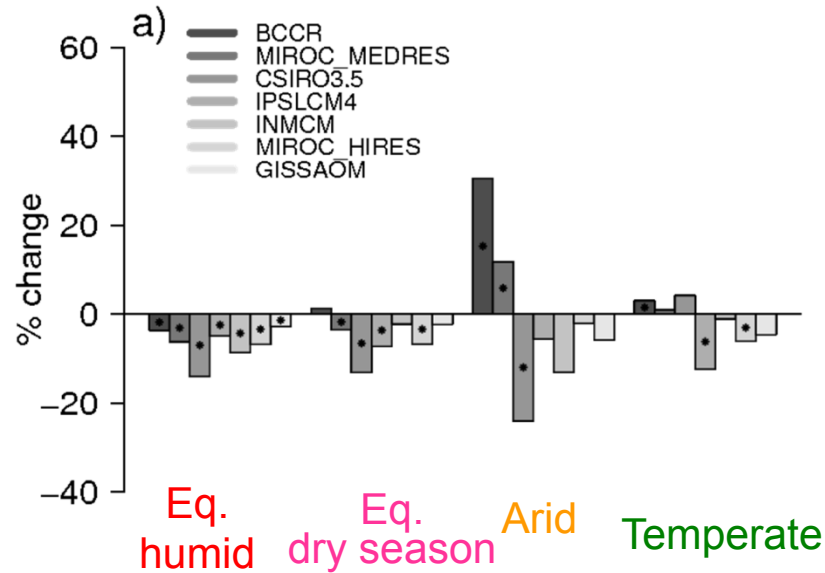
A1B



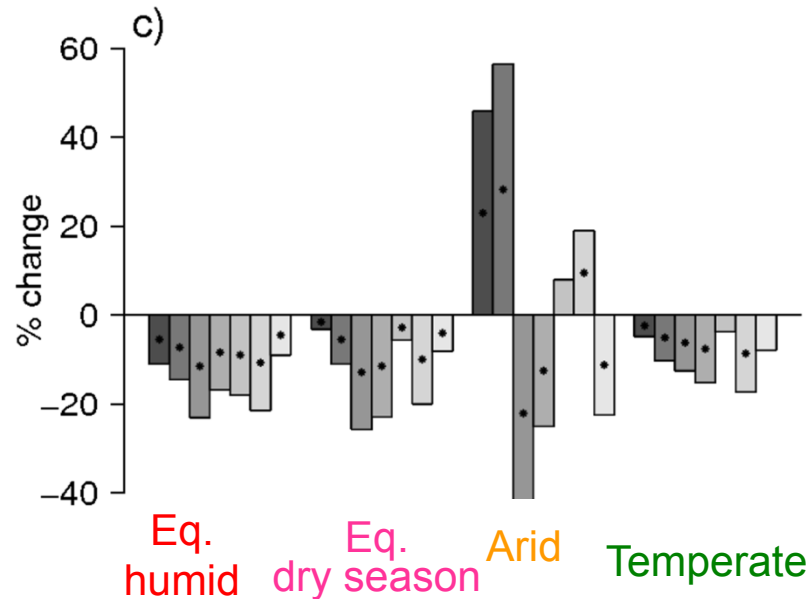
Yield change

A1B scenario

By 2035
(2020-2050)



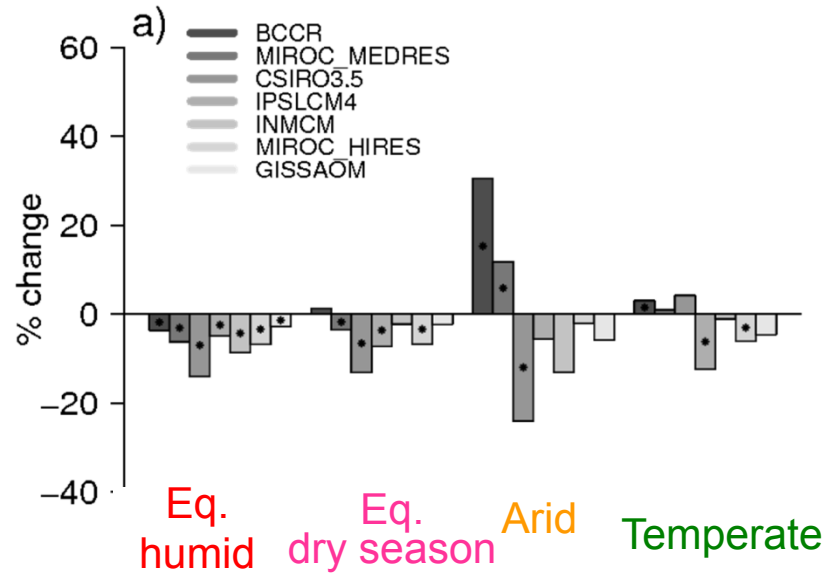
By 2085
(2070-2100)



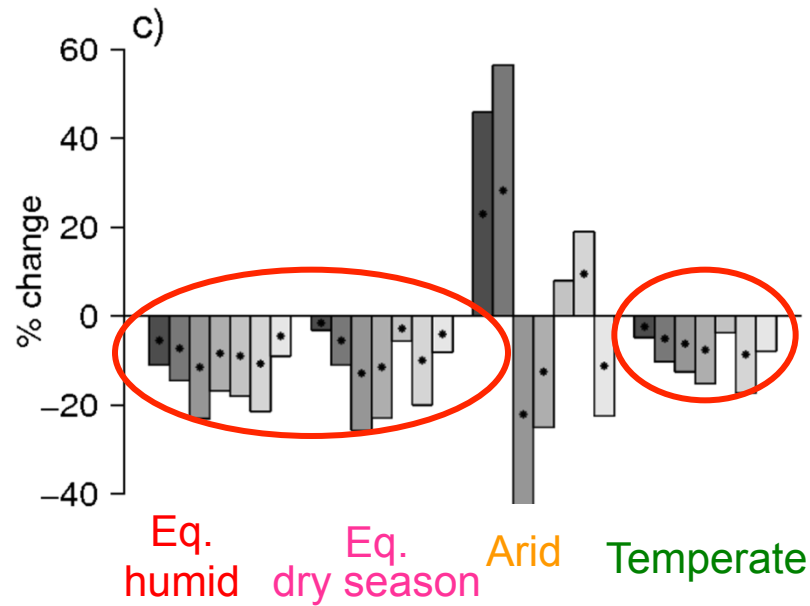
Yield change

A1B scenario

By 2035
(2020-2050)



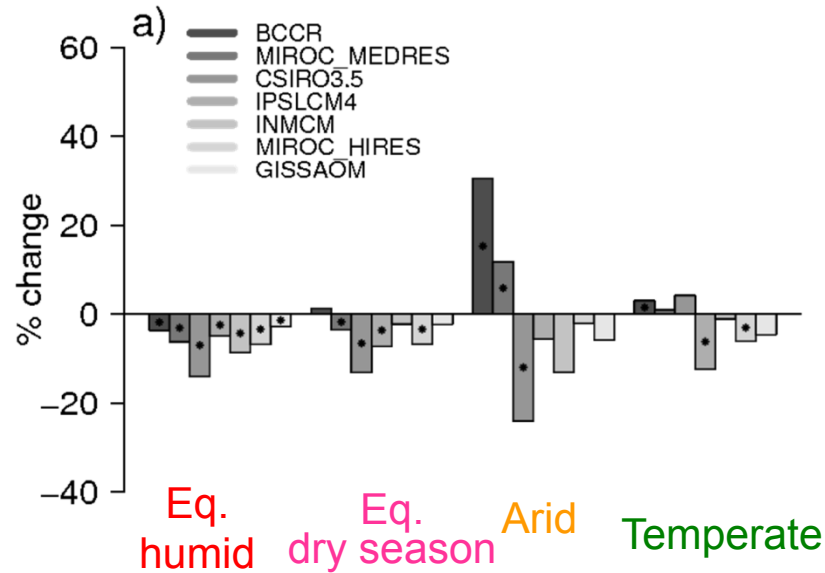
By 2085
(2070-2100)



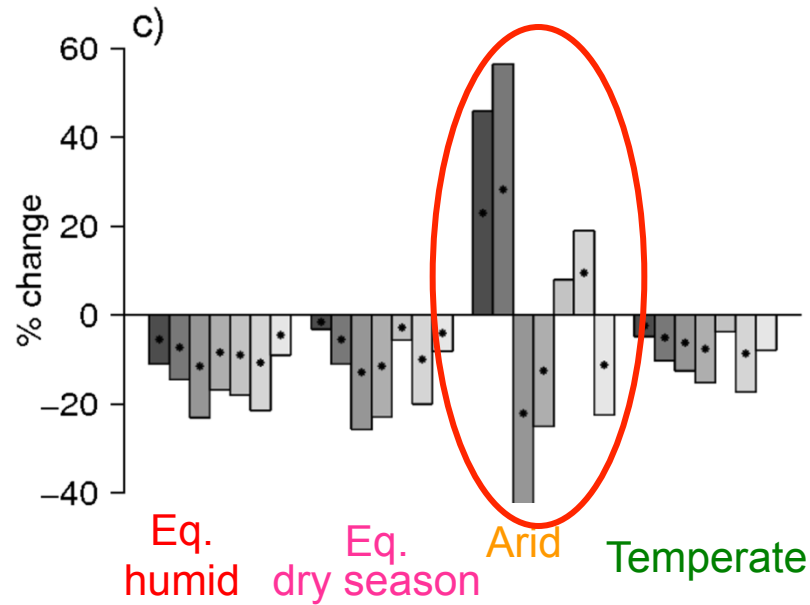
Yield change

A1B scenario

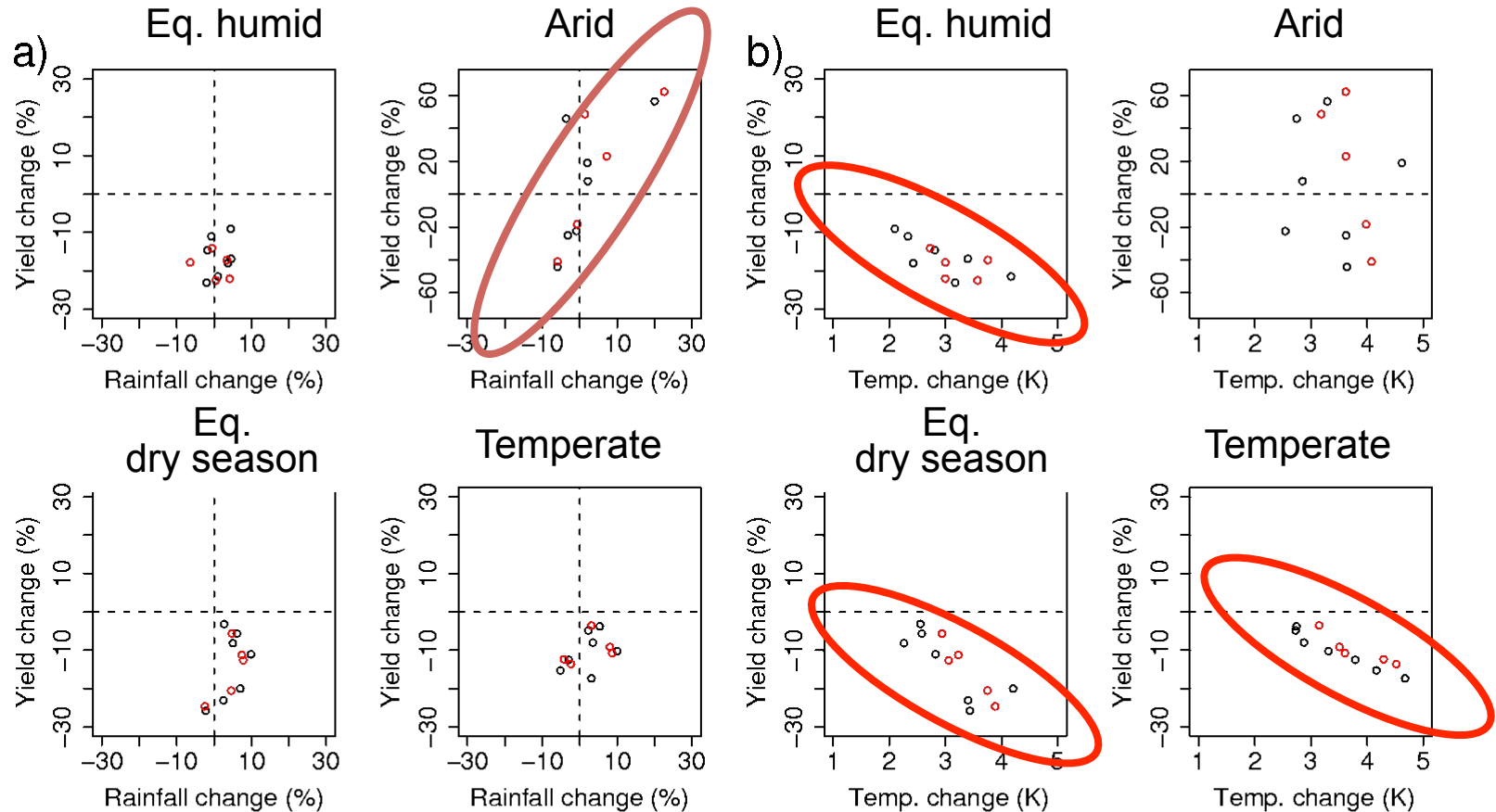
By 2035
(2020-2050)



By 2085
(2070-2100)



Rainfall change, Temperature change and Yield change



➡ Rainfall effect only in “dry zones”

➡ T° effect in other zones = acceleration of phenology



Consistency of yields change on different zones < consistency of climate projections for T/P

Projections of climate change impacts on potential C4 crop productivity over Africa and India

Limitations:

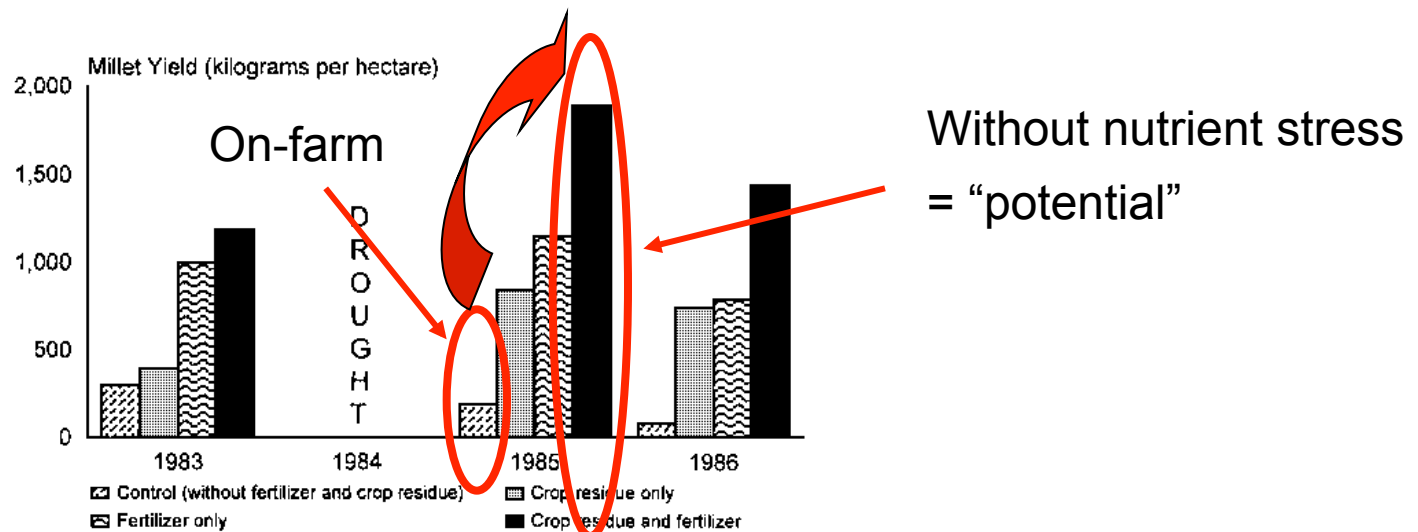


- Not all climate impacts are considered:
 - climate extremes (heat waves, floods)
 - interactions between climate, CO₂ and pests/diseases

Projections of climate change impacts on potential C4 crop productivity over Africa and India

Limitations:

- Scope of potential climate-related impacts only :
 - possibility to **adapt** agricultural practices to climate change: water management, cultivars, cropping systems...
 - possibility to improve yields today = “**fill the yield gap**”



ICRISAT data, Niger (Vlek and Mkwunye 1988).

L'inefficacité de l'agriculture en Afrique est avérée

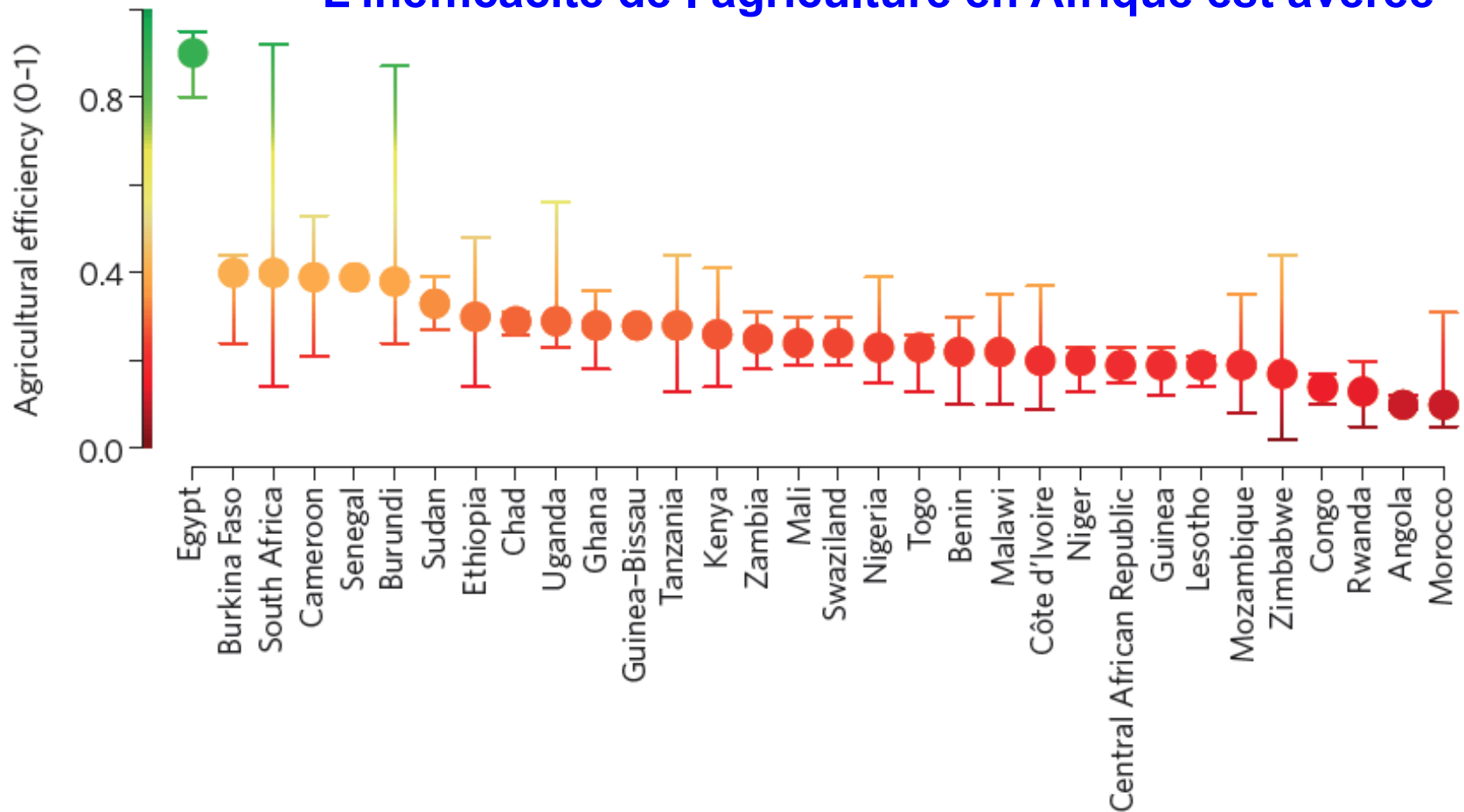
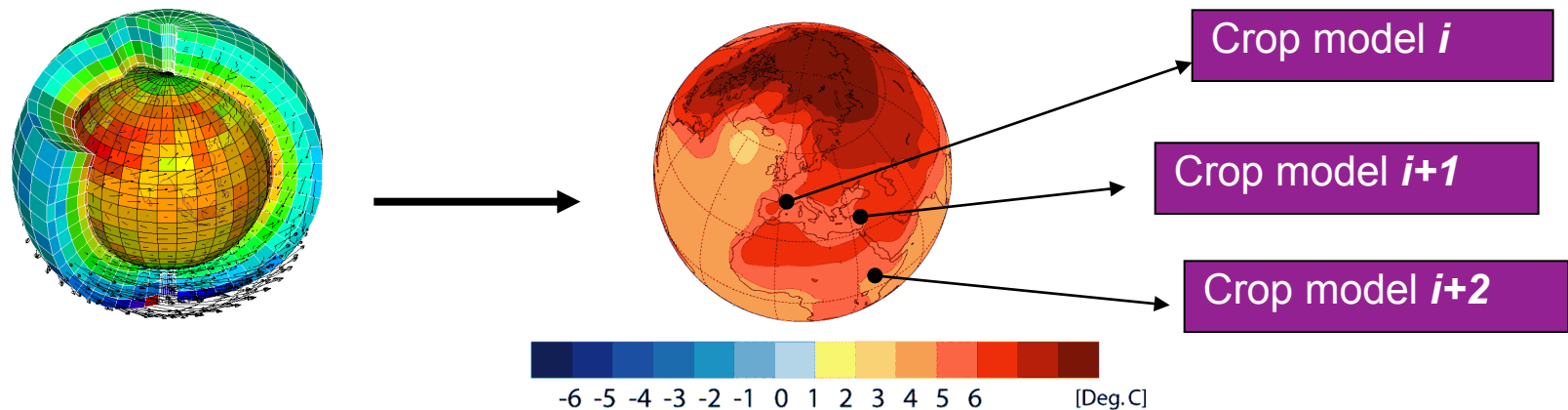


Figure 1 | Agricultural inefficiency in Africa. Climate change impacts are likely to hit agricultural production systems hard in Africa. These systems suffer from substantial inefficiencies, which can be largely attributed to limited market access⁸, but they also have considerable potential for improvements with the appropriate investments². Data are mean (dots), minima and maxima (whiskers) efficiencies for maize production systems in African countries from ref. 8.

Que valent de telles projections?

Comment les combiner avec ce qui est fait de façon plus 'traditionnelle' (GIEC)?



Leur valeur est d'autant plus importante que les résultats 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

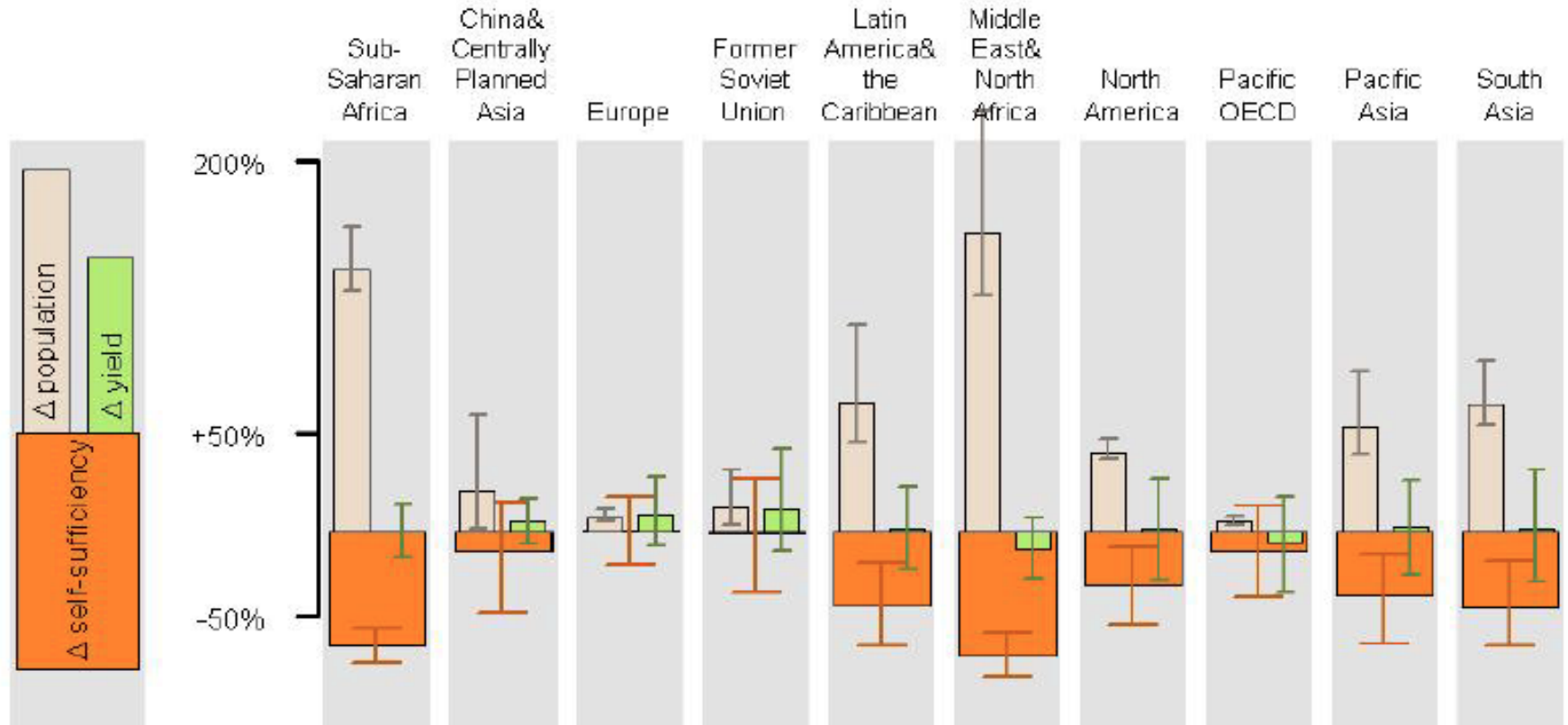
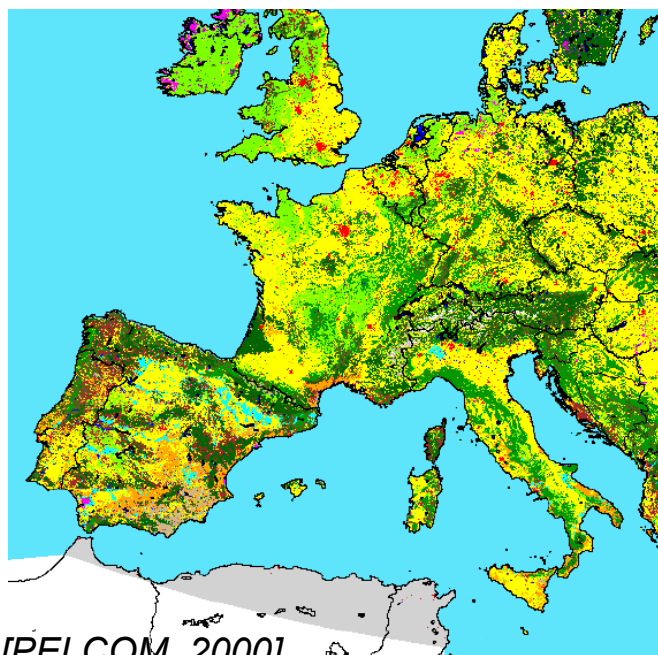


Figure 2.2.1: Mean change in crop yields (green bars) from 1996-2005 to 2046-2055 in all 30 scenarios considered here. Whiskers indicate the range of impacts, which is mainly determined by the effectiveness of CO₂ fertilization. Tan-coloured bars indicated projected changes in population (Nakicenovic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

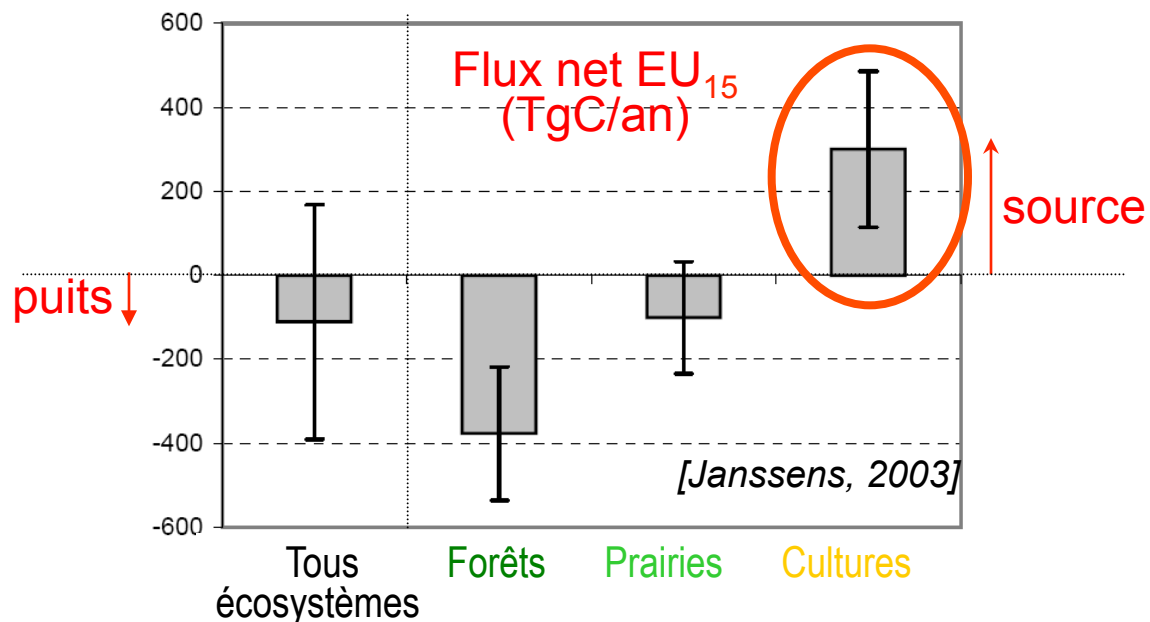
Les DGVMs 'agro' ne sont pas utilisés
que pour des projections de
changements de productivité. Ils sont
aussi utilisés pour évaluer les puits et
sources de CO₂ par région/pays/
continent

Smith et al. 2010

Incertitudes sur le puits de carbone européen



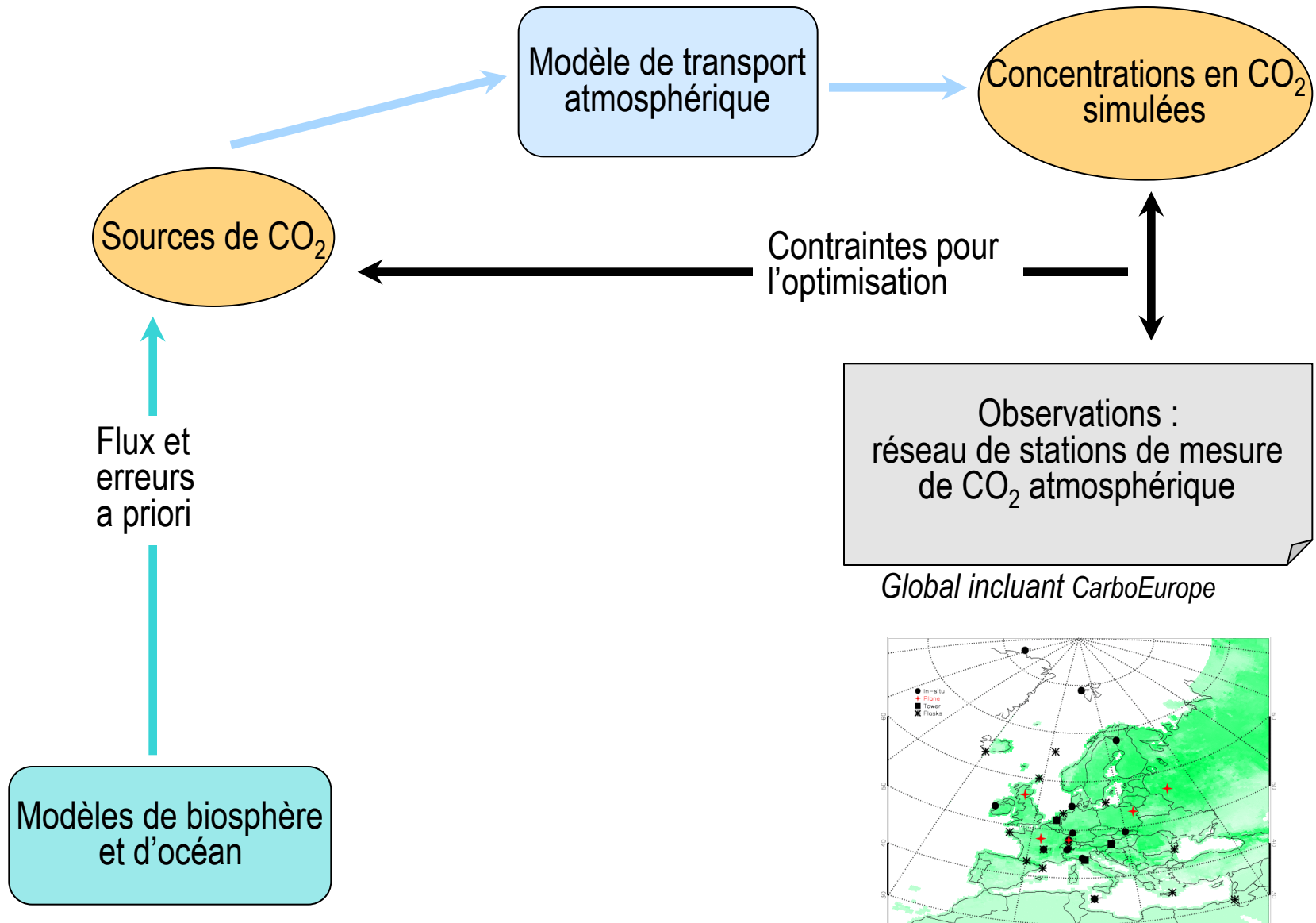
En Europe **cultures** ~35%
prairies + **cultures** ~70%



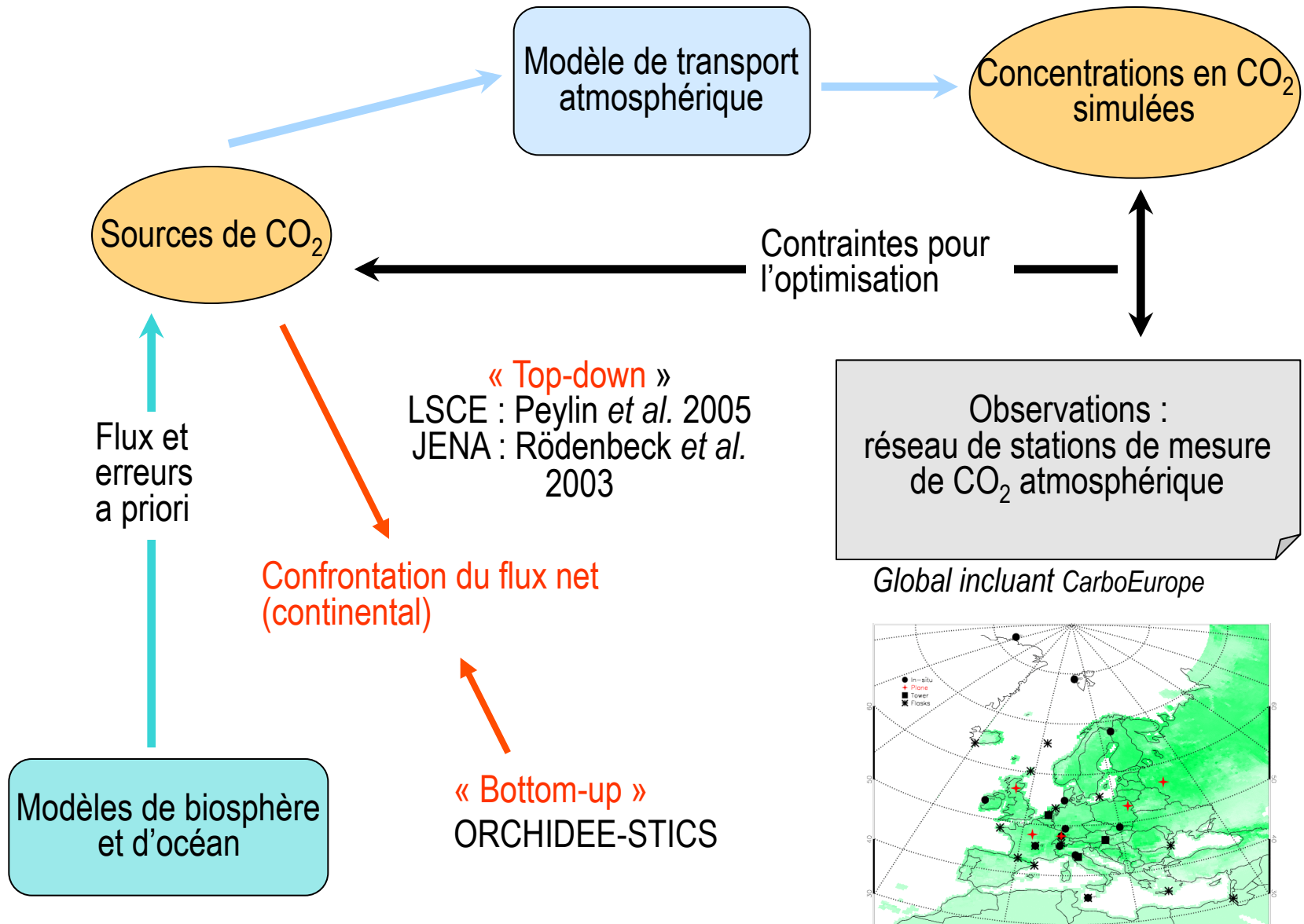
Grandes \neq entre écosystèmes et incertitude forte
→ cultures plutôt source actuellement, quid futur ?

Besoin d'outils pour mieux estimer le bilan des cultures
→ Forte hétérogénéité spatiale et variabilité inter-annuelle

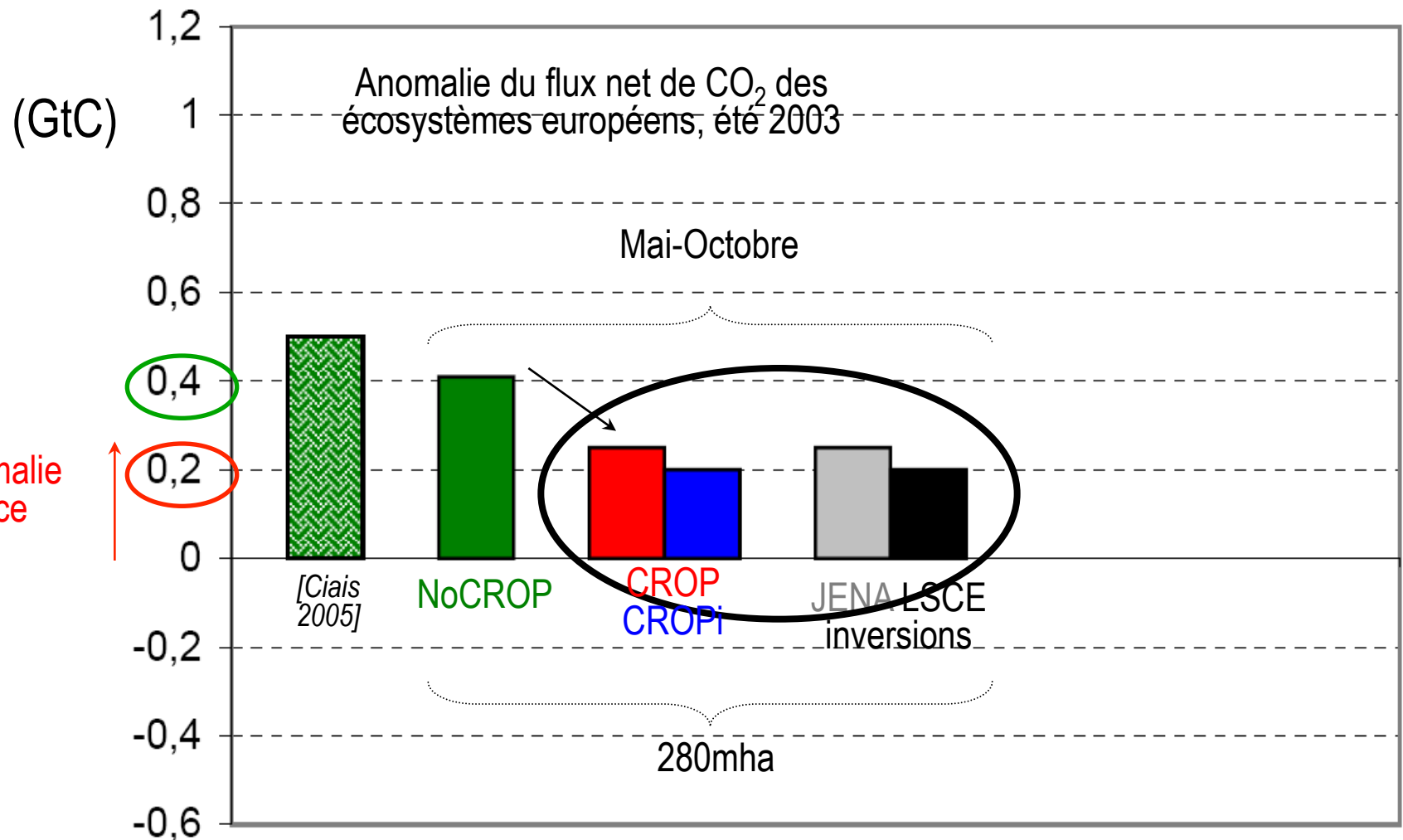
Principe des inversions atmosphériques



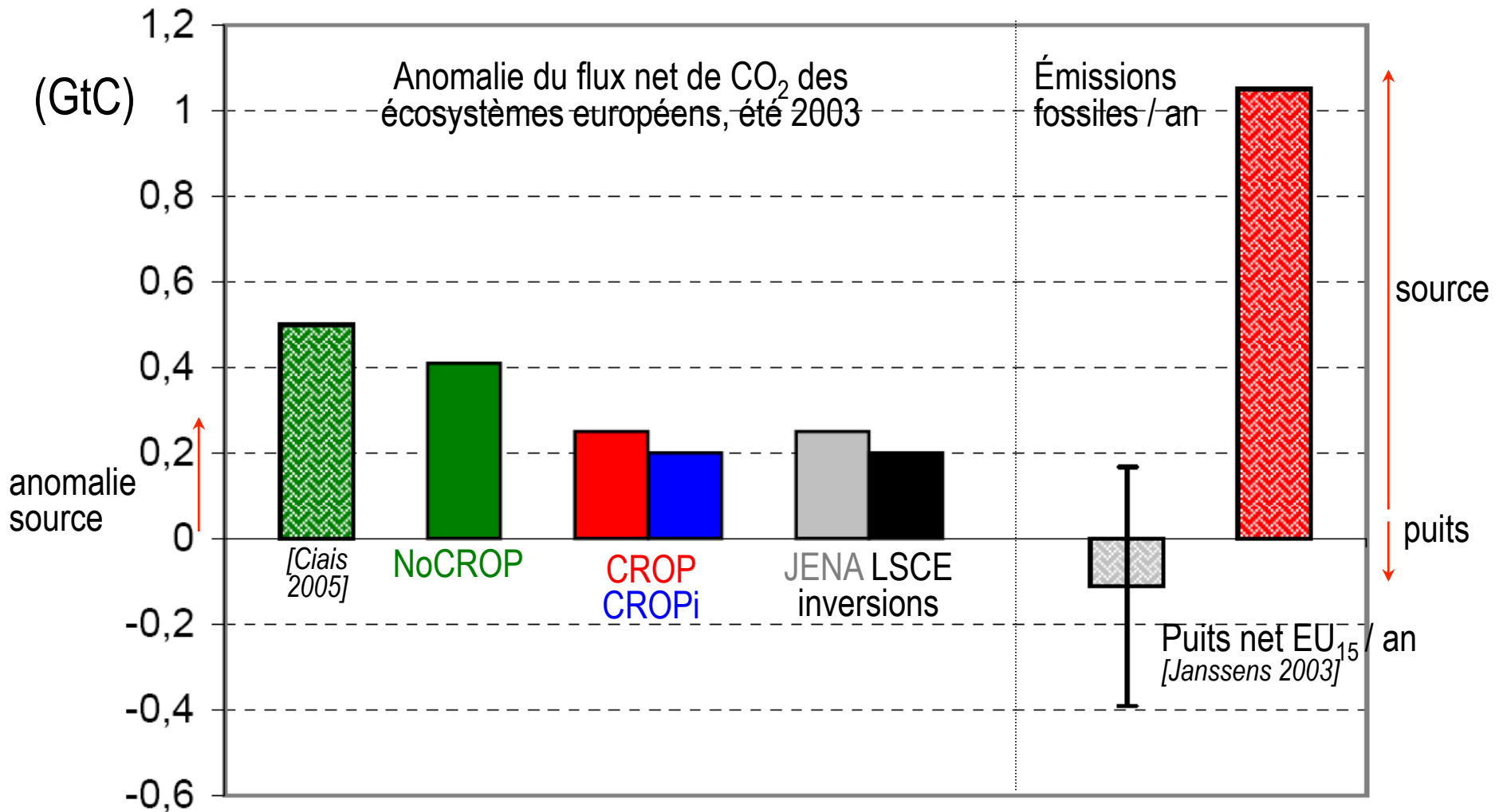
Principe des inversions atmosphériques



Europe : source anormale de CO₂ en 2003



“bottom-up” vs. “top-down” : prise en compte agriculture →
anomalie comparable aux inversions



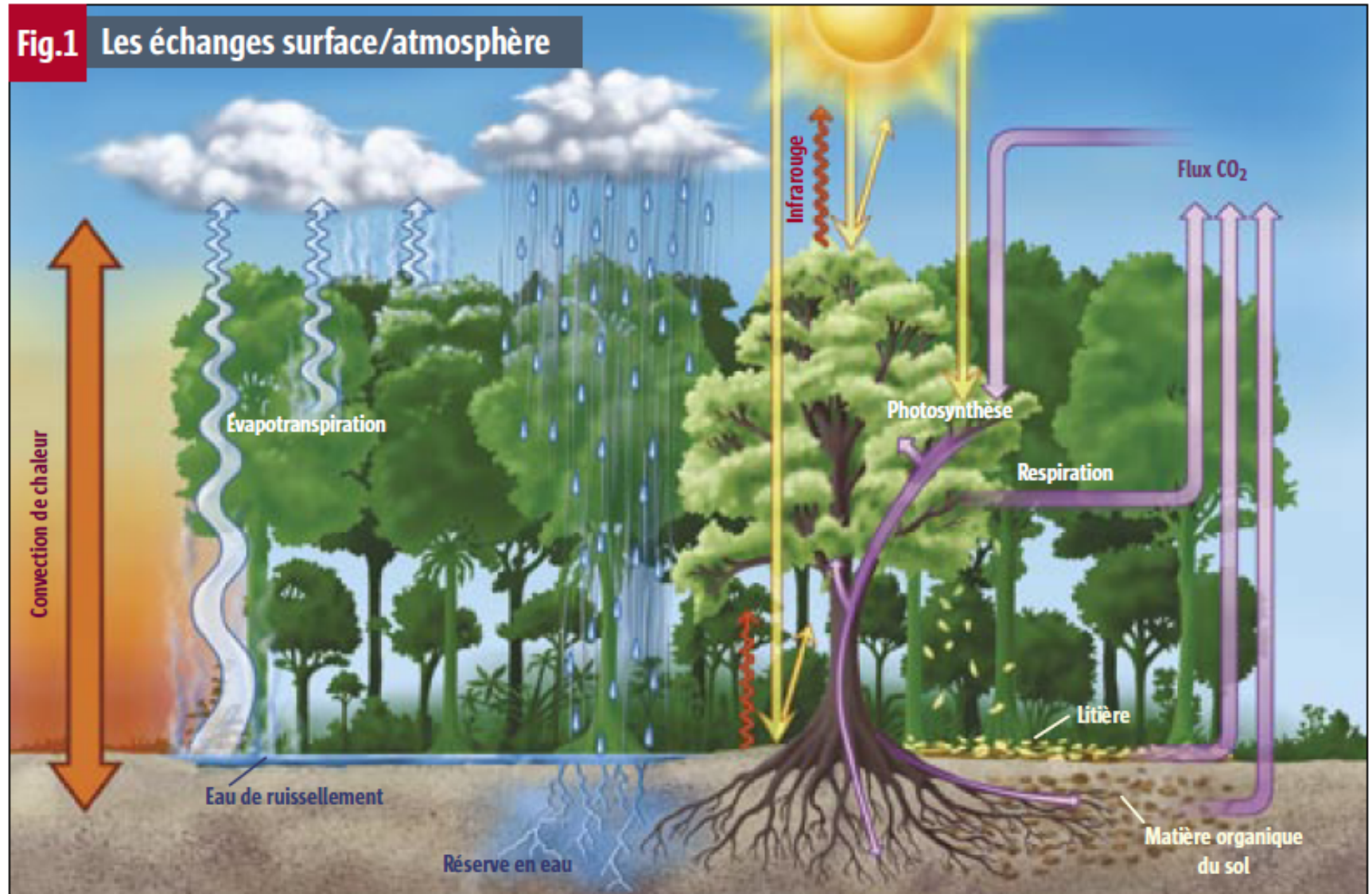
Anomalie 2003 annule bénéfices de 2 années de puits biosphérique européen (soit ~20% du puits biosphérique annuel global)

PARTIE-2

Pourquoi peut-on attendre
*des impacts du changement d'usage
des terres sur le climat ?*

Pourquoi / comment l'usage des terres peut-il avoir un impact sur le climat ?

Fig.1 Les échanges surface/atmosphère



LES MODÈLES ACTUELS prennent en compte divers flux entre les surfaces forestières et l'atmosphère. Le carbone de l'atmosphère est fixé dans la végétation par photosynthèse. Il est stocké dans les feuilles, le bois, les racines et le sol. Il est réémis lors de la combustion ou de la décomposition de la matière organique. Les arbres réévalorent l'eau de pluie interceptée par les feuilles ou prélevée dans le sol. Les forêts renvoient dans l'infrarouge une partie du rayonnement solaire reçu. Elles transfèrent de la chaleur à l'atmosphère par convection. © INFOGRAPHIE PASCAL PINEAU

depuis quand l'Homme
perturbe-t-il le climat?

Depuis ~2 siècles,
augmentation sans précédent des GES (CO_2 , CH_4)

L'ère baptisée Anthropocène par Crutzen et Stoermer (IGBP Newsletter, 2000) aurait commencée aux environs de l'an 1800

OR

Ruddiman émet l'hypothèse que les premières activités agricoles (déforestation, usage des sols, pratiques d'irrigation anciennes) ont déjà, depuis plusieurs millénaires, perturbé le cycle global du carbone et modifié le climat → il positionne les débuts de l'Anthropocène il y a environ 8000 ans

4 arguments étayent l'hypothèse de Ruddiman

- Les niveaux de CO_2 et de CH_4 dans l'atmosphère auraient dû commencer à diminuer il y a environ 8000 ans OR le CO_2 s'est remis à augmenter il y a 8000 ans, et le CH_4 il y a 5000 ans
- Les explications avancées pour attribuer ces anomalies à des phénomènes naturels peuvent être réfutées
- La Terre aurait déjà dû entrer en glaciation
- Il existe de nombreuses évidences archéologiques, culturelles, historiques, qui montrent que l'agriculture s'est développée massivement en Eurasie il y a environ 8000 ans, et que l'irrigation du riz a débuté il y a environ 5000 ans

En résumé, l'hypothèse de Ruddiman conduit à l'amplification suivante

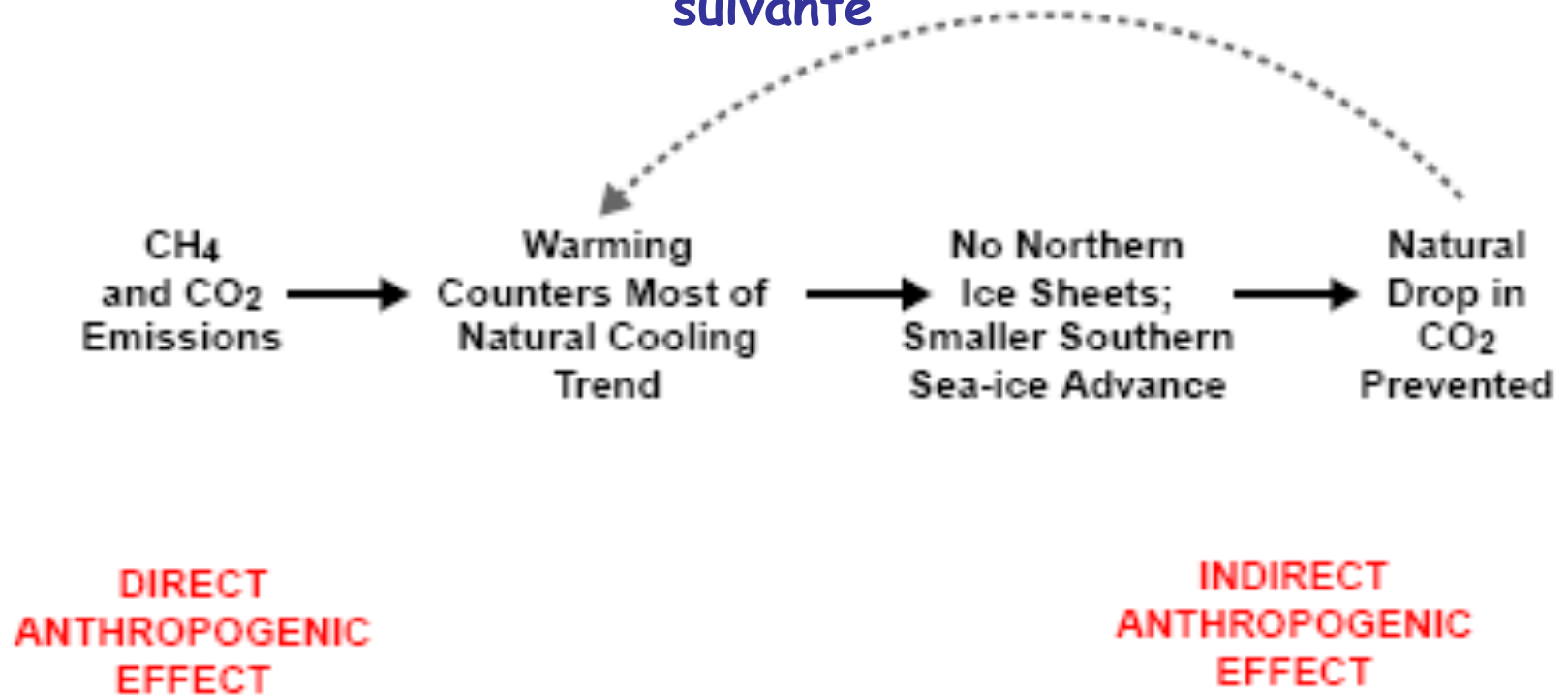


Fig. 8. Direct anthropogenic emissions explain most of the Holocene CH₄ anomaly but only part of the CO₂ anomaly. The rest of the CO₂ anomaly may result from the prevention of a natural CO₂ drop that occurred in previous interglaciations but was overridden in the Holocene by anthropogenic warming.

Quelques références sur l'hypothèse de Ruddiman :

Ruddiman (Climatic Change 2003)

Ruddiman (Climatic Change 2005)

Controverses:

Joos et al. (Global Biogeochemical Cycles 2004)

Claussen et al. (Climatic Change 2005)

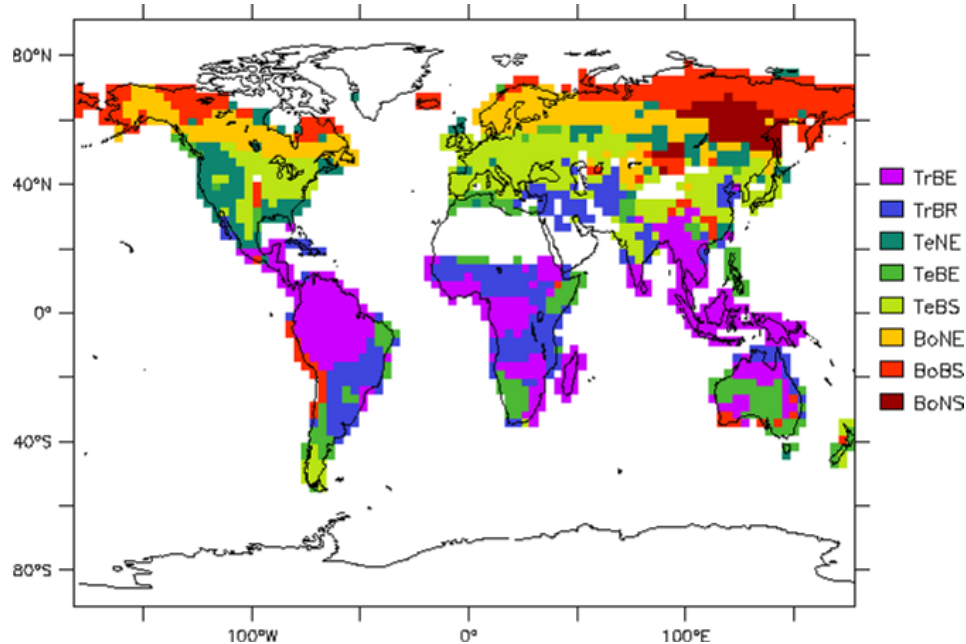
Crucifix et al. (2005)

**Les impacts bio-géophysiques
d'une déforestation sont-ils les
mêmes à toutes les latitudes ?**

Davin et de Noblet-Ducoudré (2010), *Journal of Climate*

Expériences

❑ Expériences idéalisées de déforestation massive:



FOREST

GRASS : forests are all replaced by grass

ALB : Sole effect of surface albedo

EVA : Sole effect of changes in evapotranspiration efficiency

RGH : Sole effect of roughness length

*Davin et de Noblet-Ducoudré (2010) Journal of Climate
Thèse Edouard Davin (2008)*

Changement de densité foliaire en été boréal (Juin-Juillet-Août)

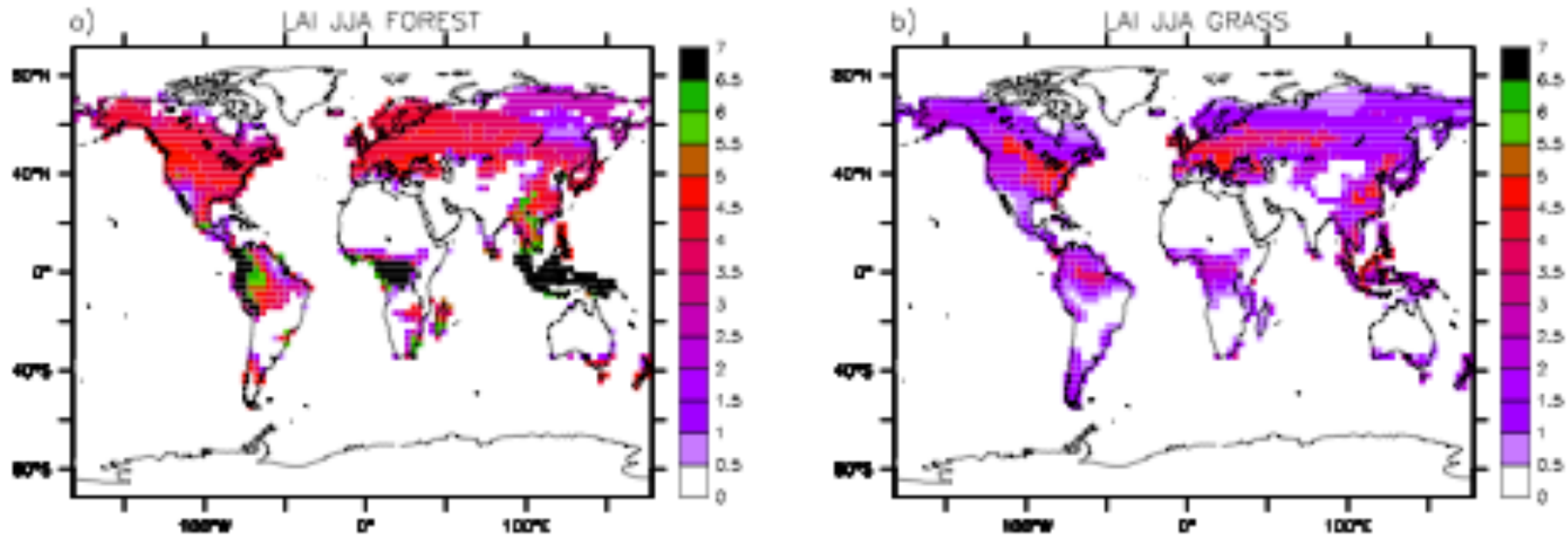
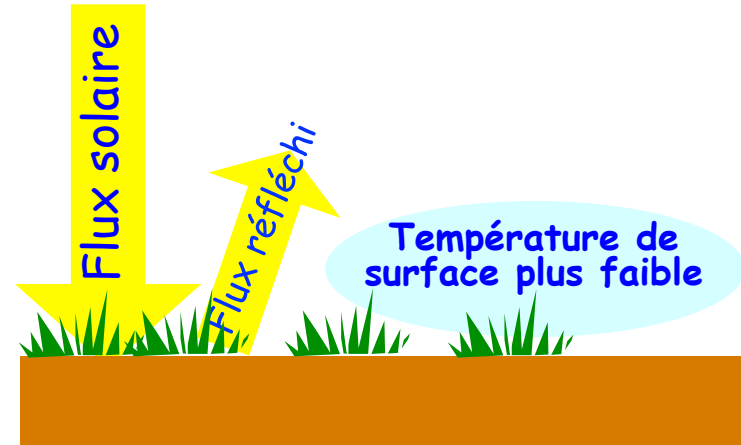
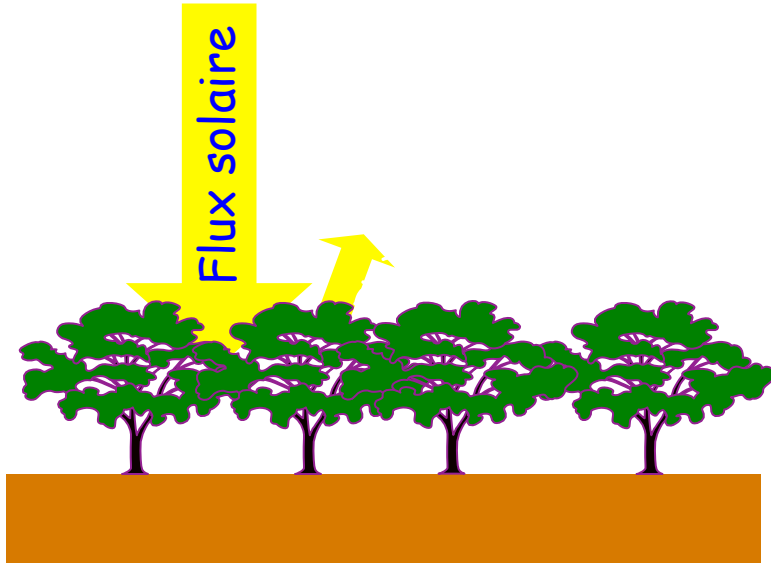
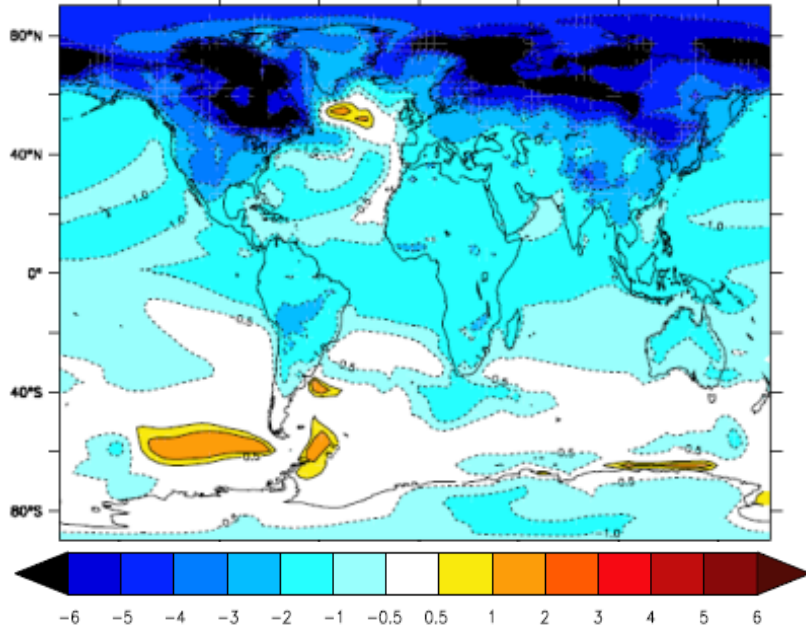


FIG. 3.5 Simulated summer (JJA) leaf area index for a) simulation FOREST and b) simulation GRASS.

Rôle de l'albédo de surface



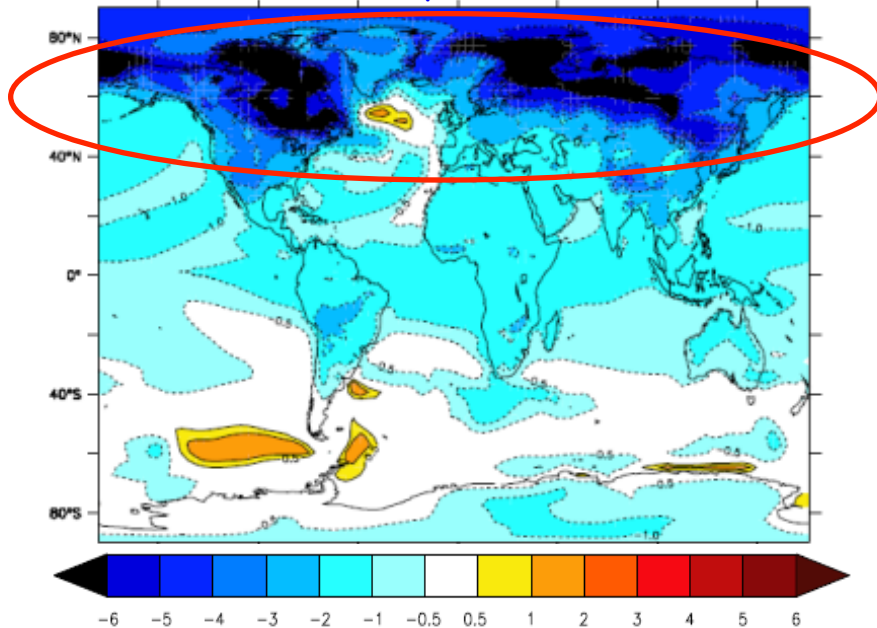
Anomalie de température de surface



Rôle de l'albédo de surface

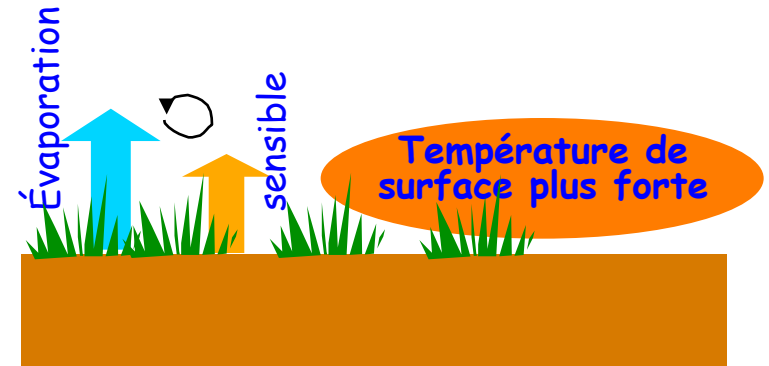
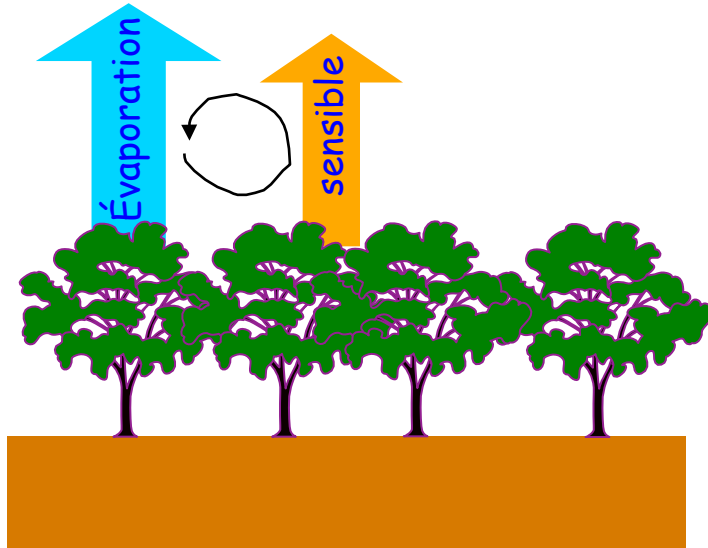


Anomalie de température de surface

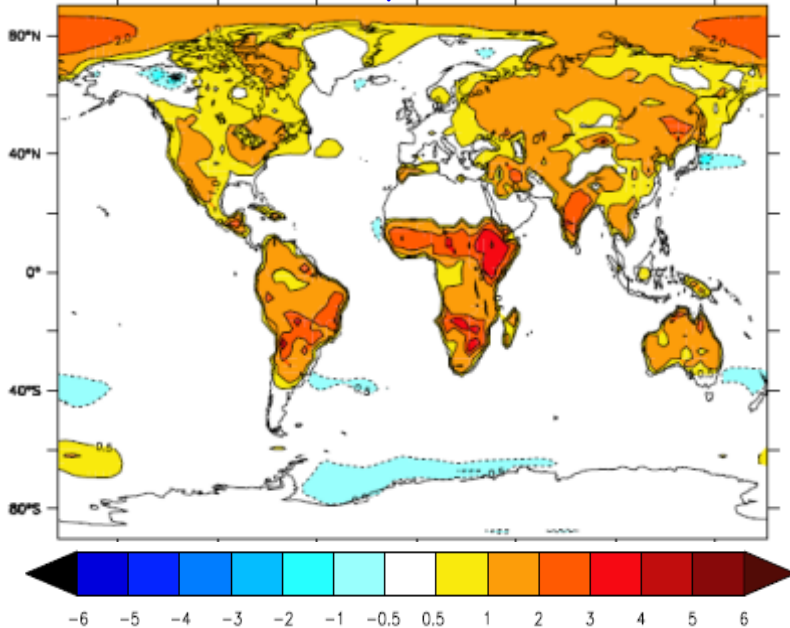


Refroidissement plus important dans les hautes latitudes à cause de la présence de neige qui amplifie l'augmentation d'albédo après déforestation.

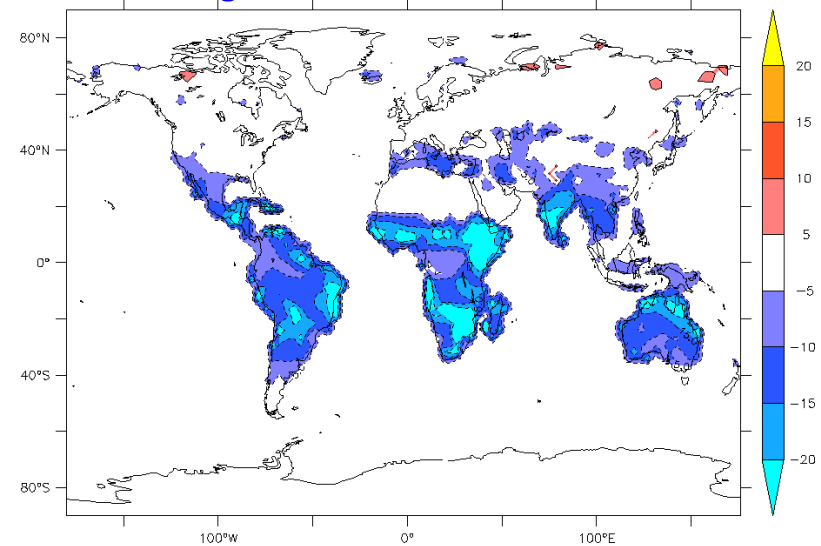
Rôle de la rugosité



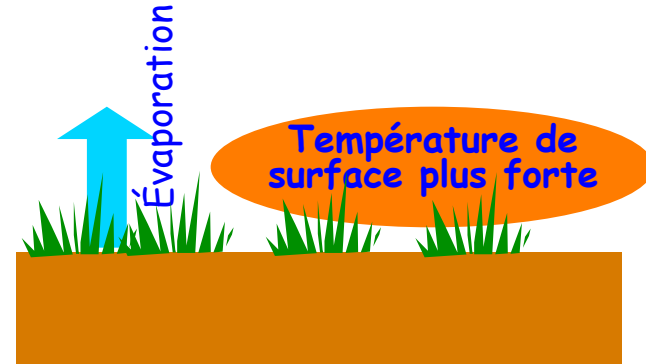
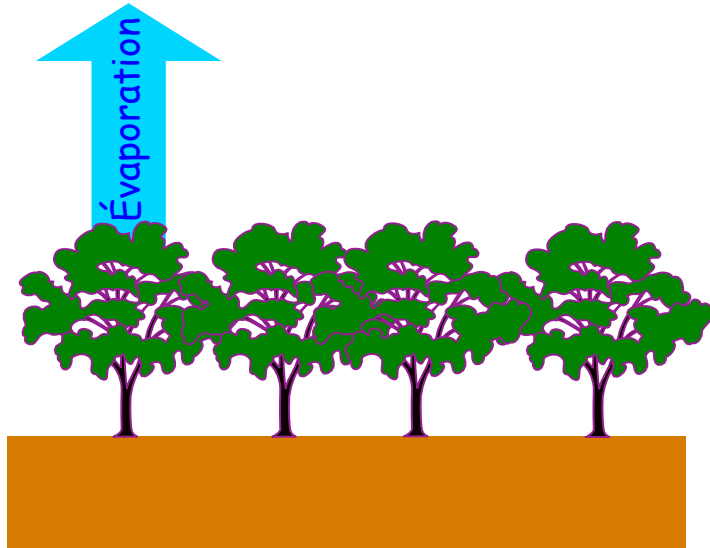
Anomalie de température de surface



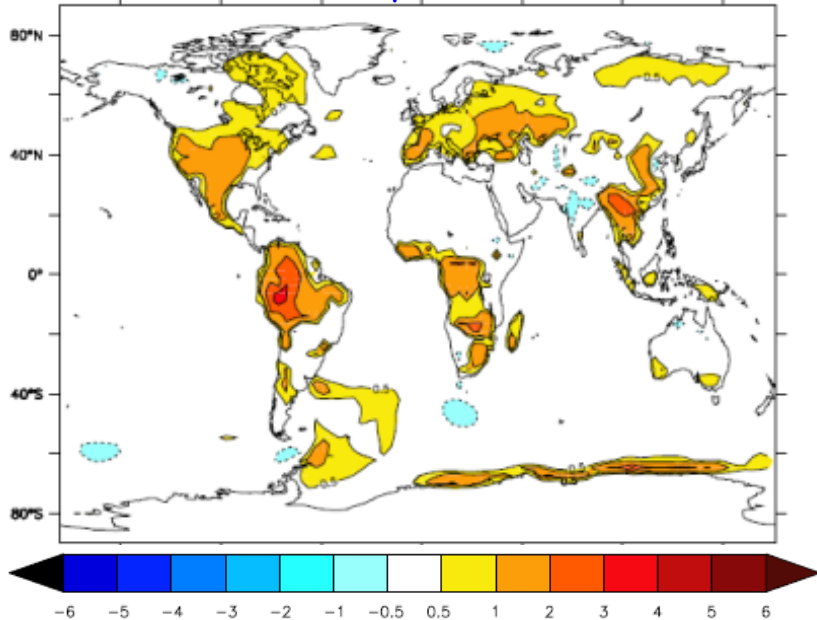
Changement des flux turbulents



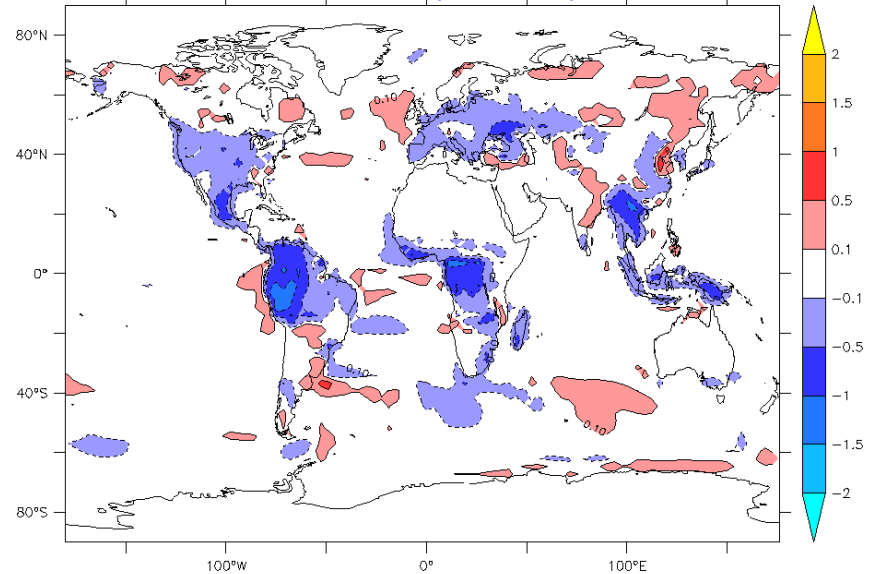
Rôle de l'efficacité évaporative



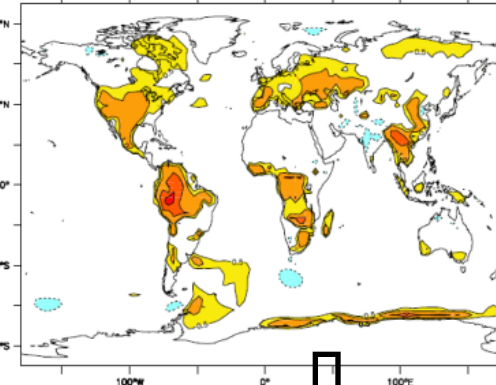
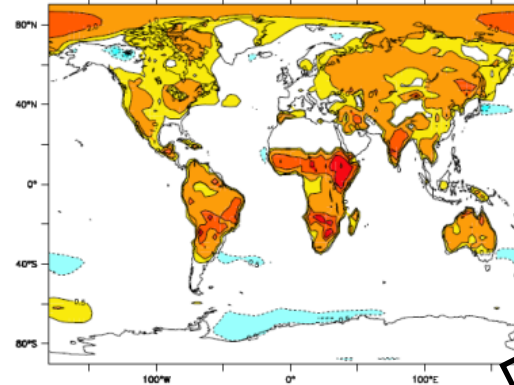
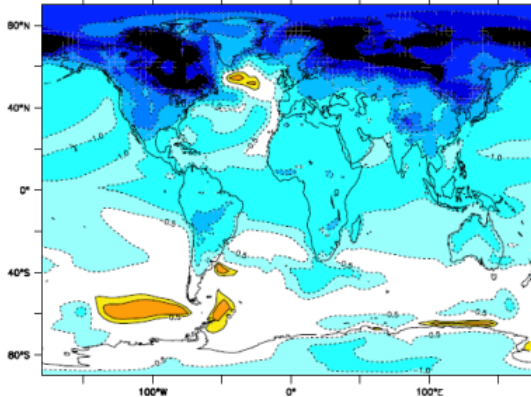
Anomalie de température de surface



Anomalie d'évapotranspiration



Deux types de processus très différents



Changement d'albédo

☐ Effet refroidissant

☐ Effet sur les continents et sur les océans

☐ Effet plus marqué dans les régions froides

☐ Déséquilibre énergétique au sommet de l'atmosphère -> forçage radiatif

Changement de rugosité et d'efficacité évaporative

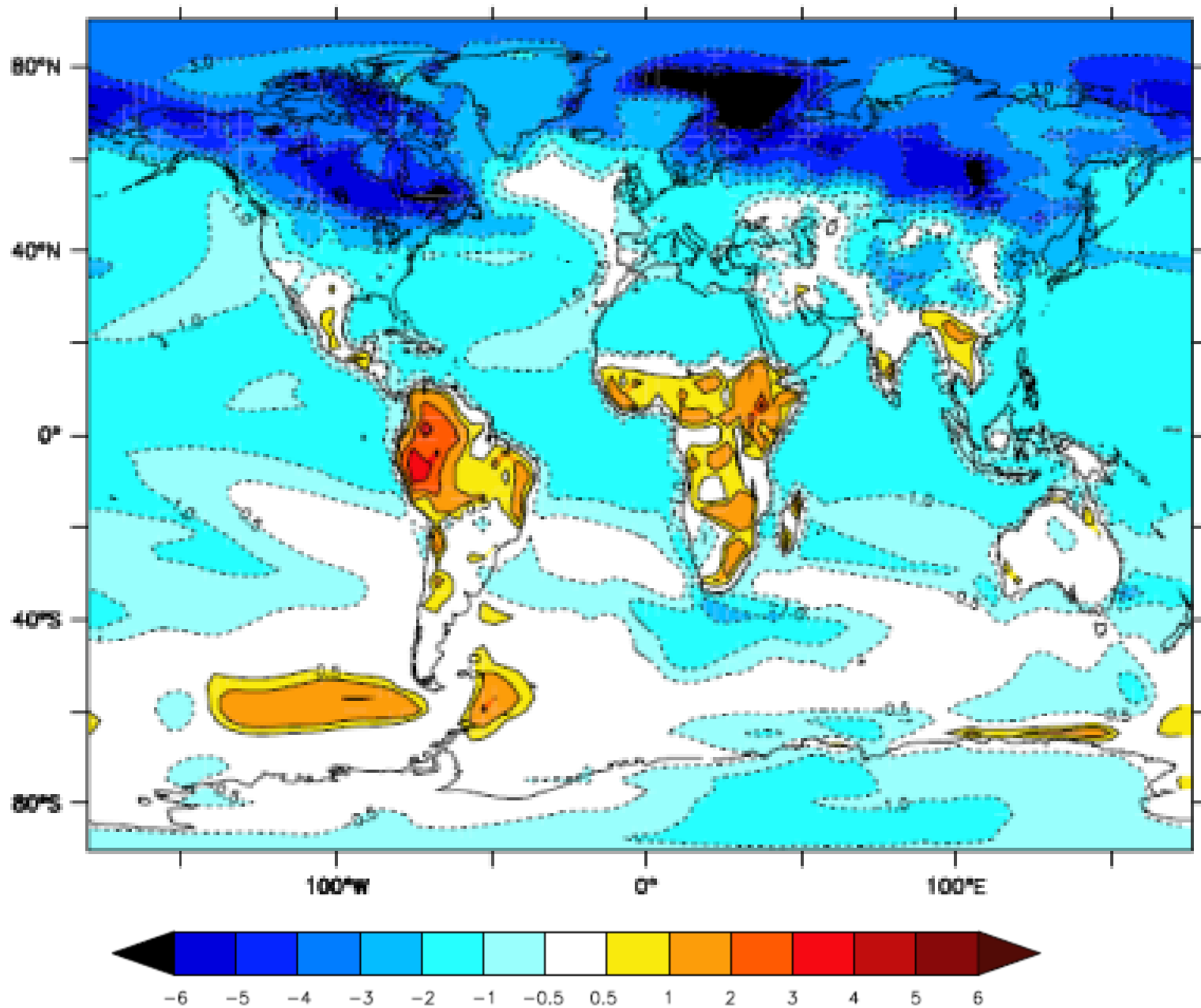
☐ Effet réchauffant

☐ Effet localisé sur les continents

☐ Effet légèrement plus marqué dans les régions chaudes à forte évaporation

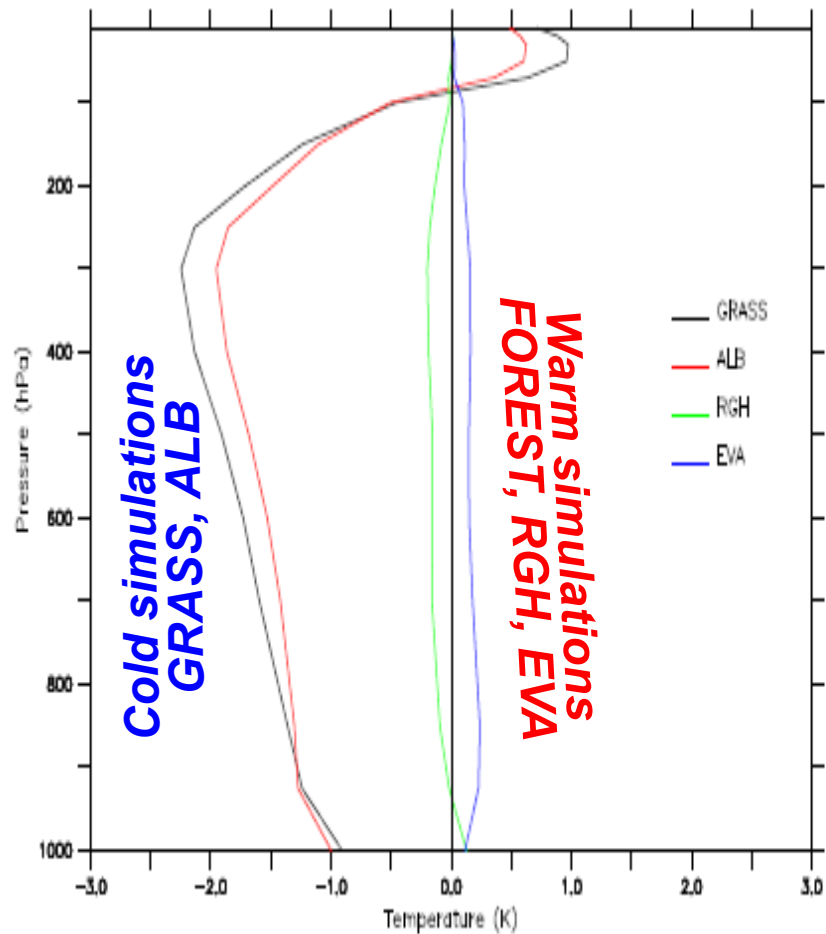
☐ Pas de déséquilibre énergétique au sommet de l'atmosphère -> forçage non-radiatif

Effet biophysique total de la déforestation

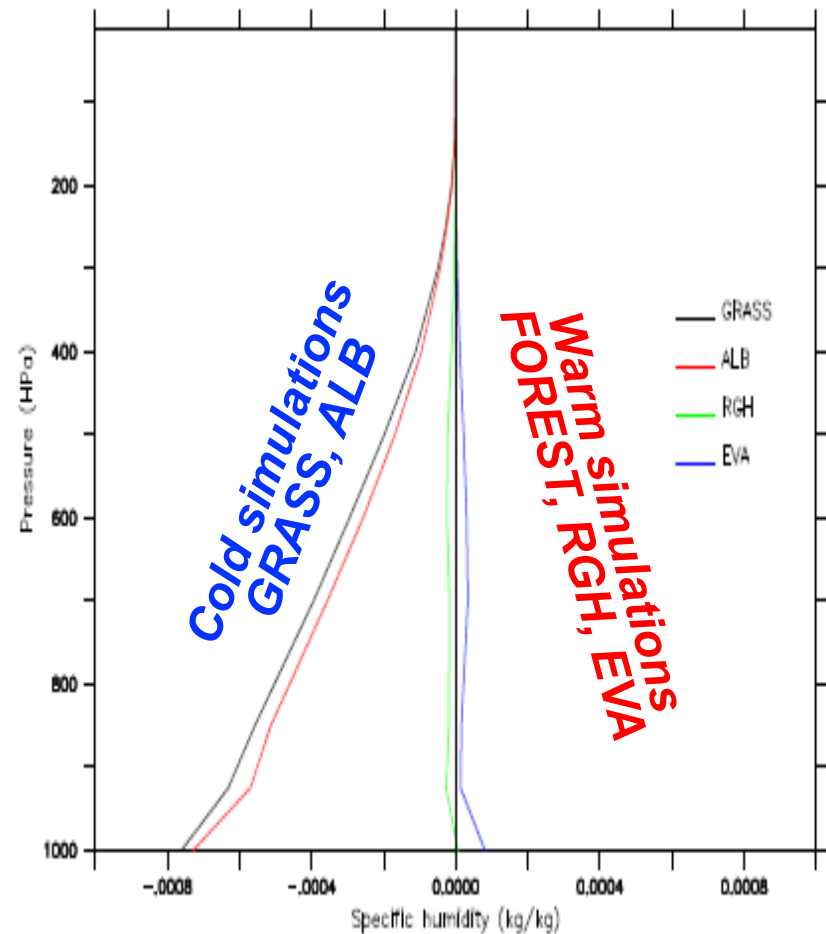


Changes in vertical profiles of temperature and humidity

a) Temperature

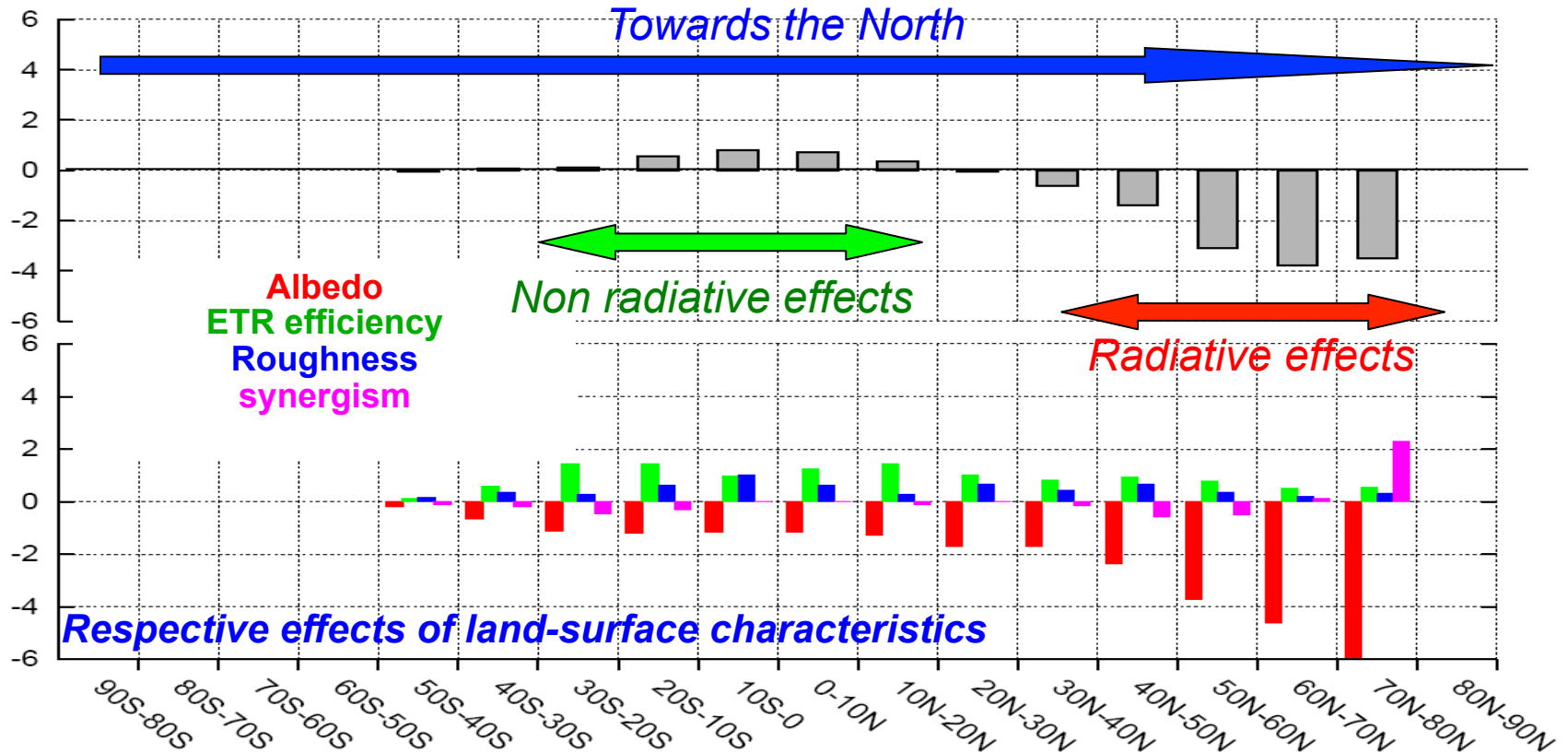


b) Specific humidity



Deforestation → global cooling

Changes in mean annual surface temperature, per latitudinal band, over the continents

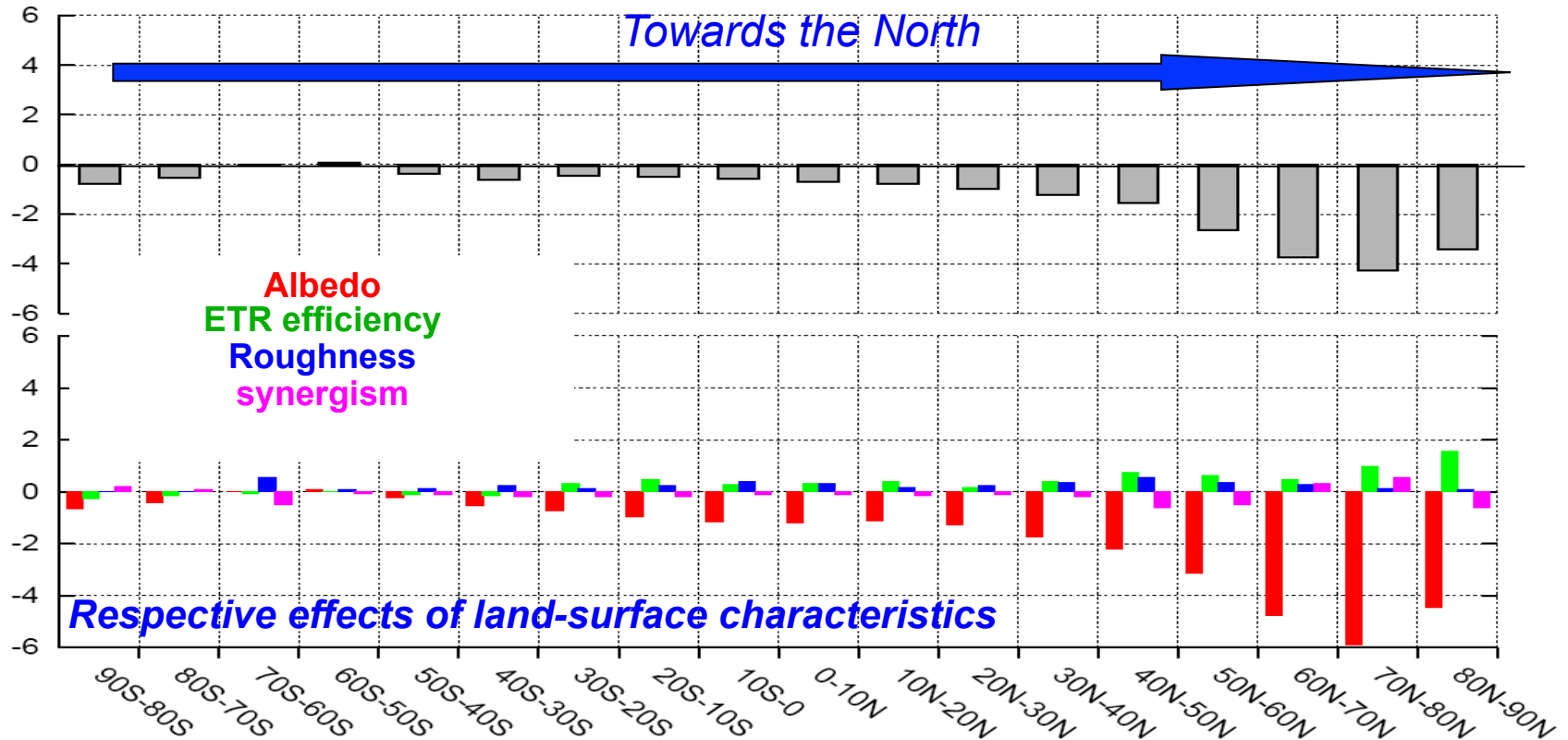


Changes in continental surface temperatures are dominated by :

- *albedo change in the mid to high latitudes*
- *changes in the non-radiative characteristics in the tropics*

Deforestation → global cooling

Changes in mean annual surface temperature, per latitudinal band, over continents & oceans



Changes in mean ocean + continents surface temperatures are dominated by :

the albedo change

Impact latitudinal d' une déforestation : conclusion

The cooling resulting from the biophysical effects of deforestation results from the changes in surface albedo

Changes in surface albedo have an impact throughout the troposphere, and induce an oceanic cooling

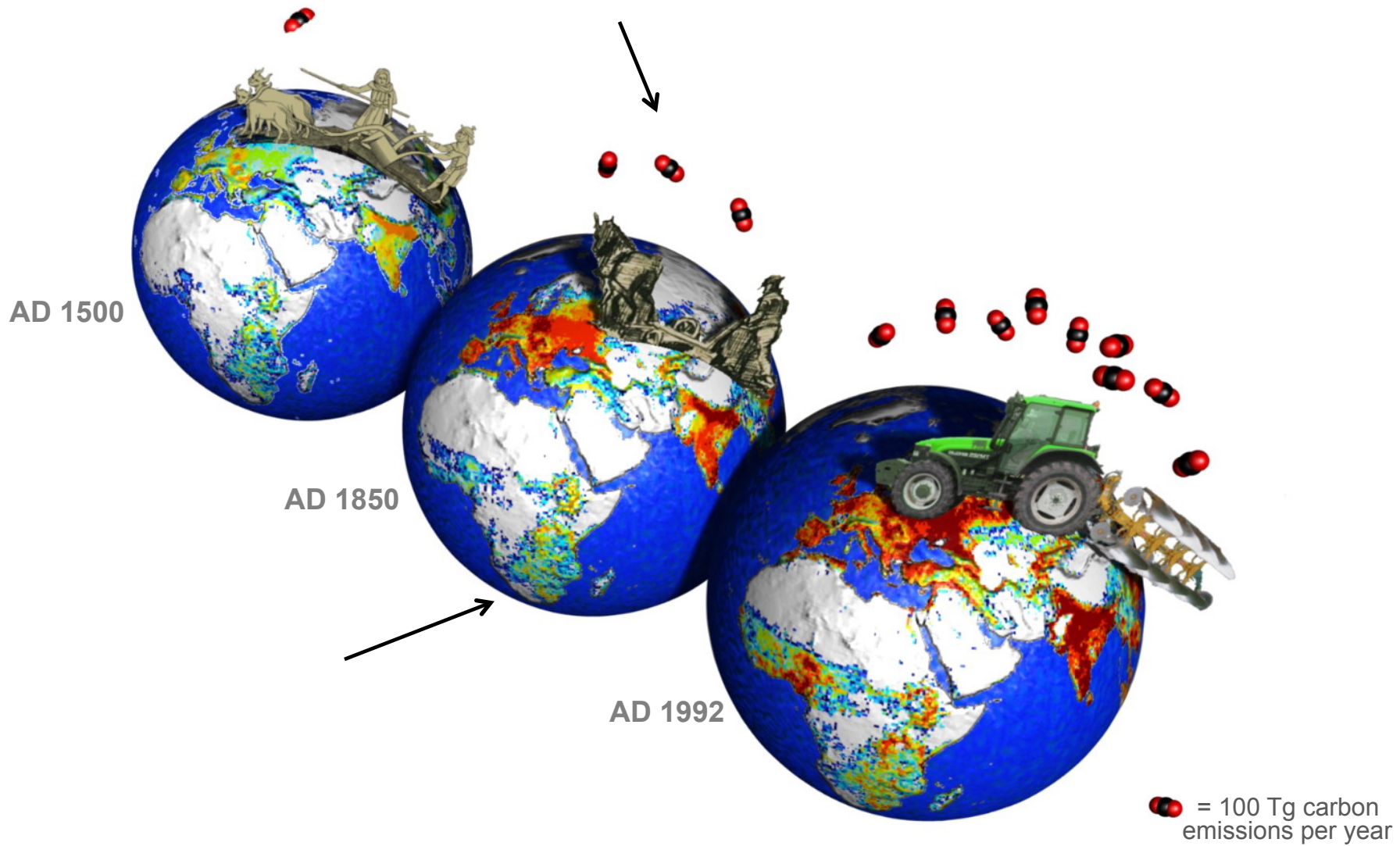
Changes in other biophysical properties (roughness, ETR efficiency) have a surface warming impact, but no effect is seen on the ocean, nor in outside the boundary layer

Over the continents, deforestation leads to a warming in the tropics that, as we move north, progressively becomes a cooling. At temperate latitudes, there is a competing effect between the radiative and non-radiative properties of the land that lead to a no-change'

Quels sont les impacts d'une
déforestation si on combine effets
bio-géophysiques et bio-
géochimiques ?

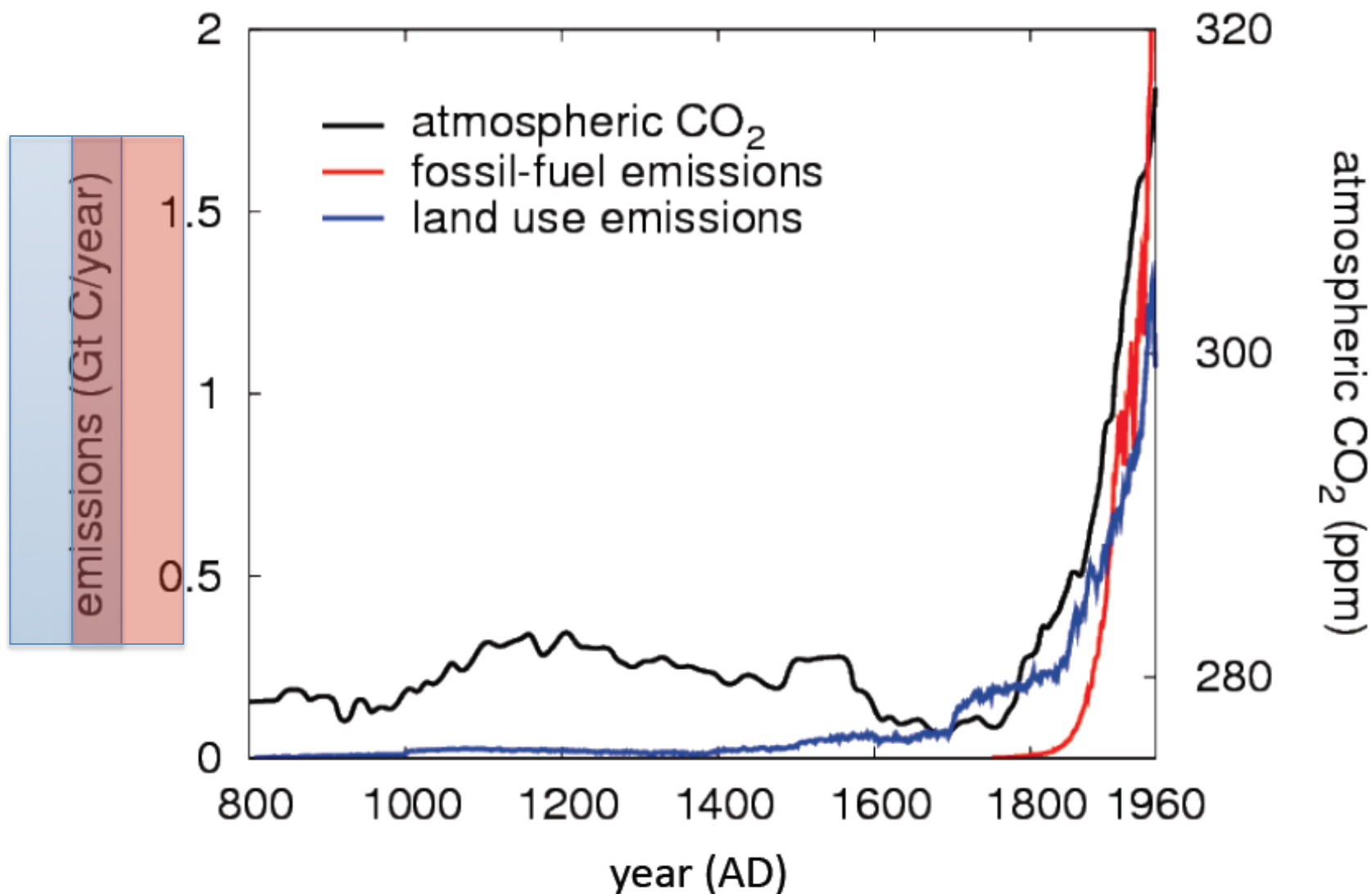
Pongratz et al. (2010), *Geophysical Research Letters*

Effet d'une déforestation sur les émissions de CO₂



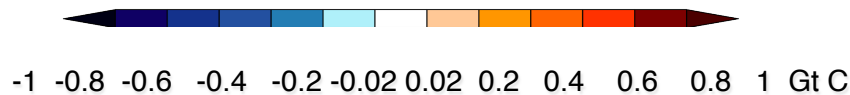
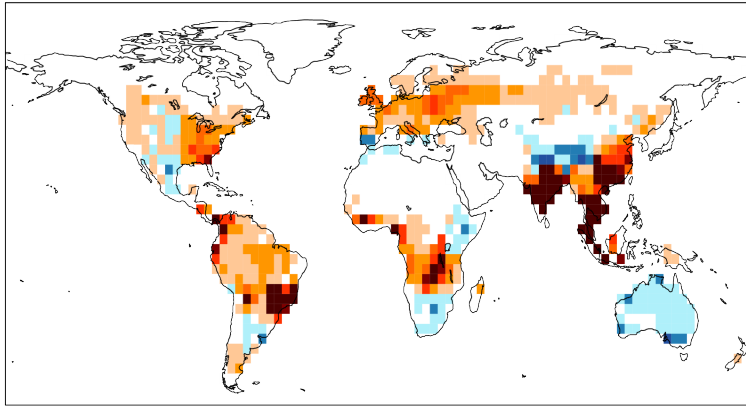
Early land use emissions were substantial

(Pongratz et al., *Global Biogeochem. Cycles*, 2009)

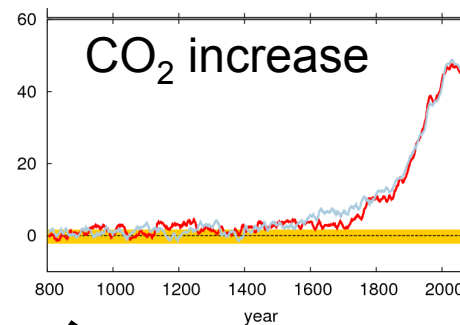


Carbon cycle effects of local land cover change

Gross emissions AD 800-2000:



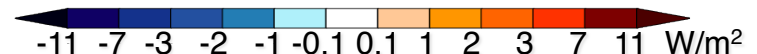
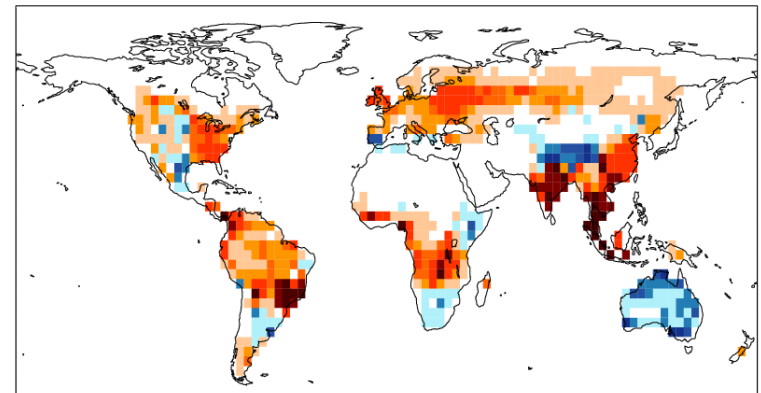
„Scale“ to global CO₂ increase
(convolution with
response function)



Map of contribution to
CO₂ increase (ΔC in ppm)

$$\text{CO}_2 \text{ RF} \\ \Delta F_{\text{CO}_2} = 5.35 \cdot \ln(1 + \Delta C / C_0)$$

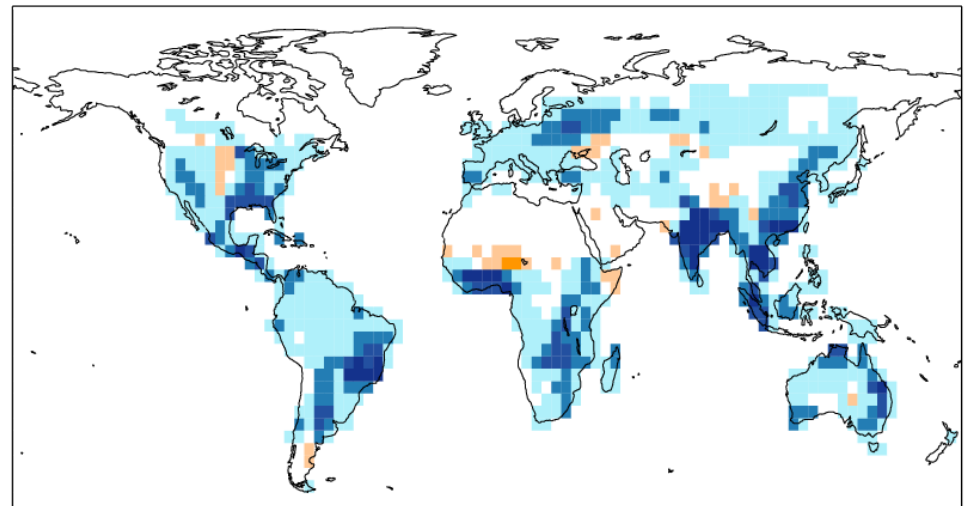
“RF”: radiative forcing



Biophysical effects of local land cover change

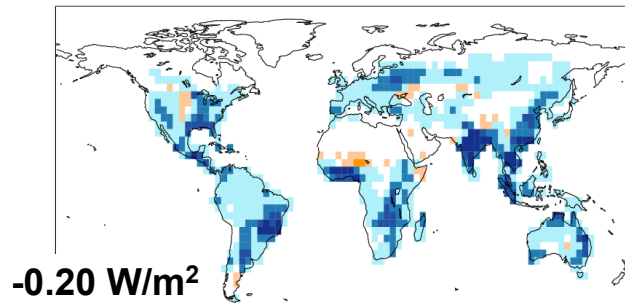
Instantaneous radiative forcing of **surface albedo** changes.

Since changes in evapotranspiration tend to act in direction of CO₂ effects (warming), albedo forcing is maximum estimate of counteracting biogeophysical effects.

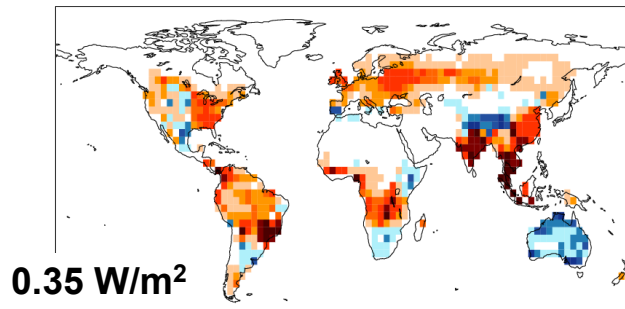


Combined effects of local land cover change

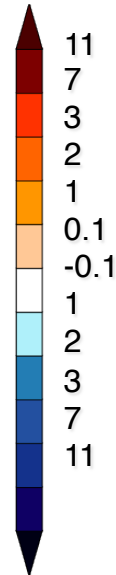
Surface albedo RF



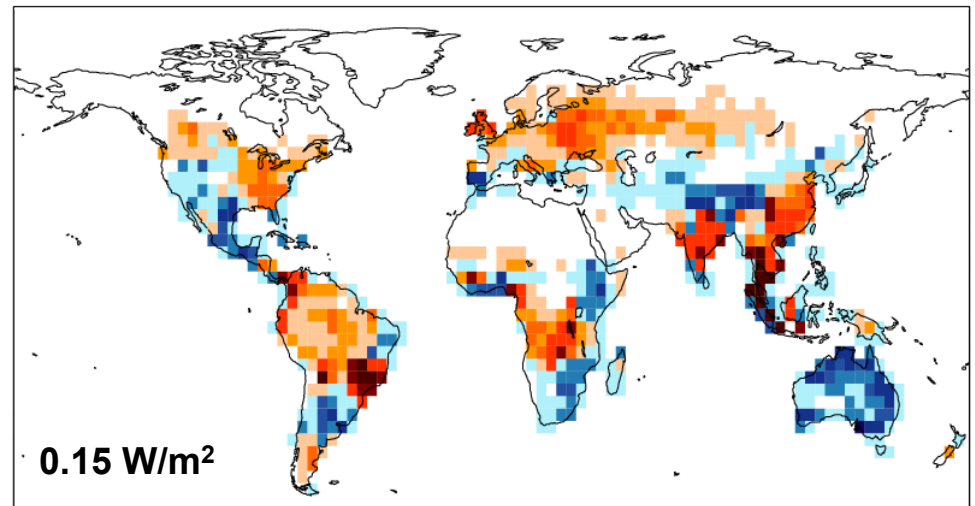
CO₂ RF



ΔF (W/m²)



Total RF



most regions historically contributed a warming signal to global climate

Impact d'une déforestation historique en tenant compte à la fois des impacts bio-géophysiques & bio-géochimiques

- Combinaison de refroidissement et de réchauffement
- Incertitudes liées aux modèles et aux protocoles expérimentaux
- Si l'on s'intéresse aux changements futurs – déforestation tropicale – les effets réchauffants en surface seront additifs.

les incertitudes sur les modèles sont importantes

Pitman et al. (2009), *Geophysical Research Letters*
de Noblet-Ducoudré et al. sous presse, Boisier et al. submitted

LUCID

(Land-Use and Climate: IDentification of robust impacts)

**What have been the robust bio-geophysical impacts
Of land-use induced land-cover changes
on climate since 1850 ?**

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

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

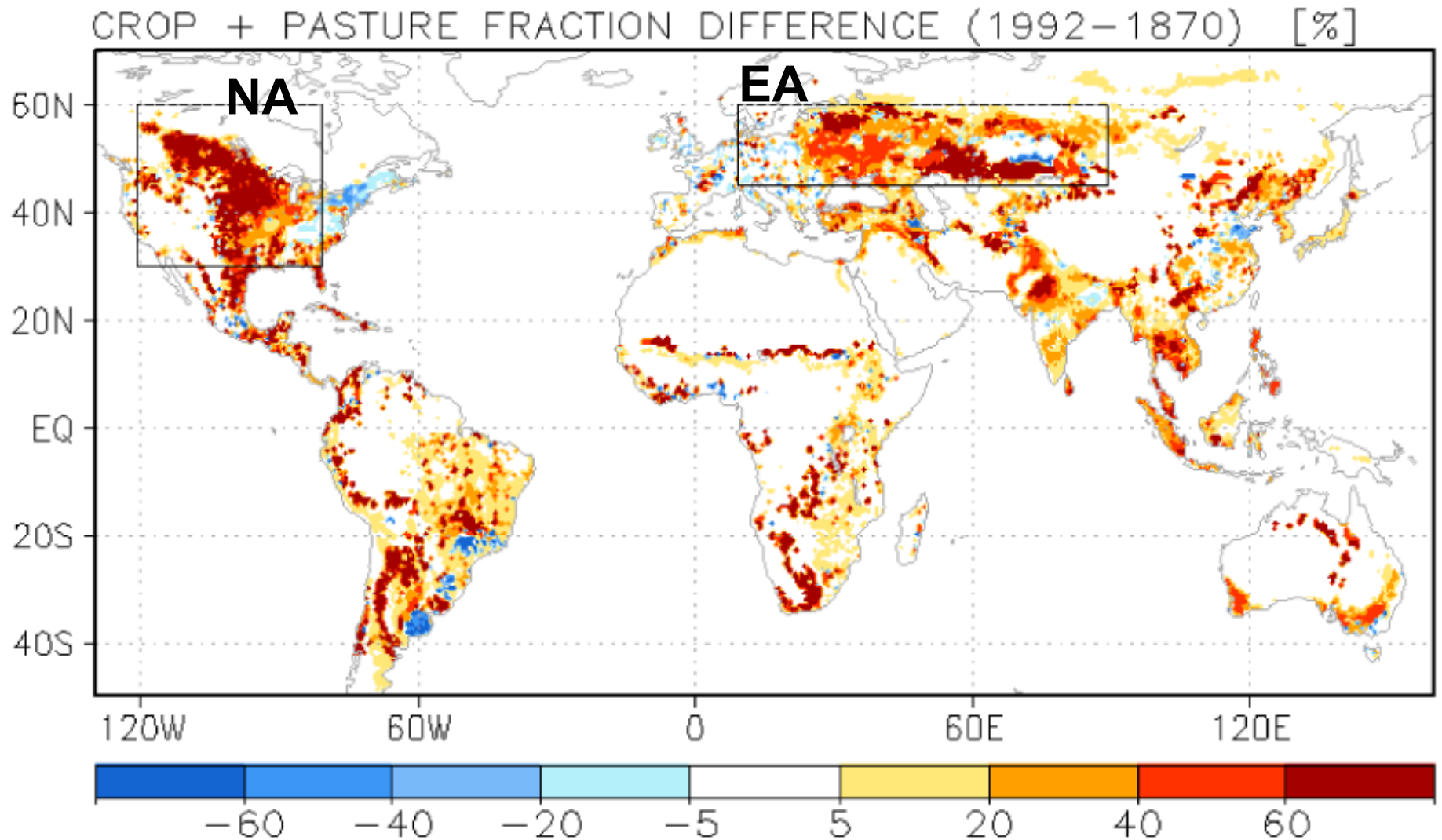
> LCC-induced changes : {PD-PDv, PIV-PI}

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

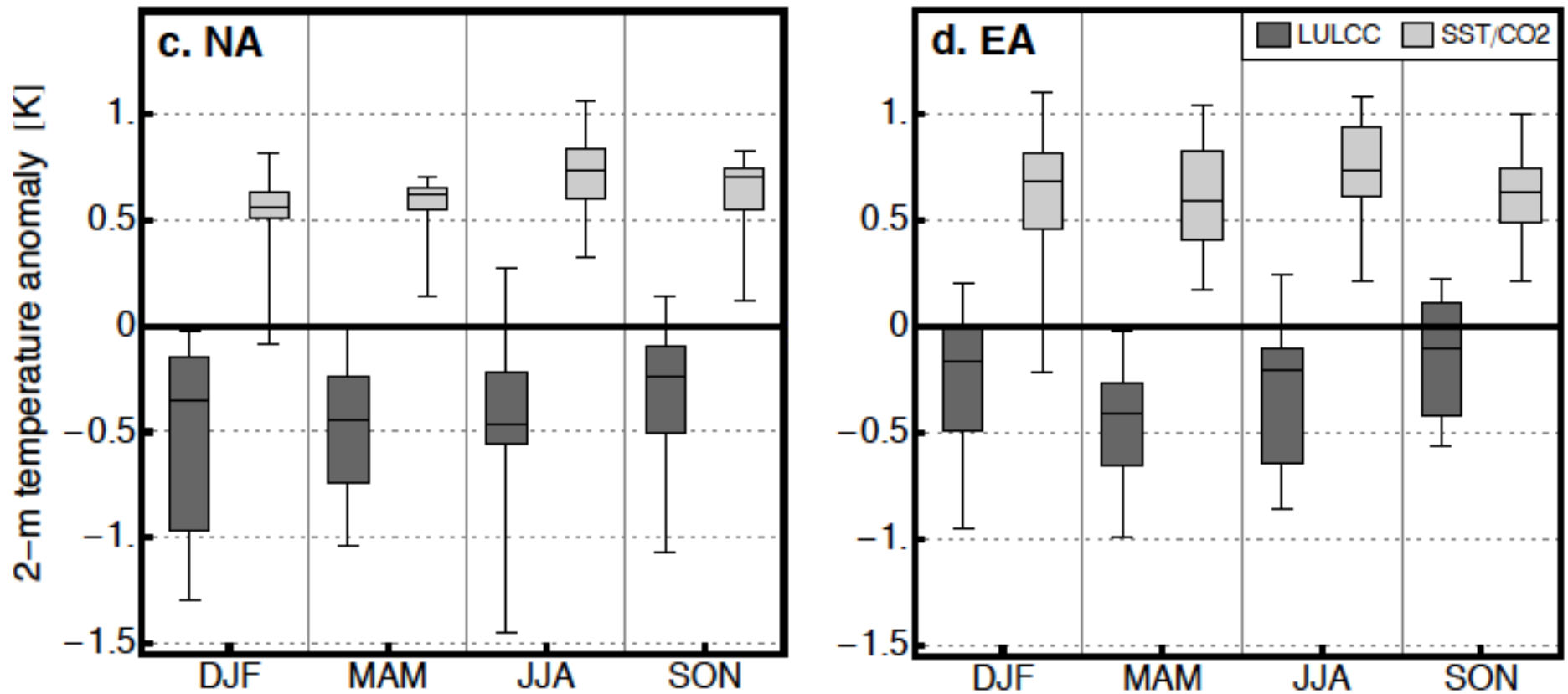
Name of Climate Model	Name of Land-surface Model
ARPEGE	ISBA
CCAM	CABLE
CCSM	CLM
ECearth	TESSEL
IPSL	ORCHIDEE
SPEEDY	LPJmL
ECHAM5	JSBACH

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



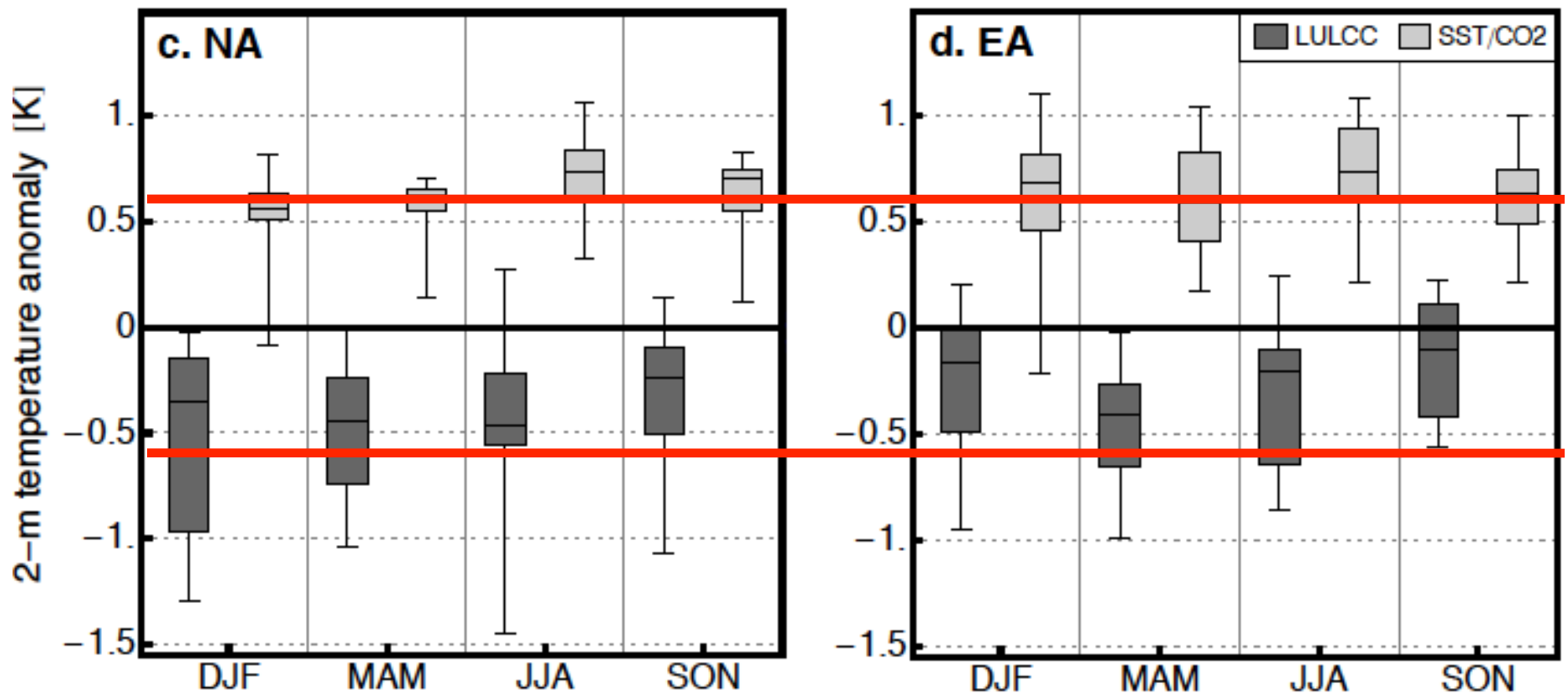
Impacts on the simulated 2m air temperature



Impact of LCC

Impact of SSTs+SiC+CO₂

Impacts on the simulated 2m air temperature

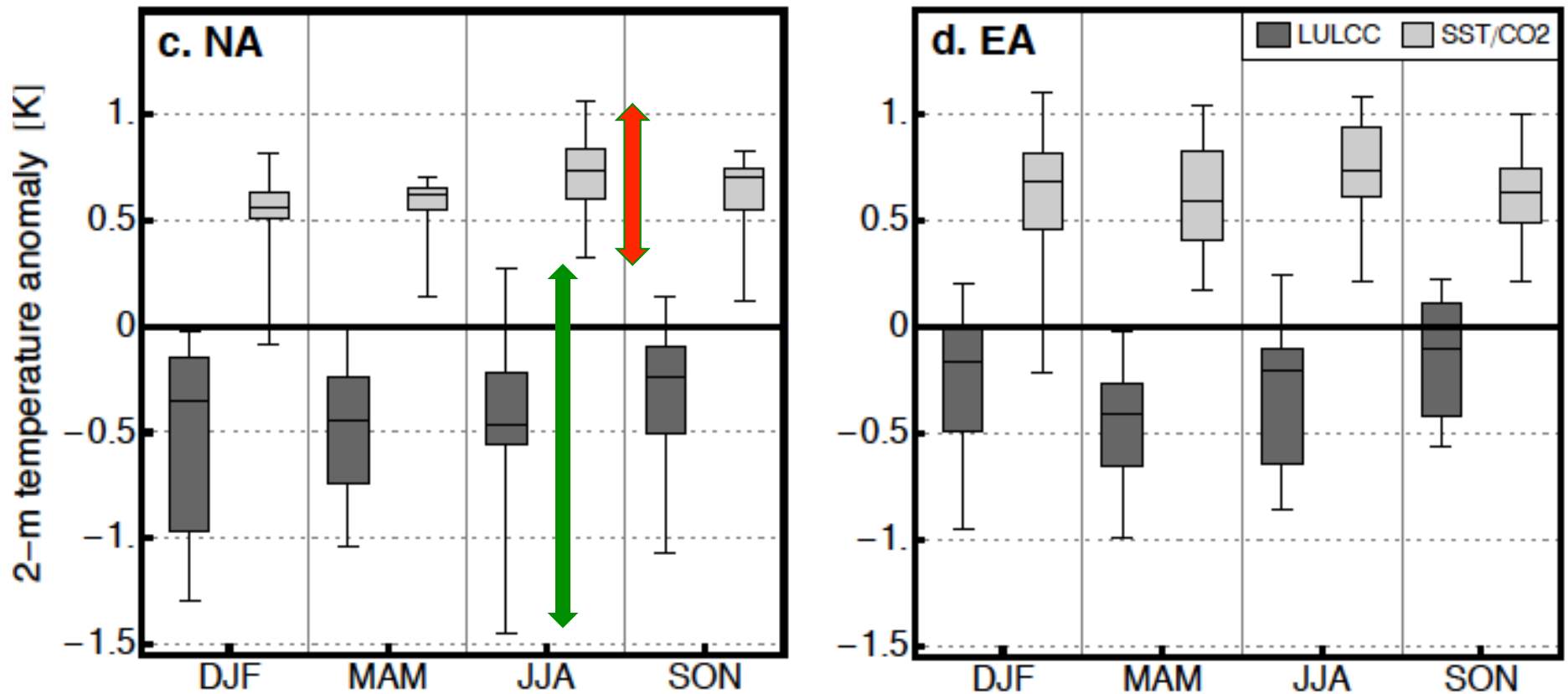


Impact of LCC

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

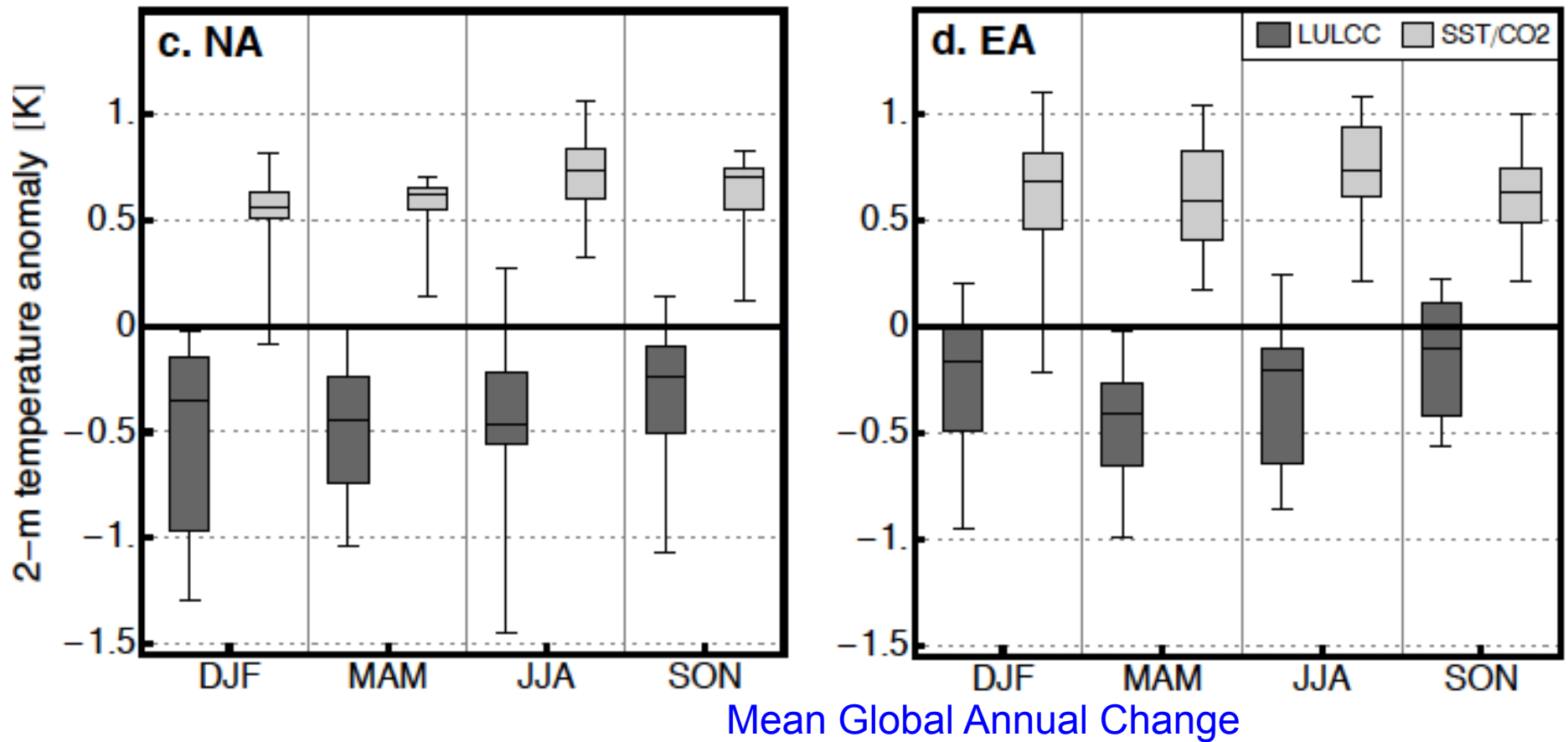
Impact of SSTs+SiC+CO₂

LULCC impacts

→ larger inter-model variations

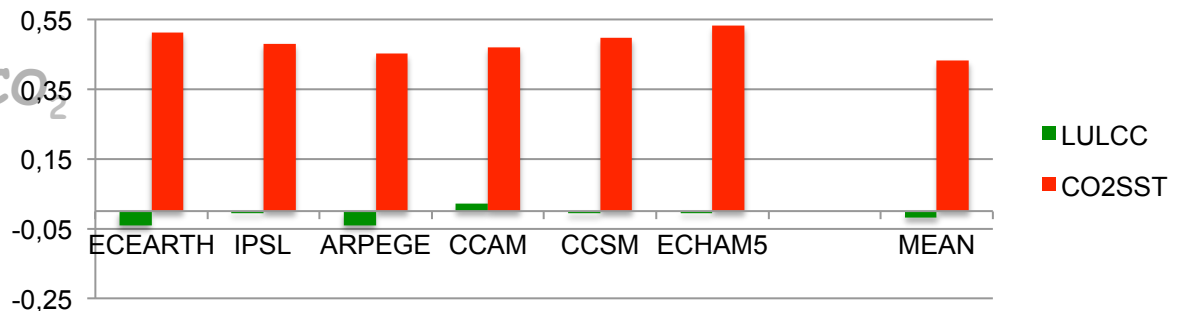
Impacts on the simulated 2m air temperature

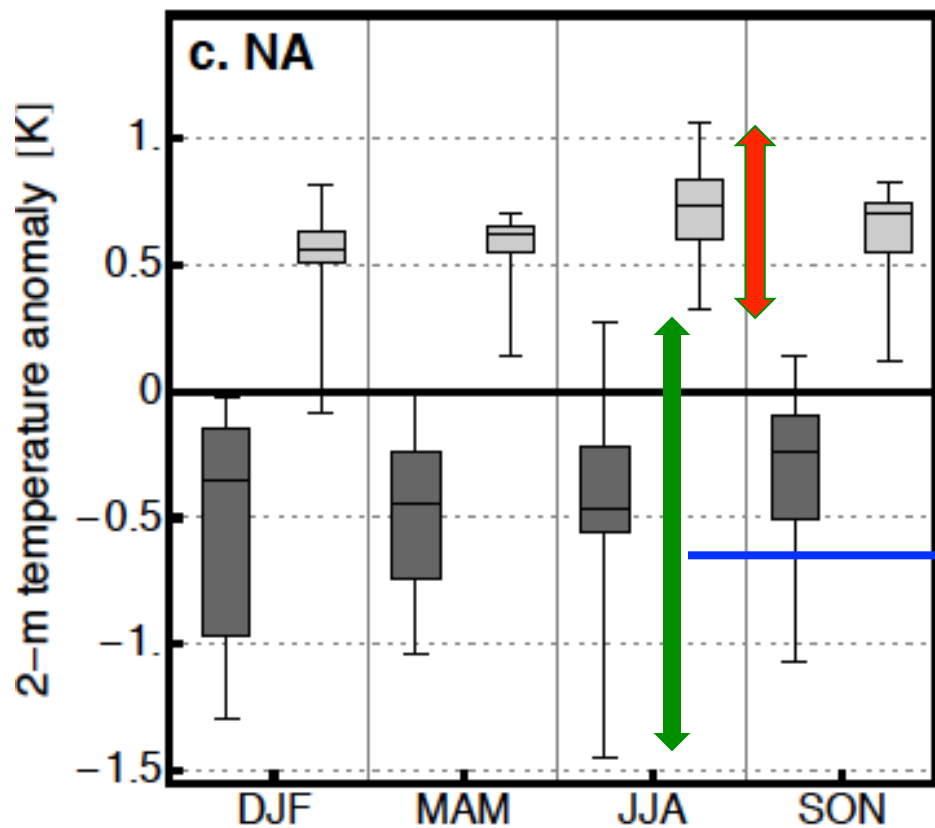
Large and Significant Regional Changes. No Global changes



Impact of LCC

Impact of SSTs+SiC+CO₂





Where does this large spread come from?

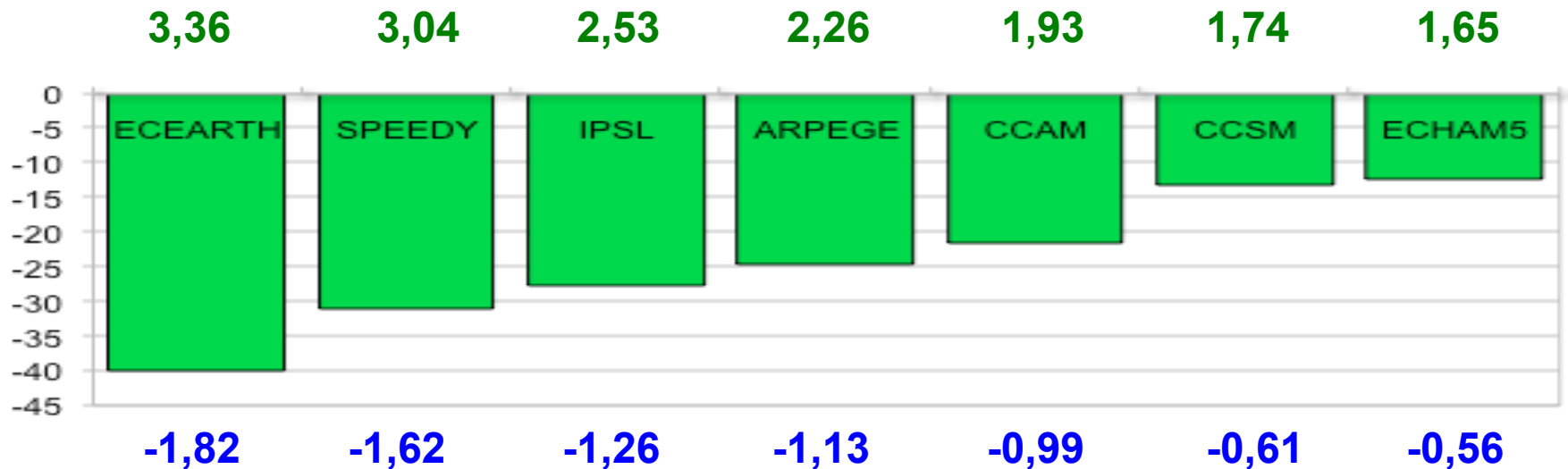
Impact of LCC

Impact of SSTs+SiC+CO₂

Implementation of crop&pasture maps
lead to very different land-cover maps and changes!

Increased crop at the expense of forests in many regions

Forest extent in North America (10^6 km^2) in 1870

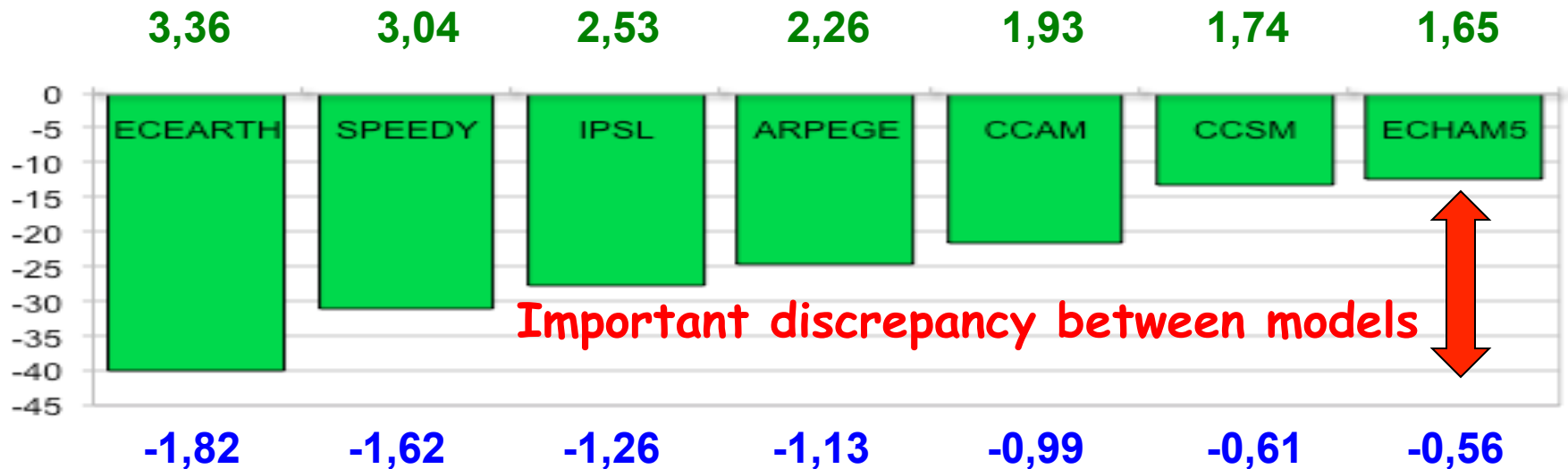


Changes in forest extent in North America
(bars in %, numbers in 10^6 km^2)

Implementation of crop&pasture maps
lead to very different land-cover maps and changes!

Increased crop at the expense of forests in many regions

Forest extent in North America (10^6 km^2) in 1870



Changes in forest extent in North America
(bars in %, numbers in 10^6 km^2)

Decision strategies are different

(a)



(b)



(c)

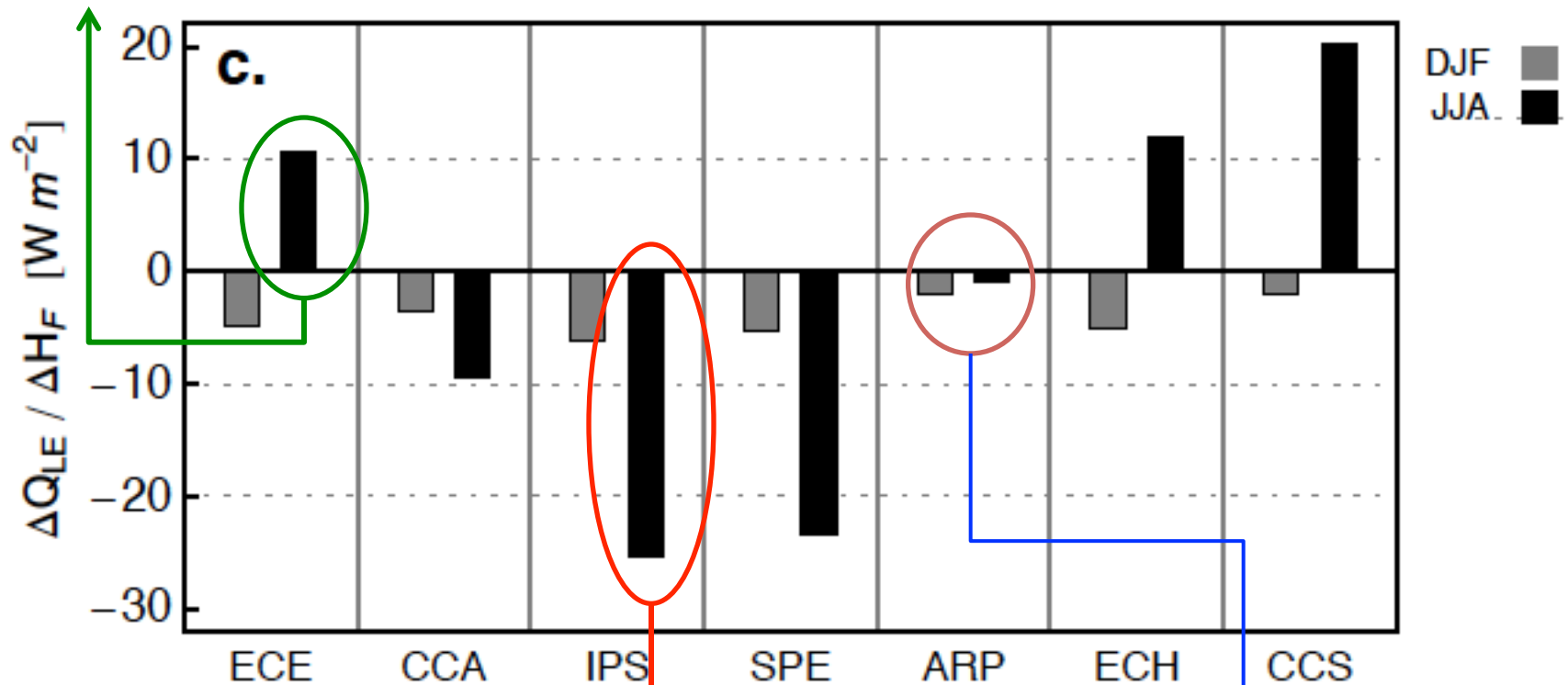


(d)



The change in latent heat flux is completely different from one model to another, even if the change in herbaceous fraction is similar !

Moderate sensitivity to LULCC
LE increases when herbaceous area increases



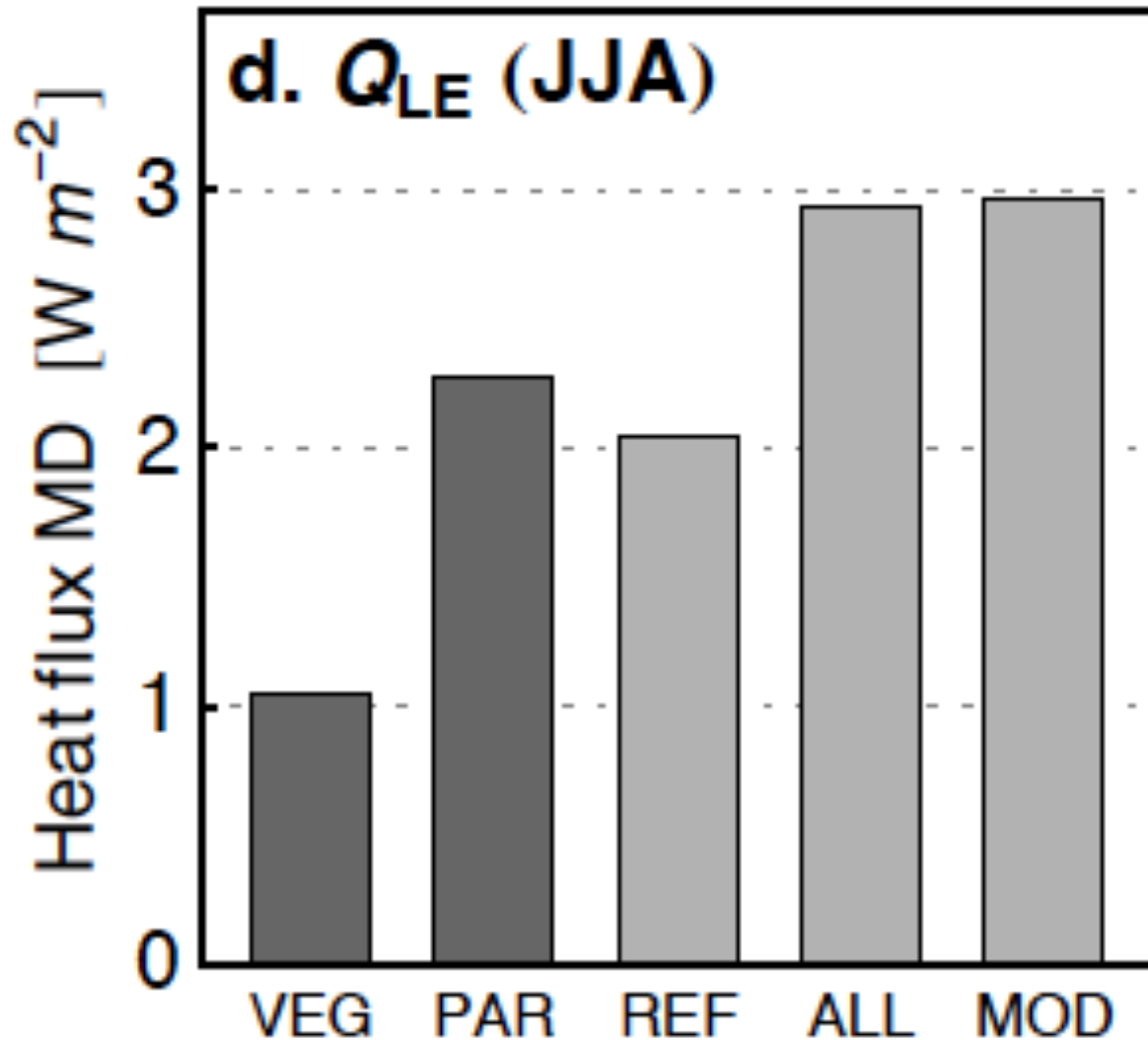
No sensitivity to LULCC

Very large sensitivity to LULCC
LE decreases when herbaceous area increases

Contribution to the inter-model differences in Q_{LE} of:

VEG : Vegetation distribution. PAR : Land-Surface Parameters & parameterizations

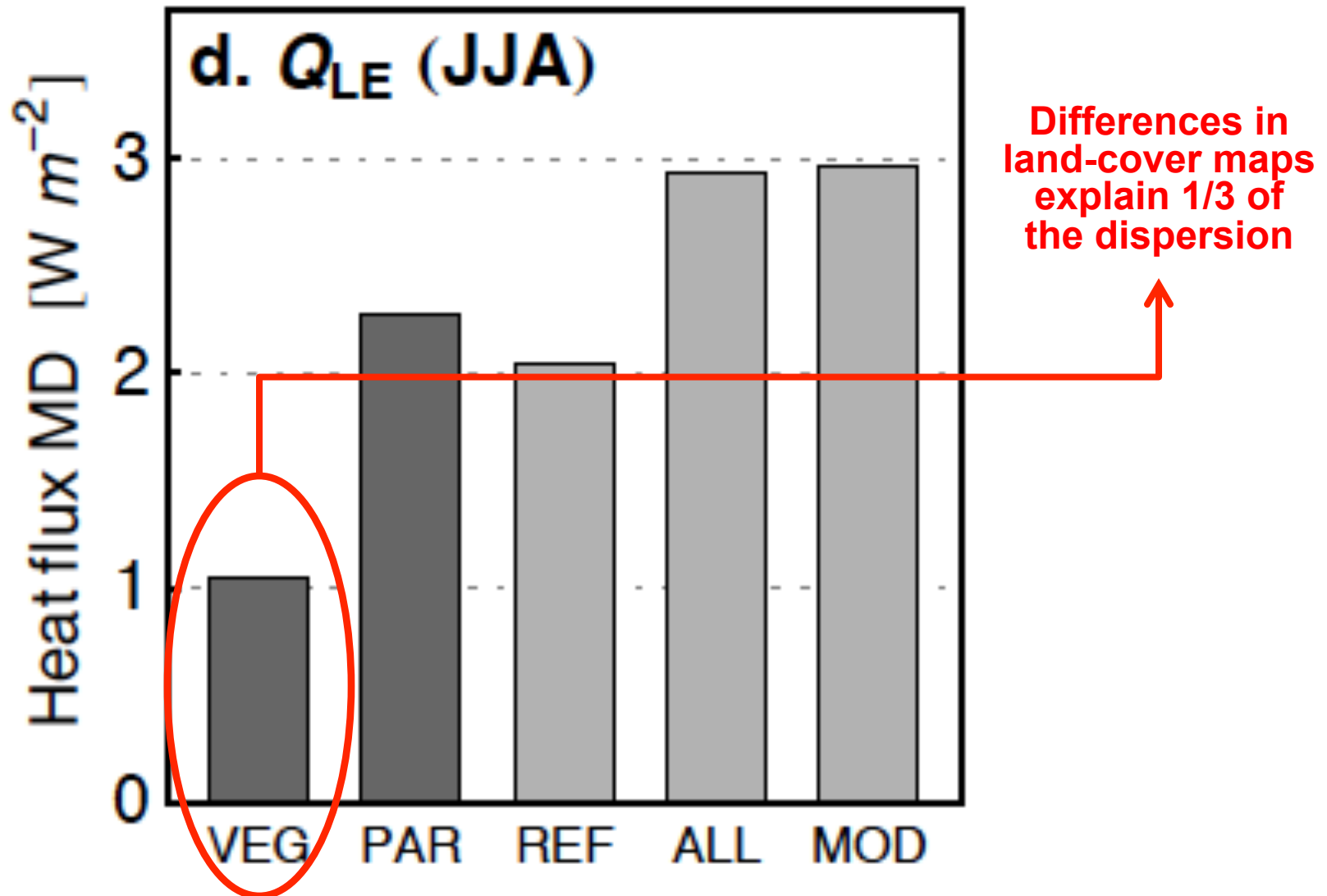
REF : combines VEG & PAR. ALL & MOD = REF + remaining influences



Contribution to the inter-model differences in Q_{LE} of:

VEG : Vegetation distribution. PAR : Land-Surface Parameters & parameterizations

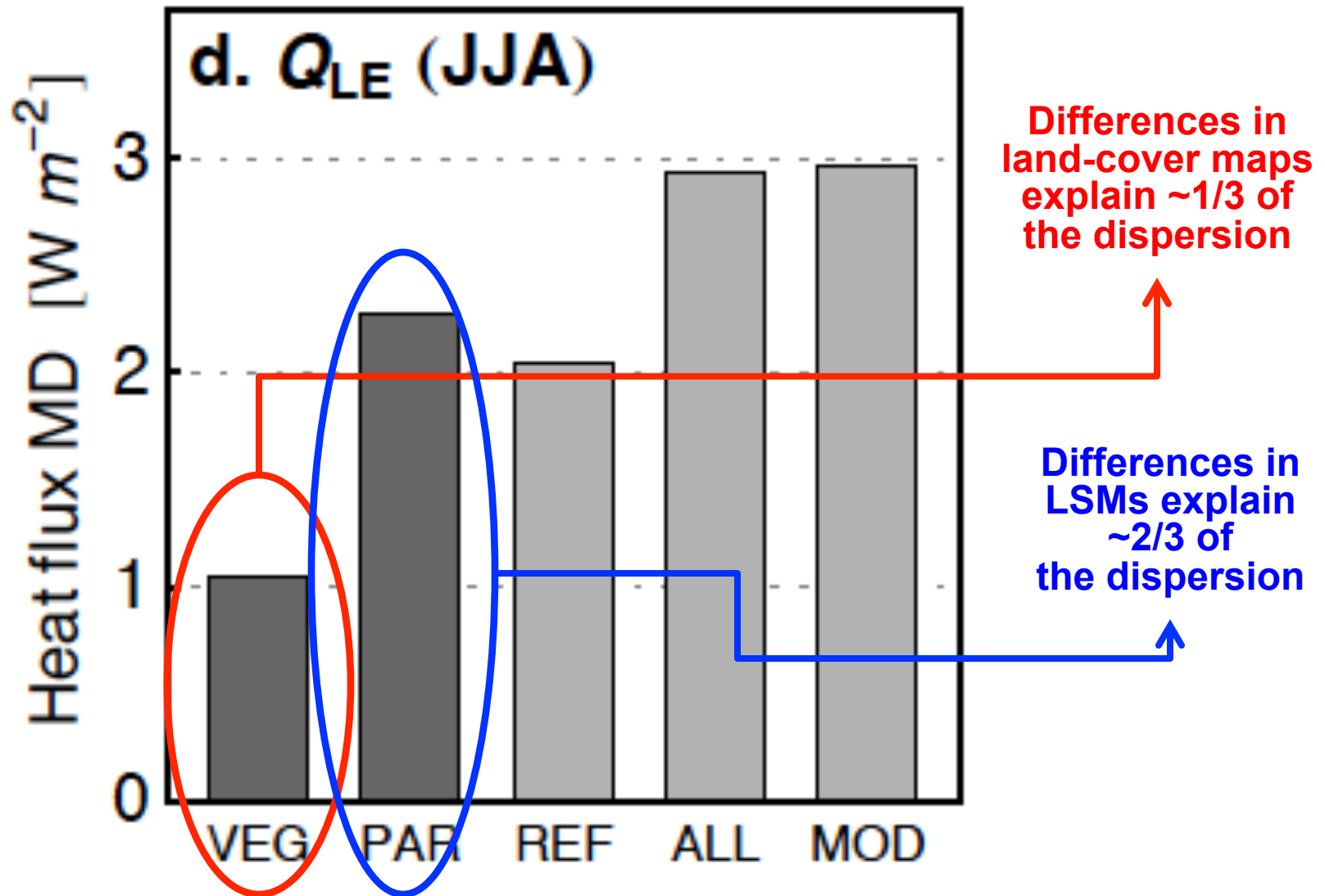
REF : combines VEG & PAR. ALL & MOD = REF + remaining influences



Contribution to the inter-model differences in Q_{LE} of:

VEG : Vegetation distribution. PAR : Land-Surface Parameters & parameterizations

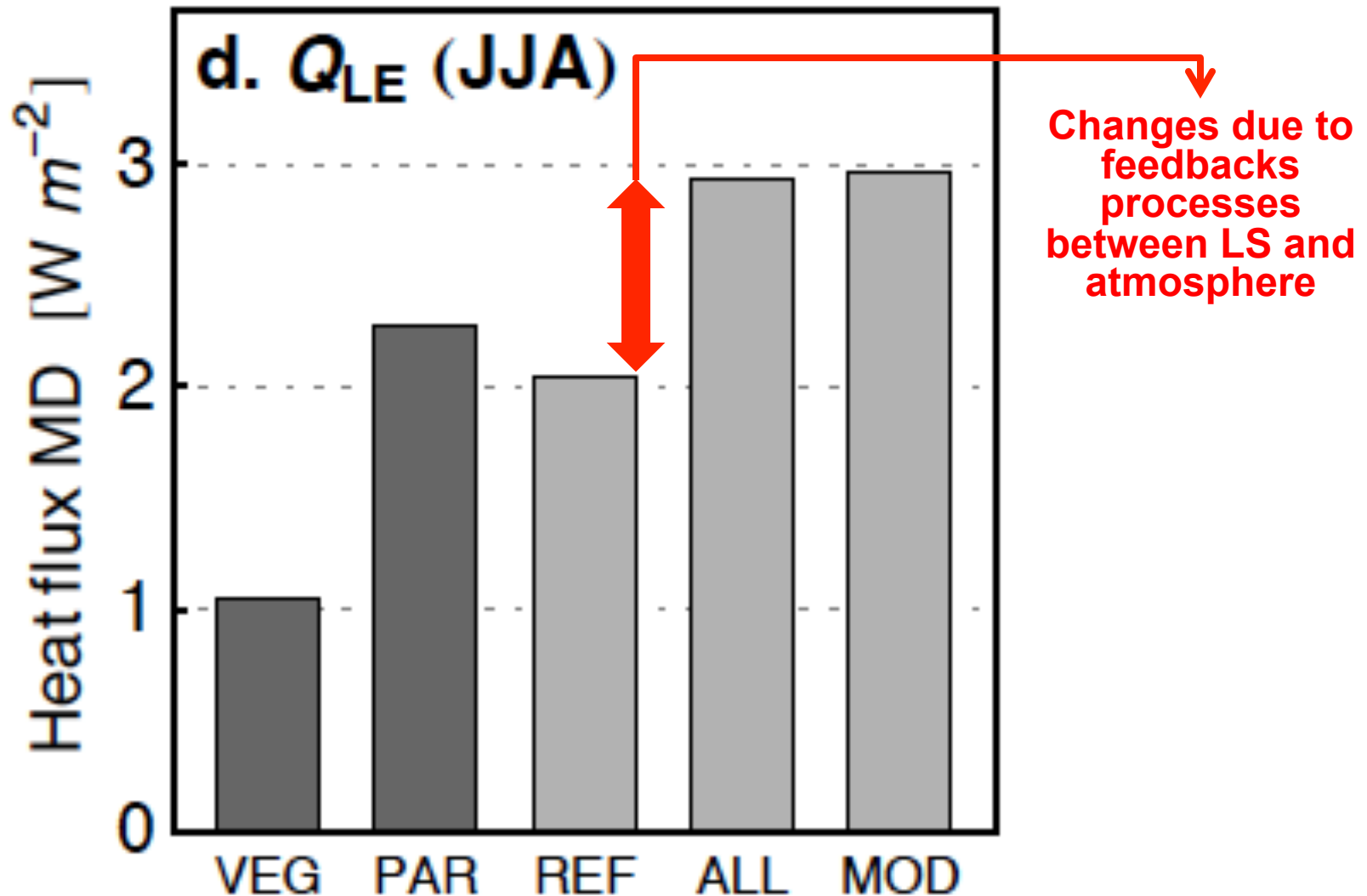
REF : combines VEG & PAR. ALL & MOD = REF + remaining influences



Contribution to the inter-model differences in Q_{LE} of:

VEG : Vegetation distribution. PAR : Land-Surface Parameters & parameterizations

REF : combines VEG & PAR. ALL & MOD = REF + remaining influences



les effets comparés du changement d'usage des sols et du changement de température de la surface des océans

Findell et al. (2009), Journal of Climate

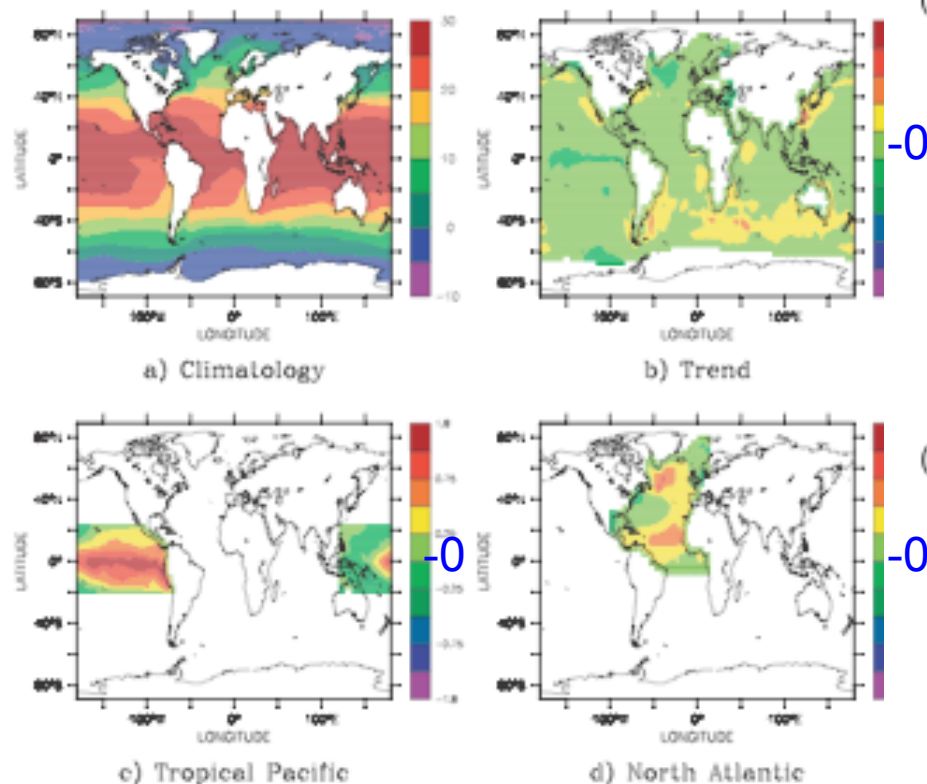


FIG. 1. SST forcing patterns ($^{\circ}\text{C}$) (a) climatology derived from the Hadley Centre dataset spanning the years 1901–2004; (b) warming trend anomaly; (c) tropical Pacific ENSO-like warm phase anomaly; and (d) North Atlantic NAO-like warm-phase anomaly.

TABLE 1. Configuration of experiments discussed in this paper.

Experiment	SST field	Land cover field
Control	Climatology (1901–2004); Fig. 1a	Potential natural vegetation
LCC	Climatology (1901–2004); Fig. 1a	1990-like conditions
WTr	Climatology + global trend anomaly; Figs. 1a,b	Potential natural vegetation
WENSO	Climatology + tropical Pacific anomaly; Figs. 1a,c	Potential natural vegetation
WNAO	Climatology + North Atlantic anomaly; Figs. 1a,d	Potential natural vegetation

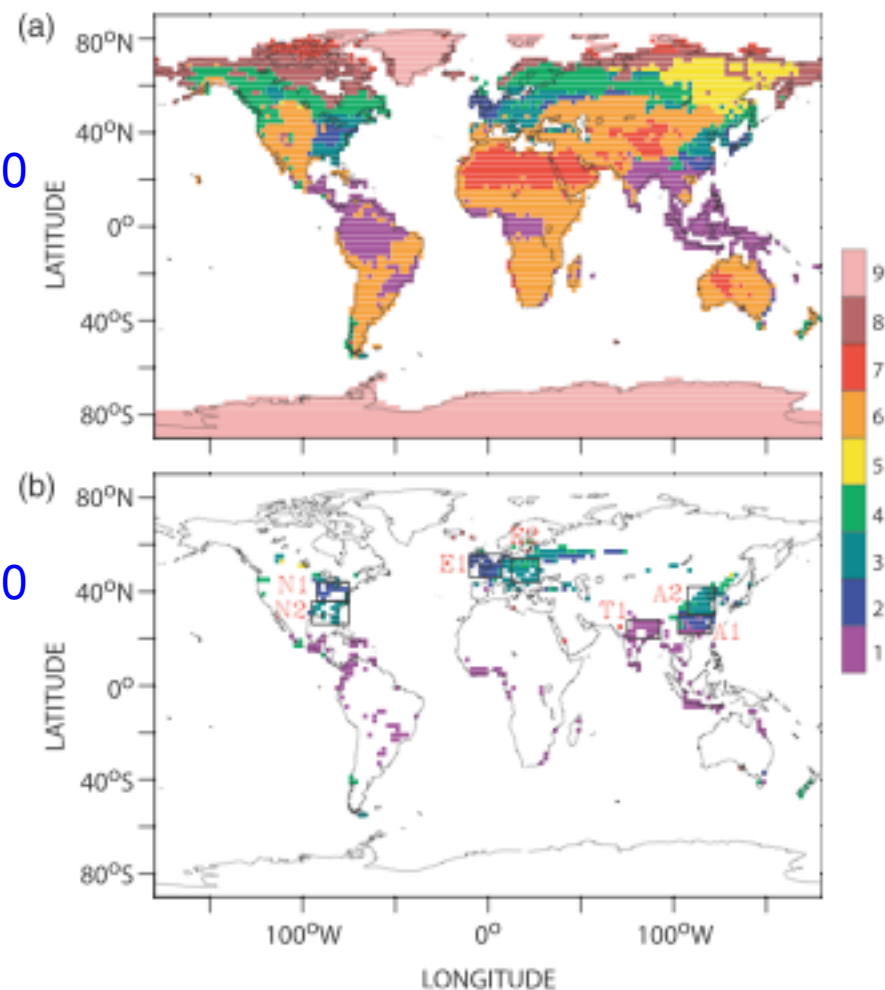


FIG. 2. (a) Preanthropogenic cover type distributions. 1 = broadleaf evergreen, 2 = broadleaf deciduous, 3 = broadleaf/needleleaf, 4 = needleleaf evergreen, 5 = needleleaf deciduous, 6 = grassland-crops-pasture, 7 = desert, 8 = tundra, 9 = glacier. (b) Differences in cover type between the 1990 distribution and the preanthropogenic distribution; 11.6% of the land surface is converted to grasslands. Colors in (b) are representative of the original cover type shown in (a). Boxes in (b) are used to indicate regions used in analyses and discussion later in the paper: North American boxes: N1, N2; European boxes: E1, E2; Asian boxes: A1, A2; tropical box: T1.

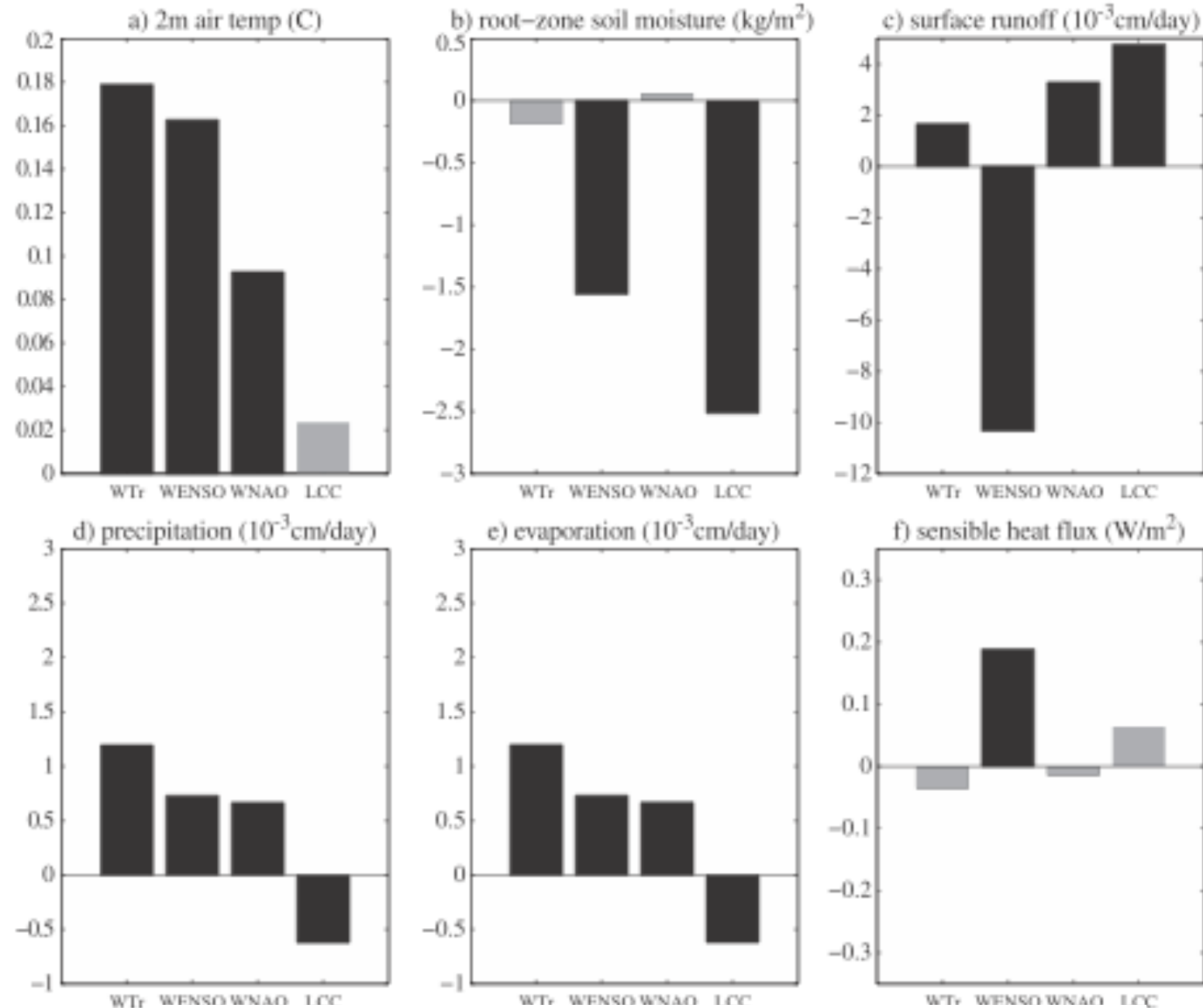


FIG. 3. Annual global mean differences between the four experiments and the control (labels as in Table 2). Black (gray) bars indicate significance (nonsignificance) at the 95% level according to the modified t test.

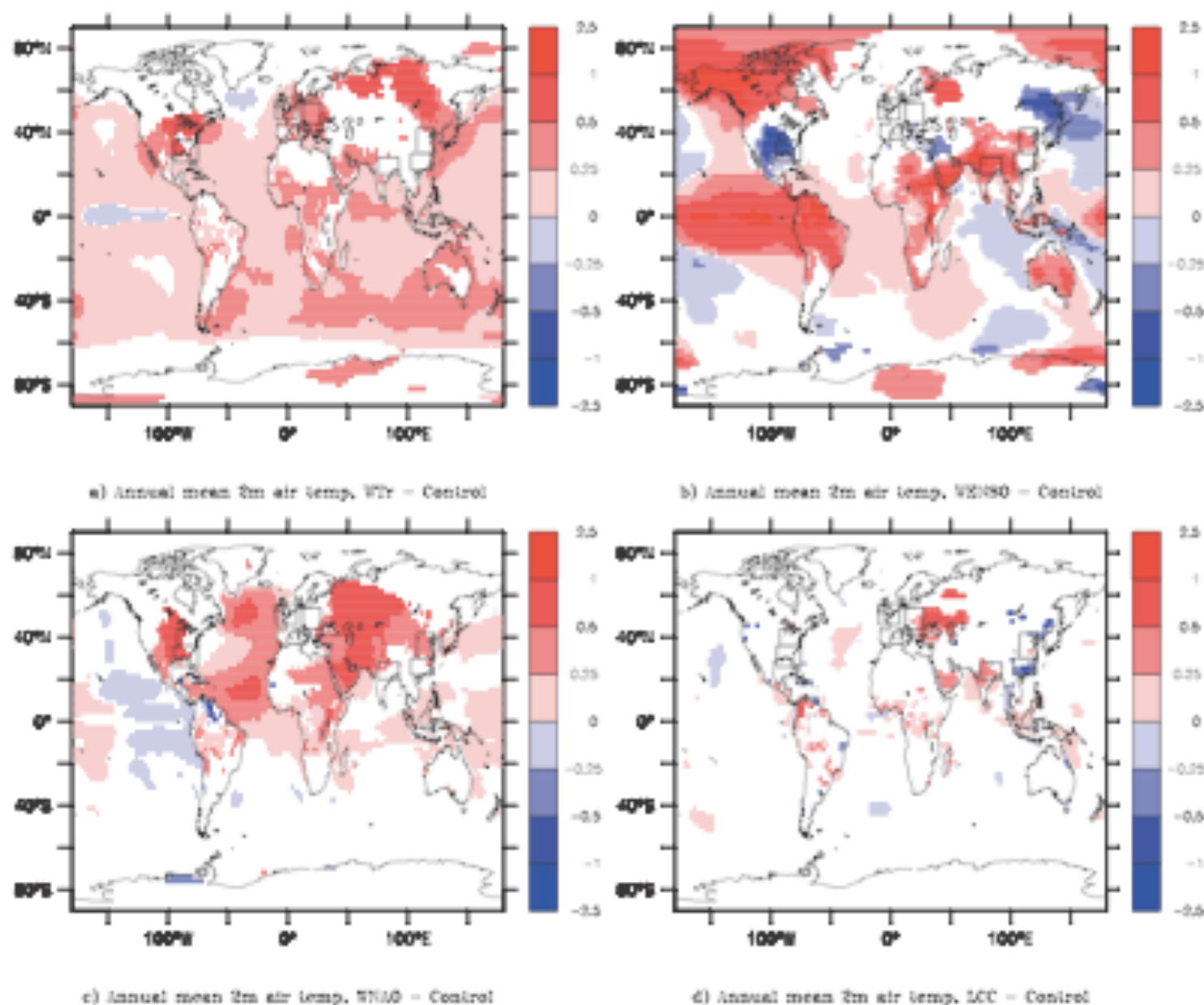


FIG. 4. Annual 2-m reference air temperature differences ($^{\circ}\text{C}$) between the four experiments and the control simulation. (a) WTr - control; (b) WENSO - control; (c) WNAO - control; (d) LCC - control. Differences are only shown where they are statistically significant at the 95% significance level according to the modified t test.

PARTIE-3

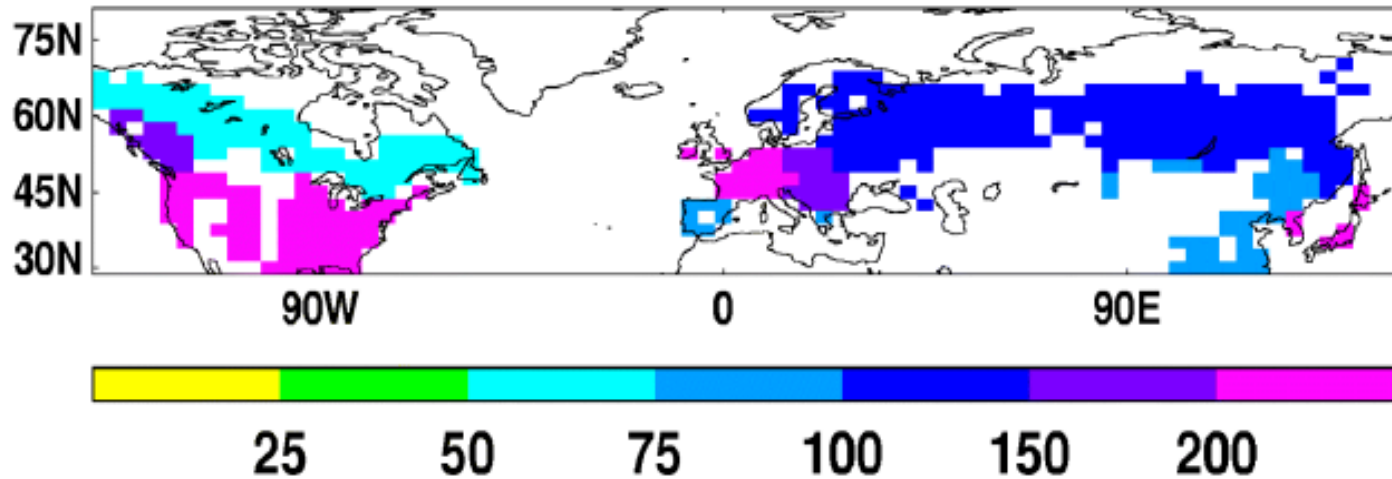
Travailler sur l'usage des terres
pour contrer le changement
climatique (ou global) ?

Planter des forêts dans les hautes latitudes Nord ?

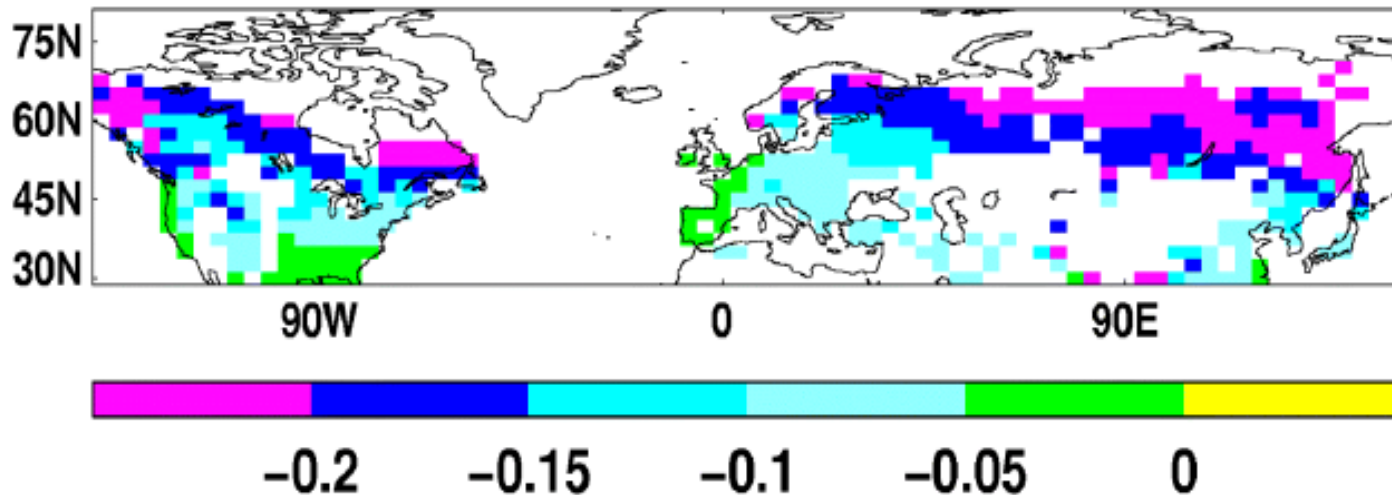
Betts (Nature 2000)

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

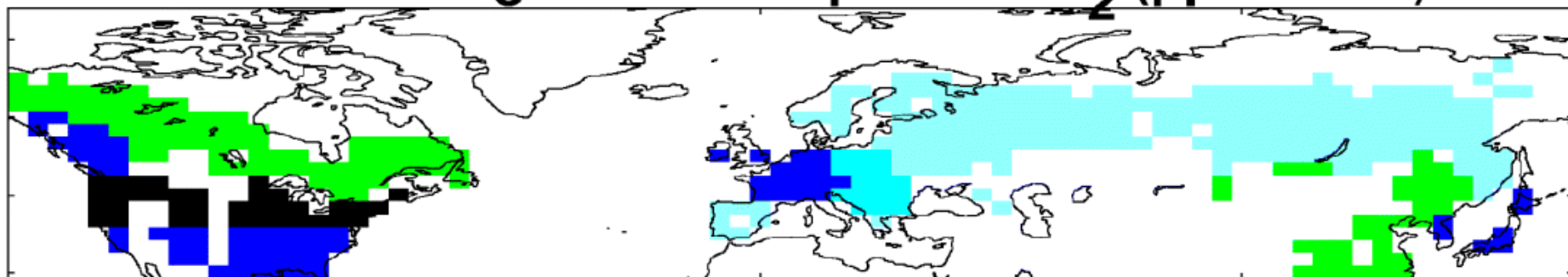


Albedo difference, dense coniferous forest - open land



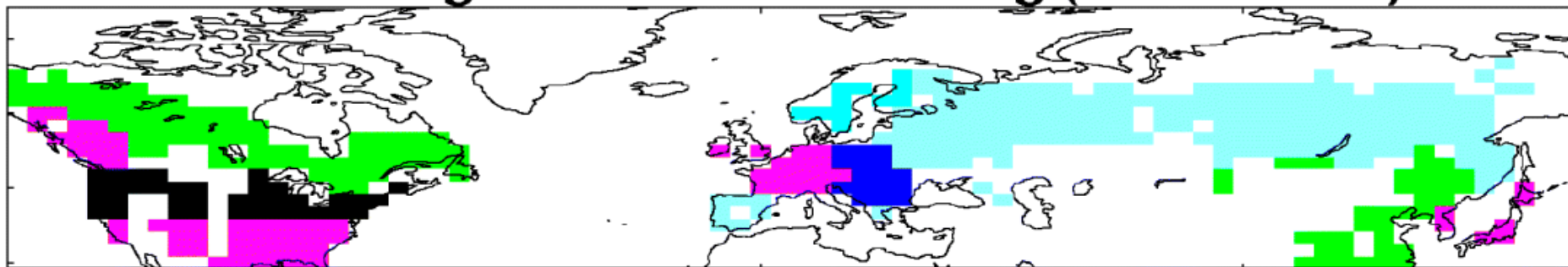
Radiative forcing due to carbon sequestration in a 1 ha plantation in different locations

Reduction in global atmospheric CO₂ (ppmv ha⁻¹)



1e-8 2e-8 3e-8 4e-8 5e-8 6e-8

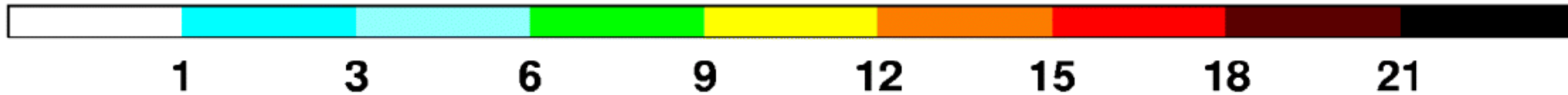
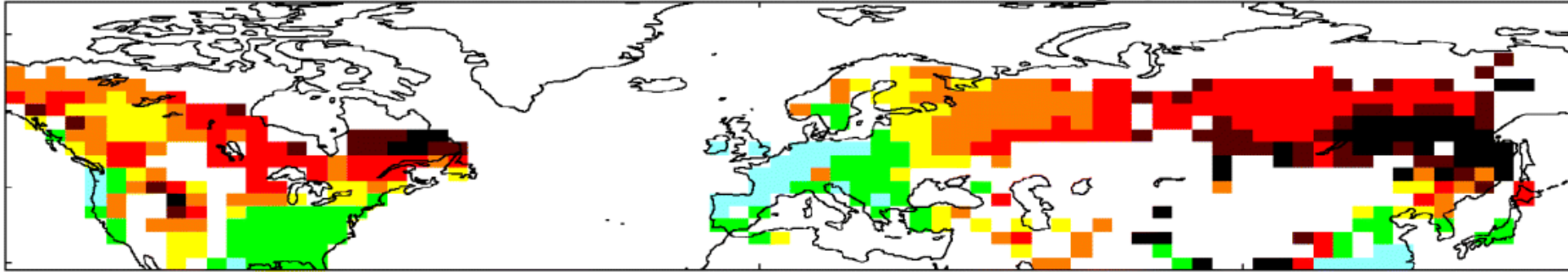
Global longwave radiative forcing (nW m⁻² ha⁻¹)



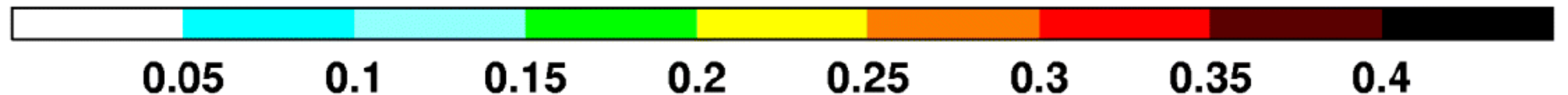
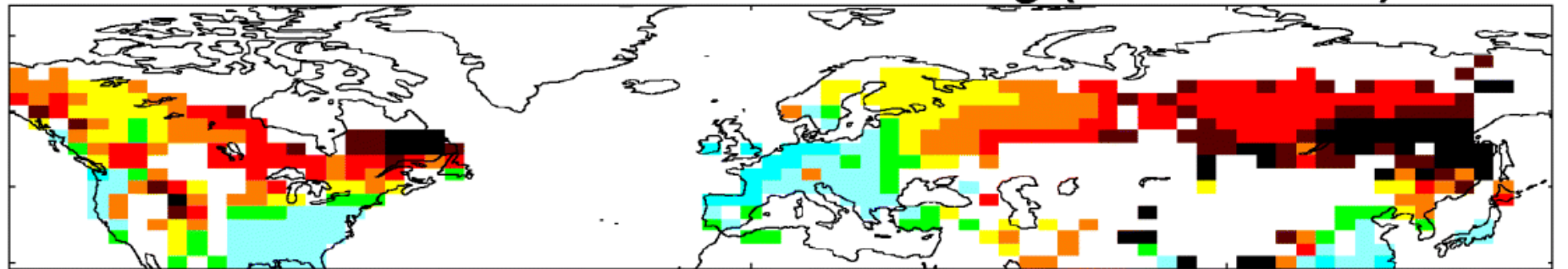
-0.8 -0.6 -0.5 -0.4 -0.3 -0.2

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

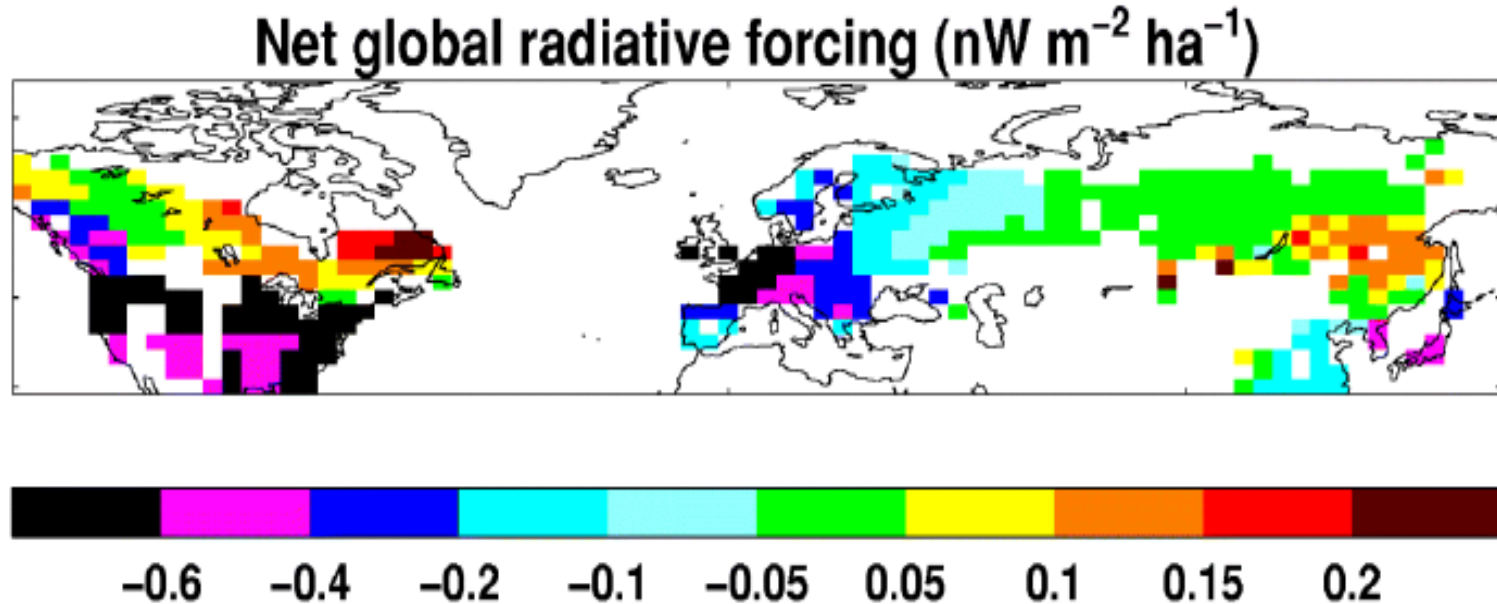
Local shortwave radiative forcing (W m^{-2})



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

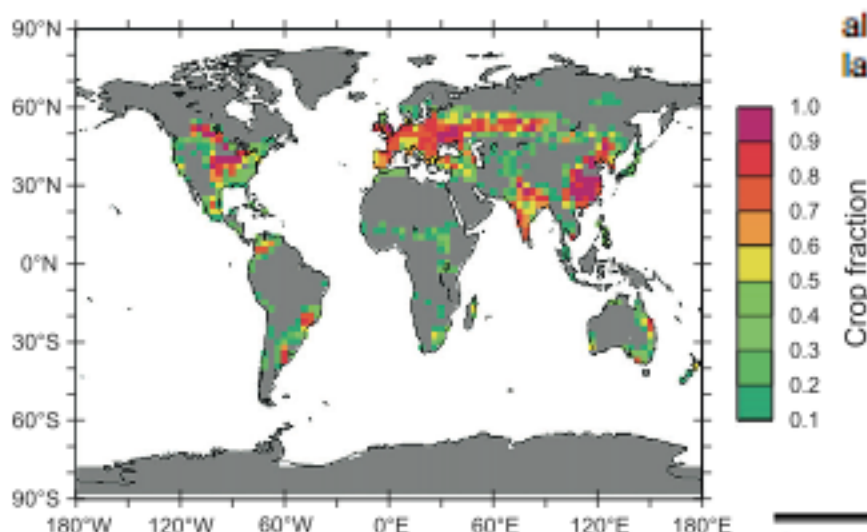
Some regions still see net negative forcing (cooling) - but smaller than that expected from carbon sequestration alone

Choisir des cultures à plus fort albédo ?

Ridgewell et al. (2009)

Tackling Regional Climate Change By Leaf Albedo Bio-geoengineering

Andy Ridgwell,^{1,*} Joy S. Singarayer,¹
Alistair M. Hetherington,² and Paul J. Valdes¹



We have assessed the potential of albedo bio-geoengineering in helping mitigate future global warming using a fully coupled climate model [8], which accounts for ocean and atmosphere circulation, sea-ice, and terrestrial vegetation. In the terrestrial vegetation component, we prescribe an increase in the canopy albedo of C₃ and C₄ vegetation in areas designated as “crop-land” [4] (Figure 1), as detailed in Experimental Procedures. In

Atmospheric CO ₂ Concentration	Maximum Canopy Albedo ($\alpha_{g_{max}}$)
350 ppm	0.2
700 ppm	0.2
700 ppm	0.22
700 ppm	0.24
700 ppm	0.28

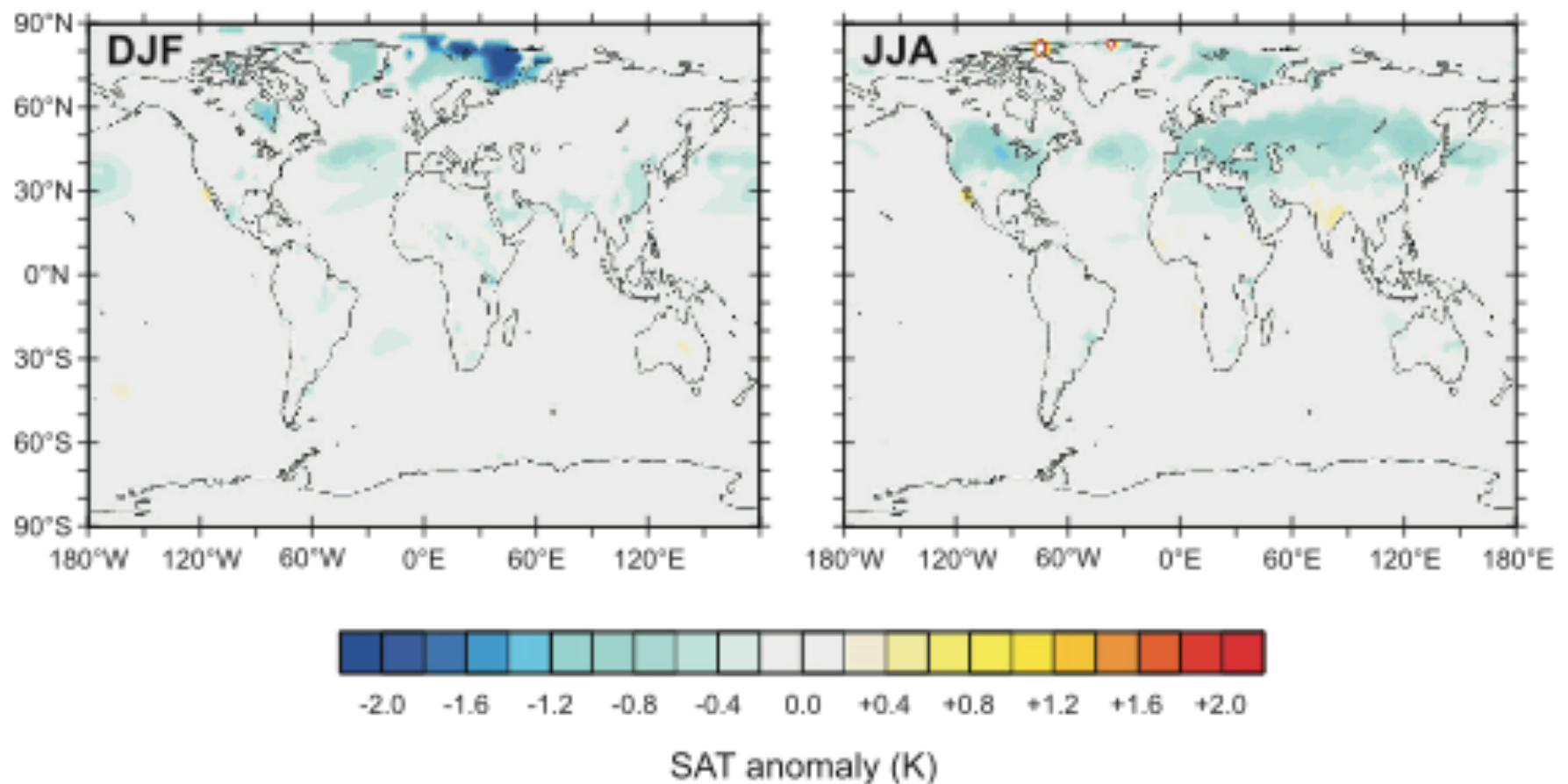


Figure 2. Climatic Impacts of Bio-geoengineering

Global anomalies of summer (JJA) and winter (DJF) surface air temperature resulting from a +0.04 increase in maximum crop canopy albedo and an elevated atmospheric CO_2 concentration of 700 ppm, calculated relative to the (700 ppm CO_2) control experiment. Only differences that are statistically significant at a 99% confidence level, as given by a Student's *t* test, are plotted. The small "hotspots" of cooling or warming are mostly associated with localized changes in seasonal sea-ice extent or snow cover relative to the control, induced by the cropland albedo changes elsewhere.

Conclusions

Increasing canopy albedo of vegetation in designated cropland areas in a global climate model by 20% (0.04) drives a $>1^{\circ}\text{C}$ reduction in summertime surface air temperatures in a wide latitudinal band spanning North America and Eurasia. Genetic modification or selective breeding of crop plants for specific leaf-surface properties and canopy structure could provide further mitigation of surface warming. Because the main investment is in research and field trials, the relatively low cost of implementation of crop albedo bio-geoengineering makes it potentially very attractive when compared to the equivalent costs of geoengineering or carbon sequestration.

PARTIE-4

**Quelques éléments de réflexion sur
une science en marche**

- Même si le rôle de l'usage des terres sur certaines variables climatiques importantes est avéré (température, cycle hydrologique, vent, ...), il reste à mettre en regard l'ordre de grandeur des changements induits, vis-à-vis d'autres changements connus, avérés (GES, ENSO, NAO, ...) et ce de façon concertée (plusieurs modèles, même protocole, choix pertinent de diagnostics, ...)

- Gros progrès restent à faire pour calculer de façon robuste et significative risques de changement de productivité à l'échelle mondiale: les changements dans une région doivent pouvoir être comparés à ceux dans une autre région
 - ➔ comment articule-t-on les modèles de végétation de grande échelle aux modèles stationnels?
 - ➔ comment compare-t-on les impacts issus de différents modèles de climat? (par région géographiquement localisées? Par régions définies sous forme d'enveloppes climatiques? Autres?)

- 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?)

et certainement bien d'autres encore

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