modextreme
agriculture facing extreme climatic events

Simulating frost impact on crop production

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with contributions from other WP1 members

Introduction

- A single event of frost may reduce crop yield and/or quality

Freeze damage to wheat crop.

Introduction

Freeze damage to apple flowers and reduced quality of fruits

Introduction (cont.)

- Frost damage only occurs after the onset of freezing
- When a tissue temperature is below the critical temperature for the tissue for enough time, usually not more than half an hour, damage occurs.
- LT10, LT50 and LT90 (10%/50%/90% damage) have been compiled for most crops (Snyder and De Melo-Abreu, 2005).
- Critical temperatures are published in relation to
  - Species/cultivar
  - Phenological stage
- In general, critical temperatures are published for the most relevant organ in a given stage, without explicitly naming it.

Introduction (cont.)

- Some models exist for frost damage estimation.
- DEST, that was published by us, is one of them that is general propose, but has some limitations, namely that it does not account for hardening due to low temperatures.
- Some other models account for hardening, namely the wheat winter survival models from Bergjord et al. (2008) and Lecomte et al. (2003). However they have the inconvenience of having many parameters (e.g, five) and input variables such as soil temperature at some depth and/or snow depth. Also, the effects of the second, third and subsequent frost periods have not been simulated properly.
- Our study aimed at developing a simple-generic model approach that may calculate frost damage at the scale required by MODEXTREME.

Material and Methods

- Literature review
  - A detailed literature review, covering the publications of the last ten years, regarding the critical temperatures for frost damage was done.
  - All collected data were organized according to the following items: 1) Crop common name; 2) Crop Scientific name; 3) Cultivar; 4) Crop type (Season, training system, etc.); 5)Lethal Temperature %; 6) Lethal Temperature; 7) Crop Stage; Damaged organ; 8) Field/Laboratory Experiment; 9) Dry/Wet Surface Condition; 10) Hardened/unhardened; 11) Source; 12) Other Comments.
  - The critical temperatures of a total of 25 crops and hundreds of cultivars were thus compiled.
  - All the crops relevant to Modextreme are fully documented.

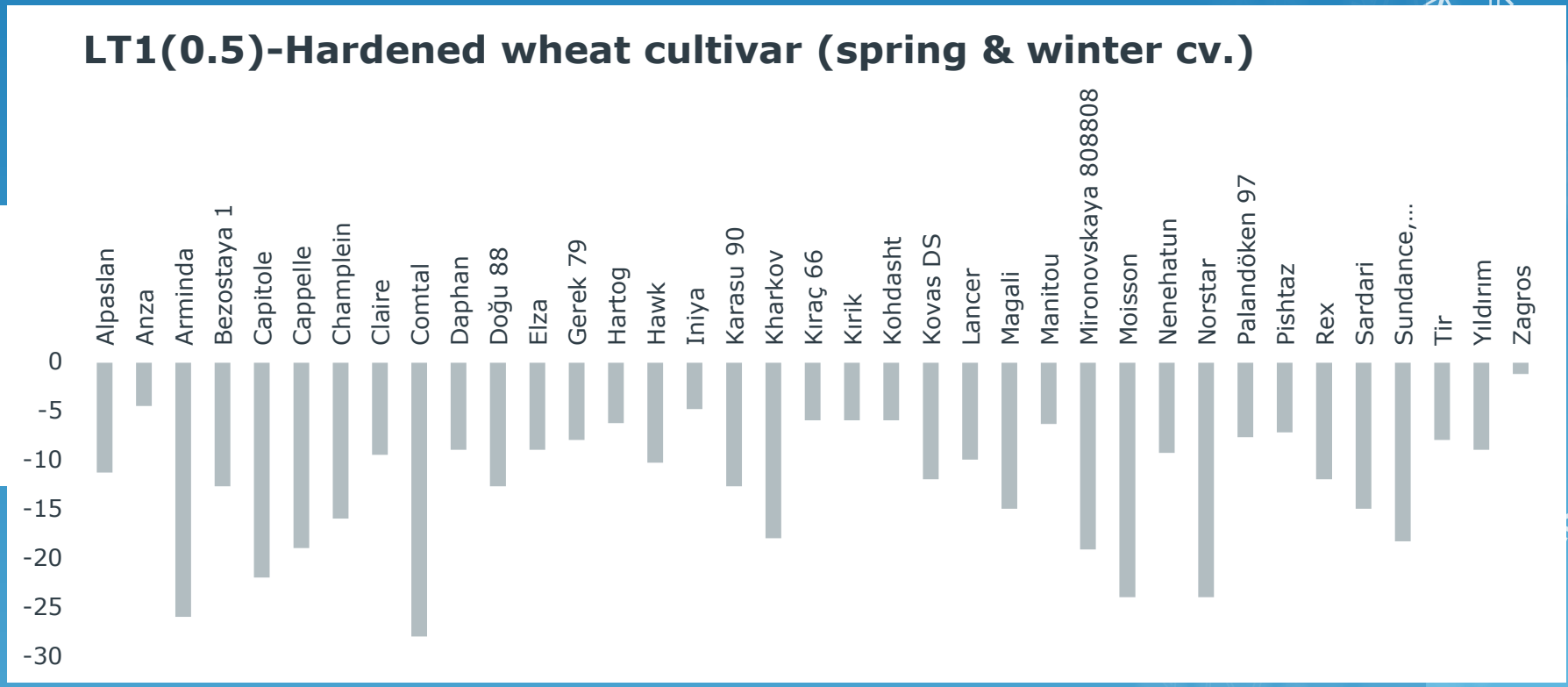
Material and Methods (Cont.)

- In this study, critical temperatures were subdivided into two types (LT1 and LT2):
  - 1) LT1(0.0-1.0) – Critical damage temperature below which a fraction of the vegetative organs is lost to frost. For example, the fraction, may affect the state variable LAI.
  - 2) LT2(0.0-1.0) – Critical damage temperature below which a fraction of the reproductive organ or reproductive structure is lost to frost. For example, the fraction, may affect the state variable number of fruits, DM of fruits, or HI.
- Validation datasets
  - A dataset including hundreds of frost damage events to the olive crop were collected.
  - Datasets from fruit tree damage (apples) and corresponding weather are available.

Results & Discussion

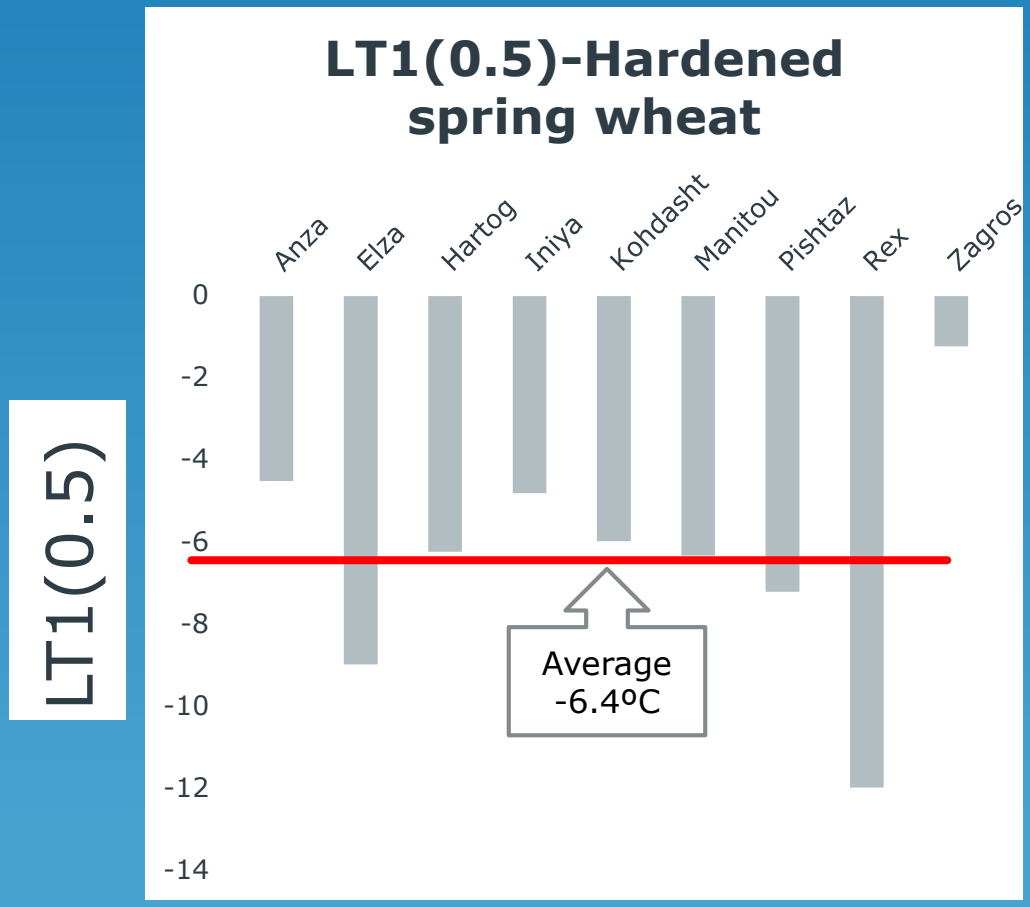
Due to the volume of the dataset collected we will present only the wheat and olive results!

Hardened wheat: LT1(0.5) around tillering. Note that there is a great cultivar-related dispersion of values around the mean



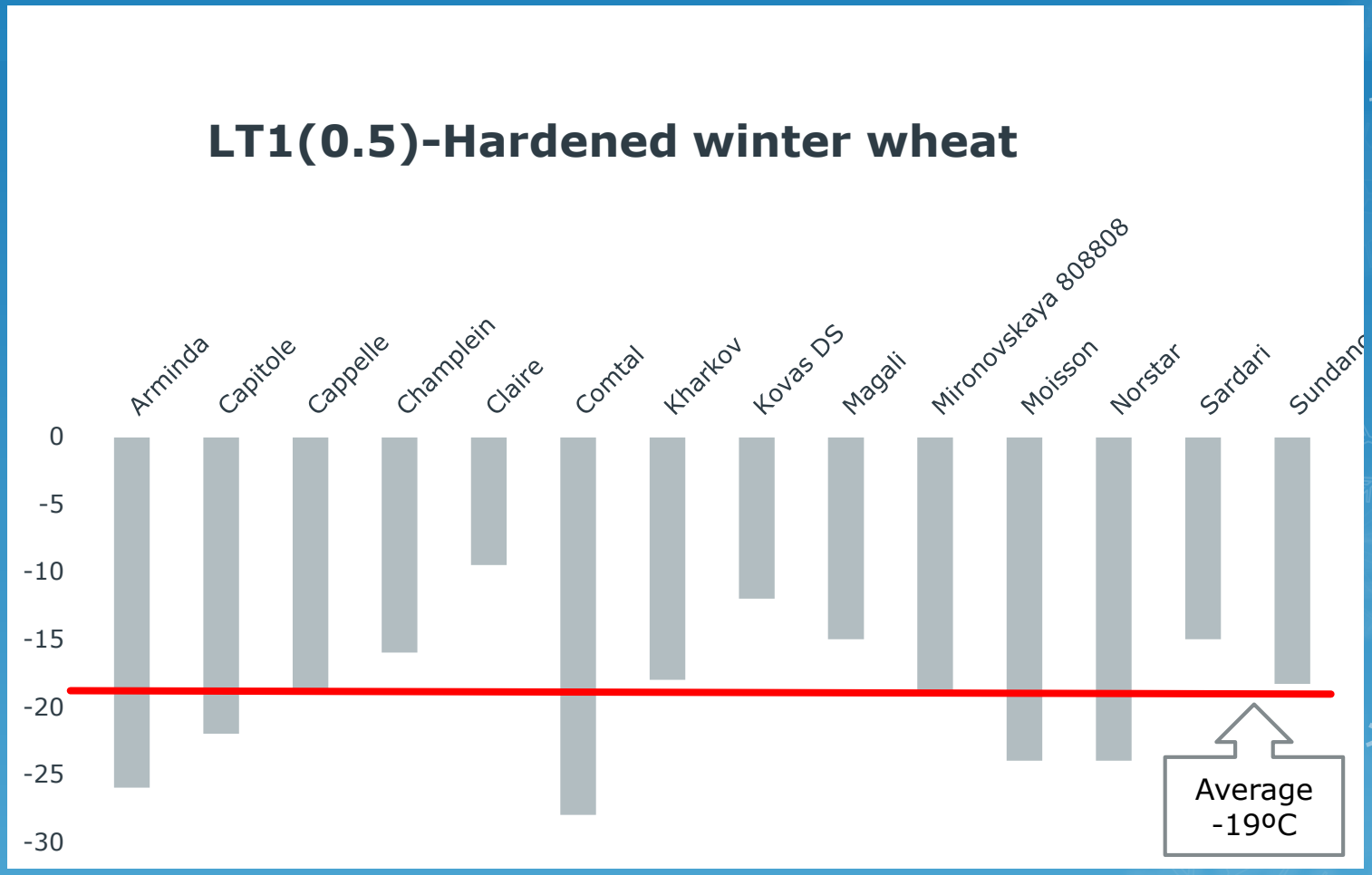
Results & Discussion

Hardened wheat (only spring cv.): LT1(0.5) around tillering. Average (-6.4 ºC)



Results & Discussion

Hardened wheat (only winter cv.): LT1(0.5) around tillering. Average (-19ºC).



Results & Discussion

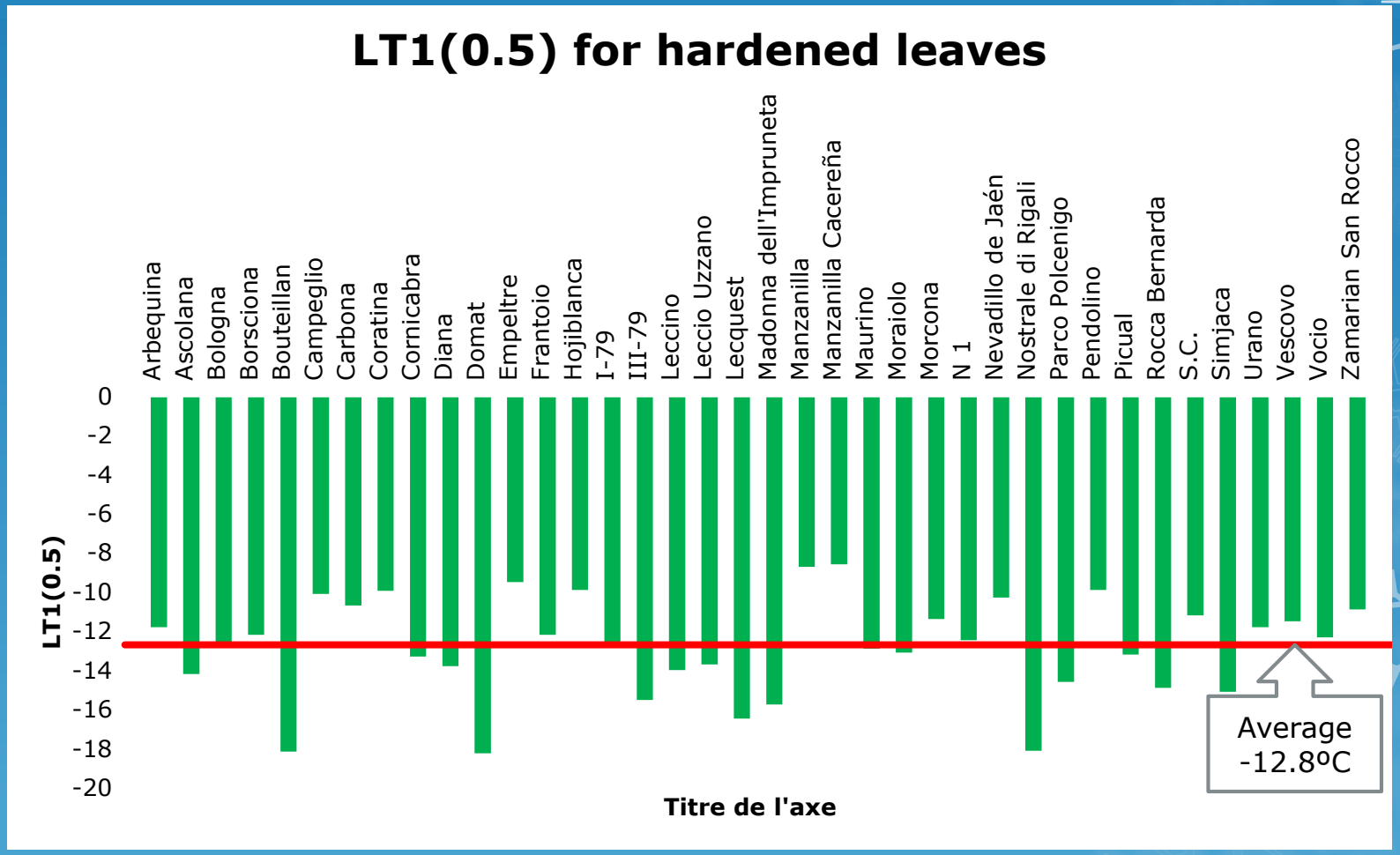
Critical damage temperatures for wheat (final form)

Values in brackets refer to unhardened organ following a period with abnormally high temperatures.

Spring bread wheat	Stage	Germination / emergence	Tillering	Ear emergence-flowering	Flowering-grain set	Early grain growth
	NDS (approx.)	0	0.3-0.4	0.85-1.0	1-1.1	1.1-1.6
	LT1(0.0)	-7(-3)	-7 (-3)	-2	-2	-2
	LT1(1.0)	-11(-7)	-12 (-7)	-6	-6	-6
	LT2(0.0)			-2	-1	-2
	LT2(1.0)			-8	-4	-5
Winter bread wheat	**Stage**	**Germination / emergence**	**Tillering**	**Ear emergence-flowering**	**Flowering-grain set**	**Early grain growth**
	NDS (approx.)	0	0.3-0.4	0.85-1.0	1-1.1	1.1-1.6
	LT1(0.0)	-7 (-3)	-18 (-3)	-2	-2	-2
	LT1(1.0)	-13 (-7)	-24 (-7)	-6	-6	-6
	LT2(0.0)			-2	-1	-2
	LT2(1.0)			-8	-4	-5

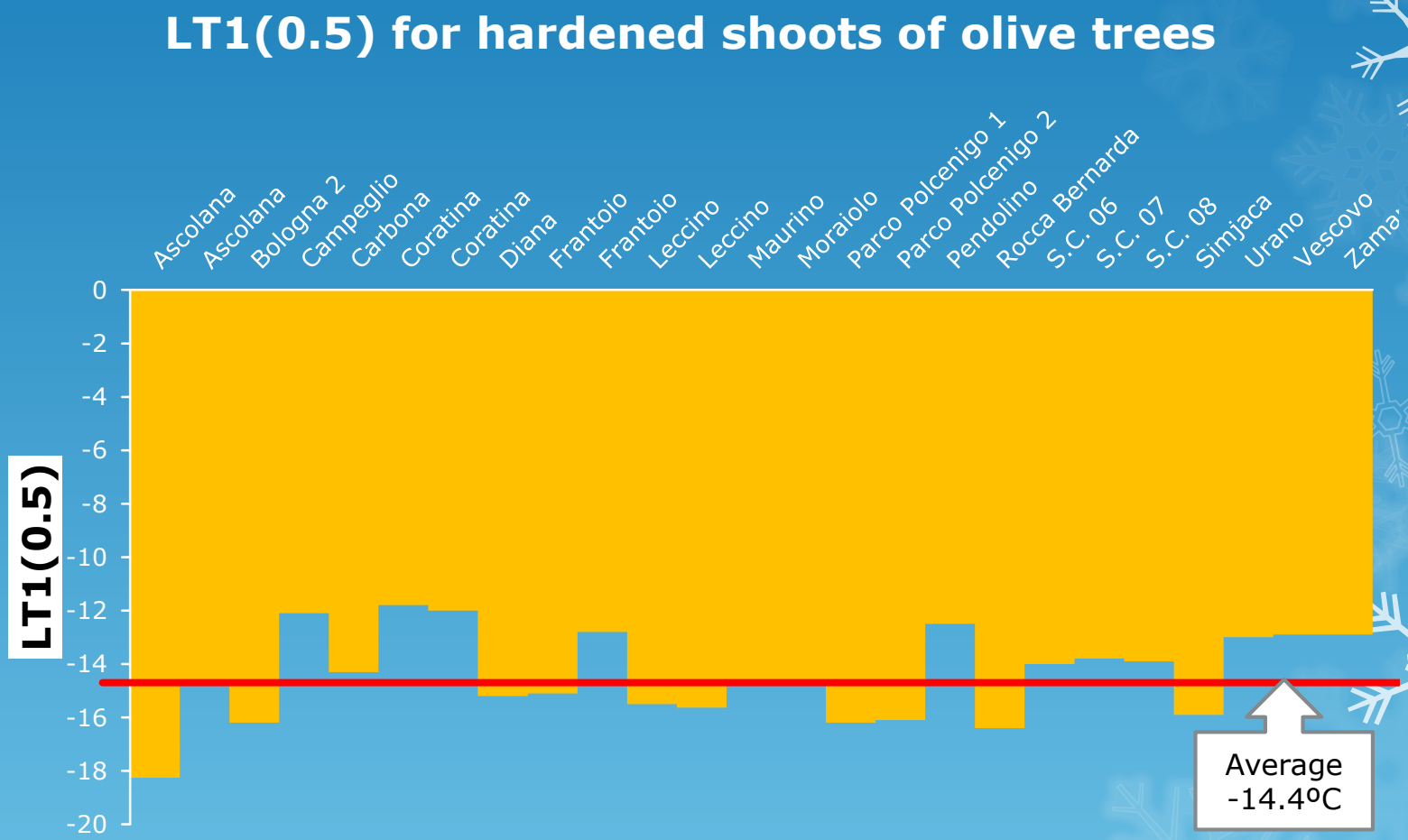
Results & Discussion

Olive tree: leaf critical damage temperatures (hardened)



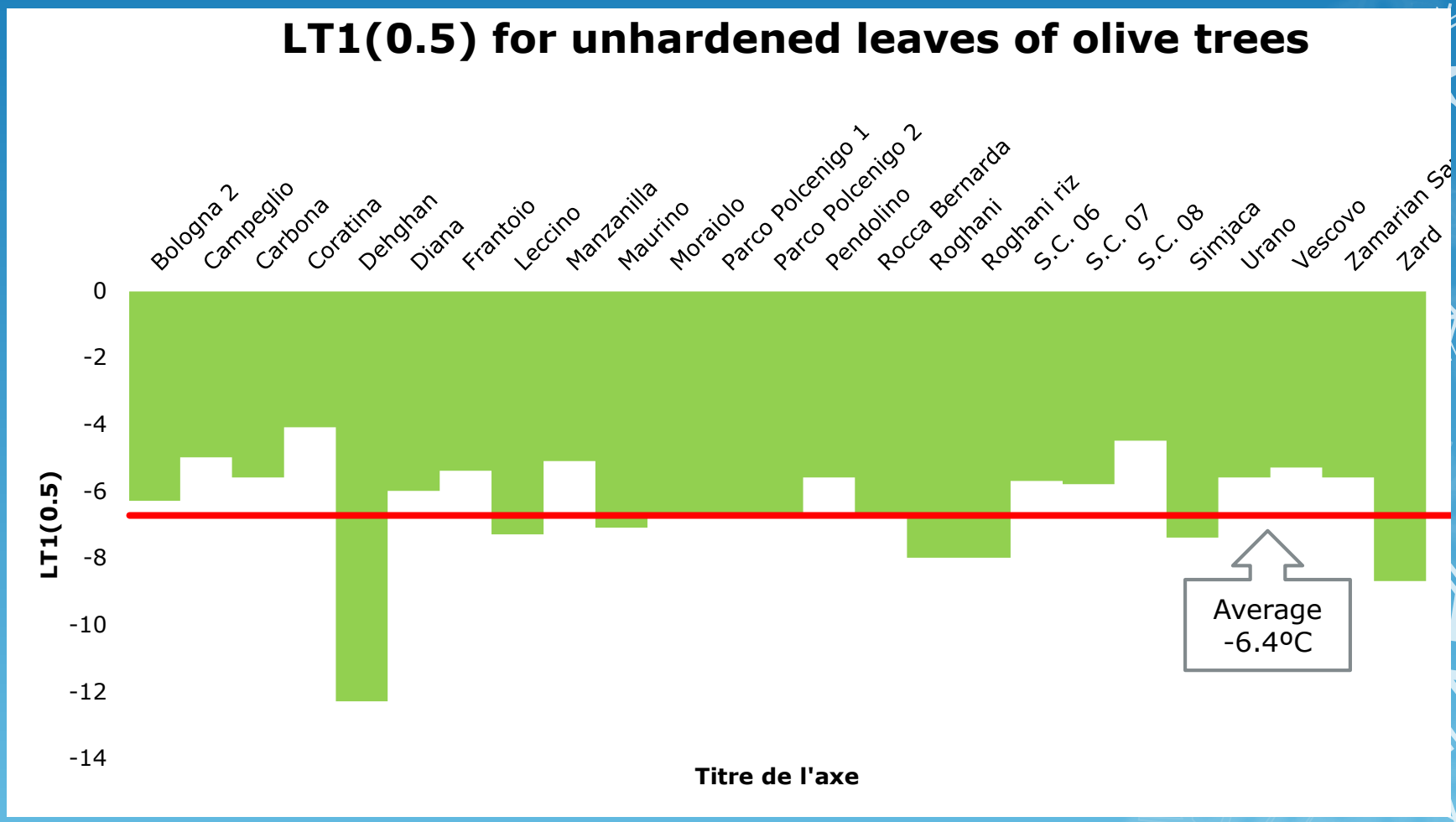
Results & Discussion

Olive tree: shoot critical damage temperatures (hardened)



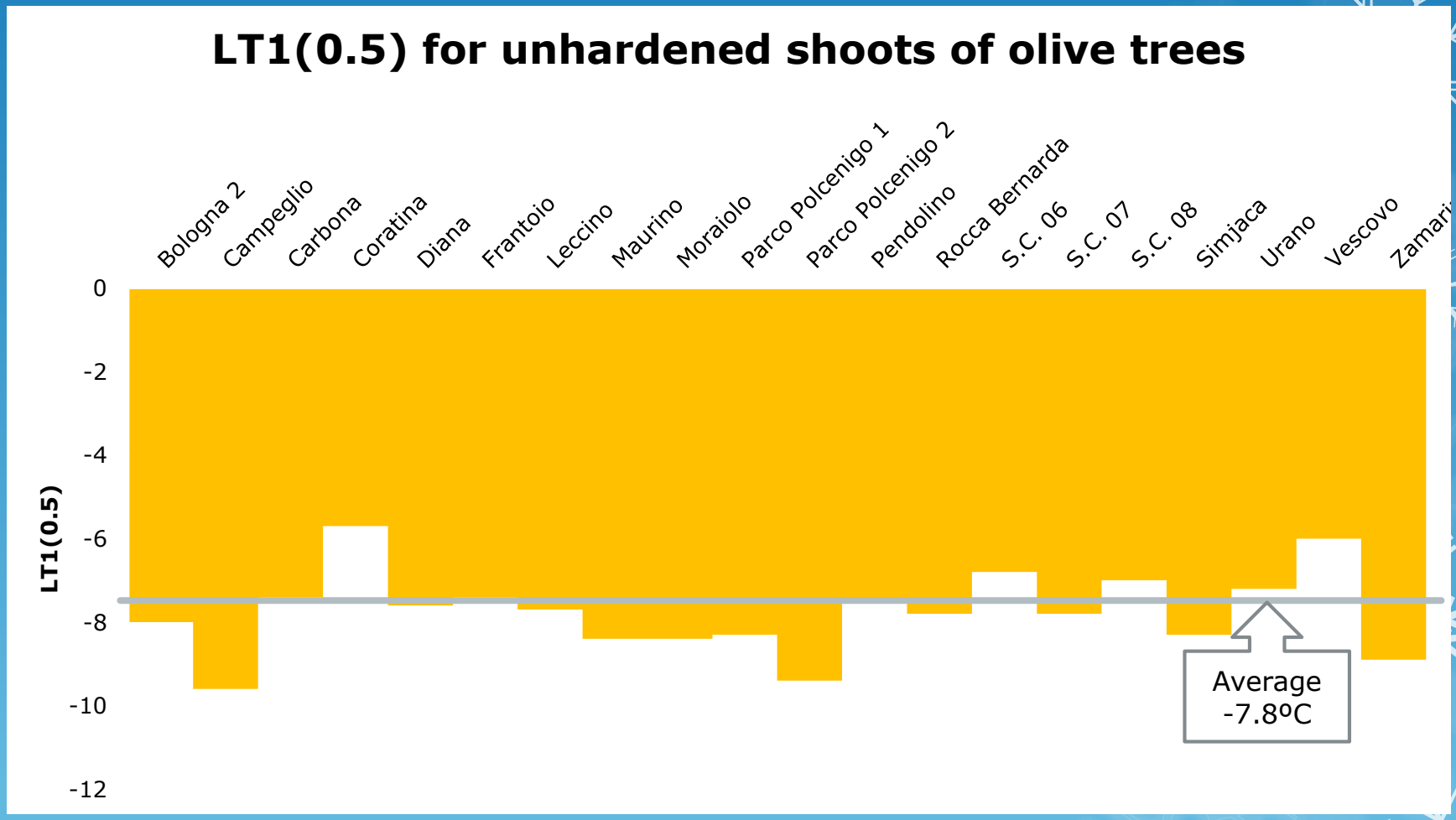
Results & Discussion

Olive tree: leaf critical damage temperatures (unhardened)



Results & Discussion

Olive tree: shoot critical damage temperatures (unhardened)



Olive LTs

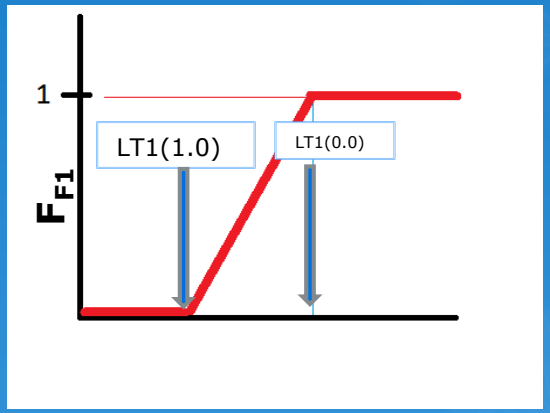
Olive	Stage:	Dormancy	Active Growth
	LT1(0.5) (Leaf)	-12.8 (-6.4)	-6.4
	LT1(0.5) Shoots & branches	-14.4 (-7.8)	-7.8
	LT2(0.5) Floral buds/Fruits	-13	-1
	LT1(0.0) Roots (secondary)	-8.9	-8.9
	LT1(0.0) Roots (primary)	-10	-10

Modelling approach

Calculation of daily value of response function F_{F1} and F_{F2}

- Two response functions for frost damage are computed daily.
- $F_{F1,}$ is the response function to frost that has its impact on LAI:

$$F_{F1} = \begin{cases} 0 & T_N \le LT1(1.0) \\ \dfrac{(T_N - LT1(1.0)}{(LT1(0.0) - LT1(1.0)} & LT1(1.0) \le T_N \le LT1(0.0) \\ 1 & T_N \ge LT1(0.0) \end{cases}$$



where T_N is minimum daily canopy temperature, and the critical temperatures (*LT1*(0.0) and *LT1*(1.0)) are the ratio 0.0 or 1.0 of the number, weight or area of leaves or whole plants (often replaced by fraction of canopy LAI) that are damaged at temperature T_N.

- F_{F2} is the response function that impacts on HI. It uses a formula that is formally equal to the previous formula, but the critical temperatures are different because the ratios relate to number of flowers or grains (replaced by harvest index, *HI*).

Modelling approach (cont.)

- **Aggregation of daily values of response function FF1 and FF2**

Recalculation of LAI due to frost impact may be done daily, theoretically at mid-night, or in the end of a given number of days, *n*. Recalculation of LAI on day *j* is

$$LAI_j = LAI_{j-1} \times F_{F1}$$

and for a given period is

$$LAI_n = LAI_0 \prod_{1}^{n} F_{F1}$$

where LAI_0 is *LAI* before the given period.

Modelling approach (cont.)

- **Aggregation of daily values of response function FF1 and FF2 (cont.)**

Harvest index (HI) recalculation on day j is

$$HI_j = HI_{j-1} \times F_{F2}$$

and for a given period is

$$HI_n = HI_0 \prod_{1}^{n} F_{F2}$$

where HI_0 is HI before the given period.

Modelling approach (Cont.)

Selection of frost damage critical temperature

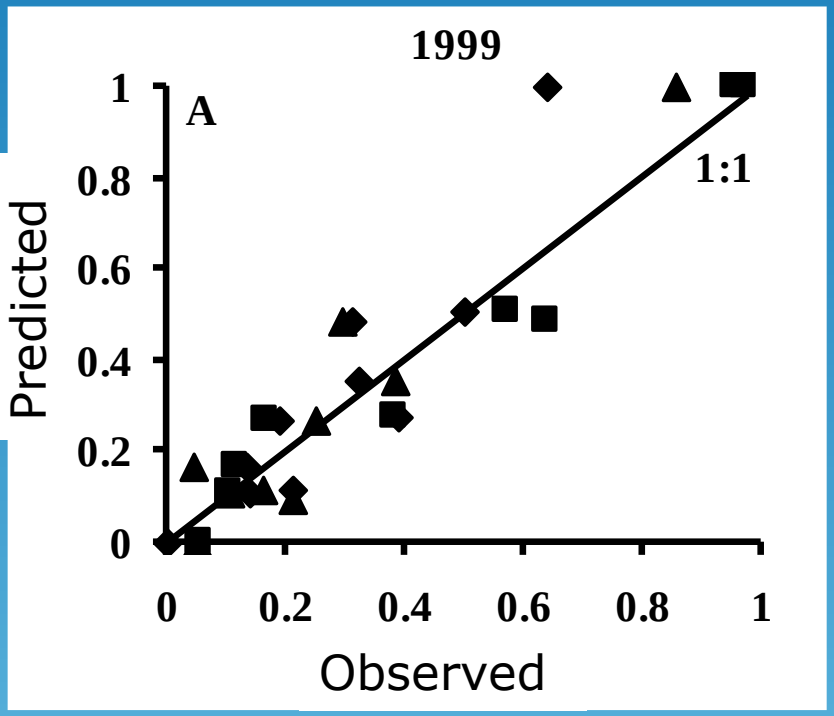
- Critical temperatures (*LT*1(0.0), *LT*(1.0), *LT*2(0.0) and *LT*2(1.0)) for each species are tabulated in relation to stage and whether the plants are hardened or not.
- Acclimation decreases *LTs* in the vegetative phase of cereals, deciduous fruit trees, olive trees.
- Within a species, unhardened plants depict similar *LTs.*
- However, minimum *LTs* for fully acclimated plants vary widely with cultivar.
- Thus, the approach to simulate the *LTs* for partially harden plants must be, at least, species specific.

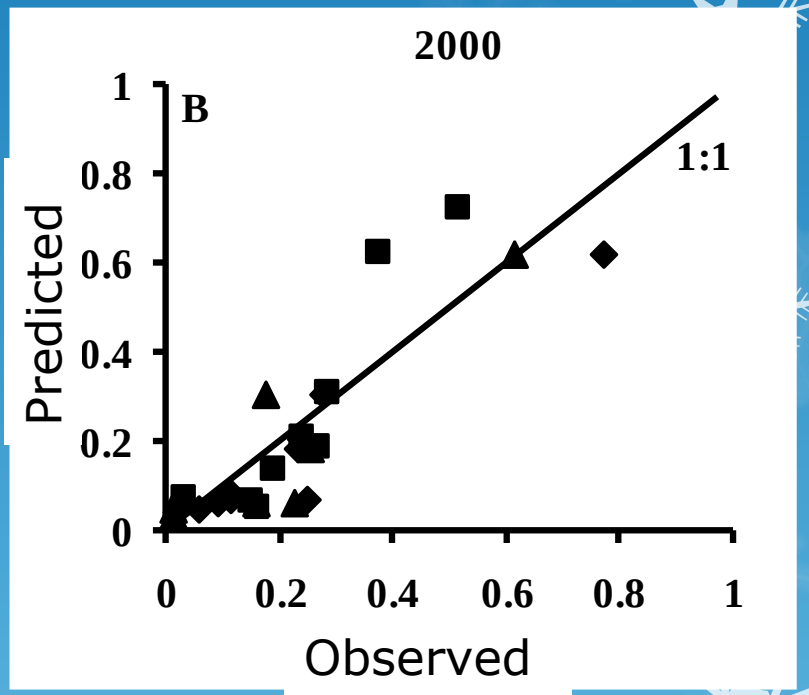
Modelling approach (Cont.)

Selection of frost damage critical temperature

- In order to keep the modelling approach compatible with the objectives of MODEXTREME, we report, in the case of acclimated plants, only *LTs* for estimated "average" cultivar frost resistance.
- If required, we may tabulate *LTs* for acclimated plants, with cultivar specific values.
- We recommend that for winter cereals, in the vegetative phase, if required, the acclimation is achieved after four weeks below a threshold temperature (e.g., 15ºC). Then the model uses the values of LT1 for hardened plants. Using a 5-day running average of air temperature (T5av) the loss of hardening occurs is the average temperature greater than a given threshold temperature (e.g., 0ºC).

Validation of the approach in the prediction of frost damaged apple flowers





Conclusions

- The modelling approach and parameters are ready to produce a module that may improve the performance of existing models.
- The level of detailed is still debatable, but I think that for this kind of model further detail may cause more harm than good.
- In the next months we will send all the information required by the programmers.
- We appreciate that you give us your opinion!

Thanks!

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