Impacts of climate change on crops

Jean-Louis Durand

INRAE

Impact of climate change on crops

Jean-Louis Durand
INRAE Lusignan

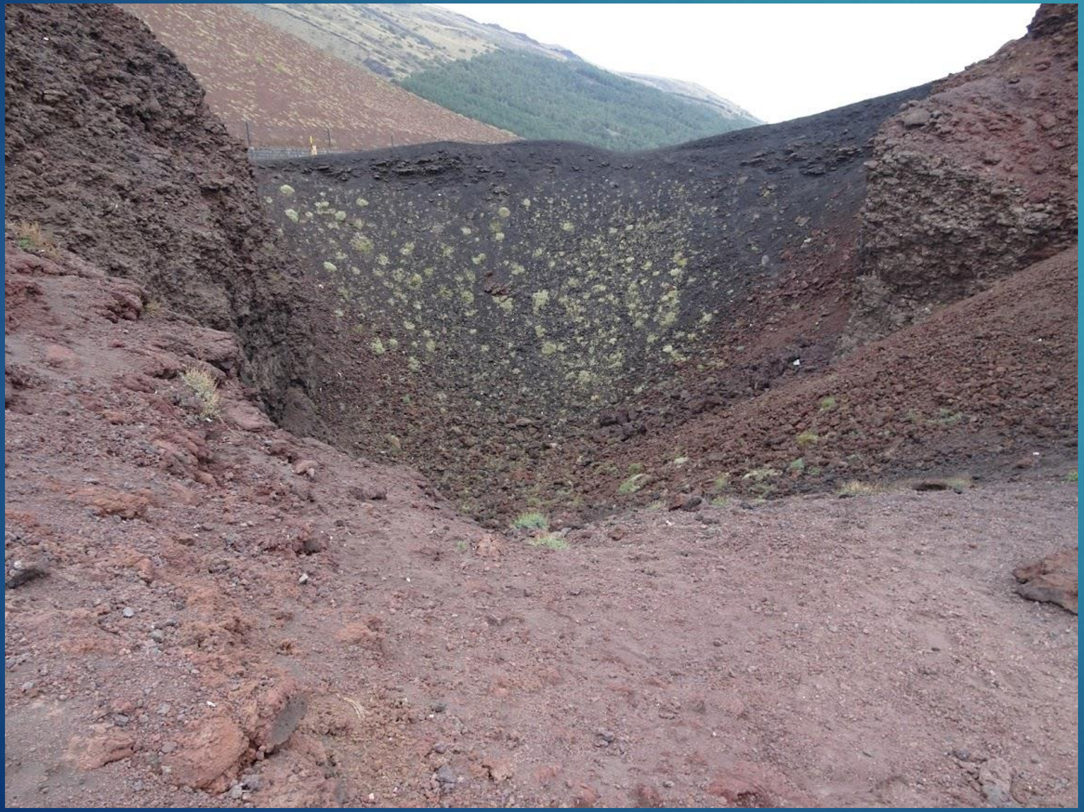
1. What climate change ?
2. How do crops relate to climate variables ?
3. Crop models and impacts
4. Some findings and projections
5. Impacts on actual food production
6. Conclusions

Since first plants took step on earth, atmospheric stresses are the main issue.

Elles forment alors sur les continents la **Phytosphère** .

Elles se sont fixées en transformant la surface continentale et y produisent le **sol**.

Etna 2004



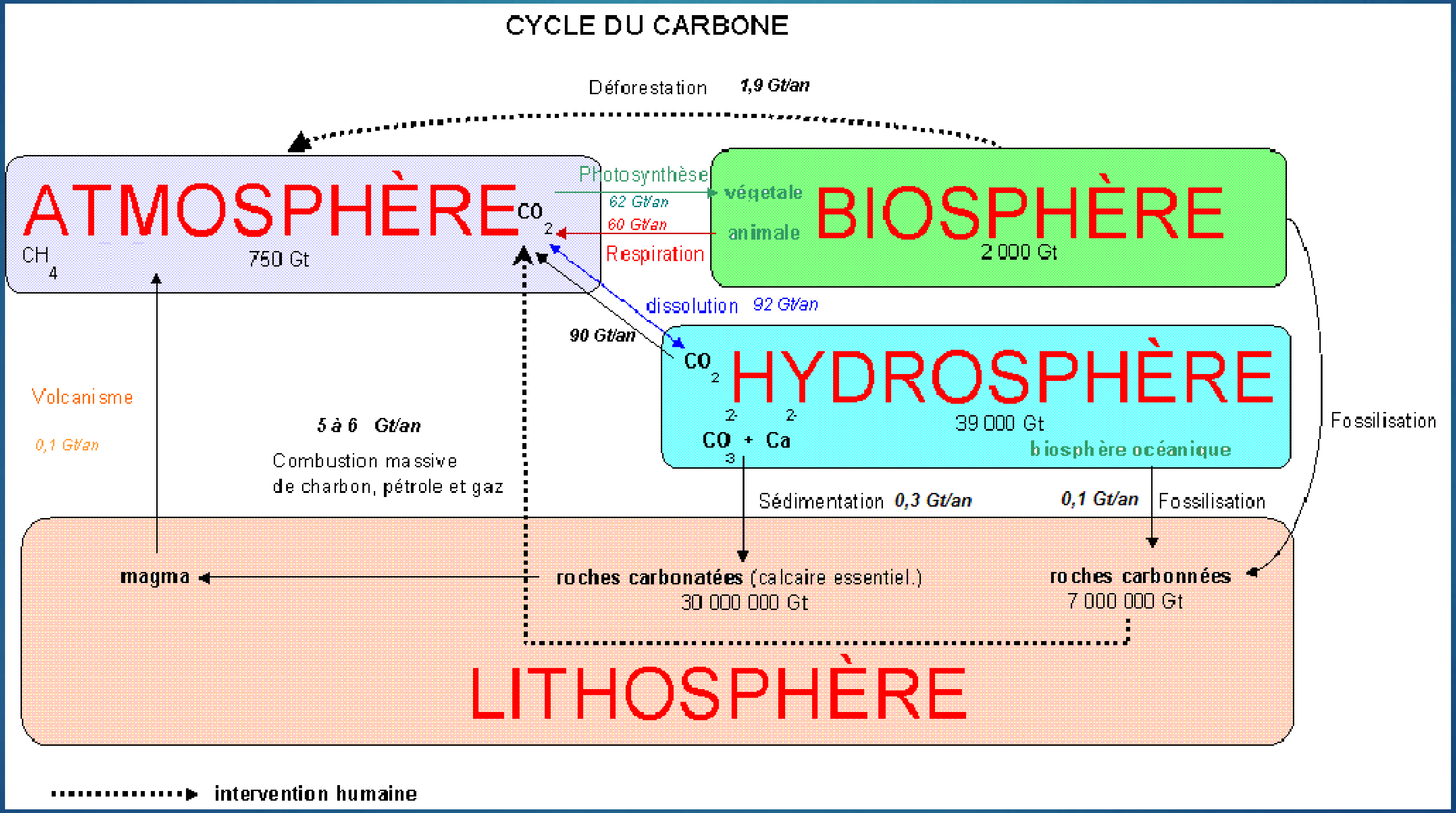
Etna 1986

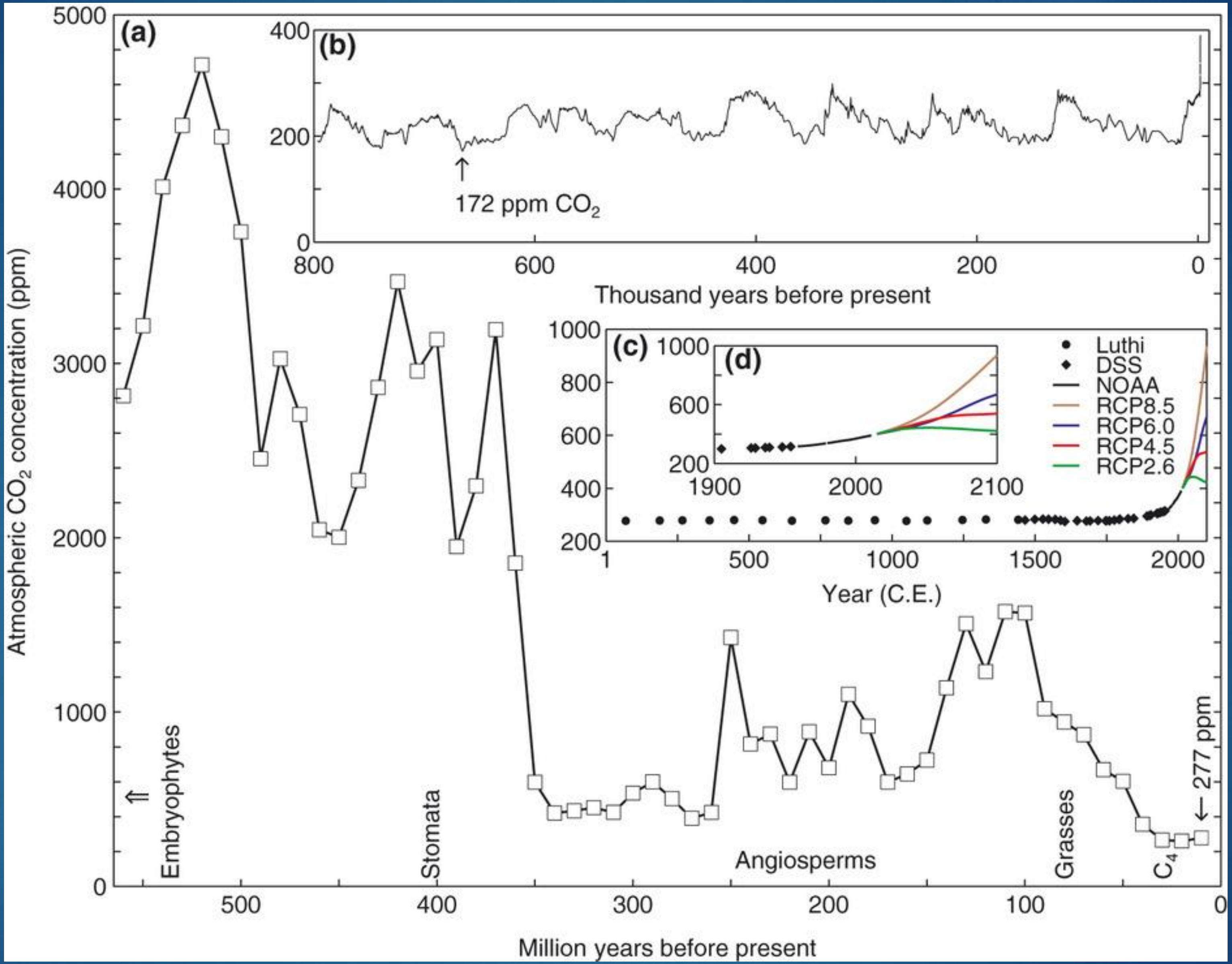
Climate variables and crops

1°) Solar radiation
2°) Climate Change variables

- Temperature
- Water
- CO_2

Impact of vegetation on [CO_2]

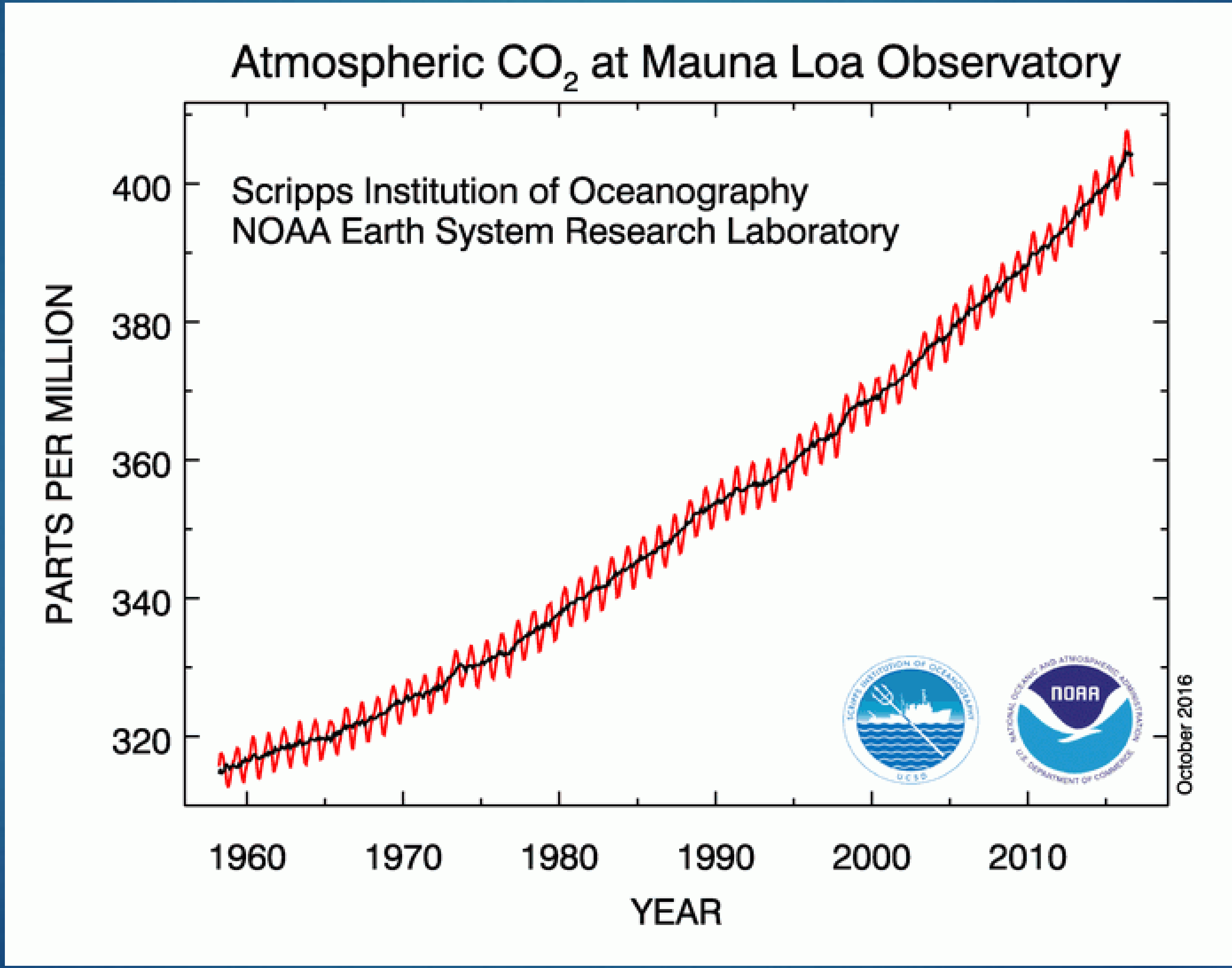




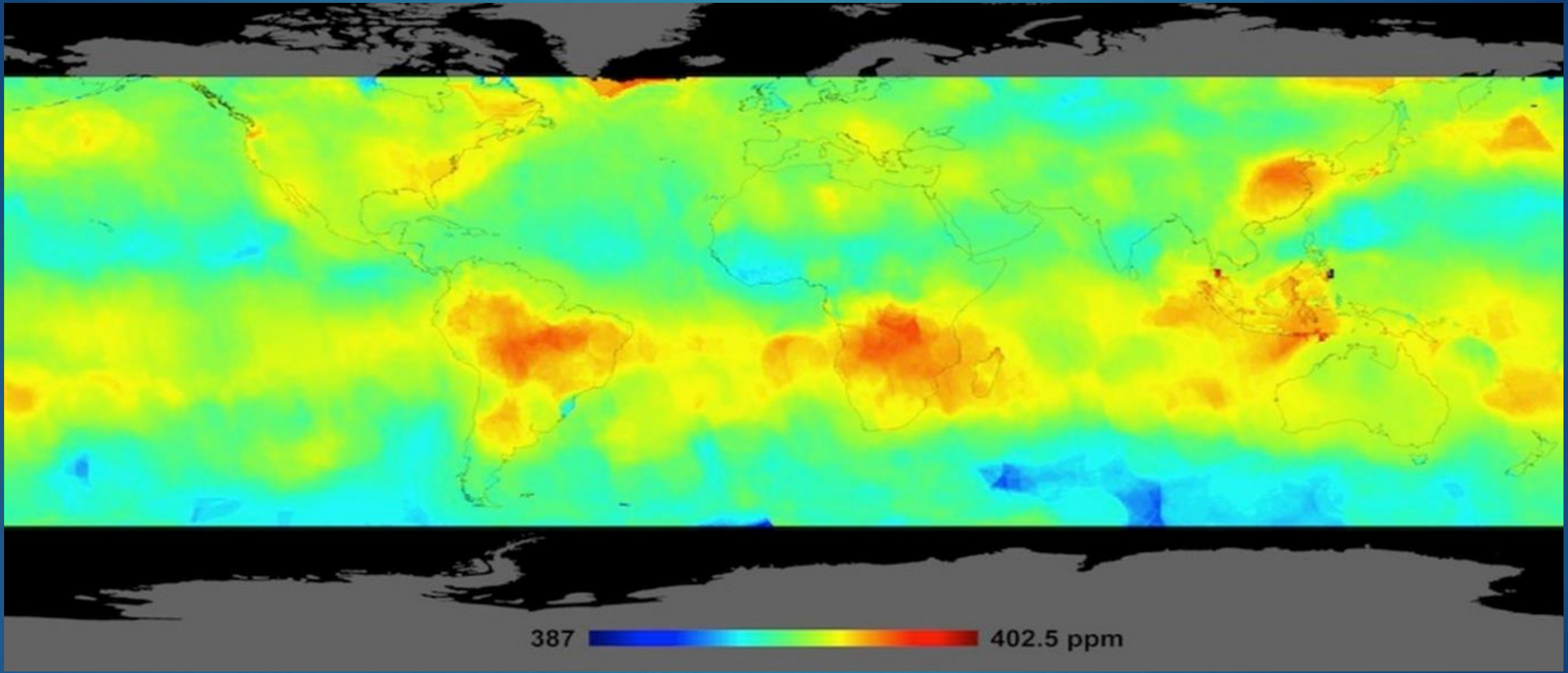
Sensitivity of plants to changing atmospheric CO2 concentration: from the geological past to the next century

New Phytologist, Volume: 197, Issue: 4, Pages: 1077-1094, First published: 25 January 2013, DOI: (10.1111/nph.12104)

Changing $[CO_2]$



Variations of [CO_2] on Earth



Composite image from NASA's Orbiting Carbon Observatory-2, [CO2] observed between 1er Oct.et le 11 novembre 2014.: *NASA/JPL-Caltech*

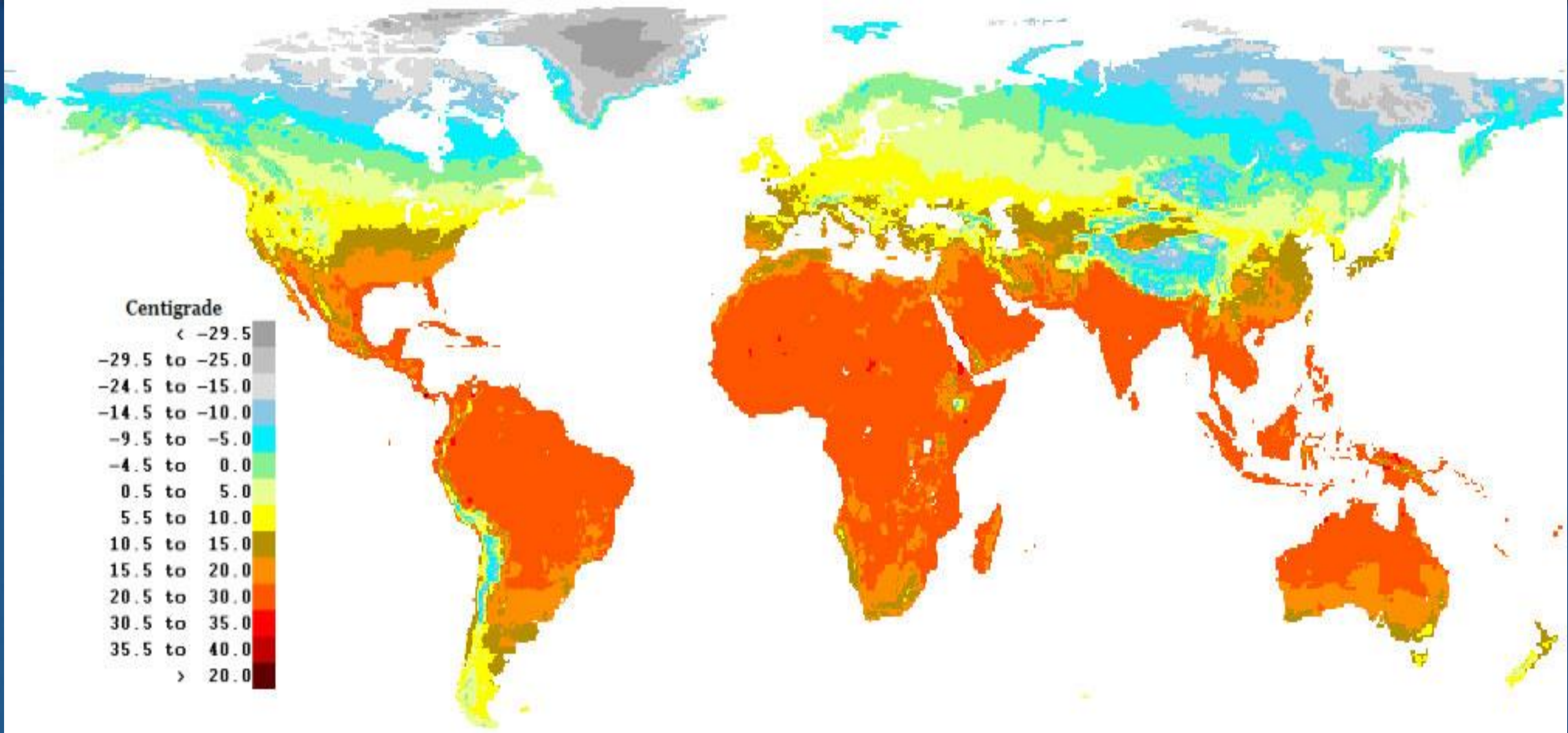
Projection of [CO_2]

Table AII.4.1 | CO_2 abundance (ppm)

Year	Observed	RCP2.6	RCP4.5	RCP6.0	RCP8.5	A2	B1	IS92a	Min	RCP8.5[&]	Max
PI	278 ± 2	278	278	278	278	278	278	278			
2011[obs]	390.5 ± 0.3										
2000		368.9	368.9	368.9	368.9	368	368	368			
2005		378.8	378.8	378.8	378.8					378.8	
2010		389.3	389.1	389.1	389.3	388	387	388	366	394	413
2020		412.1	411.1	409.4	415.8	416	411	414	386	425	449
2030		430.8	435.0	428.9	448.8	448	434	442	412	461	496
2040		440.2	460.8	450.7	489.4	486	460	472	443	504	555
2050		442.7	486.5	477.7	540.5	527	485	504	482	559	627
2060		441.7	508.9	510.6	603.5	574	506	538	530	625	713
2070		437.5	524.3	549.8	677.1	628	522	575	588	703	810
2080		431.6	531.1	594.3	758.2	690	534	615	651	790	914
2090		426.0	533.7	635.6	844.8	762	542	662	722	885	1026
2100		420.9	538.4	669.7	935.9	846	544	713	794	985 ± 97	1142

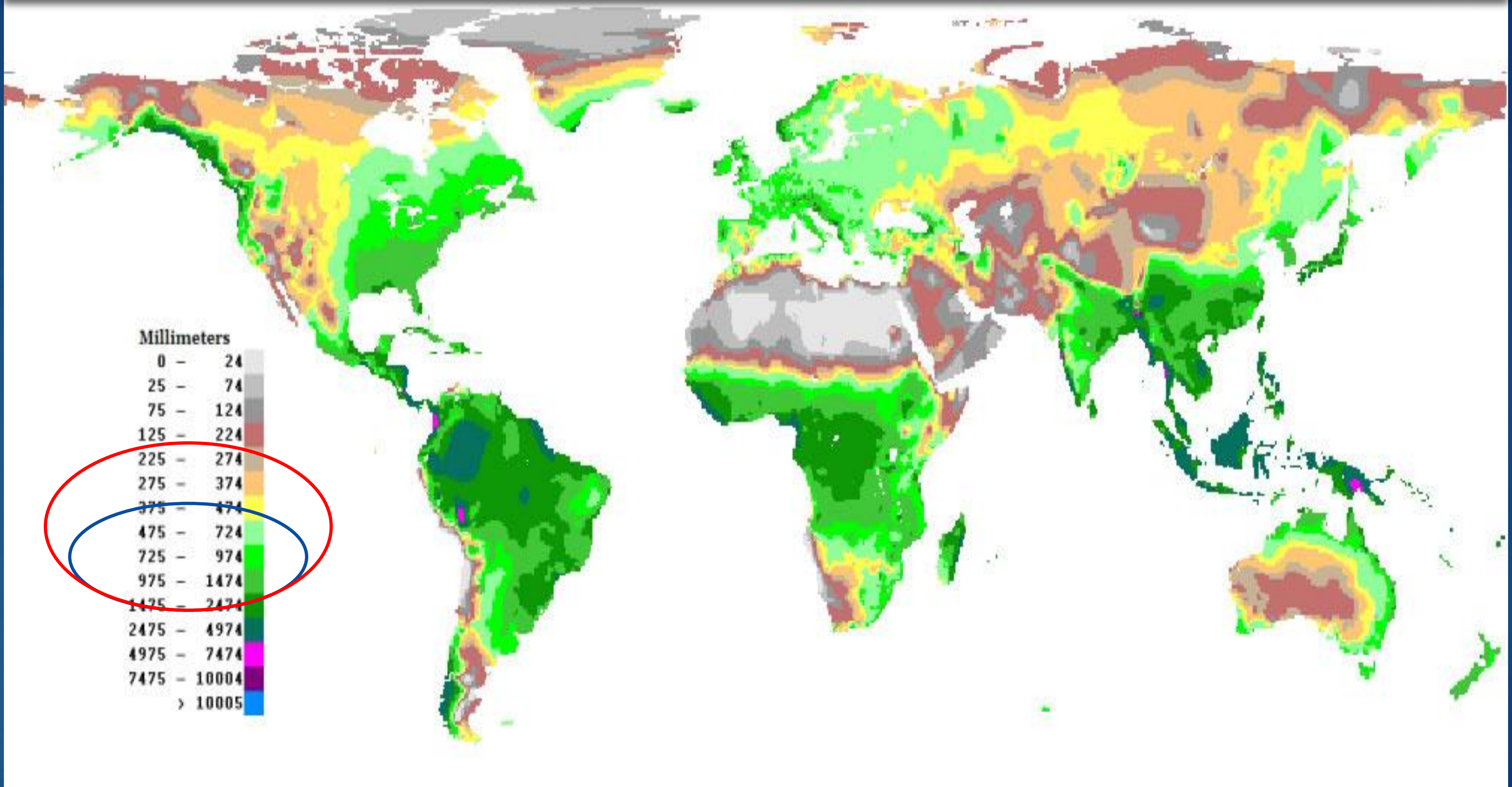
IPCC annexe II Report AR5.

Spatial variations of T on Earth

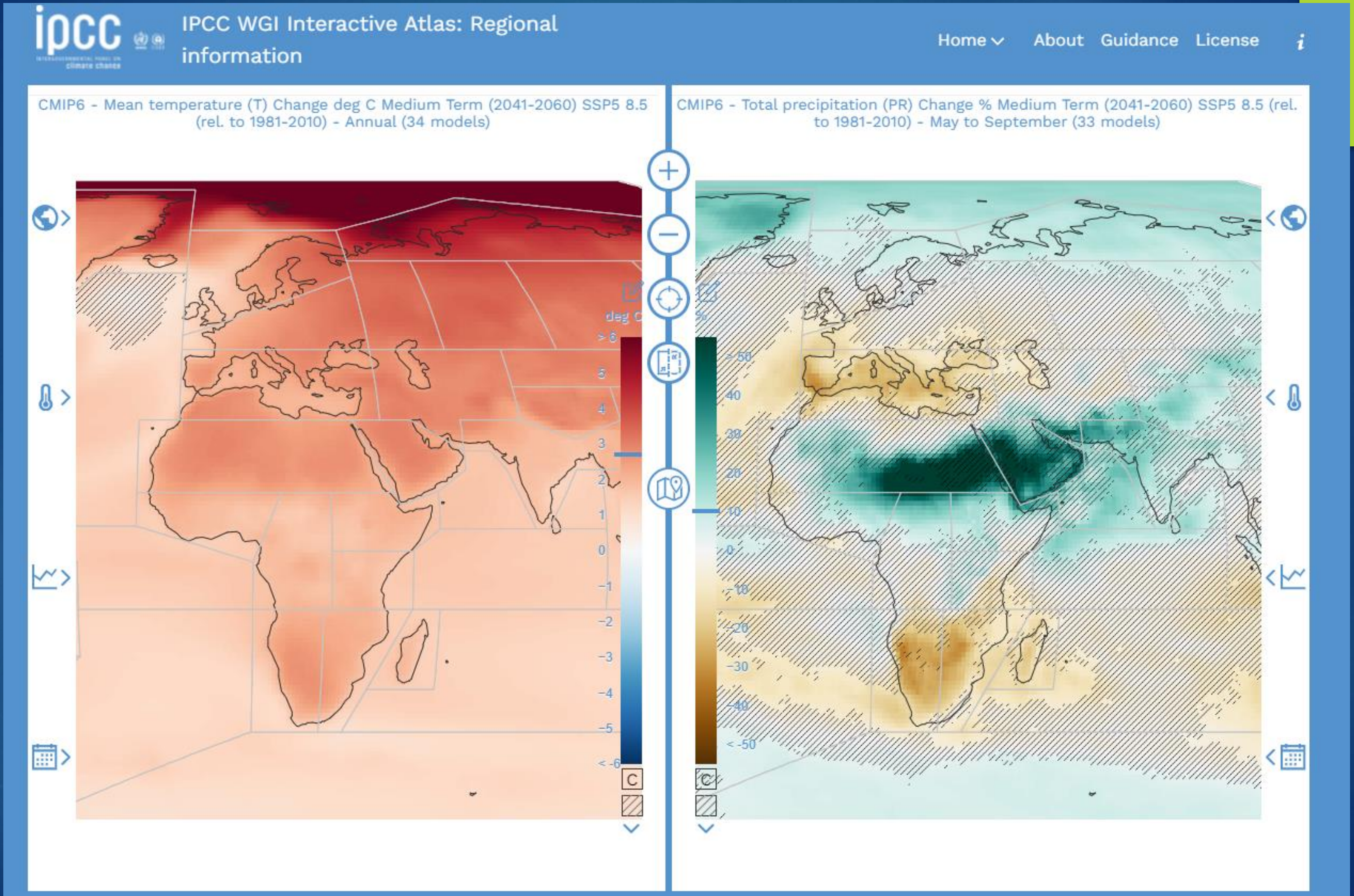


Mean Annual Temperature

Spatial variations of T on Earth

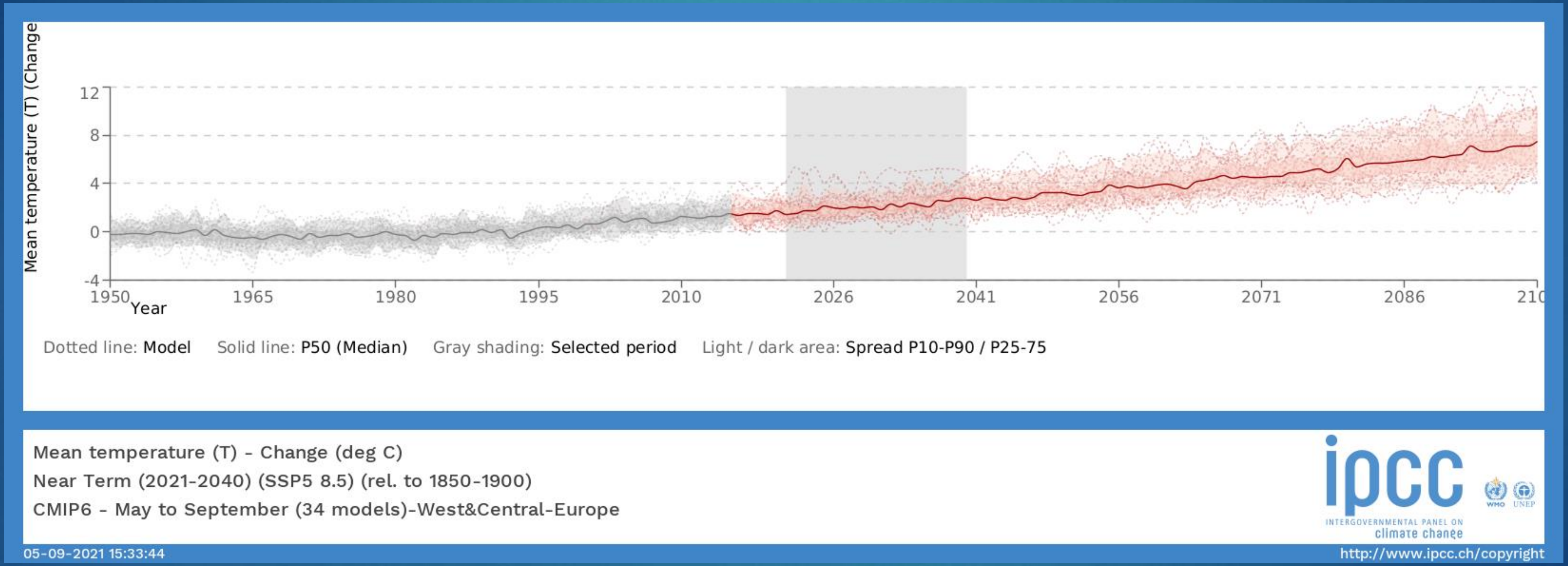


Total annual precipitation



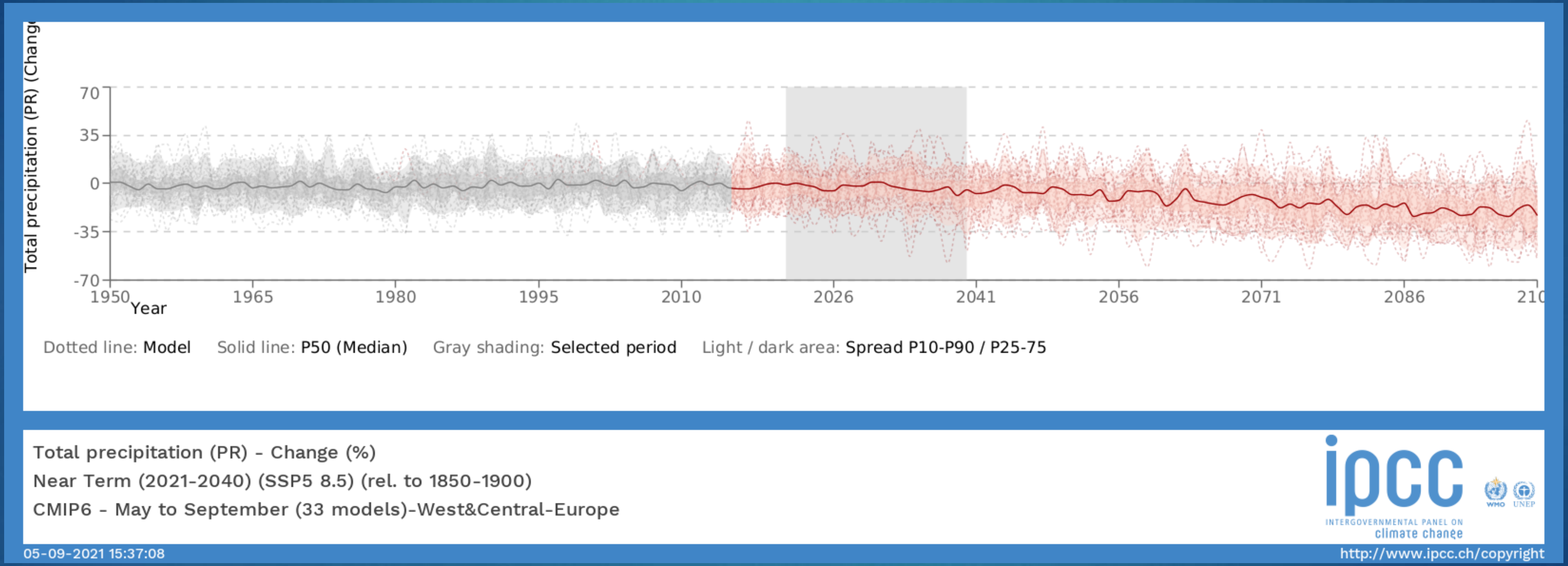
https://interactive-atlas.ipcc.ch/

Mean temperature increase



https://interactive-atlas.ipcc.ch/

Annual precipitations decrease on the long term

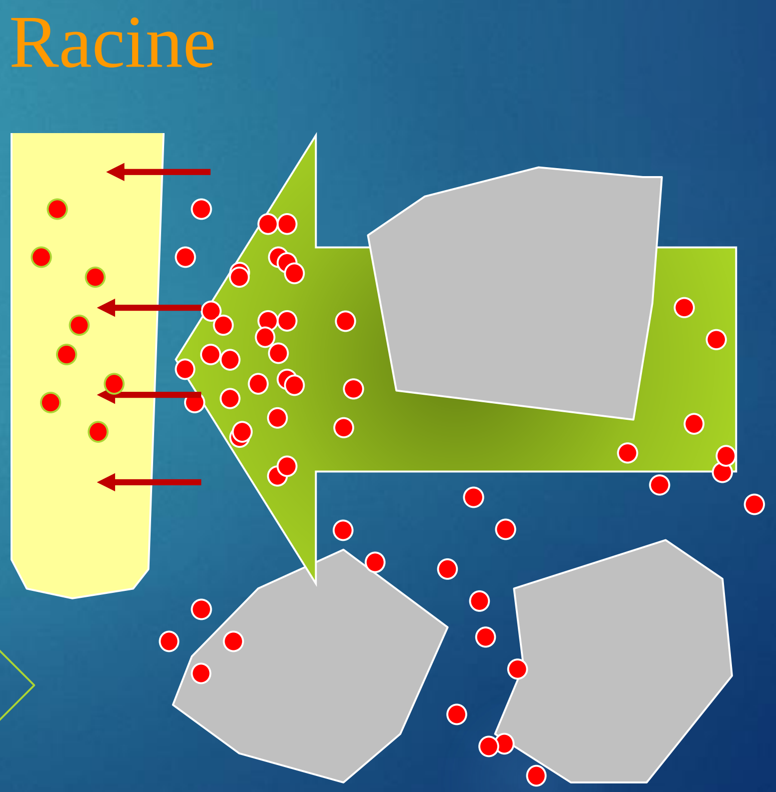


https://interactive-atlas.ipcc.ch/

Main vegetative functions

Trophic functions

- Assimilation chlorophyllienne
- Absorption et assimilation de l'azote
- Fixation symbiotique de l'azote
- Interaction entre réponses des fonctions aux contraintes.



Gonzalez-Dugo, V., Durand, J. L., & Gastal, F. (2010). Water deficit and nitrogen nutrition of crops. A review. *Agronomy for sustainable development*, *30*(3), 529-544.

PRINCIPALES FONCTIONS VÉGÉTALES IMPLIQUÉES DANS LES SERVICES DE L'AGRICULTURE

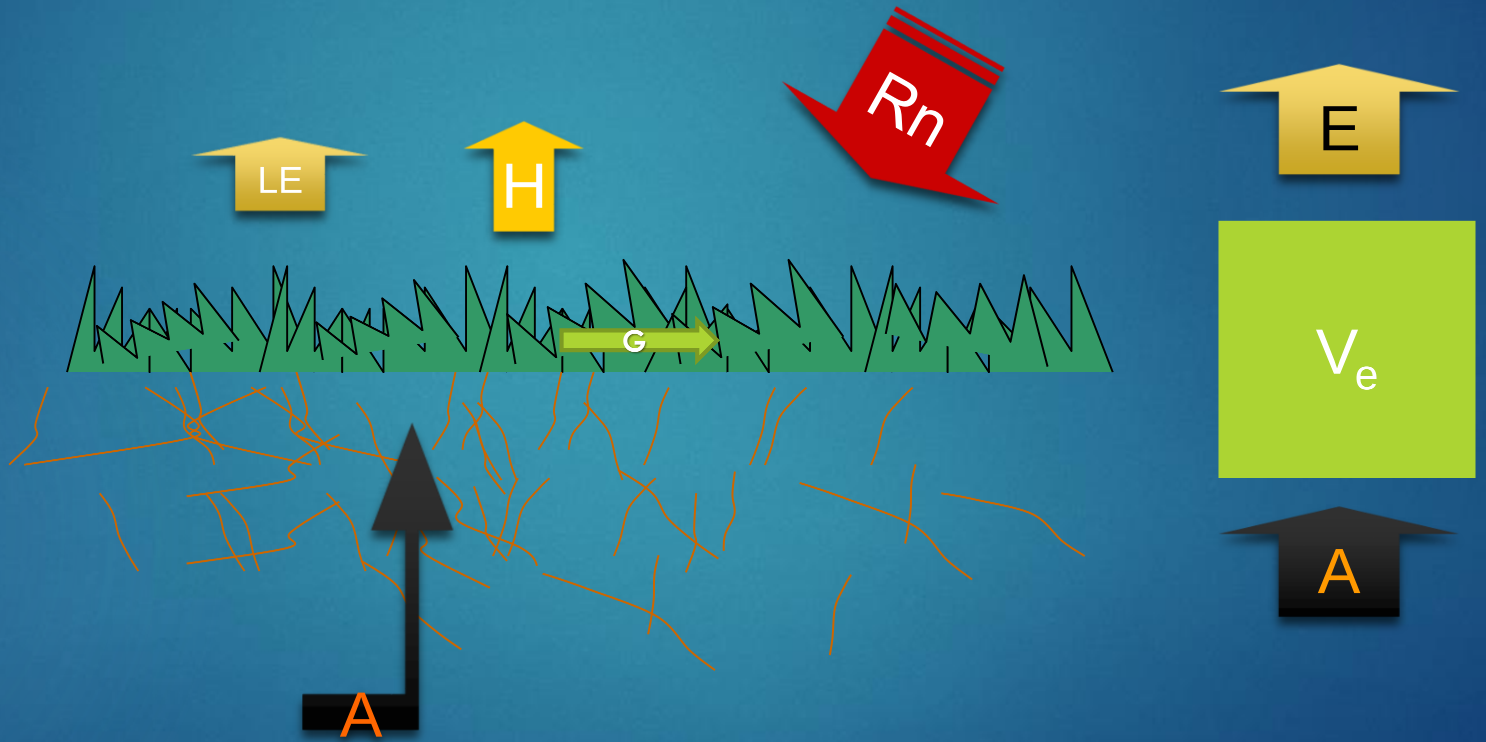
Morphogenetic functions

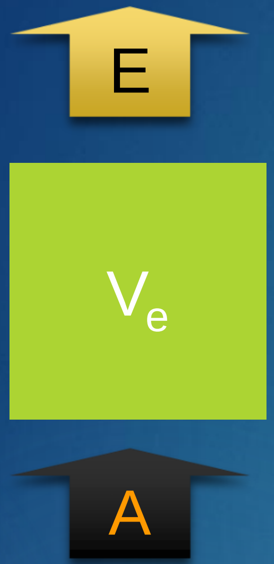
- Organogenèse (production et croissance des méristèmes)
- Expansion des organes végétatifs
  - Croissance primaire
  - Croissance secondaire
  - Déploiement spatial des organes aériens et souterrains
- Ramification des tiges

Most sensitive to climate

Most genetically variable

From energy balance to plant water potential





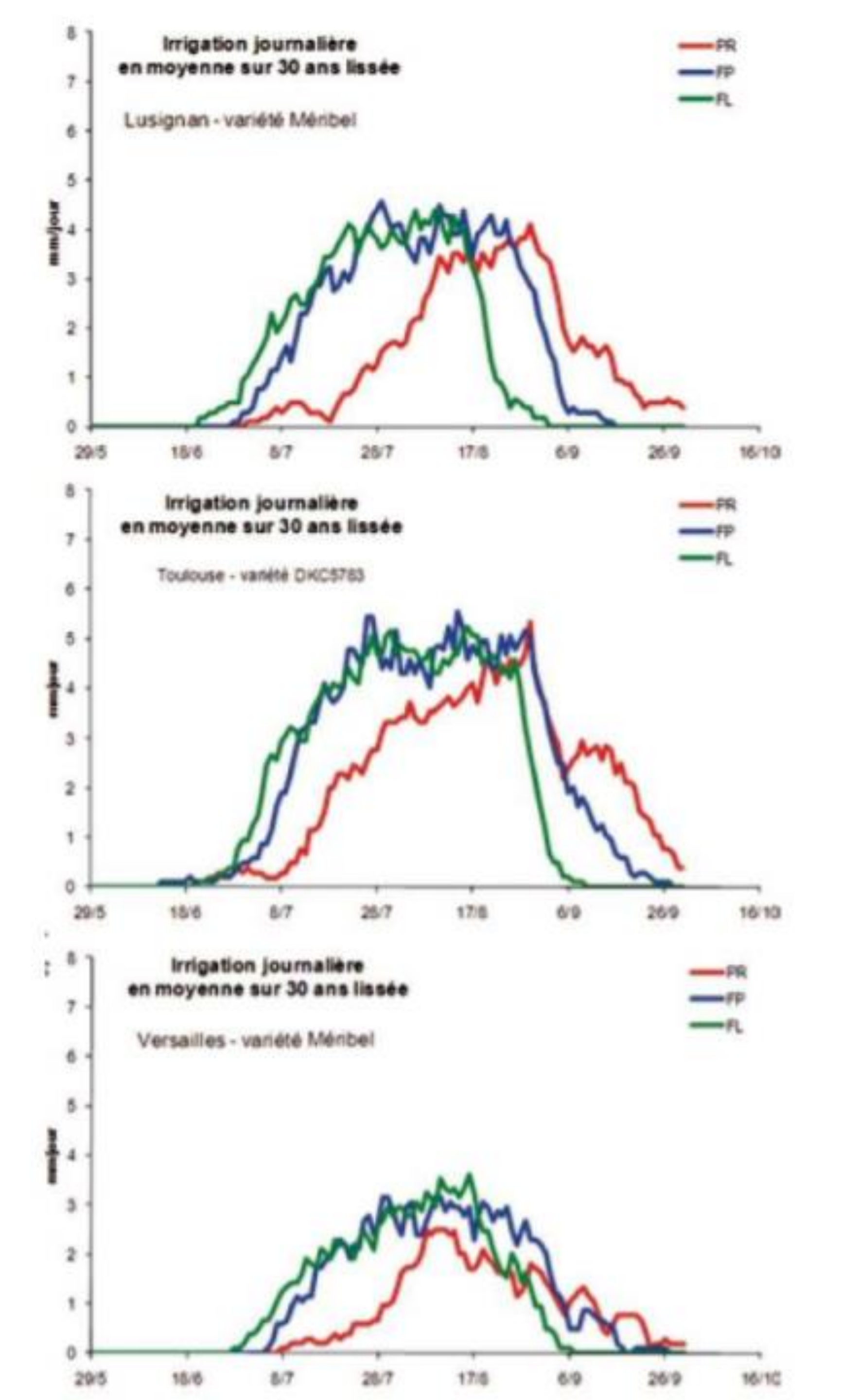
$$A - E = \frac{dV_E}{dt}$$

$$E \sim A = \frac{\Psi_{sol} - \Psi_{plante}}{R_{sol/plante}}$$

$$\Psi_{sol} = f(H_{sol}) \qquad \frac{dH_{sol}}{dt} = -A + \mathrm{RR} + \mathrm{I}$$

$$\Psi_{plante} = \mathrm{P}(V_E) - \pi(V_E)$$

- H_{sol} humidité volumique du sol
- A absorption
- E transpiration
- $\mathit{\Psi}_{sol}$ potentel hydrique du sol
- *$\mathit{\Psi}_{plante}$ potentiel hydrique de la plante*
- *P pression hydraulique dans la plante*
- *π pression osmotique dans la plante*
- *Ve volume d'eau dans la plante*



Earlier and higher potential evapotranspiration impact on needs for irrigation of maize in Lusignan, Toulouse and Versailles.

This includes the impacts of T [CO_2] and Air humidity

Brisson et al 2010 .
CLIMATOR

Response to temperature

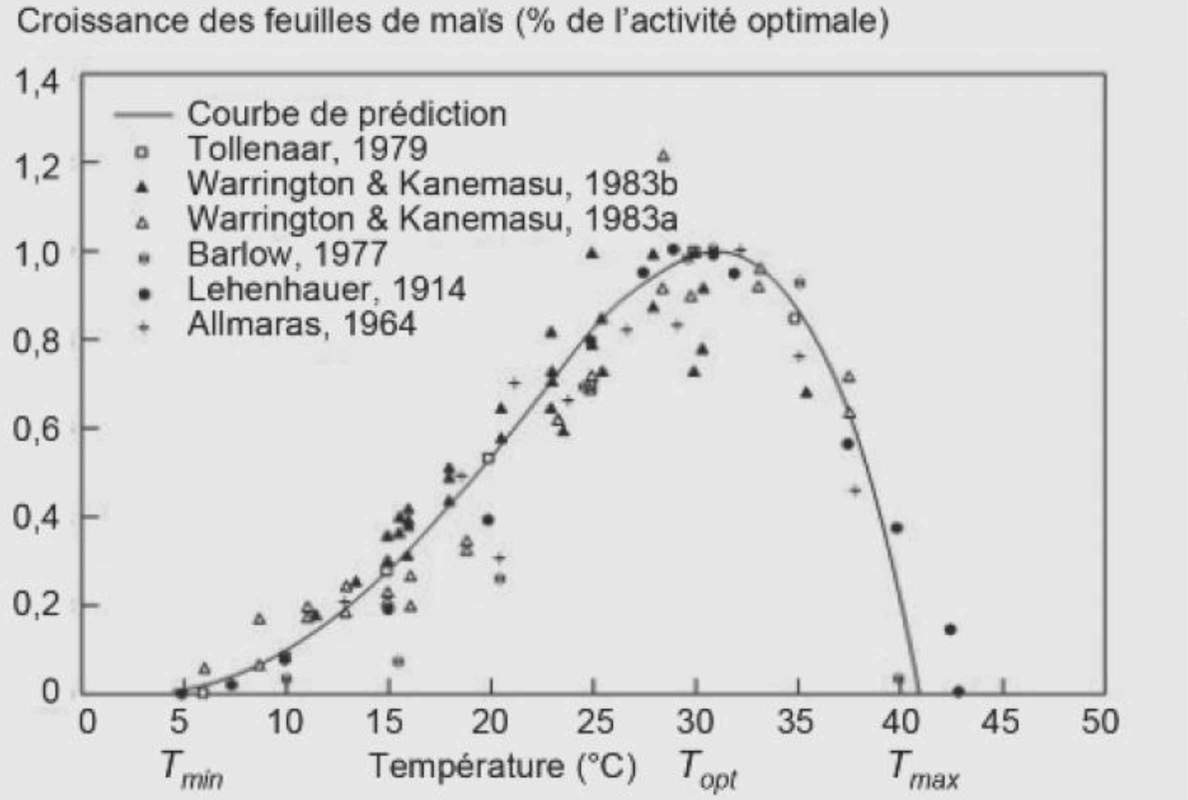


FIGURE 1 : **Réponse à la température de la croissance des feuilles de maïs** (d'après YAN et HUNT, 1999).

- Impacts on transpiration
- Impact on cell death
- Impact on pollen fertility

Response to water deficits

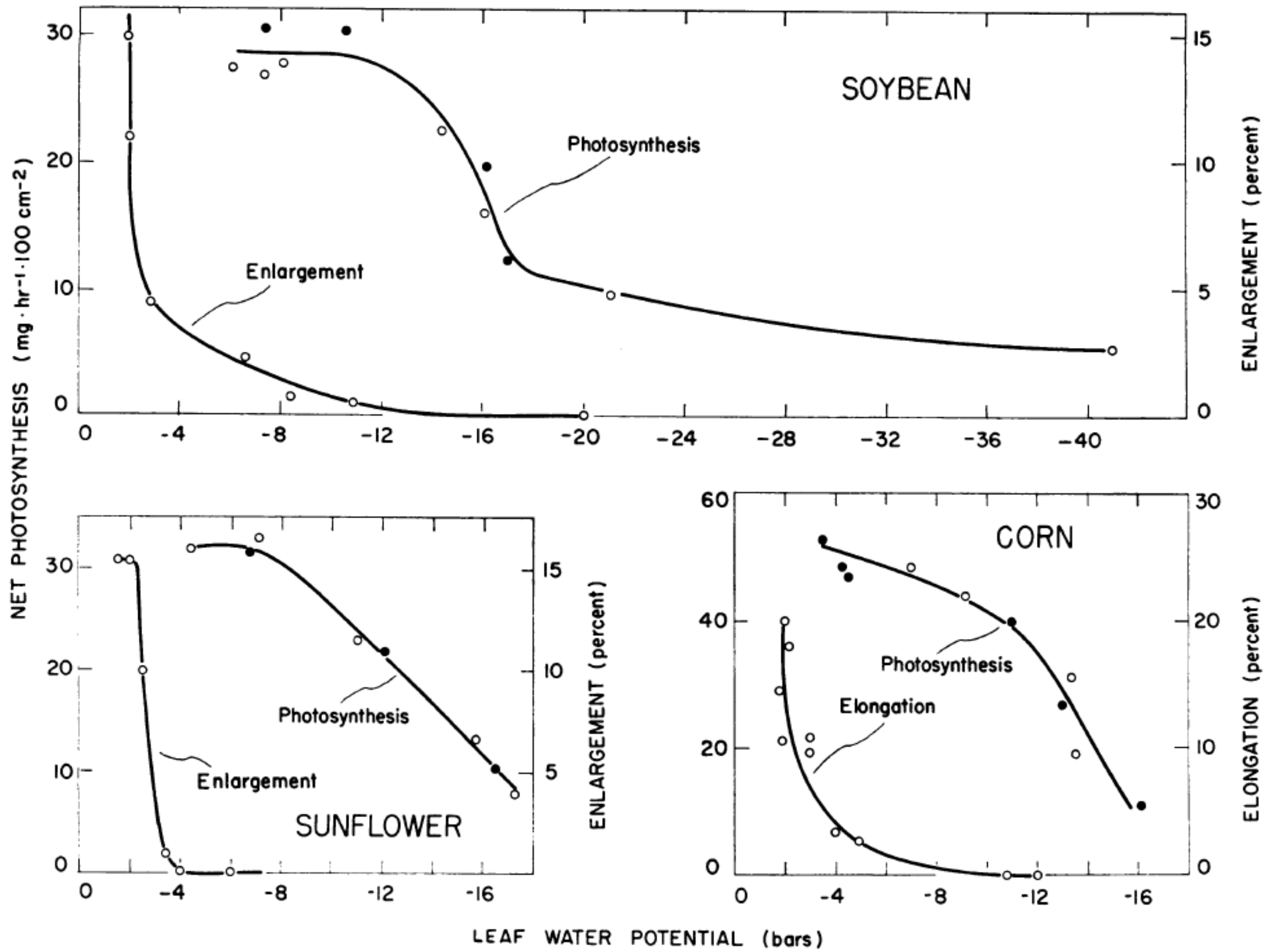
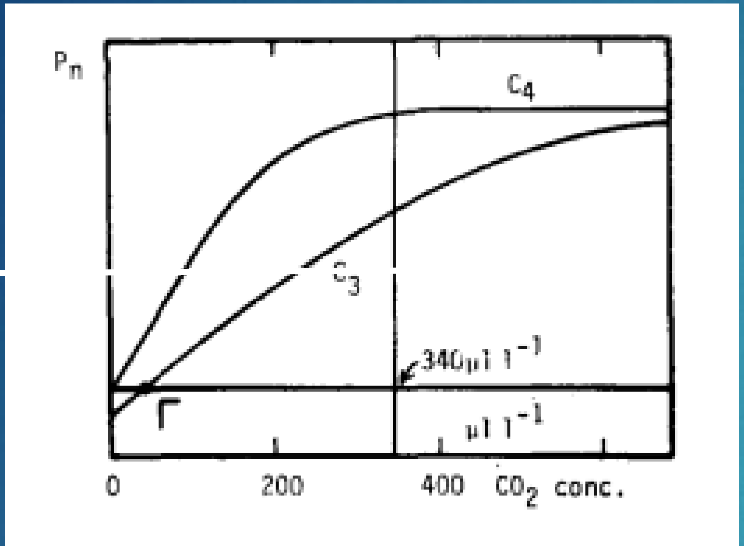
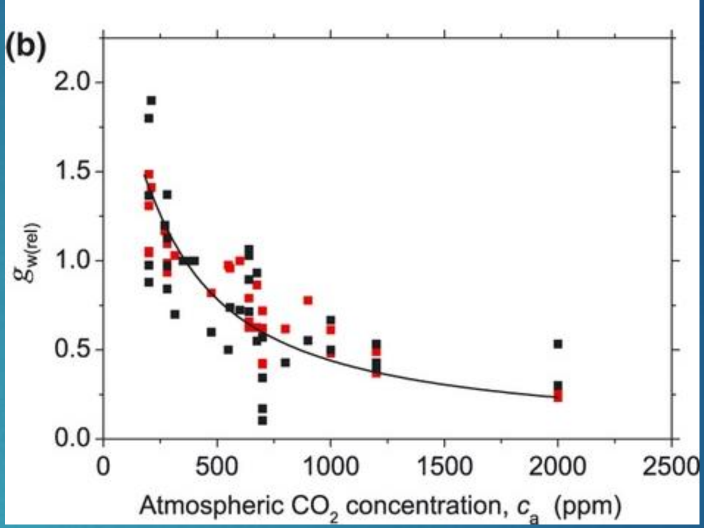


FIG. 1. Rates of leaf enlargement and net photosynthesis in corn, soybean, and sunflower plants at various leaf water potentials. The photosynthesis data were collected from two different plants for each species (●: Plant 1; ○: Plant 2). The plants were 45 to 60 cm tall. The growth data for soybean and sunflower represent enlargement of the fourth and sixth leaves from the base of the plant, the leaves having an area of about 20 and 60 cm², respectively, at the beginning of the 24-hr growth period. For corn, growth was determined as elongation of the sixth leaf blade. The corn leaf blades were initially 25 to 35 cm long.

Boyer JS, 1970. Leaf Enlargement and metabolic rates in corn, soybean and sunflower at various leaf water potentials. J Exp Bot 233-235

Response to CO2





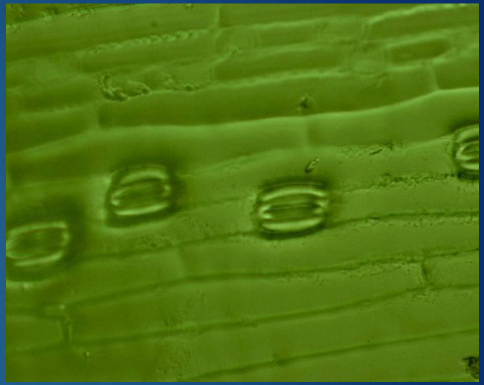
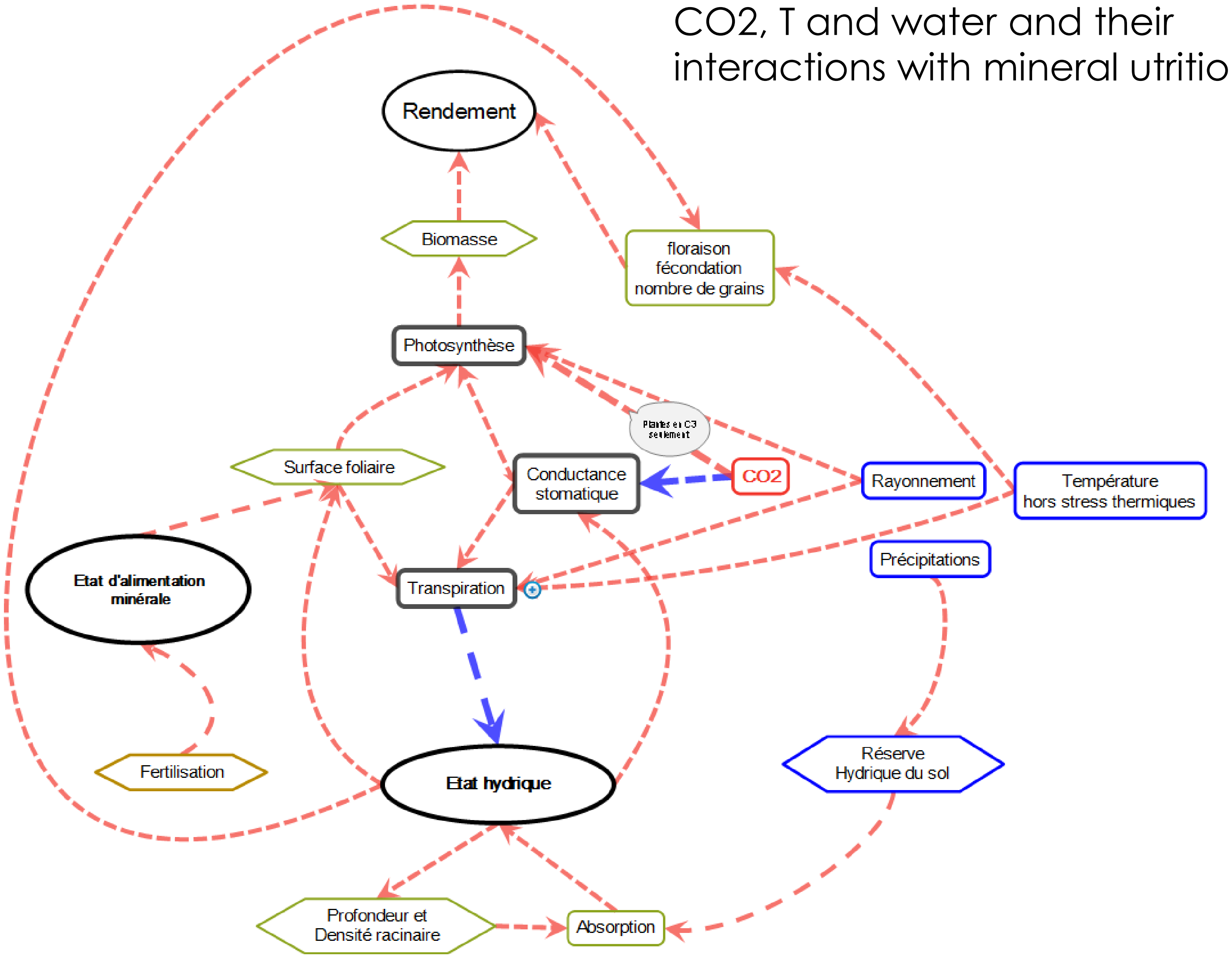


Figure 2. (a) Comparaison des réponses de l'assimilation nette maximale de CO_2 en fonction de la teneur en CO_2 atmosphérique ([CO_2]) entre 0 et 700 ppm, en conditions optimales de lumière et d'alimentation minérale et hydrique, pour les plantes en C3 et en C4 ; d'après Saugier (1983) ; (b) réponse à la teneur en CO_2 de la conductance stomatique normée à sa valeur prise aux concentrations standard au moment de l'expérience. Cette réponse est identique pour les plantes en C3 et C4 ; d'après Francks et al. (2013).

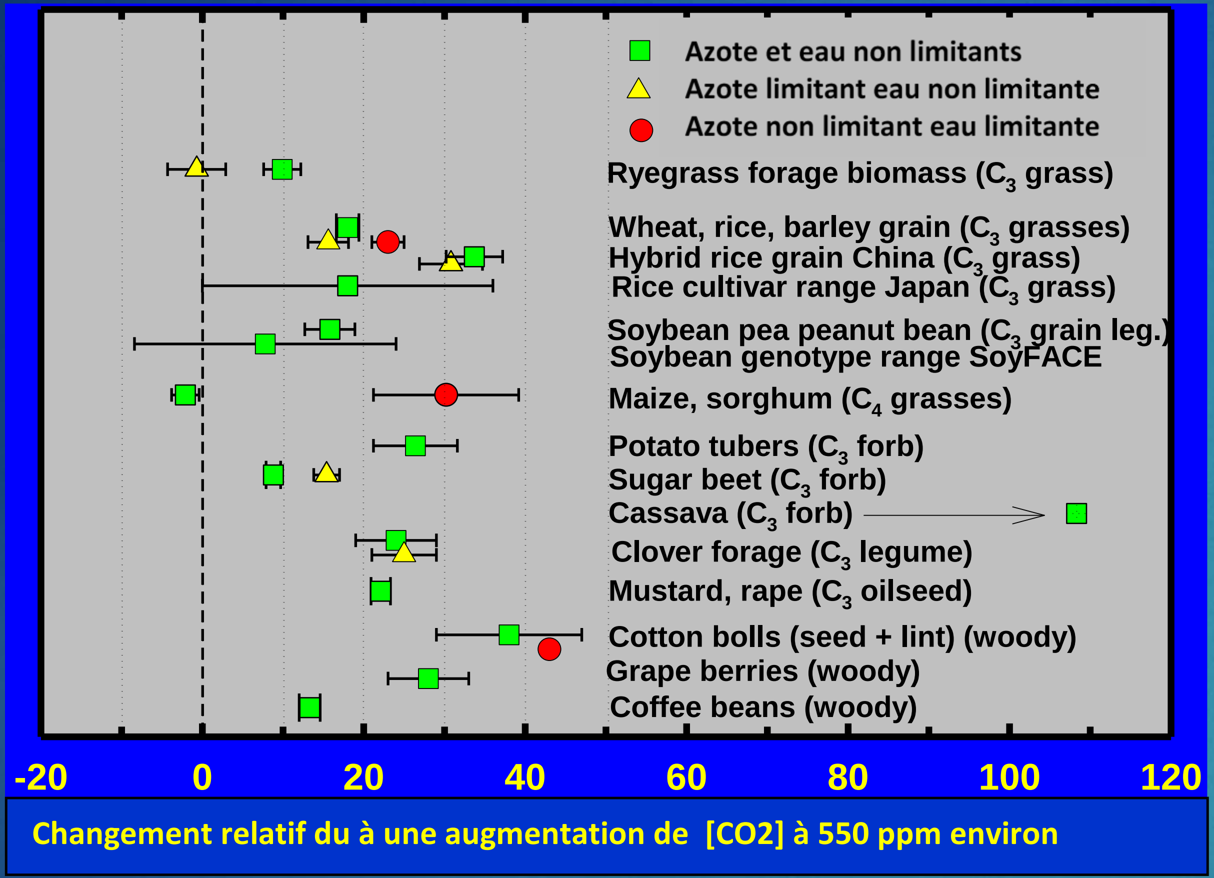
Tibi, A., Forslund, A., Debaeke, P., Schmitt, B., Guyomard, H., Marajo-Petitzon, E., ... & Planton, S. (2020). Place des agricultures européennes dans le monde à l'horizon 2050.c

The complexity of responses to CO2, T and water and their interactions with mineral utrition



Tibi, A., Forslund, A., Debaeke, P., Schmitt, B., Guyomard, H., Marajo-Petitzon, E., ... & Planton, S. (2020). Place des agricultures européennes dans le monde à l'horizon 2050.c

The yields responses to [CO2]



Kimball, B. A. (2016). Crop responses to elevated CO2 and interactions with H2O, N, and temperature. *Current opinion in plant biology*, *31*, 36-43.

Figure 5. Effets sur les rendements en % mesurés dans des dispositifs FACE d'une élévation de la teneur en CO_2 de 350 à 550 ppm, approximativement (que veut dire cet « approximativement » ?), pour différentes cultures, sous différentes conditions hydriques et azotées. Le nombre de données répertoriées est de 18 pour le ray-grass, 151 pour les céréales en C3, 29 pour les protéagineux, 12 pour les céréales en C4, 6 pour la pomme de terre, 2 pour la betterave sucrière, 1 pour le manioc,10 pour le trèfle et 2 pour le colza. D'après Kimball (2016).

The spatial changes of adaptatbility of grasses

Poirier, M., Durand, J. L., & Volaire, F. (2012). Persistence and production of perennial grasses under water deficits and extreme temperatures: importance of intraspecific vs. interspecific variability. *Global Change Biology*, *18*(12), 3632-3646.

Déqué, M. (2015, November). Le changement climatique en France et en Europe atlantique: les domaines méditerranéens et tempérés. In *Colloque présentant les méthodes et résultats du projet Climagie (métaprogramme ACCAF)* (pp. 223-p). INRA.

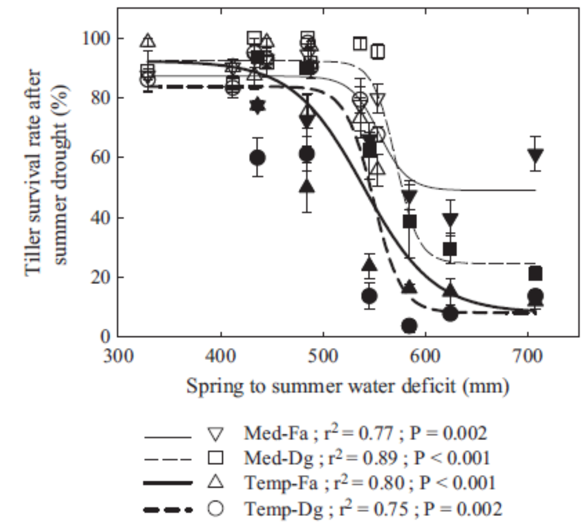
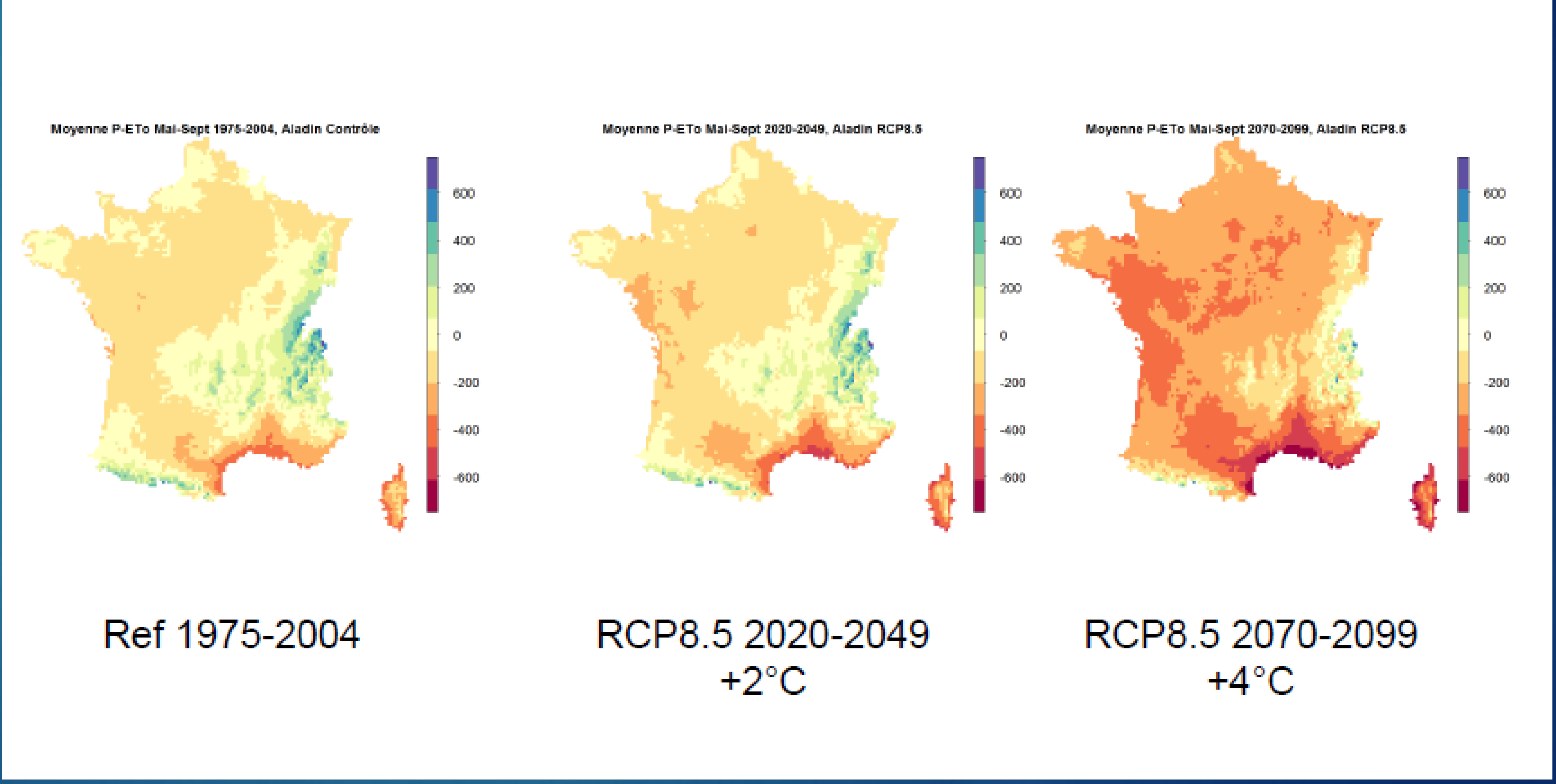
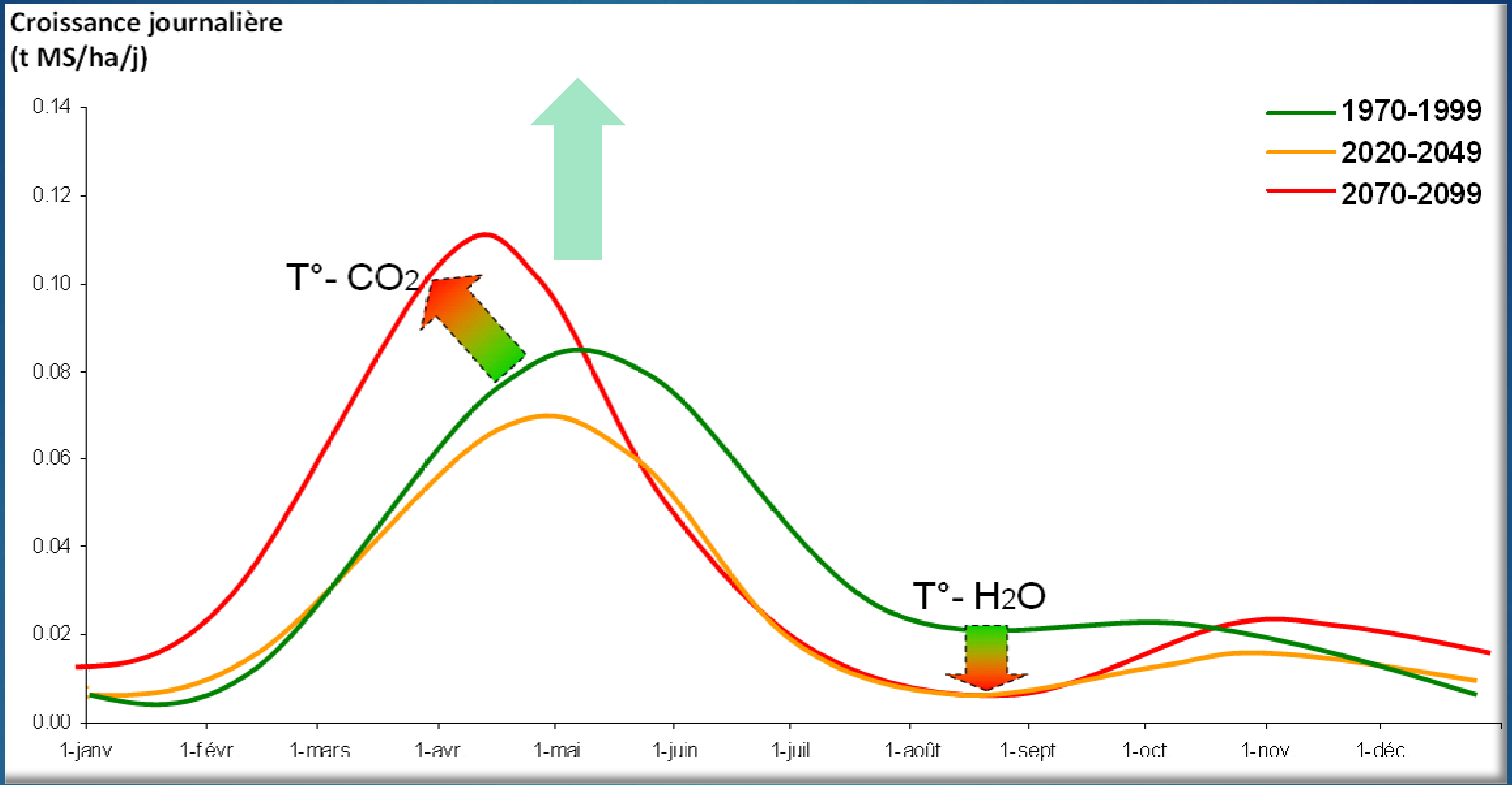


Fig. 4 Summer tiller survival rates expressed as the ratio between the tiller density rate measured in the autumn and the tiller density rate at the end of the previous spring, for two species Fa (*Festuca arundinacea*) and Dg (*Dactylis glomerata*) either of Mediterranean (Med) or Temperate (Temp) origin, under 14 climatic scenarios at a Mediterranean site (Med-site, closed symbols) and Temperate site (Temp-site, open symbols; mean, $n = 4$, ± SE) as a function of the water deficit |Water supply (WS) – Evapotranspiration (ET°)| cumulated during the period of soil water depletion in spring and summer. The lines indicate nonlinear regressions (sigmoid curve: $f(x) = y_0 + a/(1 + \exp^{(-(x-x0)/b)})$).



Poirier, Durand, Volaire, 2012

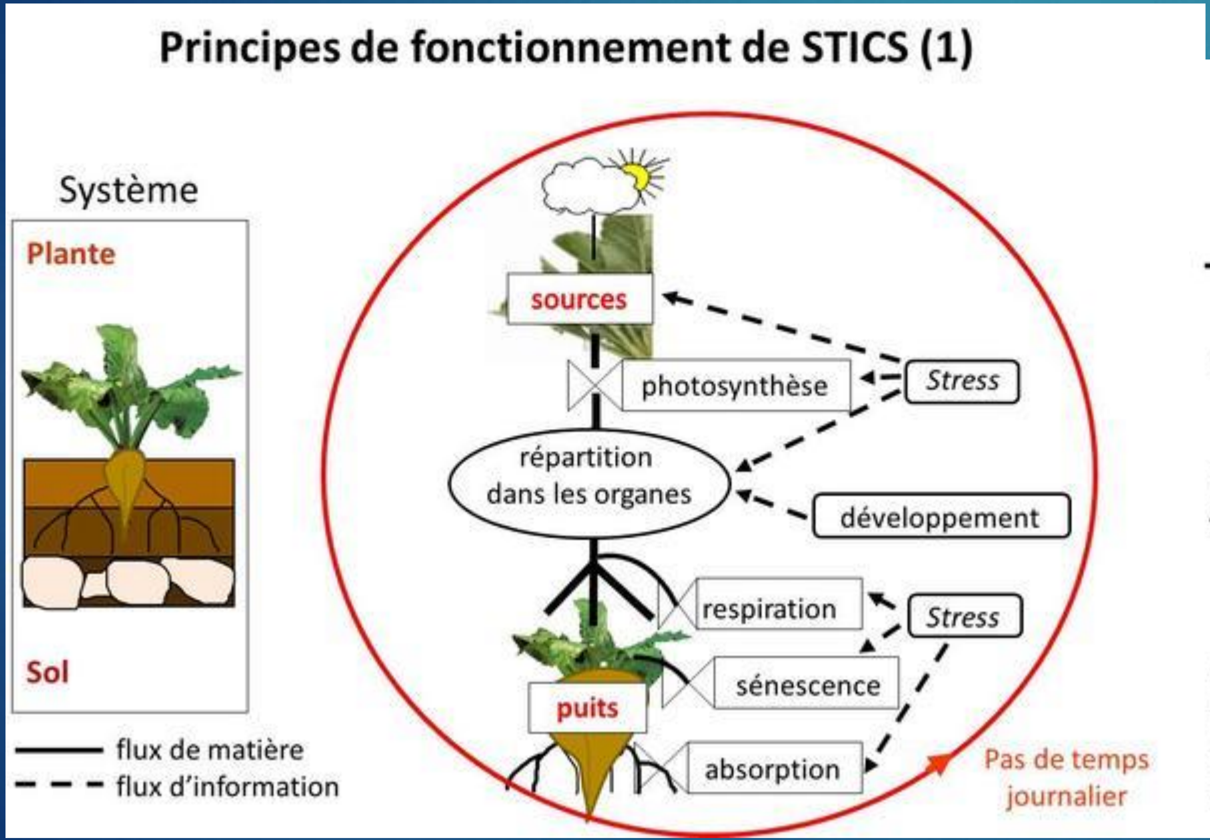
Déqué, Huard, 2015

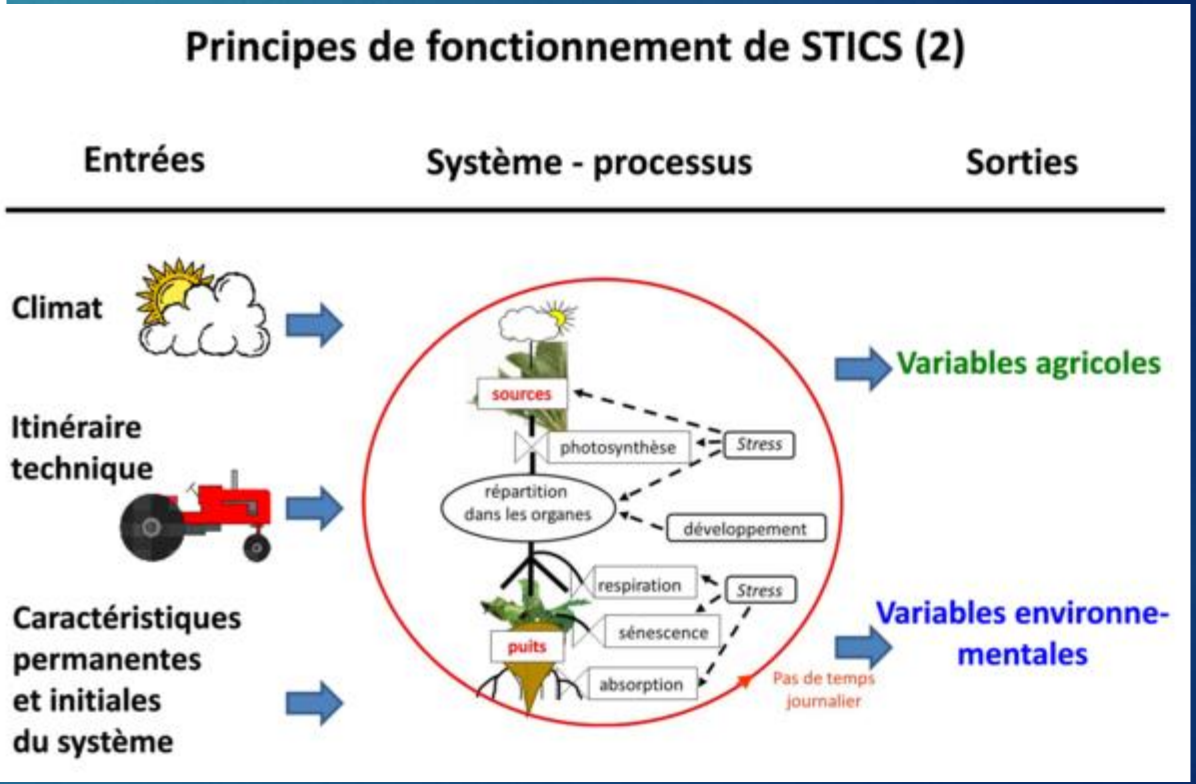


Evolution annuelle de la production journalière au cours de l'année – Exemple de la fétuque cultivée à Rennes sur sol superficiel, scénario A1B simulé avec STICS avec la méthode de régionalisation climatique QQ.

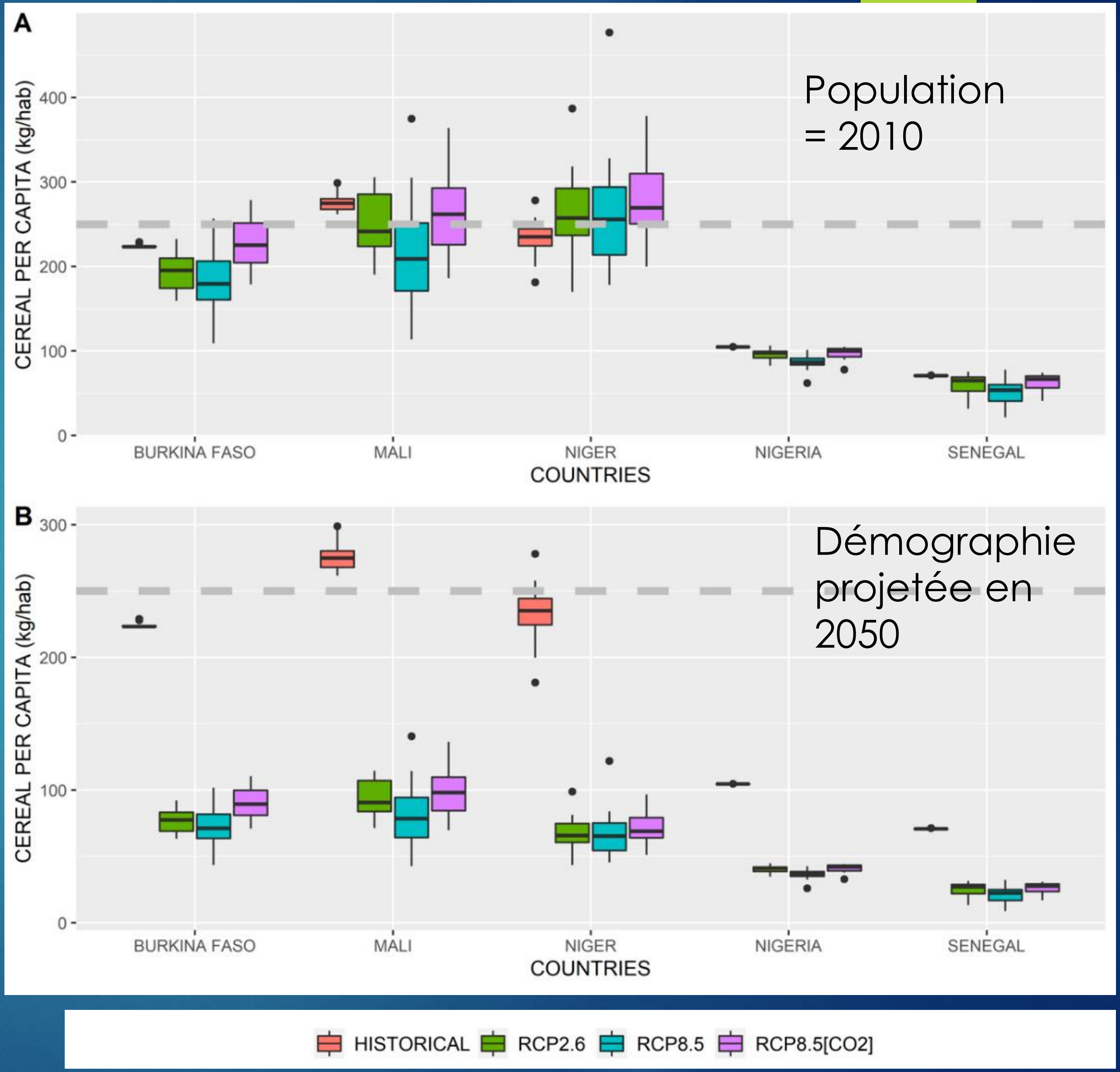
Durand, J. L., Bernard, F., Lardy, R., & Graux, A. I. (2010). Changement climatique et prairie: l'essentiel des impacts.

To make an estimate of the impact of climate change on yields and environmental impacts : Crop models





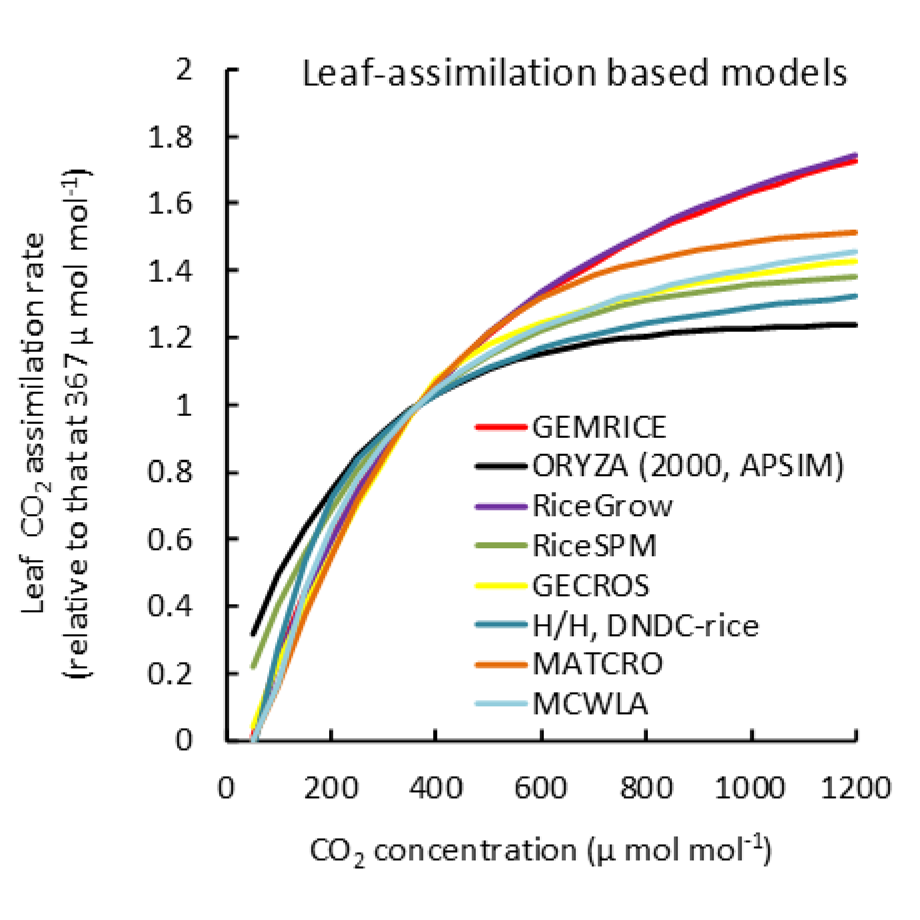
Projection on yields and demand satisfaction level using Sara O

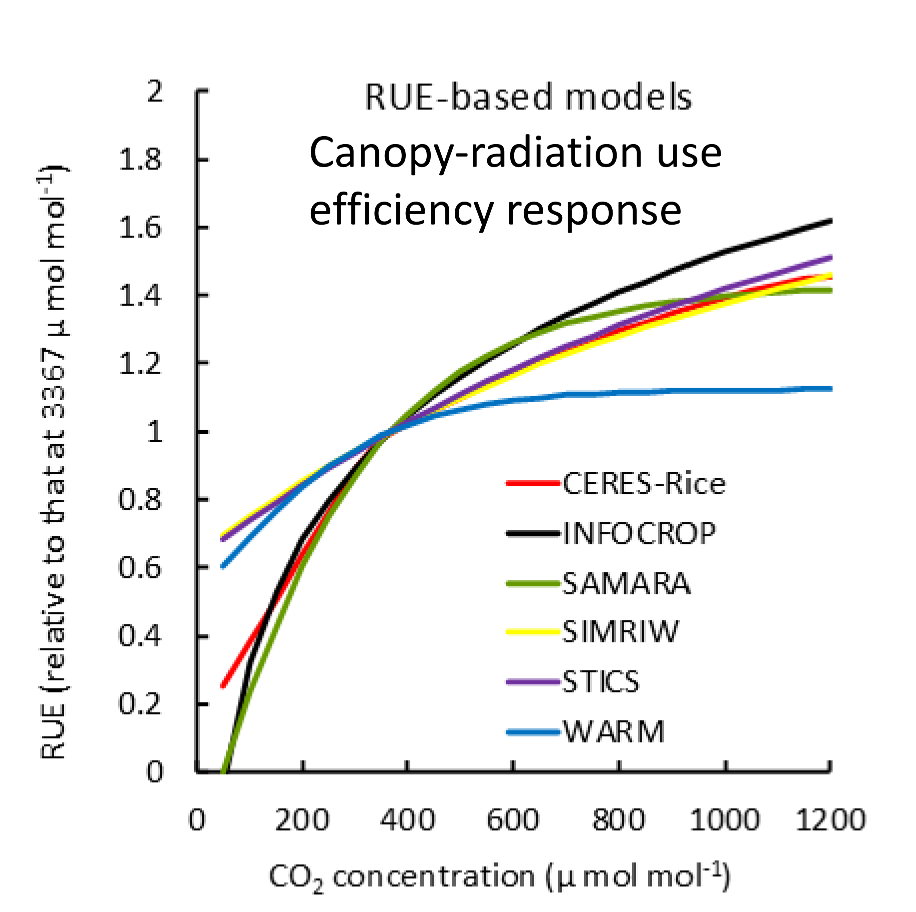


Defrance, D., Sultan, B., Castets, M., Famien, A. M., & Baron, C. (2020). Impact of climate change in West Africa on cereal production per capita in 2050. Sustainability, 12(18), 7585.

Utiliser plusieurs modèles

Réponse au [CO_2] de 16 modèles de simulation de rendement du riz différents certains integrant un modèle de photosynthèse détaillée , les autres un coefficient d'efficience de conversion du rayonnement absorbé

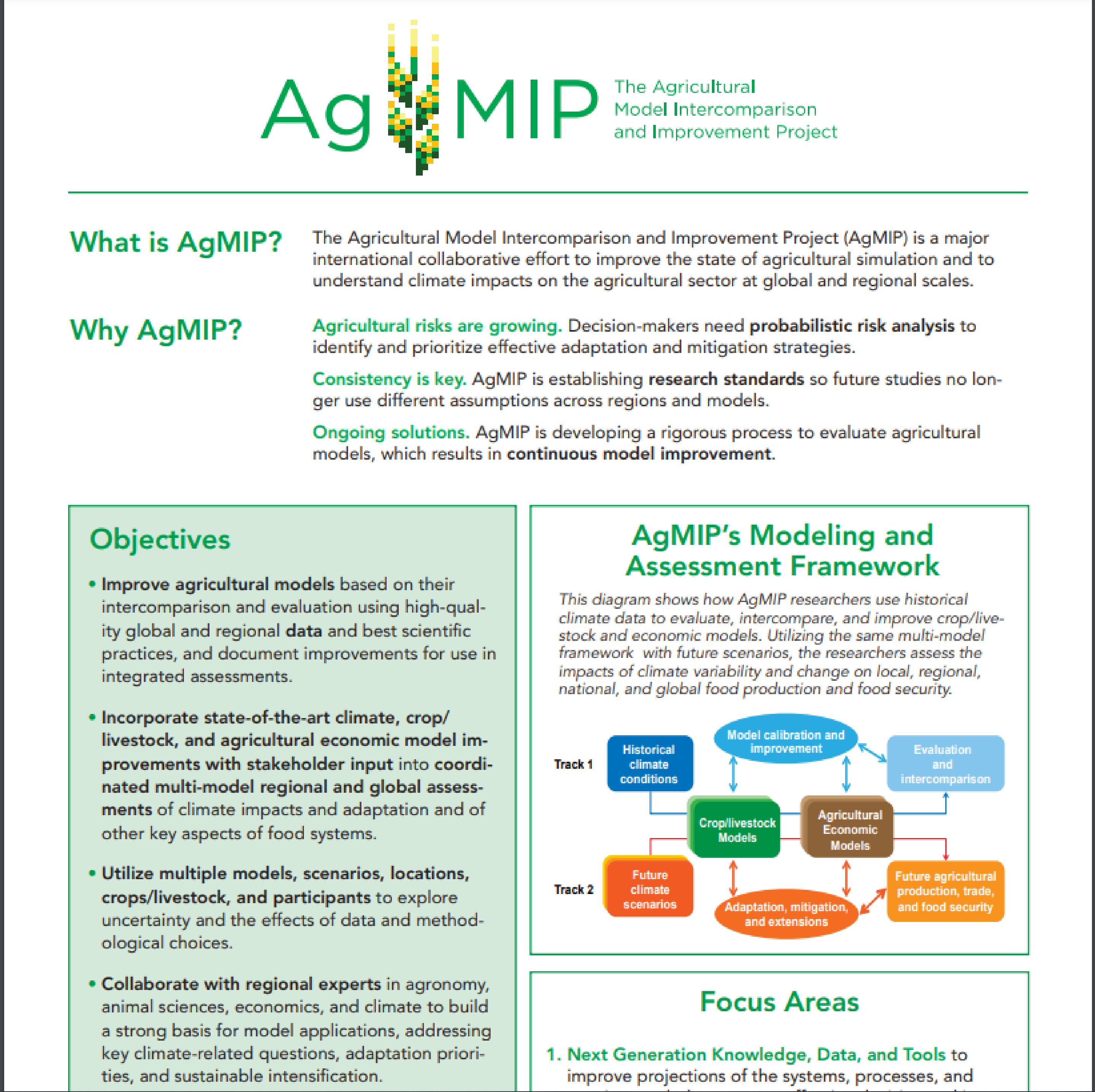




Hasegawa, T., Li, T., Yin, X., Zhu, Y., Boote, K., Baker, J., ... & Zhu, J. (2017). Causes of variation among rice models in yield response to CO 2 examined with Free-Air CO 2 Enrichment and growth chamber experiments. Scientific reports, 7(1), 1-13.

From CMIP to AGMIP

https://agmip.org/



AgMIP The Agricultural Model Intercomparison and Improvement Project

What is AgMIP?

The Agricultural Model Intercomparison and Improvement Project (AgMIP) is a major international collaborative effort to improve the state of agricultural simulation and to understand climate impacts on the agricultural sector at global and regional scales.

Why AgMIP?

Agricultural risks are growing. Decision-makers need **probabilistic risk analysis** to identify and prioritize effective adaptation and mitigation strategies.

Consistency is key. AgMIP is establishing **research standards** so future studies no longer use different assumptions across regions and models.

Ongoing solutions. AgMIP is developing a rigorous process to evaluate agricultural models, which results in **continuous model improvement**.

Objectives

- **Improve agricultural models** based on their intercomparison and evaluation using high-quality global and regional **data** and best scientific practices, and document improvements for use in integrated assessments.
- **Incorporate state-of-the-art climate, crop/livestock, and agricultural economic model improvements with stakeholder input** into **coordinated multi-model regional and global assessments** of climate impacts and adaptation and of other key aspects of food systems.
- **Utilize multiple models, scenarios, locations, crops/livestock, and participants** to explore uncertainty and the effects of data and methodological choices.
- **Collaborate with regional experts** in agronomy, animal sciences, economics, and climate to build a strong basis for model applications, addressing key climate-related questions, adaptation priorities, and sustainable intensification.

AgMIP's Modeling and Assessment Framework

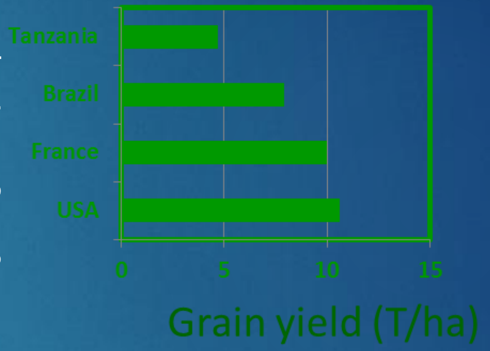
This diagram shows how AgMIP researchers use historical climate data to evaluate, intercompare, and improve crop/livestock and economic models. Utilizing the same multi-model framework with future scenarios, the researchers assess the impacts of climate variability and change on local, regional, national, and global food production and food security.

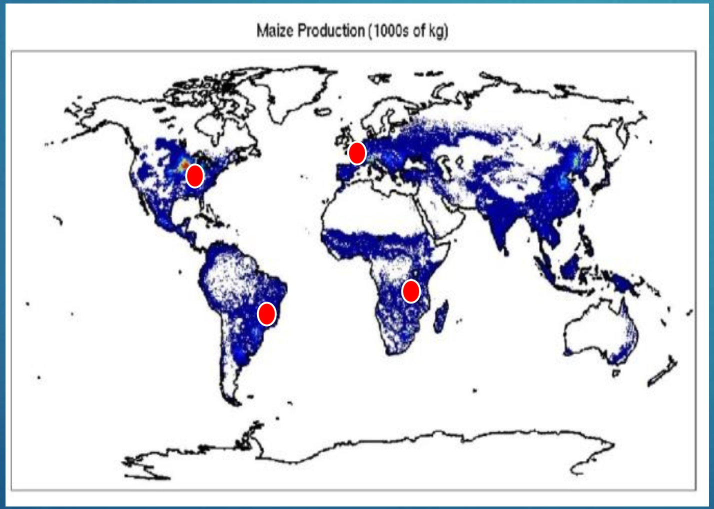
Focus Areas

1. Next Generation Knowledge, Data, and Tools to improve projections of the systems, processes, and

AgMIP Maize models sites used to test models

- High input calibration maize simulations vs. climate factors
  - 19 models for temperature
  - 15 models for CO_2
- 4 contrasting field experiments
  - Morogoro, Tanzania (06.50°S; 37.39°E) Tavg. 22.5 °C st.dev.1.4
  - Rio Verde, Brazil (17.52°S; 51.43°W) Tavg. 23.3 °C st.dev.1.7
  - Ames, Iowa, USA (42.01°N; 93.45°W) Tavg. 20.6 °C st.dev.4.5
  - Lusignan, France (46.25°N; 00.07°E) Tavg. 16.8 °C st.dev.3.8



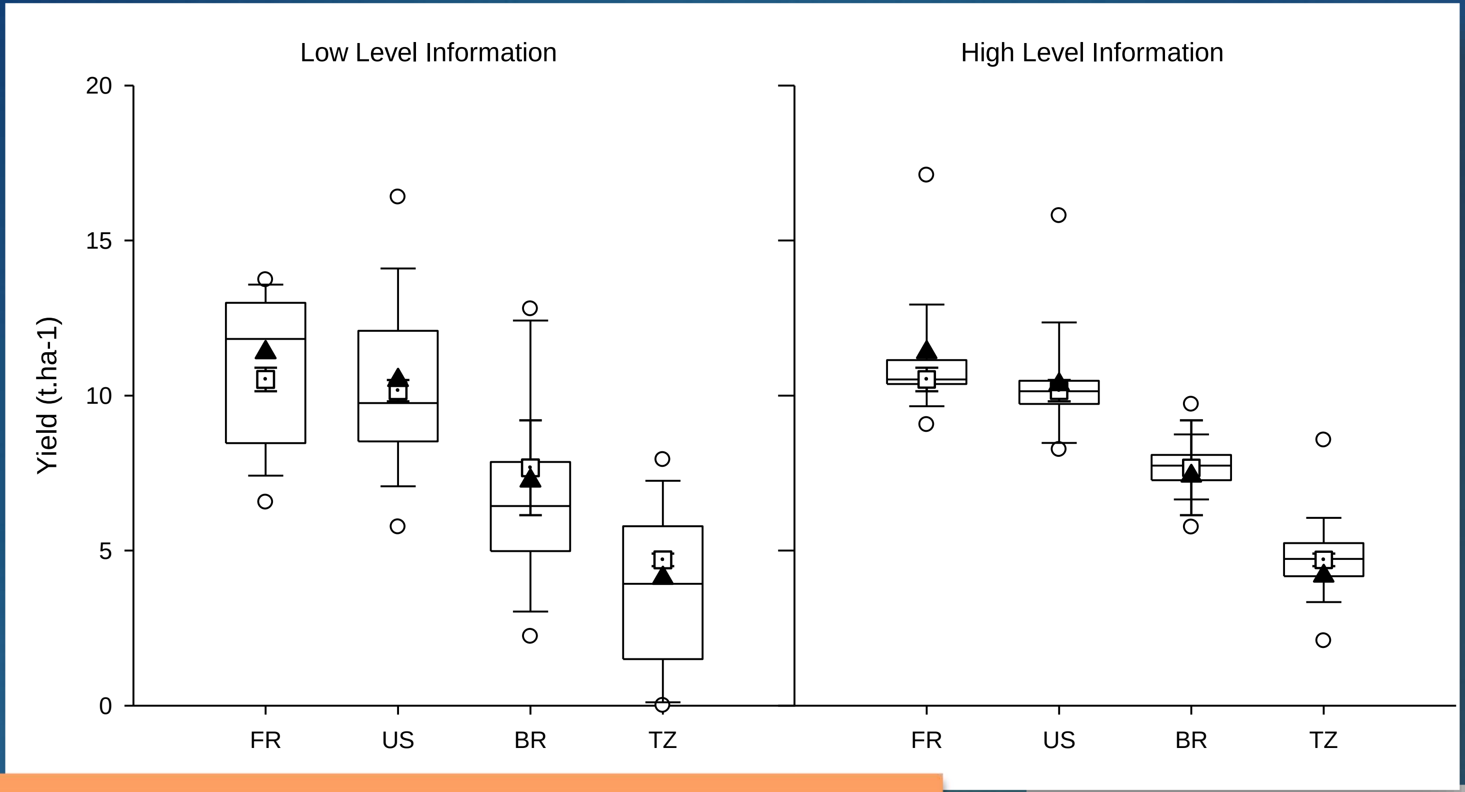


Bassu et al, 2014. How do various maize crop models vary in their responses to climate change factors? Global Change Biology, 20, 2301–2320..

Simulation protocoles

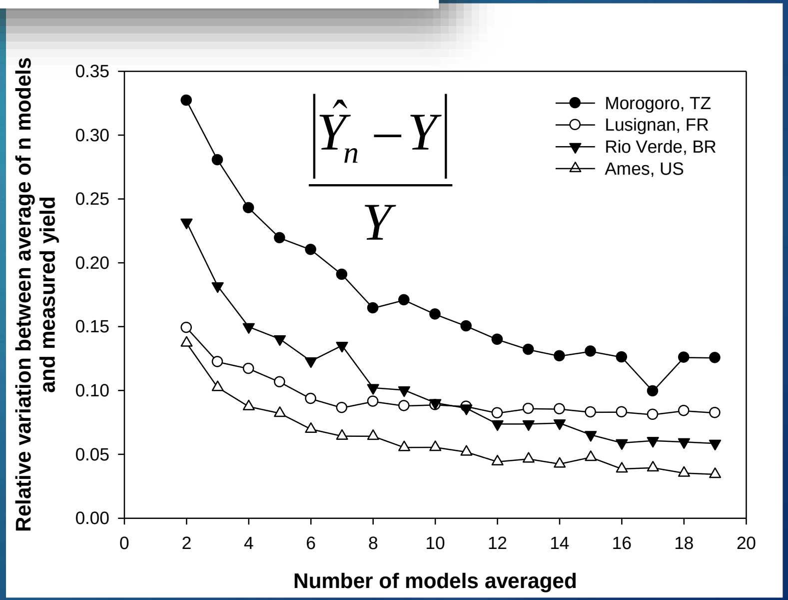
Each model under the responsability of one particular team with 3 successive tasks.

1. Simulate observed yields and water use at 4 sites with a minimum of local data: cv phenology, soil, weather, techniques.
2. Adjust parameters with all experimental data on yields, LAI, nitrogen etc…
3. Simulate the ΔCO_2 * ΔT responses over 30 years.

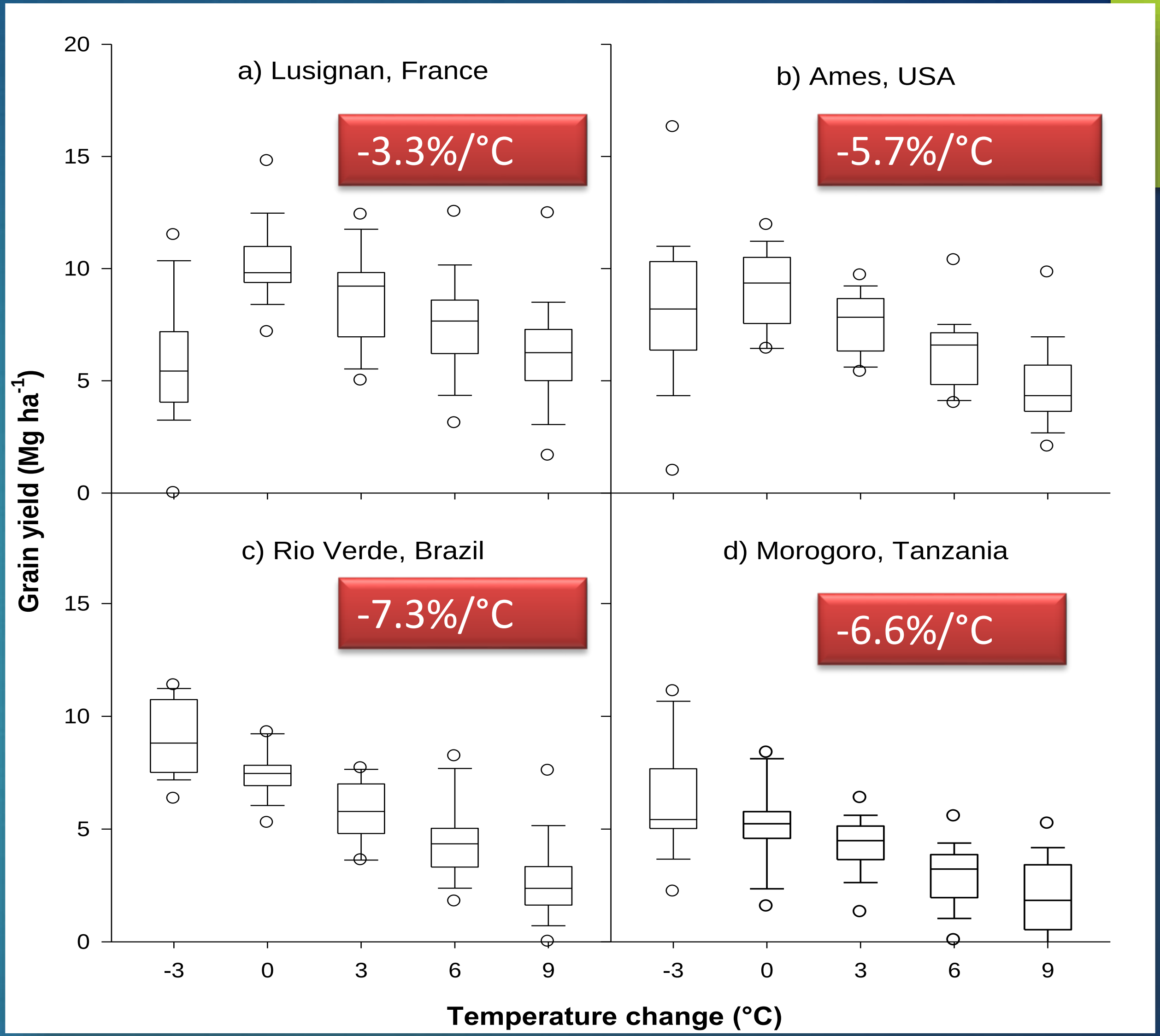


High yield variability challenges simulations of best models.
Ensemble 23 models simulated yields accurately with a low level of input information (weather, soil and techniques).
The minimum number appears linked to the site[2].

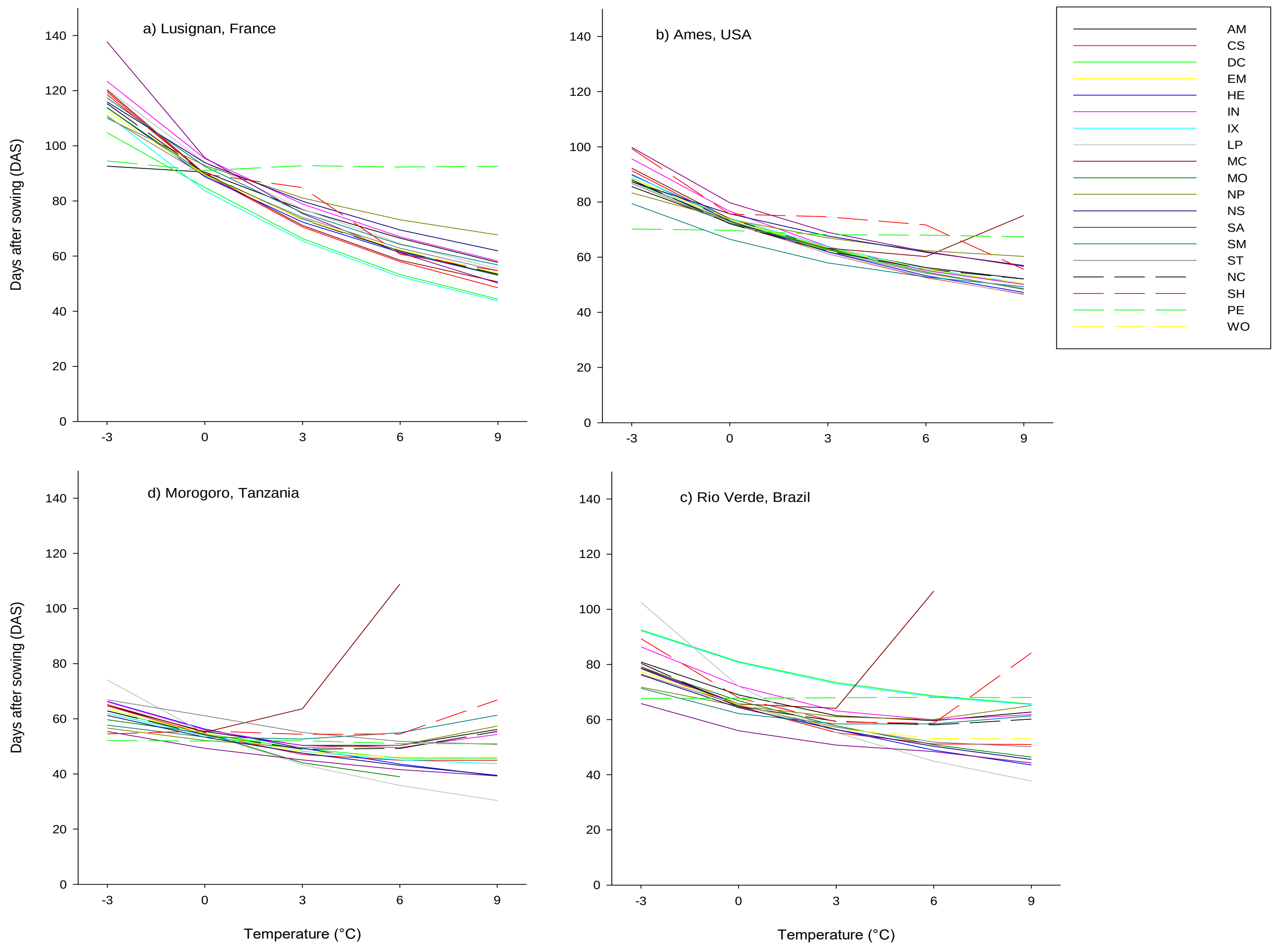
Martre et al. 2015. Multimodel ensembles of wheat growth: many models are better than one. Global Change Biology.



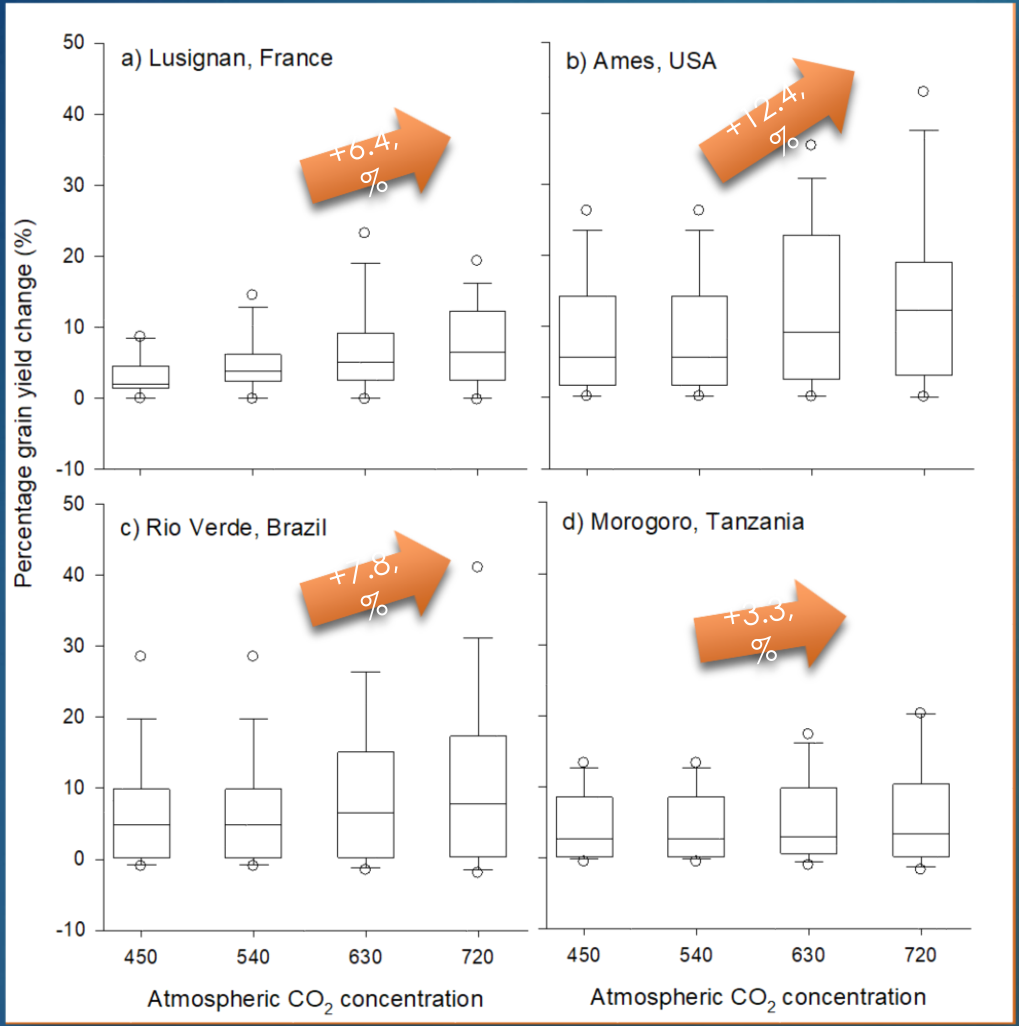
Most models: maize yield declines in response to temperature increase



Models agree about the response of phenology to temperature increase:



% yield increase with doubling [CO2]



Slight **positive** impact of $[CO_2]$ but with **high variability**:

- **Reliable ?**
- **How is it related to water use?**

Feedback of CC impact on Maize environmental variables for wheat and maize

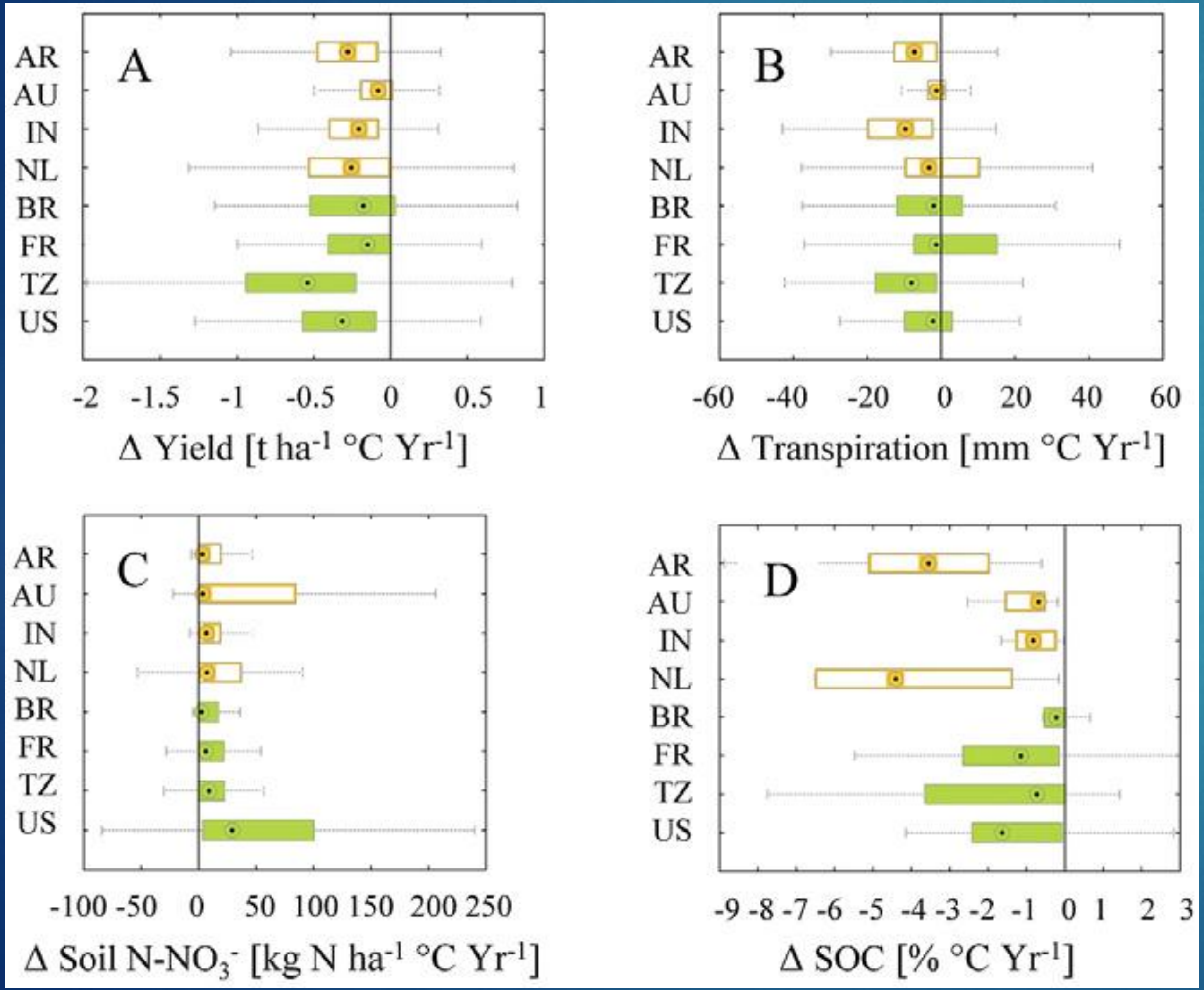
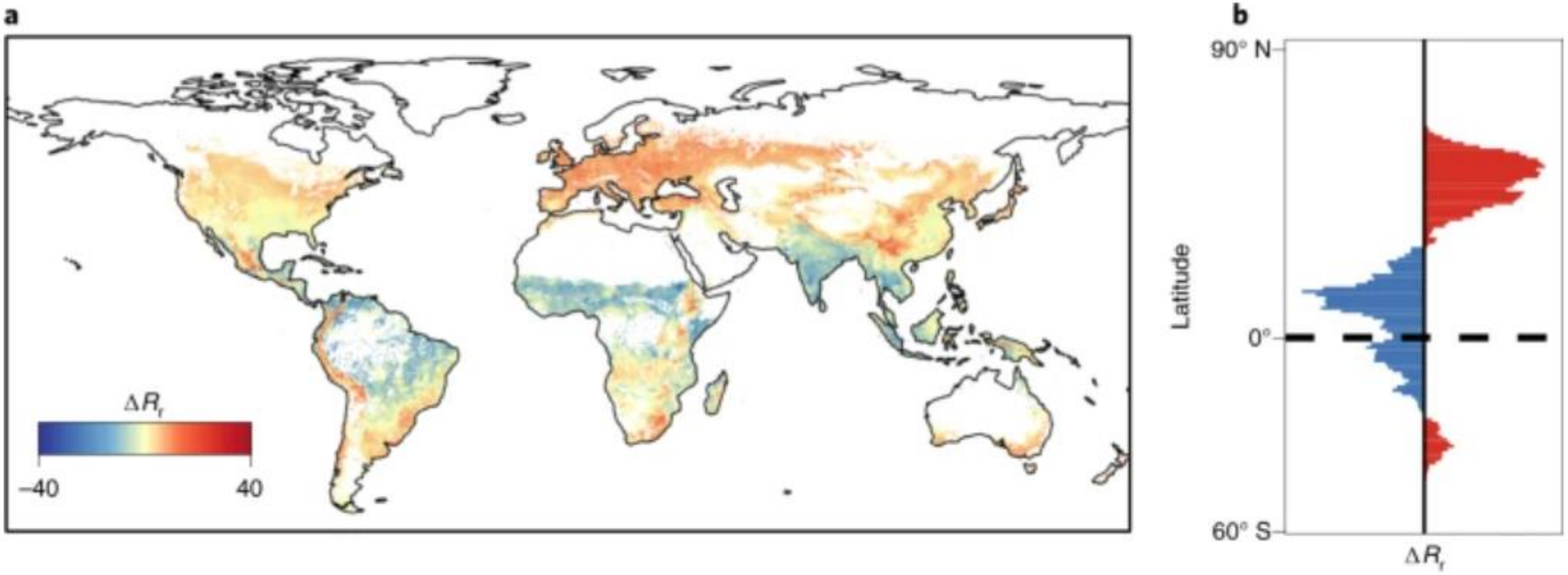


Fig. 1. Modeled average 30-yr changes in (A) yield, (B) transpiration, (C) soil nitrate, and (D) soil organic carbon (SOC) as a function of mean temperature increase over the range 0, +3°C, +6°C, under [CO_2] baseline conditions (360 ppm) for wheat (empty bars: AR, Argentina; AU, Australia; IN, India; NL, the Netherlands) and maize sites (filled bars: BR, Brazil; FR, France; TZ, Tanzania; US, United States). For each boxplot, the black dot represents the median (50th percentile), while the bars span 25th to 75th percentiles and lines span 10th to 90th percentiles of model ensemble results.

Basso, B., Dumont, B., Maestrini, B., Shcherbak, I., Robertson, G. P., Porter, J. R., ... & Rosenzweig, C. (2018). Soil organic carbon and nitrogen feedbacks on crop yields under climate change. *Agricultural & Environmental Letters*, *3*(1), 180026.

Fig. 2: Average change in R_r and pathogen turnover under RCP 6.0 across all months.



Chaloner, T. M., Gurr, S. J., & Bebber, D. P. (2021). Plant pathogen infection risk tracks global crop yields u nder climate change. *Nature Climate Change*, *11*(8), 710-715.


NathaCharbonnier - Radio France