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ΜΕΤΕΩΡΟΛΟΓΙΚΗ
ΥΠΗΡΕΣΙΑ
HELLENIC NATIONAL METEOROLOGICAL SERVICE

Heat stress conditions based on ICON-GR forecasts

Flora Gofa, Dimitra Boucouvala

WG5 parallel session, COSMO GM 2023, Gdansk

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Human response to heat: **Determining Factors**

Basic physical elements of thermal environment

- Air Temp, mean radiant Temp (sources), absolute humidity, air movement (wind speed)

Basic physiology elements of thermal environment

- work load, clothing, duration of exposure, health condition

Thermal Stress Indicators (TSI) Study

Table 2 | The environmental parameters used by the 187 meteo-based thermal stress indicators.

ID	Thermal Index	First Author	Year	Unit	Temperature	Humidity	Radiation	Wind
172	Wet Bulb Temperature[90]	Liljegren	2008	°C	✓	✓	✓	✓
173	Wet Bulb Temperature[120]	Malchaire	1976	°C	✓	✓	✓	✓
174	Wet Bulb Temperature[149]	Stull	2011	°C	✓	✓		
175	Wet Cooling Power[73]	Landsberg	1972	mcal/cm²/s	✓	✓	✓	✓
176	Wet Globe Temperature (Botsball)[appr.150]	Botsford	1971	°C	✓	✓	✓	✓
177	Wet Kata Cooling[82]	Maloney	2011	W/m²	✓	✓	✓	✓
178	Wet Kata Cooling Power[105]	Chamber of Mines of South Africa	1972	mcal/cm²/s	✓	✓	✓	✓
179	Wet Kata Cooling Power[151]	Krisha	1996	W/m²	✓	✓	✓	✓
180	Wet Kata Cooling Power[152]	Hill	1919	mcal/cm²/s	✓	✓		✓
181	Wet-Bulb Dry Temperature[123]	Wallace	2005	°C	✓	✓	✓	✓
182	Wind Chill[153]	OFCM/NOAA	2003	°C	✓			✓
183	Wind Chill[154]	Siple	1945	kg cal/m²/hr	✓			✓
184	Wind Chill[155]	Steadman	1971	cal/m²/s	✓	✓	✓	✓
185	Wind Chill Equivalent[156]	Quayle	1998	°C	✓			✓
186	Wind Chill Equivalent Temperature (wind of 1.34 m/s)[157]	Falconer	1968	°C	✓			✓
187	Winter Scharlau Index[cit:133]	Sharlau	1950					

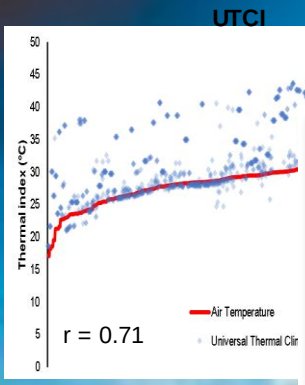
187 meteorologically based indices
Tested and correlated to human response

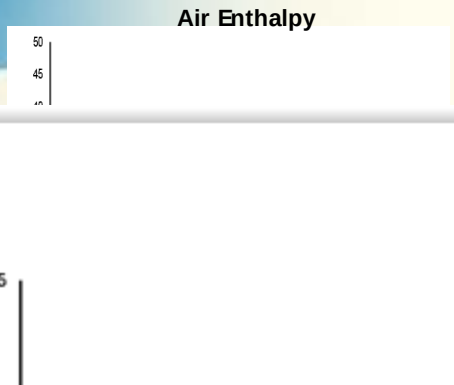
Information on complex parameters used for the computation of some thermal indices.
In case where the calculation of a thermal index requires any of the following parameter, that para

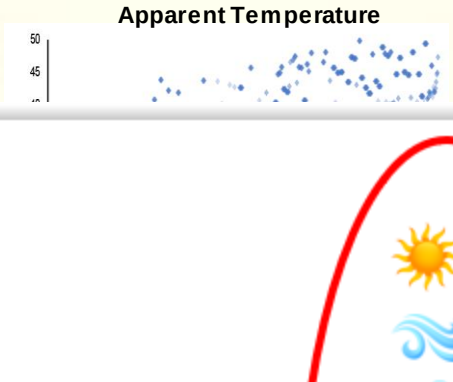
	Temperature	Humidity	Radiation	Wind
Mean Radiant Temperature	✓	✓*	✓	✓
Dew point	✓	✓		
Wet Bulb Temperature	✓	✓	✓	✓*
Globe Temperature	✓	✓	✓	✓*
Vapor Pressure	✓	✓		
Saturated Vapor Pressure	✓			
Wet Bulb Globe Temperature	✓	✓	✓	✓
Psychrometric Wet Bulb Temperature	✓	✓		✓

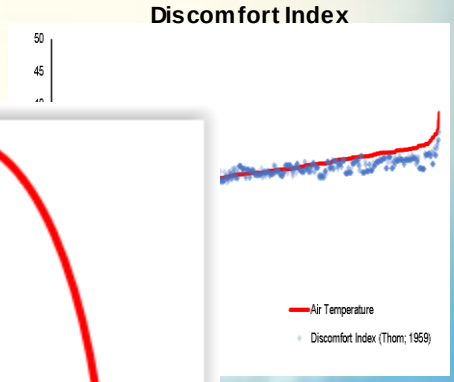
*indirect use of a parameter incorporating that factor

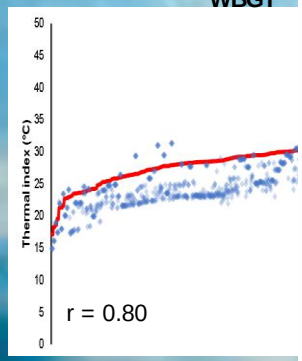
Air Temp VS Thermal Stress indices

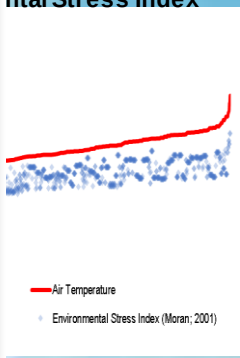


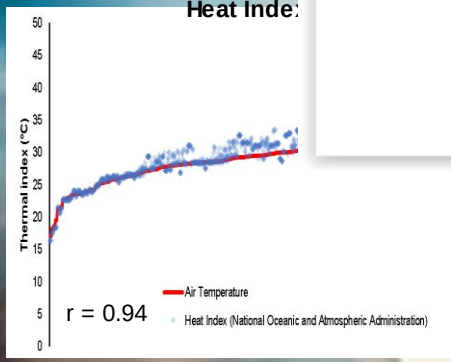


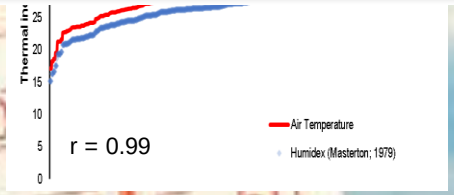


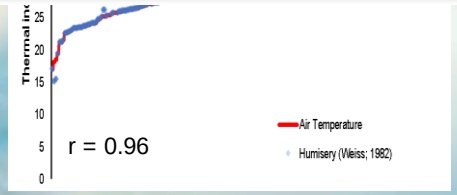


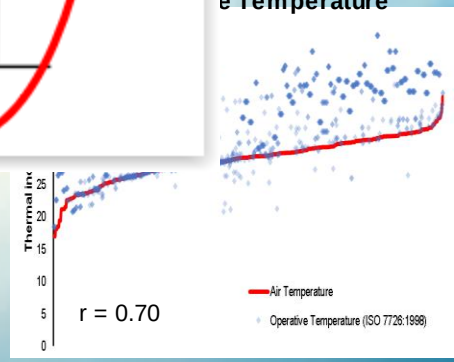












WGBT Wet Bulb Globe Temperature Index

Measure of Heat Stress – widely accepted (since +50yrs) based on **sun** and **wind** effect

- Its limitations result from the non-standard instrumentation and calibration procedures which erode its accuracy
- Various estimation approaches from air temp and humidity (omit radiant Temp and/or WindSpeed)
- Limitations: formula of WGBT leads to underestimation of heat stress when restricted evaporation exists. Keep in mind that WGBT results from a combination of elements, so human response to a given level of the index are not uniform

WBGT - Liljegren προσέγγιση

James C. Liljegren , Richard A. Carhart , Philip Lawday , Stephen Tschopp & Robert Sharp (2008) Modeling the Wet Bulb Globe Temperature Using Standard Meteorological Measurements, Journal of Occupational and Environmental Hygiene, 5:10, 645-655,

The (outdoor) WBGT is the weighted sum of the natural wet bulb temperature T_w, the globe temperature T_g, and the dry bulb (ambient) temperature T_a:

$$\mathrm{WBGT} = 0.7T_w + 0.2T_g + 0.1T_a. \quad \textbf{(1)}$$

Separate models for the natural wet bulb temperature and the globe temperature are necessary to accurately model the WBGT.

$$T_w = T_a - \frac{\Delta H}{c_p}\frac{M_{H2O}}{M_{Air}}\left(\frac{\mathrm{Pr}}{Sc}\right)^a\left(\frac{e_w - e_a}{P - e_w}\right) + \frac{\Delta F_{net}}{A\,h}.$$

$$\frac{\Delta F_{net}}{A} = \sigma\varepsilon_w\left[\frac{1}{2}(1+\varepsilon_a)T_a^4 - T_w^4\right] + (1-\alpha_w)S\left[(1-f_{dir})\left(1+\frac{D}{4L}\right) + f_{dir}\left(\frac{\tan(\theta)}{\pi}+\frac{D}{4L}\right)+\alpha_{sfc}\right].$$

WBGT model has been developed that is based on the forecast of weather parameters. It consists of modules for the calculation of Tw and the Tg.
Each modules is developed based on fundamental heat and mass transfer principles.
Code available in R.

$$T_g^4 = \frac{1}{2}(1+\varepsilon_a)T_a^4 - \frac{h}{\varepsilon_g\sigma}(T_g - T_a) + \frac{S}{2\varepsilon_g\sigma}(1-\alpha_g)\left[1+\left(\frac{1}{2\cos(\theta)}-1\right)f_{dir}+\alpha_{sfc}\right].$$

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WBGT thresholds (color code)

ΧΡΩΜΑΤΙΚΟΣ ΔΕΙΚΤΗΣ WBGT

Κατηγορία	WBGT (F°)	WBGT (C°)	Χρώμα Κατάστασης
1	≤78…81,9	≤25,6…27,7	λευκό
2	82…84,9	27,8…29,4	πράσινο
3	85…87,9	29,4…31	κίτρινο
4	88…89.9	31,1…32,1	κόκκινο
5	≥90	≥32,2	μαύρο

ΛΕΥΚΟ: Κανονική δραστηριότητα

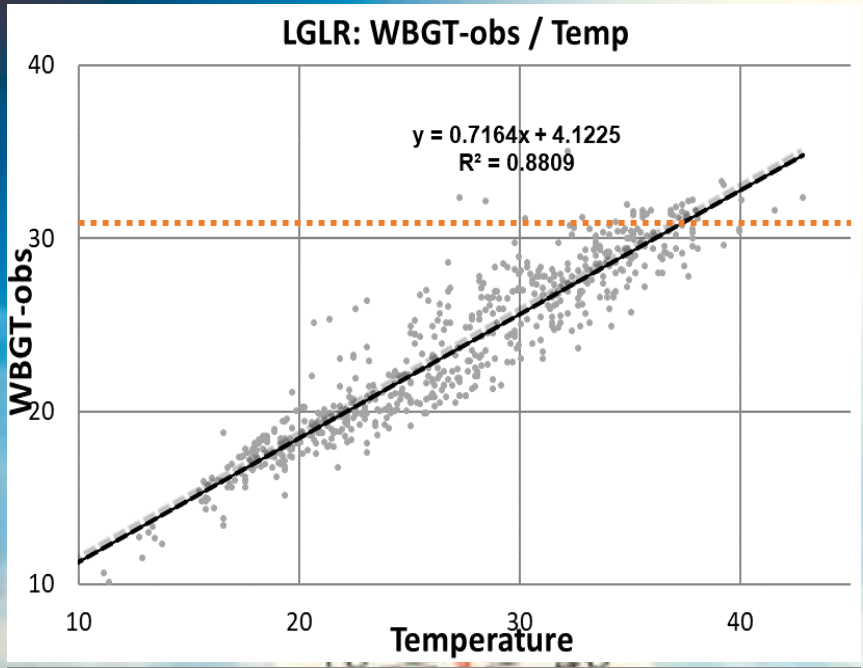
ΠΡΑΣΙΝΟ: Διακριτική ευχέρεια για εκπόνηση βαριάς εργασίας από μη εγκλιματισμένο προσωπικό. Οριακή τιμή δείκτη. Συχνή κατανάλωση νερού (ανά 1 ώρα)

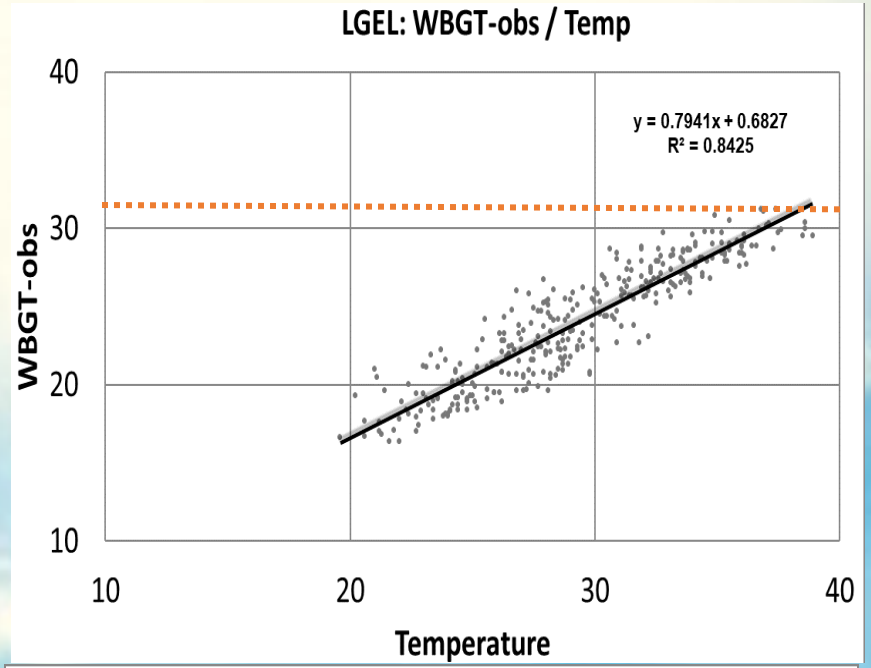
ΚΙΤΡΙΝΟ: Περιορισμός στην έντονη εργασία για μη εγκλιματισμένο προσωπικό. Να αποφευχθεί η εργασία σε μέρη χωρίς σκίαση. Φροντίδα για διαστήματα ανάπαυσης. Κατανάλωση νερού (ανά 30 λεπτά)

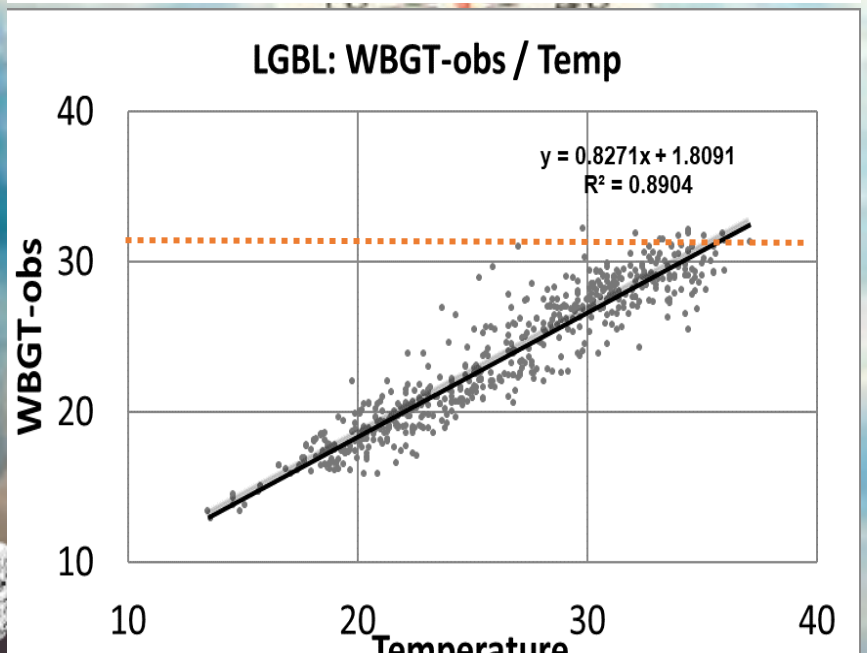
ΚΟΚΚΙΝΟ: Συνιστάται αποφυγή εργασίας στο άμεσο ηλιακό φως. Μεγάλα διαστήματα ανάπαυσης. Κατανάλωση νερού (ανά 15 λεπτά).

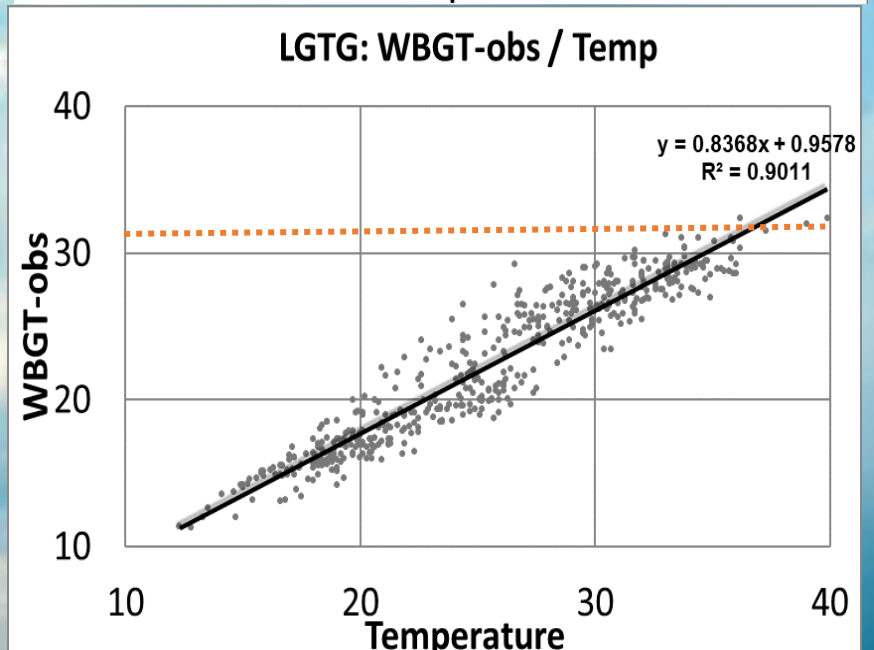
ΜΑΥΡΟ: Συνιστάται παύση κάθε εξωτερικής εργασίας σε χώρους χωρίς σκιά.

Correlation: WBGT-Temp OBS

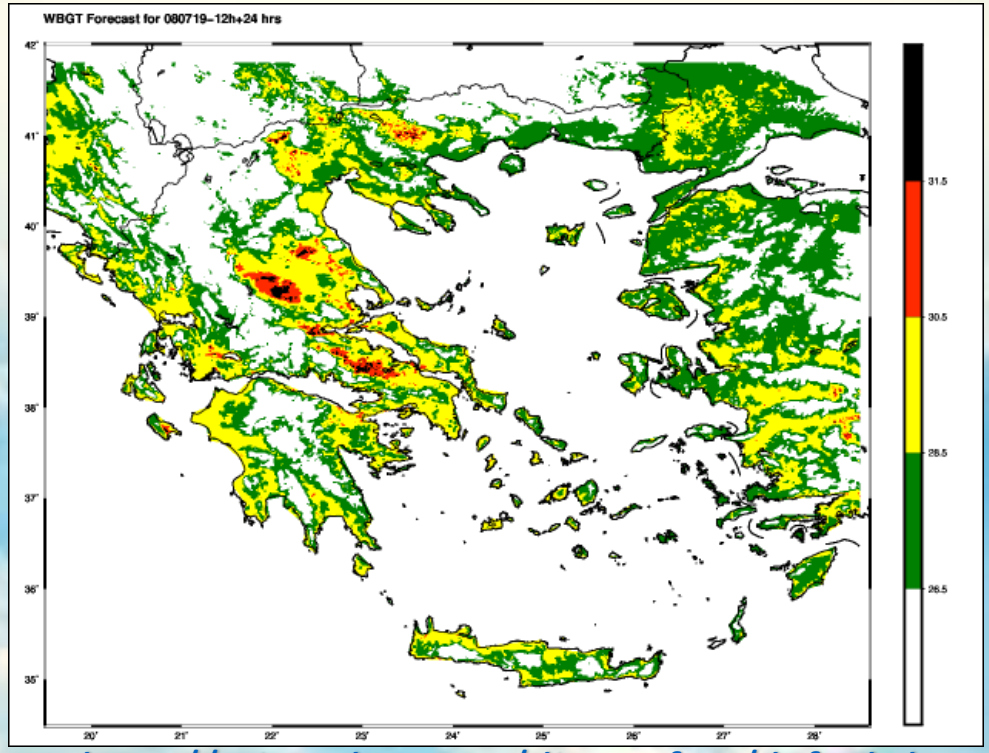




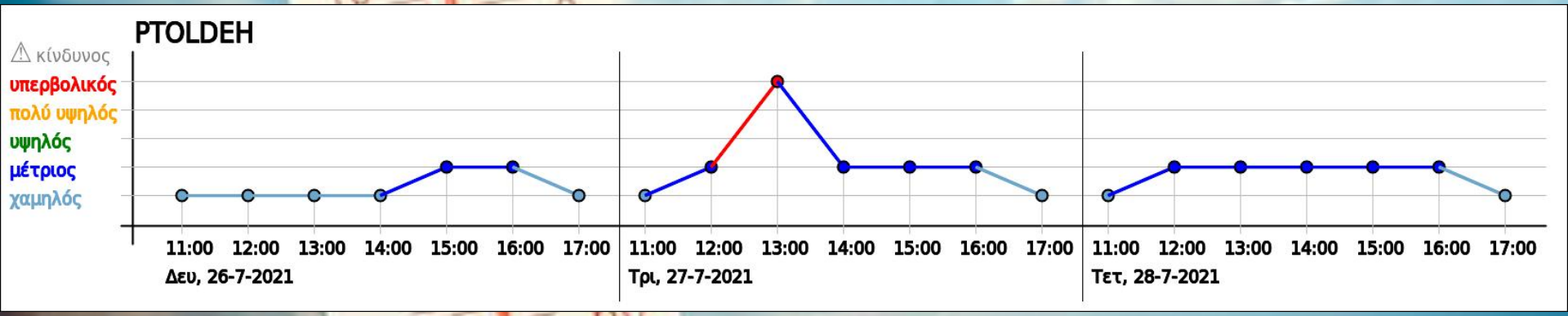




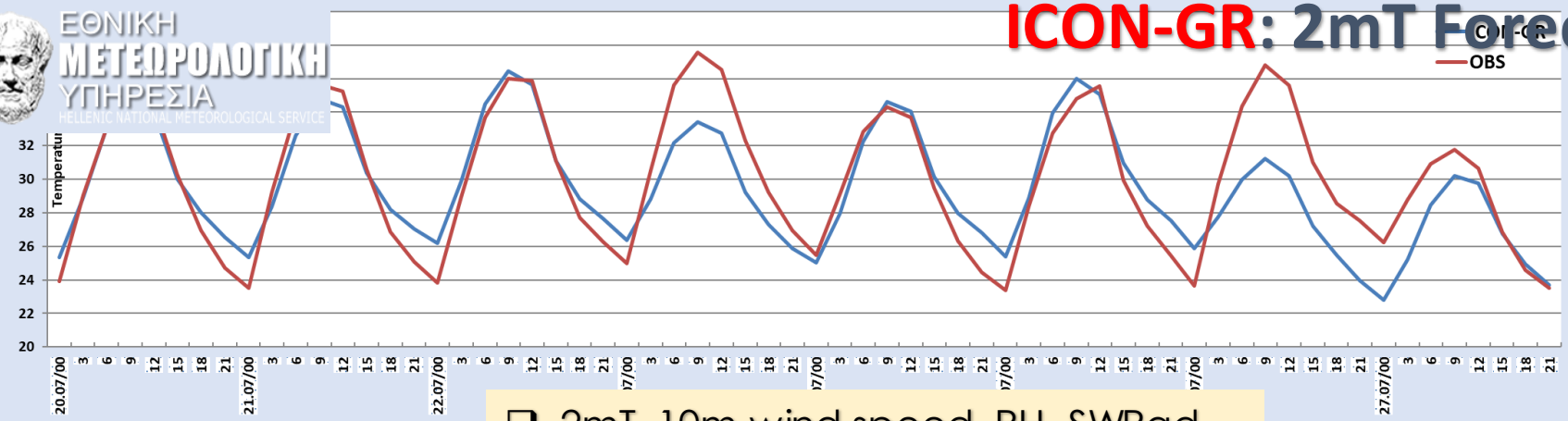
Daily WBGT and other bioclimatic indices forecasts at HNMS



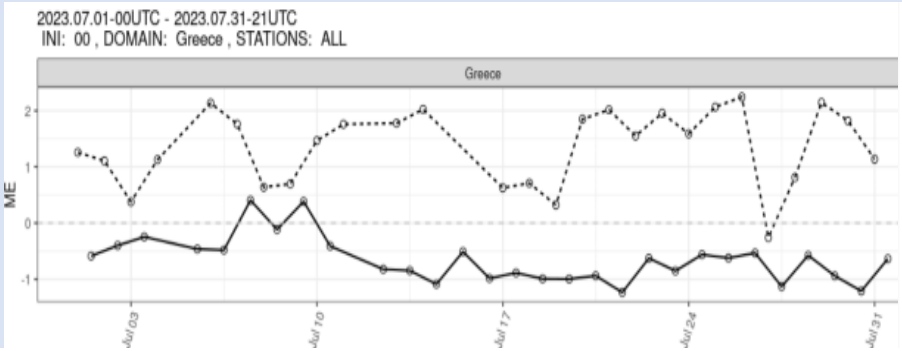
http://minya.hnms.gr/discomfort/default.htm

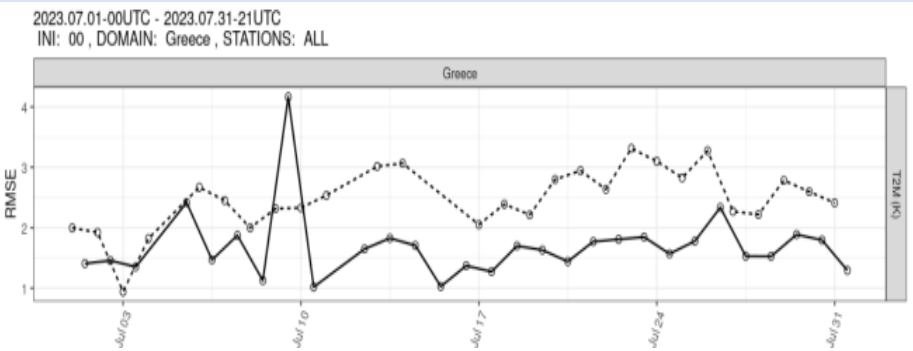


ICON-GR: 2mT Forecasts



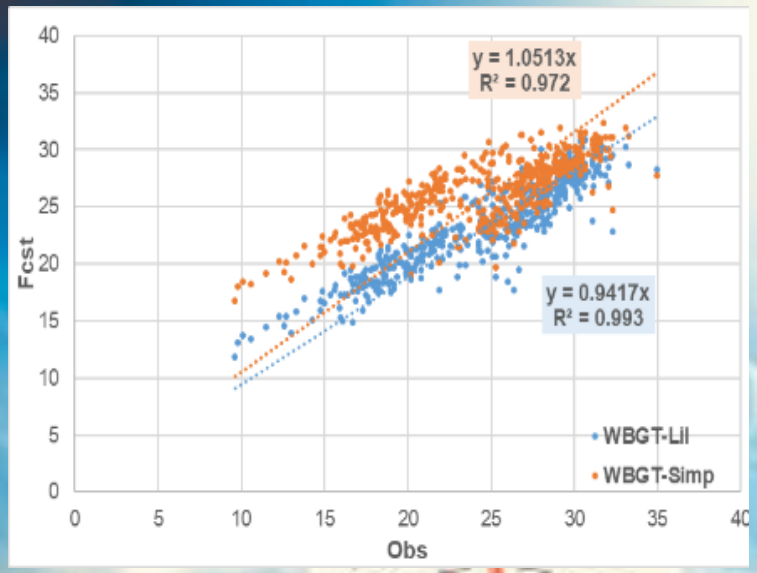
- 2mT, 10m wind speed, RH, SWRad 48h forecasts from **ICON-GR**
- **WBGT** forecasts twice per day targeted to the warm period of the day.
- Heat wave: 17-27 July
- Municipalities in Attica and Ministry of Labor based extra measures of external work on WBGT forecasts
- No WBGTobs available to verify…..

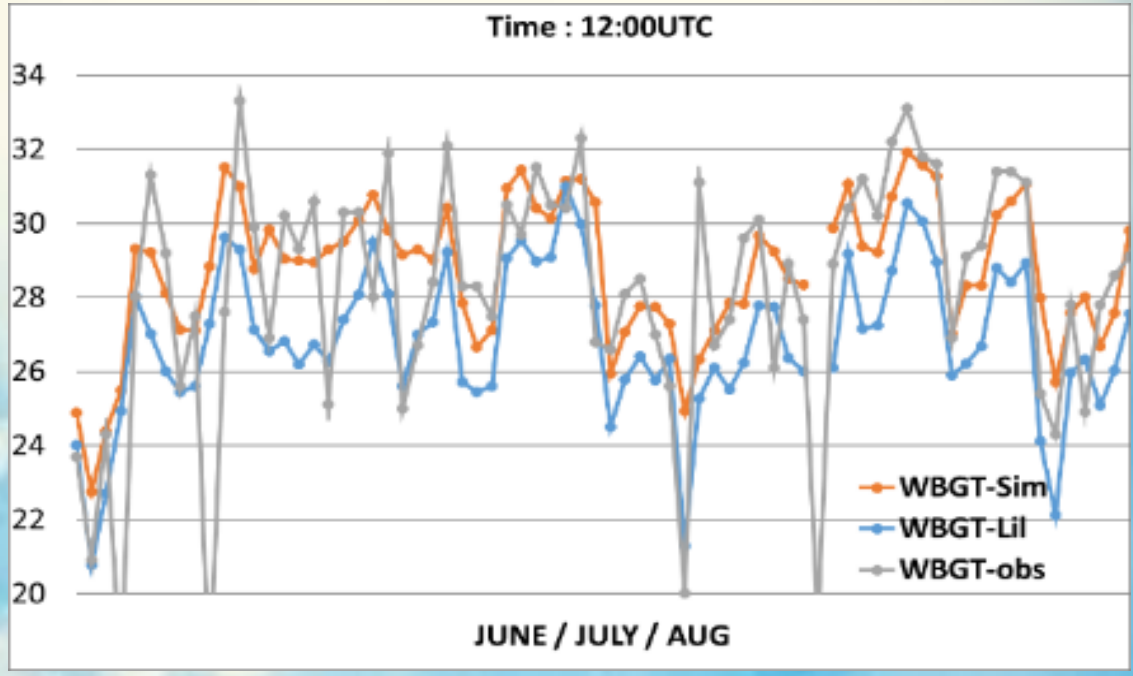




- Constant underestimation of maximum 2mT during summer, leads to similar error of WBGT forecasts
- Higher 2mT max discrepancies in **urban areas**

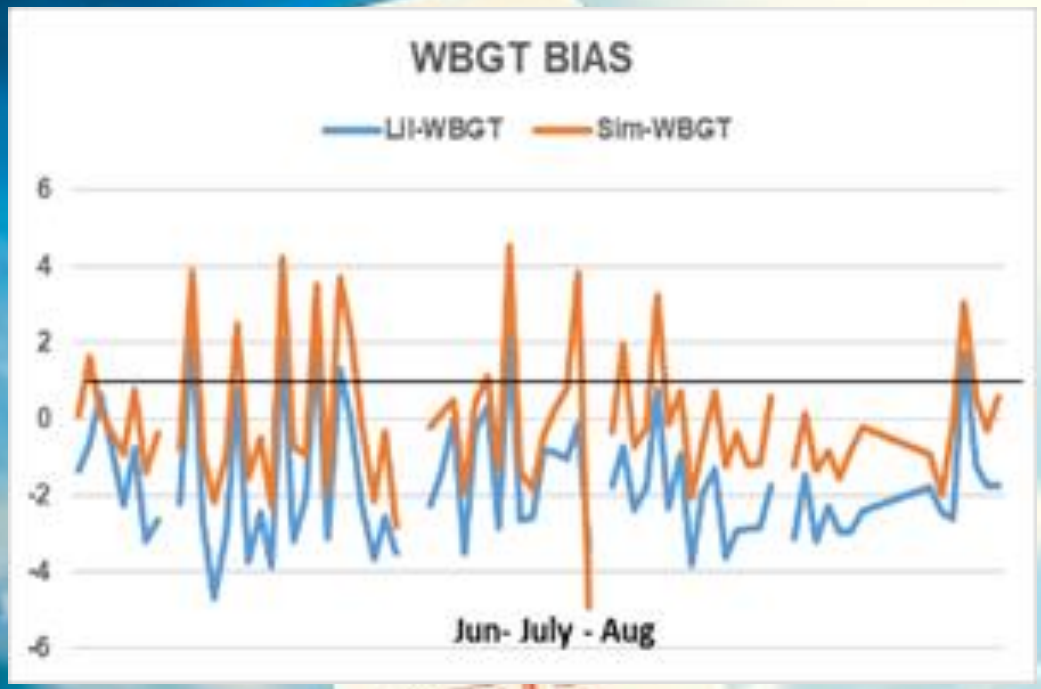
WBGT - Forecasts





- Scatter plot: WBGT forecasts correlated with the actual observation.
- Correlation coefficient for WBGT-Lil and WBGT-Sim are 0.97 and 0.99 respectively
- Use of the Liljgren approach leads to improved forecasts of WBGT
- Time series (only 12UTC values), WBGT-Sim forecast tends to overestimate obs values at lower ranges.
- WBGT-Lil forecasts **underestimate observed values**, which is especially obvious at the observed maxima.

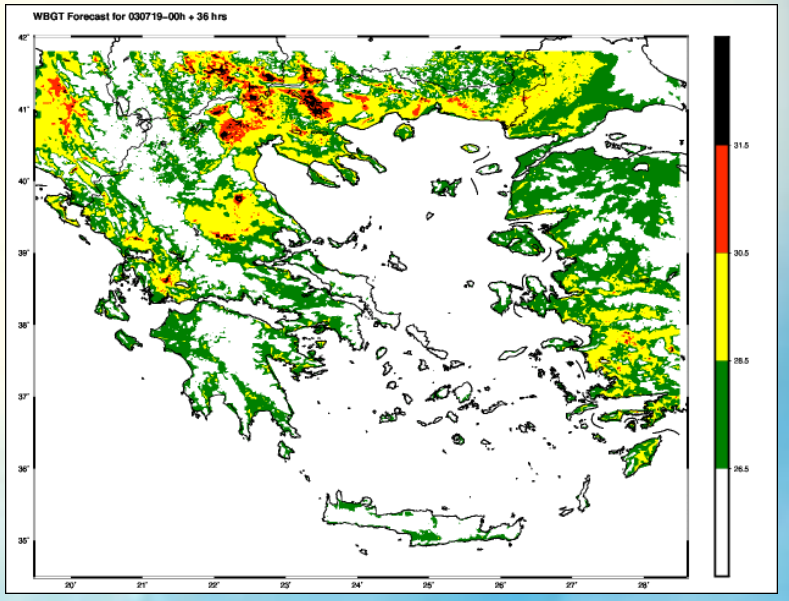
WBGT Forecasts: Statistical Evaluation

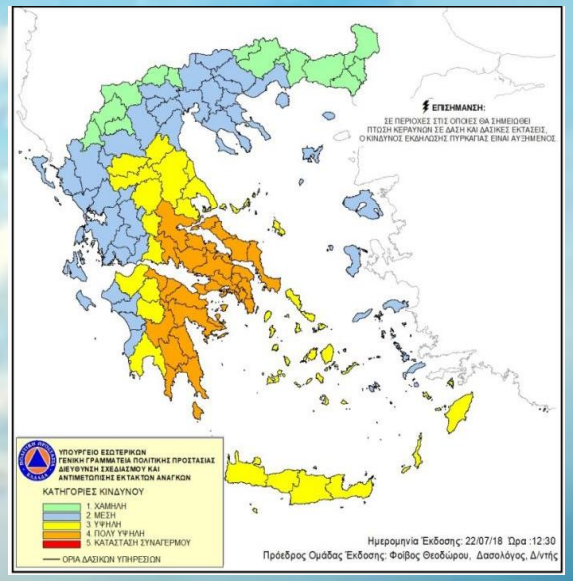


- Obs comparison with Fcs values
- Only the LGLR values for 12:00UTC (warmer part of the day) were used for June, July and August
- Mean BIAS is **+1.87** for WBGT-Sim, which indicates overestimation, while the mean BIAS for WBGT-Lil is **-1.15**, indicating an underestimation.
- Average RMSE is **3.74** and **2.42** for the WBGT-Sim and WBGT-Lil respectively.
- Use of the more sophisticated formula enables more reliable prediction.

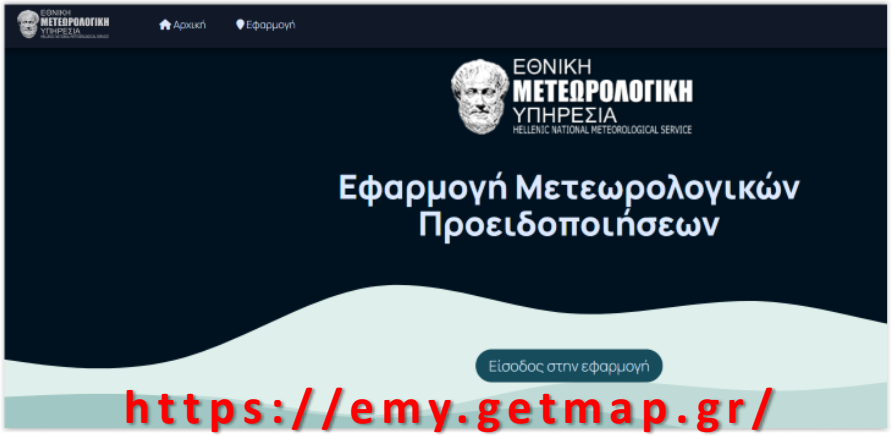
Next steps

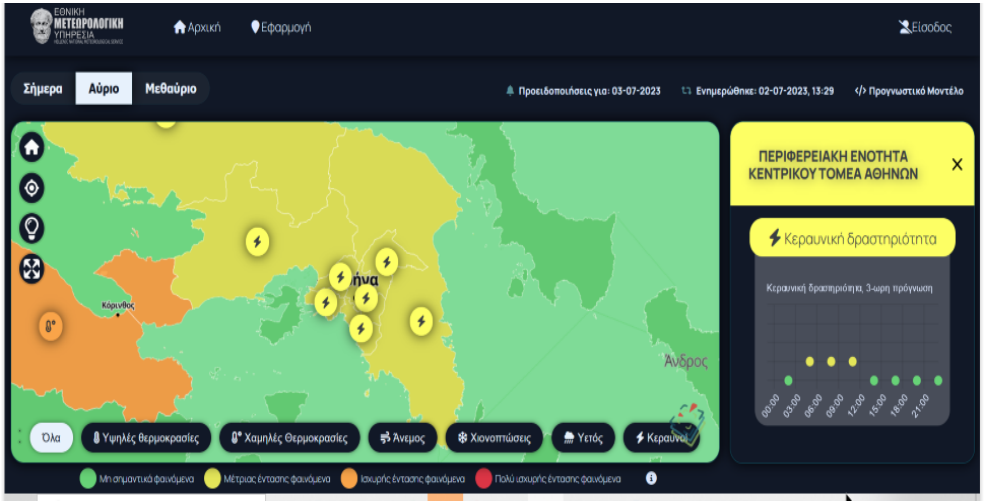
- Installation of WBGT sensors in main airports as reference
- Calculate **Hazard Color Approach** per municipality as part of daily forecast for the public
- Include Heat Stress Index (WBGT) in HNMS Climate Atlas based on climate data series of weather parameters – Trends
- The ongoing **climate change** makes temporal and spatial variations of workplace heat exposure into key public health and occupational health issues in our area.
- Necessity for **legislation for occupation in heat stress conditions** based on TSIs to protect the health and productivity of working people.





AUTOWARNING SYSTEM





Επίπεδα ειδοποίησης (alert)

- Μη σημαντικά φαινόμενα: Τα φαινόμενα που αναμένονται δε χρήζουν ιδιαίτερης επαγρύπνησης.
- Μέτριας έντασης φαινόμενα: Τα φαινόμενα που αναμένονται δεν είναι ασυνήθιστα μπορούν όμως να γίνουν επικίνδυνα.
- Ισχυρής έντασης φαινόμενα: Αναμένονται ισχυρά μετεωρολογικά φαινόμενα, τα οποία μπορούν να προκαλέσουν ζημιές και ατυχήματα. Συνίσταται να είστε προσεκτικοί.
- Πολύ ισχυρής έντασης φαινόμενα: Αναμένονται πολύ ισχυρά μετεωρολογικά φαινόμενα, τα οποία είναι συνήθως επικίνδυνα και μπορεί να προκαλέσουν μεγάλες ζημιές και ατυχήματα. Συνίσταται να είστε προσεκτικοί και να ακολουθείτε τις οδηγίες των αρχών.

Heat stress conditions based on ICON-GR forecasts

Thank you

- *Establishing heat stress indicators for work in a warming world: multi-country field evaluation and consensus recommendations, September 2022, ISEE Conference Abstracts 2022(1)*
- *Indicators to assess physiological heat strain – Part 2: Delphi exercise, March 2022, Temperature 9(2):1-11*

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NWP high resolution predictions at HNMS

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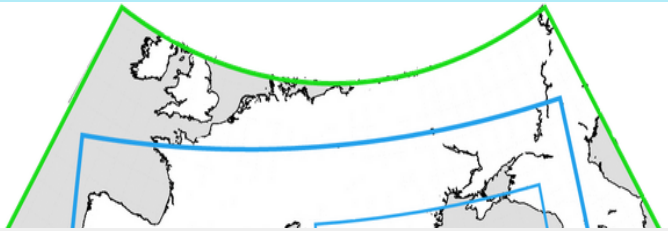
The areas involved in this 4km+1km "operational" cycle are:

The **IFS domain** provides the Boundary Condition fields for the 4km-Cosmo. It a regular lat-lon area, 65x35deg, with 0.1deg resolution (651x351 points), containing all vertical levels of IFS. Its files are provided by local dissemination, for 72-hours (per 3hours).



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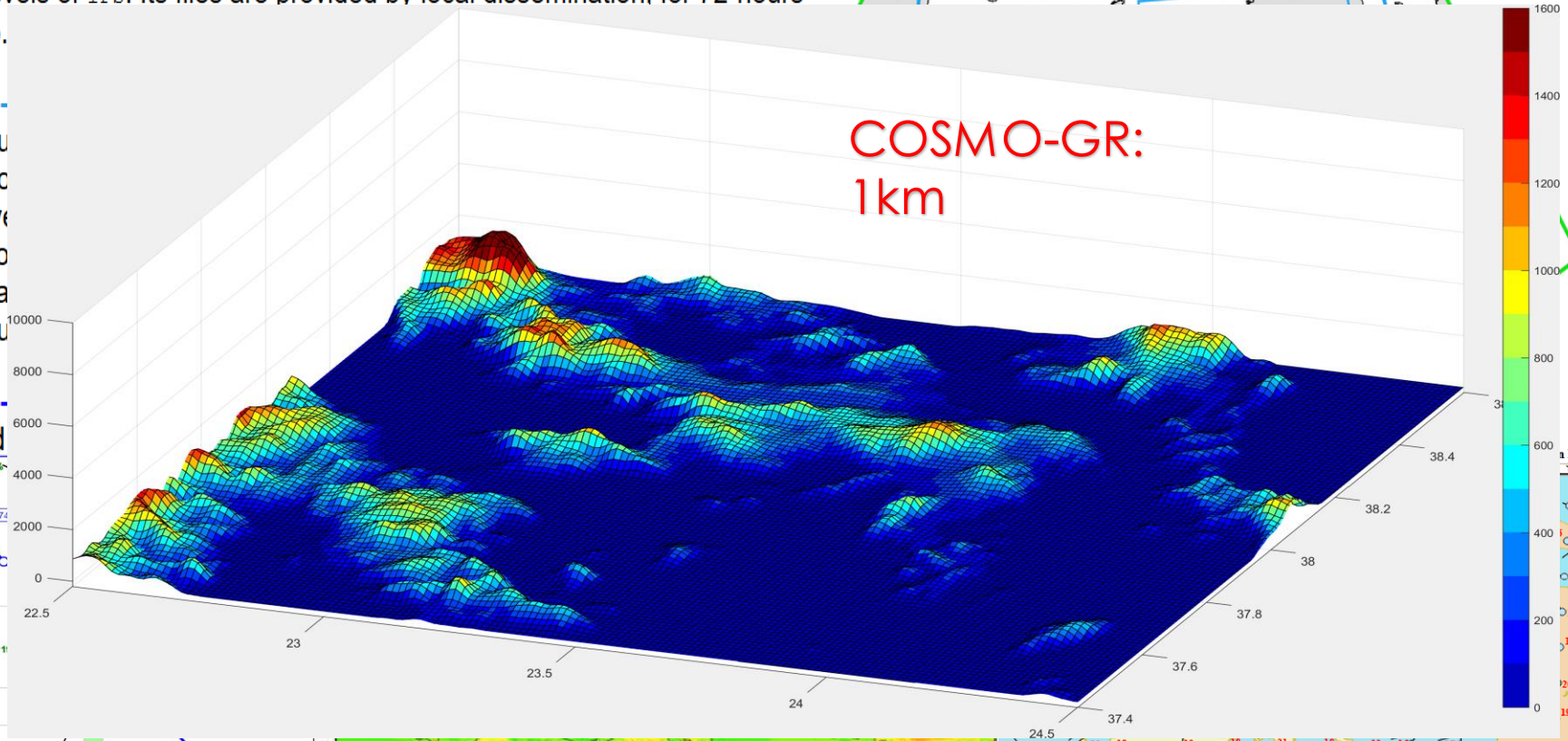

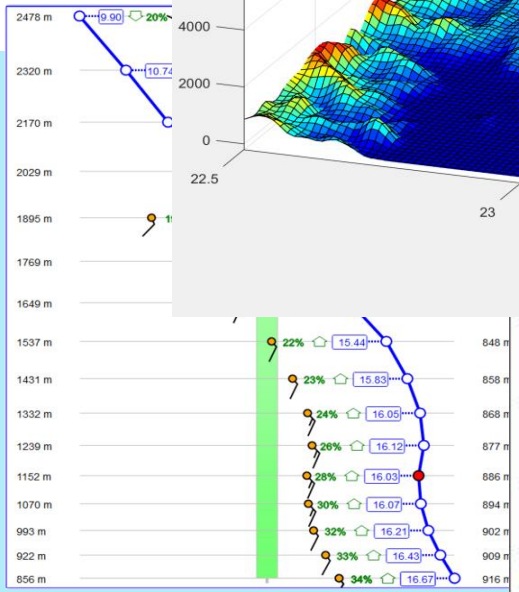

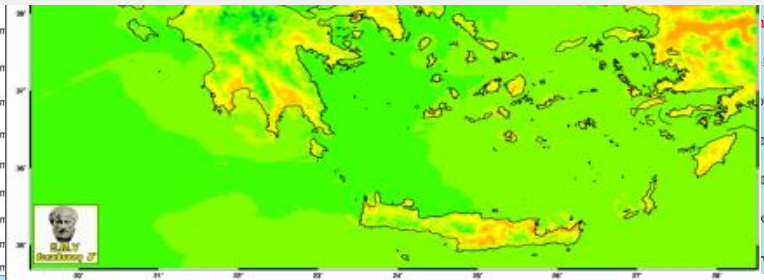

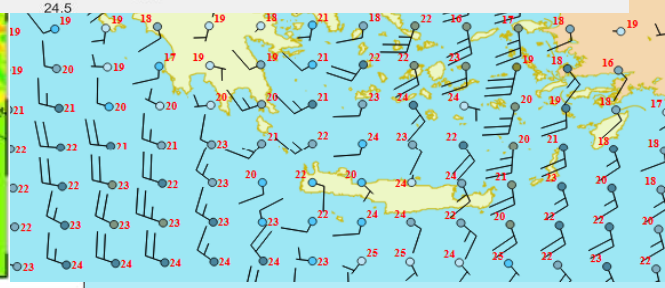

Collaboration of HNMS with Minitry of Labor/University of Thessaly

- Measurements of WBGT were performed near meteorological stations inside airports. Specifically, sensors were put in Larissa (**110**) , Nea agchialos (**111)** and Tanagra (**114**) military airports.
- The sensors were provided by the University of Thessaly FAMELab (**F**unctional **A**rchitecture of **M**ammals in their **E**nvironment] research team.
- Tha data were analyzed and compared to empirical relations for the estimation of WBGT and also were used for the evaluation of forecasted values from NWP model.
- Experimental period: May-September