FORECASTING FLIGHT ALTITUDES AND SOARING PERFORMANCE OF MIGRATING RAPTORS BY THE ALTITUDINAL PROFILE OF ATMOSPHERIC CONDITIONS

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Summary

Large migratory birds such as raptors, storks or pelicans, predominantly use soaring- gliding flight tactic on their journey between Eurasia and Africa. In this study we compare forecasts for the upper convective boundary and the strength of thermal convection with the flight characteristics of migrating raptors. To forecast soaring conditions, we measured atmospheric conditions by radiosondes at midnight and applied the numerical convection model ALPTHERM. Raptor migration was studied in southern Israel (Arava Valley) in spring and fall 1992 by means of a tracking radar. Maximum flight altitudes per day of raptor migration were correlated with the predicted convective depth; the predicted upper boundary of the convective layer showed good agreement with observed data. Diurnal course of climbing rates in thermal circling agreed with model predictions. Thus, altitudinal distribution and soaring performance of migrating raptors are predictable by analyzing the atmospheric structure and may lead to specific applications, for example to prevent bird hazards in countries with high concentrations of diurnal soaring migration.

Introduction

Flight altitudes of soaring migrants depend on thermal convection. Altitudes show a typical increase during the morning hours and reach maximum values around noon or in the early afternoon (1, 2). Flight altitudes increase with increasing climbing rates in thermal circling and, thus, reflect the strength of thermal convection (3, 4, and 5). Maximum flight altitudes and density of migration show a great day-to-day variation.

Atmospheric conditions determine the strength and the upper limit of thermal convection.

Solar radiation warms up the surface of the earth and the air masses in contact with it. As air density decreases with increasing temperature, this warm air rises because of the difference in density to the surrounding air. There are two counteracting effects when a thermal bubble rises: as long as the initial temperature difference to the surrounding persists, the rising speed increases with altitude above ground. Simultaneously, the warmer air in the thermal bubble is mixed with colder surrounding air, which decreases the rising speed. The thermal bubble rises up to an altitude were temperature differences are balanced.

Midnight radiosondes inform about the structure of atmospheric conditions by measuring air pressure, temperature and humidity at different heights. These parameters allow predictions on soaring conditions and the upper boundary of the convective layer for the following day.

The numerical convection model ALPTHERM calculates the strength and the upper boundary of the convective field (6, 7). It was developed to predict soaring conditions for glider pilots and is in operational use in Switzerland and Germany.

The risk of bird hazards imposes a serious problem for countries with a high density of diurnal soaring migration (8, 9, 10, and 11). The possibility of predicting flight altitudes of soaring migration would provide a helpful means to plan flight activities and to prevent bird hazards.

In this study we test the possibility to forecast the altitudinal distribution of raptor migration by using the ALPTHERM predictions which are based on the structure of the atmosphere at midnight. Furthermore, we compare climbing rates in thermal circling with model predictions.

Methods

Study site

Raptor migration was studied in southern Israel in the Arava Valley near Hazeva (30° 49' N, 35° 16' E) (Figure 1). Observations covered the whole day and took place from 1 March to 20 May 1992 and from 10 August to 18 September 1992.

Flight paths were registered by a tracking radar of the type "Superfledermaus"; for details see Bruderer et al. (12). Medium sized raptors can be tracked up to distances of about 8 km. During daytime, an experienced observer identified the tracked target through a 12.4x telescope mounted parallel to the radar beam. Birds were selected at random, and therefore, the results represent the real height distribution. For each diurnal migrant, the occurrence of wing beats was verified visually and recorded systematically. Maximum flight altitude per day is the maximum altitude of the highest tracked raptor. To compare model predictions and observations, only flight paths without wing beats between 8.00 h and 17.00 h local time were taken for calculations. Pilot balloons, released and tracked every four hours, provided data on wind speed and direction at all flight levels up to at least 3000 m above ground level (a.g.l.). Flight altitude of a bird is the maximum altitude within a single flight path.

Radiosondes

Every day, radiosondes were released at midnight (24.00 h local time, 02.00 h UTC) from the radar site to measure atmospheric conditions at levels up to 5000 m a.g.l. These measurements included temperature, air pressure, and humidity.

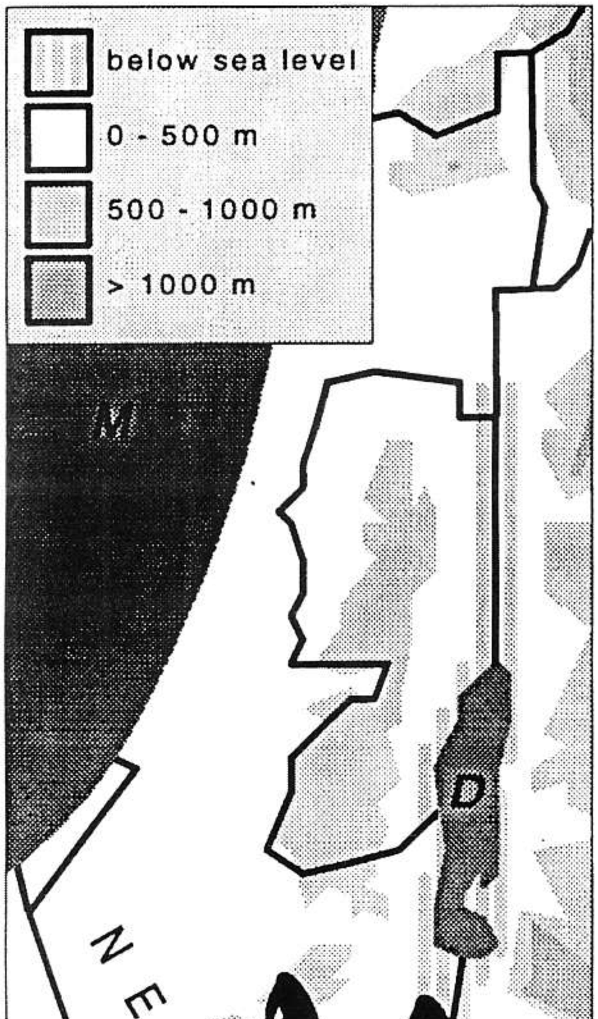

Figure 1. Observation (radar) sites in southern Israel. Only data from the radar station in the Arava Valley are considered in this paper.

The program ALPTHERM: parameters and output

For details of the program see Liechti and Neininger (6) and Liechti and Lorenzen (7). The parameter of the ALPTHERM program was adjusted to the geographical situation in the Arava Valley. Daily maximum temperatures are a good test for the validity of the meteorological predictions and were used to calibrate the model. Maximum ground temperatures are in good agreement with predicted maximum temperatures (Figure 2). The difference of predicted and measured maximum temperature at ground level was 0.23 ± 0.13 °C (N = 102, mean + SE). On 9 days, the maximum temperature was at least 2 °C higher than predicted, mainly due to warm southerly winds from the Sahara. The ALPTHERM program predicts the strength of thermal convection and the upper limit of the convective layer with a temporal resolution of half an hour (Figure 3).

Results

Flight altitudes of raptor migration

Distribution of flight altitudes of raptor migration showed a great variation from day to day (Figure 4). Flight altitudes were slightly higher in autumn (780 ± 360 m a.g.l, N = 178; mean + SD) than in spring (700 ± 400 m a.g.l., N = 781; t-test: $t_{957} = -2.34$, $P < 0.02$). Maximum daily flight altitudes of soaring raptors varied between 400 and 2,330 m a.g.l. Maximum flight levels varied in the course of the day (Figure 5; Kruskal-Wallis ANOVA: $H_{8,959} = 79.3$, $P < 0.0001$): flight altitudes increased during the day and reached maximum values in the early afternoon. Towards sunset, flight altitudes decreased only slightly. Maximum flight altitude of raptor migration increased with increasing climbing rate in thermal circling and increasing tailwind support (Figure 6).

Predicted and observed maximum fight altitudes

We compared maximum observed flight altitudes for soaring migrants with the predicted upper boundary of the convective field (Figure 7). Observed values showed a positive correlation with the predicted values, but were generally lower compared to the model prediction. We do not expect a very high correlation between observed maximum flight altitudes and predicted upper boundary of the convective field because of the method used: we tracked raptors randomly and we did not especially search for high migrants. Therefore, the chance was low to track a bird at the upper most part of the convective field. On three days only, maximum flight levels were slightly higher than predictions. If considering the local time for the highest tracked bird and the model, the results do not improve and are very similar to those presented in Figure 7.

Predicted and observed climbing rates in thermal circling

Climbing rates varied during daytime (Figure 8). Predicted and observed climbing rates did not differ statistically (Wilcoxon matched pair test: N = 1293, Z = 1.34, n.s.). Both predicted and observed values varied significantly during the day (Kruskal-Wallis ANOVA: predicted climb-

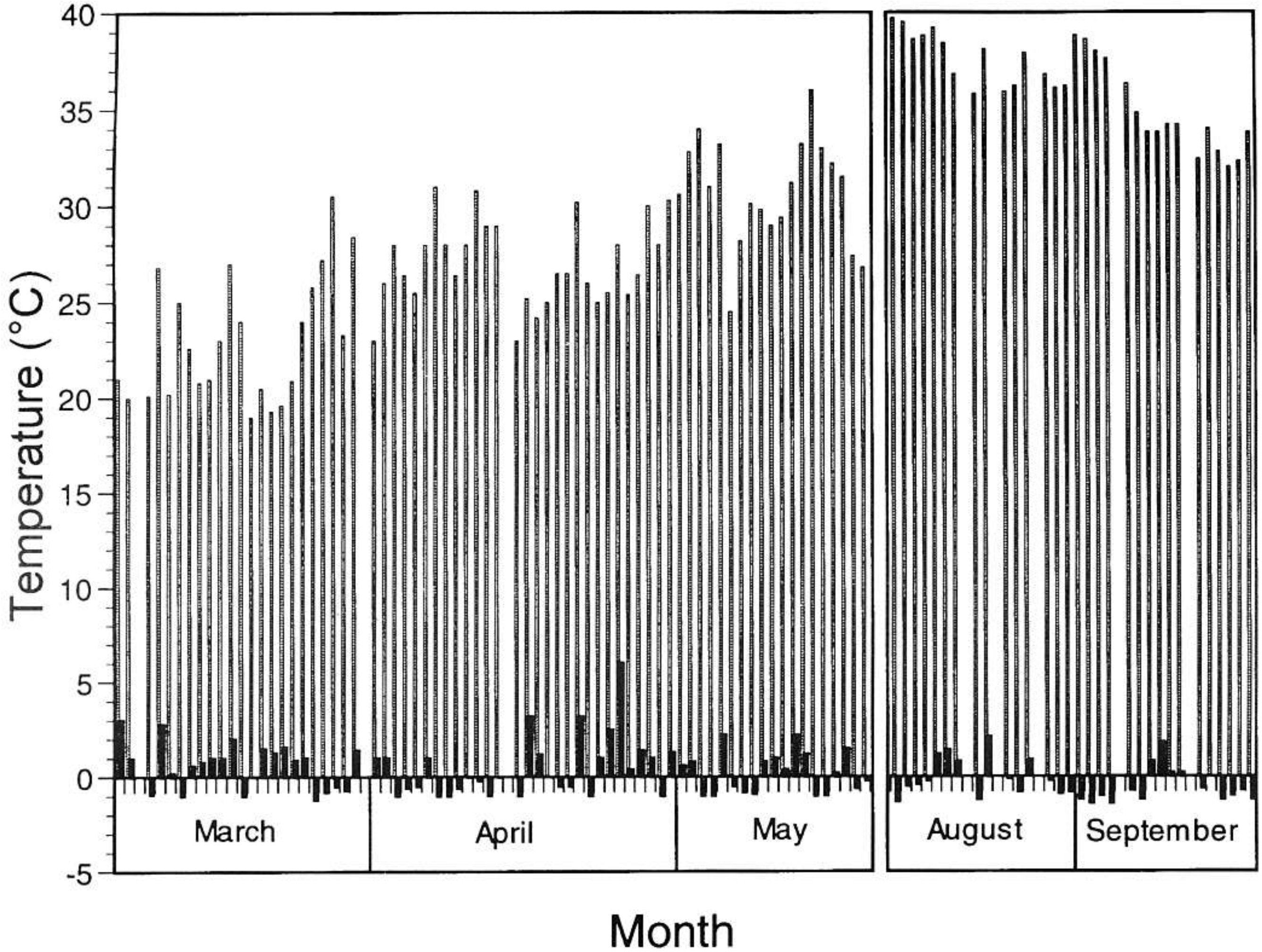

Figure 2. Daily maximum temperatures (1.5 m above ground) in the Arava Valley in spring and autumn 1992 (grey bars). Black bars indicate temperature differences to the predicted maximum daily temperatures of the alptherm-model ($\Delta t = t_{alptherm\text{-}model} - t_{ground}$).

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ALPTHERM Aravatal (Israel) am 160992 [,ASTA nil,NUM ARA]

UTC    Temp   Tp  Lift profile [0.5m/s] Climb Cumulus  Base-Top  Ac/Ci
hh:mm   [C]   [C] 0km  1km  2km  3km  4 [m/s] [octas] [m] - [m]  [octas]
 6:00   26    18  :-...:----:----:----: 0.2                        /
 6:30   27    18  :-122.----:----:----: 0.6                  900   /
 7:00   29    18  :12221----:----:----: 0.9                 1000   /
 7:30   29    18  :22333.---:----:----: 1.2                 1100   /
 8:00   29    18  :233342---:----:----: 1.4                 1200   /
 8:30   30    18  :233443---:----:----: 1.4                 1300   /
 9:00   30    18  :233444.--:----:----: 1.5                 1300   /
 9:30   31    18  :2334442--:----:----: 1.4                 1400   /
10:00   31    18  :2334442--:----:----: 1.5                 1400   /
10:30   32    17  :2334444.-:----:----: 1.7                 1500   /
11:00   32    17  :23344441-:----:----: 1.6                 1600   /
11:30   33    17  :23344442-:----:----: 1.6                 1600   /
12:00   33    17  :23344442-:----:----: 1.7                 1600   /
12:30   33    17  :23344444-:----:----: 1.7                 1700   /
13:00   33    17  :12233433.:----:----: 1.4                 1700   /
13:30   33    16  :.1122221-:----:----: 0.7                 1600   /
14:00   33    16  :----:----:----:----:                            /
14:30   33    16  :----:----:----:----:                            /
15:00   32    16  :----:----:----:----:
15:30   31    16  :----:----:----:----:
16:00   30    16  :----:----:----:----:
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Figure 3. Output of the program ALPTHERM. UTC + 2h = local time. Example for 16 September 1992.

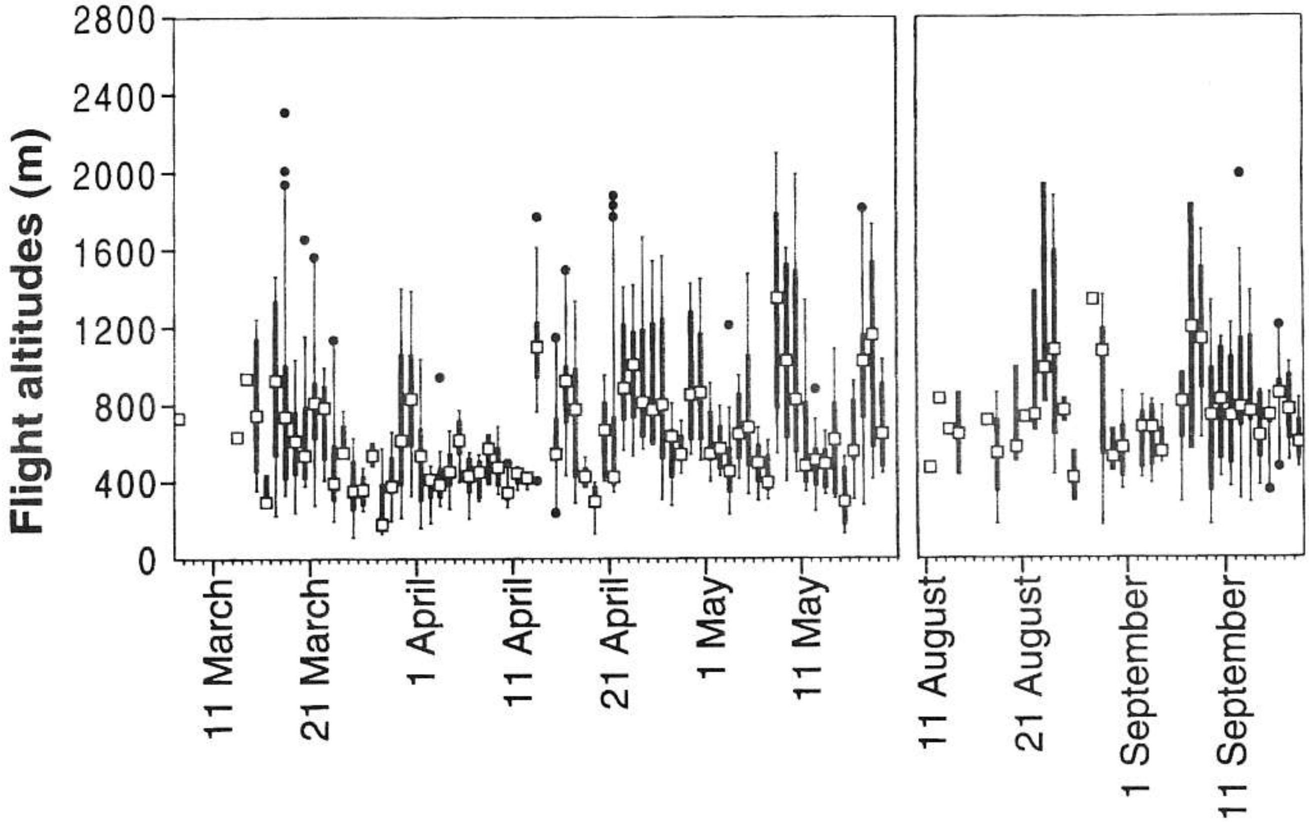

Figure 4. Daily flight altitudes of migrating raptors in the Arava Valley in spring and autumn 1992. Median (□), 25-75% range (black box), 10-90% range (line), and outliers (•, outside the 1.5 box length from the upper and lower value) are given.

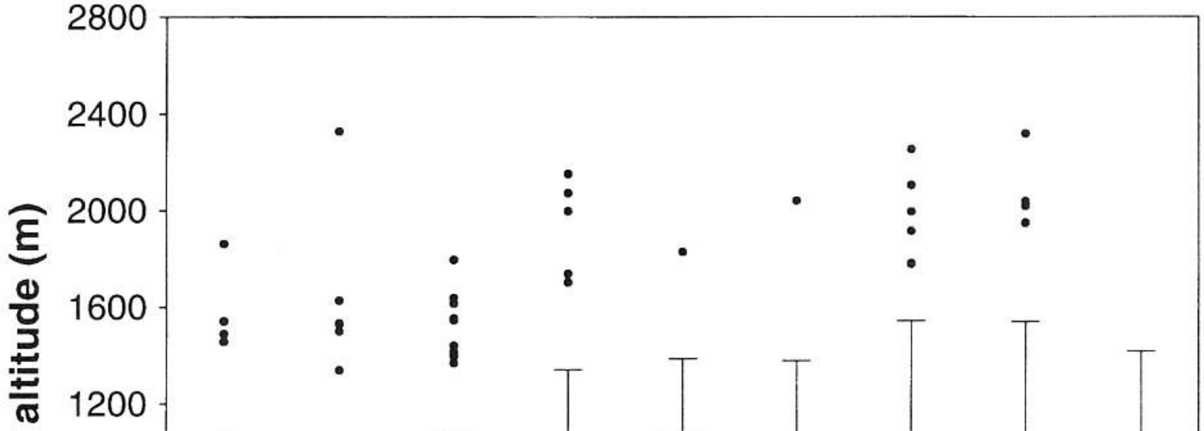

Figure 5. Diurnal variation in flight altitudes in the Arava Valley in spring and autumn 1992 (N = 959). Median (□), 25-75% range (box), 10-90% range (line), and outliers (•, outside the 1.5 box length from the upper value) are given. The line was derived by a negative exponentially-weighted smoothing procedure.

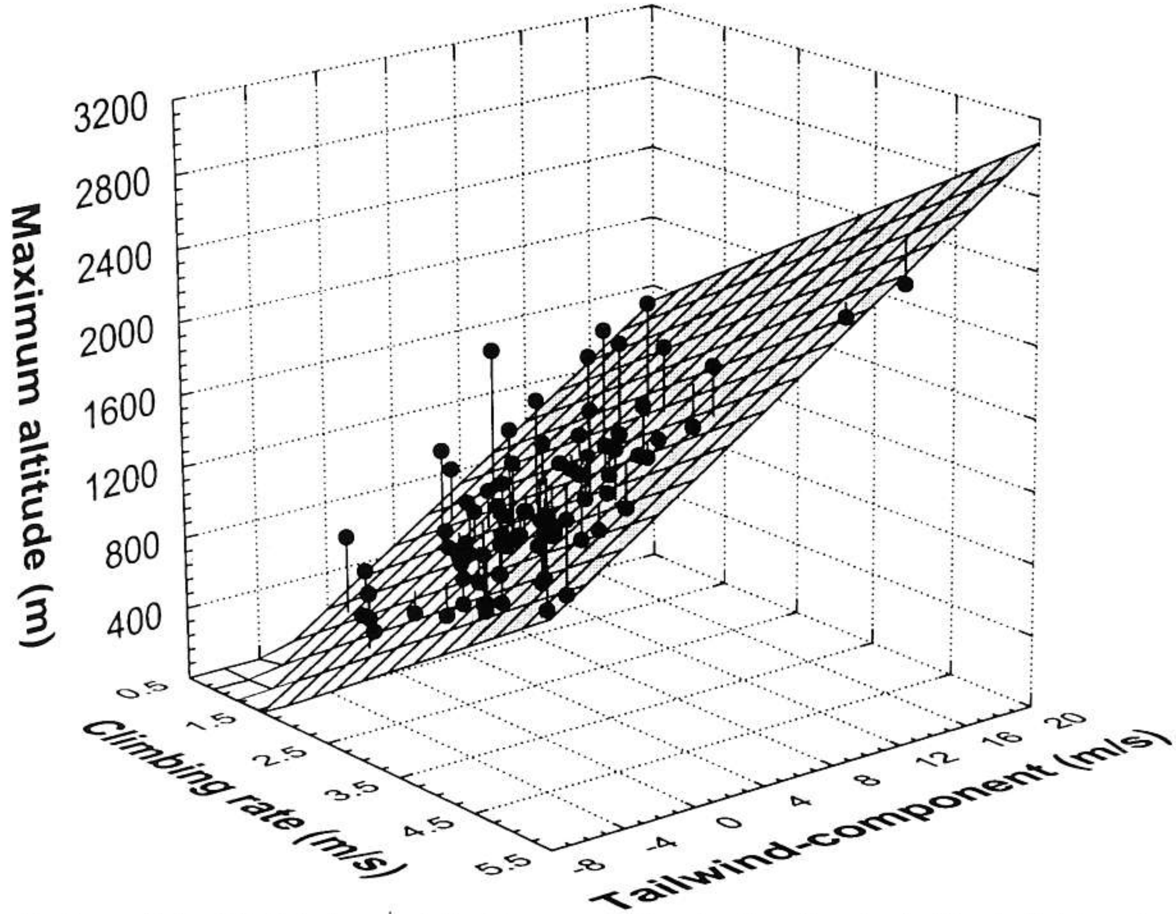

Figure 6. Maximum flight altitude (m) versus tailwind-component in migratory direction (m/s) and climbing rate in thermal circling (m/s). 2 of 87 cases were removed because of missing wind measurements. Multiple Regression: dependent factor: maximum flight altitude; factors in the equation ($P < 0.001$): tailwind-component (beta = 0.41±0.07 (SD)) and climbing rate in thermal circling (beta = 0.54 ± 0.07). Intercept = 29, t_{82}=0.26, n.s. Equation: maximum flight altitude = 66 wind component + 331 • climbing rate + 29; R^2= 0.63, $F_{2,82}$ = 70.8, $P < 0.0001$.

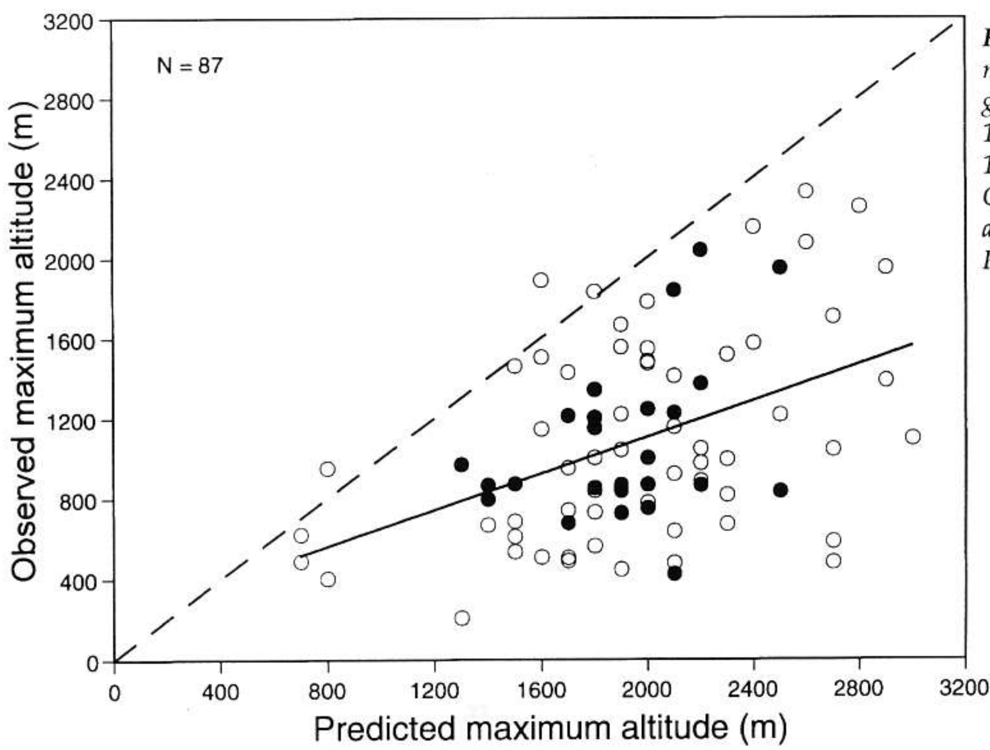

Figure 7. Predicted versus observed maximum flight altitudes above ground in the Arava Valley in spring 1992 (O, N = 61 days) and autumn 1992 (•, N = 26 days). Equation: Observed altitude=0.45 • Predicted altitude + 198; R^2=0.19, $F_{1,85}$ = 19.9, $P < 0.0001$.

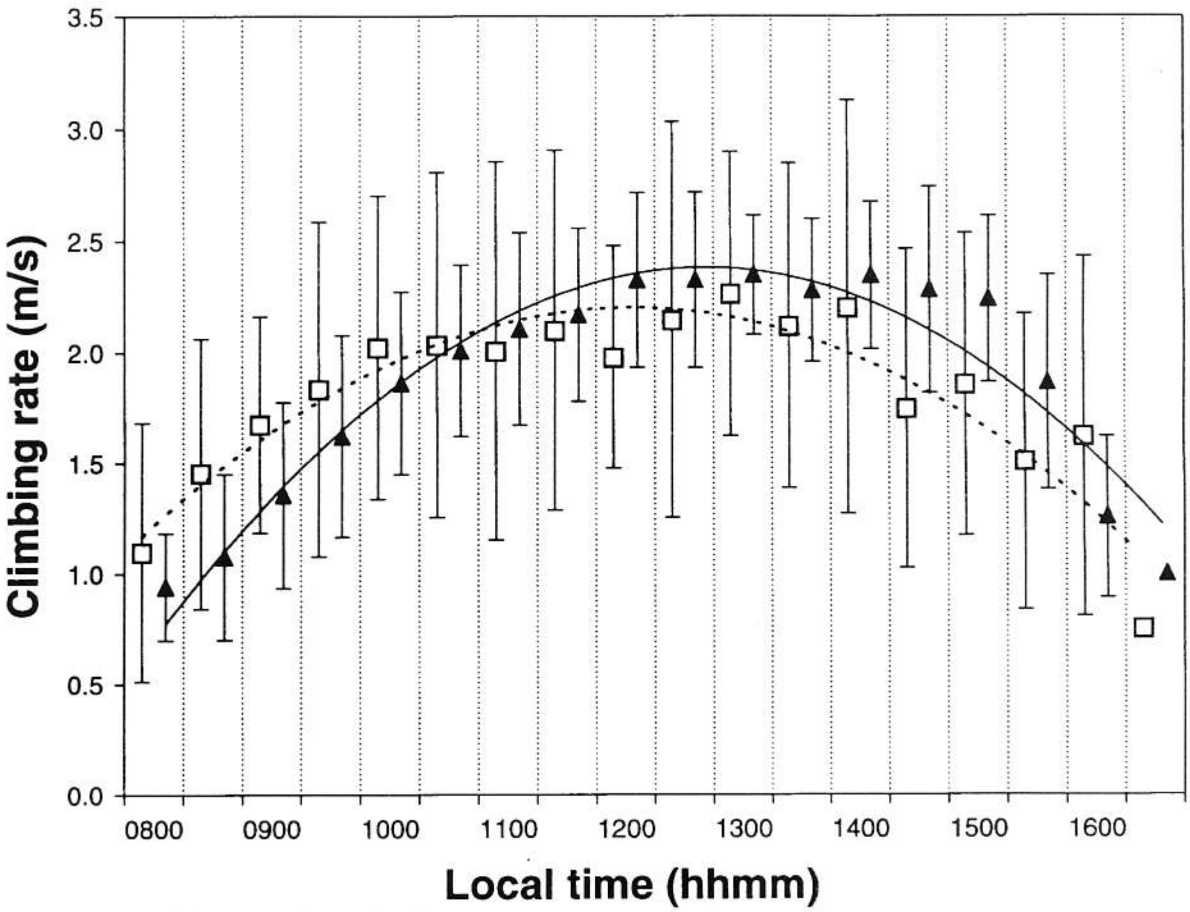

Figure 8. Observed (□) and Predicted (▲) climbing rates in the course of the day (N=1,293). Mean ±SD given. The longest climbing phases (≥ 60 s) per track were taken for analysis. Predicted strength of convection was reduced by 0.5 m/s, because birds in thermal circling have sinking rates in this order (5). Lines in the diagram derived by negative exponentially-weighted smoothing procedure. Linear registration of observed data: Observed climbing rate = 0.42 • predicted climbing rate = 0.94; $R^2 = 0.18$, $F_{1,1291} = 280.7$, $P < 0.0001$.

ing rate, $H_{9,1292} = 909.5$, $P < 0.0001$; observed climbing rate, $H_{9,1292} = 175.0$, $P < 0.0001$). Diurnal courses of observed climbing rates in thermal circling agreed well with model predictions. Raptors reached slightly higher climbing rates than predicted in the early morning hours (local time <= 10.00 h; Wilcoxon matched pair test: N = 471, Z = 2.74, P < 0.01), whereas climbing performance in the afternoon hours did not differ statistically from predictions (local time >= 14.30 h; Wilcoxon matched pair test: N = 279, Z = 1.05, n.s.).

Discussion

There is a considerable variation in flight altitudes from day to day. This variation is mainly caused by varying meteorological conditions. The meteorological situation in the Negev Desert in southern Israel is quite stable. However, the trade wind system providing northerly winds in the lower atmosphere (below 1500-2000 m above sea level) was often disturbed in spring by cold fronts coming from the west.

Predictions of the ALPTHERM program allow a reliable estimation of the upper flight altitudes of soaring migrants. Migrating raptors often do not use the whole convective field. Maximum altitudes of different species in soaring-gliding flight were about 2,300-m a.g.l. in buzzards (Honey Buzzards Pernis apivorus and Steppe Buzzards Buteo buteo vulpinus), 2000 m in Griffon Vultures Gyps fulvus, 1800 m in Steppe Eagles Aquila nipalensis, 1700 m in harriers Circus sp. and 1500 m in falcons Falco sp. Occasionally, birds are observed soaring at high altitudes in lee waves generated by the Negev Mountain ridges (13). An other soaring tactic is straight-line soaring which is mainly observed in larger species such as eagles and vultures (5, 14). Flight altitudes found in our study agree with other reported flight altitudes in Israel (15). The height band used by soaring-gliding migrants is quite variable and depends on soaring conditions (15). Other soaring species such as White Stork Ciconia ciconia, White Pelican Pelecanus onocrotalus and Crane Grus grus observed at the same location had similar flight altitudes compared to raptors (16, unpublished data)

The numerical convection program ALPTHERM is a useful tool to investigate flight altitudinal distribution and climbing performance of soaring migrants. However, other groups of diurnal migrants, such as herons, cranes, gulls, but also raptors regularly migrate by flapping flight and, thus, are not restricted to the convective field and may migrate at higher altitudes. Migration at high altitude has been reported in southern Israel up to 7000 m a.g.l. (F. Liechti, pers. comm.)

Conclusions

When investigating flight altitudes and climbing performance of soaring migration, the numerical convection model ALPTHERM provides realistic and useful results. Maximum flight altitudes of soaring raptor migration did not exceed the predicted upper boundary of the convective layer. On most days, maximum flight altitudes were lower. Maximum flight altitudes are correlated with the predicted upper boundary of the convective layer. The diurnal course of climbing rates in thermal circling is in good agreement with the predicted climbing performance. In areas with high densities of soaring migration, there is a need for information allowing to improve flight safety (18), e.g. by planning human flight activity in consideration of the temporal and spatial distribution of other users of the air space. Adjusted to the specific geographical situation, ALPTHERM is a valuable tool to describe risk areas in space and time. Combined with phenological data and observations, this integrated system will provide good forecasts on soaring migration and may help to prevent air strikes.

Acknowledgements

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Climbing rate in thermal circling is an important factor in soaring-gliding migration. Higher climbing rates result in higher flight altitudes (4, 5). Furthermore, raptors adjust inter-thermal gliding airspeed according to the actual climbing rate in thermal circling and, therefore, maximize cross-country speeds in soaring-gliding flight (17). Institute (Switzerland). We thank F. Liechti and G. Pasinelli for valuable comments on the manuscript.

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