Modelling climate change impacts on grasslands – example of the ModVege model

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  - Involvement of livestock breeding
  - Expected future climate changes
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  - Simulation of climate change impacts with ModVege and critical analysis of results

Part 1 – What is climate change ?

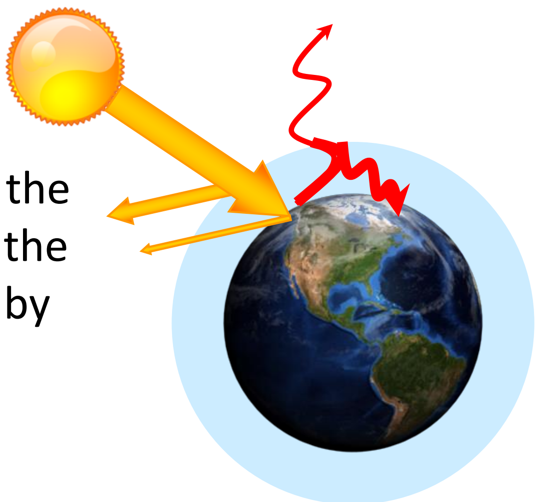
- Processes, origines, components
- Involvement of livestock breeding
- Expected future climate changes

Greenhouse effect and climate change

Half of **incoming solar radiation** passes through the atmosphere then is absorbed by the Earth's surface and warms it

1/3 is reflected to space by the atmosphere and the Earth, the remaining part is absorbed by the atmosphere

To compensate for this incoming energy, the Earth emits **infrared radiation (IR)**

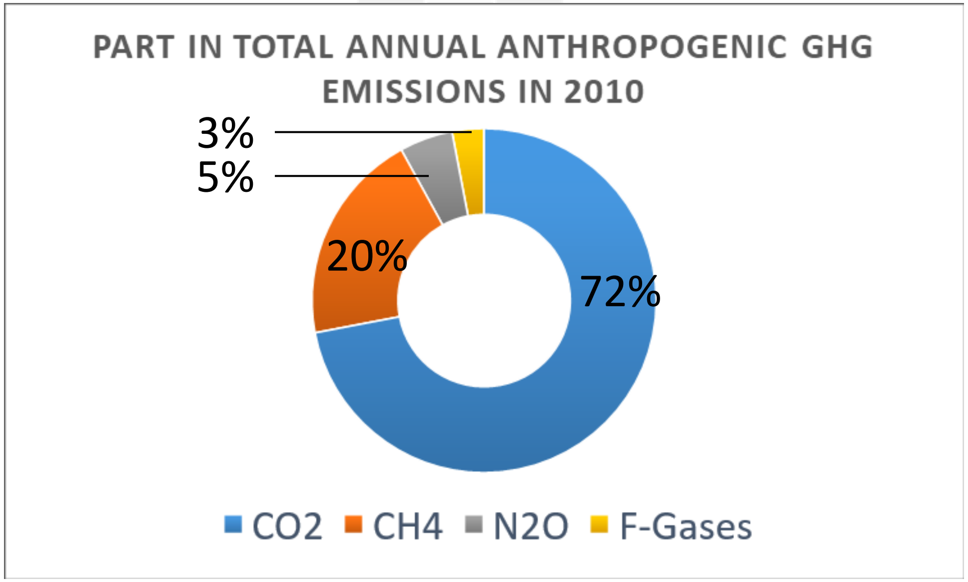


Some gases in the atmosphere called **greenhouse gases** aborb most of this IR and reemit it in all directions, warming the Earth's surface : This is the **greenhouse effect**

The greenhouse effect is a **natural phenomenon** and has **positive impact** on the Earth's surface that would be -18°C otherwise

The increase of the greenhouse effect is the cause of climate change

Main greenhouse gases (GHG)



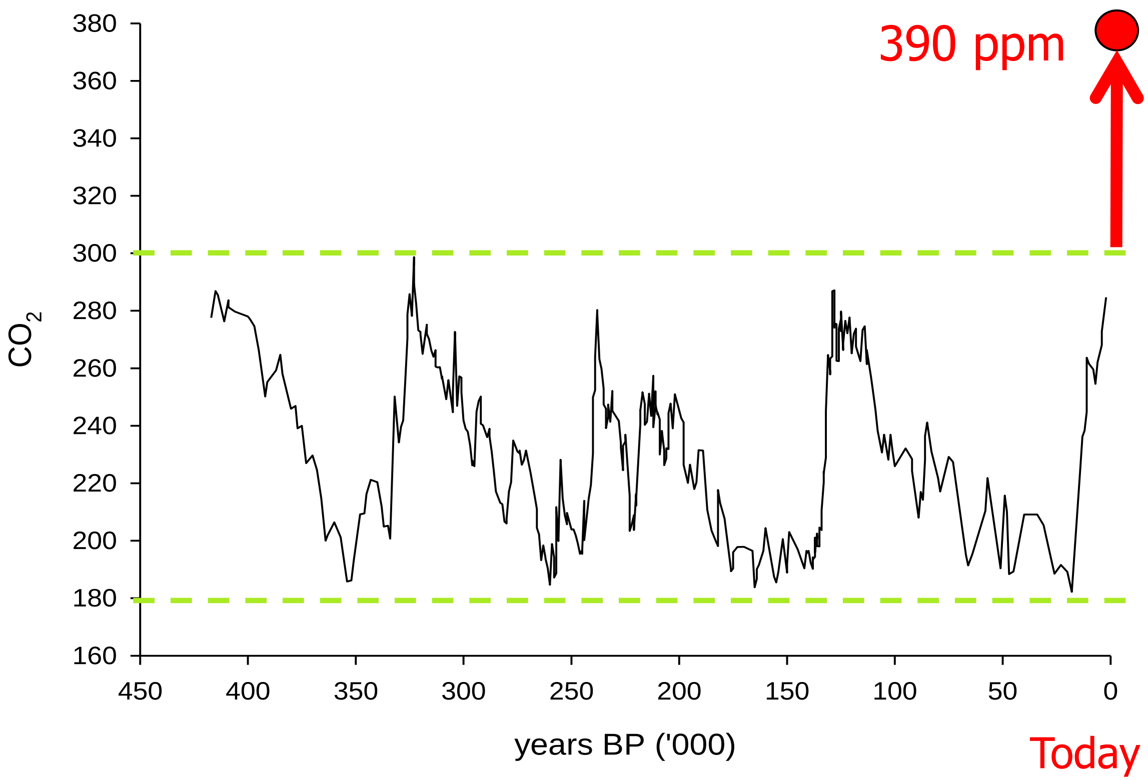
	Lifetime (years)	GWP (100-yr)
CO_2	100	1
CH_4	12	28
N_2O	121	265

Lifetime and GWP of GHGs

- GHG are assigned a **global warming potential (GWP)**= cumulated radiative forcing (ability to warm the climate system) over a specific time horizon
- It is expressed **relatively to the GWP of CO_2** (fixed to 1)
- It is computed for different **time horizons** (20-yr, 100-yr or 500-yr), and accounts for the **lifetime** of each GHG

Source: IPCC 2013

Evolution of the atmospheric CO_2 concentration since the last 450000 years



Variation of atmospheric CO_2 concentration at Vostock (Antarctica)

Source : Petit et al. 1999

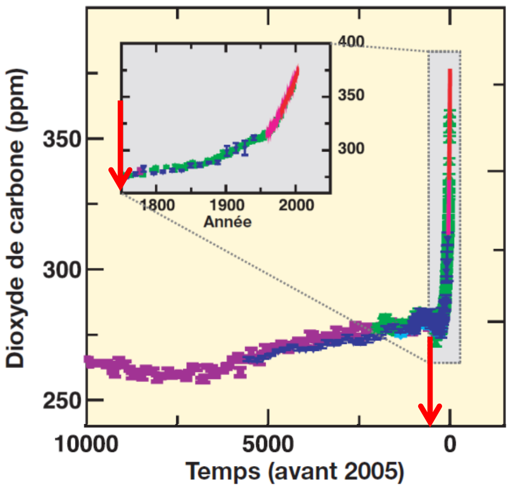
The analysis of air bubbles trapped in the ice showed **high variations of the atmospheric CO_2 concentration** the last 450000 years.

The CO_2 concentration has always varied. However **it has never varied so fast and so strongly** than the last years

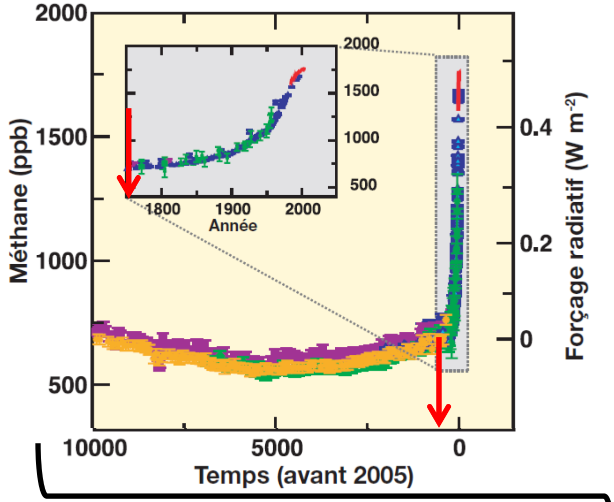
Evolution of GHG concentrations since the industrial revolution (1750)

- **Exponential increase** far beyond preindustrial levels **(+70% between 1970 and 2004)**

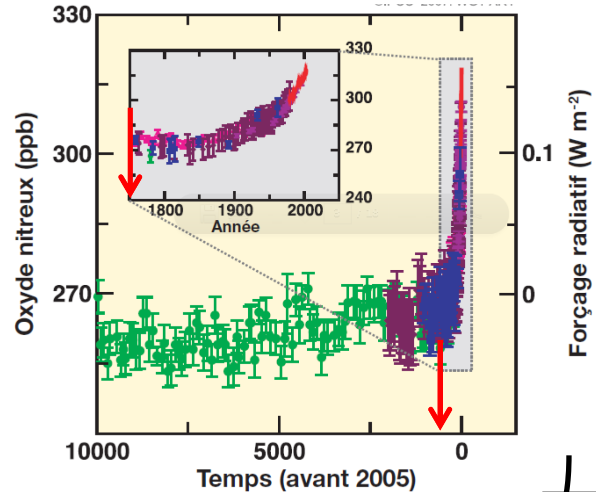
Carbon dioxide (CO_2)



Methane (CH_4)



Nitrous oxide (N_2O)



↗ use of fossil energy
Land use changes

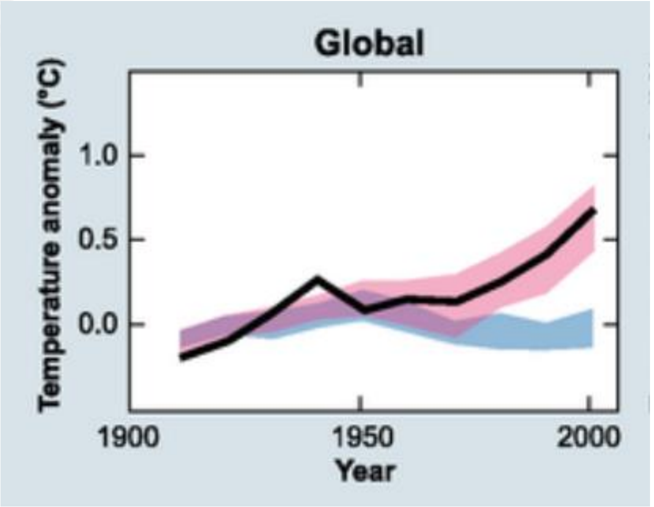
Agriculture development

Source: IPCC 2007

Attribution of the observed warming to human activities

Comparison of observed global-scale changes in surface temperature with results simulated by climate models

Source: IPCC 2007



Models using both natural and anthropogenic forcings

← Observed temperature

Models using only natural forcing

The influence of natural causes (volcanic activity, changes in solar radiation) alone should have cooled climate

Only models that account for anthropogenic forcing succeed in simulating the observed warming and its flucturations

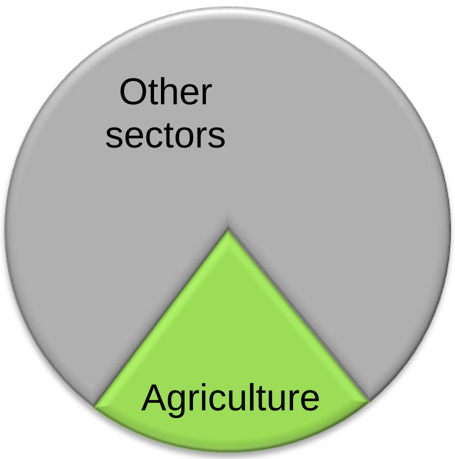
Contribution of agriculture to global GHG emissions in France

Agriculture acounts for :

84% of **N_2O** emitted in France
80% of **CH_4**
3% of **CO_2**

21,2% of GHG in France

Source: CITEPA 2009



N_2O : Fertilisation, manure management

CH_4 : enteric fermentation by ruminants, rice fields

CO_2 : Respiration soil plant animal, fermentation processes

French breeding accounts for **10%** of GHG

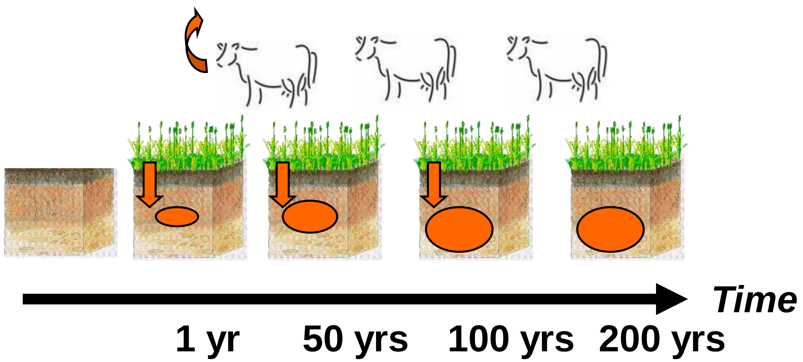
Grasslands are potential C sinks

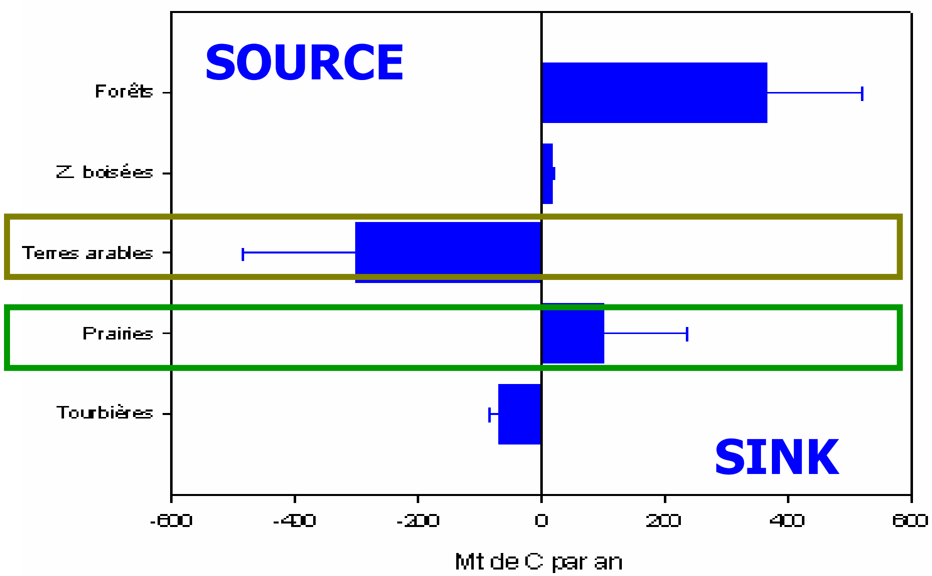
Le **stockage** du **C réduit les émissions de CO_2** donc l'implication de l'élevage dans le CC

Chez les **prairies**, le **stockage** se fait dans le **sol**, lentement mais en très grande quantité

En comparaison des **prairies**, **les grandes cultures** sont une **source faible ou forte** de C selon l'état initial du sol. Le C s'y constitue lentement mais s'y vide rapidement (labour)

Les prairies temporaires à rotation rapide sont un modèle comparable

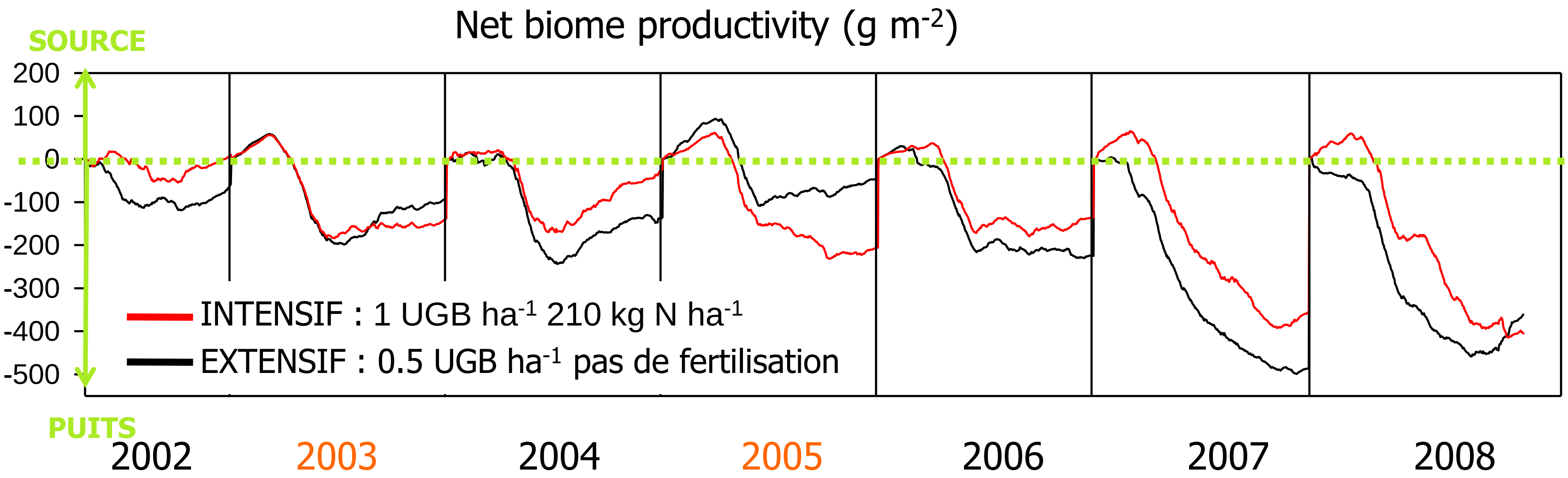




Source: Janssens et al. 2003

Grassland C sequestration is influenced by climate and management

<u>*Bilan de carbone sur 6 années (SOERE-ACBB, Site Laqueuille)*</u>



- Maintien de la **fonction puits de C** au cours du temps (**2t C ha^{-1} an^{-1}**)
- Le stockage de C est supérieur en **gestion extensive** (non significatif) sauf en année sèche (2003, 2005) où la tendance s'inverse

Source : Klumpp, Tallec, Guix & Soussana GCB 2011

The per mille or 4 per 1000 initiative

Context and objective

- **launched during COP21** in December 2015 and supported by almost **150 signatories** (countries, regions, international agencies, private sectors and NGOs)
- ↗ **global soil organic matter stocks by 0.4 % per year** as a compensation for the global emissions of GHG by anthropogenic sources

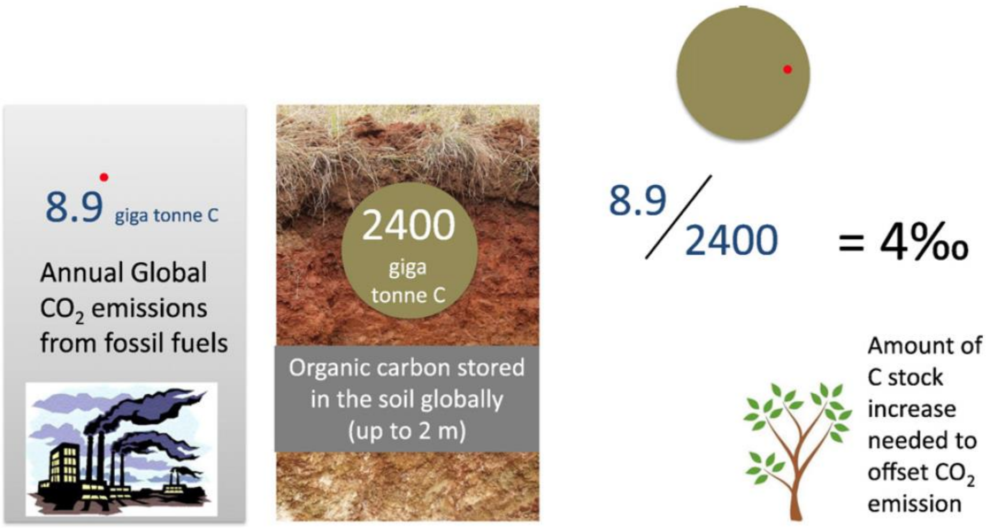


Fig. 1. The 4 per 1000 soil carbon sequestration initiative (adapted from Ademe, 2015).

Source: Minasny et al. 2017

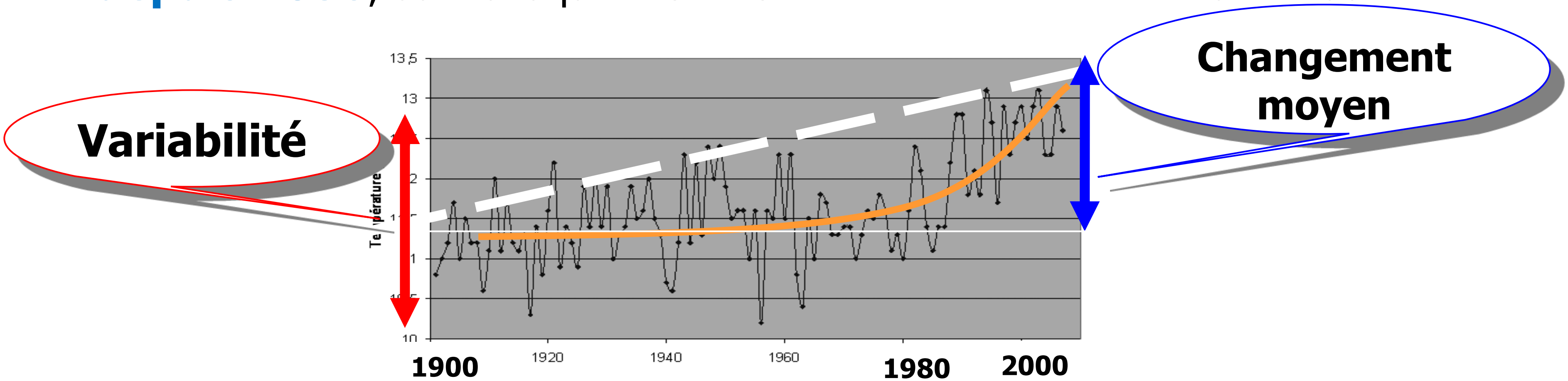
The per mille or 4 per 1000 initiative

Sources:
https://www.4p1000.org/
https://www.youtube.com/watch?v=AY9YVwJZDvw
https://www.youtube.com/watch?v=ORncZnlKOZg

Nous sommes sur une trajectoire de réchauffement rapide

Le **réchauffement** du système climatique (continents, océans) est **sans équivoque**

12 des **années** de **1995-2006** figurent parmi **les plus chaudes depuis 1850**, date à laquelle ont commencé les relevés instrumentaux



Evolution des températures moyennes annuelles en France métropolitaine

Les **journées** et les **nuits froides** ont diminué tandis que les journées et nuits **chaudes** ont augmenté, la fréquence des **vagues de chaleur** s’est accentuée

Source: GIEC 2007

Climate change is not limited to global warming

Le réchauffement observé s'accompagne de :

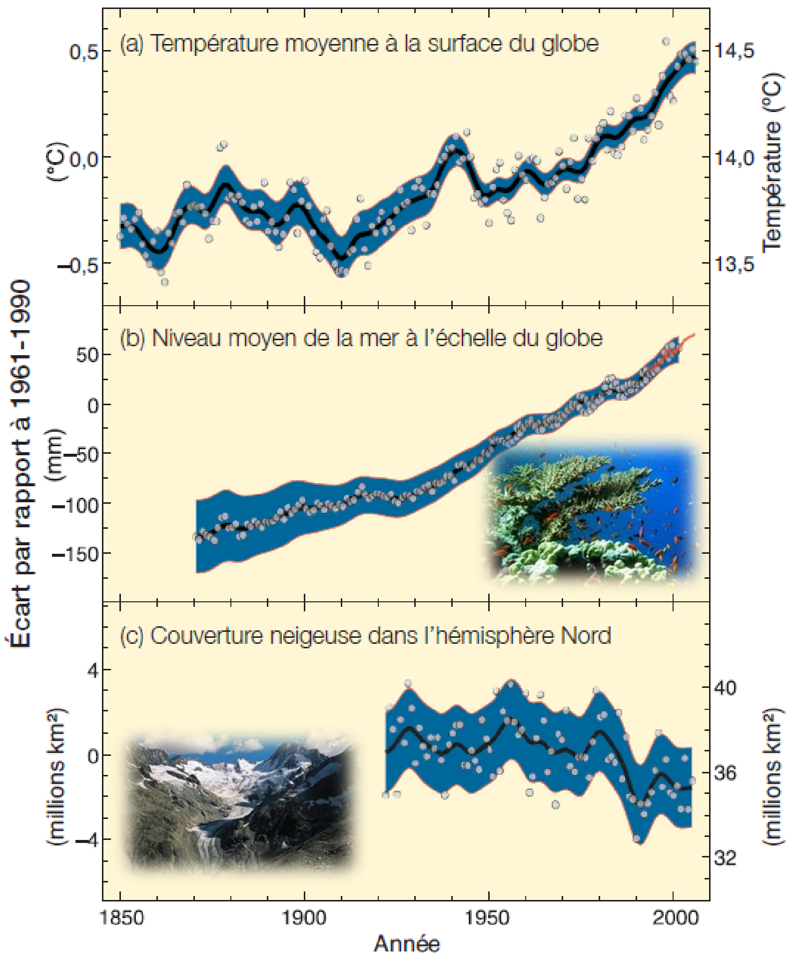
Une **élévation** du **niveau de la mer** et de la **réduction** du **manteau neigeux** et des **calottes glaciaires**

Une **acidification** des **océans** liée à la dissolution du CO_2

Une **baisse graduelle** de la **circulation thermohaline** ('Gulf Stream')

Une augmentation des épisodes de **fortes pluies** dans la plupart des régions

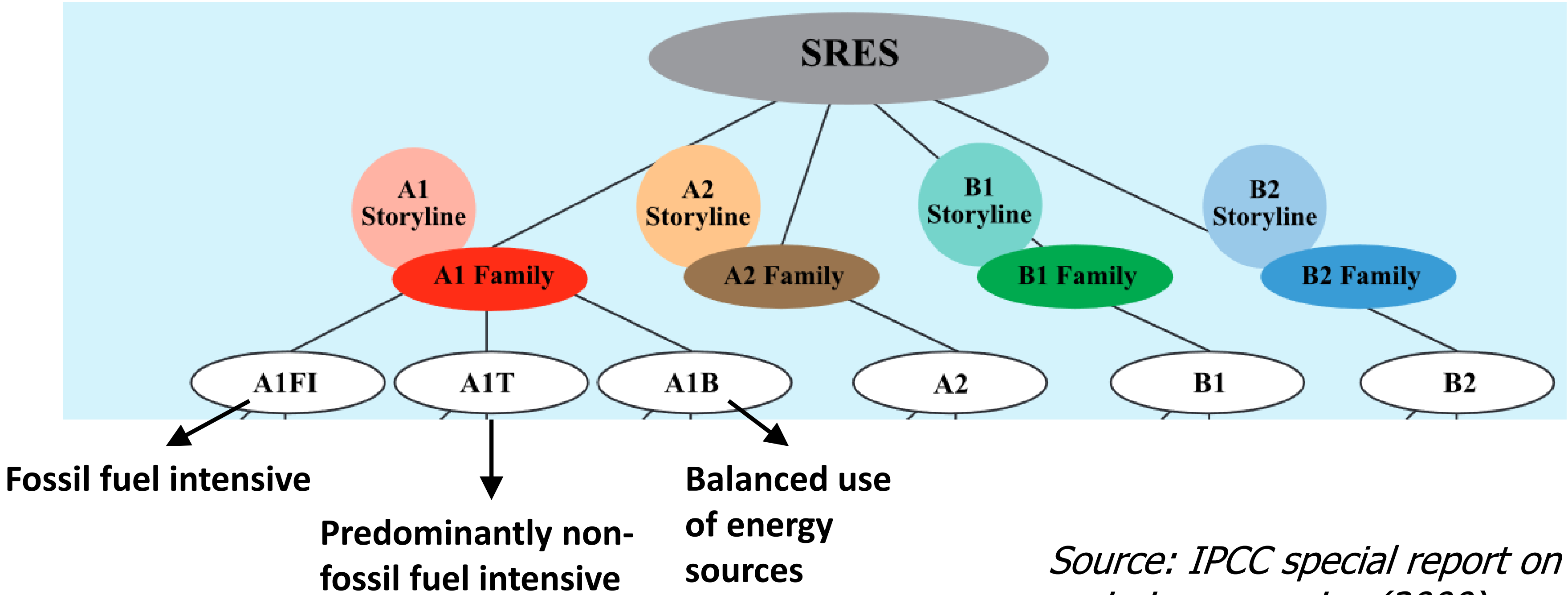
Une augmentation de **l'activité cyclonique** tropicale dans l'Atlantique Nord



Source: IPCC 2007

SRES storylines and scenarios

- *4 different narrative storylines* : ***A1, A2, B1 and B2*** *to describe the* ***relationships between emissions and their driving forces*** *: the demographic, social, economic, technological, and environmental developments*
- *Scenarios* = ***alternative images of how the future might unfold***. *All the scenarios based on the same storyline constitute a scenario "family"; The corresponding climate is simulated by different global climate models*



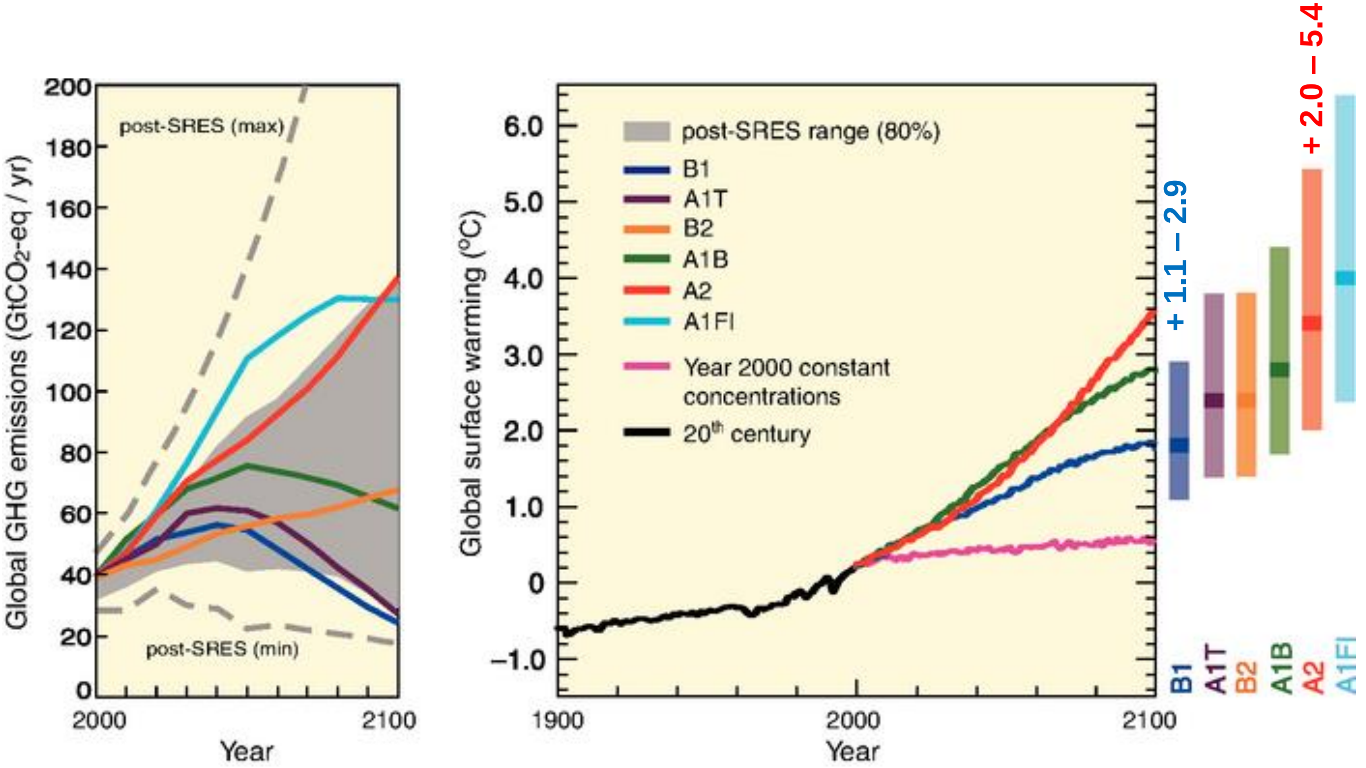
Source: IPCC special report on emission scenarios (2000)

SRES storylines and scenarios

Scenario	description
A2 (pessimist)	Very heterogeneous world ; increasing global population ; regionally-oriented economic development ; more fragmented and slower economic growth and technological changes
A1B (medium)	Global population increases until 2050 then decreases; Very rapid economic growth with rapid introduction of new and more efficient technologies; convergence among regions
B1 (optimist)	convergent world; global population increases until 2050 then decreases; development of service and information economy and of clean and resource-efficient technologies

Future GHG emissions and associated warming

- **Global GHG emissions (in $GtCO_2$-eq) in the absence of climate policies: six illustrative SRES marker scenarios**

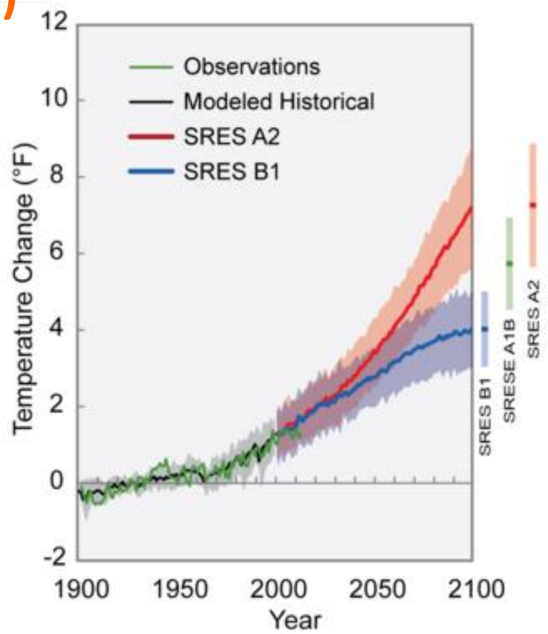


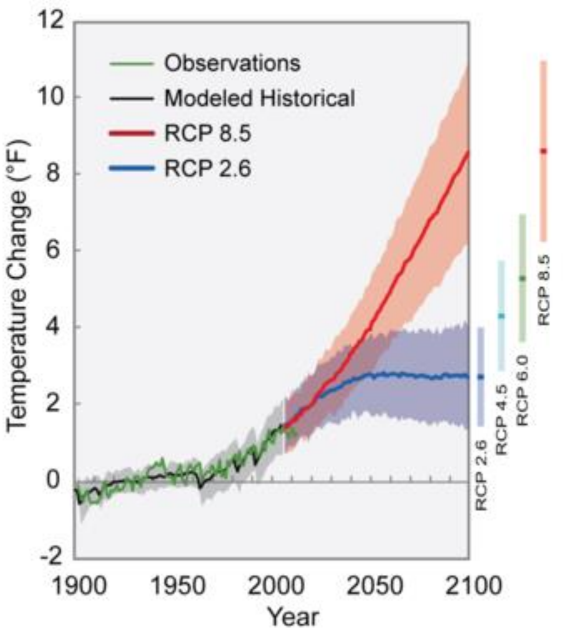
- The **expected increase of temperature** in 2100 is between **+1.1 to +6.4°C** according to the SRES scenarios

Source: IPCC 2007

Previous vs present scenarios (5th IPCC AR)

- **SRES scenarios** have been replaced by **Representative Concentration Pathways (RCPs)**





Name	Radiative forcing	CO_2 equiv (p.p.m.)	Temp anomaly (°C)	Pathway	SRES temp anomaly equiv
RCP8.5	8.5 Wm^2 in 2100	1370	4.9	Rising	SRES A1F1
RCP6.0	6 Wm^2 post 2100	850	3.0	Stabilization without overshoot	SRES B2
RCP4.5	4.5 Wm^2 post 2100	650	2.4	Stabilization without overshoot	SRES B1
RCP2.6 (RCP3PD)	3Wm^2 before 2100, declining to 2.6 Wm^2 by 2100	490	1.5	Peak and decline	None

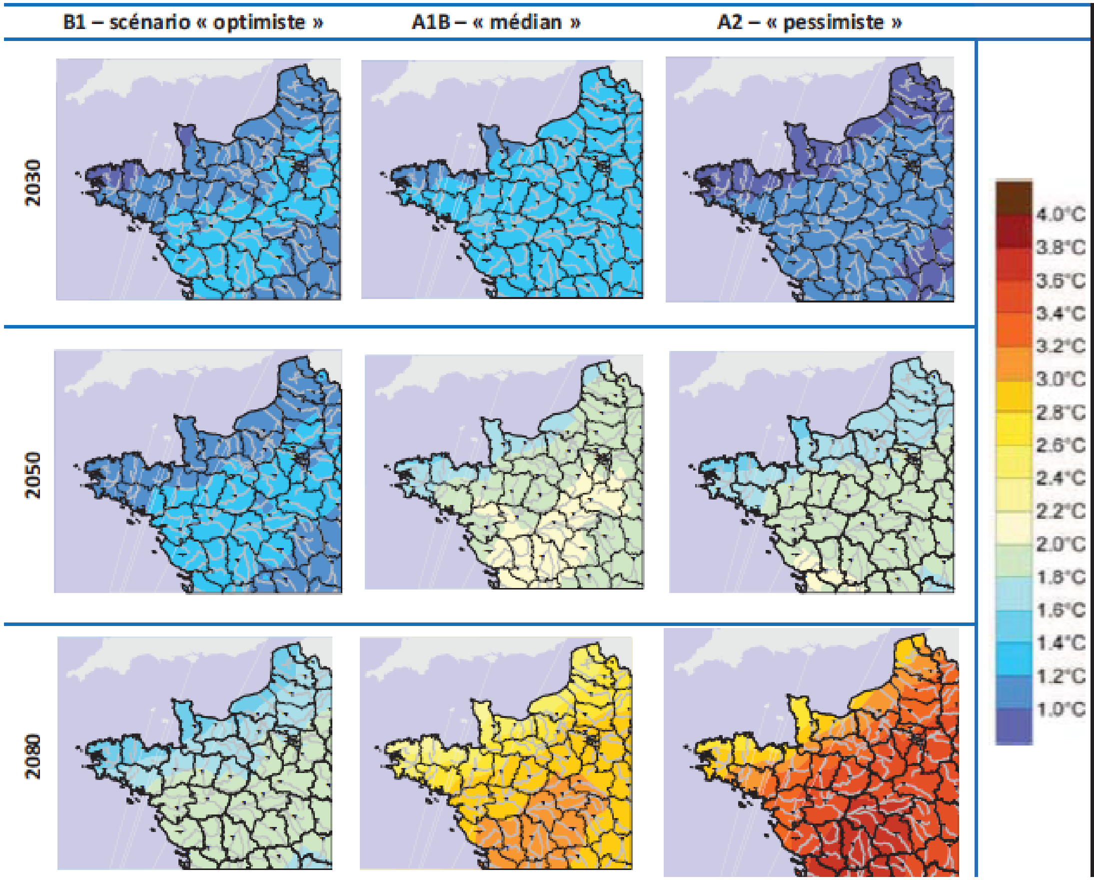
Projected climate changes in the « Grand-Ouest » region – Annual temperature

- **What is expected ?**

- ↗ **temperature** whatever the scenario
- **Faster warming** in the South of Bretagne and in the Loire Valley
- Higher ↗ **in summer** than in winter, higher summer increase in the **Loire Valley** and the **region Centre**

Source: Météo-France (2010)

Average annual temperature anomaly (°C) relatively to the reference period (1971-2000)

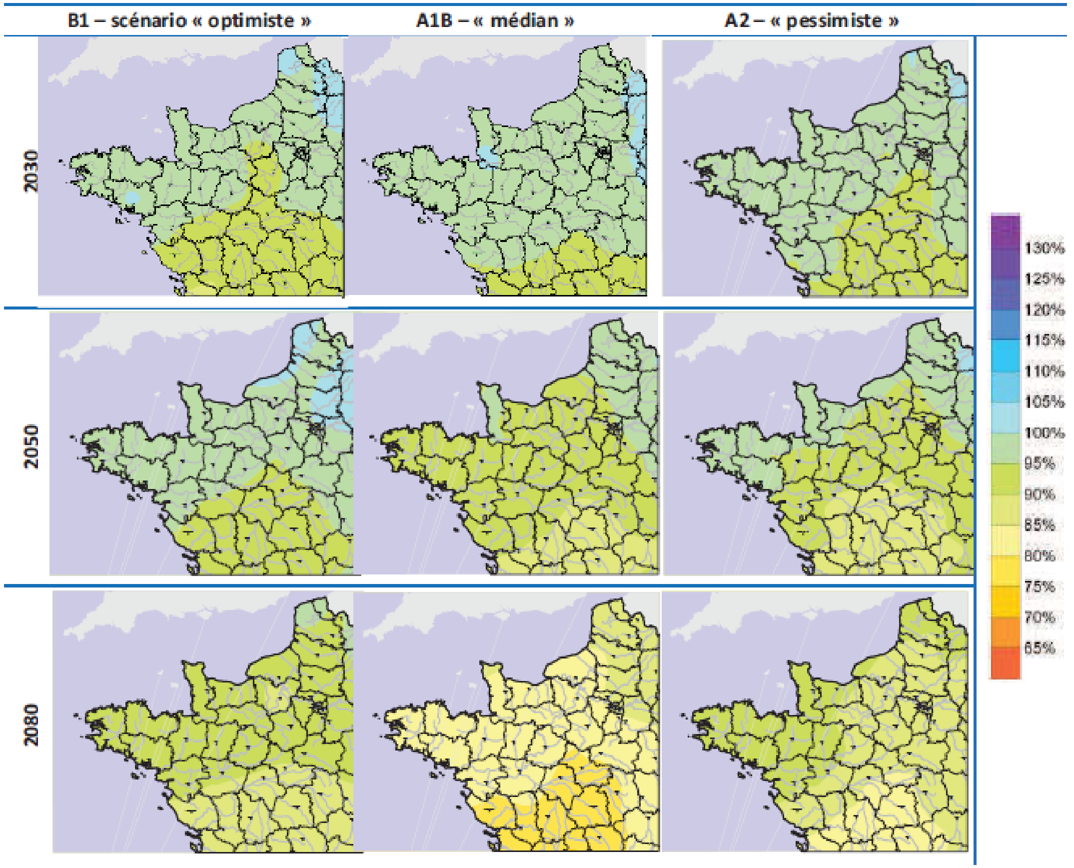


Projected climate changes in the « Grand-Ouest » region – Annual rainfall

- **What is expected ?**
  - **↘ of annual rainfall**, more pronounced below a line from Loire-Atlantique to Eure-et-Loire departments
  - Similarly to temperature, **greater ↘ of summer rainfall** than winter rainfall
  - Higher ↘ of summer rainfall in the **West part**

Source: Météo-France (2010)

Average annual rainfall anomaly (%) relatively to the reference period (1971-2000)



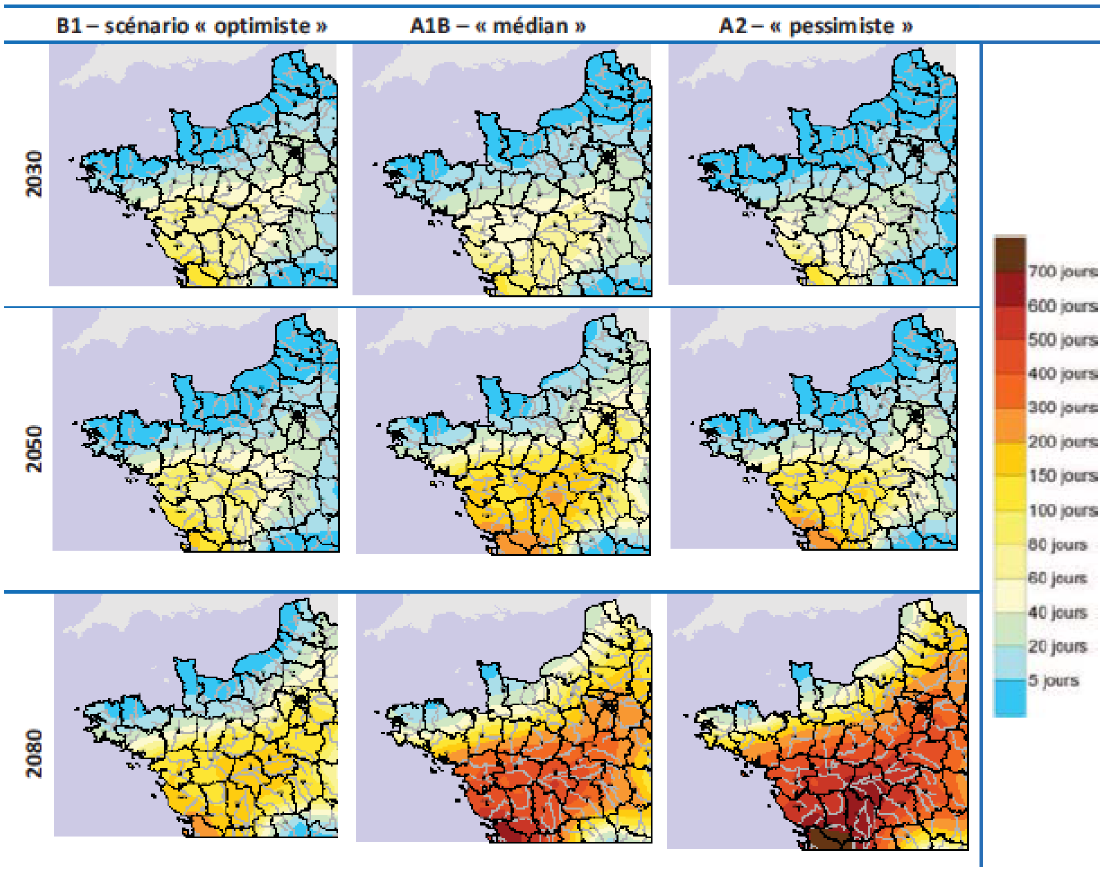
Source des cartes : Météo-France – DATAR, 2010.

Projected climate changes in the « Grand-Ouest » region – Heat waves (T_{min}≥18,5°C and T_{max} ≥33,5°C)

▪ What is expected ?

- **↗ of heat wave days,** especially in the **Loire Valley**
- Up to 700 days over 30 yrs => **6% of time spent in heat wave conditions**

Cumulated Days of heat waves over 30 years



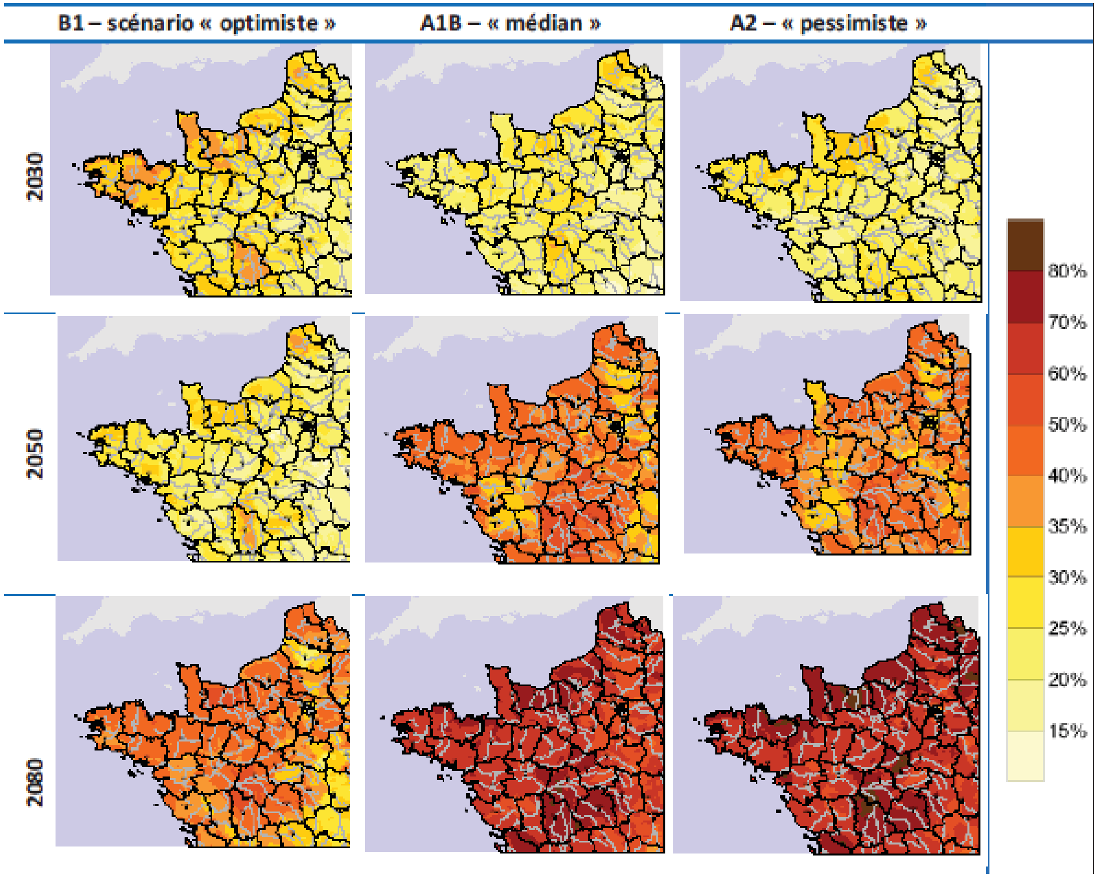
Source: Météo-France (2010)

Projected climate changes in the « Grand-Ouest » region – Drought

- **What is expected ?**
  - **↗ of time spent in drought conditions** whatever the scenario; A1B ≈ A2
  - The A1B et A2 scenarios projected **in 2080 from 60 to 80 % of the time spent in drought conditions** (especially in the region Centre and the northern coast of France)

Source: Météo-France (2010)

% of time spent in drought conditions over 30 years



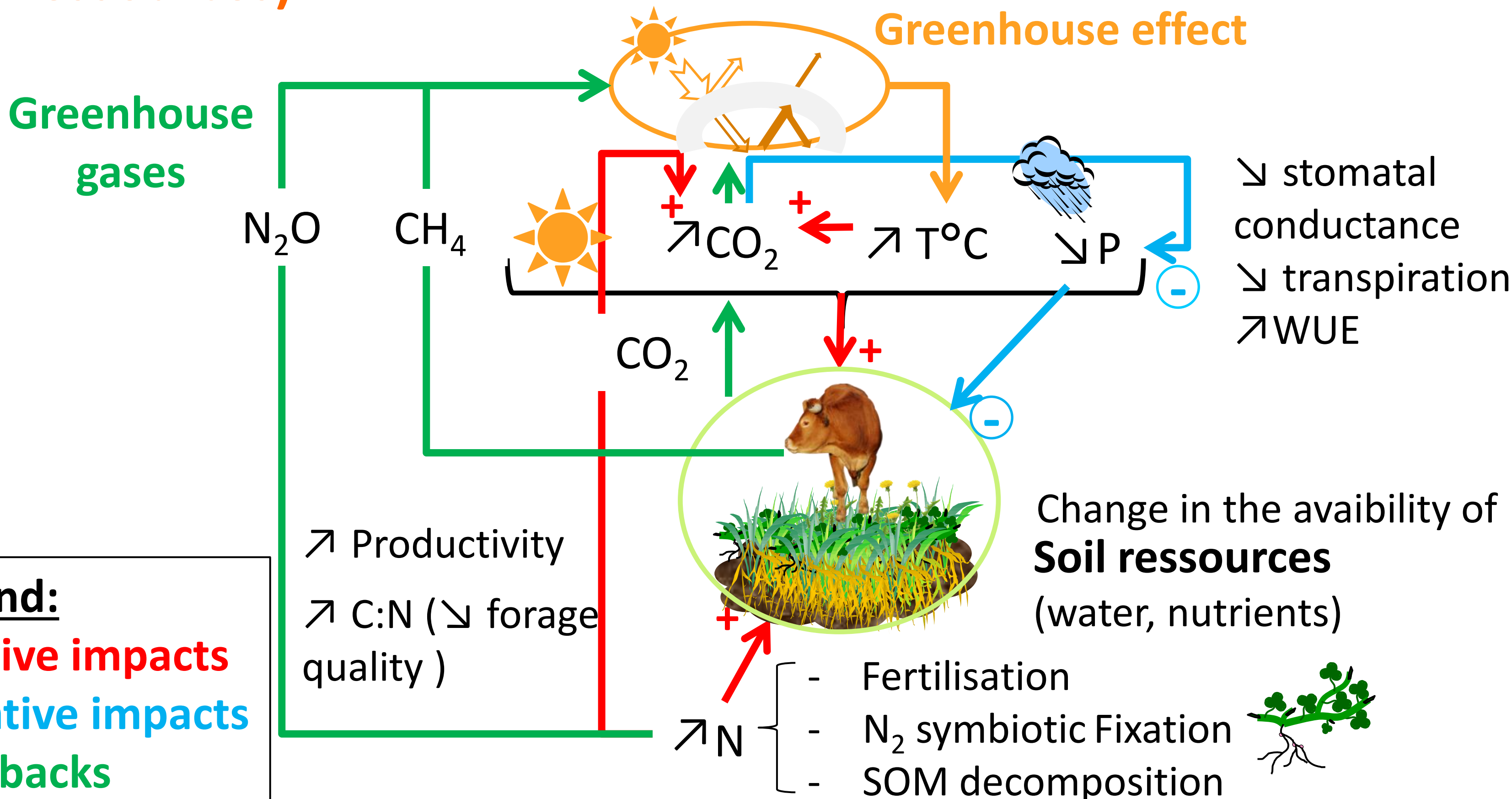
Climate Change 2013: The Physical Science Basis

Part 2 – Climate change impacts on grasslands

- What is the current knowledge about climate change impacts on grasslands over the short-term ?
- Simulation of climate change impacts with ModVege and critical analysis of results

What do we know about climate change impacts on grasslands over the short-term ?

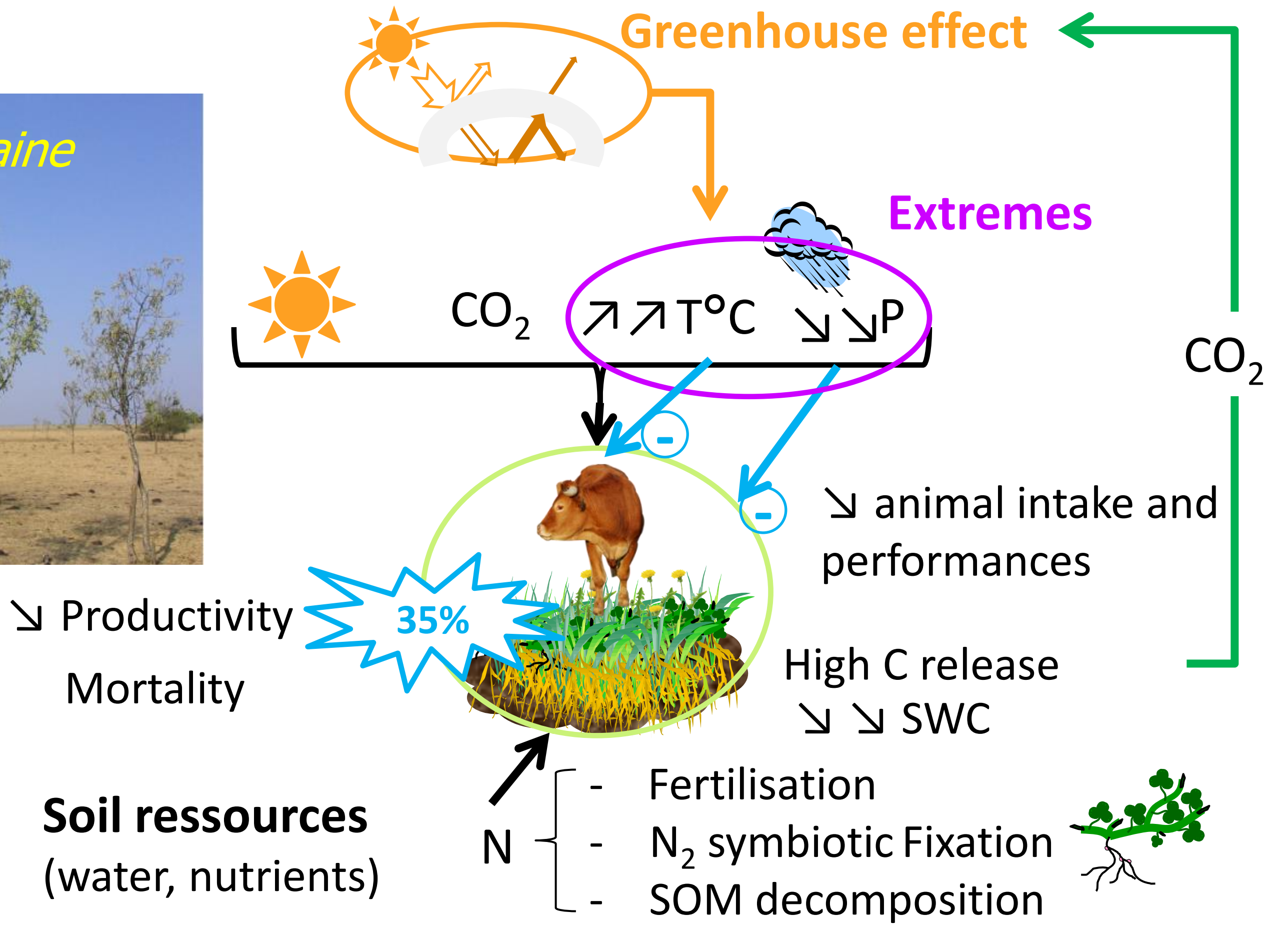
- **Responses to abiotic factors (CO_2, climate variables and soil ressources)**



Legend:
Positive impacts
Negative impacts
Feedbacks

What do we know about climate change impacts on grasslands over the short-term ?

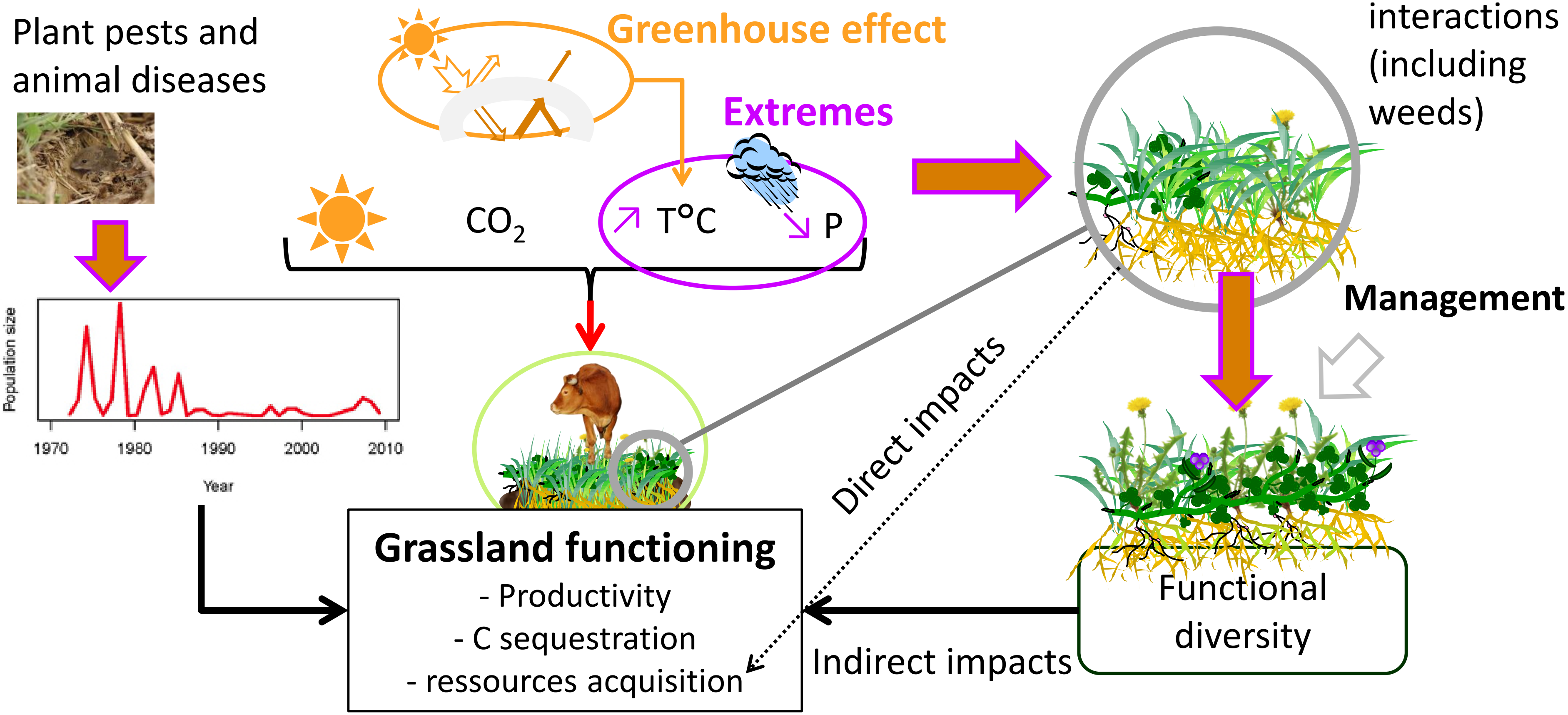
- **Responses to climate extremes (droughts, heat waves)**



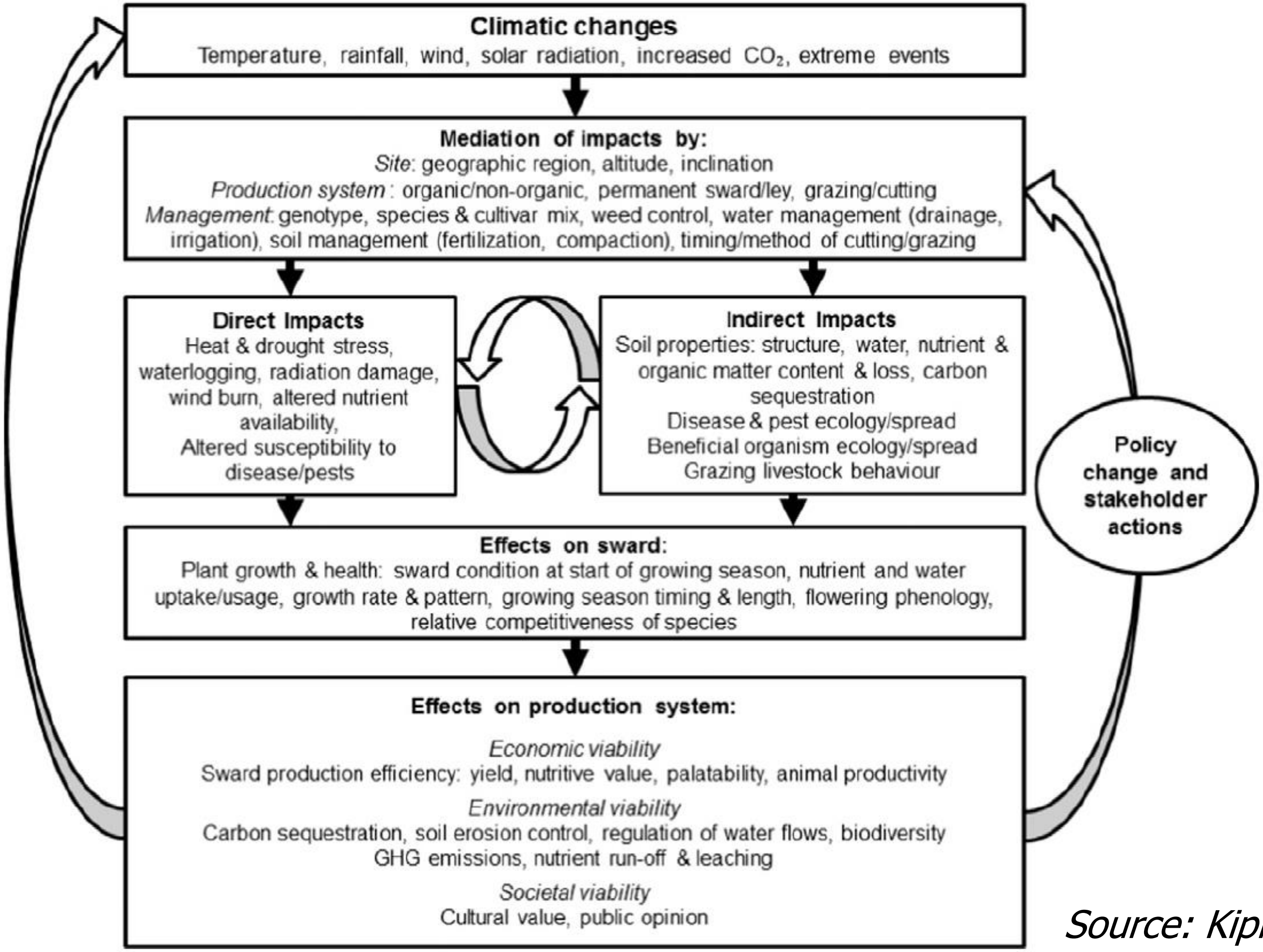
Legend:
Positive impacts
Negative impacts
Feedbacks

What do we know about climate change impacts on grasslands over the short-term ?

- **Responses to biotic factors (pests and diseases, species interactions, vegetation change)**



Map of impacts of climate change on grasslands, including feedbacks



Source: Kipling et al., 2017

Using ModVege model to adress climate change issues

Model predicting dynamics of biomass, structure and digestibility of herbage in managed permanent pastures. 1. Model description

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*INRA, Unité de Recherches sur les Herbivores, St Genès Champanelle, France, and †INRA, Unité d'Agronomie, Clermont-Ferrand, France

Based on the reading of this publication

1. Which **influencing factors** could we account for with this model?
2. Which **impacts** could we simulate with this model?

Using ModVege model to adress climate change issues

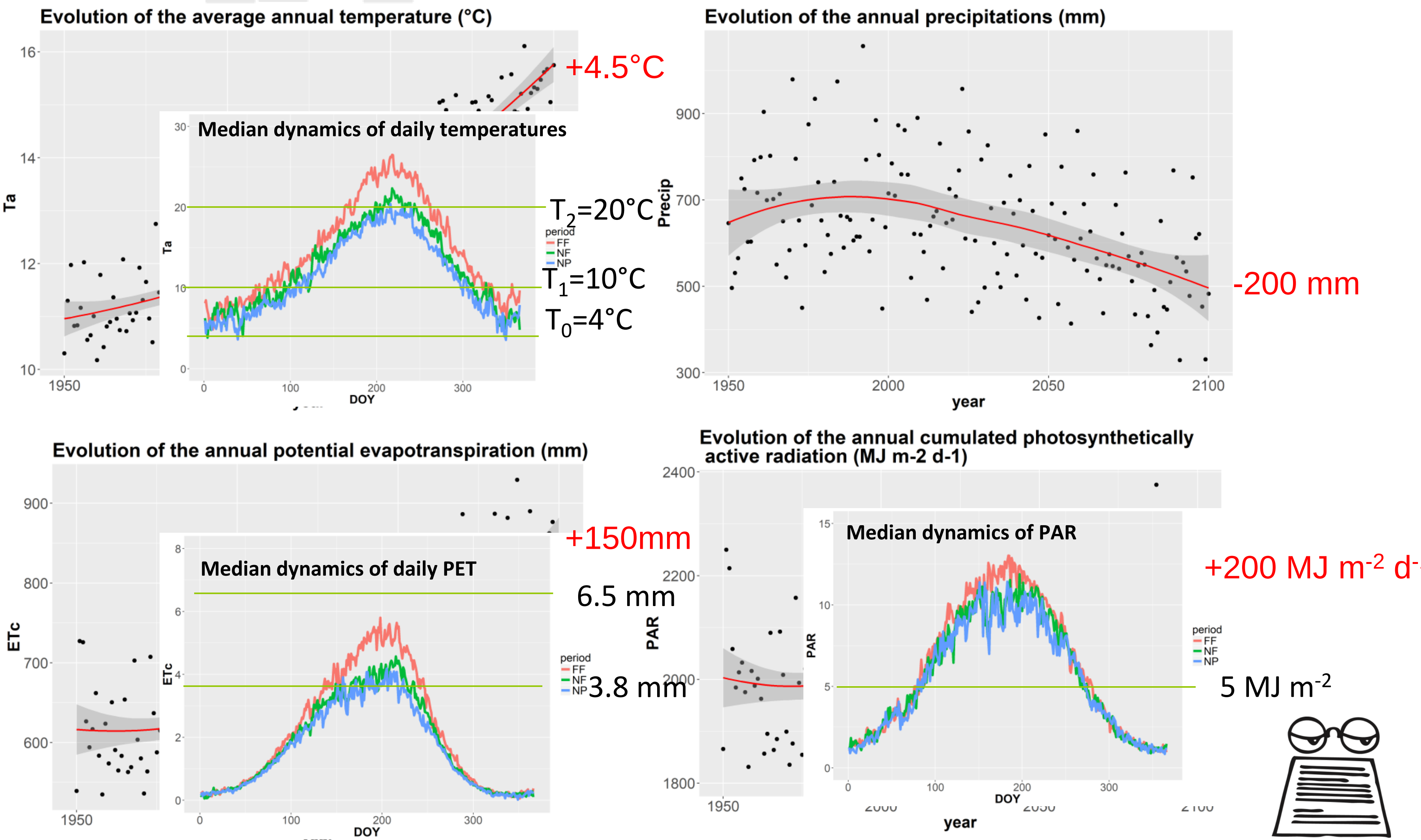
- ## The influencing factors that are accounted for
  - **Climate** (Temperature, Precipitations, Par, ETc)
  - **Availability of soil ressources** (water holding capacity, nutrition index)
  - **Cutting management frequency and intensity** (number of cutting events, cutting height)
  - **Grassland type** (A, B, C, D)
- ## The climate change impacts that could be simulated
  - **Environmental conditions** for grass growth (climate, soil, management)
  - Grassland **growth**, standing **biomass** and **yield** (quantity and digestibility)

Simulation of climate change impacts on managed grasslands using ModVege

Simulation design

- **1 climate scenario** (1950-2100) : SRES **A2**
- **1 site** : Rennes
- **1 grassland functional group**: A (100%)
- **1 soil** : SWC = 180 mm, NI = 0.85
- **1 cutting frequency** (with 5 fixed dates : 25/04, 01/06, 10/07, 01/09, 15/10)
- **3 comparative climate periods to analyse results**
  - **Near past : 1971-2000**
  - **Near future : 2020-2049**
  - **Far future : 2070-2099**

The projected annual climate at Rennes (A2 scenario)



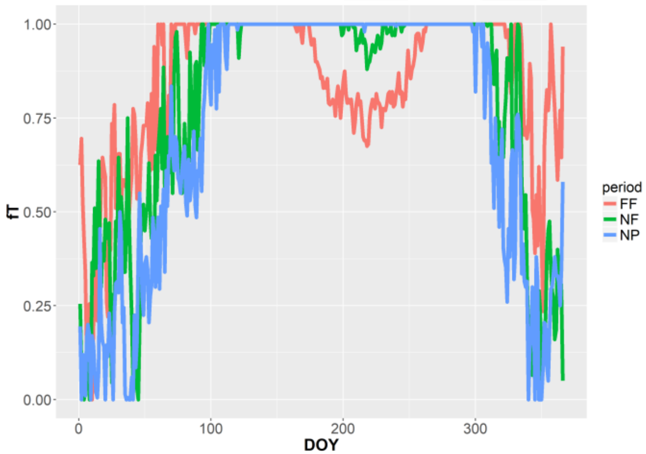
According to the modelled effects of climate in ModVege, what could you expect ?

Environmental conditions for grass growth

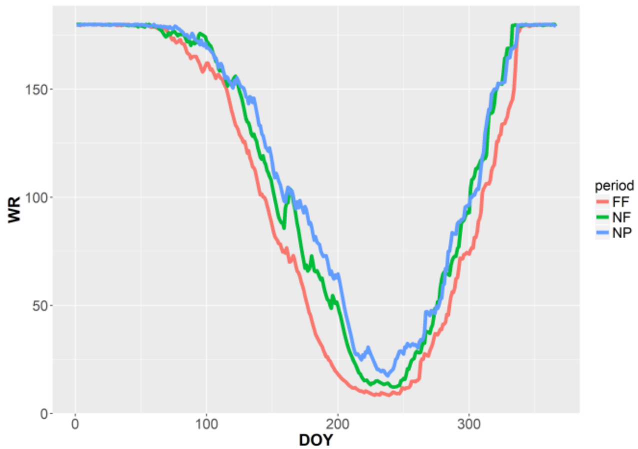
- **The modelled effects of climate** (PAR, precipitations and Etc) **in ModVege, what could you expect ?**
  - **Effects of a temperature increase**
    - ↘ of actual growth in FF (according to temp. threshold values)
    - ↗ of compartment age
    - ↗ of senescence for $T < 0$ and $T > T_0 = 4°C$
    - ↗ of abscission for $T > 0$
  - **Effects of a PAR increase**
    - ↗ of potential growth
    - ↘ of actual growth (When PAR > 5 MJ m^{-2})
  - **Effects of the precipitation decrease and PET increase**
    - ↘ SWC and ↗ of water stress
    - ↘ of actual growth

Environmental conditions for grass growth

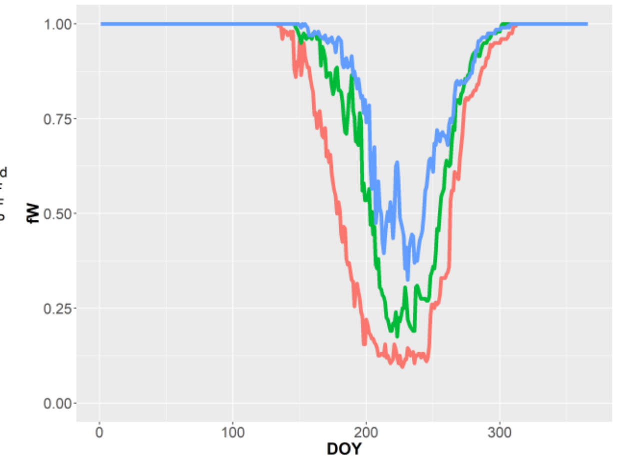
Temperature effect



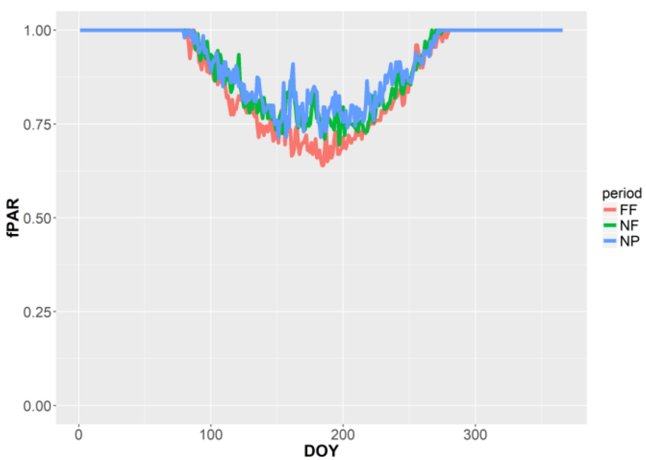
Water reserves



Water stress



Radiation effect



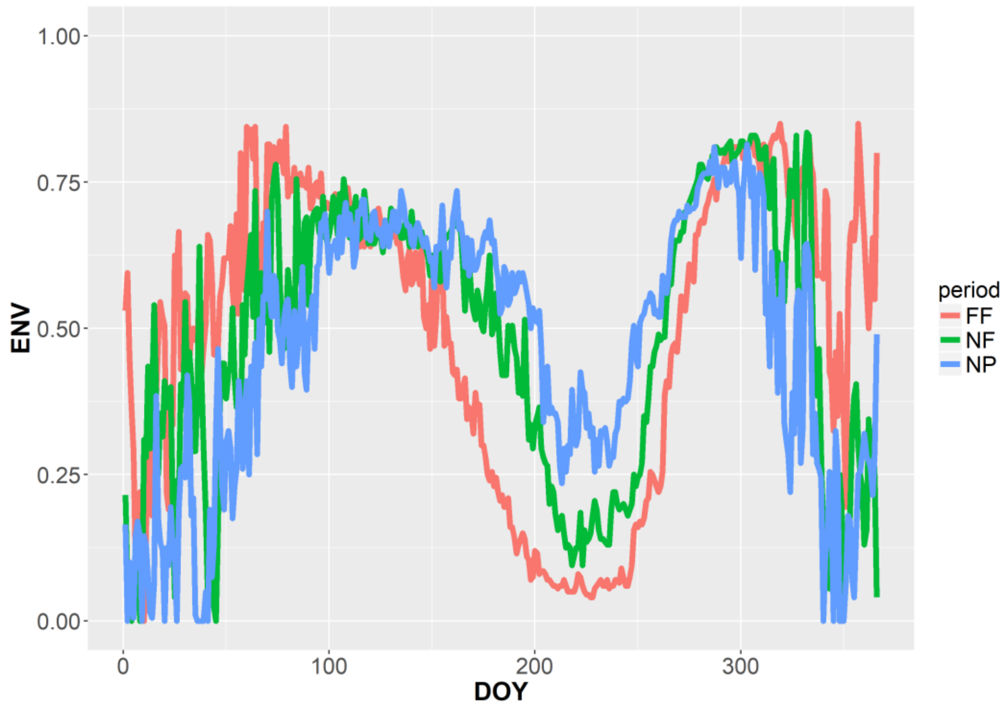
In comparison with Near Past

- **In Near Future :** better temperature conditions in winter/spring but increased summer temperature stress and water deficit
- **In Far future :** similar but stronger effects than in NF with, in addition, a decreased radiation use efficiency in summer

What is the assumption about the nature of interactions between fT, fW and fPAR ?

Environmental conditions for grass growth

Total environmental effect

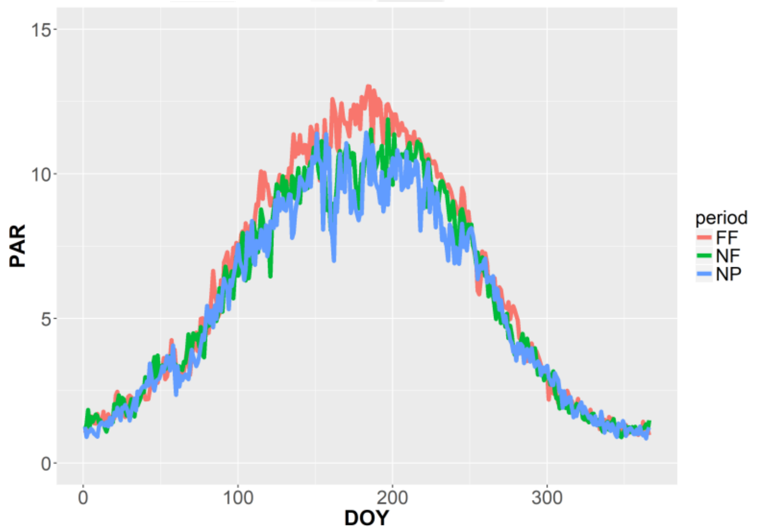


At Rennes, with the A2 SRES scenario, in comparison with Near Past

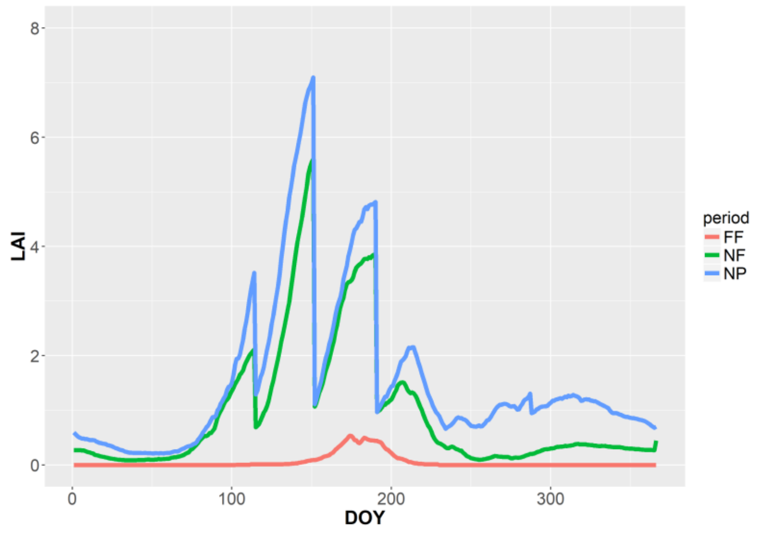
- **In Near Future :** better environmental conditions in winter and spring but degraded conditions in summer
- **In Far future :** similar but stronger effects than in Near Future

Potential growth

Photosynthetically active radiation (MJ m^{-2})

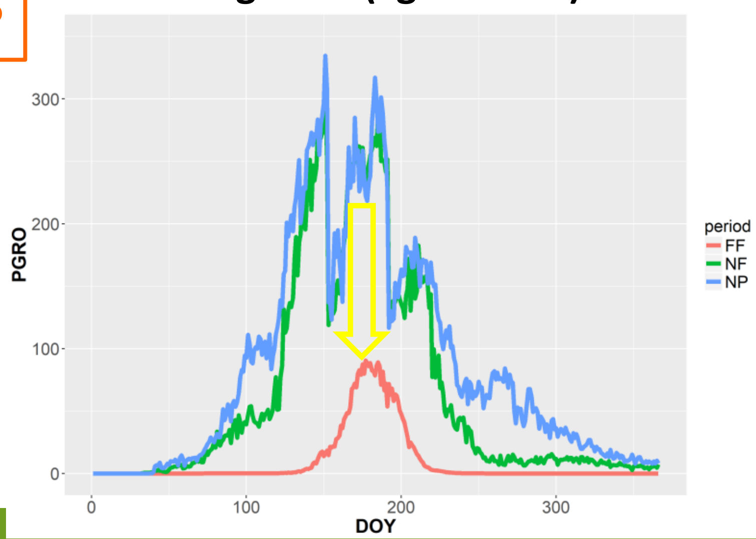


Leaf area index (m^2 m^{-2})



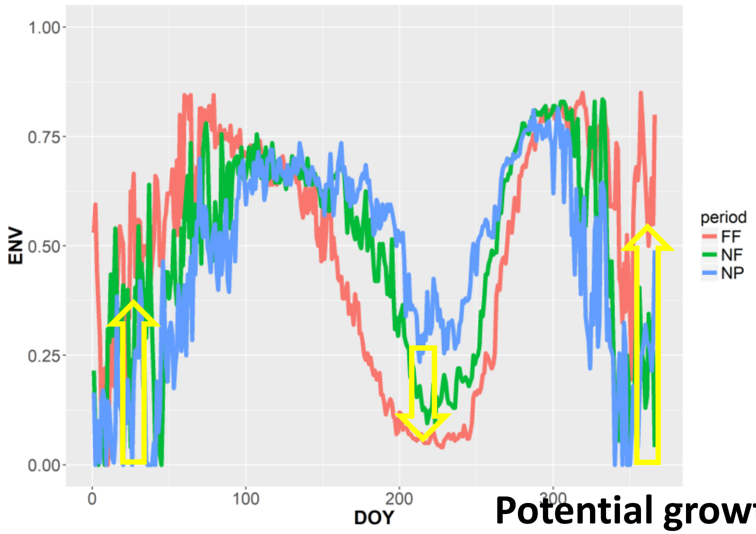
what could you expect ?

Potential growth(kg DM ha^{-1})

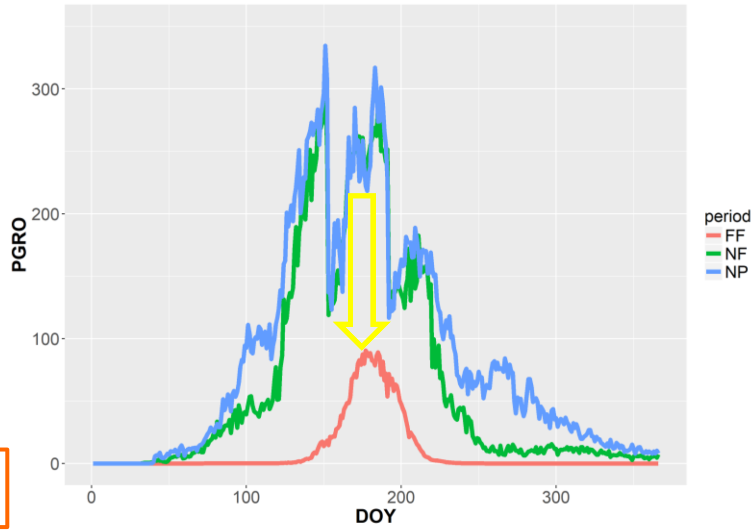


Components of the actual growth calculation

Environmental conditions for grass growth



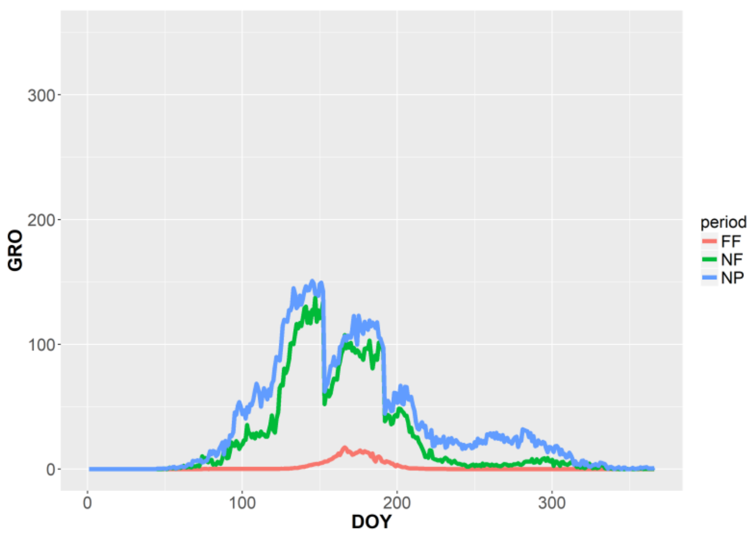
Potential growth (kg DM ha^{-1})



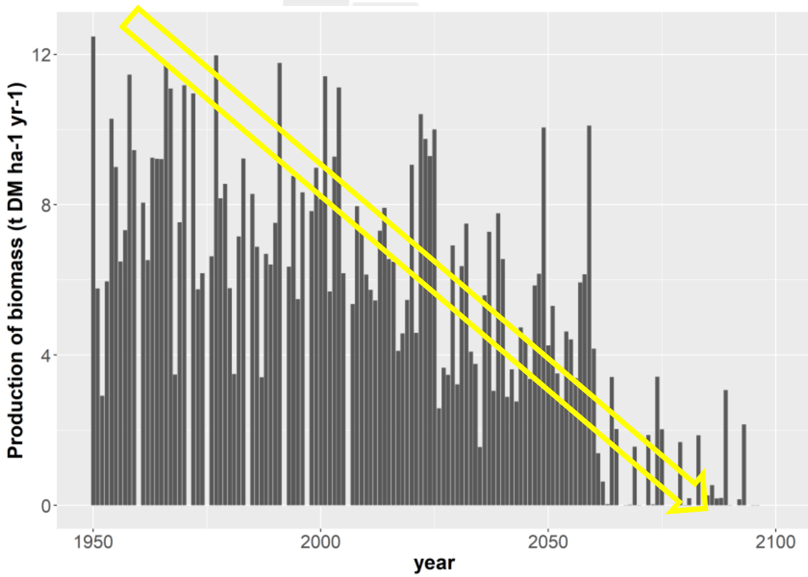
what could you expect ?

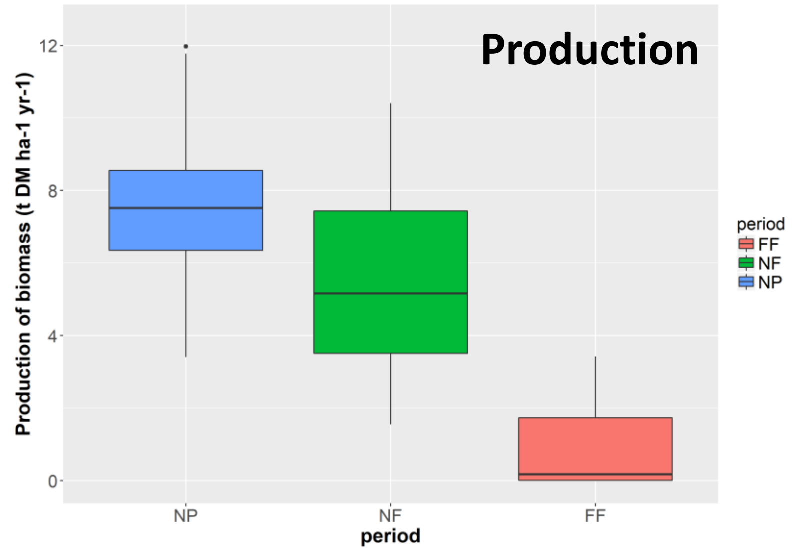
Actual growth

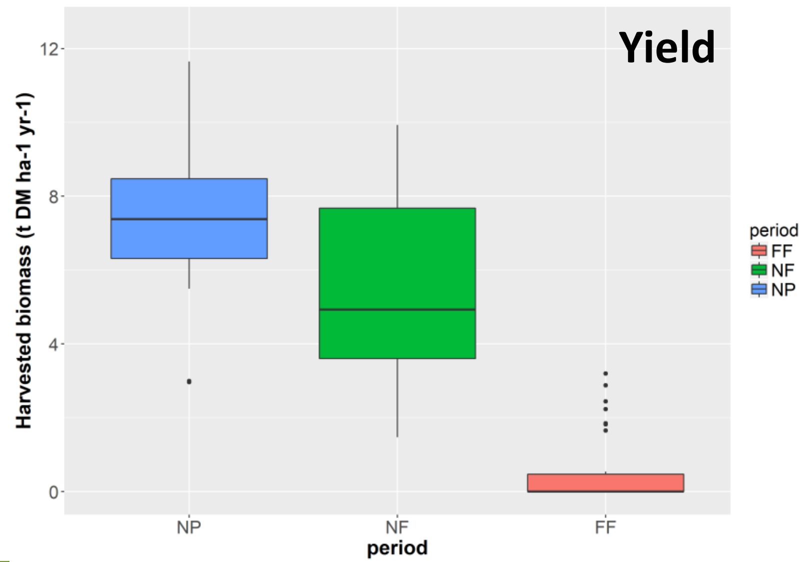
Actual growth (kg DM ha^{-1})



Biomass production and yield







Critical analysis of results

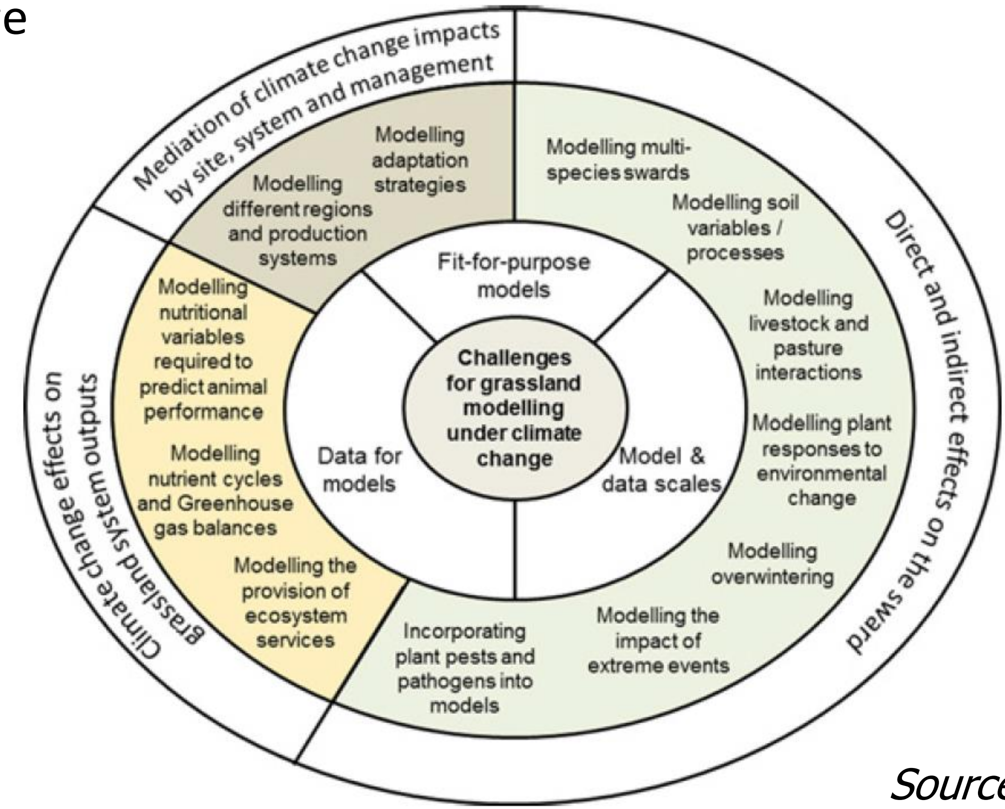
- What do you think about these results ?
- **Which influencing factor are not accounted for** by the model that could change the present results ?
- **How could you change the present results ?** (processes that could be added)
- **What are the other limits of the model ?**
  - What **interactions** are not represented ?
  - What **management practices** are missing ?
  - What **compartment** is neglected ?

Critical analysis of results

- **The effect of atmospheric CO_2 increase** is not accounted for
  - Taking into account this factor could give **better results**
  - The **processes** that would be influenced by CO_2 are the actual **evapotranspiration** and actual **growth**
- The **other limits** of the model include
  - **Interactions** between management, climate and the vegetation composition => must add **the possibility to simulate a mixture of different functional types** whose abundace in changing in response to the environmental conditions including management
  - **Grazing and fertilisation** are missing, with however the possibility to change the initial NI
  - The representation of **soil and root compartments** are neglected=> must add the effects of soil nutrients availability and of the plant reserves on growth

Research perspectives

- **Understanding how key interactions impact grassland functioning and services** remains a priority for better quantifying climate change change on grasslands
- **12 key challenges and priorities** for european grassland modelling under climate change



Source: Kipling et al., 2017

IPCC fifth Assessment Report – Synthesis report

https://youtu.be/fGH0dAwM-QE