What will be the consequences of climate change on soft wheat in Normandy (France) in 2050-2100 ? Prospective impact study based on ALADIN-Climate model

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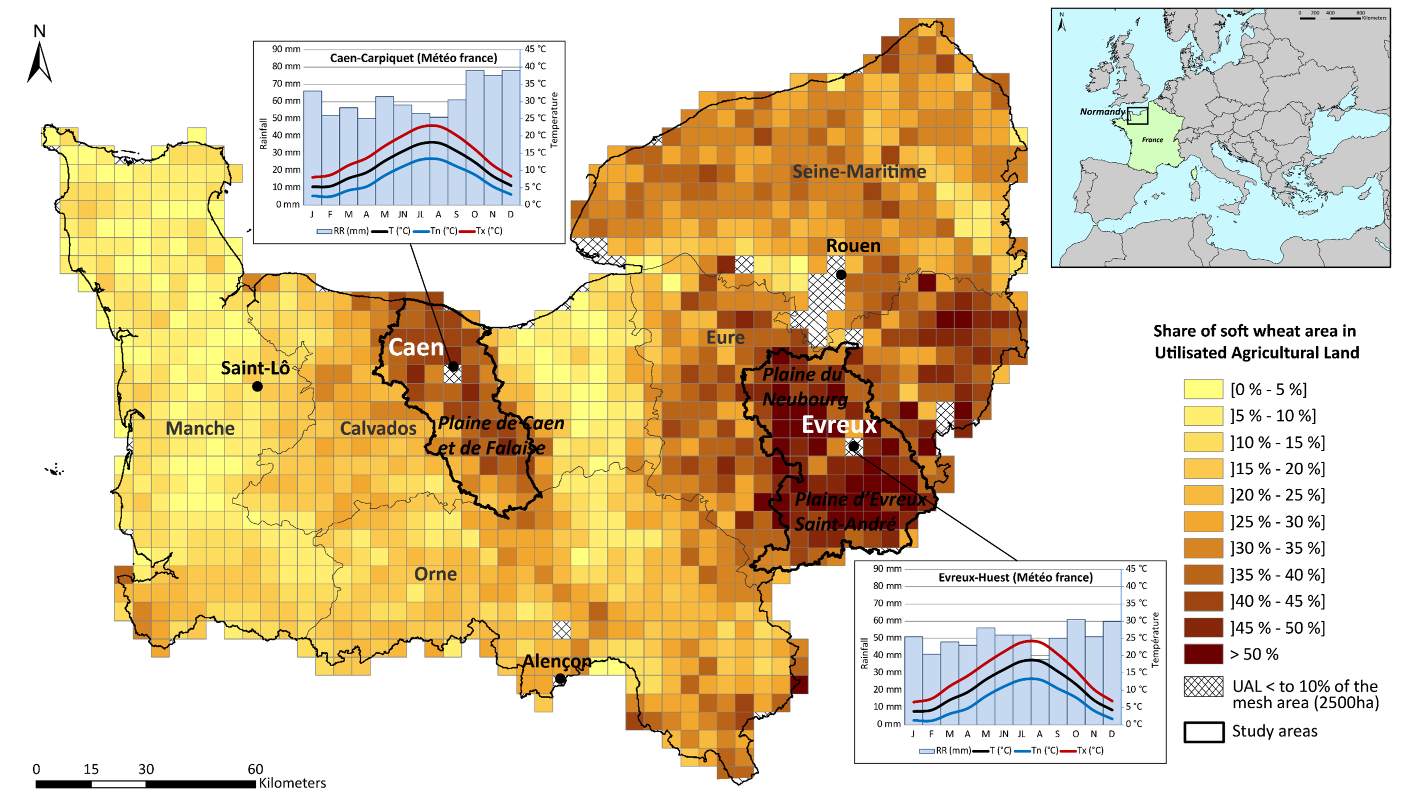
1. Introduction

France is the fifth largest producer worldwide of soft wheat. Every year over 35 million tons of wheat are harvested (average 2011-2017, data from France AgriMer) on the territory. Hence, the cereal sector occupies a key place in the French agricultural economy. Normandy makes a significant contribution to this outcome with 3,6 million tons. Most of the production is exported to Maghreb and China via ports located in Rouen and Caen.

However, because of its high dependence on atmospheric conditions, wheat production is vulnerable to climate change. Since the mid-1990s, a stagnation of yield has already been observed. According to the agronomists, climate change is responsible for that : Water deficit during stem elongation and scalding days during grain filling (Gate, 2009 ; Brisson *et al.*, 2010).

Fig.1 Location of study areas with their ombrothermal diagram and distribution of soft wheat area in used agricultural land



François BEAUVAIS., 2019 (RPG 2016 data of ASP ; aggregation of agricultural plots in the meshes with Arcmap according to the method of Marie et al, 2014)

Study areas

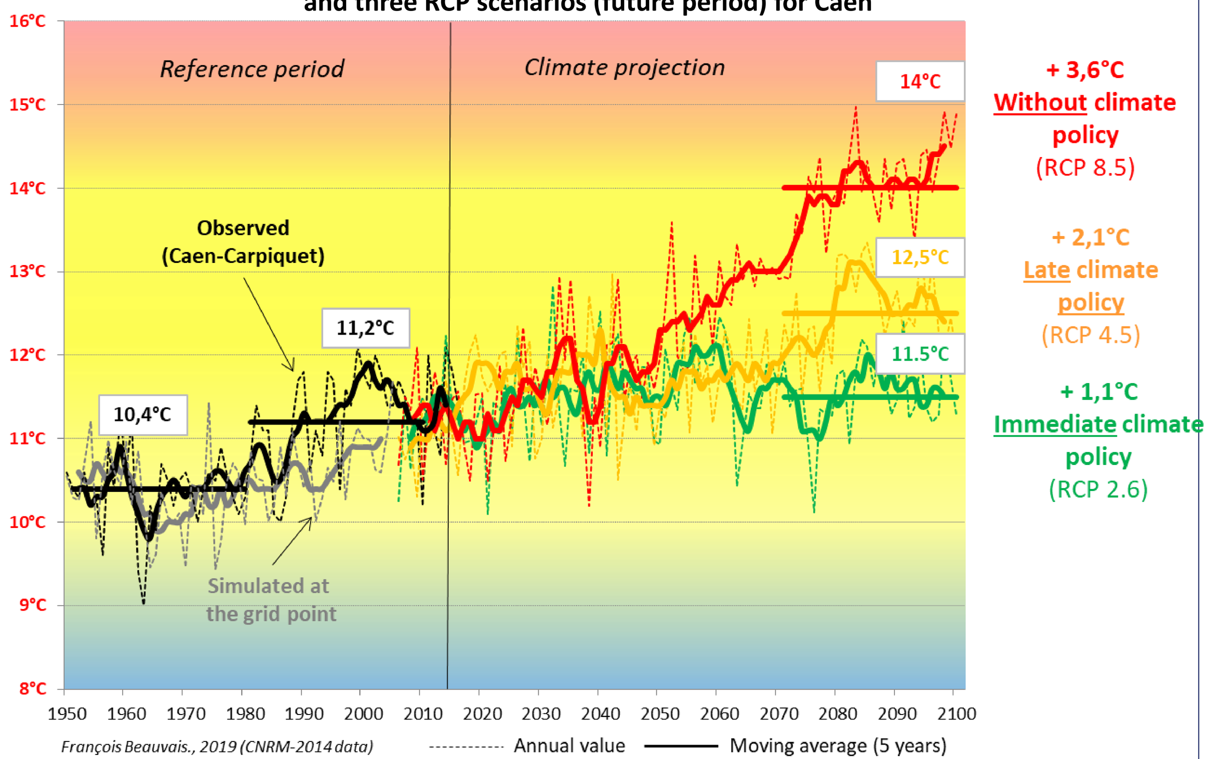
This study illustrates 2 agricultural plains containing open fields in Normandy, North-West of France. In this region, wheat locally occupies more than 50% of the agricultural land (fig.1):

- Caen plaine which is under the influence of an oceanic climate.
  (11,2 °C ; 740 mm rainfalls; 32 frost days and 23 hot days on climate normal 1981-2010)
- Evreux plaine where climate is slightly more continental.
  (10,8 °C ; 605 mm rainfalls; 52 frost days and 33 hot days on climate normal 1981-2010)

2. Climate context : observation and projection

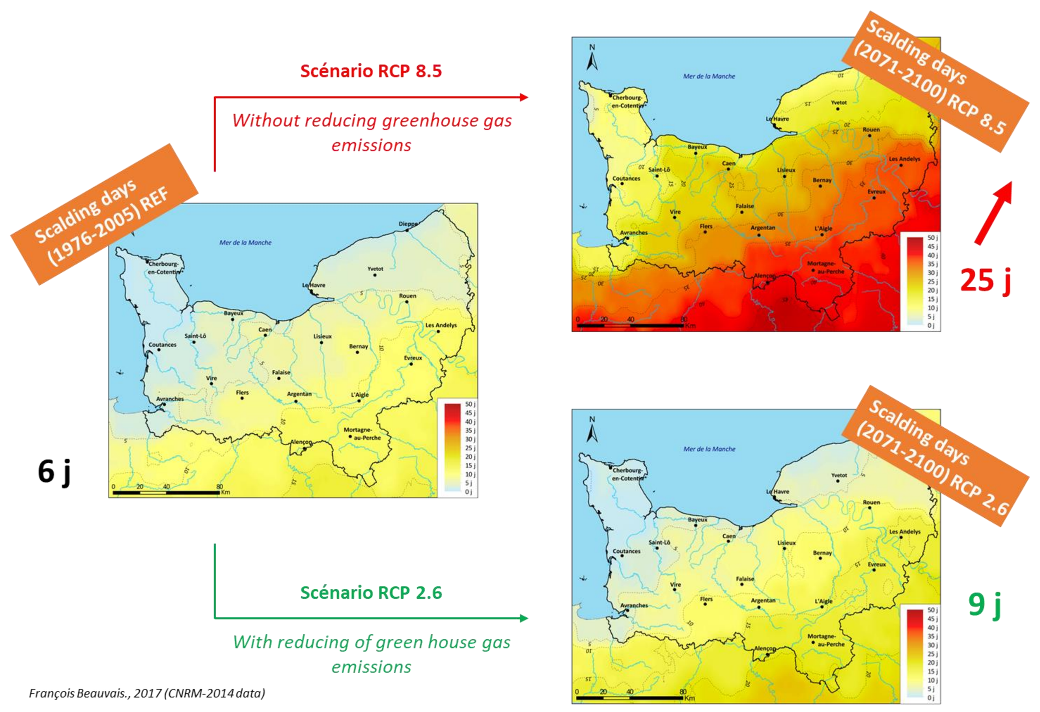
Normandy climate is favourable to wheat production. Proximity to the English Channel helps to mitigate severe frosts and summer heat waves. However, risk of water deficits in spring is not excluded, especially where the soil is thinner. But climate is changing. The average temperature has already known a +0.8°C increase between the 1951-1980 and 1981-2010 climate normal (fig. 2). It is going on, since the temperature of the last nine years is 0.5°C above of 1981-2010's normal. On the other hand, there is no significant trend concerning cumulative rainfall.

Fig.2 Evolution of the average annual temperature from 1950 to 2018 based on Caen-Carpiquet (weather station) data and CNRM-2014 data (ALADIN model) for a historical scenario (past period) and three RCP scenarios (future period) for Caen



François Beauvais., 2019 (CNRM-2014 data)

Fig.3 Evolution of scalding days (25°C) in May, June and July by 2100 in Normandy

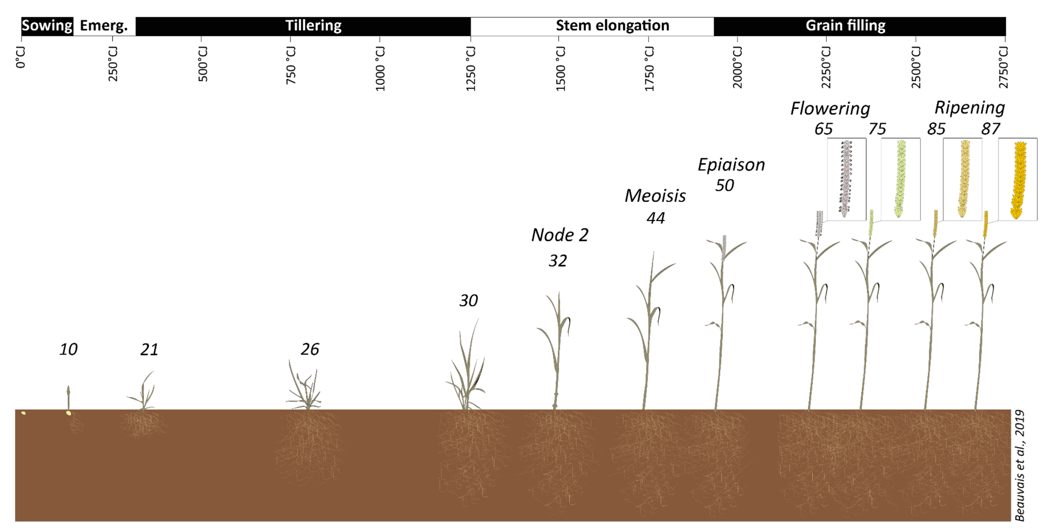


François Beauvais., 2017 (CNRM-2014 data)

The intent of this study is to present what would be the climatic conditions for soft wheat in 2050 and 2100 and to compare them with the reference period (1976-2005). The climatic data is extracted from ALADIN-Climate (data from CNRM-2014 with a spatial resolution of 8x8 km) concerning three RCP scenarios of IPCC, available on the *"Drias Les futurs du climat"* website. Without any reduction of global greenhouse gas emissions, temperature could rise by as much as +3.6°C (fig.2). The number of hot days over May, June and July would be multiplied by four (fig.3). At the same time, cumulative rainfall would decrease by -13% in spring and -30% in summer. Given the stagnation in yields already observed, this is alarming.

3. Method : bioclimatic approach

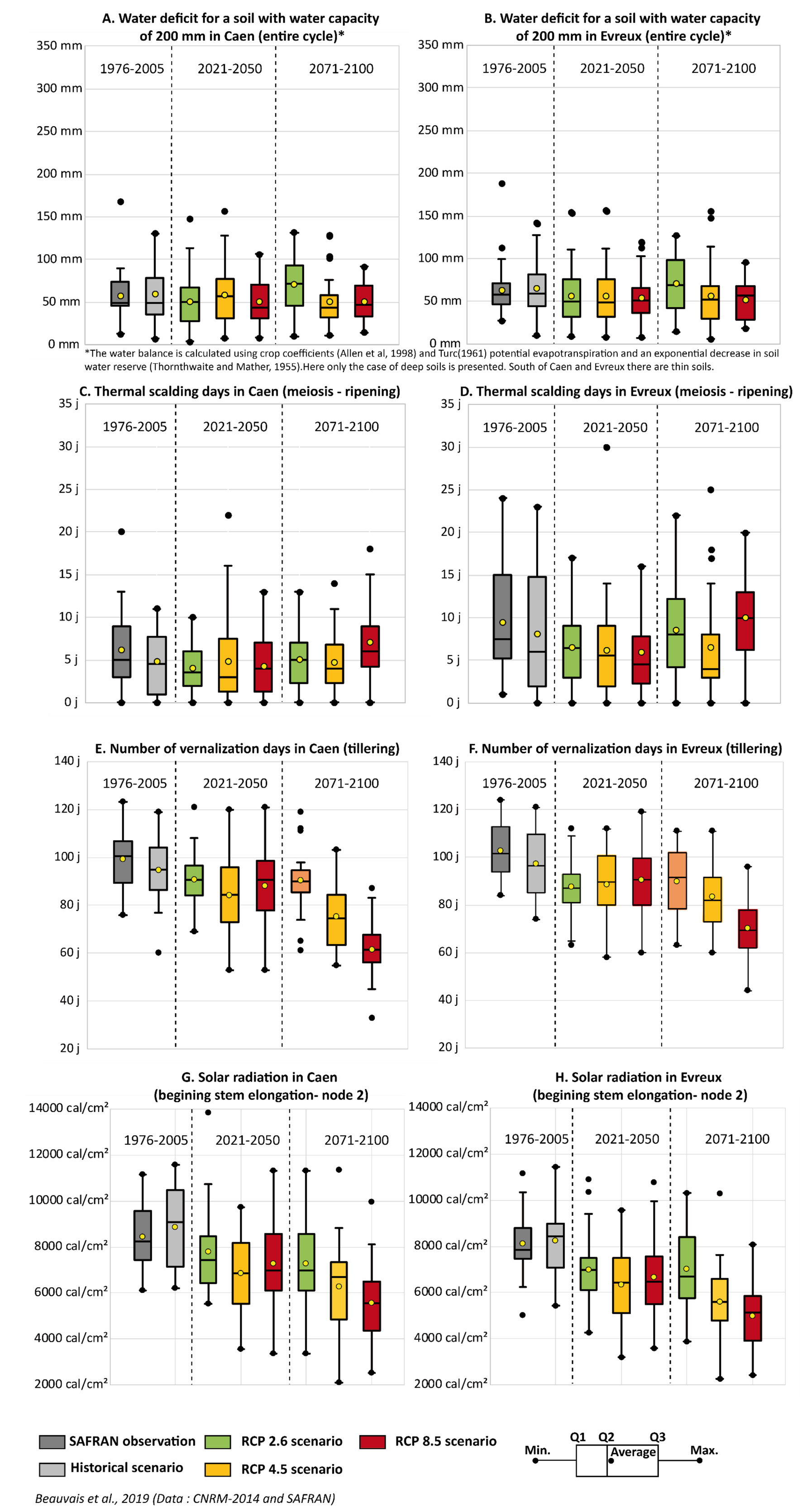
Fig.4 Soft wheat cycle: growth stages (Zadocks scale)



Phenology is simulated using the concept of degree days (base 0°C) with an associated 11h photoperiodic criterion for the beginning of the stem elongation. The occurrence of climatic hazards is linked to the phenological stages of the plant (fig. 4): water deficit (entire cycle), thermal exhaustion (scalding day : 25°C), vernalization (between 3°C – 10°C), low temperatures (< 4°C during meiosis) and radiation deficit (stem elongation ; Gate, 1995).

Indeed, those hazards are able to generate consequences to the agricultural yield. Studying the effect of climate on crops by taking into account phenology (Holzkämper et al., 2013) and its interannual variability is more precise than agroclimatic indicators for invariant dates (Caubel et al., 2015). The elements presented are a selection of the results published in Beauvais *et al.*, 2019.

Fig.5 Evolution of phenoclimatic indicators by 2050 and 2100 in Caen and Evreux for three RCP scenarios



Beauvais et al., 2019 (Data : CNRM-2014 and SAFRAN)

4. Results

Harvest on 02 August 2019 (picture : Beauvais, 2019)

Phenology anticipation : harvest in early july ?

In the reference period the physiological maturity of wheat occurs at the end of July, which corresponds to harvests in early August. In the context of a pronounced climate change, along with unchanged sowing dates by 2050 and 2100, the increase in temperatures would lead to shorten the crop cycle, and hence to a date shift in the plant phenology. In the short term, physiological maturity would show up in mid-July for the three scenarios, which corresponds to a two-weeks cycle reduction. In the long term, with the RCP 4.5 scenario, maturity would occur at the beginning of July and at the end of June for the warmest scenario. So in 2100 the wheat harvest could take place at the beginning of July.

What will be the consequences ?

Consequently, there would be a shorter overlap between the end of the crop cycle and the summer period, usually characterized by heat waves and water stress events which are expected to occur more often. Thus, high temperature triggered scalding wouldn't be observed as much as expected and the cumulated water limitation would be also lower (fig.5.A,B,C,D). The impact on grain filling would be no heavier than at present. However, because of this precocity, emerging consequences might be expected regarding deleterious effects of lower temperatures during meiosis (tab.1), and decrease of solar radiation at the onset of stem elongation (fig.5.G,H). Mild winters would also reduce the number of vernalization days (not providing the required amount of cold days during tillering ; fig.5.E,F).

In the end, given the greater occurrence of these new hazards, the fertility of the ears, and the growth and flowering of the wheat could be impacted.

Tab.1 Evolution of the occurrence of the number of years with at least one day of low temperature (Tn<= 4°C) during meiosis in Caen and Evreux

Scenario	Caen	Evreux
1976-2005		
SAFRAN observation	03/30	03/30
Historical scenario	05/30	06/30
2021-2050		
RCP 2.6 scenario	04/30	10/30
RCP 4.5 scenario	06/30	10/30
RCP 8.5 scenario	08/30	11/30
2071-2100		
RCP 2.6 scenario	09/30	12/30
RCP 4.5 scenario	07/30	12/30
RCP 8.5 scenario	09/30	11/30

Weather measurements in the field (picture : Cantat., 2018)

Soil pit (picture : Le Gouée., 2019)

Phenological observations (Beauvais., 2019)

A few references :

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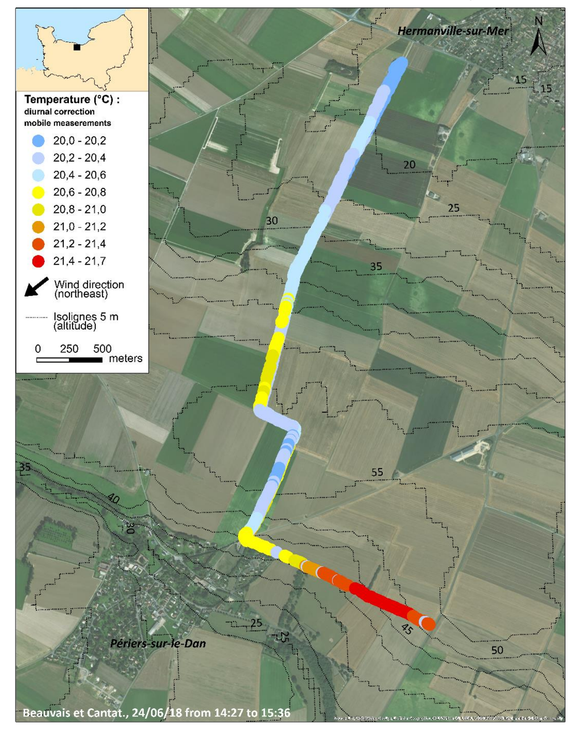
- Holzkämper A., Calanca P., Fuhrer J., 2013. Identifying climatic limitations to grain maize yield potentials using a suitability evaluation approach. *Agricultural and Forest Meteorology*, 168, 149-159. DOI: https://doi.org/10.1016/j.agrformet.2012.09.004

5. Limits and perspectives

- The agricultural areas studied are flat and open_fields. Consequently, the 8x8km climate model resolution is apposite. Nevertheless the spatial variability of temperatures (fig.6) should be considered (example of sea breeze and topography effects on a local scale). Experimental temperature measurements need to be extended, associated with soil and phenology (in the field and under controlled conditions) at several geographical scales.
- Integrate the mechanisms governing plant physiology and use a crop model to estimate yield potential.
- Develop a field survey for farmers to estimate their adaptation capacity based on their observations, perceptions and understanding of climate change.

Fig.6 The spatiale variability of temperature : example North of Caen (From 14:27 to 15: 23 the 24 june, 2018)



6. Conclusion

This study demonstrates the use of bioclimatic models to unravel the crop phenology modifications, expected to occur by the end of the century, under the main environmental climatic drivers. Without a global climate policy, the scale of climate change is substantial. Contrary to the initial hypothesis, the intensity of the feared hazards would be least. On the other hand, unexpected hazards could occur. Faced with these changes, the agricultural sector can adapt by looking for wheat ideotypes adapted to tomorrow's climate. If varietal selection or the use of old varieties does not allow adaptation, then new crop rotations will have to be considered. In this case, a similar study will have to be carried out for the crops under consideration.