modextreme
agriculture facing extreme climatic events

SEVENTH FRAMEWORK PROGRAMME

Impact of extreme meteorological events on crop yield: a common framework approach

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General framework

The hypothesis is that yield variations due to an extreme event (cold temperature, high temperature or water deficit) is mediated by a change in Harvest Index (HI), while the main effect of weather on crop performance is already captured by existing crop models.

Before anthesis:

the main effects over LAI or biomass. Considered for frost (see "Response to frost")

Around anthesis:

the main effects of cold temperatures are related to pollination, while frost or very high temperature may kill flowers or seeds. Water deficit may reduce seed set.

For each day of the time window of duration d_A, response functions ranging from zero to one, are calculated for temperature (F_T), as a function of mean crop temperature, and water stress (F_W). The overall value of the response function will be:

$$F = \frac{1}{d_A} \sum_{1}^{d_A} \min(F_T, F_W)$$

In addition, the effect of frost (function of minimum crop temperature) or extreme heat (function of maximum crop temperature) is overlapped by corresponding functions (F_F and F_H).

$$F_A = F \prod_{1}^{d_A} \min(F_F, F_H)$$

The value of F_A represents the fraction of maximum HI that may be attained after anthesis is completed (HI_{AA}):

$$HI_{AA} = F_A \, HI_{max}$$

From anthesis to maturity

the model assumes that HI increases linearly during this period from zero to HI_{AA}:

$$HI = \frac{HI_{AA}}{d_{PA}} \, t$$

where t is time after anthesis, and d_{pa} is duration of the phase (both in calendar days). Any event of frost or heat occurring during this period (e.g. at time t_1) will have an impact calculated as:

$$HI = HI_{AA} \left[(1-F)\frac{t_1}{d_{PA}} + F \right]$$

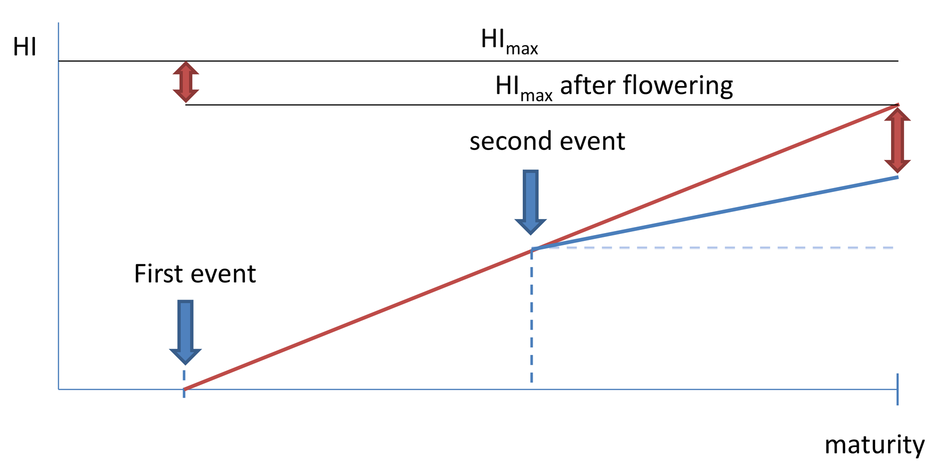


Figure 1: Schematic action of the functions considered in this framework

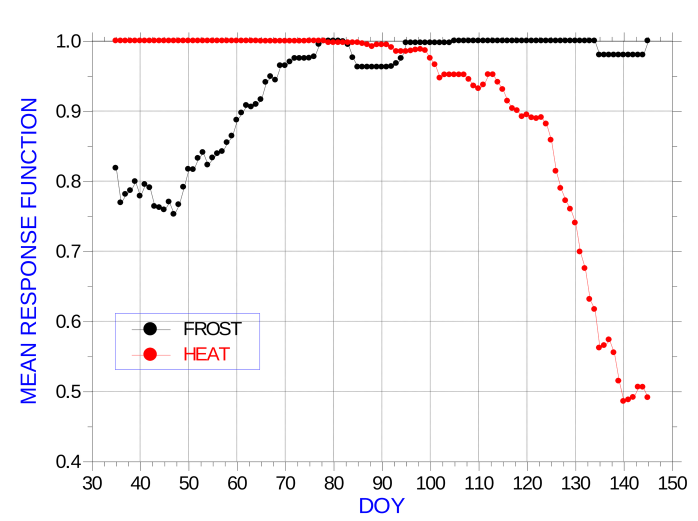


Figure 2: Example of the effect of response functions for frost and heat over wheat. The lines represent the average response functions for HI over the real climate of Córdoba, Spain, from 1964 to 2013.

Response to extreme water stress

Our hypothesis is that the extreme stress is better represented by the cumulative reduction in transpiration since transpiration (E_p) becomes limited. The water content when this happens is equivalent to the concept of Allowable Depletion (*AD*); the table for different crop types provided by FAO (Doorenbos and Pruitt, 1977) may be fitted to the following expression where AD_5 is a specific parameter:

$$AD = 0.04\, AD_5\, (5 - ET_0) \qquad [0.1 < AD < 0.8]$$

For a given value of relative transpiration ($r=E_p/E_{pmax}$), the cumulative reduction in transpiration since the onset of water deficit is calculated as:

$$0.5\,(1-r)^2\,(1-AD)$$

As the maximum transpiration reduction is 0.5, the fraction of transpiration not reduced is:

$$f_E = 1 - (1-r)^2\,(1-AD)$$

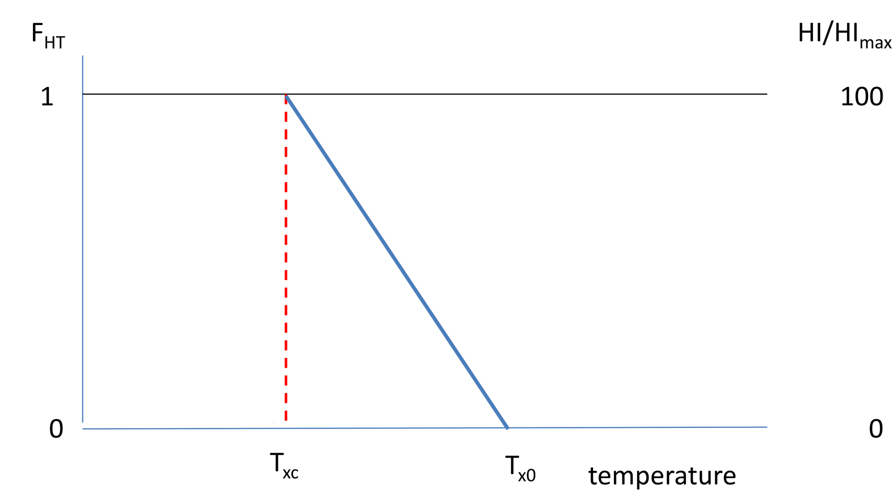
The response function to extreme water stress will be:

$$F_w = \frac{f_E}{f_{Ecrit}}$$

Which is set to unity if f_E exceeds the parameter f_{Ecrit}, which is crop dependent.

Response to heat

F_{HT} is one whenever maximum crop temperature does not exceed a temperature threshold (T_{xc}). For higher values, F_{HT} decreases linearly down to zero at T_{x0}.



Response to frost

The simulation approach uses two response functions for frost damage that are computed daily. The response function to frost that has its impact on harvest index (F_{F1}) and another response function that impacts on LAI (F_{F2}).

$$F_{F1} = \begin{cases} 0 & T_N \le T_{100} \\ \dfrac{(T_N - T_{100})}{(T_0 - T_{100})} & T_{100} \le T_N \le T_0 \\ 1 & T_N \ge T_0 \end{cases}$$

where T_N is minimum daily temperature, and the critical temperatures (T_0 and T_{100}) relate to number of flowers or grains (replaced by harvest index, HI).
The calculation of F_{F2}, uses a formula that is formally equal to the previous, but the critical temperatures are different because they relate to number of leaves or whole plants (replaced by canopy LAI)

Calculation of maximum canopy temperature

We compute maximum canopy temperature as:

$$T_c = T_a + [(1-f_G)\,R_n - LE]\,\frac{r_{aH}}{\rho\, C_p}$$

where T_c and T_a are canopy and air temperature (ºC), f_G is the fraction of net radiation invested in soil heat flux (taken as 0.1 during the daytime), LE is latent heat flux, r_{aH} is aerodynamic resistance for heat exchange, ρ is air density and C_p is specific heat of air.
This equation is evaluated at the time of maximum temperature (assumed 3h after solar noon). Both LE and Rn are assumed to follow a sine function, thus they can be estimated from daily integrals:

$$R_n = (1-\alpha)\; 0.84 \times \frac{\pi}{2}\, x\, \frac{10^6 R_{sd}}{3600\, N} - L$$

$$LE = \frac{\pi}{2}\, x\, \frac{2.45\, ET}{10^{-6}\, 3600\, N}$$

Calculation of r_{aH} for unstable conditions may be performed using the simplified equation of Thom and Oliver as a function of wind speed:

$$r_{aH} = \frac{4.72}{1 + 0.54\, U} \left[log\left(\frac{z-d}{z_0}\right) \right]^2$$

Calculation of minimum canopy temperature

We compute minimum canopy temperature as:

$$T_c = \frac{(1-f_G)[-\varepsilon_v\, a + \varepsilon_a\, a + \varepsilon_a\, b\, T_{aw}]\, r_a\, \gamma^* + \rho\, C_p\, [T_a\,(\Delta + \gamma^*) - D]}{\rho\, C_p\,(\Delta + \gamma^*) + (1-f_G)\,\gamma^*\, r_a\, \varepsilon_v\, b}$$

with:
γ = 0.067 kPa K^{-1}
γ^* = $\gamma\,(1+r_c/r_a)$
D = vapor pressure deficit (kPa)
T_{aw} : air temperature measured at weather station (ºC)
Δ = slope of saturation vapor pressure versus temperature (kPa K^{-1})
Δ' = slope of Δ versus temperature (kPa K^{-2})
r_c ; canopy resistance (700 s m^{-1} for dry canopy, 0 for wet canopy)
ε_v : emissivity of vegetation (0.98)
ε_a : emissivity of the atmosphere (see below)
a : coefficient of the linear form of the Stefan-Boltzmann equation (see below)
b : coefficient of the linear form of the Stefan-Boltzmann equation (see below)

The fluxes of downward and upward long wave radiation are calculated using the equation of Stefan-Boltzmann in a linearized form:

$$L_d = \varepsilon_a\,(a + b\, T_a)$$

$$L_u = \varepsilon_v\,(a + b\, T_c)$$

The atmospheric emissivity is calculated as:

$$\varepsilon_a = c + (1-c)\; 1.72 \left(\frac{e}{273 + T_{aw}}\right)^{0.14282}$$

Doorenbos, J. and W. O. Pruitt (1977). Guidelines for predicting crop water requirements. Rome, Food and Agriculture Organization of the United Nations.
Thom, A. S. and H. R. Oliver (1977). *On Penman's equation for estimating regional evaporation.* Quarterly Journal of the Royal Meteorological Society **103**(436): 345-357.

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This work has been funded by the European Commission FP7 project KBBE.2013.1.4-09 No. 613817 “Modextreme” (http://modextreme.org)