USING A CONVECTION MODEL TO PREDICT ALTITUDES OF WHITE STORK MIGRATION OVER CENTRAL ISRAEL

Research Note

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Abstract. Soaring migrants such as storks, pelicans and large birds of prey rely on thermal convection during migration. The convection model ALPTHERM was designed to predict the onset, strength, duration and depth of thermal convection for varying topographies for glider pilots, based on atmospheric conditions at midnight. We tested ALPTHERM predictions as configured for two topographies of central Israel, the Coastal Plains and the Judean and Samarian Mountains in order to predict altitudes of migrating white storks (*Ciconia ciconia*). Migrating flocks of white storks were tracked with a motorized glider, to measure maximum altitudes of migration during spring 2000. A significant positive correlation was found between the maximum daily altitudes of migration measured and the predicted upper boundary of thermal convection for the Coastal Plains and Samarian Mountains. Thirty-minute predictions for the Coastal Plains and Samarian Mountains correlated positively with measured maximum migration altitudes per thermal. ALPTHERM forecasts can be used to alter flight altitudes in both civil and especially military aviation and reduce the hazard of serious aircraft collisions with soaring migrants.

Keywords: Flight safety, Israel, Migration, Soaring, Thermal convection, White storks.

1. Introduction

The migration altitudes of soaring birds over Israel have been studied in the past using motorized gliders and radar (Leshem and Yom-Tov, 1996; Spaar, 1997; Spaar et al., 2000). Changes in the altitudes of migration show a fairly regular daily pattern (Kerlinger, 1989; Leshem and Yom-Tov, 1996; Liechti et al., 1996), with altitudes increasing in the morning and then decreasing in the afternoon. However, maximum flight altitudes and daily duration of migration show a great deal of variation from day to day.

Thermal convection is an essential factor in the flight performance of soaring birds. The development, strength and duration of thermal convection is affected by topography as well as changing atmospheric and environmental conditions. The convection model ALPTHERM was developed to predict soaring conditions for glider pilots, in relation to local topography (Liechti and Neininger, 1994) and is in

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operational use by the German, Austrian and Swiss weather services. The model is initialized with nightly radiosonde data to predict the daily development of thermal convection, depth and strength. ALPTHERM's applicability for forecasting the altitudes of soaring birds of prey, measured by tracking radar, was tested in the Arava in southern Israel (Spaar et al., 2000) where a positive correlation was found between predicted thermal depth and observed maximum flight altitudes as well as with predicted thermal strength and climbing rates.

Collisions between birds and aircraft pose a serious hazard to military and civil aviation worldwide (Richardson and West, 2000; Robinson, 2000). For example, the Israel Air Force has lost nine aircraft since 1972, suffered damages costing hundreds of millions of dollars and the loss of lives from collisions with soaring birds (Leshem 1996). In regions where soaring birds are active, military aviation is particularly susceptible to serious collisions due to the relatively low altitudes of flight maneuvers in comparison to civil aviation where flight altitudes are often much higher than soaring bird flight. The application of a model forecasting thermal conditions in relation to soaring bird behaviour could give essential information needed for military flight squadrons to assess the relative risks in advance, change their training tactics and thus reduce the risk of a serious bird strike.

The aim of our study was to determine if ALPTHERM predictions of thermal depth in central Israel, based on regional topography and atmospheric conditions at midnight, could be used to forecast changes in white stork (*Ciconia ciconia*) maximum altitudes of migration.

2. Methods

2.1. TRACKING BIRDS

White stork migration was tracked during spring 2000 in central Israel using the Airport Surveillance Radar (ASR-8) at Ben Gurion International Airport as well as the MRL-5 radar at the International Center for the Study of Bird Migration at Latrun. Once birds were identified on radar, a two-seater motorized glider (IS28M2, Romania) equipped with a 2 litre, 80 horse power Limbach engine took off from Sde Dov Airport in central Israel. When the observer and/or pilot located a flock the glider joined the flock with the engine on, in neutral. The aircraft remained approximately 100 m from the flock, close enough to record the altitudes, time and geographic coordinates at which the flock entered and left thermals while soaring without disturbing their flocking behaviour. White storks acclimatised to the presence of the aircraft within several minutes, for more details see (Leshem and Yom-Tov, 1996). Flocks of at least 20 birds or more were tracked for several hours when possible. Flocks were not always tracked continuously for the entire duration of flight over Israel, and occasionally several flocks were followed during the same flight.

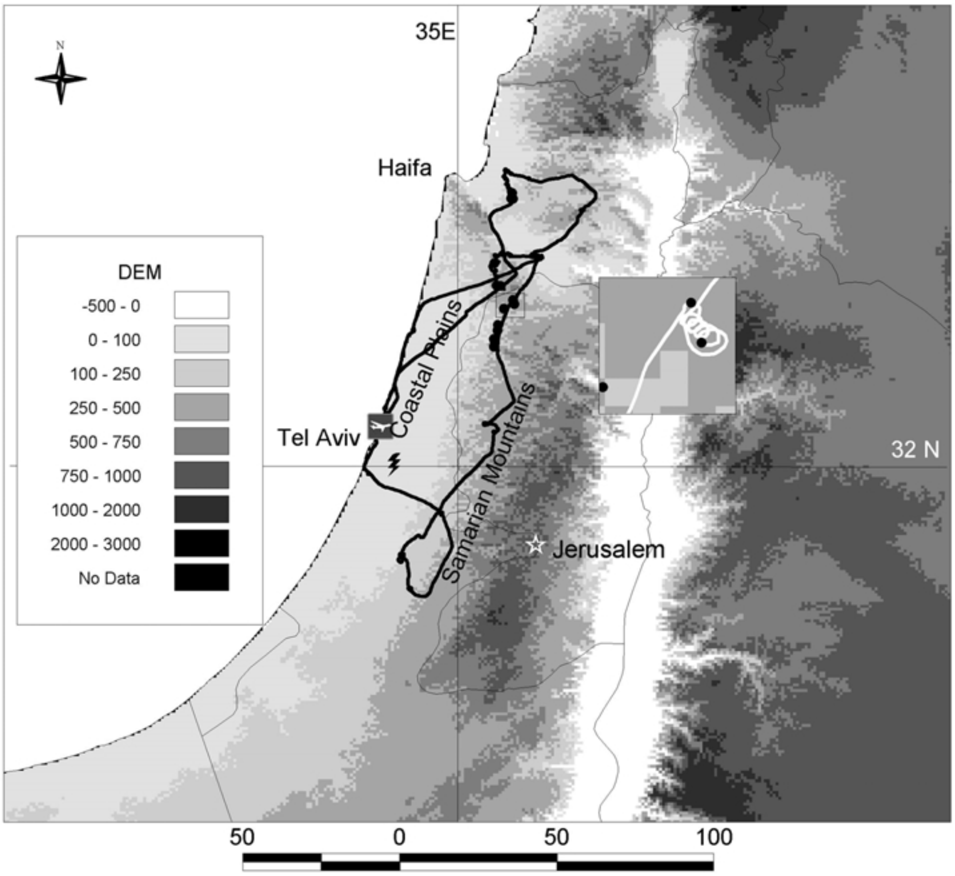

Figure 1. Topographic map of central Israel with the Coastal Plains along the Mediterranean Sea inland to approximately 100 m altitude and the western slopes of the Judean and Samarian Mountains, which gradually rise to several hundred metres. Horizontal scale is in kilometres. The legend shows elevation in metres. The bold dark line represents the motorized glider flight on 11 April 2000 as tracked with the GPS. Circles (●) represent where storks entered and exited thermals. Sde Dov airfield (✈) and Bet Dagan (ϟ), where radiosondes were launched, are also shown. Inset on right: An example of one thermal including the entrance and exit point. The base map is GTOPO30 a global digital elevation model with a horizontal grid spacing of approximately 1 km (data source: http://edcdaac.usgs.gov/gtopo30/gtopo30.html).

2.2. STUDY LOCATION

Central Israel comprises two parallel north-south, main topographic regions, the Coastal Plains along the Mediterranean shore and the western slopes of the Judean and Samarian Mountains, which gradually rise to altitudes of several hundred metres (Figure 1).

2.3. DATA COLLECTION

A Garmin Global Positioning System (GPS) receiver was used to record the coordinates where the flock entered and left a thermal as separate waypoints. The route of the entire glider flight was recorded automatically at a two-second interval using the GPS (Figure 1). Route and waypoint data were downloaded to a PC using PCX5AVD software. Migration tracks and thermals were plotted on a Geographic Information System (GIS) using ArcView 3.2 software (ESRI, 1999) on a global digital elevation model with a horizontal grid spacing of approximately 1 km (GTOPO30 data source: http://edcdaac.usgs.gov/gtopo30/gtopo30.html). The aircraft altimeter was used to determine the altitude of flight above sea level.

White storks were tracked with the motorized glider during spring migration 2000 on 28 and 30 March and 11, 14, 24, 25, 28 and 30 April. Flights on 10, 13 and 27 April were cancelled due to unsuitable weather for flying and/or no soaring migrants identified on the radar. Due to a technical error, GPS data for regional analysis of soaring data were only available for five days of the study.

2.4. METEOROLOGICAL DATA

The Israel Air Force Meteorology Unit provided vertical atmospheric profiles of temperature, air pressure and humidity from radiosondes. Radiosondes were released every night at 0000 UTC (Coordinated Universal Time), at Beit Dagan, in central Israel (32°00′ N, 34°49′ E).

2.5. THE ALPTHERM PROGRAM

The convection model ALPTHERM was used to predict thermal convection (Liechti and Neininger, 1994) including the strength, upper boundary and duration of convection for each day of the experiment. The model was initialised with 0000 UTC radiosondings. The model was calibrated to the topography of central Israel by creating two predictive topographical regions, the Coastal Plains and the Samarian Mountains, representing the Judean and Samarian Mountains in central Israel. The convection model ALPTHERM provides several forms of output (Liechti and Neininger, 1994; Liechti and Lorenzen, 1998) such as the daily evolution of the thermodynamic profiles, as well as the predicted changes in ground temperature and dew point, the formation of clouds and the strength and depth of the thermal boundary layer every 30 min. The program also provides an assessment of the overall soaring potential for a particular day, "Potential Flight Distance" (PFD) based on the strength and duration of thermal convection and flight performance of a model glider.

2.6. DATA ANALYSIS

The predicted upper boundary of convection was compared to the maximum altitude of migration per flock per day as well as the maximum altitude of migration per thermal. When geographic data were available in the region birds were migrating within (Coastal Plains vs. mountains), maximum altitudes of migration were compared to predictions of the upper boundary of convection for the relevant region. Data of unknown locations were compared to the upper boundary of convection for both topographic regimes.

3. Results

The maximum daily altitudes per flock measured for white storks ranged from 488 m to 1615 m above sea level (ASL). The maximum daily altitude of each flock was compared to the predicted upper boundary of convection for that time in the Coastal Plains and the Samarian Mountains. There was a significant positive correlation between the predicted upper boundary of convection and the observed maximum daily altitude of flight per flock for the Coastal Plains ($r^2 = 0.57$, $P = 0.01$, $n = 10$) as well as for the Samarian Mountains ($r^2 = 0.30$, $P = 0.06$, $n = 12$).

The ALPTHERM model provides 30-minute predictions of the strength and depth of convection. To test predictions for the daily evolution of convection, the measured maximum altitude of migration in each thermal was compared to the relevant prediction of the upper boundary of convection in time and space. As flock behaviour is dynamic and birds may leave and enter a certain flock, each thermal was treated as an individual measurement. A total of 79 thermals were observed, 13 in the Coastal Plains and 22 in the Samarian Mountains. Geographic information was not available for 44 thermals; these measurements were compared to predictions for both topographic regimes. Significant positive correlations were found between the predicted upper boundary of convection and measured maximum altitudes per thermal for both the Coastal Plains ($r^2 = 0.35$, $P < 0.001$, $n = 57$) and the Samarian Mountains ($r^2 = 0.33$, $P < 0.001$, $n = 66$) (Figure 2). Comparing 30-minute predictions of the upper boundary of convection to the maximum altitude measured every 30 minutes improved the regression for the Coastal Plains ($r^2 = 0.42$, $P = 0.005$, $n = 17$) and showed a slightly weaker correlation for the Samarian Mountains ($r^2 = 0.29$, $P = 0.006$, $n = 25$).

Measured altitudes only exceeded predictions for the Coastal Plains upper boundary of convection in three thermals on 24 April 2000 (no geographic data available); maximum altitudes of migration did not exceed predictions for the Samarian Mountains. The mean difference between the predicted boundary-layer depth and maximum altitudes of migration per thermal was significantly lower in the Coastal Plains (368 m) than in the Samarian Mountains (701 m), (two sample T-test assuming unequal variance: $t_{31} = -4.76$, $P < 0.001$).

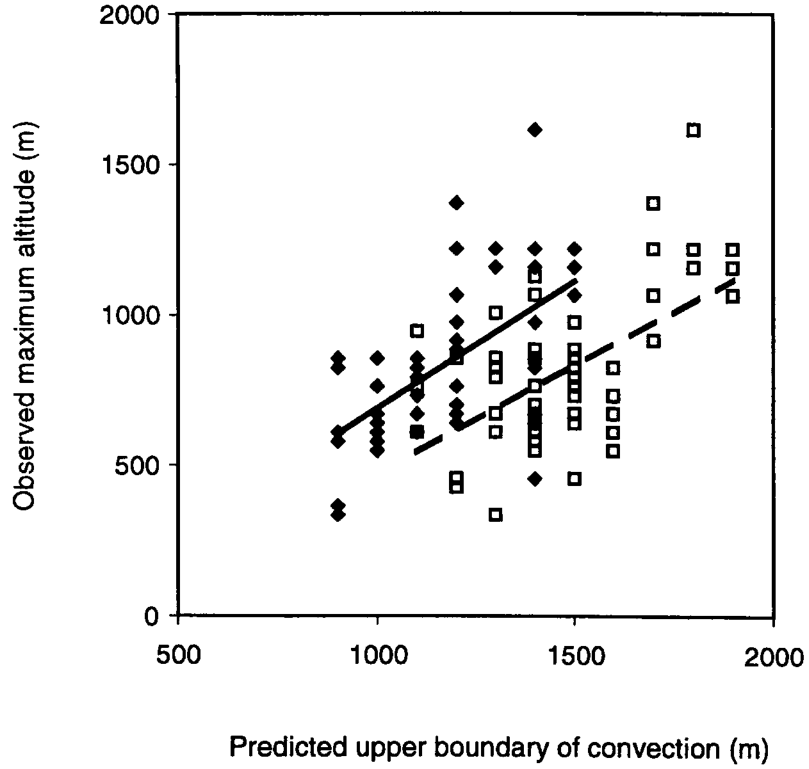

Figure 2. Predicted upper boundary of thermal convection versus the observed maximum flight altitude per thermal of migrating flocks in relation to local time over central Israel in Spring 2000. White storks measurements versus Coastal Plains predictions; ◆, $y = 0.84x - 152.4$ ($r^2 = 0.35$, $P < 0.001$, $n = 57$), bold trend line. White stork measurements versus 'Samarian Mountains' predictions; □, $y = 0.72x - 248.7$ ($r^2 = 0.3$, $P < 0.01$, $n = 66$), dashed trend line.

4. Discussion

The convection model ALPTHERM uses radiosonde data to predict the onset, duration, strength and depth of daily thermal convection. In order to compensate for different topographies in central Israel, ALPTHERM was programmed to predict two convective schemes including the Coastal Plains and the Samarian and Judean mountains along the western slopes. The predictions for thermal convection in the Coastal Plains and Samarian Mountains show that regional differences occur in thermal convection. The maximum altitudes of the migration of soaring birds vary greatly from day to day, as shown in this study and others, and predictions for the upper boundary of convection for both topographic regimes correlated positively and significantly with maximum altitudes of migration per thermal and per day. Data from Spaar et al. (2000) were reanalysed for this study and maximum daily altitudes of white stork migration in the Arava in southern Israel, for flocks of 20 birds and more, were positively and significantly related to predictions of the upper boundary of convection ($r^2 = 0.46$, $P = 0.006$, $n = 15$). In all three regions, storks did not use the full depth of convection, flying on average 368 m, 701 m and 787 m below the upper boundary of convection in the Coastal Plains, Samarian Mountains and the Arava Desert respectively. White storks seem to show regional differences in the use of thermal convection.

The ALPTHERM model can also be used to predict changes in migration altitude within each day. A positive and significant correlation was found between 30-minute changes in altitude and the predicted upper boundary of convection at the respective times for both the Coastal Plains and the Samarian Mountains. Variability in 30-minute migration altitudes can be attributed to several factors. The convective model represents the average thermal depth for each region. Whereas white storks use a varying sample of thermals available, which they find while flocking and following other birds, this sample will in part determine the altitudes of migration rather then overall regional conditions. Bradbury (2000) mentions that pilots making cross-country gliding flights remain within the band of maximum lift to maximize flight speed and refrain from using the upper part of the thermals where the lift becomes weak. In this study white storks were found to stay within the band of maximum convection. Shannon et al. (2002) recorded similar results for the American white pelican (*Pelecanus erythrorhynchos*) whose migration altitudes were compared to boundary-layer forecasts in the United States. Liechti et al. (1996) found that, although white storks did not differentiate between strong and weak thermals as clearly as certain birds of prey, they did leave weak thermals more quickly than other species. Other issues influencing model predictions are changing local conditions such as wind speed and direction and the development and spatial progression of the sea breeze, none of which was integrated into the present phase of ALPTHERM model. Migrants are known to shift their axis of migration during the day along an east-west axis, following the daily progression of the sea breeze (Leshem and Yom-Tov, 1998; Alpert et al., 2000). The sensitivity of the ALPTHERM model can be improved by calibrating the predictions with the addition of synoptic data and local ground measurements of temperature.

The ability of the ALPTHERM convection model to predict thermal convection in various topographies and the relation to soaring altitudes of migrants has important implications for military flight safety. As ALPTHERM uses midnight radiosonde data, forecasts can be provided the following morning before military training begins in order to change flight tactics (such as altitude, time and region of training) and reduce the risk of serious aircraft collisions with soaring migrants. For practical applications, the upper boundary of convection predicted by ALPTHERM can be used as a guideline for the upper limit of migration and respectively alter training altitudes, as in most cases the white storks stayed within the layer of thermal convection. Predictions for regional differences in convection are also important. Shifts in migration route may occur in order to take advantage of better thermal conditions particularly on days when adverse conditions prevail in one region, but not the other. Additional information provided by the model that may be used includes the onset and duration of thermal convection to provide the times to expect masses of migrants. An additional application in this study is the use of white storks (fitted with appropriate equipment) as markers of thermal depth and intensity over large and diverse regions, a new possibility for meteorology recently tested by Shannon et al. (2002) for American white pelicans.

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