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Article

Thermal Convection Forecast using a Theoretical Model Calibrated with Statistical Data from Soaring Flights

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Abstract: A forecasting scheme of the thermal updraft velocity based on a theoretical model and data collected from flights records at gliding competitions, is presented. The forecasting scheme was based on the hypothesis that there is linear relationship between the overheat function at ground surface and the temperature difference between soil and air. The proportionality factor of this relationship was determined experimentally using observations recorded during gliding flights. The results showed that based on this simple scheme forecasting thermal convection is possible at any geographical location.

Keywords: Thermal updraft velocity; Thermal convection; Soaring; Atmospheric Boundary Layer; Soaring birds; Sailplane; Aviation safety.

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1. Introduction

Thermal convection forecasting play an fundamental role in free flying activities, but is also important for general aviation. Since 1924, at soaring competitions, forecasts about thermal condition were made. At the beginning those forecast ware make by sounding atmosphere every morning to see the Atmospheric Boundary Layer (ABL) structure [1,2]. Currently, several platforms dedicated to forecasting thermal convection have been developed such as Regional Atmospheric Soaring Prediction (RASP) created by Jack Glendening[1], or ALPTHERM a PC-based model for atmospheric convection over complex topography operationally used by German, Austrian and Swiss weather services [3,4]. Visoiu et al. (2018) [5] have studied the performances of the RASP model at the 2017 edition of the Romanian Gliding Championship and showed that the model can result in errors up to 50%.

Forecasting thermal convection is also important for civil and military aviation and knowledge of forecasting of thermal convection can help pilots to avoid incidents [4]. The risk posed, for example, by collision between soaring birds and aircrafts is relatively high and can lead to fatal accidents [6]. In case, to avoid such accidents, is important to know not only the updraft velocity but also the boundary layer (BL) height. Many migratory birds such as White Pelican, White Stork, Lesser Spotted Eagle, or Honey Buzzard do not climb up to top of the ABL, but up to a height positively correlated with the thermal convection intensity or prefer to stay in the band of maximum convection, which also depends on the thermal convection intensity [7,8]. Beyond the importance of the thermal convection practice for the soaring and the safety of civil and military aviation, the prognosis of thermal convection can play a fundamental role in global weather and climate prediction [e.g., 9].

Lee (2012) [2] showed that the link between glider pilots and the scientific community has led to many important scientific contributions that have helped meteorologists and glider pilots to better

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1 http://www.drjack.info/RASP/index.html, accessed on 2 September 2018

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understand the atmosphere. In this article we further explore the link between two communities by using a theoretical model in conjunction with data provided by flight recorders fitted on sailplanes. The aim is to develop a predictive model that can be of benefit to glider pilots during gliding completions.

2. Theoretical Model

Zakinyan et al. (2015) [10] express the ascending stream velocity as

$$w_{max} = \sqrt{\alpha g(\gamma - \gamma_a)z} \sin kx. \tag{1}$$

where γ is the surrounding air temperature gradient, γ_a is the dry-adiabatic temperature gradient, $\alpha = 1/T_0$, $T_0 = 273°\text{C}$, and z is defined as

$$z = \frac{2\Delta_0 T}{\Delta\gamma}. \tag{2}$$

Substituting $\Delta\gamma$ from (2) in (1):

$$w_{max} = \sqrt{\alpha g \frac{2\Delta_0 T}{z} z} \sin kx \implies \overline{w_{max}} = 0.64\sqrt{2g\alpha z \Delta_0 T}$$

$$\overline{w} = \overline{w_{max}} \sin kz \implies \overline{w} = 0.41\sqrt{\frac{2g}{273} z \Delta_0 T}. \tag{3}$$

where $\Delta_0 T$ is the overheat function at ground surface. The overheat function at ground surface can not be forecasted at required resolution (under 100 m). Thus, it was hypothesized that between the overheat function at ground surface and the temperature difference between the soil (T_{skin}) and 2-m air temperature (T_{2m}) there is a direct proportional relationship.

$$\Delta_0 T = c(T_{skin} - T_{2m}) \tag{4}$$

Difficulty, therefore, remains in the assessment of the proportionality ratio. For this purpose, observations recorded in August 2018 during sailplane flights over southern Romania were used. This hypothesis is providing the value of the vertical component of the wind, but the value of the upward trend of the thermal currents (if they occur) in the studied area.

The value of w obtained from the model developed by Zakinyan et al. (2015) [10] need to include also the effect of atmospheric instability. Thus, the velocity of parcel of air is proportional with the potential energy (E_{pot}) which represent the area between the dry adiabat and the environmental temperature between the ground and the level of interest (i.e., boundary layer height, BLH).

$$E_{pot} = \int_{ground}^{BLH} (\theta_0 - \theta) d\ln p \tag{5}$$

Assuming that $w = 0$ at ground level and w_{max} is occurs at the BLH, the velocity of the parcel can be express as

$$w_{\pm} = \sqrt{2E_{pot}} \tag{6}$$

A factor of 0.41 was added to Eq. 6 because we are interested in the average value. Also, it has been shown that due to several limitations of the parcel theory only half of the maximum available speed is reached by the parcel [11,12]. Thus, Eq. 6 can be written as

$$w_{\pm} = 0.5 \times 0.41\sqrt{2E_{pot}} \tag{7}$$

From the final velocity is neded to reduce the sink rate of the sailplane while spiraling in the thermal (i.e., 1 m s^{-1}) [3].

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3. Data and methods

3.1. Study area

The study area is located in the southern Romania between 43.5°N–44.5°N and 23°E–25.25°E, with a restriction for gliders in the north side of Craiova city (Fig. 2). This is a plain area with an elevation of between 25–200 meters, mainly used agricultural purposes (i.e., wheat and maize crops) which also contains forests and wetlands.

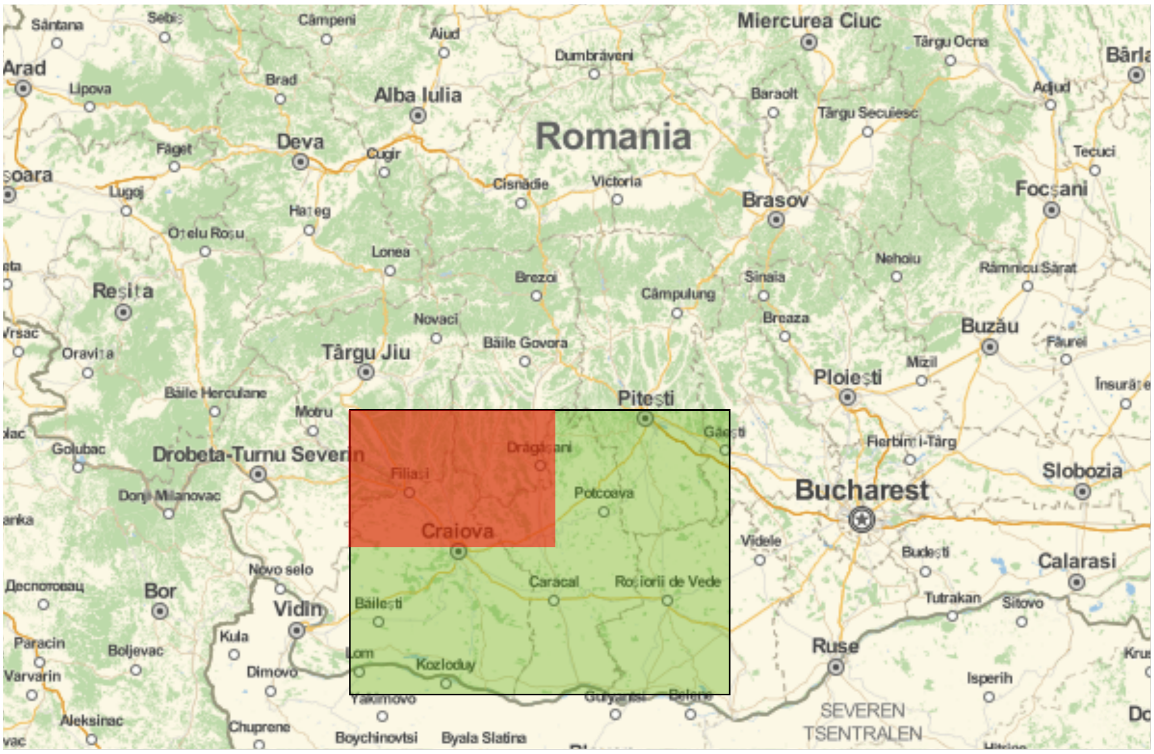

Figure 1. Study area (green background), with restricted area, denoted by red background.

3.2. Meteorological data

Weather Research and Forecasting Model (WRF) [13] was run every morning at 0000 UTC and run for 24 h with output every 30 min, with initial and lateral boundary conditions from the 0.25° Global Forecast Model (GFS) analyses. The simulation used a single 234 × 294 gridpoint domain with 2.2-km horizontal grid spacing and 51 vertical levels. The following parameters were extracted form the daily simulations: surface skin temperature, temperature at 2 meter, Atmospheric Boundary Layer height, ground level, potential temperature, and water-vapor mixing ratio.

3.3. Sailplane flight

In essence, gliding is based mainly on those weather phenomena which generate updrafts, as slope updrafts, lee waves and thermal convection. Slope soaring is the oldest form of soaring, meaning the utilization of updraft which exist at the windward slope of hills or mountains. Flight time is limited by the duration of usable lift which means that in most of the cases the flight in thermal convection can be achieved only during the daytime, in the presence of insolation from the sun. Once a flight reaches a position from which a return to the take-off airfield necessitates an additional climb, it is called a cross-country flight. For such flying, pilots need route or area meteorological forecasts for planning

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purposes. To optimize progress and flight safety, they constantly adapt their flight tracks to changing meteorological conditions [14,15].

For a glider in steady circular flight, the sink rate w changes with the radius *r* of the turn [16]. Slow gliders can climb in quite narrow thermals with diameters of 30 m to 50 m, while faster sailplanes need wider updraughts with diameter of about 150 m in order to gain altitude. The typical sink rate in circular flight is between the range of 0.8 m s^{-1} and 1.2 m s^{-1}, and the minimum time needed for a full circle is between 10 s and 20 s. Atmospheric lift pattern must exceed all these thresholds values in terms of size, strength and life-time in order to allow gliders to climb. Typically, thermal convection generates a lift pattern of localized updraughts centered around a core. For instance, a lift with a core updraught of 3 m s^{-1} and a radius of 150 m suitably describes a thermal of moderate strength. Strong thermals are often wider, while weak thermals are more confined. A circling glider climbs when its sink rate is less than the updraught velocity. All these flight parameters mentioned, namely the airspeed and the rate-of-climb and descent are measured with appropriate on-board instrumentation, respectively the tachometer and variometer.

3.4. Data from sailplanes

The data from sailplanes used in this study were recorded between 28 July and 11 August at the Romanian Gliding National Championship 2018 in Craiova[2]. The competition took place in two categories, the Club Class and the Mixed Class, and the best flights were analyzed. Recorded flight data resulted during the flight competition which were downloaded from an IGC (International Gliding Commission) approved Flight Recorder, type LX Colibri. The primary task of this unit is to produce a secure flight record containing at least GPS position, GPS altitude and pressure altitude of the glider at pre-determined intervals during the task for subsequent analysis. Data provided by the flight recorder on the aircraft location, expressed in 4D coordinates (position in space + time plots), permit the calculation of the thermal updraft velocity along the glider course.

Thus, during the first 7 days, 85 flights were analyzed, resulting in approximately 1000 data. To obtain the updraft velocity of the thermal, the *SeeYouNaviter*[17] flight analysis software was used. The software analyzes the entire flight route and provides information on the ascending velocity and the mean climb velocity of the glider (Fig. 2). The last two days of flights were used to verify the model (i.e., 24 flights and 288 thermals).

4. Results

In order to determine the proportionality constant, the average of the ascending speeds was made every hour in the 7 days. The proportionality constant was calculated by comparing these averages per hour with the mean value of the predicted ascendants for the area where the gliders flew, according to the relationship:

$$c = \frac{(w_i^{sailplanes} - w_{\pm} + 1)^2}{1.23(T_{skin} - T_{2m})} \tag{8}$$

because, as showed in section 2:

$$w_i = 1.11\sqrt{c(T_{skin} - T_{2m})} + w_{\pm} - 1\, m\, s^{-1} \tag{9}$$

where $w_{\pm}$ was defined in Eq. 7 and i index from $w_i^{sailplanes}$ denotes the LT hour. Table 1 shows the different coefficient (c) obtained as showed before.

[2] 58th Romanian Gliding National Championship https://www.soaringspot.com/en_gb/58th-romanian-national-championship-2018-balta-verde-2018/, accessed on 9 September 2018

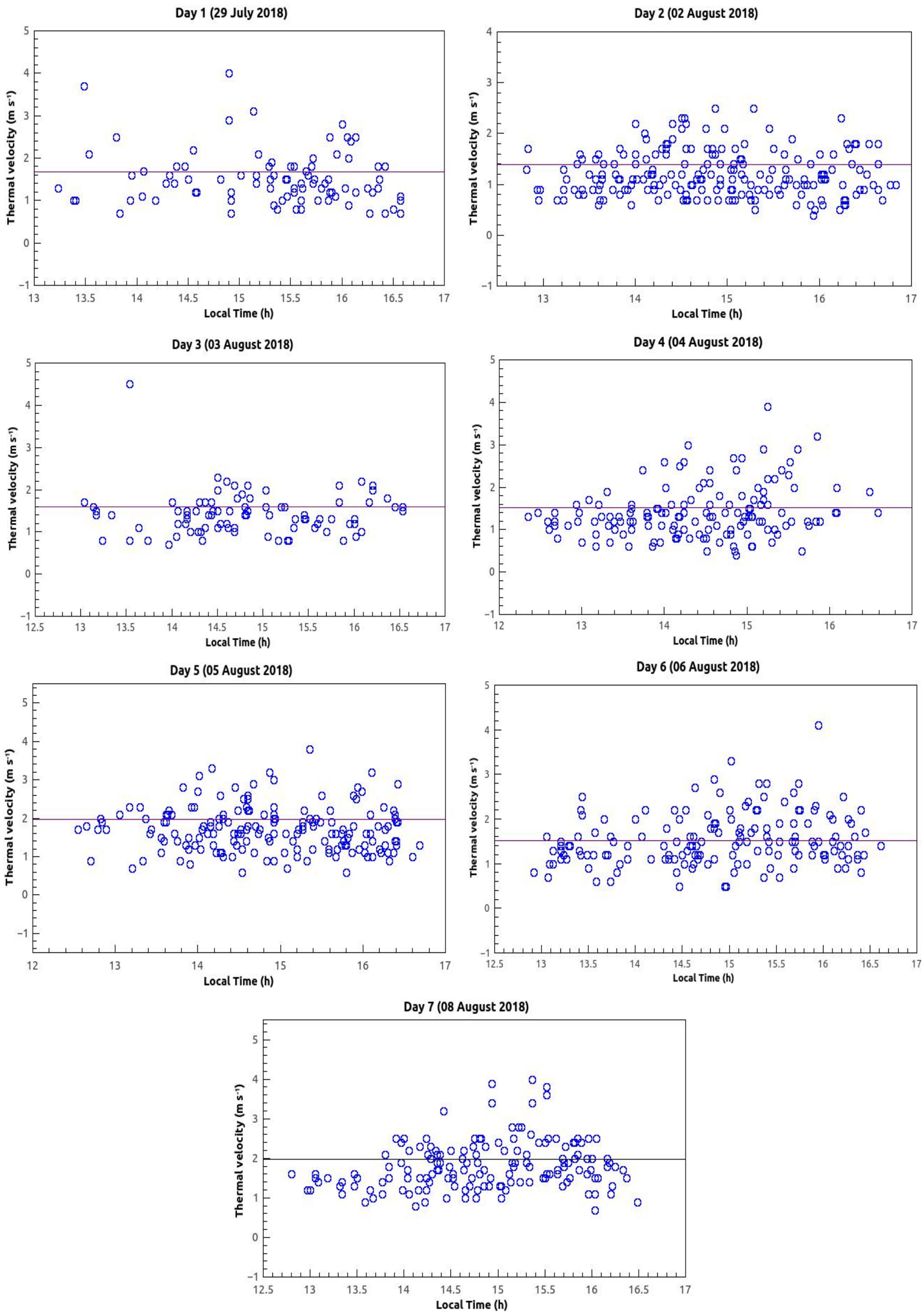

Figure 2. Thermal updraft velocity recorded by sailplanes during flights at the Romanian Gliding National Championship 2018 in Craiova (28 July–11 August). The data were collected during the first 7 days of the championship using *SeeYou Naviter*[17], a sofware dedicated to glider flight analysis.

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Table 1. The calculated values of the proportional constant (c) which best fits the observed values of the thermal updraft velocity in the first 7 days of the Romanian Gliding National Championship 2018 in Craiova (28 July–11 August) compared with the WRF forecasts. Local time (LT) is UTC+3 hours.

Hour	1300LT	1400LT	1500LT	1600LT
29 July	0.058	0.059	0.062	0.063
02 Aug	0.059	0.059	0.059	0.062
03 Aug	0.059	0.059	0.061	0.061
04 Aug	0.057	0.058	0.059	0.063
05 Aug	0.062	0.062	0.064	0.065
06 Aug	0.058	0.058	0.058	0.058
08 Aug	0.058	0.058	0.062	0.062
$\bar{c}$	0.06			

After calibration, the theoretical model was verified against observations from 9–10 August 2018. The result show that the predicted values are approaching the measured ones, within the limits of the measurement errors, except for the 1600LT time where the predicted values were underestimated (Figs. 3, 4). In order to show the accuracy of the model, Mean Absolut Error was calculated from forecast data and flight recorders, using the average values of the thermal updraft velocity per hour, as in (Figs. 3 and 4).

$$MAE = \frac{1}{8}\sum_{i=1}^{8} |w_i^{sailplanes} - w_i^{forecasted}| \tag{10}$$

$$MAE = 0.2775\ m\,s^{-1}$$

Resulting in a relative error of about 15%.

As shown in Fig. 4 round 1400LT, the sailplanes climbed at higher speeds than predicted. This does not necessarily indicate the failure of the forecast, considering that during competition, the pilots want to reach high flight speed and for this. Thus, during the last part of the competition, when the pilots have attained a comfortable height, they choose to spirals only in climbs above average and choose, like migratory birds, to stay in the band of maximum lift [18].

Based on the comparison between observation and forecasting, the thermal updraft velocity (m s^{-1}) can be forecast in any plain region using a very simple model:

$$w = 0.272\sqrt{g(T_{skin} - T_{2m})} + 0.29\sqrt{E_{pot}} \tag{11}$$

for positive values of E_{pot} (instability), or:

$$w = 0.272\sqrt{g(T_{skin} - T_{2m})} - 0.58\sqrt{E_{pot}} \tag{12}$$

for negative values of E_{pot} (stability).

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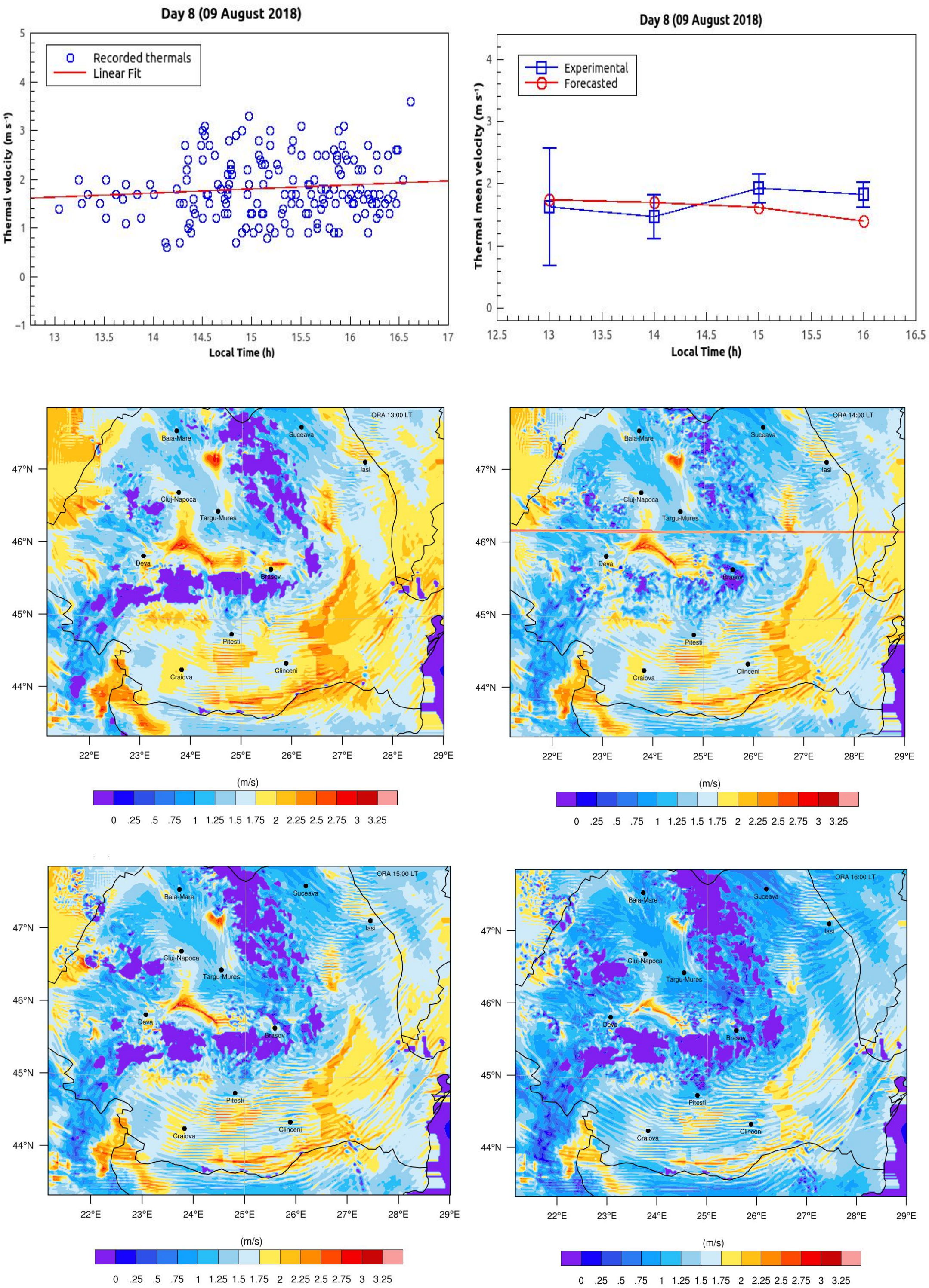

Figure 3. Thermal velocity (m s^{-1}) from observations from 9 August 2018 compared with WRF model. For calculating the average values, the arithmetic mean of the hour values was used, and the error is $1/\sqrt{N}$, where N is the number of the thermals. The averaged predicted value is the arithmetic mean of all values in the study area.

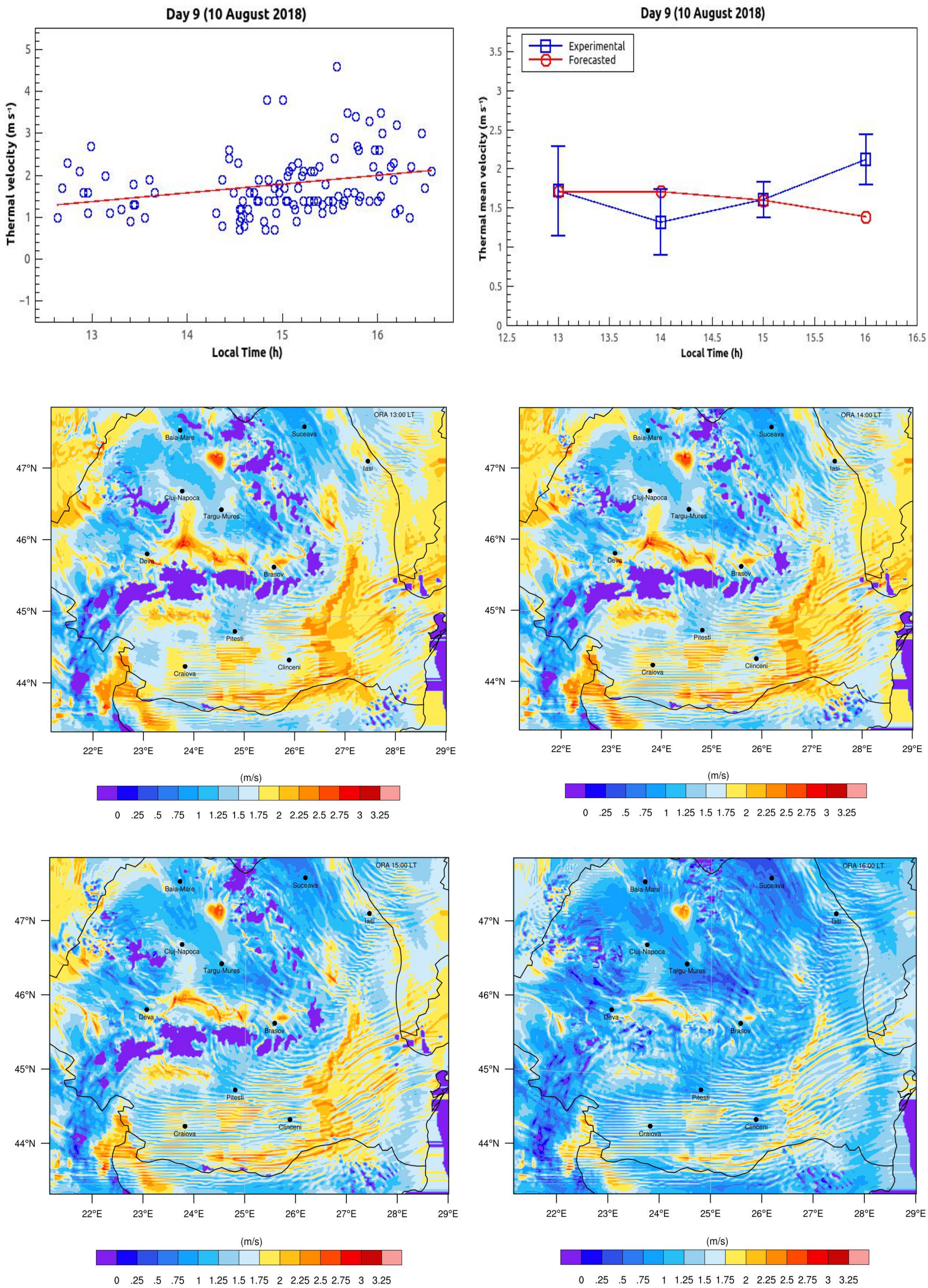

Figure 4. As in Fig. 3 but for 10 August 2018.

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5. Conclusions

Our results show that thermal updraft velocity can be predicted using soil and air temperature at 2 meters. However, the interaction between the soil and the atmosphere is much more complicated than the assumption on which this model was based, with the need for future studies to show how overheat function at ground level can be predicted according to soil characteristics, or how it depends by vegetation and the type of soil vegetation or by wind and turbulence at ground level. Also, the model does not take into account forests or dynamics between the atmosphere and the mountainous areas (other than those used by the WRF), which are phenomena in close connection with the genesis of the thermal convection.

Thus, the theoretical models combined with experimental results provided by flying gliders can help in predicting the thermal convection that helps pilots to better plan their flight strategy and flight route elected and general aviation to better monitor the migratory to avoid collisions with bird.

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Author Contributions: C.V.V. conceived the model and designed the experiments, wrote the paper, performed the experiments and analyzed the data; B.A. contributed to designing the experiments and to manuscript improvement and revisions; D.V. contributed to manuscript improvement.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zanrosso G. *History and Evolution of the Glider. Volume II*, Egida, 1996, 125 pp.
2. Lee R.E. Know the Sky: A History of Interaction between Meteorology and Soaring, *Technical Soaring*, **2012**, 36, 84–93.
3. Liechti, O.; Neininger, B. ALPTHERM a PC-Based Model for Atmospheric Convection over Complex Topography, *Technical Soaring*, **1994**, 22, 73–78.
4. Shamoun-Baranes, J.; Liechti, O.; Yom-Tov, Y.; Leshem, Y. Using a convection model to predict altitudes of White Stork over central Israel, *Boundary-Layer Meteorology* **2003**, 107, 673–681.
5. Visoiu, D.; Vraciu, C.V.; Picui, L.A. The study of inflight data from sailplane flights to determine a better forecast of the atmospheric boundary layer used for soaring, *EMS Annual Meeting*, Budapest, Hungary (2018).
6. Richardson, J.; West, T. Serious Birdstrike Accidents to Military Aircraft: Updated List and Summary, *Proceedings of the 25th International Bird Strike Committee*, Amsterdam, The Netherlands, 67–97 (2000).
7. Shannon, H.D.; Young, G.S.; Yates, M.A.; Fuller, M.R.; Seegar, W.S. Measurements of Thermal Updraft Intensity over Complex Terrain Using American White Pelicans and and a Simple Boundary-Layer Model, *Boundary-Layer Meteorology*, **2002**, 104, 167–199.
8. Shamoun-Baranes, J.; Leshem, Y.; Yom-Tov, Y.; Liechti, O. Differential use of thermal convection by soaring birds over central Israel, *Condor*, **2003**, 105, 208–2018.
9. Sherwood, S.C.; Bony, S.; Dufresne, J-L. Spread in model climate sensitivity traced to atmospheric convective mixing, *Nature*, **2014**, 505 37–42.
10. Zakinyan, R.G.; Zakinyan, A.R.; Lukinov, A.A. Two-dimensional analytical model of dry air thermal convection, *Meteorol Atmos Phys*, **2014**, 127, 451–455.
11. Doswell, C.A.; Markowski, P. Is buoyancy a relative quantity?, *Monthly Weather Review*, **2004**, 132 853–863.
12. Markowski, P.; Richardson, Y. *Mesoscale Meteorology in Midlatitudes*, Wiley-Blackwell: West Sussex, UK 2010, 407 pp.
13. Skamarock, W.C.; and Coauthors, A description of the Advanced Research WRF version 3, *NCAR Tech. Note NCAR/TN-475+STR*, 2008, 113 pp.
14. Irving F. *The Path of Soaring Flight*, Imperial College Press: London, UK, 1998, 133 pp.
15. Liechti, O.; Lorenzen, E.; Thehos, R.; Olofsson, B. Verification of Thermal Forecasts with Glider Flight Data, *Technical Soaring*, **2006**, 31(2), 42–51.
16. Thomas F. *Fundamentals of Sailplane Design*, College Park Press: Silver Spring, USA, 1999, 286 pp.

 doi:10.20944/preprints201810.0684.v1

17. SeeYou Naviter. *SeeYou Help Version 6.03*, Naviter, https://www.naviter.com/blog/ (accessed on 9 September 2018), 2014.
18. Bradbury T. *Meteorology and Flight: A Pilots Guide to Weather*, A and C Black: London, UK, 2000, 186 pp.