Application and verification of ECMWF products 2014

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2. Use and application of products

2.2 Use of products

Following a request of the Public Service of Wallonia (Service public de Wallonie, hereafter SPW), a product based on ECMWF medium-range ensemble forecasts was designed to generate automated warnings of heat stress for workers performing strenuous outdoor duties during summer. The product is based on the prediction of the 'Wet Bulb Globe Temperature' index (*WBGT*) for a time horizon of up to one week. The *WBGT* - see e.g. Parsons (2006) for a more complete discussion - is a composite temperature used by the international standard ISO 7243 to quantify heat stress in hot environments. This index accounts not only for the ambient temperature, but also for the ambient humidity and radiation. It is expressed as:

$$WBGT = 0.7T_{nw} + 0.2T_g + 0.1T_a, \qquad (1)$$

where T_a is the ambient air temperature, T_{nw} is the natural wet-bulb temperature (the temperature of a wet-bulb thermometer directly exposed to the ambient air), and T_g is the temperature of a 150 mm diameter black globe. An example of device used to estimate the $WBGT$ from Eq.(1 is shown on the photograph in Fig. 1. The SPW must take preventive measures consisting mainly of an adaptation of the working schedules when the $WBGT$ is expected to reach or exceed the threshold value of 20°C during any one day of the following week. For convenience, the preventive measures remain in place from that day for the rest of the working week.

Figure 1 – Three-thermometer device used to estimate the *WBGT* from readings of the ambient air temperature (right), the natural wet-bulb temperature (middle) , and the globe temperature (left). Source: http://www.heatstress.nl.

The forecasts are issued every Friday at 11h30 CEST over the period May-October (6 months). The product consists of a simple 3x4 table containing logical values "false" (predicted $WBGT < 20°C$) or "true" (predicted $WBGT \geq 20°C$) for the following Monday, Tuesday, Wednesday and Thursday in three sub-regions of Wallonia. The forecasts for the following Friday are not included in the product at this stage. Figure 2 below shows a concrete example of forecast table.

Vendredi 11/07/2014				
Zone	Lundi 14/07/2014	Mardi 15/07/2014	Mercredi 16/07/2014	Jeudi 17/07/2014
B	F	F	T	T
D	F	F	T	T
E	F	F	F	T

Figure 2 – Forecast table issued on Friday 11th July 2014 at 11h30 CEST for sub-regions B, D and E. The logicals "T" (true) and "F" (false) are used to indicate whether or not the *WBGT* threshold of 20°C is predicted to be reached or exceeded on any one day of the next working week between Monday 14th and Thursday 17th. Zone B refers to the sub-region north of the the rivers Sambre and Meuse and the southern tip of the Province of Luxembourg, zone E refers to the Ardennes and D to the remainder of Wallonia.

The forecasts are thus expressed in a deterministic binary format using probabilistic information from the ECMWF medium-range ensemble prediction system. The methodology used to convert the probabilistic forecasts into deterministic “either false or true” forecasts is explained below.

Each of the three sub-regions of Wallonia is represented by a set of locations for which reliable synoptic observations are available. Every Friday, maximum 2-m temperature (T_x) and 2-m dew-point temperature (T_d) forecasts are retrieved for these locations from the latest ensemble run (51 forecasts, initial time 00UTC, 6-hourly time steps). For each forecast day, the ensemble distribution of the daily maximum $WBGT$ is estimated from the daily maximum T_x and daily maximum T_d of each ensemble member. This approach inflates the estimates of the daily maximum $WBGT$ somewhat because T_x and T_d do not necessarily culminate together. Some underestimation, on the other hand, is induced by the fairly coarse 6-hour granularity of the ensemble forecasts and by the fact that the daily maximum T_d is estimated from 6-hourly dew-point temperature instead of 6-hourly maximum dew-point temperature, the latter variable being unavailable from ECMWF ensemble forecast data.

As in this case the $WBGT$ must be calculated with reference to meteorological data (weather forecasts and synoptic observations), the formula of Eq. 1 has been adapted as shown by Eq. 2 below (from Lemke and Kjellstrom, 2012):

$$WBGT \approx 0.67T_{wb} + 0.33T_{db} - 0.048 * \log_{10} v(T_{db} - T_{wb}), \qquad (2)$$

where T_{db} is the 2-m (dry-bulb) temperature, T_{wb} the wet-bulb temperature and v the surface air speed. The parameter v has been set to 0.3 *m/s* so that the computed $WBGT$ match closely with the official reference $WBGT$ tables published by the Belgian Federal Public Service *Employment, Labour and Social Dialogue.* These tables use air temperature and relative humidity as entries instead of air temperature and dew-point temperatures. Furthermore, many sensors at automatic observing stations also measure relative humidity rather than dew-point temperatures because measurements of the latter entail more maintenance costs. The wet-bulb temperature T_{wb} is therefore calculated from the dry-bulb temperature T_{db} and relative humidity RH (expressed in %) using an empirical fit based on gene-expression programming (Stull, 2011):

$$\begin{aligned} T_{wb} = {} & T_{db} \arctan(0.151977(RH + 8.313659)^{1/2}) + \arctan(T_{db} + RH) - \arctan(RH - 1.676331) \\ & + 0.00391838 RH^{3/2} \arctan(0.023101 RH) - 4.686035. \end{aligned} \qquad (3)$$

RH is not directly available as forecast variable and must derived from the available T_d by means of the well-known August-Roche-Magnus approximation (Alduchov and Eskridge, 1996):

$$RH = 100 \frac{\exp\left(17.625T_d / (T_d + 243.04)\right)}{\exp\left(17.625T_{db} / (T_{db} + 243.04)\right)}. \qquad (4)$$

Probabilities that the $WBGT$ will be reached or exceeded at any one day are estimated simply by taking the proportion of forecasts where the corresponding daily maximum $WBGT$ is equal to or greater than 20°C. In order to convert these probability forecasts into simple binary forecasts, suitable cut-off probabilities had to be determined. In order to do this, an analysis of past ensemble forecasts runs with the same model version has been performed for the period May-October 2013. The strategy adopted to select optimal probability thresholds is based on simultaneously maximising the hit rate H (the proportion of observed daily maximum $WBGT \geq 20°C$ that were correctly forecast) and minimising the false alarm rate F (the proportion of observed daily maximum $WBGT < 20°C$ that were incorrectly forecast). In order to have a sufficient sample size, all ensemble forecasts from 00UTC and 12 UTC during that period have been used for the analysis – so not just forecasts starting from Friday at 00 UTC. Figure 3 shows H and F obtained with probability thresholds ranging from 10% to 90% for all ensemble runs from 00 UTC (184 forecasts) out to 15 days at station 06447 (Uccle). As expected, detection is improved (solid lines) when the chosen cut-off probability threshold is set lower, but the price to pay for more hits is an increase in the number of false alarms (dashed lines). Overall, the scores worsen at greater ranges due to skill loss. As we focus on ranges between 4 and 7 days (from Monday to Thursday when using forecasts starting from Friday at 00UTC), a threshold of 30% (cyan lines) manages to keep H high (~80%) while maintaining F as far as possible below 10%. In principle, probability thresholds could be set individually for every location of interest and for each day in the forecast range. However, H and F do not vary significantly from day 4 to 7 with a cut-off probability of 30%. Moreover, results at other locations are fairly similar. Consequently, for simplicity’s sake, a constant cut-off probability threshold of 30% has been chosen at all ranges and stations of interest. This rather low

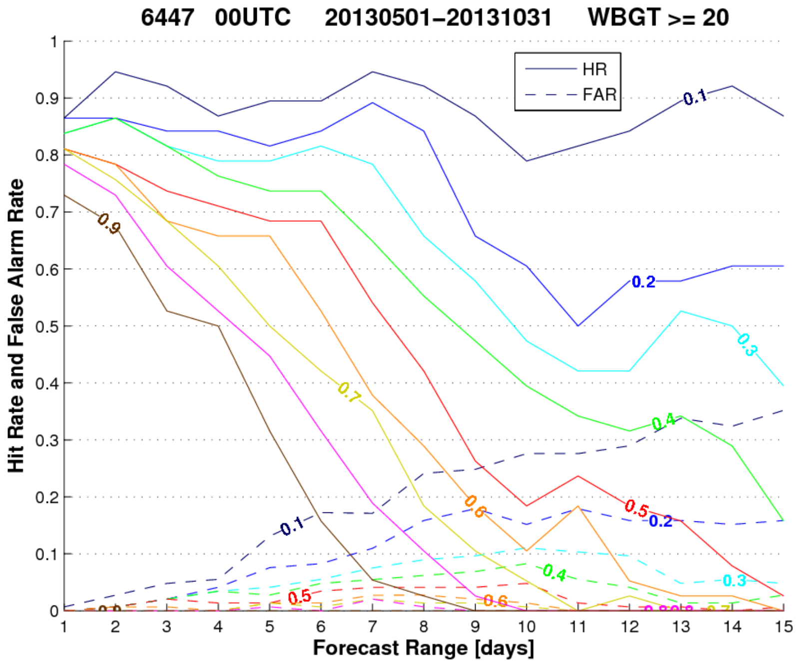

Figure 3 – Hit rate (solid lines) and false-alarm rate (dashed lines) for various probability thresholds (from 0.1, or 10% to 0.9, or 90%). Predicted event: daily maximum *WBGT* ≥20°C. 15-day ECMWF ensemble forecasts, all 00-UTC runs. Period: 1st May to 31st October 2013. Location: Uccle (WMO ID 06447).

threshold value of 30% is consistent with and compensates for the negative biases that predominate in the forecasts of daytime 2-m temperatures and 2-m dew-point temperatures.

For each sub-region, the state of the warning ("true" or "false") is set to "true" if at least one of the stations belonging to that sub-region is in state "true", otherwise it is set to "false". Figure 4 features results from the 2013 analysis with a cut-off probability threshold of 30% for sub-region B.

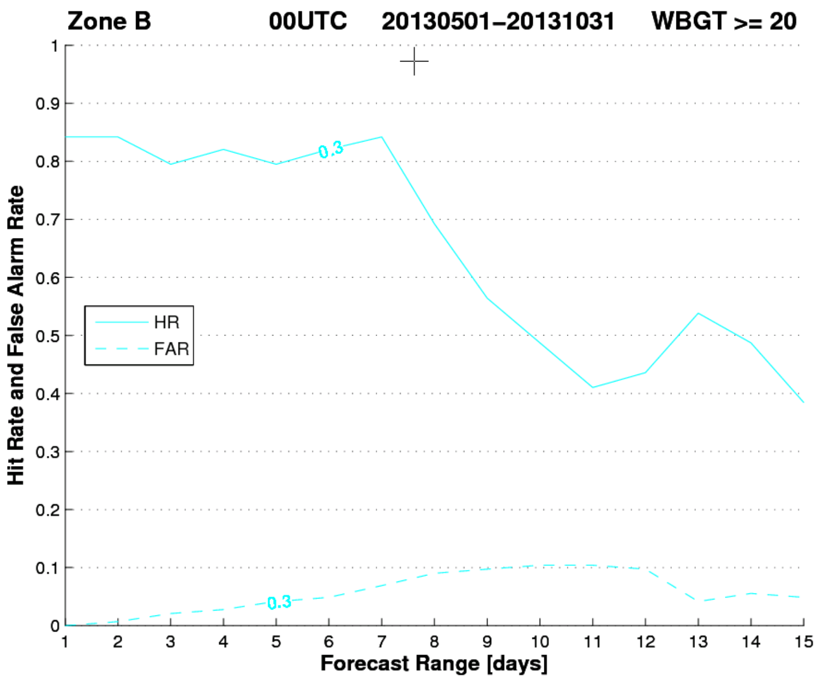

Figure 4 – Hit rate (solid line) and false-alarm rate (dashed line) over Zone B.

The results for 2013 presented above have provided a basis to set up the operational system currently in place. It is planned to improve this warning system when feedback from the user and verification results for 2014 are available.

4. References

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