Weather induced variations in raptor migration

A study of raptor migration during one autumn season in Kazbegi, Georgia, 2010

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Preface
The idea of this study was borne during the long days of raptor counting in Batumi, Georgia which I have had the opportunity to contribute to two weeks during the autumn of 2009 and three weeks during the autumn of 2010, including one week in Kazbegi. This study was made in co-operation with Batumi Raptor Count who provided me with raptor migration data from Kazbegi. Unfortunately there was not enough time to include a further analysis of remote sensed cloud cover data over the Caucasus, but the result of the cloud cover analysis can be seen in an upcoming article in *Sandgrouse*, the journal of the Ornithological Society of the Middle East.

Acknowledgements

I would like to thank my supervisor Margareta Johansson for her guidance during this project. I would also like to thank the board of Batumi Raptor Count; Wouter Vansteelandt, Brecht Verhelst and Johannes Jansen for the good times in Georgia and for making this study possible. I am also grateful to Dr. Nils Kjellén at the Department of Animal Ecology, Lund University, for guidance and giving me access to his library.

*Title page:* Black kites *Milvus migrans* soaring in a thermal updraft in Batumi, Sept 2009.
Abstract

Raptors migrate by using either soaring and gliding flight or a combination of gliding and powered flight. The energy consumption when using powered flight increases rapidly with body mass and is therefore mainly used by the smaller raptors, such as Falcons, Sparrowhawks and Harriers. Soaring and gliding flight are mainly used by the larger raptors such as Buzzards, Kites and Eagles. When using soaring and gliding flight, birds are dependent on updrafts from thermals or orographic winds to gain height. This dependence makes them vulnerable to environmental conditions which would inhibit the creation of these updrafts and result in variations in the amount of migrating raptors that can be seen from a given point. Thermal updrafts are created by uneven solar heating of the ground where certain spots are heated more quickly than others due to its low albedo. The warm surfaces then conduct heat to the overlaying air which expands and rises. Orographic updrafts come from horizontal winds that are deflected upwards by for example a mountain ridge. Large mountain chains act as physical barriers for migrating raptors due to the different environmental conditions such as precipitation, fog and strong winds that affect the creation of thermals and thereby the energy consumption during migration. In this study a number of meteorological variables are tested for correlation to raptor migration data from one autumn season in Kazbegi, Georgia. The results show mostly weak correlations, but three correlations are significant at \( \alpha = 0.05 \); Black Kite – cloud height, Honey Buzzard – wind speed and Levant Sparrowhawk – wind speed. Some other general trends can also be seen. When investigating the weather conditions during the days prior of the first pronounced migration peak it is obvious that the migration is held back by unfavorable conditions with low cloud height, low visibility, low temperatures and winds from the north sector. On the day of the peak there is a pronounced change of weather with maximum cloud height, maximum visibility, higher temperatures and winds from the south sector which results in the largest migration peak of both soaring and flapping raptors.

**Key words:** Kazbegi, migrating raptors, weather, thermal updrafts, flight strategies.
**Sammanfattning**


**Nyckelord:** Kazbegi, sträckande rovfåglar, väder, termik, flyktstrategier.
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Introduction

Every autumn millions of raptors migrate from their breeding grounds in northern Europe and Asia to their wintering grounds in Africa and the Arabian Peninsula (Moreau, 1972). This migration goes unnoticed in most areas, but in certain areas where topographical features concentrate the raptors, this migration become a seldom seen spectacle with tens of thousands of raptors passing overhead in a day. One of these places is Georgia, due to its geographical location in the middle of the main Eurasian migration corridor (Zalles and Bildstein, 2000). The topographical features of southern Georgia additionally concentrate the migrants to a narrow strip between the Black Sea and the highlands some kilometers inland, which makes this place an optimal location to monitor the annual raptor migration (Batumi Raptor Count, 2009). A significant proportion of the world population of many raptor species can be seen passing by the counting stations close to Batumi, just north of the Turkish border every autumn (Batumi Raptor Count, 2009). This provides a unique opportunity to detect trends in raptor populations originating from the vast area of land between Eastern Europe and Western Siberia of which otherwise would be difficult to get an overview (Batumi Raptor Count, 2009).

Many raptor species are experiencing negative population trends due to various anthropogenic factors affecting them on their breeding grounds, migration pathways and in the wintering areas (Zalles and Bildstein, 2000). It is therefore important to conduct long term monitoring of the migration at bottlenecks such as Batumi so that rapid population declines can be detected on an early stage and further investigations of possible causes can be made.

Since the migration pathways through the Middle East are still relatively unknown, the validity of the importance of Batumi as a major bottleneck had to be tested. This was done in 2010 when a pilot count was made in Kazbegi, which is located in a deep north-south oriented valley through the Caucasian mountain range approximately 250 km to the East of Batumi. This valley is the deepest valley that cuts through the mountain range and is bordered by some of the highest peaks of the region, and is therefore a likely route for many of the raptors crossing the Caucasus. Birds that pass here should theoretically go further to the east and is therefore not seen from Batumi.

Most raptors migrate by using so called soaring flight (Kerlinger, 1989). This means that they utilize thermal updrafts to gain height with minimal energy consumption. When reaching the top of the thermals they glide in the wanted migration direction in search of the next thermal updraft (Kerlinger, 1989). These thermal updrafts are created by solar heating of a surface which transfers this heat to the overlaying air, which then expands and rises (Ahrens, 2000). Birds using this kind of flight are therefore sensitive to weather which would inhibit this kind of rising air, especially when crossing physical barriers.
such as mountain ranges or vast areas of open water where it is important to be energy efficient (Kerlinger, 1989).

Most of the raptors that are counted from Batumi are thought to have crossed mountain passes in the western part of the Caucasus, similar to the Kazbegi valley a day or two before they are registered in Batumi. It is for that reason important to understand the correlation between the weather conditions in the Caucasus and the variation in migration intensity between days and between seasons.

**Aim**

The aim of this thesis is to analyze the effects of a number of local weather variables upon the daily numbers of migrating raptors during one autumn season in Kazbegi, Georgia. This work also includes a literature study on the general effects of weather and physical barriers on migrating soaring birds.

To achieve the overall aim, a series of specific questions were addressed;

- Is there any correlation between local weather conditions and daily numbers of migrating raptors in Kazbegi?
- What/which weather variable(s) is the strongest determinant of migration numbers?
- During which weather conditions do the largest peaks in migration occur?
- How do migrating raptors react when facing a physical barrier such as a mountain range during migration, and how is this influenced by weather?
Background

The origin of vertical winds

Thermal updrafts

The most important source of rising air and thus a possibility for soaring raptors to gain height comes from thermals (Kerlinger, 1989, Alerstam, 1990). Thermals are the cause of solar heating of the surface and the transfer of this heat to the overlying air by conduction (Ahrens, 2000). On a sunny day the ground surface absorbs different amount of radiation from the sun due to the surface’s albedo and topography. Albedo is the reflectance of a surface and is measured in percent (the amount of reflected radiation in relation to the total amount of radiation hitting the surface). Different surfaces have different albedo due to the color and structure of the surface. Fresh snow for example has an albedo ranging from 75 to 95% and therefore absorbs very little incoming radiation, dark soil on the other hand absorbs up to 95% of the incoming radiation and is heated more quickly (Ahrens, 2000). The heating of a surface also depends on the inclination of the surface relative to the sun. A surface that is tilted towards the sun receives more rays per area unit then a surface that is flat or tilted away. The wind velocity also have an impact on the heating of the air since it affects the time the air is in contact with the warm surface (Norman, 2010).

These warm surfaces then conduct sensible heat to the air above, which gets warmer than the surrounding air, expands and rises, and a thermal updraft is borne (Ahrens, 2000). Open fields and hill slopes facing the sun are common sources of thermals. Thermals usually do not form over forests even though the albedo is low (Norman, 2010).

As long as the air in the thermal is warmer than the surrounding air it will continue to rise. According to the dry adiabatic lapse rate the air will cool 10°C for every 1000 m it rises as long as no condensation takes place (Ahrens, 2000). If the temperature profile of the atmosphere is favorable (unstable air, getting colder with height) the thermals will rise to heights of up to 1.5 km (Konrad and Robison, 1973). If the air cools enough to reach its dew-point temperature a cumulus cloud will form and latent heat is released during condensation. The released heat will help the air to raise even higher (Ahrens, 2000). If there are cumulus clouds around it is therefore a sure sign that there are also thermals (Norman, 2010). In warmer latitudes it is however common with so called dry thermals where the rising air does not reach saturation point and therefore do not form clouds. If a lot of cumulus clouds form, the sky will eventually be obscured and the source of the thermals will be cut off (Norman, 2010). But usually there is plenty of blue sky between the cumulus clouds due to sinking air around it. Air sinks around cumulus clouds partially due to evaporation in the edges of the cloud which makes the air colder.
and denser and partially due to that the rising air has to be replaced by air around it (Ahrens, 2000).

The ascent of air within a thermal increases towards its center and could in cross section be said to resemble a normal distribution curve (Kerlinger et al, 1985). The velocity of the rising air has been measured to be between 3-5 m/s approximately 10 m from the center of thermals by measuring the climbing rate of hawks with the use of radar (Kerlinger et al, 1985).

The rising column of air will lean in the direction of the horizontal wind and eventually detach from its source. New thermals will form in its place and follow the same direction and thereby creating thermal streets which will continue as long as there are sufficient heating of the ground (Norman, 2010).

Figure 2. Schematic illustration of a gliding and soaring migrant’s use of thermal updrafts. Modified from Elkins (1983).

Sea breeze fronts

Sea breeze fronts have recently been recognized as an important source of uplift in some parts of the world. Alpert et al (2000) report that migrating raptors in Israel actively seek out the sea breeze front, and follow it during the migration. A sea breeze front is created by the thermal circulation started by uneven heating of land and sea surface (Ahrens, 2000). When air above a land surface is heated more rapidly than over the adjacent sea there is a shallow low pressure created over land and a shallow high over the sea. Consequently the air starts to flow from the high pressure towards the low pressure. This flow gets stronger as the day goes and as the pressure difference gets deeper. As it moves inland the leading edge of a sea breeze is known as a sea breeze front. If there is a sharp contrast in temperature across the front the warmer inland air will rise over the colder ocean air and this often makes good conditions for soaring (Ahrens, 2000).
Orographic winds and lee waves

Vertical winds can have other sources than explained above. Orographic winds are created by horizontal winds that are forced upwards by obstacles on the land surface such as trees, hills, ridges or buildings (Ahrens, 2000). These winds usually do not extend as far up as thermal updrafts as they are quickly deflected to a horizontal course by more fast flowing winds aloft (Kerlinger, 1989). Orographic winds created by smaller obstacles like hills are therefore not very useful for soaring birds. However when winds are forced up by for example a mountain ridge, large air masses are involved and the updrafts can extend horizontally for many kilometers. If the mountain ridge in addition follows a suitable direction for migration it can become an important source and leading line for many raptors, especially in the morning when thermals have not yet developed (Kerlinger, 1989).

Another source of updrafts associated with mountainous regions is known as lee waves (Ahrens, 2000, Barry, 1992). These “waves” form on the leeward side when stable air flows over a mountain and can extend for several hundreds of kilometers. The waves can be made visible for the naked eye when lens shaped lenticular clouds form on their crests (Ahrens, 2000, Barry, 1992). Kerlinger (1989) speculate that these lee waves are seldom used by migrating raptors because they are difficult to reach (occurs at great heights) and form infrequently. However, it has been reported that lee waves may help raptors migrate across the strait of Gibraltar (Evans and Lathbury, 1973).

Figure 3. A) Schematic illustration of orographic updraft created by an obstacle on the ground. Note how the updrafts are stronger close to the obstacle and deflected horizontally higher up. B) Illustration of standing waves known as lee waves, with lenticular clouds on the crests. Modified from Barry (1992).
How do raptors migrate?

Orientation and navigation
The orientation and navigation skills of migrating birds have eluded scientists for centuries. It is just in recent years and by endless amounts of laboratory and field studies that the very complex way that birds use to orientate has started to clear. Still there are lots of mysteries and far from everything has been understood. In order to understand how birds navigate one has to understand that the sensory world of birds is very different from humans.

Firstly, birds are able to see polarized light which help them to pinpoint the direction of the sun even when it is clouded. The eyes are also equipped with a very high density of visual cells distributed equally over almost the entire retina. A bird’s sight is probably therefore almost as sharp over the entire visual picture as the point of the humans fixed stare. In addition to seeing polarized light birds also see UV light which help them to see polarization patterns exceptionally clearly (Alerstam 1990).

Birds can also detect low frequency infra-sounds. Infra sounds travel very far in the air, up to thousands of kilometers, due to the long wavelength and is created by for example waves breaking at a shoreline or wind over a mountain top. Birds can therefore hear a vast “soundscape” which is totally unknown to us humans and probably help them navigate (Alerstam 1990).

It has also been proven that birds can detect small changes in air pressure down to 0,1 -1 millibar. Human’s sensitivity is about 4 millibar change. This is important for birds to predict changes in weather during migration and to maintain a constant flight height (Alerstam 1990).

The most important discovery is probably that birds have a built in magnetic compass in their head. During the 1970’s the suspicions of such a mechanism was borne since tests had revealed that birds could detect changes in artificial magnetic fields. In 1979 it was discovered that they have small crystals of magnetite in their heads. The magnetic field created from the head indicates that they have a total of about 10 to 100 million small magnetite crystals with a total weight of about one ten-thousands of a milligram. This enables birds to follow constant geomagnetic courses and detect if they are deflected in an east-westward direction (Alerstam 1990).

Other compass senses include the sun-compass which enables a bird to determine the compass direction by using the sun’s position and a well-developed biological clock. Most small birds migrate during the night and therefore make use of the stars for
direction. The Pole Star lies in the direct extension from the earth’s northern axis and forms a rotation center in the northern sky. Since the Pole Star always lies due north, migrating birds use it as compass direction all through the night without the aid of a biological clock. (Alerstam 1990). These compass senses often complement each other and can be used in combination in different situations. Studies indicate that migrants use their magnetic compass to determine their flight direction and then the sun or star compass to maintain the direction as a sort of auto pilot (Wiltschko and Wiltschko, 1975).

All these orientation cues help birds to migrate in an appropriate direction, but to successfully reach their exact wintering ground or breeding area they have to “know” more exactly where they are going and where they are. This requires a good geographical or map sense. By tracking homing pigeons fitted with radio transmitters it has been found that they maintain an unaltered direction until the near end of the flight where they make an abrupt change of direction and fly straight to the pigeon loft. This indicates that migrating birds can use a combination of compass based orientation and geographical navigation to find their way to their goal (Alerstam 1990).

Significant differences in migration strategies between juvenile and adult birds indicate that the map sense is acquired and shaped throughout a bird’s life. For example it has been revealed by migrating Ospreys Pandion haliaetus and Honey Buzzards Pernis apivorus fitted with satellite trackers that juveniles show no signs of compensating for wind drift in any direction whilst adults compensate for lateral drift and maintain an appropriate direction (Thorup et al 2003).

Few studies have been made specifically on raptors and what mechanisms they use during migration. Thorup et al (2006) tested weather raptors follow constant geographical or geomagnetic courses. This was made by analyzing the flight path of 25 Peregrine Falcons Falco peregrinus during autumn migration in North America and 7 Honey Buzzards Pernis apivorus and 13 Ospreys Pandion haliaetus during migration between Europe and Africa, all fitted with satellite trackers. The study showed that the flight path of the tested species showed better agreement with constant geographical courses, indicating that the geographical compass (based on celestial cues) is of greater importance for the raptor’s long distance orientation.

**Weather and migrating raptors**

Weather conditions strongly affect the migration of birds (Shamoun-Baranes, 2010). Local weather conditions affect, among others, the start and duration of migration, energy cost, migratory routes, flight speed and flight strategy of raptors (e.g. Shamoun-Baranes, 2010; Shamoun-Baranes et al, 2006; Vardanis, 2011; Maransky, 1997). The effects of weather conditions on migrating raptors are complex and differ depending on for example species, region and season. It is therefore important to integrate meteorology
into research on migration to help understand the variation in daily numbers seen at raptor watch sites (Shamoun-Baranes, 2010). Since raptors are relatively large in size and travel during daylight one would think that studying the effects of weather upon the migration would be quite straightforward. This has shown not to be the case since raptors can travel in broad front over vast areas and observations from one point get easily biased when local environmental conditions like wind drift and topography affect the counted numbers (Richardson, 1978). To reduce the bias one can use simultaneous visual observations from closely spaced watch sites or, ideally, telemetry or satellite tracking of individual raptors (Richardson, 1978).

Previous studies have found correlations with autumn migrating raptors and, among others; wind direction, passage of cold fronts, pressure and cloud cover (e.g. Allen et al, 1996, Mueller and Berger, 1961, Rudebeck, 1950)

It has been shown that the effects of weather can change during the length of a season. Maransky et al (1997) analyzed the effects of a number of meteorological variables upon the migration of Red-Tailed Hawks *Buteo jamaicensis* during three autumn seasons at Hawk Mountain Sanctuary, Pennsylvania. They saw that the response to decreasing relative humidity declined over the migration period, while the responses to wind direction and wind speed increased. Decreases in relative humidity are generally associated with fair, and thus thermal producing weather, and increased wind speeds often generate good orographic uplift. They interpret this shift as a shift in the Red-Tailed Hawk’s dependence of thermal soaring over the migration period. A shift from thermal soaring to flapping flight over the autumn migration period has also been seen for Levant Sparrowhawk *Accipiter brevipes* in Israel (Stark and Liechti, 1993).

**Description of analyzed species and flight strategies**

According to Kerlinger (1989) there are two basic types of flight strategies among birds. The first is gliding which is the simplest and “cheapest” of the two. The bird holds its wings outstretched in a fixed position and no flapping occurs. The flight path of a gliding bird is always downward relative to the air but can be upward relative to the ground if the updrafts are strong enough. If the bird glides in circles in a thermal it is called soaring. The other type is called powered flight and is characterized by constant flapping with the wings to move the bird forward through the air. Powered flight can be divided in sub-categories depending on if the flight path is undulating, have segments of gliding etc (Kerlinger, 1989).

Migrating raptors use either gliding-soaring or a combination of powered flight and gliding (Spaar, 1997). The energy consumption during flapping flight is increased rapidly with body mass (Pennycuick, 1975). For example a large bird such as White Stork *Ciconia ciconia* consumes 12 times as much energy during flapping flight than during
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gliding (Pennycuick, 1972). Therefore flapping-gliding flight is used mainly by smaller raptors such as Falcons and Sparrowhawks whilst the larger Buzzards and Eagles are reluctant to use powered flight during migration (Kerlinger, 1989).

As a result of this, species with different flight strategies respond differently to environmental conditions, such as abundance of thermals and unfavorable winds during migration (Spaar, 1997).

**Buzzards, Kites, Eagles and Vultures**

Even though the group consists of many different genetically separated taxa, all species are morphologically relatively similar and therefore use similar flight techniques (Spaar 1997). These birds are characterized by medium to very large wingspan and broad wings with broad rounded wingtips. See Figure 4 and 5 for examples. Due to the large size and body mass of these birds they use almost exclusively soaring and gliding flight during migration (Spaar, 1997).

In Southern Israel a study of raptor flight techniques revealed that Buzzards, Eagles and Kites use soaring and gliding flight for 97% – 100% of the observed time, with Black Kite *Milvus migrans* and Booted Eagle *Hieraaetus pennatus* being most willing to use flapping flight (3 % of the time) (Spaar, 1997). These species are therefore highly dependent on updrafts such as thermals and orographic winds to gain height and should thereby be sensitive to unfavorable weather conditions during migration (Spaar, 1997).

**Figure 4.** Steppe Eagle *Aquila nipalensis*. Note the broad wings and rounded wing tips, typical for a soaring and gliding migrant.

**Figure 5.** Steppe Buzzard *Buteo buteo vulpinus*. Another example of a typical broad winged soaring migrant.
**Sparrowhawks, Falcons and Harriers**

The group consist of small to medium sized raptors with relatively low body mass. The morphology in this group is more heterogeneous than in the above but they have similar flight techniques (Spaar, 1997). The Sparrowhawks (*Figure 6*) are quite small and has rather short but broad wings with rounded wingtips and long tail. Falcons are characterized by their narrow and pointed wings and small size (*Figure 8*). The Harriers consist of four species with a bit different morphology. Two of the species, Marsh Harrier *Circus aeruginosus*, and Hen Harrier *Circus cyaneus* are relatively large with broader wings and rounded wingtips, quite similar to Kites in size and shape. The other two species, Montagu’s Harrier *Circus pygargus* and Pallid Harrier *Circus macrourus* are smaller and have more narrow and pointed wings, somewhat resembling a long winged Falcon (*Figure 7*).

As a result of their smaller size and lower weight, powered flight is less costly and they can be more flexible in their choice of flight (Spaar, 1997). Their ability to alter their flight style gives them the opportunity to migrate in more varied conditions and make use of the whole day for migration, even when thermals are scarce (Spaar, 1997). Even though they to a larger degree use flapping and gliding flight than the larger species, 9-33% of the observed time in Israel, they regularly use thermals when they have the opportunity (Spaar and Bruderer, 1997).

**Figure 6.** Sparrowhawk *Accipiter nisus*. Small size and low body weight typical of migrants using flapping flight.

**Figure 7.** Pallid Harrier *Circus macrourus*. Long, narrow wings and pointed wing tips, typical for the smaller Harriers.

**Figure 8.** Hobby *Falco subbuteo*. Typical pointed wings and short tail of a Falcon.
Mountain ranges and migrating raptors

No previous studies have been made on how the migration of raptors over the Caucasus varies with weather. Bruderer and Jenni (1990) studied the occurrence and numbers of raptor species during migration in high mountain passes in the Alps and compared it to numbers seen in the lowlands. They found a negative correlation of the frequency of 11 raptor species in the Alps and their proportion of soaring during migration. For one of the most distinct soaring species, Common Buzzard *Buteo buteo*, the few individuals seen crossing the Alps occurred early in the migration period when the thermals still offered good lift. Thiollay (1967) reports that soaring raptors are regularly seen abandoning migration in high mountain passes in the Alps during strong head wind when raptors migrating mainly with powered flight still pass.

Raptors specialized to using soaring flight are known to make surprisingly large detours during their migration in order to reduce their flight cost by using thermals (Alerstam, 1981, Alerstam, 2001). For example, in the Himalayas, large numbers of mainly Steppe Eagles *Aquila nipalensis* make a detour in the migration route to make use of the thermal producing lower slopes of the mountain chain (Den Besten, 2004).
**Study site**

The migration data was collected from hill slopes close to the small town of Gergeti in the Kazbegi valley, at approximately 42° 39’ 27” N, 44° 38’ 43” E (WGS 84). Gergeti lies at approximately 1,800 meters above sea level on the western bank of the Terek River. The valley is surrounded on both sides by high mountain peaks. Approximately 5 km west of Gergeti lies Mt. Kazbek which is a 5,033 meters high extinct stratovolcano ([Encyclopædia Britannica](https://www.britannica.com), 2011a). On the eastern side of the valley the slopes quickly rises from the riverbanks to around 3,000 meters. The lower slopes are covered by grazed alpine meadows and smaller stands of mixed deciduous forests, which at a higher elevation are replaced by dwarf rhododendron. The valley, which has an aspect that is roughly north at the counting station, reaches its highest point approximately 20 km SW of Kazbegi.

![3D image of the study site area, facing north. The yellow line indicates the Russian/Georgian border. Modified from Google earth.](image)

Above approximately 2,000 meters there are prevailing westerly winds in the Caucasus which strengthen the maritime influences and generates large amounts of rainfall, with a maximum of more than 4,000 mm/year on the south and southwestern slopes of the mountain range ([Encyclopædia Britannica](https://www.britannica.com), 2011b). Since the town of Kazbegi lays at the eastern part of the Caucasus the precipitation is lower, in average 790 mm/year. The warmest month in Kazbegi is August with a daily mean temperature ranging from 5 to 10°C. The coldest month is January with a daily mean ranging from -10 to -25°C ([KNMI](https://www.knmi.nl), 2011).
Method and data

The raptor migration data was collected by experienced birdwatchers working as volunteers for Batumi Raptor Count (BRC) between 22nd of August and 29th of September 2010. The counts were made from early to mid-morning until the migration stopped, usually in the afternoon. During rain there was little coverage due to low migration intensity and harsh condition for the counters. All raptors that passed the counting station with an approximate southerly flight direction was counted, movements of the locally resident birds was ignored. For the full migration dataset, see Appendix 1.

To minimize the effects of phenology, the dates for the central 90 % of the migration of the selected species was used to limit the time series. These dates that were obtained from BRC are based on observations from two autumn seasons in Batumi, Georgia. For the Aquila Eagles the dates for Lesser Spotted Eagle *Aquila pomarina* were used since it was the dominating species and have similar phenology as the other species in this group. For Falcons the dates for Common Kestrel *Falco tinnunculus* were used for the same reasons as above. Montagu’s Harrier *Circus pygargus* and Pallid Harrier *Circus macrourus* have quite different phenology, Montagu’s Harrier migrate mainly in the beginning of the season and are gradually replaced by Pallid Harrier throughout September. To cover the migration period of both species the date for the first 5 % of the Montagu’s migration and last 5 % of the Pallid migration were used.

Meteorological data from a weather station in Vladikavkaz, Russia (see *figure 1* for location) was ordered from the NOAA National Data Centers online shop. The parameters that can be seen in table 1 are daily means from 7-8 measurements per day. The wind direction was reclassified to four sectors representing the general direction, and the daily mode (type) value was used for the correlation tests. See *table 1* for the data used in the analysis and *figure 9* and *10* for plotted visualizations. To test the correlation between the selected species/species groups and the meteorological data, linear regression and bivariate correlation was done in SPSS 17.0.
Table 1. The meteorological and raptor count data used for the correlation tests. Cells with green background symbolize the time series used in the correlation tests.

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<th>Temp (°C) *</th>
<th>Visibility (m) *</th>
<th>Cloud height (m) *</th>
<th>Wind speed (m/s) *</th>
<th>Wind direction **</th>
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<th>Aquila Eagles ***</th>
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<th>Honey Buzzard</th>
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29378 416 30134 156 2123 289 728
Weather induced variations in raptor migration

* Daily means from 7-8 measurements per day. ** Daily mode (type) value with 90° intervals, 1=N, 2=E, 3=S and 4=W. ***The group Aquila Eagles includes Lesser Spotted Eagle, Greater Spotted Eagle, Steppe Eagle, Imperial Eagle and unidentified Aquila Eagles. ****The group Falcons includes all identified and unidentified Falcon species that can be seen in appendix 1.

**Figure 9.** A plot of the raptors predominantly using soaring flight during migration (Eagles, Buzzards, Kites and Vultures) and raptors that to a larger degree use flapping flight (Harriers, Sparrowhawks and Falcons). Note the three pronounced peaks of soaring raptors (12’th, 16’th and 19’th of September), and two peaks of flapping raptors (12’th and 16’th of September).

**Figure 10.** Plot of daily means of cloud height, visibility and temperature during the counting period.
Results

The regression and correlation tests mostly showed very weak correlation and low significance between the counted numbers and weather data. However, three correlations were significant at $\alpha=0.05$; Black Kite – cloud height ($R^2=0.147 \ \alpha=0.048$), Honey Buzzard – wind speed ($R^2=0.487 \ \alpha=0.001$), and Levant Sparrowhawk – wind speed ($R^2=0.189 \ \alpha=0.03$). The correlation values show, in many cases, a clear but not significant correlation between the counted numbers and meteorological parameters. For example, Aquila Eagles tended to migrate during low SLP and high temperatures. On the other hand, when plotting Aquila Eagles together with SLP one can see that during the first half of the migration there is a positive correlation with SLP while during the second half there is a large migration peak during low SLP which influence the correlation value to be negative. When looking at the general trend of the different meteorological parameters, 4 out of 7 species/species groups have a negative correlation with SLP, 5 have a negative correlation with temperature, 6 have a negative correlation with visibility, 1 has negative correlation with cloud height, all have negative correlation with wind speed and 2 have negative correlation with wind direction.

Table 2. The result of the linear regression and bivariate correlation tests in SPSS, showing the $R^2$ value, $\rho_{X,Y}$ (Correlation coefficient) and $\alpha$ (level of significance) of each species/species group and meteorological parameter. Bold figures indicate significance at $\alpha=0.05$.

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Weather induced variations in raptor migration

**Figure 11.** Plot of sea level pressure (SLP) and the species group Aquila Eagles. During the first half of the plot one can see that on days with higher SLP there are also larger numbers of Aquila Eagles migrating. While on the second half of the plot there are no response on the migration during high SLP and instead a large peak during low SLP.

**Figure 12.** Plot of cloud height and the grouped Montagu’s and Pallid Harrier. One can clearly see signs of increased migration during days with high clouds.

**Figure 13.** Plot of cloud height and Black Kite. Again showing a connection between increased migration and days with high clouds, at least for some parts of the migration period.
**Discussion**

Based on the results from this analysis it is difficult to draw any conclusions of the influence of weather on the daily migration of raptors over Kazbegi. However, three correlations turned out to be significant at $\alpha=0.05$, Black Kite and cloud height, Honey Buzzard and wind speed and Levant Sparrowhawk and wind speed. Unfortunately no significant correlations with wind direction could be found which makes the correlation with wind speed less interesting. Steppe Buzzard showed the highest correlation to wind direction with a correlation value of 0.36, which surprisingly indicates larger migration during winds from the south and west sector. The wind speeds measured at the meteorological station in Vladikavkaz are however so low (daily means below 2.8 m/s, if correctly measured) that they should have little impact on the migration even during head winds. Interestingly the same connection was seen by Thiollay (1967) at a Swiss alpine pass, where the largest numbers were counted during moderate opposing winds, less during light winds and least during strong opposing or following winds.

The correlation between increased migration of Black Kite and higher cloud heights is however more expected. Maximum cloud heights indicate days with no or very little cloud cover and thus potential thermal producing weather. Very low cloud heights would not only inhibit thermal genesis but also reduce visibility when the clouds reach the mountain slopes. Surprisingly no other species/species group showed any significant correlations with cloud height, but as can be seen in Figure 12 and 13 there is still a clear, but not significant, connection. It is possible that the correlation values get influenced by the fluctuations of cloud height between 10,000 and 20,000 meters which probably have little impact on the raptor migration, if not also taking into account the degree of cloud cover.

Sea Level Pressure (SLP) is often correlated with a number of weather variables which could have an impact on migration. High pressures are often associated with fair, thermal producing weather and low pressures are connected with unfavorable conditions for migration e.g. cloud cover, precipitation, fog etc. The largest migration usually occurs during high or rising pressure (e.g. Rudebeck, 1950). However, no significant correlations with SLP and migration were found in this analysis. Aquila Eagles had a negative correlation of 0.3, i.e. a tendency of increased migration during low pressure. However, when plotting the two together (Figure 11) one can see that the peaks during the first half of the migration period occurs in days of high pressure, while during the second half there is no connection. When seeing this, one can draw a connection to Maransky et al (1997) who saw a decrease in the Red-Tailed Hawk’s dependence of thermals towards the end of the migration period at Hawk Mountain, Pennsylvania. Perhaps a similar shift in behavior exists in the soaring migrants in the Caucasus, if sufficient updrafts could be found from other sources than thermal (e.g. orographic, lee
waves). If such a connection exists one would however expect to see a stronger correlation with wind speed and direction.

When studying the plot of the total numbers of soaring and flapping raptors (*Figure 10*) three pronounced peaks can be found in the migration of soaring raptors at the 12th, 16th and 19th of September, and two pronounced peaks of flapping migrants at the 12th and 16th of September. Since these days protrude from the rest very clearly, the logical explanation would be that there are some external factors triggering migration these days. If comparing the peak days and the days with low migration in between with the weather in Vladikavkaz (*Figure 9, 10, Table 1.*), one can see that the three to four days prior to the first peak are characterized by very low clouds, low visibility, low temperatures and winds from the north sector. On the day of the peak there is a pronounced shift in all these weather factors, with maximum cloud height, maximum visibility, higher temperatures and winds from the south sector, which results in the largest peak of both soaring and flapping migrants of the season. During the days with unfavorable weather prior to the peak day there are probably a build up with raptors, relatively close, north of the Caucasus since they respond instantly when the weather changes to more favorable conditions. During the days with lower migration after the peak there is again a shift with low clouds, lower visibility and lower temperatures, but the winds remain from the south sector. At the next peak on the 16th the change of weather is not as pronounced, the winds are unchanged, the visibility surprisingly low but the increase in cloud height is prominent and the temperatures are rising.

**Sources of error**

One reason for the weak correlations is probably because of the relative inaccuracy of both the meteorological data and the raptor data. The raptor data has flaws in the means of reliability due to unstandardized counting methods and thus, potentially biased numbers. The counts did not follow a standardized time schedule, but varied from day to day, depending on weather and migration intensity. The counted numbers could also be biased due to the simple fact that birds are missed to a different degree in different weather conditions, even if there was the same amount of coverage in all weather.

Different conditions all have their own challenges of doing an accurate count. Fair weather with perfect soaring conditions can lead to the raptors migrating on broader front and on great heights, making them difficult to spot, and not necessarily concentrated to the valley from which the counts are made. During such conditions unidentified raptors were seen flying over the top of the 5033 meter high Mount Kazbek, which supports the theory that the raptor migration is not always confined to the valley (pers. obs.). During days with low clouds and thus restricted visibility, there is the possibility to miss birds that are concealed by the clouds. Personal observations of tens of Pallid and Marsh Harriers migrating in thick fog on the lower slopes of Mount Kazbek, during a short visit
to Kazbegi in September 2009, indicate that a significant amount of migrants could be missed on days with unfavorable weather. This could at least be suspected for the species not strictly confined to soaring and gliding migration.

The meteorological data available for the analysis is not optimal for correlation with the migration in Kazbegi either, as it comes from a meteorological station approximately 70 km north of Kazbegi, at the foot-slopes of the same valley. The distance and height difference to the counting station could do much for the local weather conditions. Unfortunately no precipitation data existed from the station which would be interesting to correlate with the raptor data. The wind speed measurements also seem a bit suspect since none of the 7 to 8 measurements per day exceed 4 m/s during the period.

In order to get good results of the analysis it is crucial to minimize the effects of phenology on the correlations. In this analysis the dates of the central 90% of migration in Batumi was used, but possibly that is not enough to exclude the effects of phenology. One way to deal with this would be to calculate weights to compensate for the lower numbers in the beginning and the end of the migration period due to a species phenology. In order to get reasonably accurate weights one would however need to have good knowledge of the distribution of migration over the season in this specific region. Since this was the first year counts were made in Kazbegi no previous references could be used from this location. However, full season counts have been made in Batumi since 2008, which should be enough to make out the general trend over the season and should be possible to apply on the Kazbegi data.

**Future studies**

To get a better understanding of the effects of weather on raptor migration in the Caucasus more studies are needed. More precise meteorological data would be necessary, preferably observations of as many variables as possible at a regular interval, including precipitation, cloud cover, visibility etc., from the same locality as the raptor count. Also remote sensed data of cloud cover etc. from a larger area north of the counting station would be desirable to correlate with the raptor data. Multiple regression analysis would be to prefer due to the interconnections of the weather variables. To get more reliable results one would also of course need longer time series of raptor migration data, covering several full seasons with more standardized counting methods.
Conclusions

The influence of weather on raptor migration over the Caucasus is most likely very high. Even though this analysis showed mostly weak correlations, the three correlations that turned out significant shows that it is indeed possible to find correlations. To get a better understanding of the connections, further studies with higher quality meteorological data is needed.

It is difficult to denote what single meteorological factor is the strongest determinant of migration numbers since most, if not all, weather variables are interrelated to each other. Even though a correlation between a species and a weather variable is found, is it hard to rule out that it is not in fact another element that is the stronger determinant. In this study the strongest correlation was found with cloud cover and wind speed. However, any weather factor that affects the development of thermal updrafts and energy consumption during migration is also likely to affect the number of migrating raptors.

In Kazbegi the largest migration peak occurred after a couple of days with unfavorable weather with low clouds, low visibility, low temperatures and winds from the north sector, which on the day of the peak shifted to maximum cloud height, maximum visibility, rising temperatures and southerly winds.

It is hard, due to the small amount of previous studies, to draw any conclusions on how raptors behave when facing a mountain range such as the Caucasus during migration. A previous study from the Alps shows that soaring migrants to a large degree avoid crossing the highest passes, probably due to limited supply of thermals. However, species that to a larger degree use powered flight might not be as limited by this. Generally the influence of weather on migration is probably greater in high alpine regions than in lowlands. The underlying stress is higher due to the ordeal of crossing the mountain range itself, and additional restrains of meteorological conditions should affect the migration more.
References


Weather induced variations in raptor migration


Thorup, K., Fuller, M., Alerstam, T., Hake, M., Kjellén, N., Strandberg, R., 2006, ‘Do migratory flight paths of raptors follow constant geographical or geomagnetic courses?’, *Animal behaviour*, vol. 72, no. 4, pp. 875-880.


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**Appendix 1**

Weather induced variations in raptor migration

The reports are available at the Geo-Library, Department of Physical Geography, University of Lund, Sölvegatan 12, S-223 62 Lund, Sweden. Report series started 1985. The whole complete list and electronic versions are available at http://www.geobib.lu.se/

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