

DOES THE LAKE HURON SHORELINE INFLUENCE DISTRIBUTIONS, ALTITUDES, AND
FLIGHT DIRECTIONS OF NOCTURNALLY MIGRATING BIRDS?

by

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ABSTRACT

An increase in the number of wind turbines caused by a developing need for renewable energy has led to concerns about their potential effects on birds and other wildlife. It is not well known whether turbines placed along shorelines may present a greater risk to migrating birds than turbines farther inland. I used five marine radars to test whether numbers and flight behaviours of migrating birds differed along a shoreline compared to inland. Radars were positioned at various distances from the Lake Huron shoreline along two transects, with one shoreline radar and one or two inland radars on each transect. Radars were operational between April 18th and May 31st 2014. The numbers of birds detected varied significantly among nights ranging between thousands to hundreds of thousands. There were small differences in the numbers of birds detected among sites, but no significant difference between shoreline and inland sites. The flight altitude varied significantly among nights, but there was no strong evidence that shorelines influenced the migratory flight altitude of birds. Flight direction varied among nights but within a night was generally similar among sites, with most birds on nights of heavy migration migrating north to north-east. The results from this study provide no evidence that placing wind turbines along the Lake Huron shoreline would present an increased risk of collisions to passing migrants.

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INTRODUCTION

An increase in the number of wind turbines caused by a developing need for renewable energy has led to concerns about their potential effects on birds (Hüppop *et al.* 2006; Liechti *et al.* 2013; Zimmerling *et al.* 2013). Birds can be affected by wind turbines in various ways. Visual or noise disturbance during and after construction may displace certain bird species from suitable habitat (Langston & Pullan, 2003; Schmidt *et al.* 2003; Pearce-Higgins *et al.* 2009, 2012). Once wind turbines are erect, birds aloft not only risk colliding with rotor blades but also with associated structures such as guy wires, power lines and meteorological towers (Drewitt & Langston, 2006). Cumulative bird mortality due to wind turbines is relatively low compared to other structures such as communication towers and transmission lines (Calvert *et al.* 2013). However, the potential effects of wind turbines on birds remain a concern because the United-States and Canada's wind energy developments continue to grow every year (Sawyer & Rave, 2015).

Locating wind turbines in areas with elevated bird activity might increase the risk of collisions. Concerns involving selecting appropriate wind turbine sites were raised after studies conducted at Altamont Pass (California, U.S.) showed a large number of avian mortalities associated with wind turbines in the area (Orloff & Flannery, 1982). Diurnal migrants such as hawks and other birds of prey rely on thermal convection for their migration and in the absence of thermals rely on cliffs for lift (Alerstam, 1990a; Barrios & Rodriguez, 2004). Wind turbine developments along geographical features

such as rolling hills or cliffs that provide rising air columns may result in diurnal migrants unintentionally flying in the same airspace as revolving rotor blades (Howell and DiDonato, 1991; Drewitt & Langston, 2006). Though there are concerns surrounding diurnal migrants, recent work shows that 80% of bird mortality due to wind turbines in North America are passerines, which are mainly nocturnal migrants (Mabee *et al.* 2006; Kuvlesky *et al.* 2007). Unlike many diurnal migrants, nocturnal migrants use powered flight for migration (Hedenström, 1993). Accordingly, nocturnal migrants may be less reliant on geographical features than diurnal migrants and are able to cross various terrains without deviation (Bruderer, 2001). There is question, therefore, as to how and whether nocturnal migrants are concentrated by geographical features.

There is some uncertainty about the extent to which North American nocturnal migrants migrate in a broad front or are concentrated by geographical features (Richardson, 1978; Williams *et al.* 1977; Bingman *et al.* 1982; Williams *et al.* 2001). Broad front migration implies that migrants travel in a fairly uniform concentration and direction across the landscape (van Dobben, 1953; Ralph, 1981). Broad fronts may contain numerous populations of birds that fly parallel to each other over a large geographic area, both over land and water (Richardson, 1978; Berthold, 2001). However, geographical barriers encountered during migration may affect a bird's navigational decisions and could lead to concentrations of birds. Geographical barriers such as large bodies of water may alter the distribution of migrants across the landscape into concentrations along shorelines, especially when the configuration of the barrier does not follow that of the endogenous migratory flight direction (Gagnon *et al.* 2011).

Many nocturnal migrants pass through the Great Lakes region every year but it is not well known whether or where they concentrate along shorelines (Diehl *et al.* 2003). Many wind turbine developments are located near shorelines, where the winds are often strongest, and thus could pose a greater risk to birds if they also concentrate in the same areas. The Great Lakes represent a barrier that birds may choose to cross or navigate around (Diehl *et al.* 2003; Ewert *et al.* 2011). Crossing may depend on a bird's physical condition, the time at which it reaches the barrier, and the environmental conditions (Able, 1972; Alerstam & Pettersson, 1977; Fortin *et al.*, 1999; Deutschlander & Muheim, 2009). Birds with lower fuel reserves, for example, may be less likely to engage in crossing because of the dangers and physical demands associated with crossing large bodies of water (Alerstam & Pettersson, 1977; Alerstam, 1978; Bruderer & Liechti, 1998; Fortin *et al.* 1999). Birds may also follow the shoreline and avoid crossing, if it is oriented more or less along the birds intended migratory direction, potentially to facilitate orientation (Alerstam *et al.* 1974 as cited in Alerstam, 1990b). The Lake Huron shoreline is oriented more or less along the endogenous migration direction of many songbirds in southern Ontario. Therefore, birds may redirect their overwater flights to fly over the shoreline. This might be expected to lead to an increase in numbers of birds along the shoreline, which could increase the risk of collisions if turbines are developed there.

To understand whether nocturnal migrants concentrate along shorelines during migration, technology must be used because they are difficult to detect visually. Studies conducted over the Great Lakes using weather surveillance radars (WSR-88D) provide

valuable information on crossing or coasting behaviours of migrating birds (Diehl *et al.* 2003), but it is difficult to use them to quantify numbers of birds and to document migration patterns at a fine scale (Gauthreaux & Belser, 2003; Gauthreaux *et al.* 2003). Small X-band marine radars allow the opportunity to detect and count individual birds at a local and regional scale. In addition, small changes in migratory behaviours such as flight altitude and flight direction can also be studied. Fine-scale assessments are essential to help address whether birds flying along shorelines are at a greater risk of wind turbine collisions.

The objective of my study was to use marine radars to test whether nocturnal migrating birds fly in higher concentrations along shorelines compared to inland. I also tested whether their flight altitude and flight direction was influenced by the shoreline. This information can be used to test whether wind turbines placed along shorelines would present a greater risk to nocturnal migrants.

METHODS

Radar locations and study period

I used two 12 kW (Furuno 1954BB) and three 25 kW (Furuno 1964BB) modified X-band marine radars to record nocturnal migrants passing near the shoreline of Lake Huron (Table 1, Figure 1 & 2). I deployed the radars at various distances from the shoreline along two transects and collected data between April 18th and May 31st, 2014. I compared the number of birds, flight altitude and flight direction within transects.

Table 1: Summary of study locations and radar types. Transect 1: A & B. Transect 2: C, D & E.

					Distance from
	Site name	Radar Type	Latitude	Longitude	Shoreline (km)
A	Pierce	25 kW	44° 07' 59.274" N	81° 40' 49.986" W	0.5
B	Gibson	12 kW	44° 04' 49.362"N	81° 34' 18.696"W	10.9
C	Wallis	12 kW	43° 36' 19.432"N	81° 42' 8.532"W	0.8
D	Dutot	25 kW	43° 35' 33.300"N	81° 37' 15.402"W	7.2
E	Hullett	25 kW	43° 36' 13.944"N	81° 27' 22.896"W	20.6

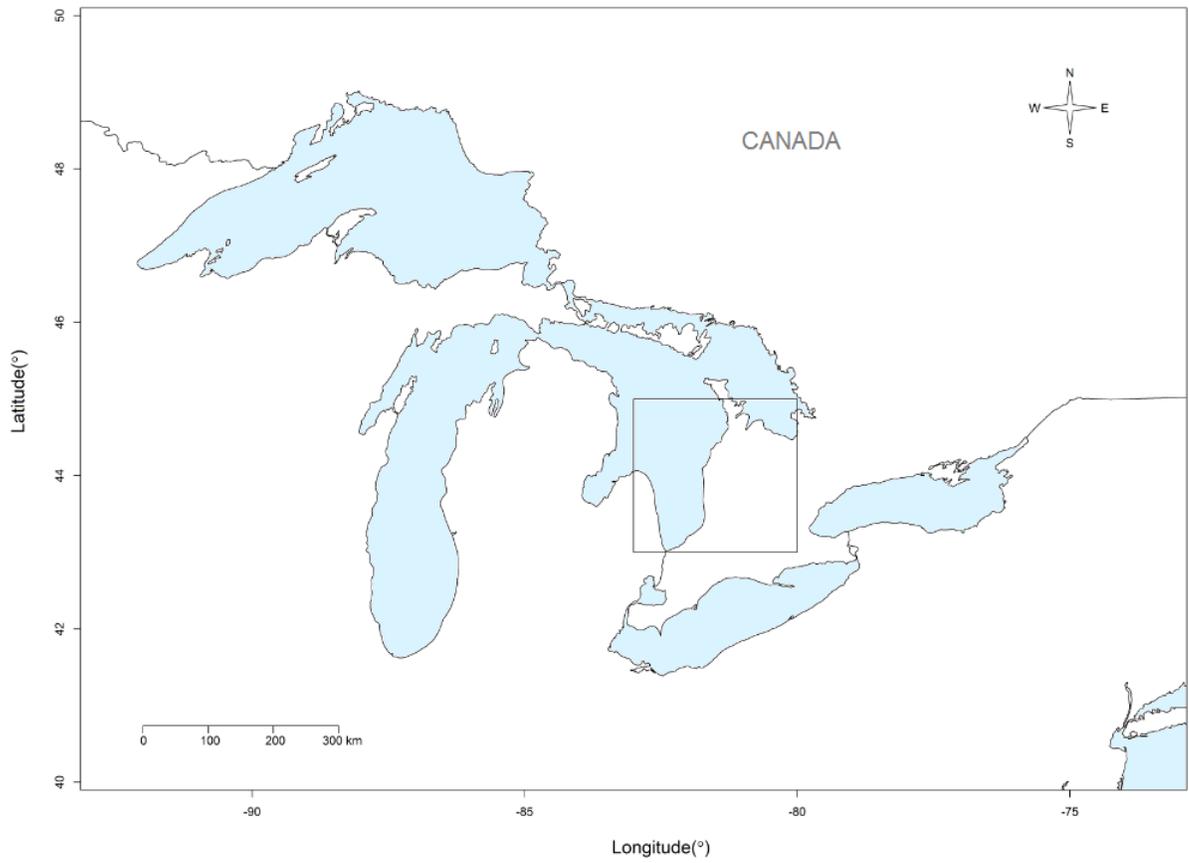


Figure 1: Map of the Great Lakes Region. Black box represents the 2014 spring bird migration study area.

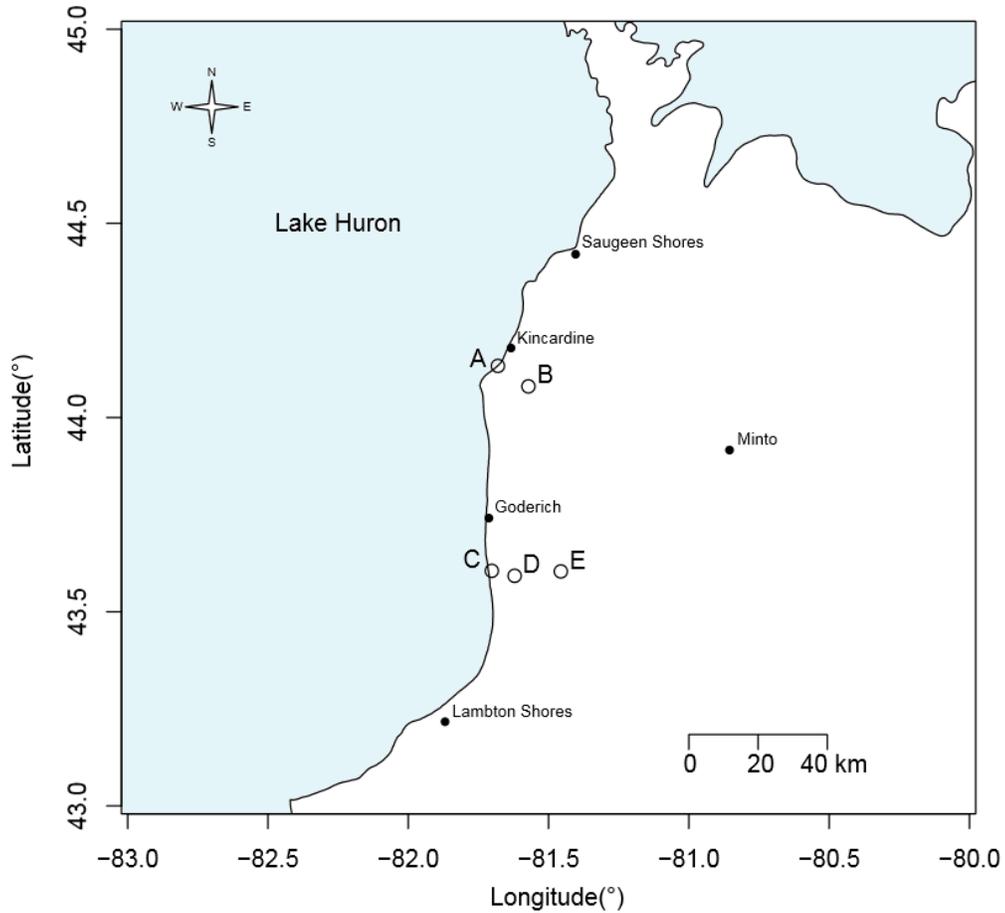


Figure 2: Map of the eastern shoreline of Lake Huron. Hollow circles and letters represent radar locations. A: Pierce, B: Gibson, C: Wallis, D: Dutot, E: Hullett.

Radar description

Radars were retrofitted with a parabolic dish that rotates 2.4 times per second for a complete scan (360°) of its surroundings. Electromagnetic beams are emitted from the radar antenna with a frequency of 9410 MHz and a beam width of $\sim 3.5^\circ$. Echoes from the emitted radar beam return to the dish if they hit an object or target in the environment. The dishes of the radars were programmed to tilt on a schedule from 15°

to 40° above the horizon by 5° increments using *radR*, an open source computer program (Taylor et al. 2010). The radar scanned the environment at each angle for five minutes before moving up to the next increment. After scanning at 40° the antenna returned to the initial angle setting of 15°.

Processing radar data

Extracting data on a bird detected by radar is meticulous and requires multiple steps to reach the end result. Outlined below is the framework used to collect radar data and identify which targets likely represent birds.

Recording blipmovies

The overall data collection process largely follows that described by Taylor et al. (2010), although a few features used updated technologies. A modified Universal Software Radio Peripheral (USRP) was used to digitize analog radar signals. *radR* was used to acquire and process the signals of each radar scan. To detect targets in the environment, *radR* computes the temporal mean and mean deviation of a user-defined area of pulses (radial dimension) and samples (angular dimension) across multiple scans to identify the average background noise in each region of the radar. If the relative intensity (z-score) of subsequent samples within a scan exceeds that of the background distribution in that portion of the scan they are considered “hot”; a collection of adjacent hot samples form a patch. Patches that fall within user-defined filtering criteria

are classified as “blips” (Table 2 & 3). In this way, much of the background noise, as well as stationary clutter (e.g., generated by buildings) is eliminated. The background map is updated continuously, to allow for changes in the clutter due to changes in the antenna angle or other changes. Each radar scan produces a new array of blips which can be saved as digital archives known as “blipmovies” to an external hard drive. Therefore, blipmovies may be analyzed at a later time. During the recording of blipmovies I used lenient maximum and minimum filtering criteria (Table 2) to reduce the risk that blips generated by birds were lost due to strict parameters. The filtering criteria were subject to change during the next phase of blipmovie processing.

Table 2: Minimum and maximum threshold values used as filtering criteria to generate blips during the recording of marine radar scans.

Criteria	Minimum	Maximum
Blip samples	30	5,000
PPI area* (m ²)	20	10,000
Angular Span (# samples)	3	-1*
Radial Span (# samples)	2	25

*-1 is equal to infinity radR’s blip processing parameters

Processing blipmovies

I tested the limits of the blip filtering criteria (seen in Table 2) in radR by playing a previously recorded blipmovie and adjusting the minimum and maximum values of

each filtering criteria to eliminate blips that are unlikely to be birds. The limits chosen for the processing of radar data are seen in Table 3. The blip samples criteria are the minimum and maximum number of samples or “hot” sample slots that make up a patch. The plan position indicator (PPI) area is the apparent size of the blip seen on the plot window in radR (see blip size differences in Figure 3). The angular (length) and radial (depth) span criteria are the minimum and maximum sample dimensions that comprise a blip. Although choosing the criteria is subjective, I found that the limits chosen encompassed the potential wide range of bird blip sizes.

Table 3: Minimum and maximum threshold values used as filtering criteria to generate blips during the processing of marine radar scans.

Criteria	Minimum	Maximum
Blip samples	30	5,000
PPI area* (m ²)	100	5,000
Angular Span (# samples)	3	-1*
Radial Span (# samples)	2	25

*-1 is equal to infinity radR’s blip processing parameters

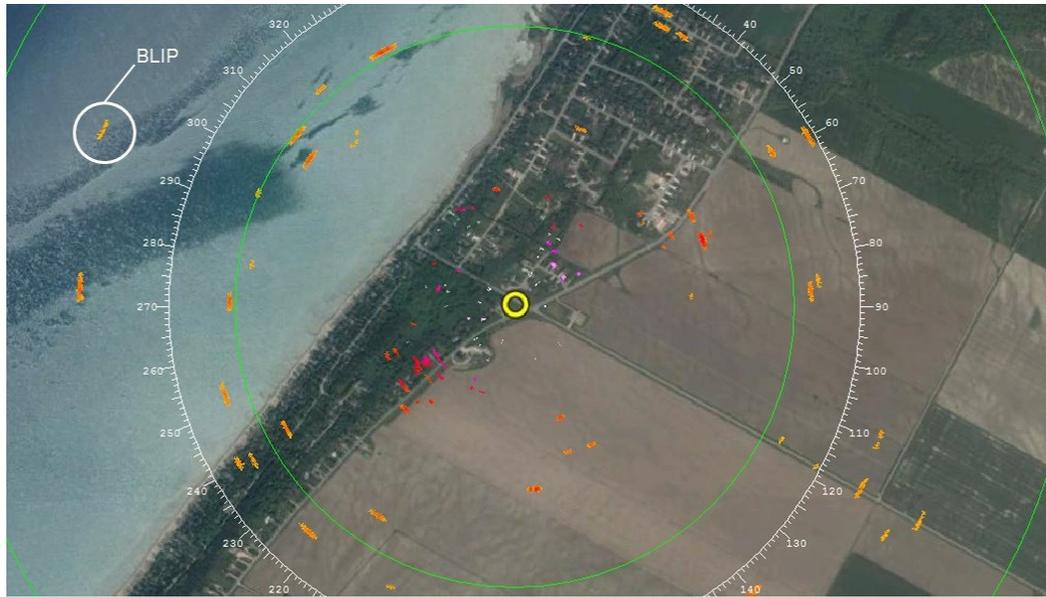


Figure 3: Example of a digitized radar scan showing variation in blip sizes and blip intensity (different colours) detected overhead at Kincardine, Lake Huron, Canada. Yellow circle indicates radar location (site name: Pierce).

Removing clutter

Persistent but fluctuating clutter (e.g. swaying trees) may also generate blips. radR's basic target finding algorithm works poorly at eliminating this type of clutter. Therefore, I removed blips generated by fluctuating clutter using radR's "declutter" plugin. Clutter patterns may differ among nights; therefore, I separated blipmovies that contained more than one night of radar scans into individual nights. The "declutter" plugin creates a cluttermap of all blips likely to be clutter on that night. I used periods of time in blipmovies with high amounts of clutter to record a cluttermap. I subsequently

saved cluttermaps as R scripts and used them to eliminate clutter during data extraction.

Eliminating rain

Precipitation also generates blips that need to be removed before extracting bird information. During data collection, persistent rain in one location is largely eliminated by radR because it becomes part of the background. Some additional rain blips may be removed by the clutter algorithm, but others remain, such that residual rain blips must be removed manually. To help identify potential rain blips, the altitude of all blips detected each night was plotted over time; periods with extensive high altitude blips are likely to be rain (Figure 4). I manually noted the start date/time and end date/time of each potential rain period in an excel file. Once clusters were identified, I replayed the blipmovie in radR to verify that they were likely rain; the spatial distribution of rain blips in blipmovies was also distinctive and helped to verify that the blips detected from the altitude plot were rain (Figure 5). Afterwards, I used an R script to eliminate all blips during any time periods when rain was occurring somewhere within the radar collection area. .

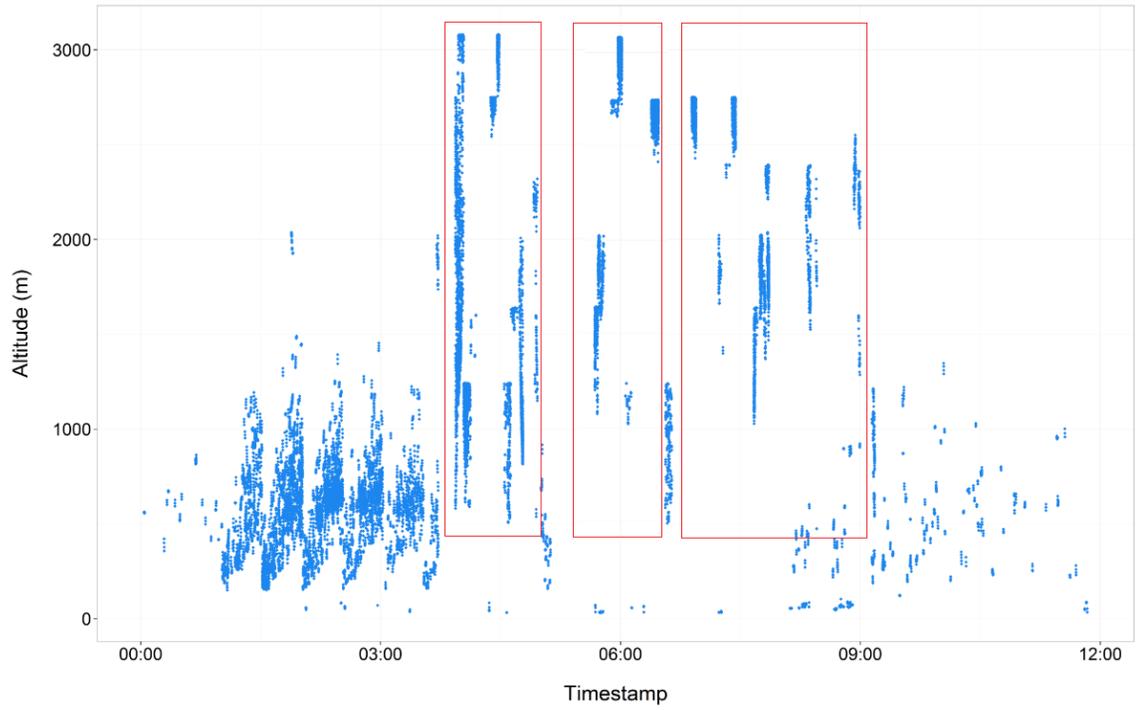


Figure 4: Example plot showing the pattern of blips generated by rain clouds on April 30th 2014 at Bayfield, Lake Huron, Canada. Rain blip pattern indicated by red boxes.

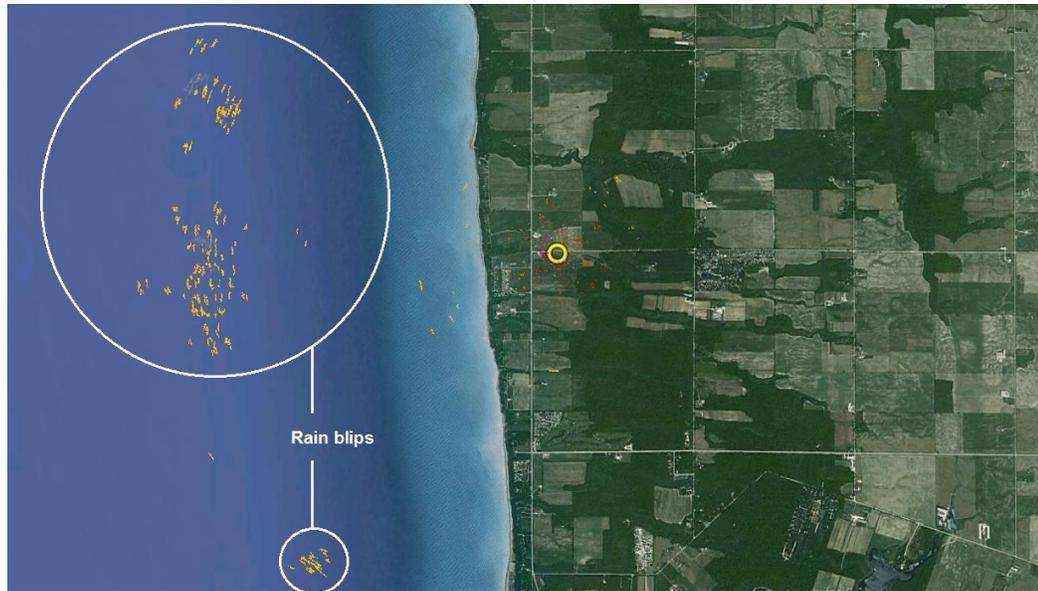


Figure 5: Example of blips generated by rain clouds from a blipmovie detected overhead on April 30th 2014 at Bayfield, Lake Huron, Canada. Yellow circle indicates radar location (site name: Wallis).

Creating tracks

A moving target needs to be detected in multiple scans in order to identify it as a biological target. One blip will be generated per scan as long as the radar beam continues to make contact with the target. Many scans may then create a series of consecutive blips. I used a multiframe correspondence (MFC) algorithm from the “tracker” plugin in radR to identify “tracks” that are likely to correspond to the same biological target (Taylor *et al.* 2010). The algorithm is implemented using the techniques described in Shafique & Shah (2005). It begins by pairing two blips on consecutive scans using a nearest neighbour approach and calculating the velocity. The algorithm then

considers all possible matches between that pair of blips and blips from the third and subsequent scans. A blip is added to a track only if it fits within user-defined parameters, “alpha” and “gain”.

Alpha is a measure of the directional consistency achieved by adding the blip to the track (values ranging from 0-1; 1 being the straightest possible track). The gain function evaluates the proximity of the new blip to the track and the consistency of the velocity when a new blip is added to the track. Gain effectively assesses the quality of the track after adding a new blip with values ranging from 0-1 (0 being a poorly matched blip to a track and 1 being a perfectly matched blip to a track). I used an alpha of 0.6 and a gain of 0.9843 based on suggestions from previous research completed using the same software (Bethany Thurber, pers. comm.). I only retained tracks with a minimum of 3 blips (e.g., Figure 6).

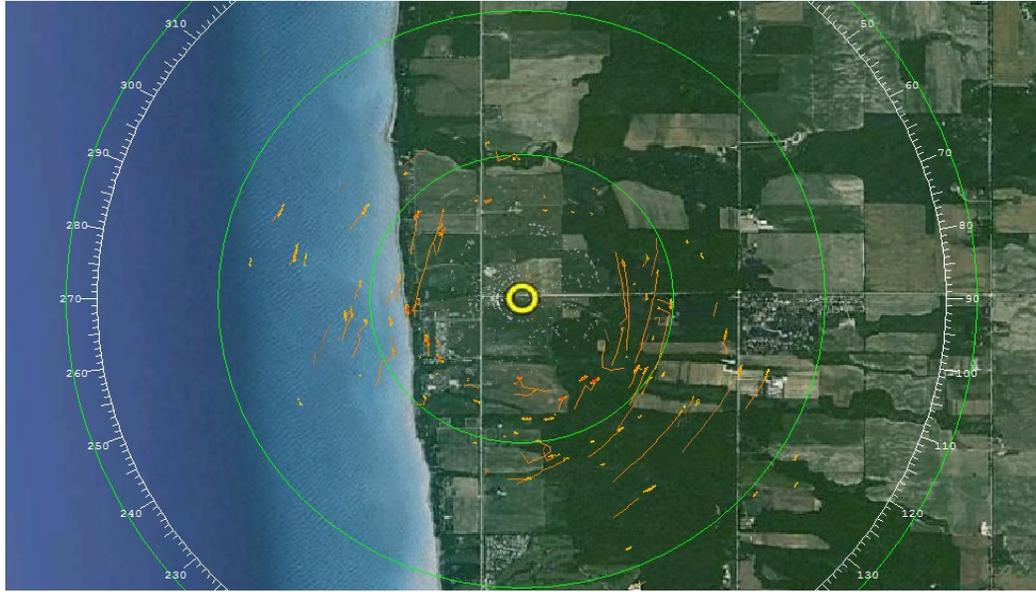


Figure 6: Example of tracks (orange lines) generated by strings of blips detected using a marine radar on May 8th 2014 at Bayfield, Lake Huron, Canada. Yellow circle indicates radar location (site name: Wallis).

Calculating track characteristics

I restricted analysis to tracks potentially corresponding to nocturnal migrants by including only tracks between sunset and sunrise. For each track, I calculated the bearing (deg), flight altitude (m) and groundspeed (m/s) using its initial and final position relative to the radar as well as the time difference between the detection of the first and last blip comprising the track. To obtain heading (deg) and airspeed (m/s), I subtracted the wind vector (wind direction (deg) and wind speed (m/s)) from the bearing. I retrieved wind data from the National Center of Environmental Predictions (NCEP) and National Center for Atmospheric Predictions (NCAR). I queried the online

datasets via an R package (RNCEP) that interpolated wind information to each radar site every half-hour (Kalnay et al. 1996; Kemp et al. 2012; R Core Team, 2013). After, I used the modelled wind speed (m/s), track altitude (m) and a wind speed profile equation to estimate the wind conditions aloft for each bird.

Separating insect tracks from bird tracks

Radars can detect and track large migrating insects as well as small birds. These are not easily distinguished based on blip size, due to the fact that echo strength is not necessarily proportional to target size, when targets are similar in size to the radar wave length (3 cm). Instead, I used airspeed to help differentiate between bird and insect tracks. I kept only tracks with airspeeds greater or equal to 7m/s. Using this airspeed as a cut-off point may likely keep some faster flying insects and eliminate some slower migration birds but will assure that the majority of tracks are comprised of bird migrants (Cabrera-Cruz *et al.* 2013).

Statistical analysis

Numbers of birds

To test for differences in numbers of birds detected among sites, while controlling for variation among nights, I used a generalized linear mixed model (GLMM) with a Negative-binomial distribution with site (A = Pierce, B = Gibson, C = Wallis, D = Dutot, E = Hullett) as a fixed effect and day of year as a random effect. The values for

day of year ranged between 108 and 151 (April 18th, 2014 to May 31st, 2014). I repeated the analysis separately for Transect 1 (Pierce and Gibson) and Transect 2 (Wallace, Dutot and Hullett).

Flight altitude

To explore potential differences in flight altitude of birds detected among sites, while controlling for variation among nights, I used a generalized linear mixed model (GLMM) with a Negative-binomial distribution to model the average flight altitude, with site (A = Pierce, B = Gibson, C = Wallis, D = Dutot, E = Hullett) as a fixed effect and day of year (108:151) nested within site as a random effect. I repeated the analysis separately for Transect 1 (Pierce and Gibson) and Transect 2 (Wallace, Dutot and Hullett).

Flight direction

I explored differences in flight direction of birds detected by first organizing data into nights that had at least one shoreline and one inland site per transect. I tested for a difference in flight direction within transects using a Watson's Large-sample Nonparametric Test for common mean direction. I then reported the test statistic and p value for every comparison.

RESULTS

Among five radar sites a total of 111 complete nights of recording were collected and 783,631 migratory birds were detected (Table 4). Radar failures resulted in many nights having no usable data and are classified as incomplete nights. Some nights had intermittent but heavy periods of rain which caused only partial nights of recording. Radar recordings on these nights recorded very little migratory bird activity. Therefore, only complete nights of recording were used for analyses.

Table 4: Summary of radar data collection during the 2014 spring migration season.

Site	Period of recording	Number of birds	Complete nights	Incomplete nights	Partial nights
Pierce	May 8 - May 31	151376	13	10	1
Gibson	May 5 - May 30	107165	17	8	2
Wallis	April 18 - May 31	136186	26	9	9
Dutot	April 19 - May 29	194592	25	9	7
Hullett	April 20 - May 31	194312	30	7	5
Total		783631	111	43	24

Numbers of birds

Numbers of birds detected varied considerably among nights, but there were no consistent differences between shoreline and inland sites (Figure 7 and 8). More birds were detected at Pierce compared to Wallis (Wald T-test = 24.320, $p = 0.0094$). More birds were also detected at Pierce compared to Hullett, but this was only marginally

statistically significant (Wald T- test = 25.056, $p = 0.0624$). Within transect comparisons revealed no shoreline effect. On Transect 1, more birds were detected at Pierce compared to Gibson but the difference was not statistically significant (Wald T-test = 17.626, $p = 0.143$). On Transect 2, fewer birds were detected at Wallis compared to either Dutot or Hullett but again this was not statistically significant (Dutot: Wald T-test = 31.784, $p = 0.166$; Hullett: Wald T-test = 31.441, $p = 0.297$).

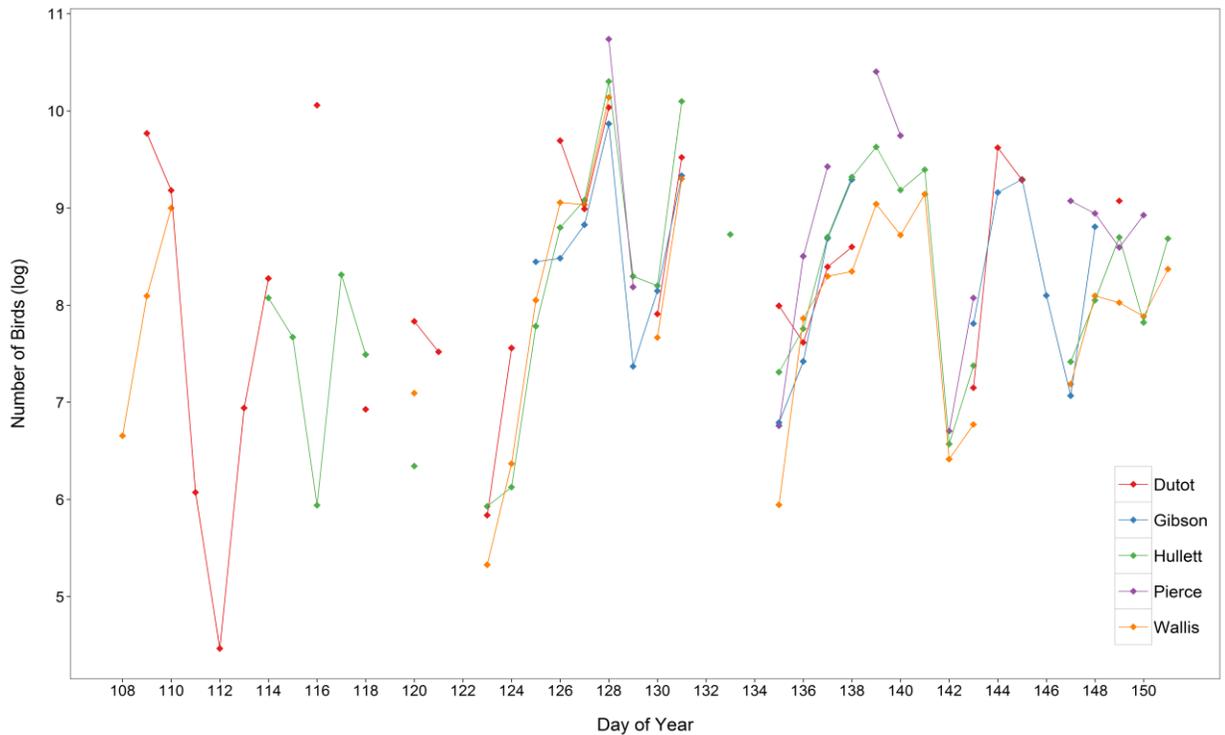


Figure 7: Number of birds detected (natural log) at five radar sites located on the shoreline of Lake Huron during the 2014 spring migration season.

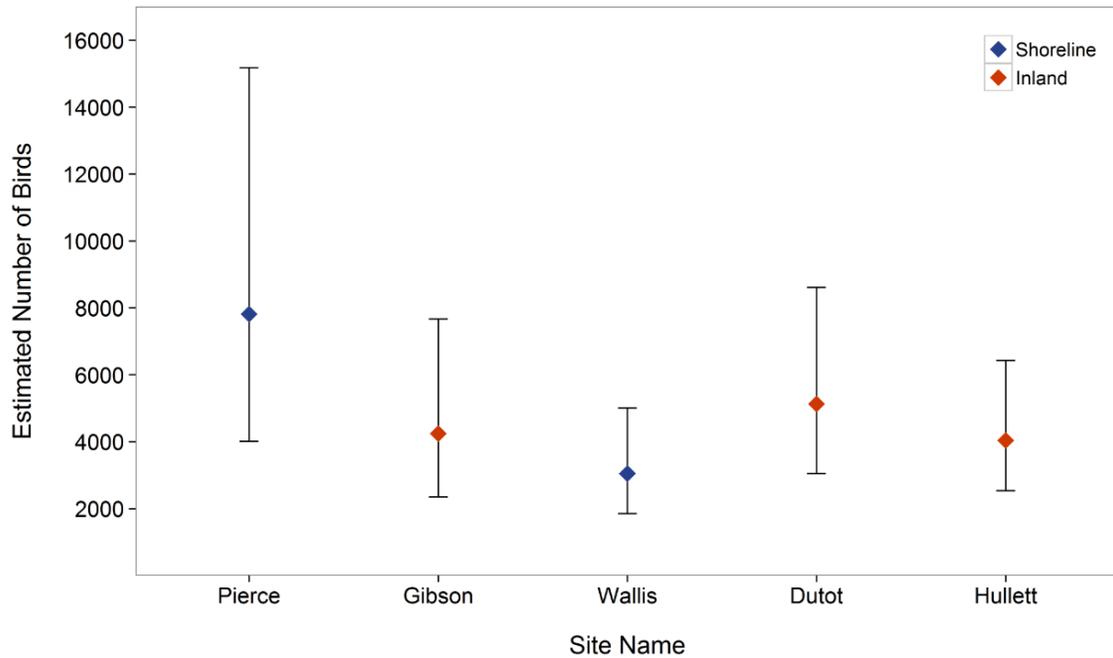


Figure 8: Comparison of the estimated mean number of birds detected per night for five radar sites during the 2014 spring bird migration season. Error bars indicate 95% confidence intervals.

Flight altitude

Across sites, most birds were detected flying below 1000 meters, with the majority more or less concentrated around 300-500 m (Figure 9). However, this does not represent the true distribution of birds, because detectability of birds varies with altitude, with high and low altitude birds less likely to be detected (Bruderer, 1997). Here, I assumed that the radars at each of the five sites in our study had common detectability issues and hence compared relative altitudes among sites.

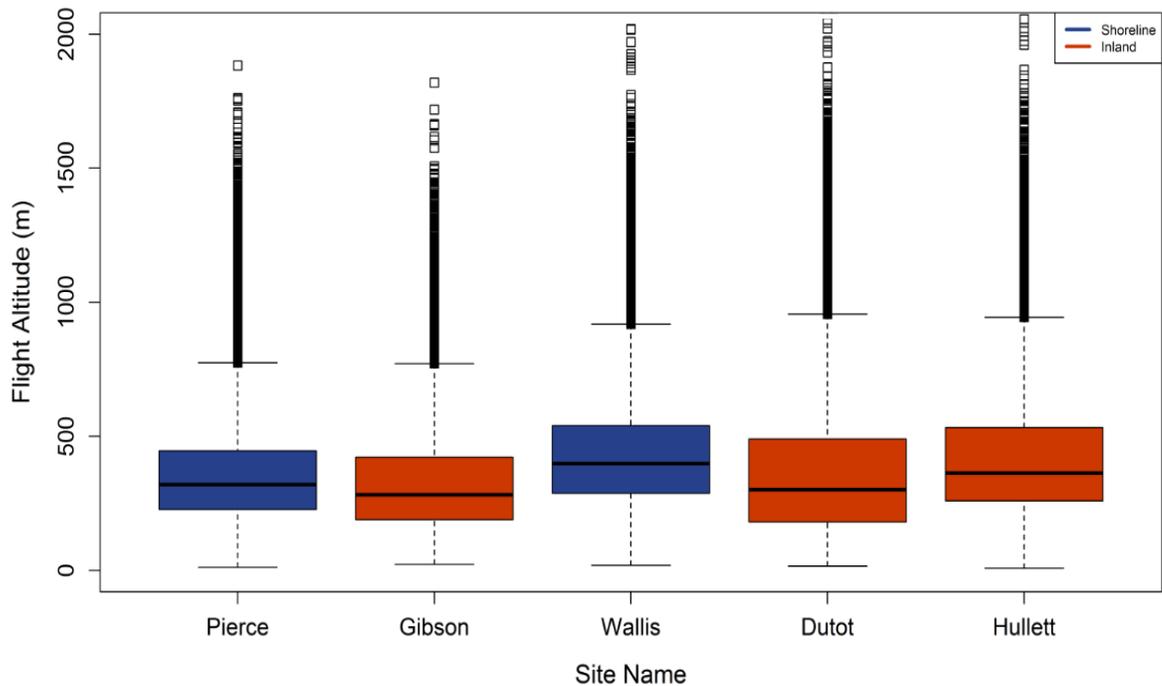


Figure 9: Box plot representing the relative flight altitude (m) distribution of nocturnal migrating birds detected at five radar sites during the 2014 spring migration season. Whiskers define data falling within the lower and upper 1.5 x interquartile range.

There were small differences in mean flight altitude among sites (Figure 10). Birds detected at Pierce flew at lower altitudes compared to Wallis, Dutot and Hullett (Wallis: Wald T-test = 139.5, $p = 1.99E^{-5}$, Dutot: Wald T-test = 137.19, $p = 0.0495$, Hullett: Wald T-test = 139.47, $p = 2.19E^{-5}$). Within transect comparisons revealed inconsistent shoreline effects. On Transect 1, there was no difference between the flight altitude of birds detected at the shoreline and inland sites (i.e., Pierce vs Gibson; Wald T-test = 71.59, $p = 0.399$). On Transect 2, birds detected at the shoreline site (Wallis) were flying at a slightly, and significantly, higher altitude than birds detected at Dutot (estimated

altitude difference per night $\sim 55\text{m}$; Wald T-test = 153.96, $p = 0.041$). However, there was no significant difference between the shoreline site and Hullett (Wald T-test = 154.39, $p = 0.312$).

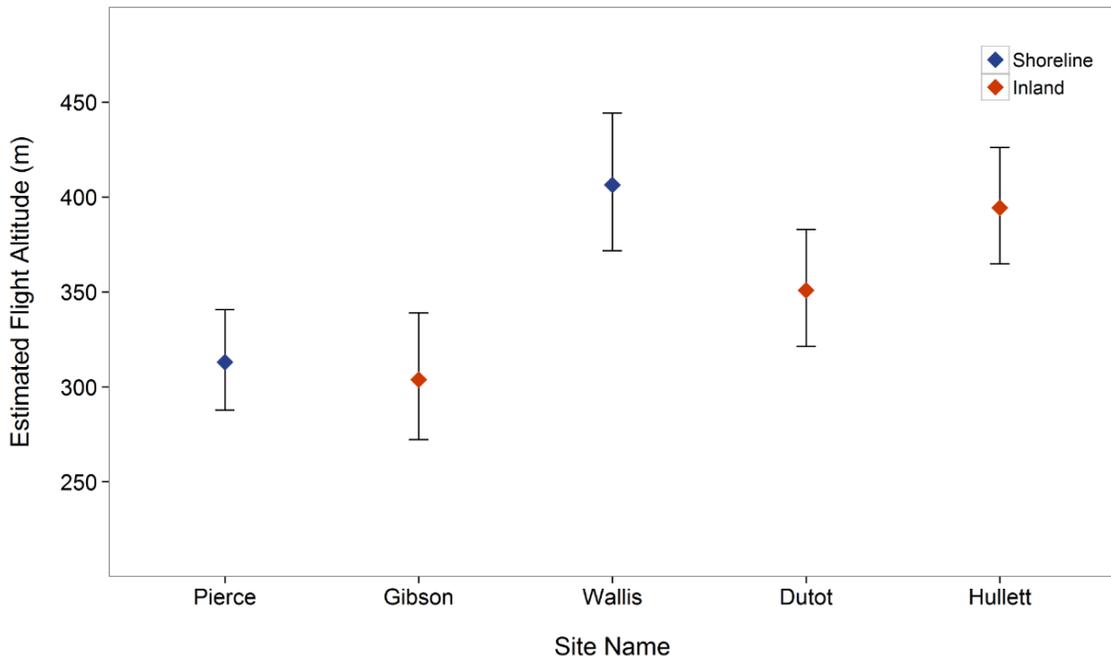


Figure 10: Comparison of the estimated mean flight altitude (m) of detected birds per night for five radar sites during the 2014 spring bird migration season. Error bars indicate 95% confidence intervals.

Flight direction

Flight direction varied among nights, potentially related to wind direction, but within nights did not appear to vary consistently among sites (Appendix B). Nights with heavy migration (minimum > 4000 birds detected per site) when all five radar sites were working (e.g., Figures 11 & 12), reveal an overall migration direction in the North to

North-East direction. Birds detected during heavy migration also show similar flight directions among sites with no indication of a shoreline effect (Figures 11 & 12).

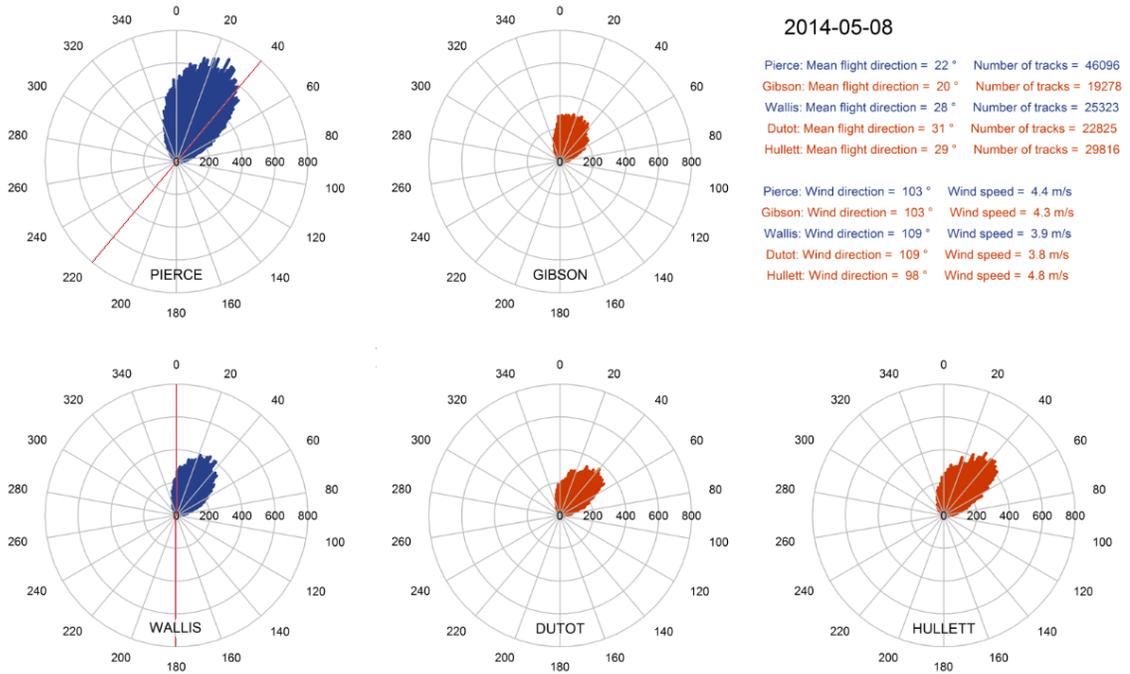


Figure 11: Circular histogram of recorded flight directions of the number of birds detected at five radar sites on May 8th 2014. Red line indicates approximate shoreline orientation.

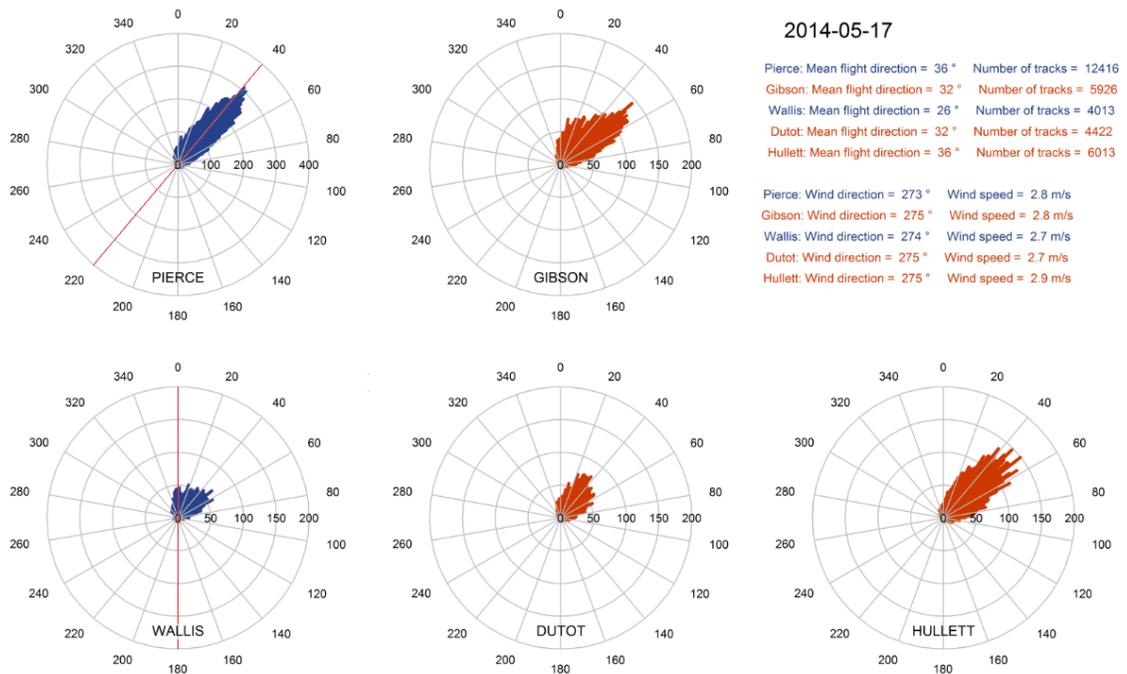


Figure 12: Circular histogram of recorded flight directions of the number of birds detected at five radar sites on May 17th 2014. Red line indicates approximate shoreline orientation.

Results from night by night comparisons within transects indicate that more often than not shoreline and inland sites share common mean flight directions. In other words, birds detected at shoreline and inland sites have the same flight directions. The mean flight direction, the measure of uniformity (ρ) and results from a Watson's Large-sample Test for common mean directions are displayed in Table 5 and Table 6 for Transect 1 and Transect 2, respectively. Values for ρ range from 0-1. A measure of 0 indicates that flight directions are highly scattered, and a measure of 1 indicates that flight directions are highly concentrated. A p value less than 0.05 rejects the null

hypothesis that there is a common mean direction. On Transect 1, no tests for common mean direction between sites yielded significant results (Table 5). On Transect 2, only 3 out of 26 tests for common mean direction yielded significant results (Table 6). Out of these 3 tests, only 2 nights showed signs that birds flying over the shoreline had a flight direction paralleling the shoreline (Table 6 & Appendix B: April 19th, May 21st 2014).

Table 5: Summary table of mean flight direction, rho, and test statistic for common mean direction (Watson’s Large-sample test) of nocturnal migrants detected on Transect 1 per night. Shoreline site: Pierce.

Site	Pierce	Gibson	Watson's L-S Test	
<i>Measure</i>	Mean (Rho)	Mean (Rho)	<i>Yg</i>	<i>p</i>
Date				
May-08	22° (0.86)	20° (0.88)	0.1137	0.7360
May-09	47° (0.79)	55° (0.77)	0.0149	0.9028
May-15	50° (0.68)	41° (0.60)	0.2013	0.6537
May-16	4° (0.18)	360° (0.39)	0.0140	0.9057
May-17	36° (0.84)	32° (0.87)	0.4037	0.5252
May-23	117° (0.37)	78° (0.35)	0.0018	0.9659
May-27	253° (0.23)	262° (0.46)	0.6838	0.4083
May-28	340° (0.79)	341° (0.53)	0.0123	0.9118

Table 6: Summary table of mean flight direction, rho, and test statistic for common mean direction (Watson's Large-sample test) of nocturnal migrants detected on Transect 2 per night. Shoreline site: Wallis. * indicates ($p < 0.05$).

Site	Wallis	Dutot	Hullett	Watson's L-S Test	
<i>Measure</i>	Mean (Rho)	Mean (Rho)	Mean (Rho)	<i>Yg</i>	<i>p</i>
Date					
Apr-19	341° (0.72)	14° (0.10)		7.9812	0.0047*
Apr-20	18° (0.83)	26° (0.65)		0.7990	0.3714
Apr-28	343° (0.35)	323° (0.90)	318° (0.91)	3.0828	0.2141
Apr-30	17° (0.85)	18° (0.29)	41° (0.74)	2.4424	0.2949
May-03	113° (0.43)	102° (0.66)	99° (0.79)	2.2808	0.3197
May-04	43° (0.33)	19° (0.20)	91° (0.32)	11.5070	0.0032*
May-05	8° (0.67)		10° (0.73)	0.0146	0.9039
May-06	354° (0.81)	354° (0.71)	347° (0.81)	4.4426	0.1085
May-07	1° (0.88)	3° (0.81)	355° (0.87)	1.2219	0.5428
May-08	28° (0.87)	31° (0.86)	29° (0.86)	5.5257	0.0631
May-10	173° (0.45)	148° (0.22)	147° (0.37)	1.7315	0.4207
May-11	17° (0.88)	17° (0.88)	22° (0.90)	2.9580	0.2279
May-15	70° (0.31)	243° (0.07)	66° (0.46)	3.0189	0.2210
May-16	334° (0.35)	3° (0.37)	2° (0.37)	4.8009	0.0907
May-17	26° (0.78)	32° (0.81)	36° (0.88)	1.9898	0.3698
May-18	32° (0.78)	39° (0.76)	38° (0.89)	2.9876	0.2245
May-19	22° (0.74)		33° (0.82)	0.0481	0.8264
May-20	13° (0.72)		12° (0.83)	0.0233	0.8788
May-21	358° (0.47)		14° (0.71)	4.5375	0.0332*
May-22	172° (0.58)		171° (0.64)	0.1849	0.6672
May-23	120° (0.40)	145° (0.24)	148° (0.60)	0.1634	0.9215
May-27	247° (0.39)		242° (0.34)	2.3114	0.1284
May-28	341° (0.74)		333° (0.86)	0.5379	0.4633
May-29	11° (0.73)		19° (0.70)	0.1970	0.6571
May-30	341° (0.65)		311° (0.58)	2.0022	0.1571
May-31	2° (0.89)		348° (0.86)	0.2217	0.6377

DISCUSSION

I found no indication that migratory birds aloft concentrated along the Lake Huron shoreline or that they followed the shoreline, contrary to my expectations and to some previous studies along shorelines (Lowery & Newman, 1966; Belrose, 1967; Richardson, 1978; Åkesson 1993). I detected similar numbers and flight directions of birds with radars placed at shoreline and inland locations along two transects away from a North-South portion of the Lake Huron Coast. Gagnon *et al.* (2011), using weather radar, found that birds approaching the St. Lawrence estuary during fall migration tended to concentrate along the North coast. Moreover, the tendency to follow the coast increased as the night progressed. Gagnon *et al.* (2011) suggested that the St. Lawrence represented a barrier to migration to some birds and promoted flight paths paralleling the estuary. Similar barrier avoidance behaviours in nocturnal migrants were documented near the Iberian Peninsula (Bruderer & Liechti, 1998) and the Mediterranean Sea (Fortin *et al.* 1999). Studies in Nova Scotia (Richardson, 1978) and in New York (Bingman *et al.* 1982) also showed nocturnal migrants following shorelines, but only under wind conditions that promoted drift.

The results from this study are contrary to what I had expected if birds were avoiding flying across the lake. Initially I speculated that birds approaching the sound shore of Lake Huron during spring migration may redirect overwater flights towards the shoreline. However, no differences were detected between shoreline and inland sites. The findings in this study may suggest that many birds continue to fly over Lake Huron. Benefits of crossing the lake may include a reduction in migration time and distance

(Alerstam, 2001; Åkesson & Hedenström, 2007). However, birds flying lengthy distances over water may be challenged with disorientation, wind drift and associated energetic expenses (Spina, 2011). The decision to cross may be a compromise between early arrival at the final migration destination and taking risks by selecting hazardous migration routes to arrive at the destination (Bruderer & Liechti, 1998). Alternatively, migrants may avoid crossing the lake, but then disperse over a large inland area east of Lake Huron. Further studies of migrant behaviour over the lake would be required to differentiate these hypotheses.

There is no indication from this study that flight altitudes of nocturnal migrants were influenced by the shoreline, although they did vary among nights. Birds may select their migratory flight altitude based on environmental conditions, particularly wind, to help minimize energy output and time migrating (Bruderer *et al.* 1995; Kalhert *et al.* 2012). Flying at low altitudes during head winds may be favoured because wind speed is reduced closer to the ground. Flying at high altitudes may be favoured in tailwinds because winds are typically stronger with height (Bruderer, 1971 as cited in Alerstam, 1990a, p. 283). Since wind direction and speed vary with altitude and from night to night, adjusting flight altitude may help migrants reduce their energetic output throughout their migration. Consequently, this may be the reason why I detected nightly variation in flight altitude (Appendix A). Testing this hypothesis may be possible in future studies by calculating the wind speed at various altitude intervals for each location on a night by night basis. It may then be possible to compare the wind speeds at various altitudes to the number of birds detected at each altitude interval and deduce

whether birds were actively selecting favourable wind conditions. It is important to note that it was not possible to compare the true flight altitude distribution of birds because of radar detectability issues. Marine radars are less likely to detect birds at high and low altitudes due to the shape of the beam (Bruderer, 1997). Nevertheless, as all of the radars had similar antennae, it seems reasonable to assume that relative comparisons of the flight altitudes of birds detected among radars are valid.

There were some challenges to overcome from using marine radars to compare migration numbers between shoreline and inland sites. Frequent radar failures resulted in a limited number of nights when all five radars were working at the same time. Consequently, the ability to thoroughly compare shoreline versus inland migration patterns was reduced. A further change is that two different radar types were used in this study, which are 12 kW and 25 kW radars. Beams emitted from a 25 kW radar have more power than 12 kW radars. Thus, echoes returning to the radar dish have more energy. This allows 25 kW radars to detect smaller targets at further distances. Accordingly, this may result in more targets being detected by 25 kW radars. While correcting for radar type differences may change the estimates of numbers of birds detected, this is unlikely to change the overall conclusions of the study. If I reduced the estimate of numbers of birds detected for 25 kW radar to resemble that of a 12 kW radar the difference in estimates between Wallis (12 kW radar) and Dutot (25 kW radar) and between Wallis and Hullett (25 kW radar) would be less than shown in Figure 8. Similarly, corrected numbers of birds detected due to radar type differences between

the Pierce (25 kW radar) and Gibson (12 kW radar) sites would also reduce the difference between the two estimates (Figure 8).

Overall, my study presents no evidence that wind turbine developments along the shoreline of Lake Huron would cause higher risks of collision to passing migrants compared to developments inland, at least during spring migration. However, this does not necessarily mean that there would be no differences during fall migration, or along other coastlines of the Great Lakes, or that the same species would be affected. The radars used in this study do not provide data that can be used to differentiate between potential bird species composition differences among sites. Therefore, there is a possibility that some bird species are found in higher concentrations along shoreline sites compared to inland. If migration strategies in these species are different than other species they may be more or less susceptible to wind turbine collisions. Furthermore, migrants may interact differently to shorelines depending on the geographical orientation of the lake and the time of year. Migrants may favour a slightly altered course to avoid crossing water if the direction of flight increasingly parallels the shoreline (Alerstam & Pettersson, 1977). Alternatively, migrants may be inclined to cross the lake if the shoreline runs perpendicular to the direction of travel (Diehl *et al.* 2003). Based on the geographical orientation Lake Ontario in relation to expected flight directions during both migratory seasons, Diehl *et al.* (2003) hypothesized and found results suggesting that migrants showed an increased tendency for lake avoidance during spring migration and a decreased tendency during fall migration.

Further studies of bird migration along other shorelines in the Great Lakes region would help to test the generality of these results. Locating marine radars at different locations in following spring migration seasons may help increase our understanding about the dynamics of nocturnal bird migration along the east coast of Lake Huron. Using a marine radar to detect birds south of Lake Huron (Figure 1: near Lambton Shores) may give researchers an idea about how nocturnal migrants react as they approach the lake. This may present a great opportunity to detect whether nocturnal migrants take off over the lake or navigate around.

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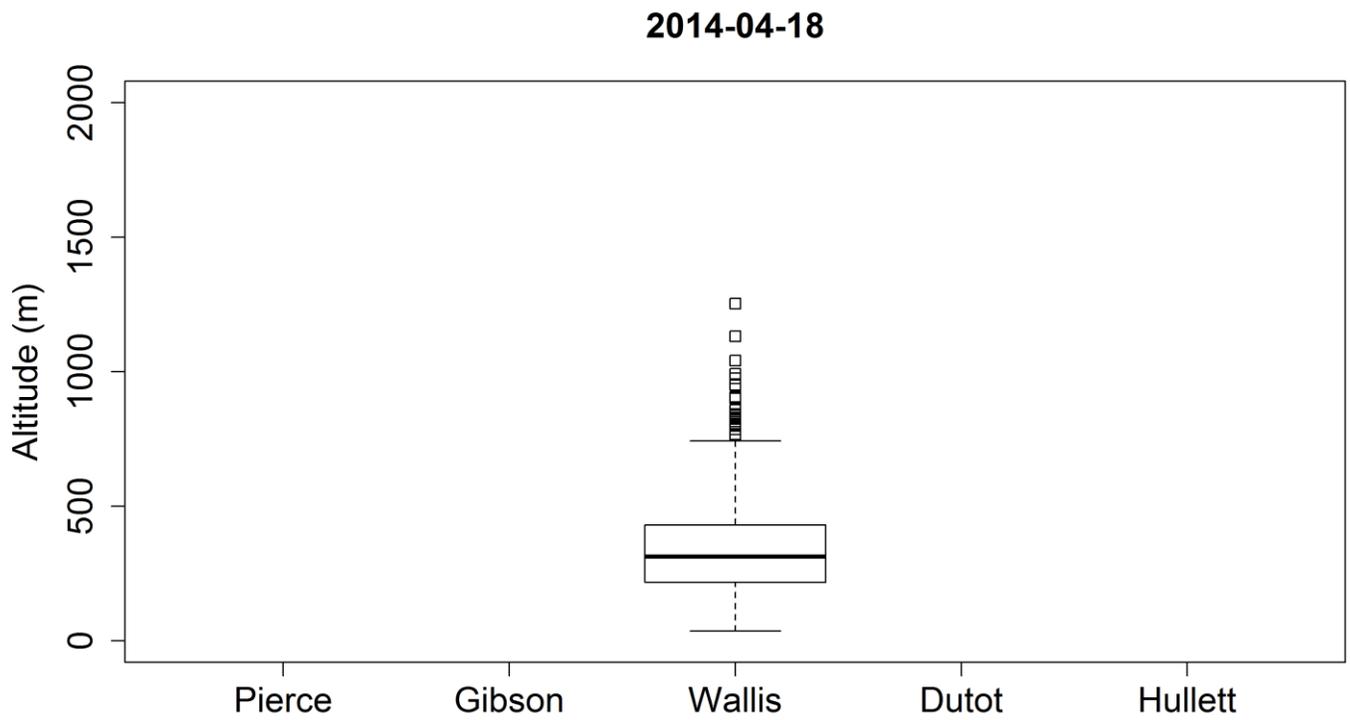
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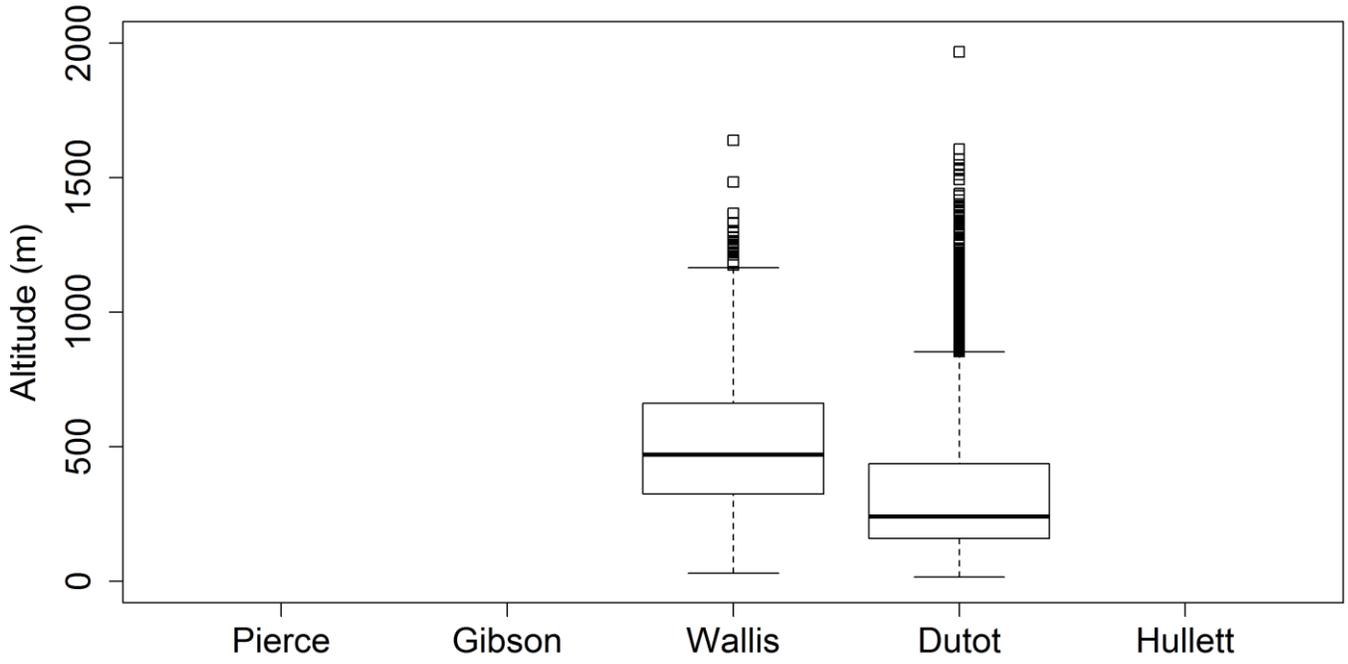
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APPENDIX A

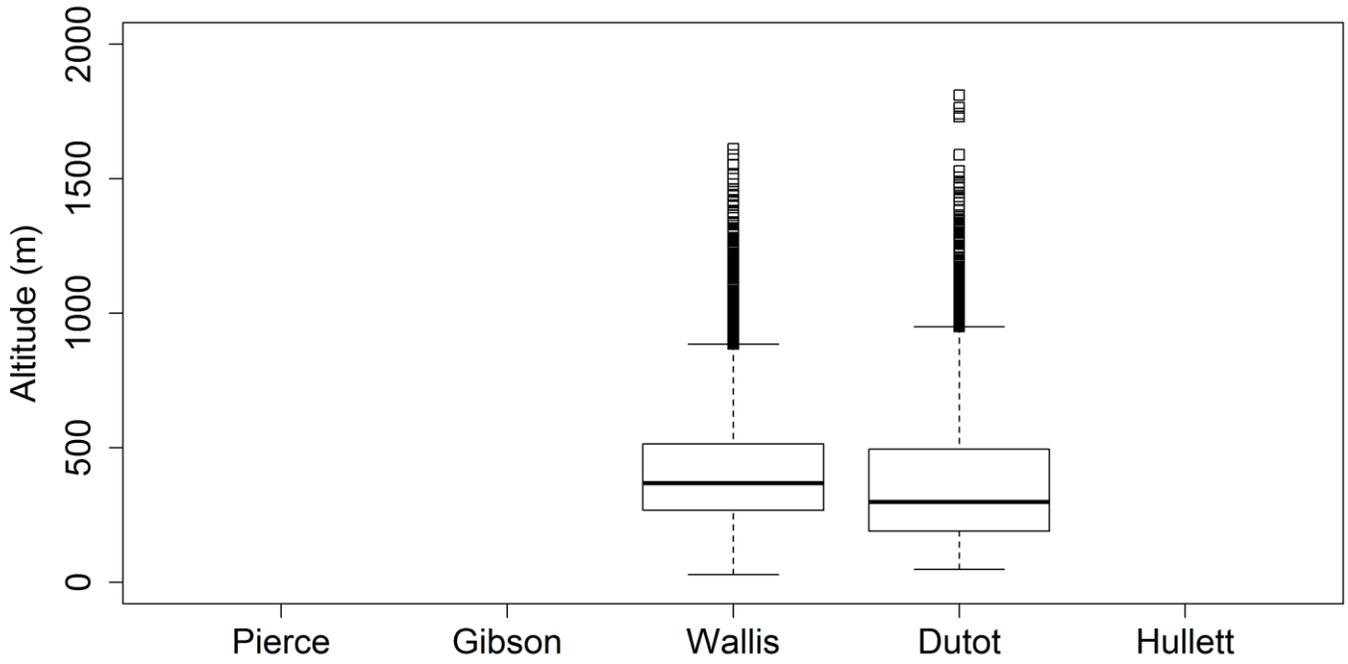
Summary of flight altitude by night of nocturnal migrants detected at five locations
along the shoreline of Lake Huron during the 2014 spring migration season



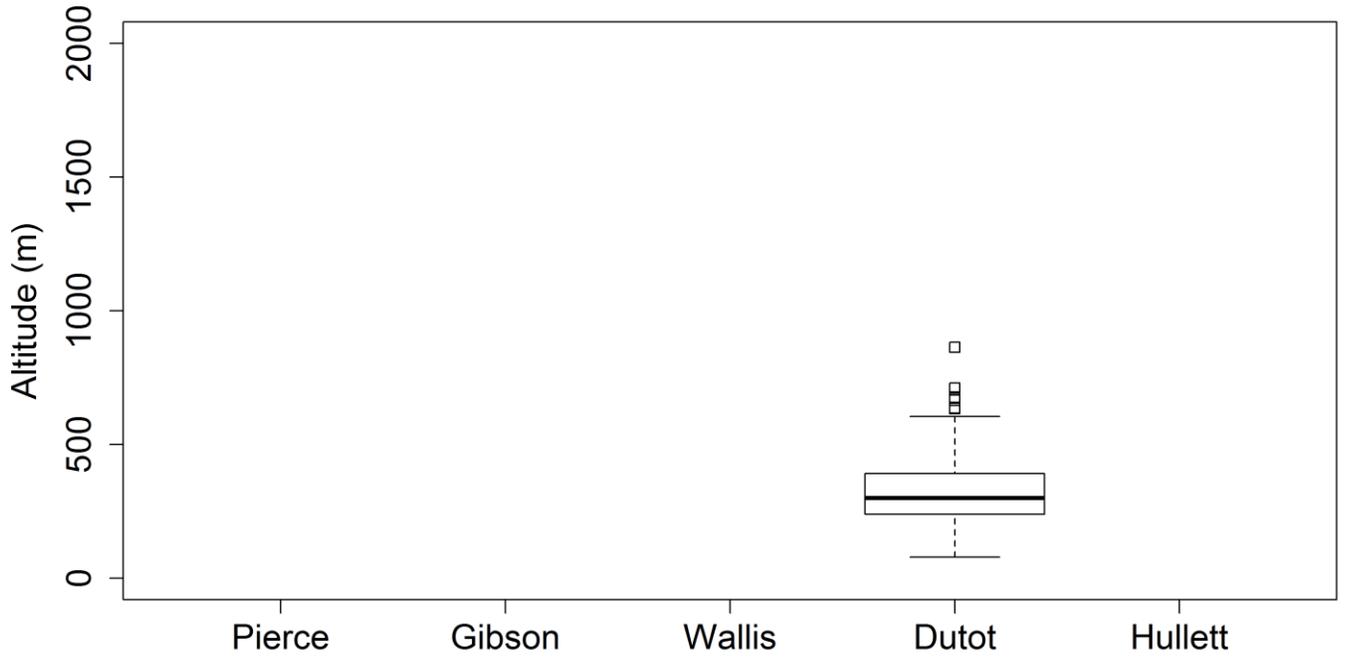
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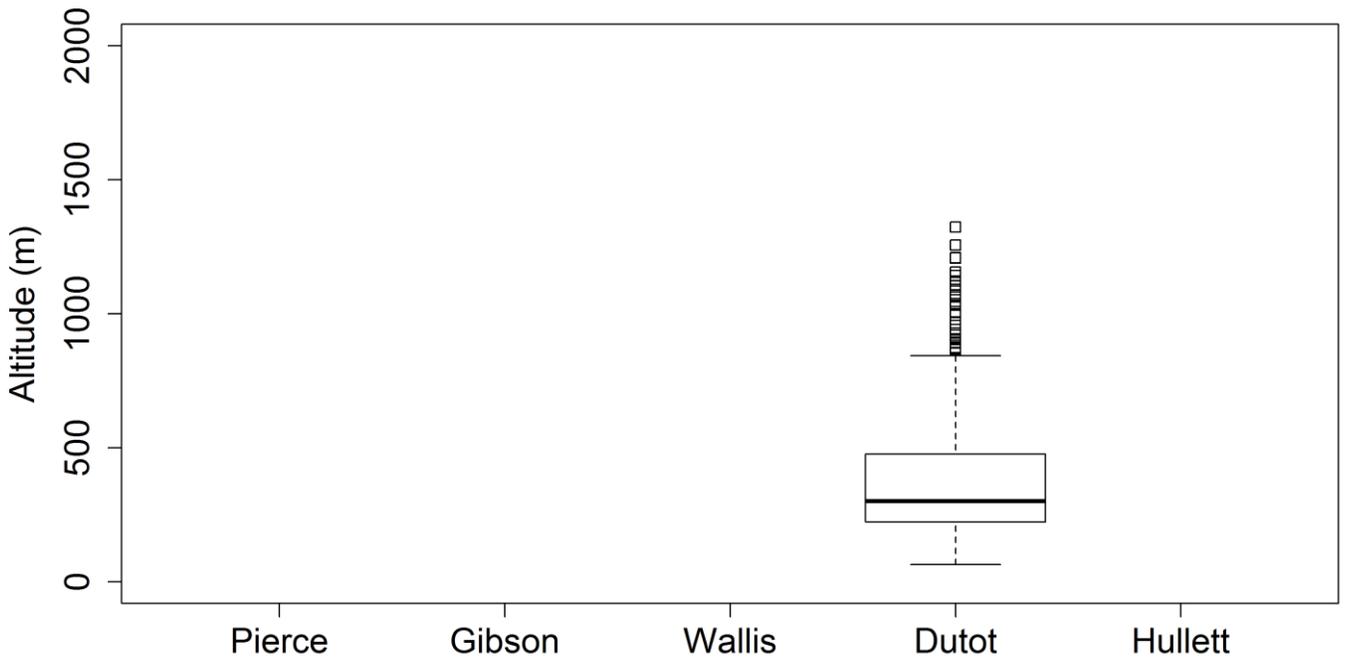
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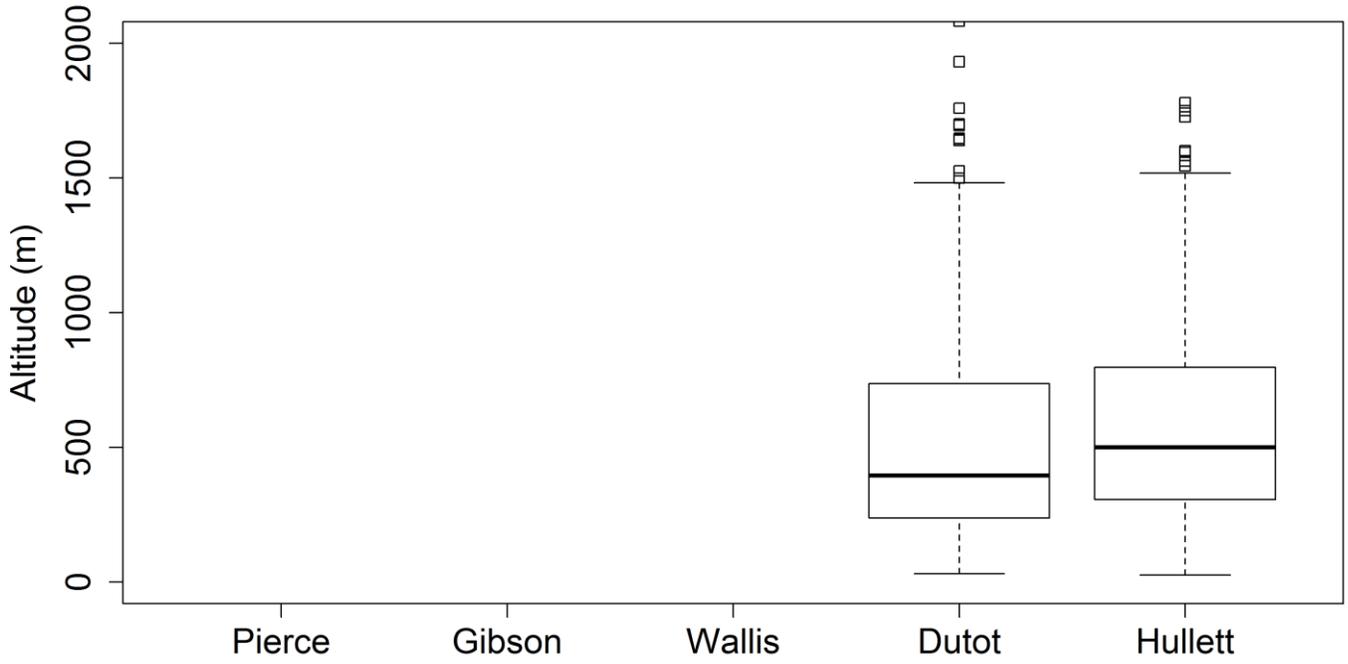
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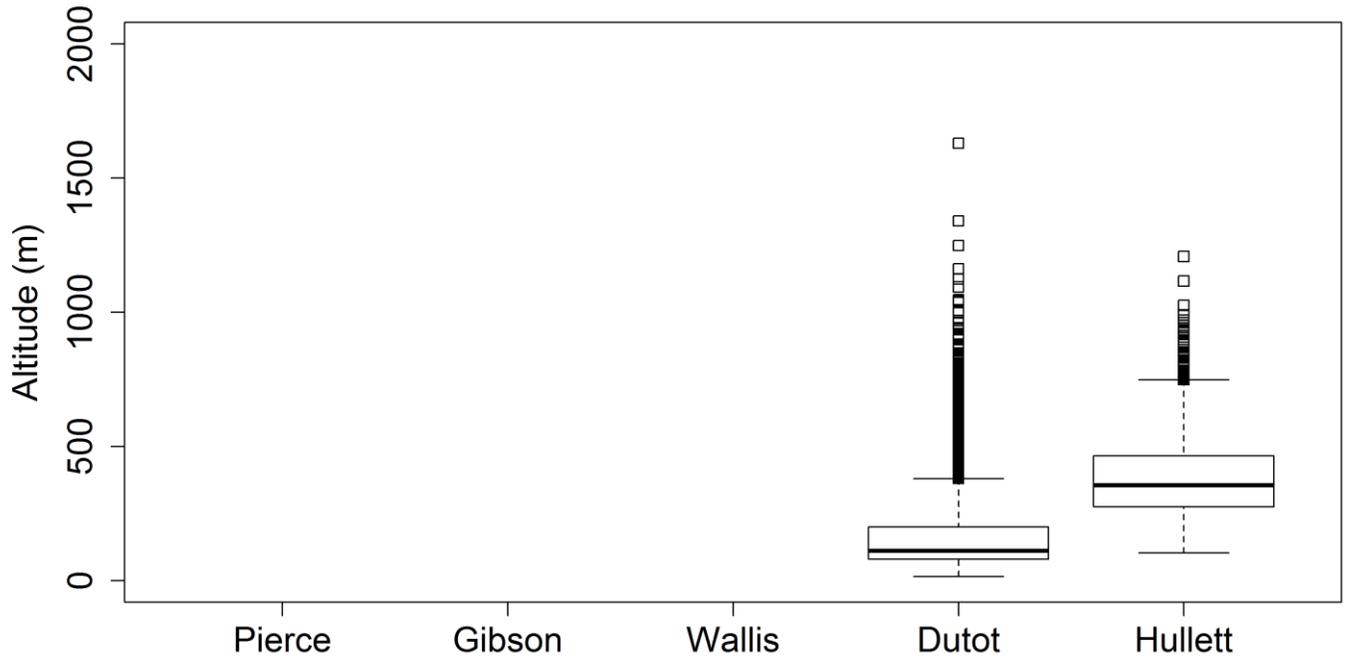
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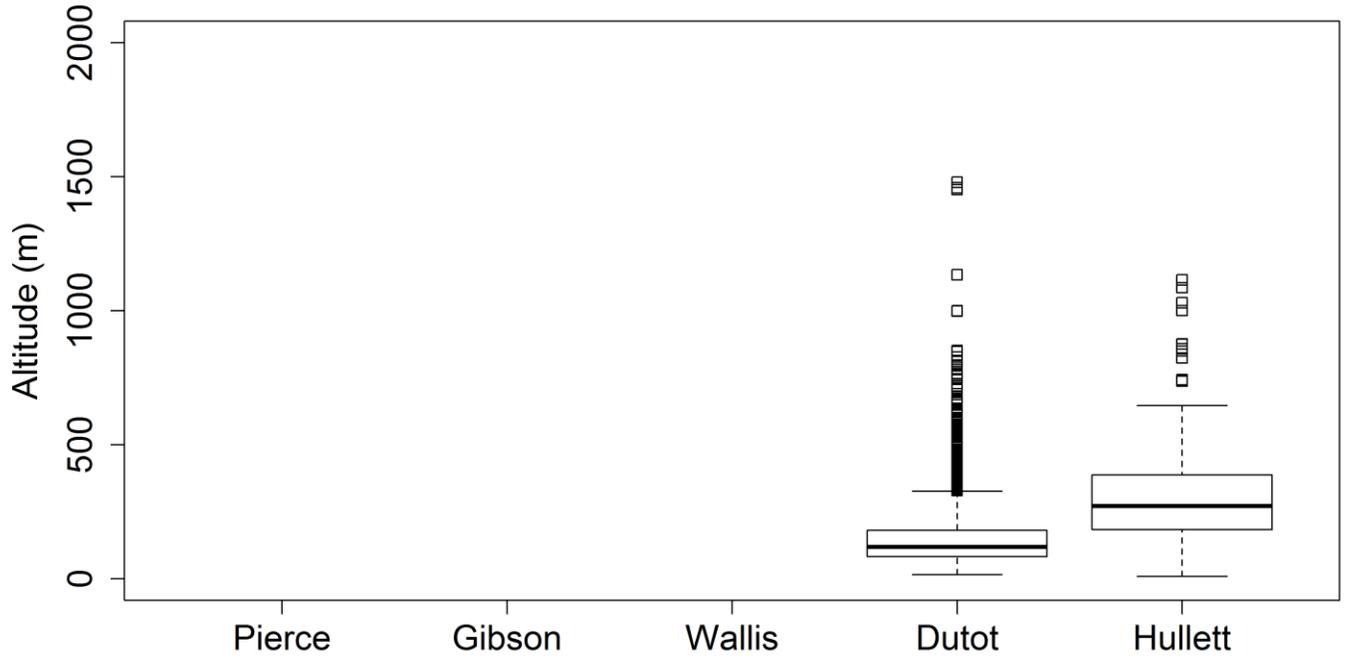
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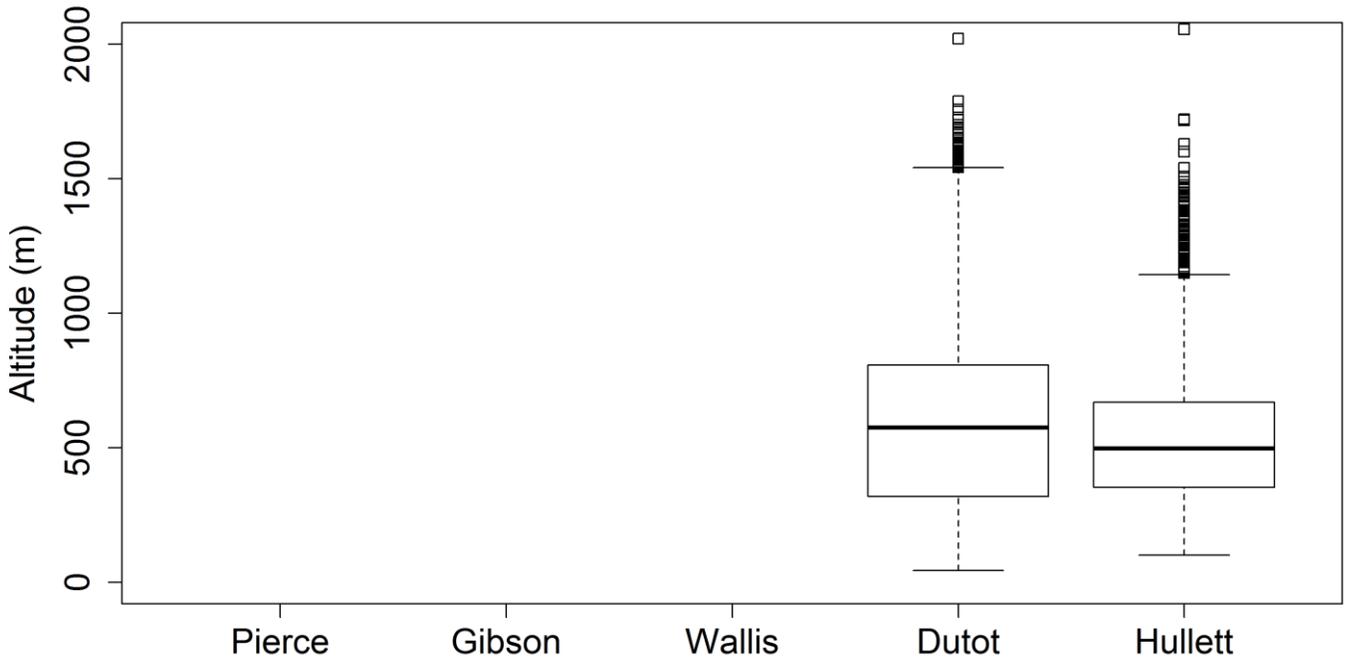
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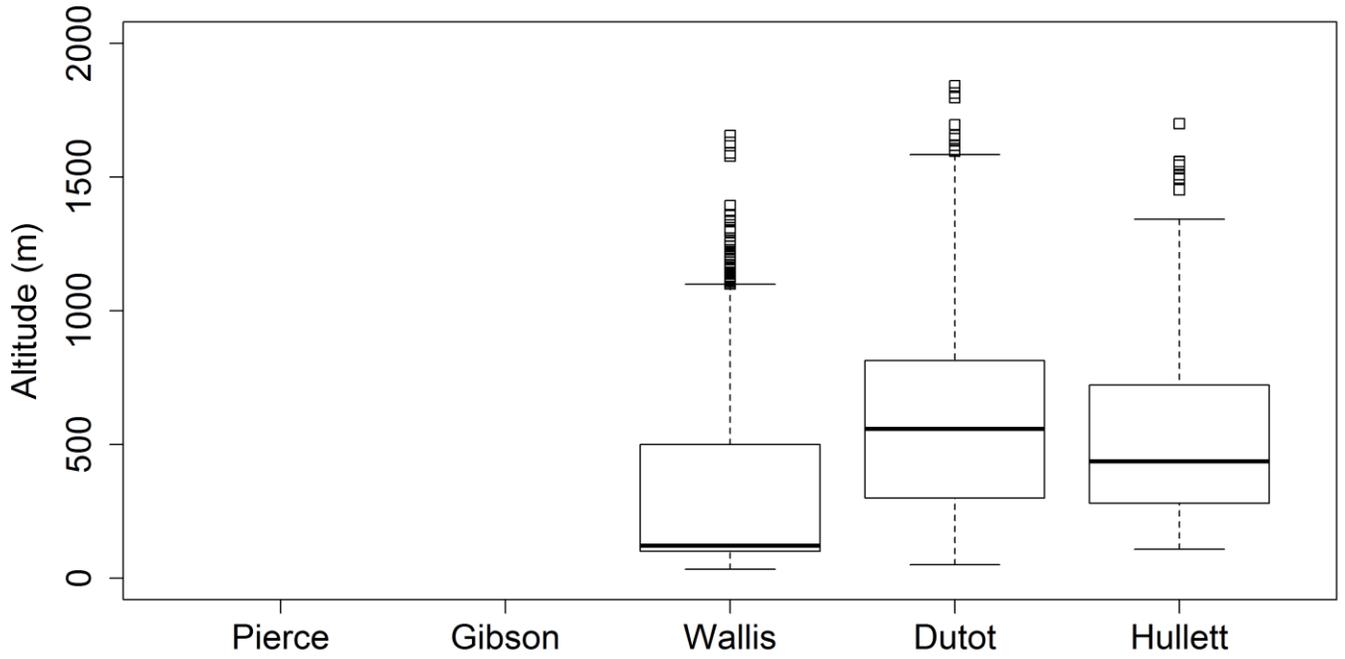
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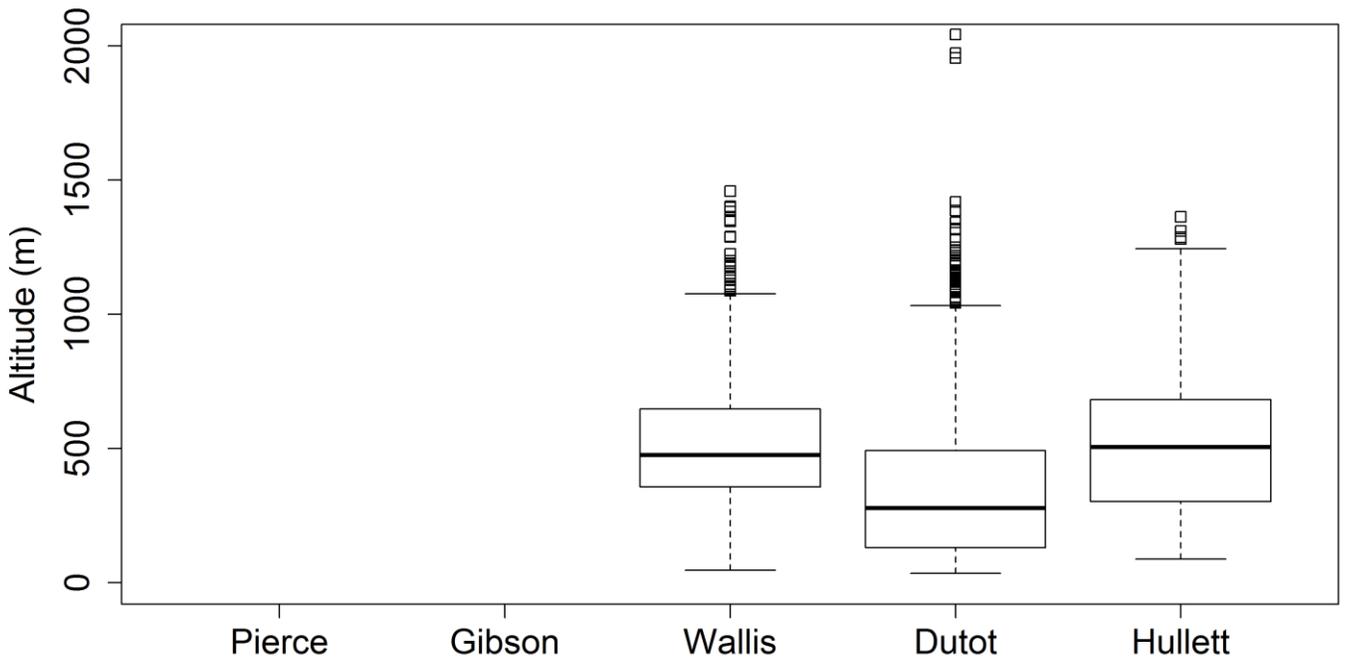
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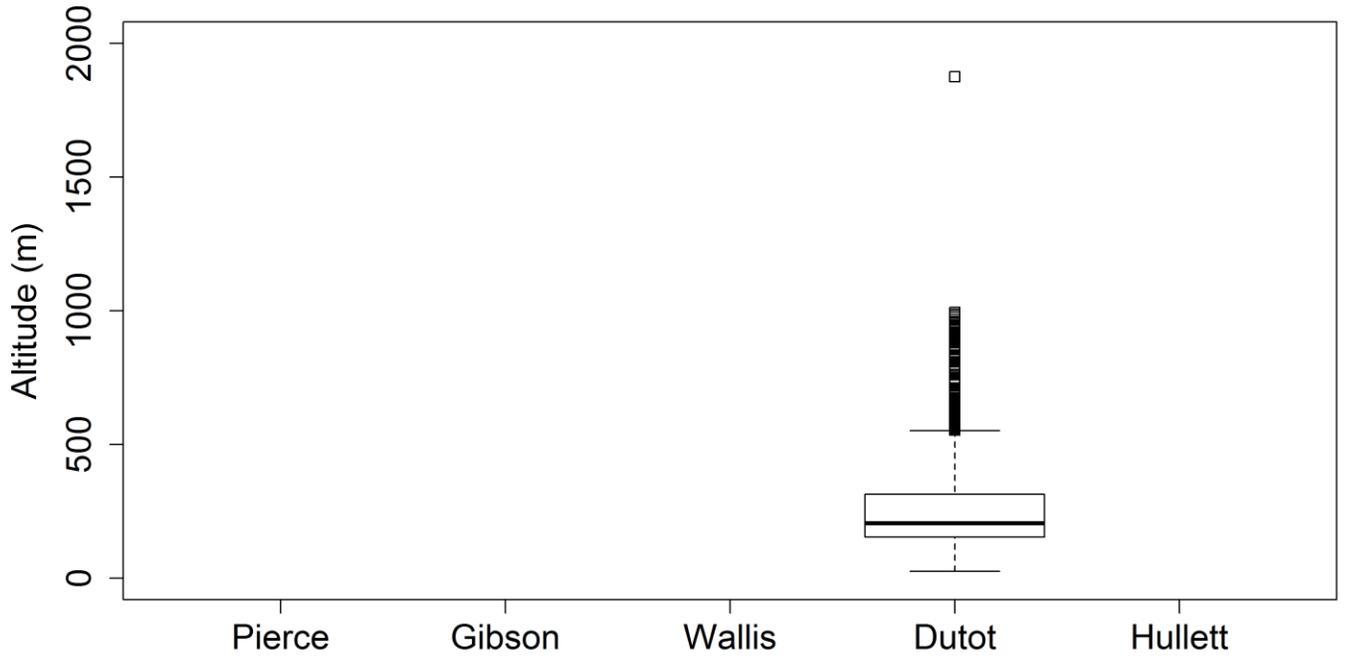
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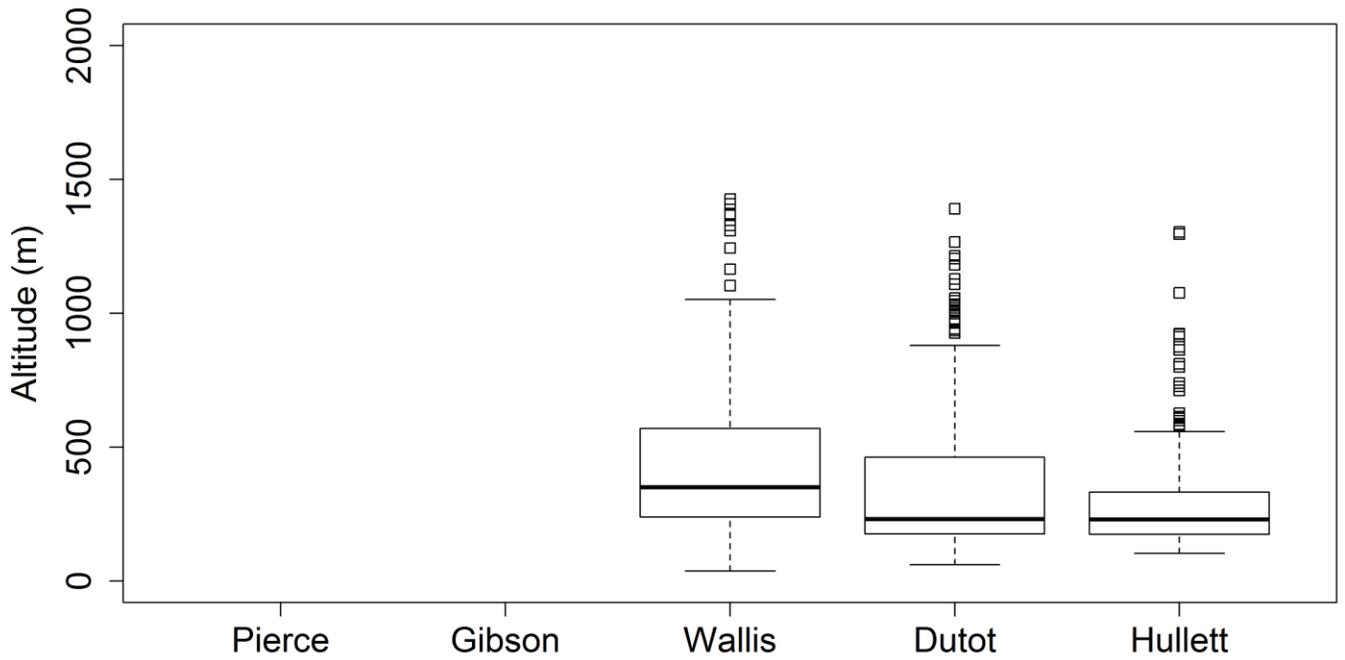
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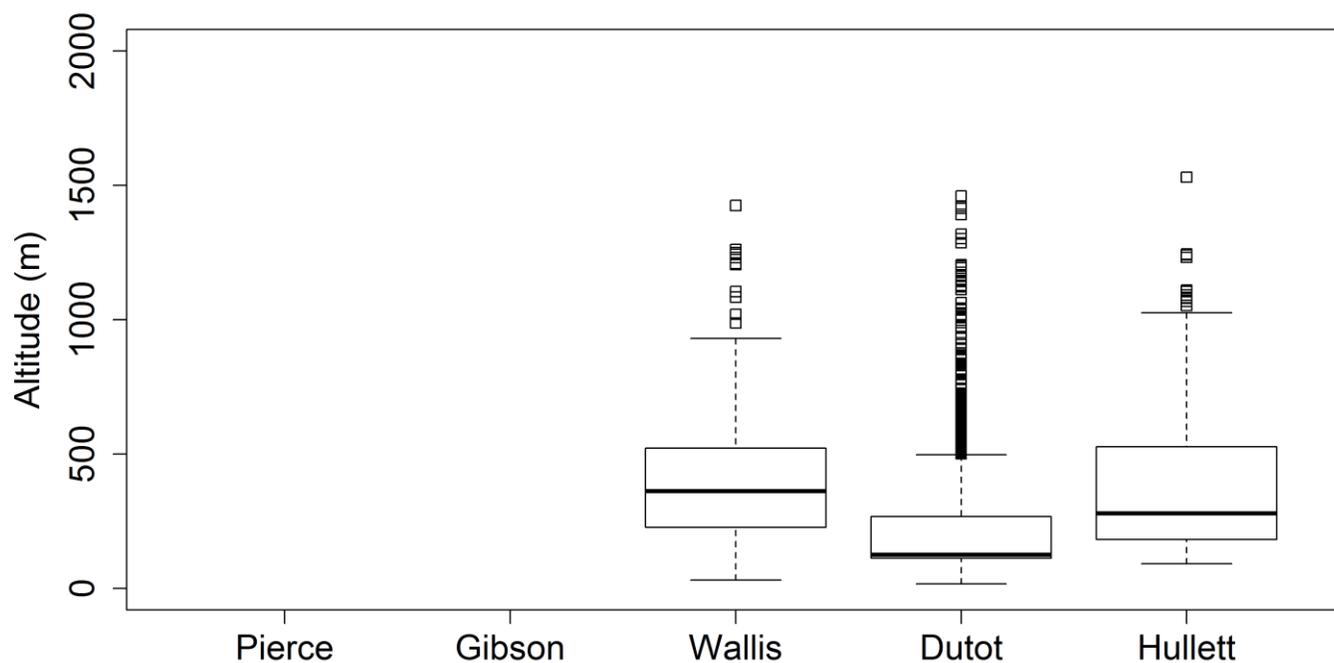
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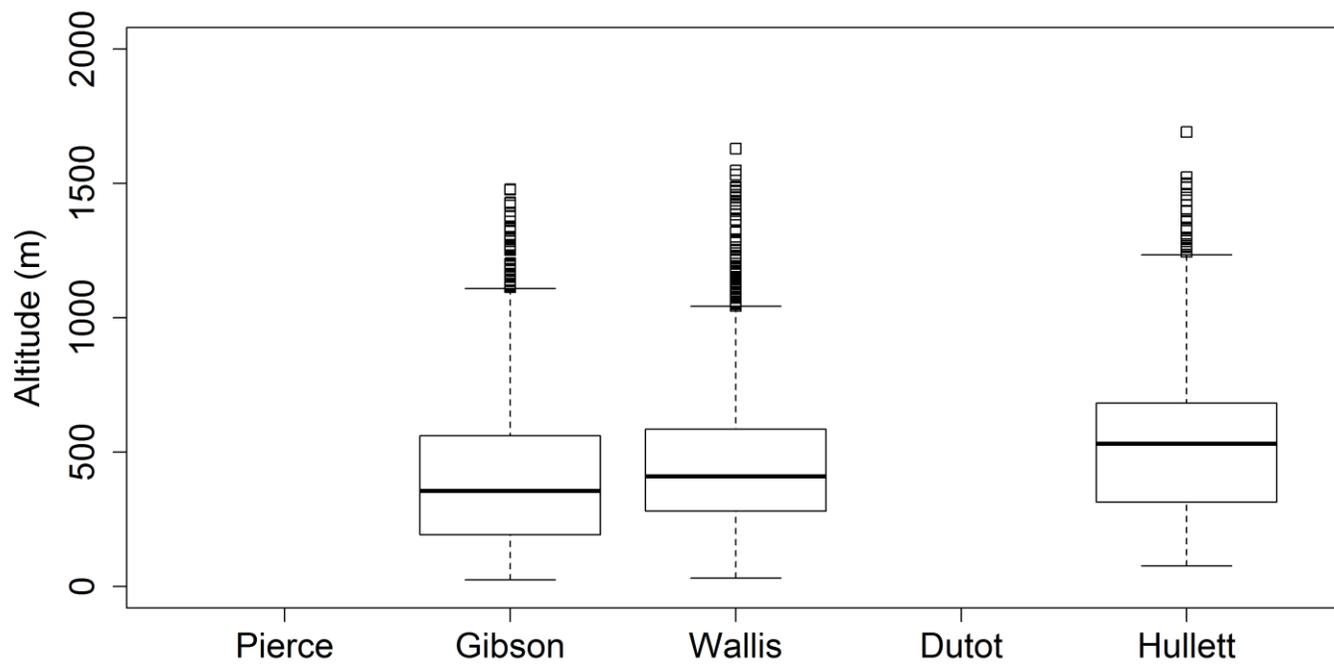
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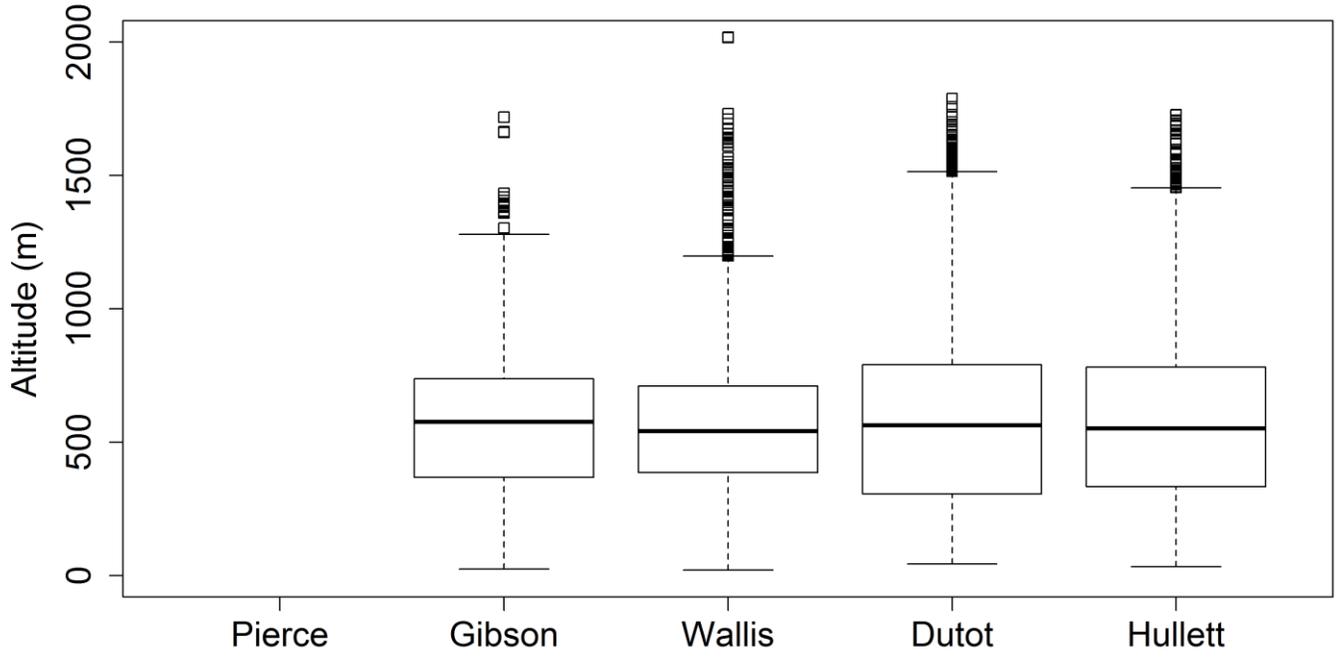
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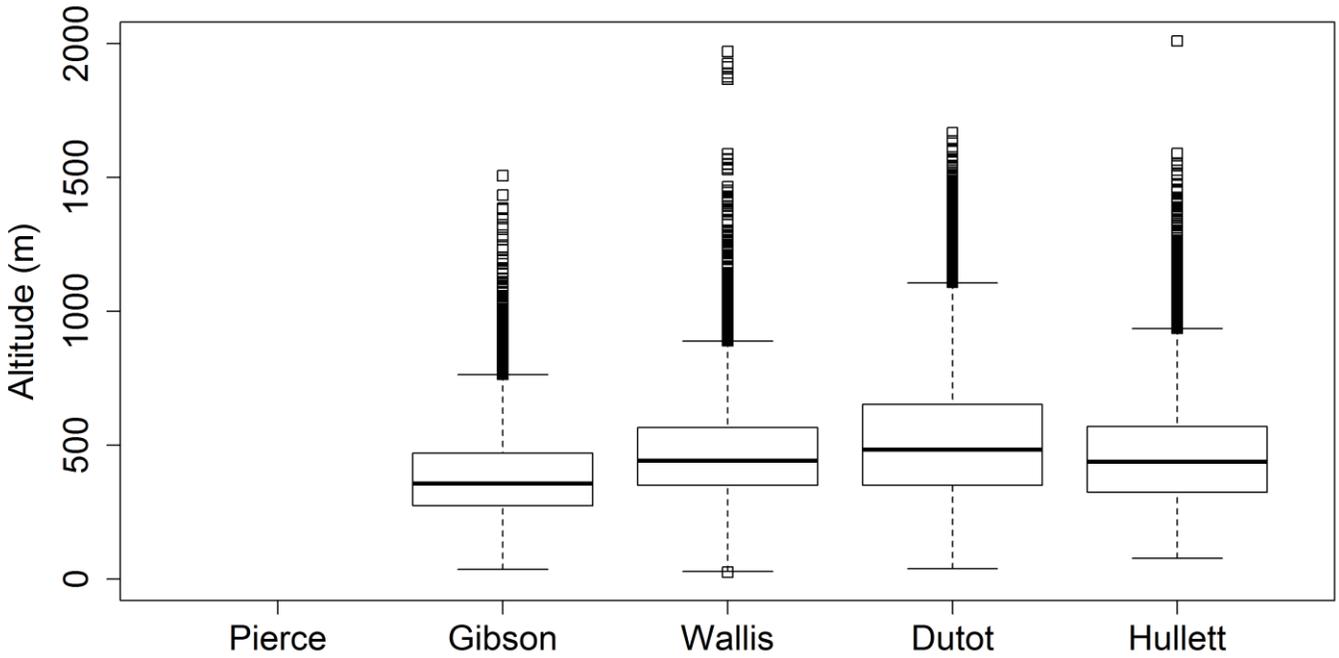
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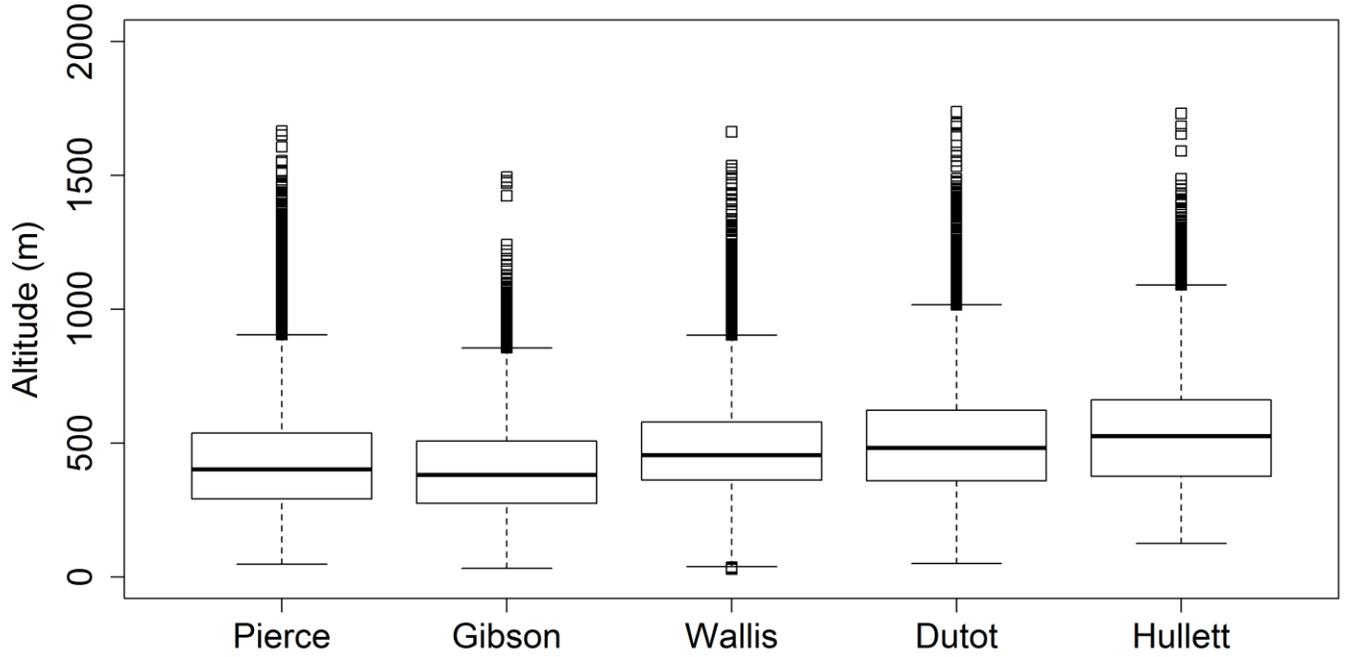
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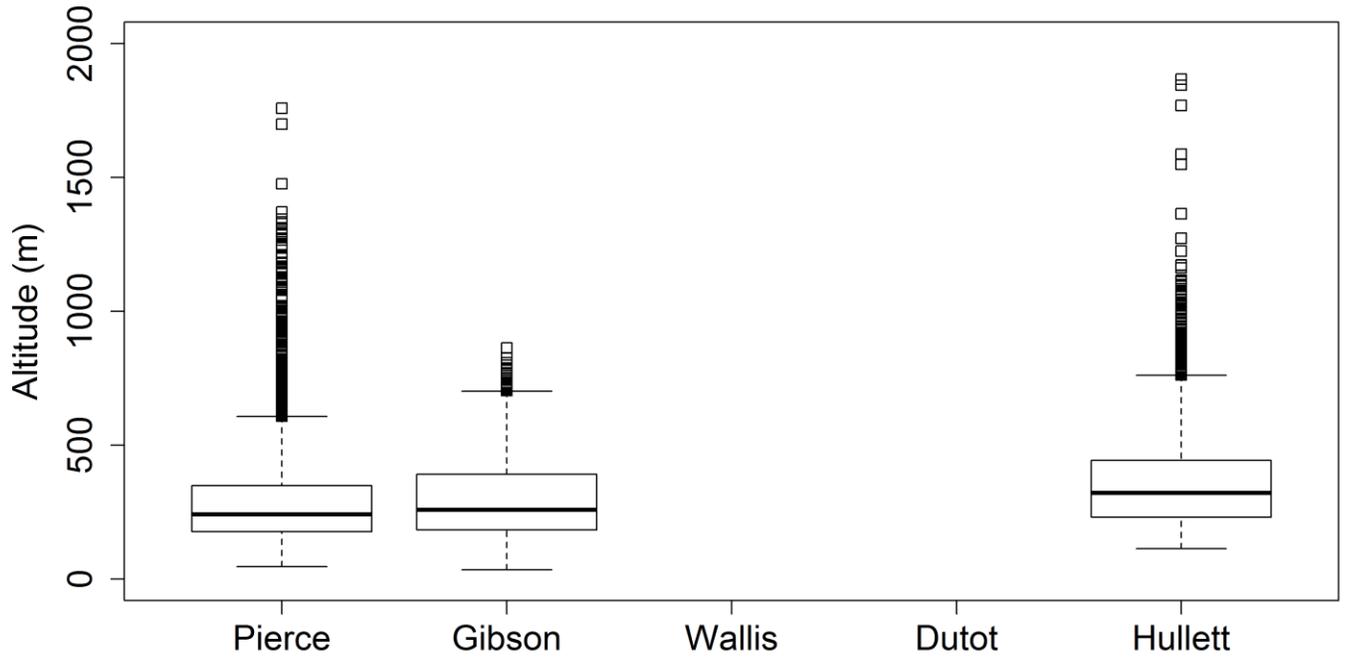
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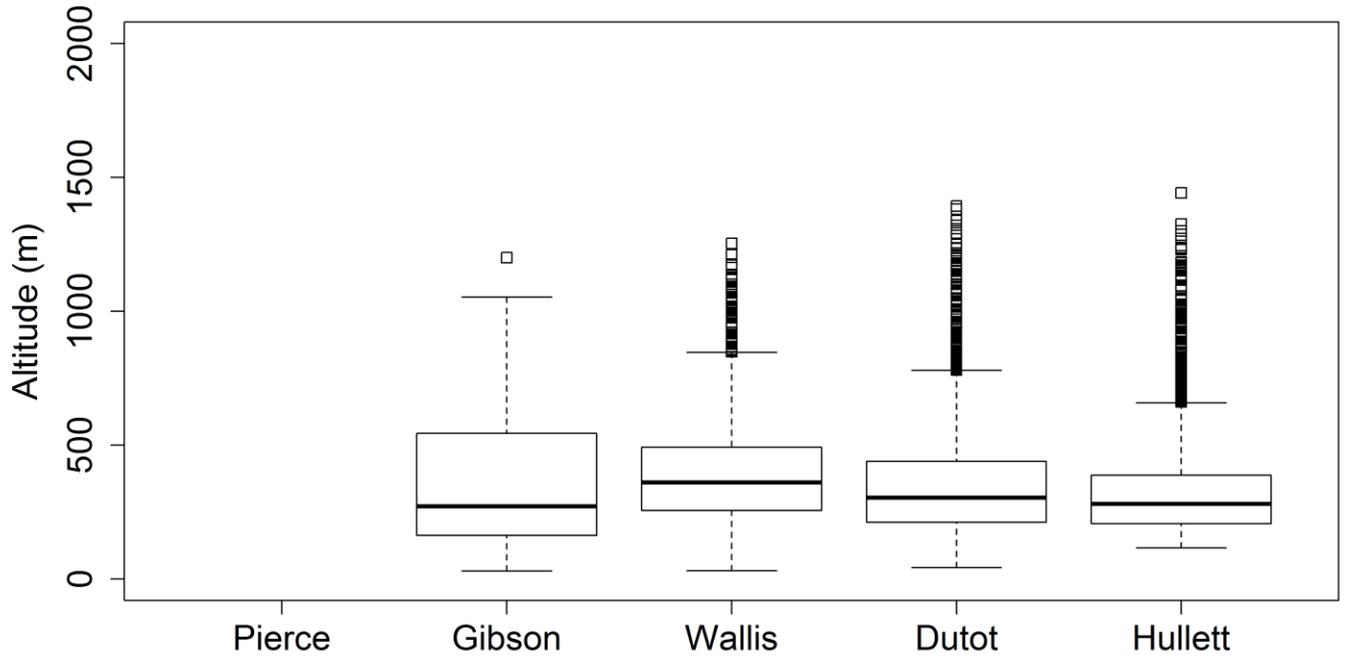
2014-05-08



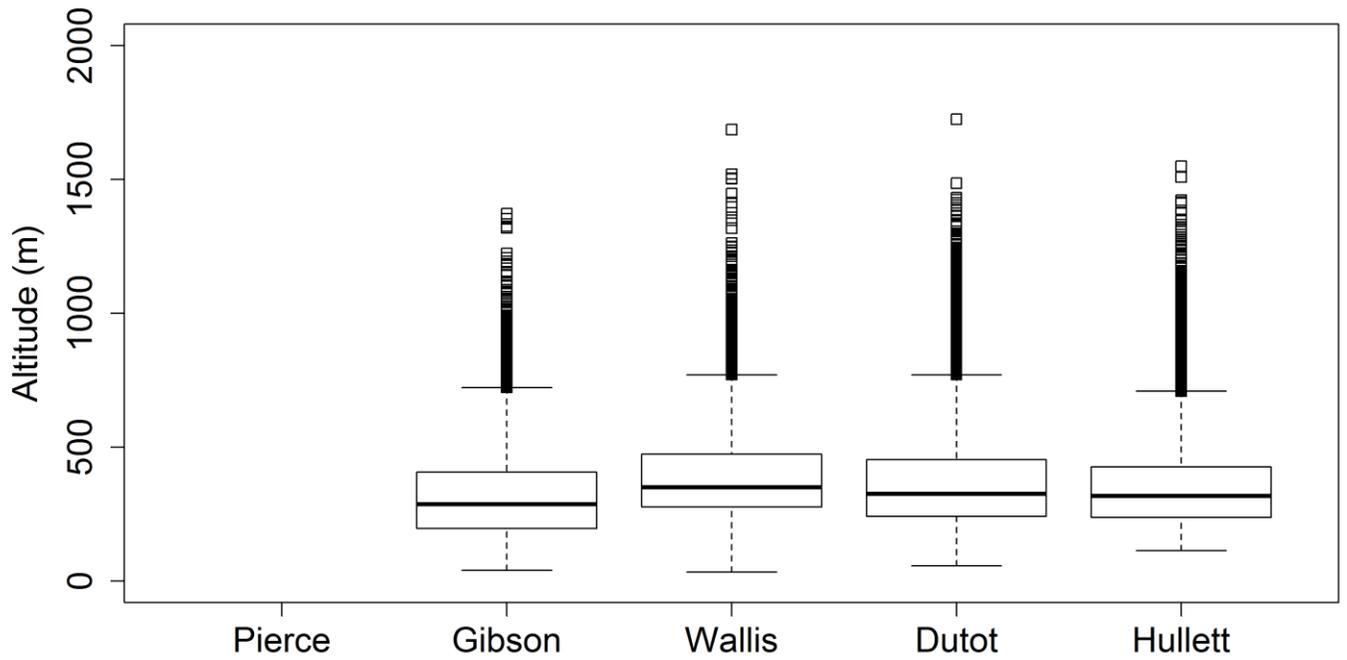
2014-05-09



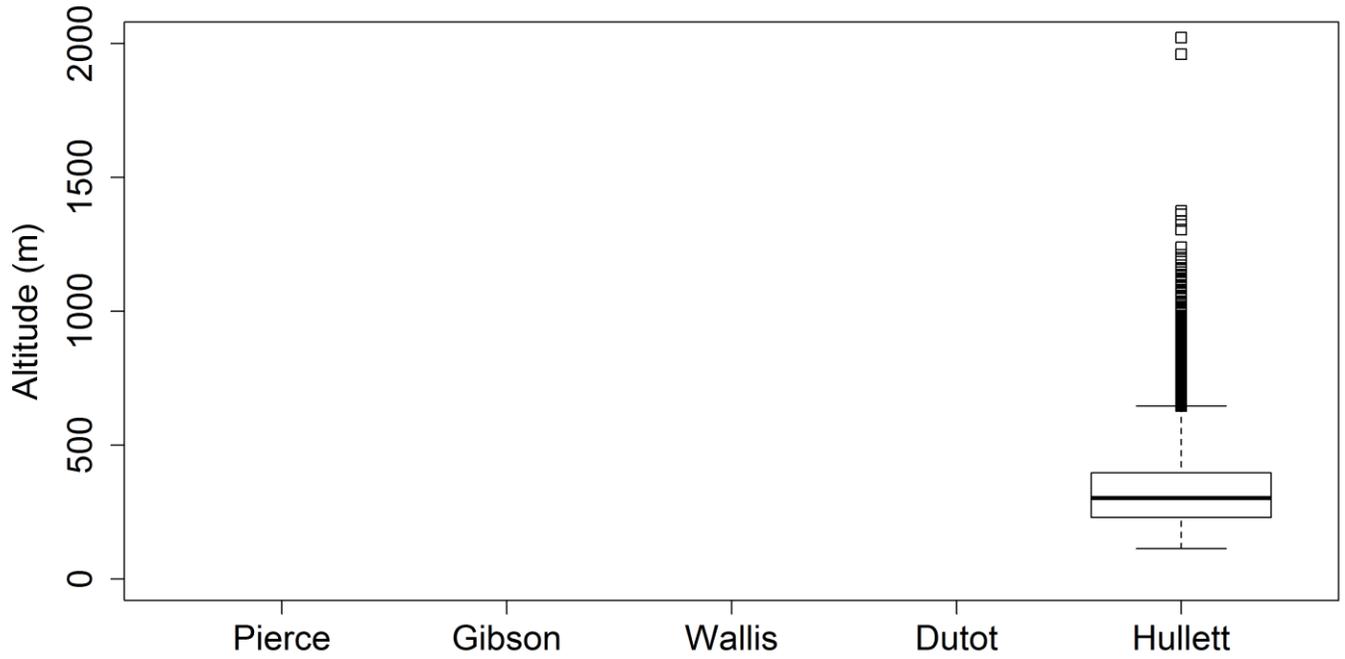
2014-05-10



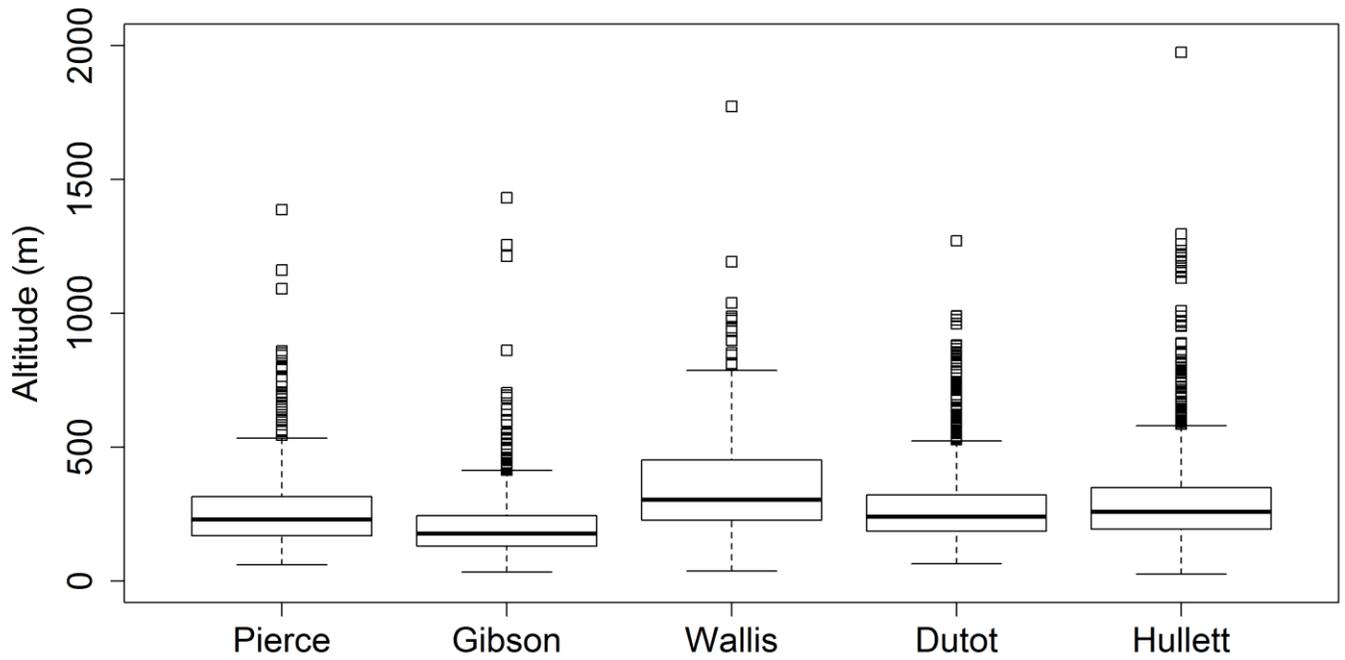
2014-05-11



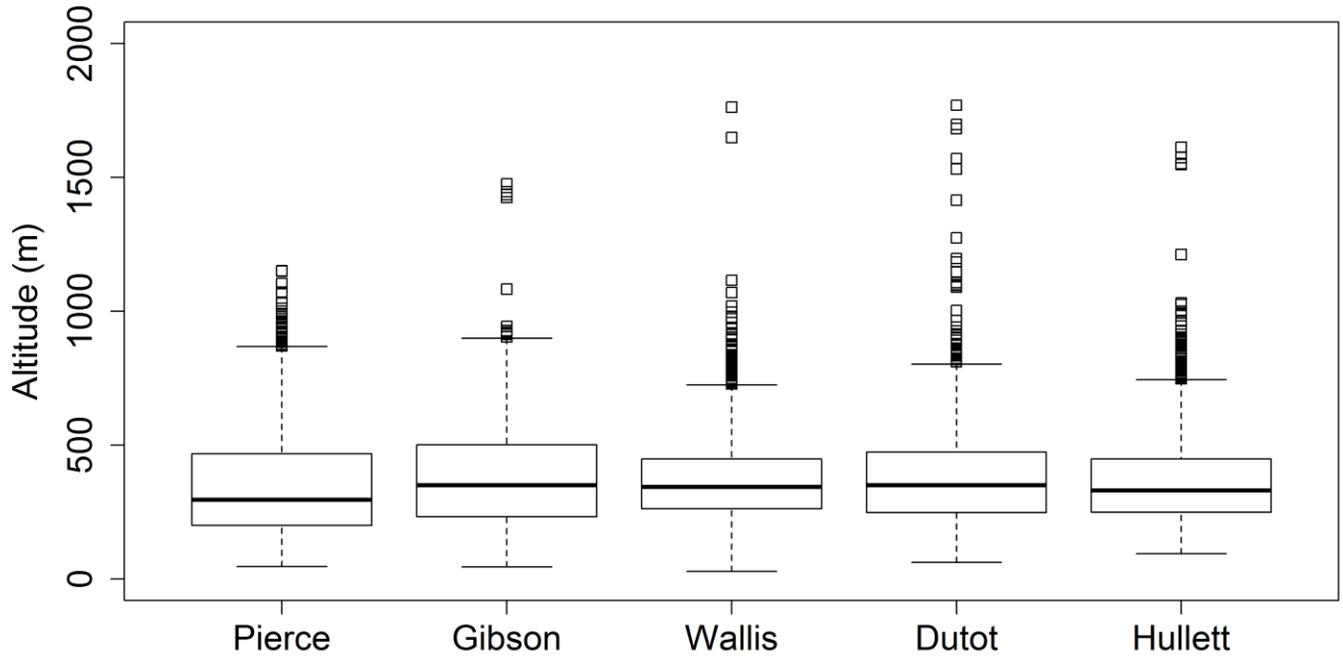
2014-05-13



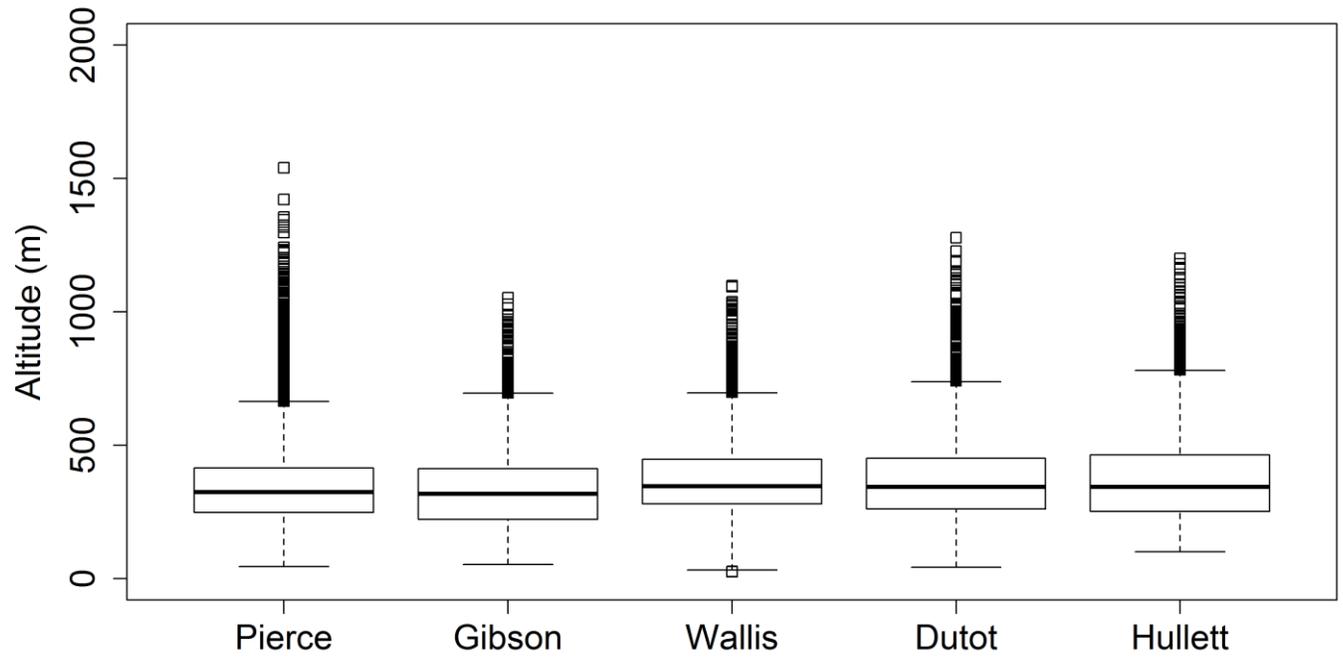
2014-05-15



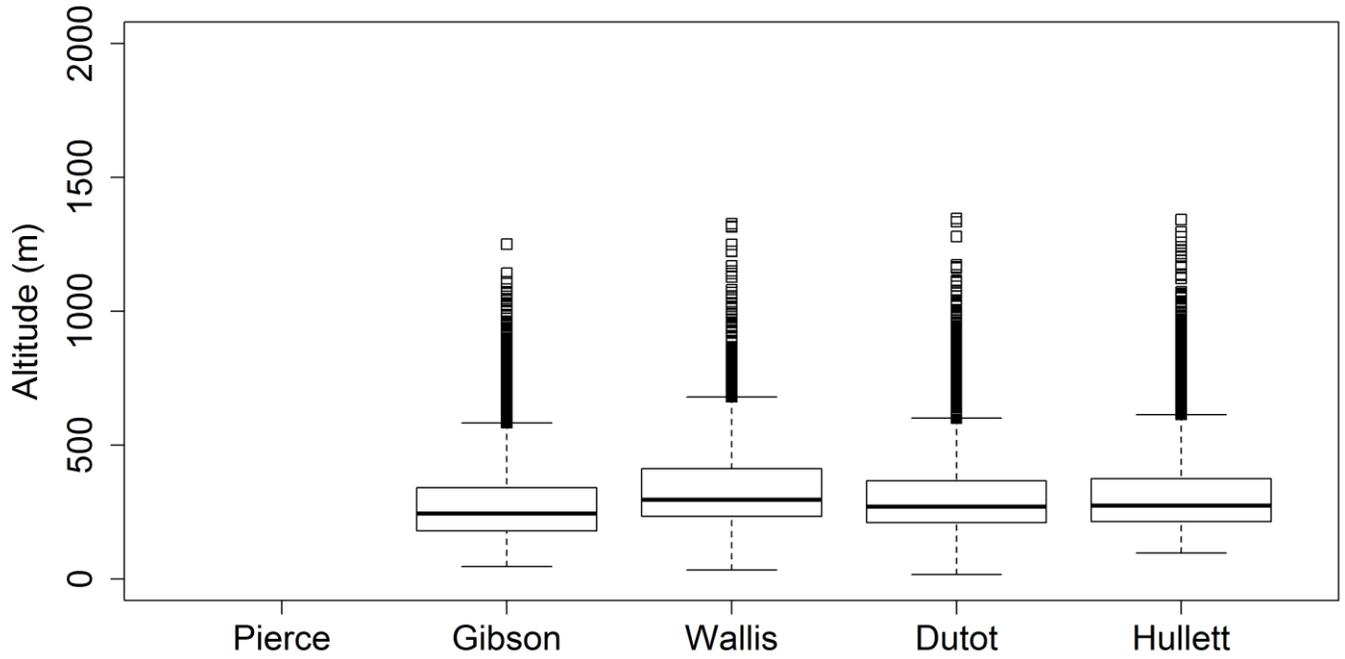
2014-05-16



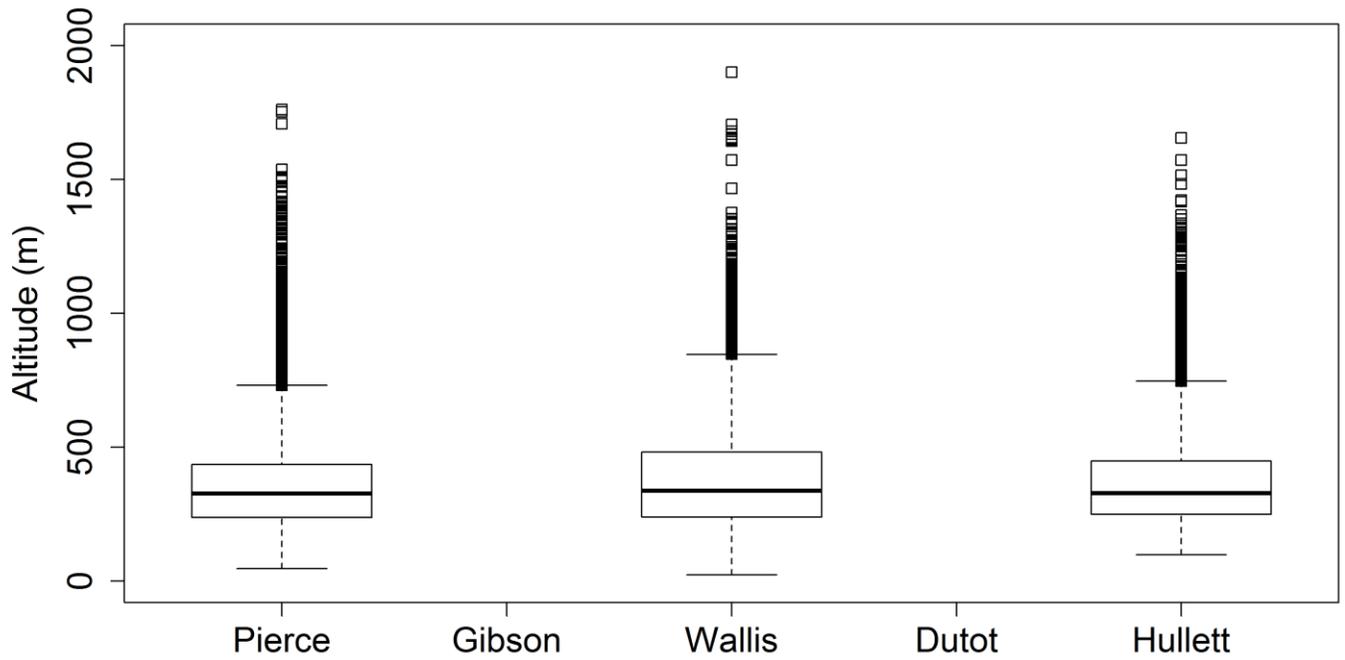
2014-05-17



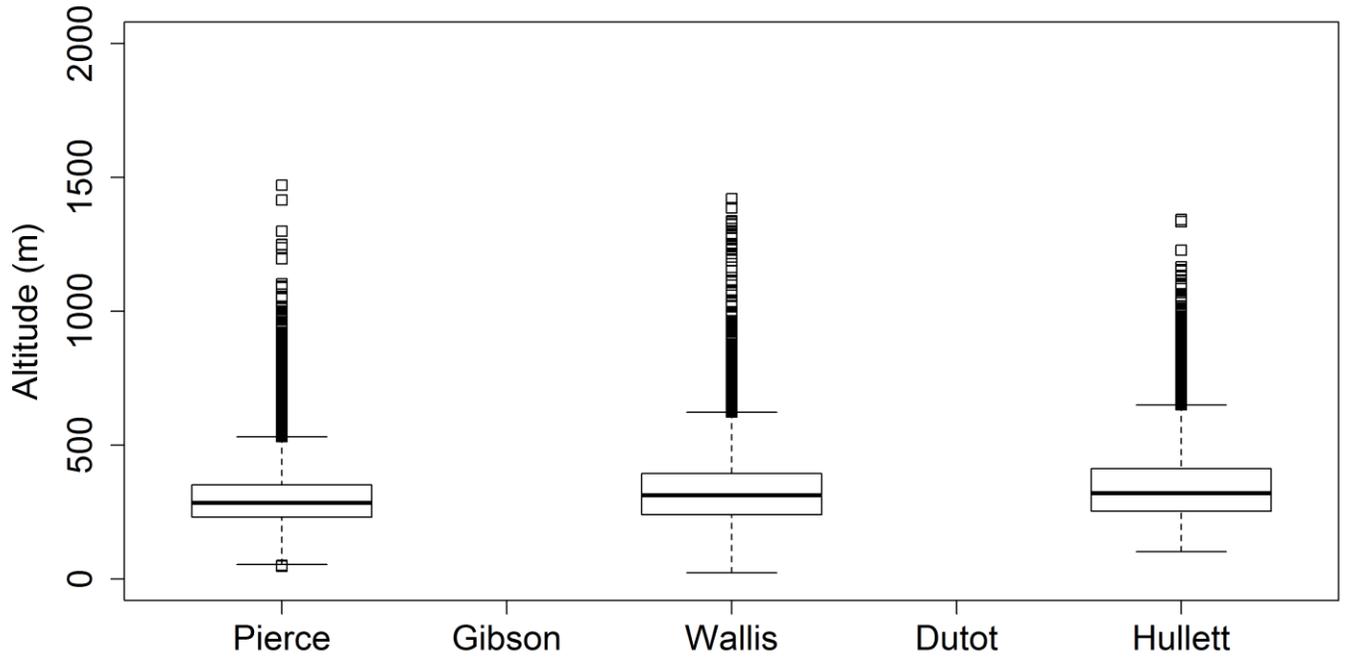
2014-05-18



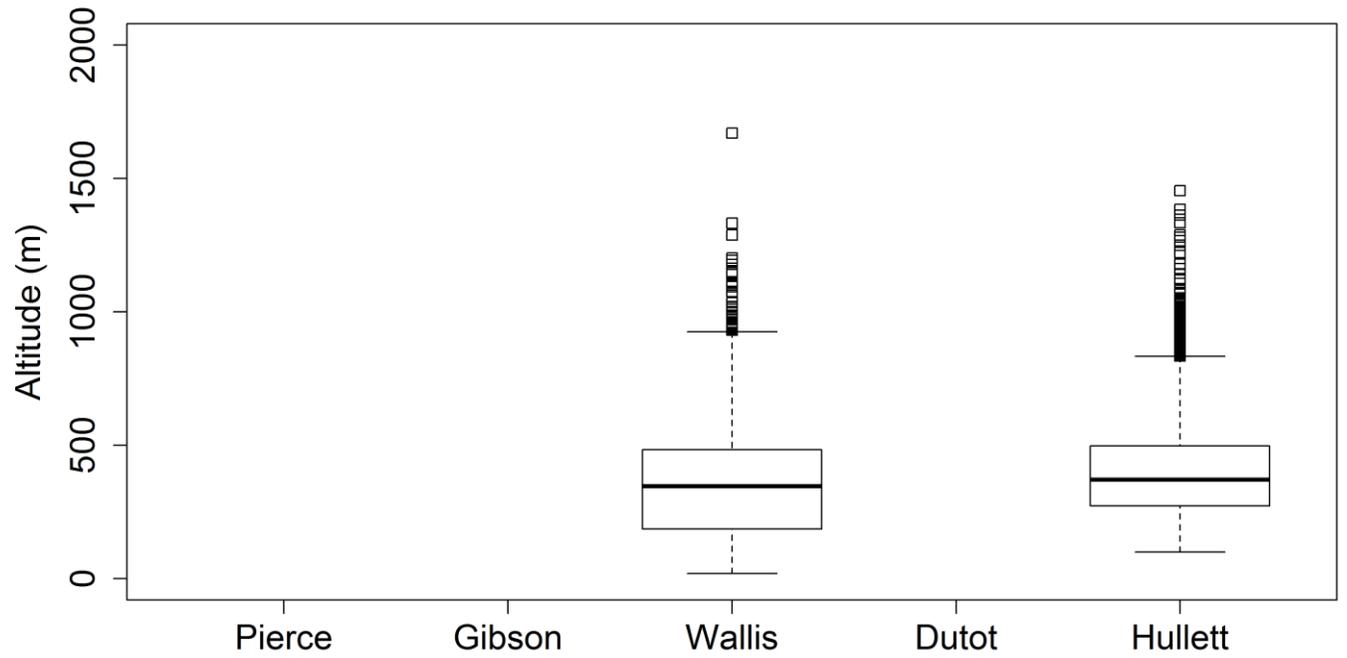
2014-05-19



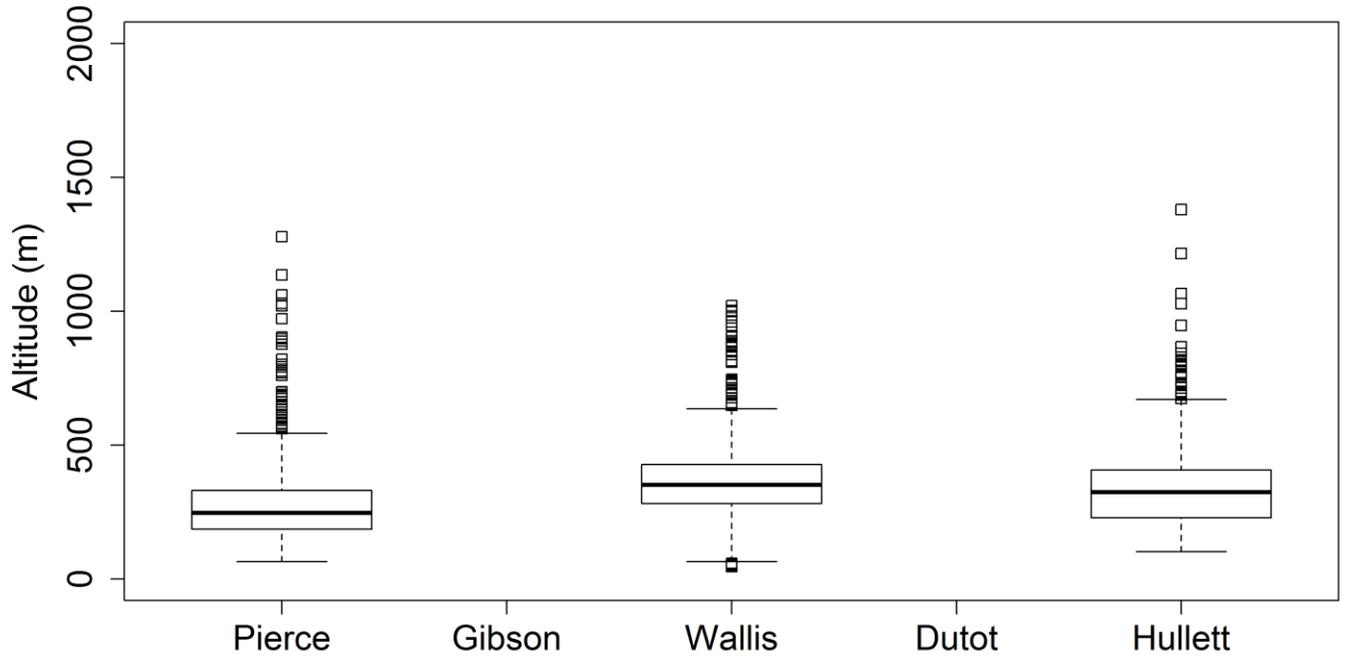
2014-05-20



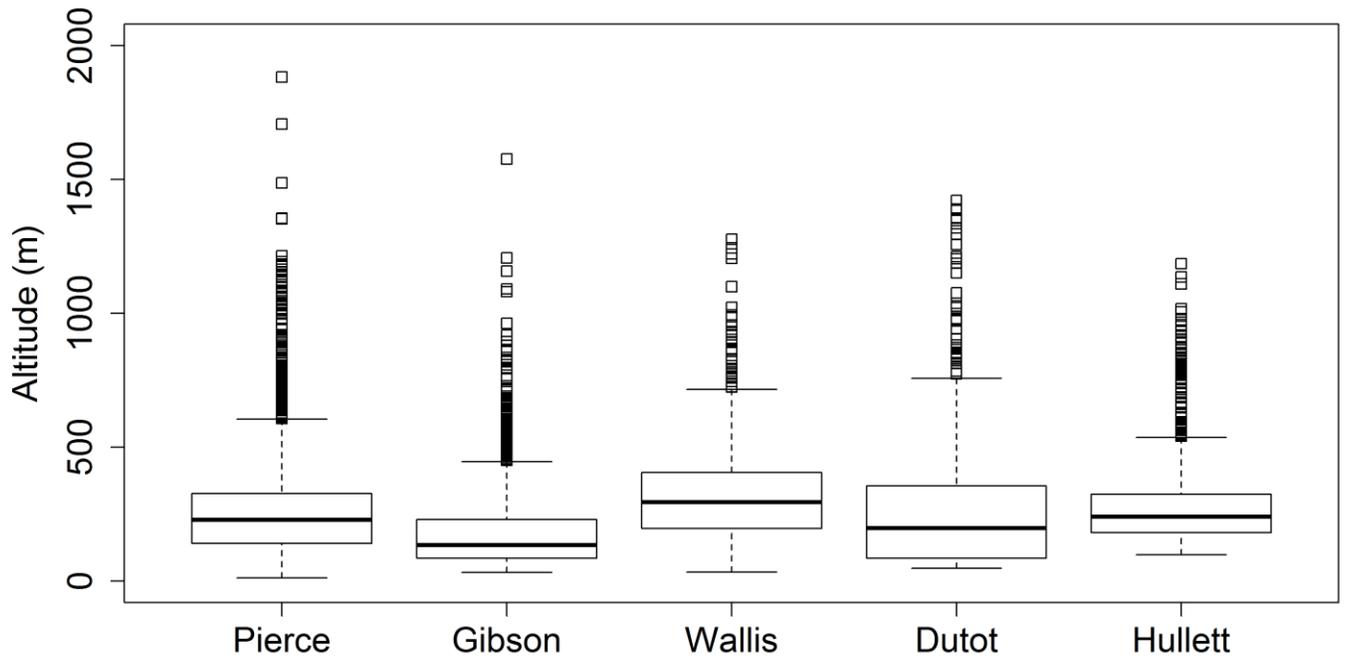
2014-05-21



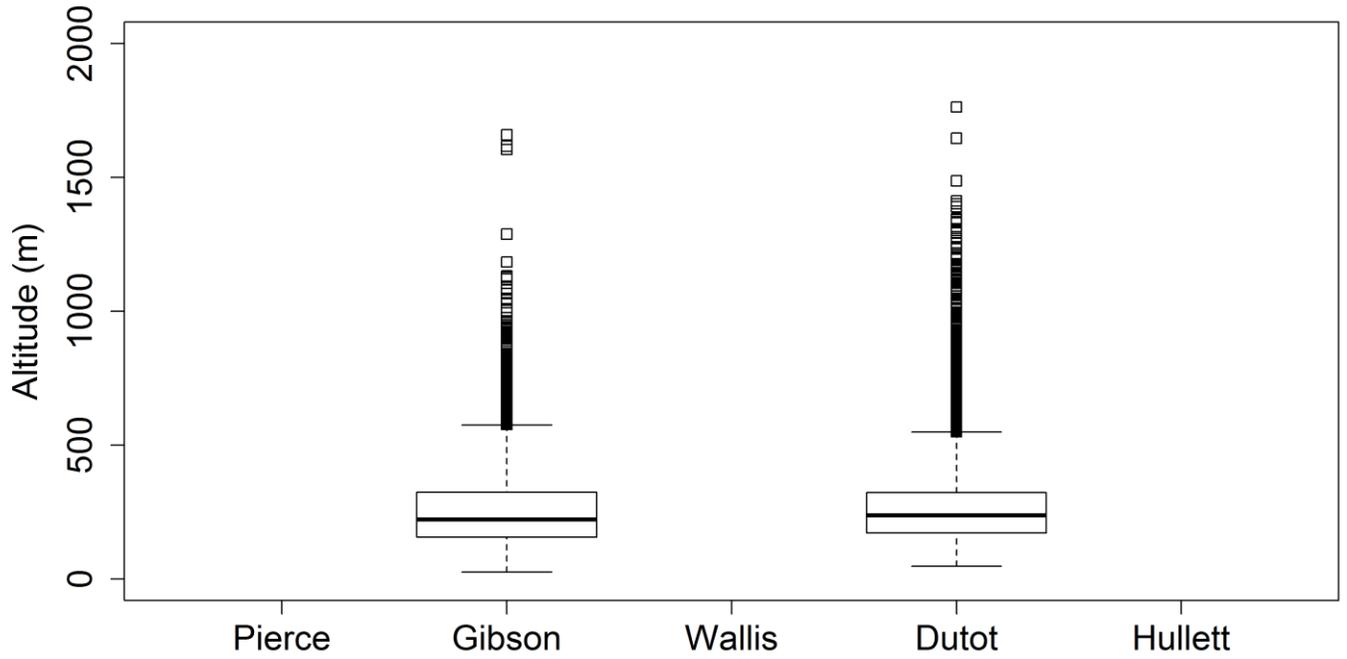
2014-05-22



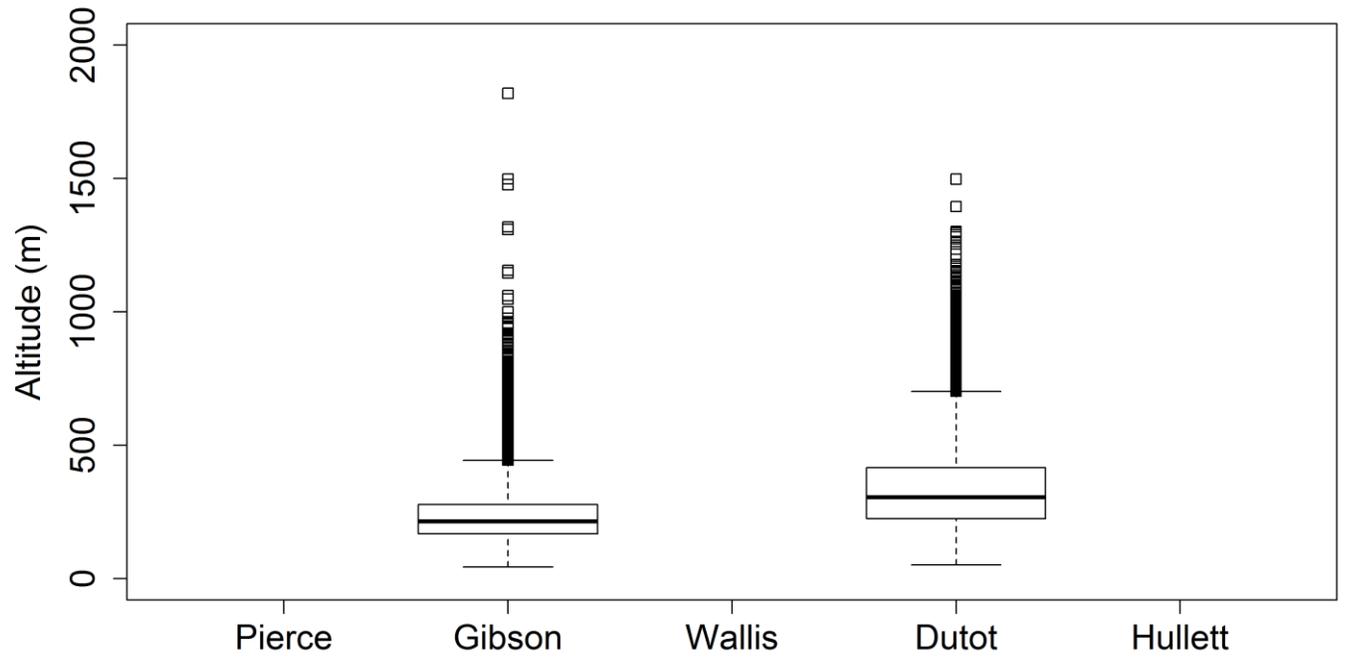
2014-05-23



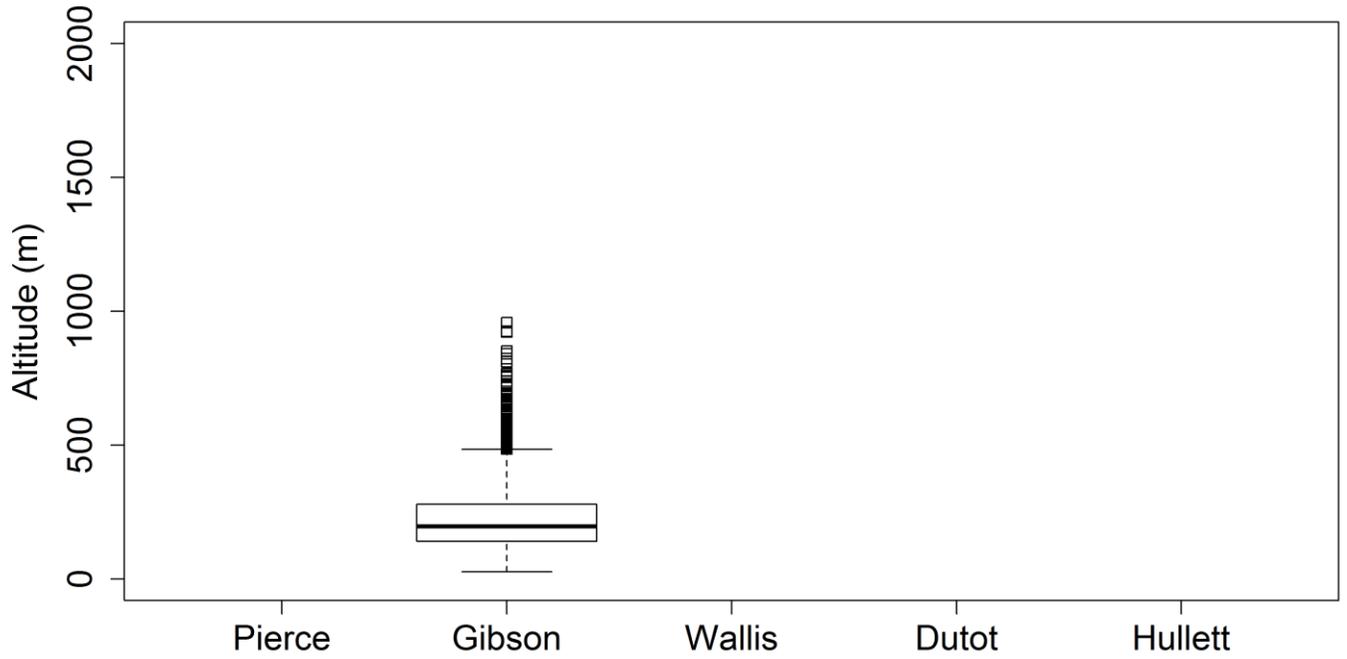
2014-05-24



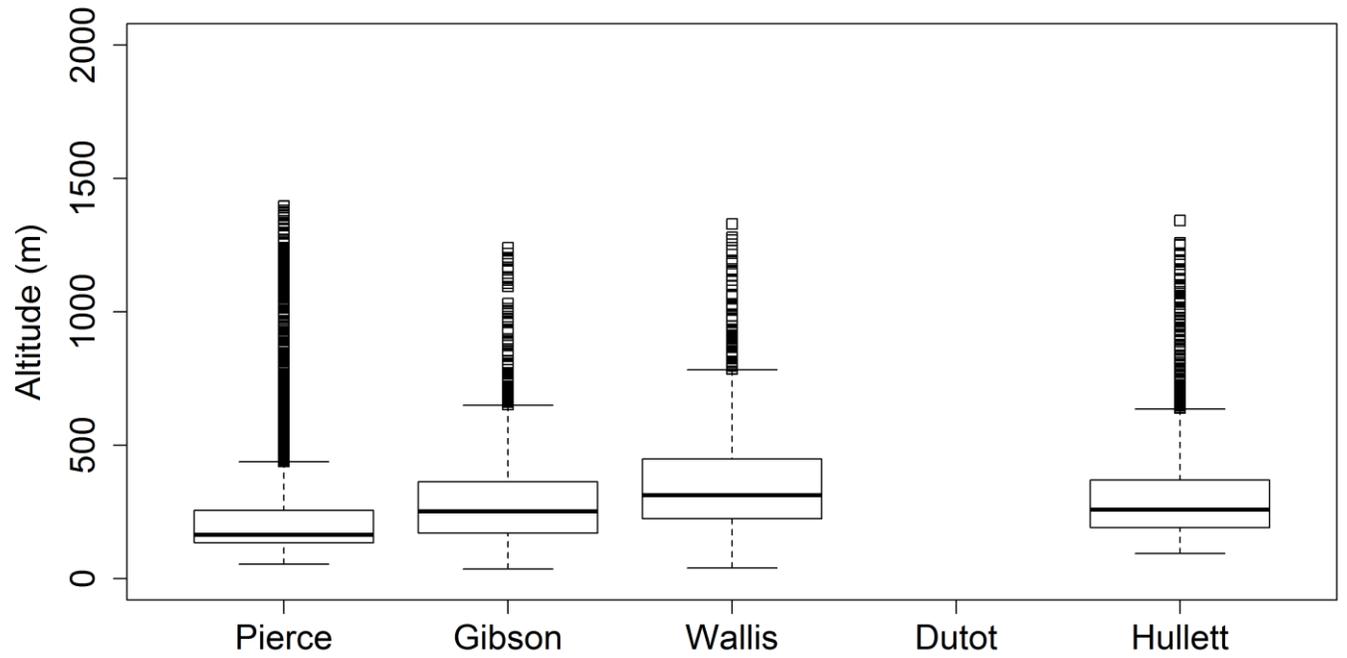
2014-05-25



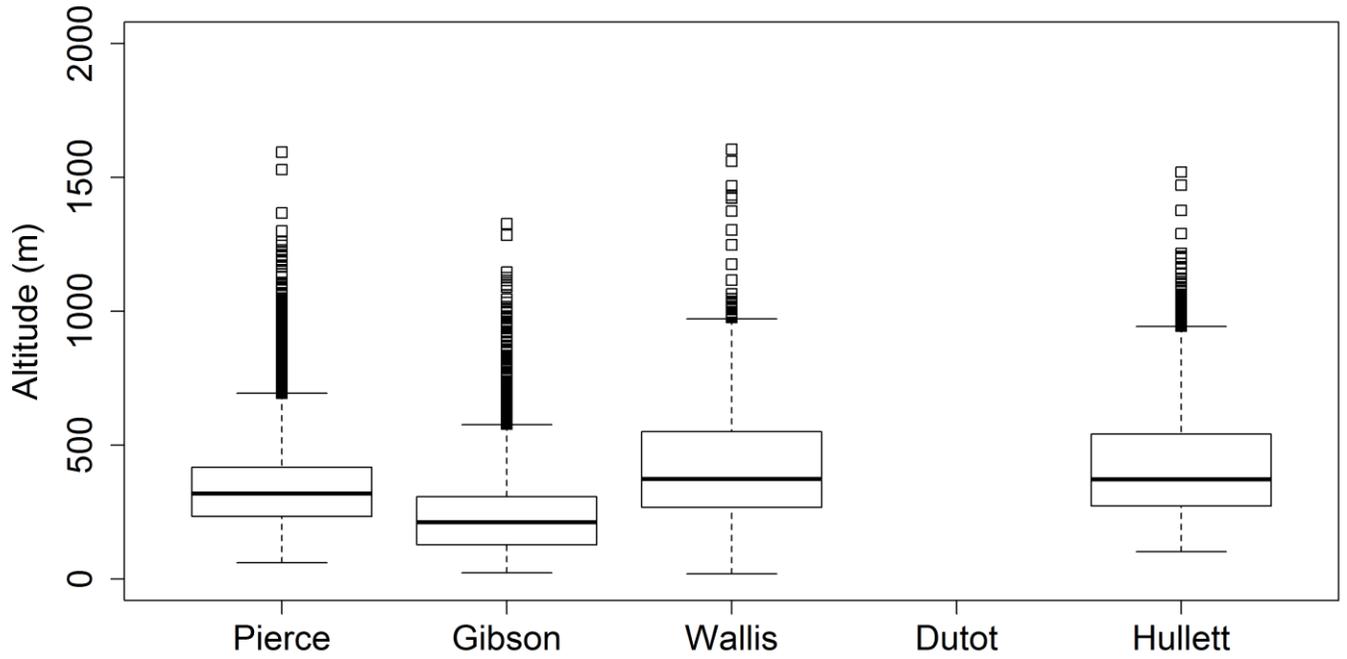
2014-05-26



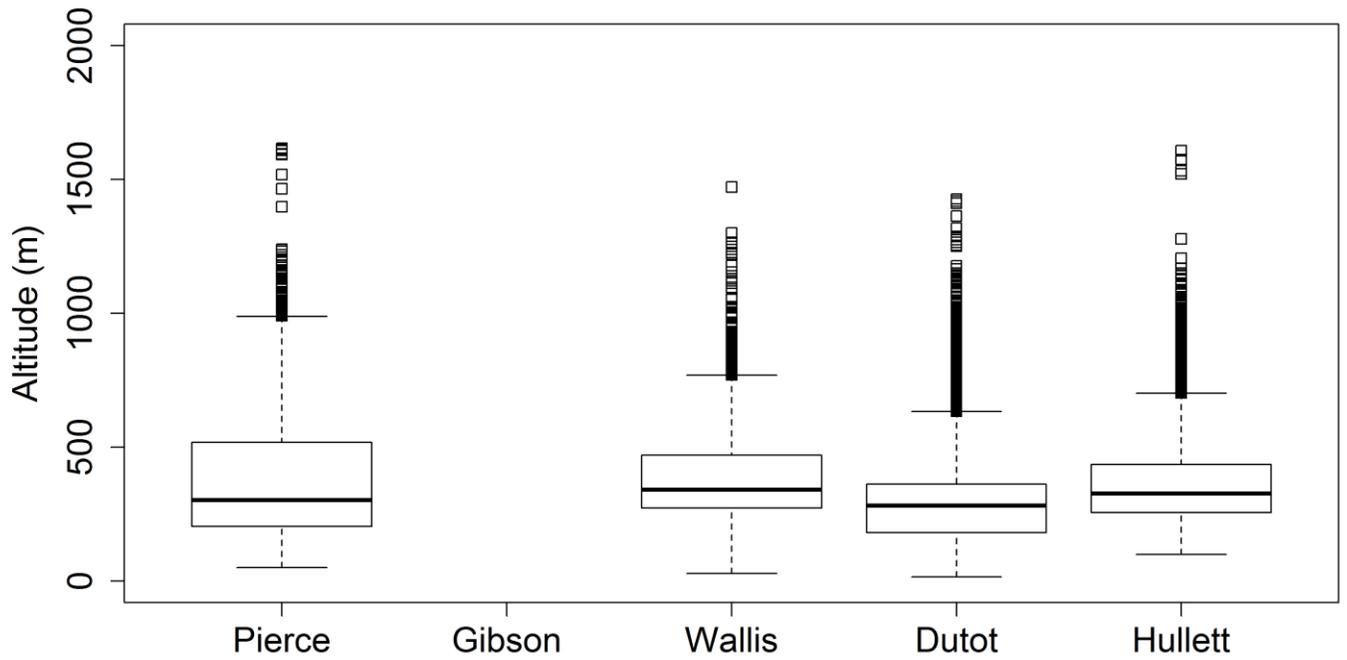
2014-05-27



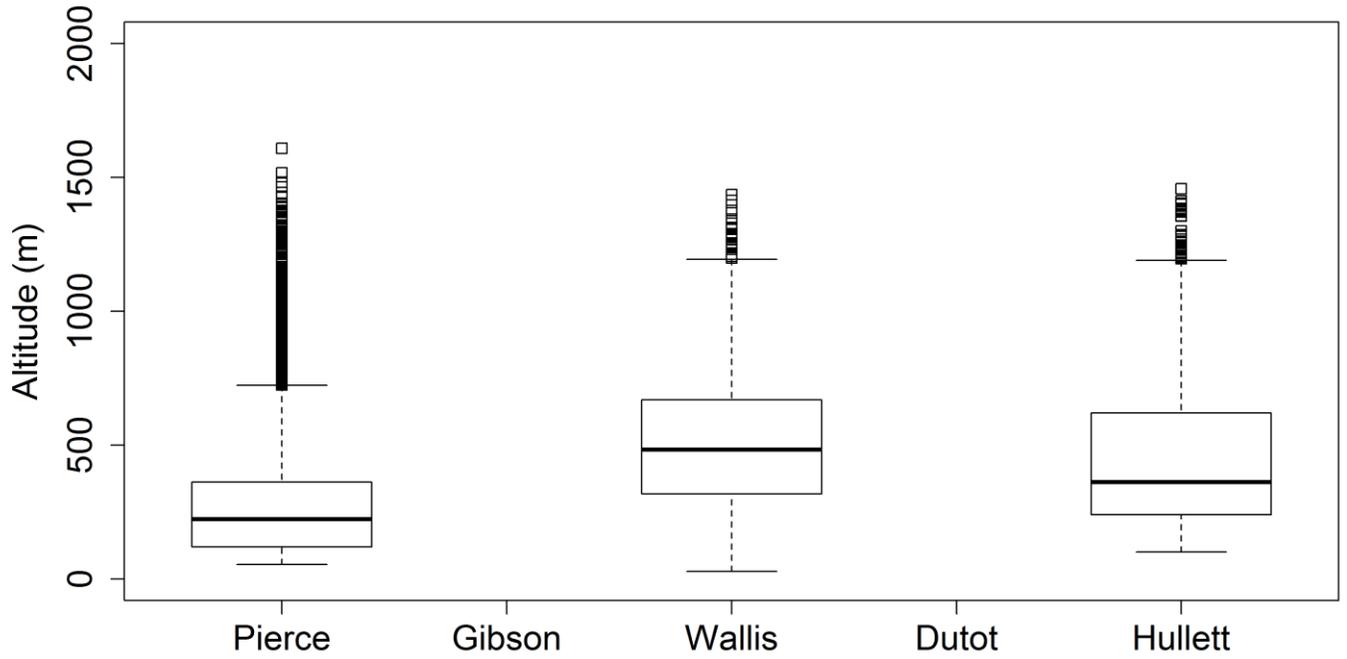
2014-05-28



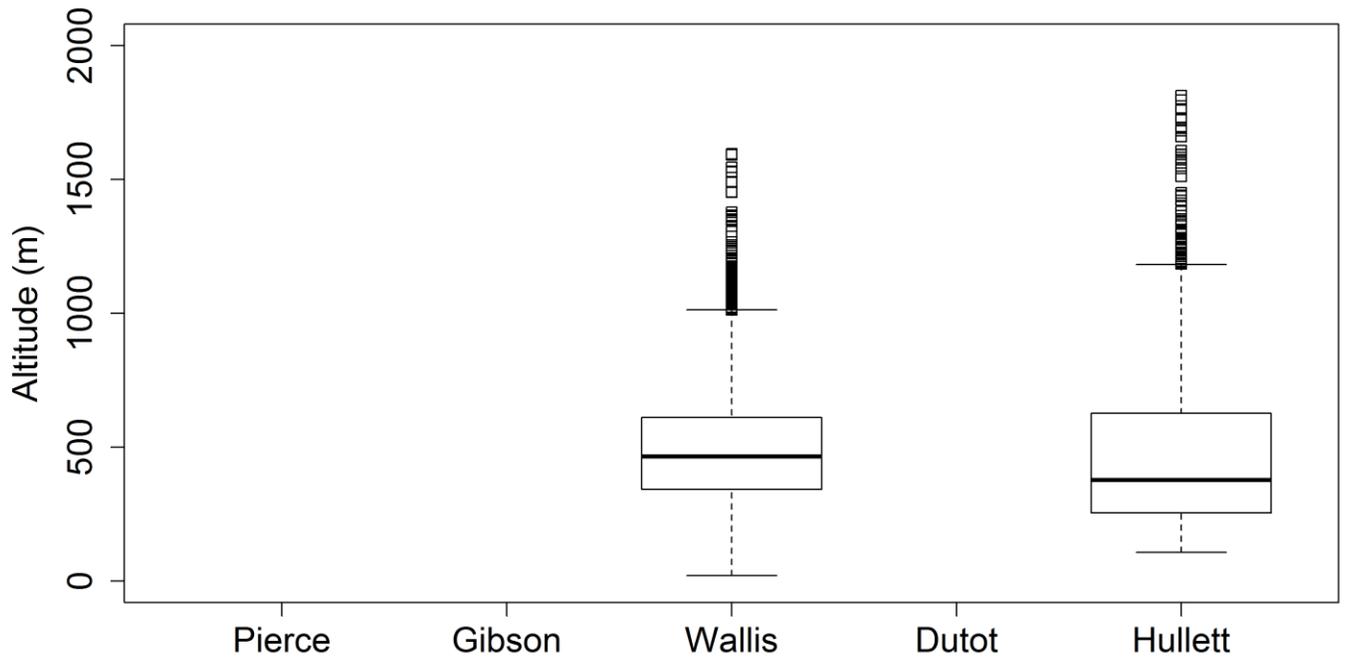
2014-05-29



2014-05-30

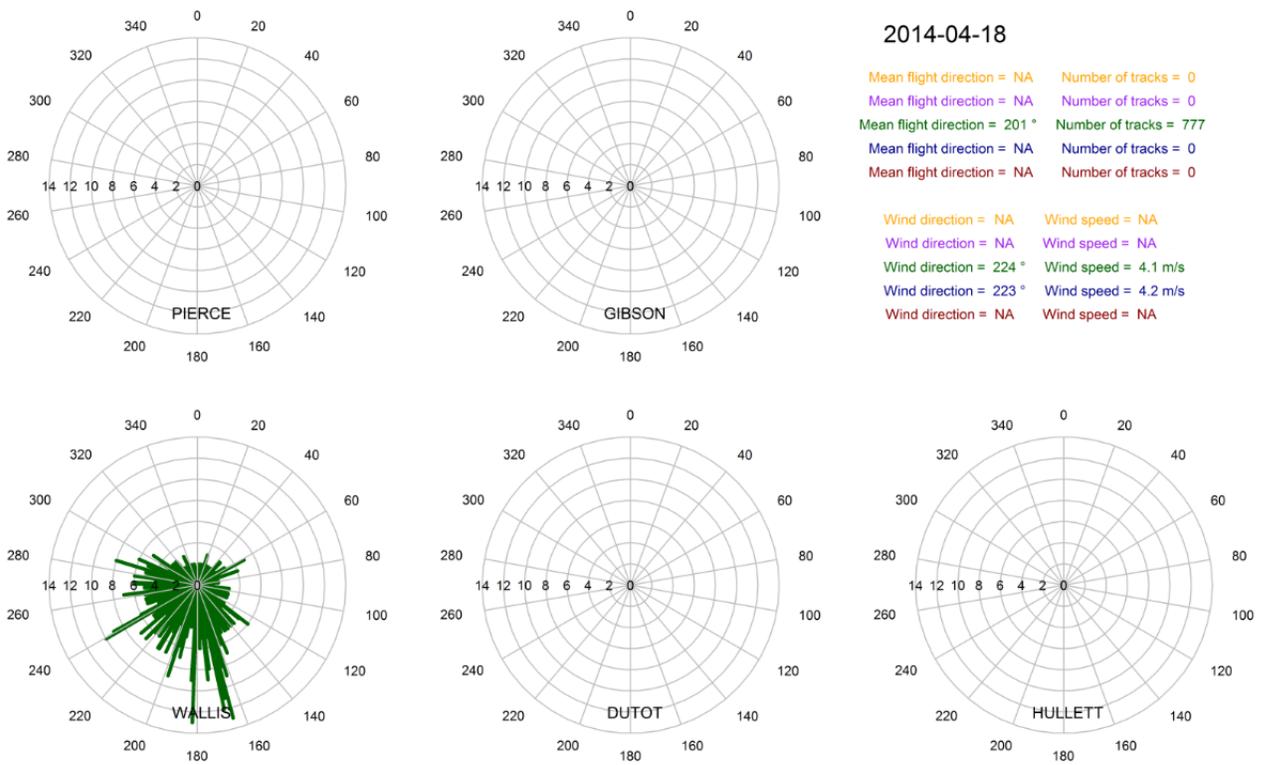


2014-05-31

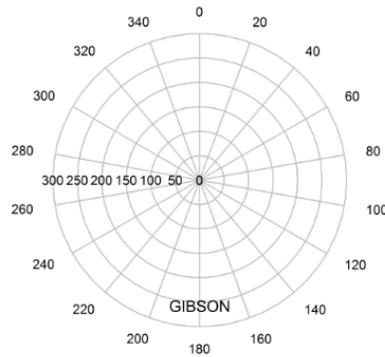
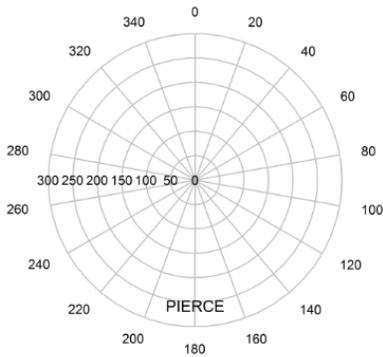


APPENDIX B

Summary of flight direction by night of nocturnal migrants detected at five locations
along the shoreline of Lake Huron during the 2014 spring migration season



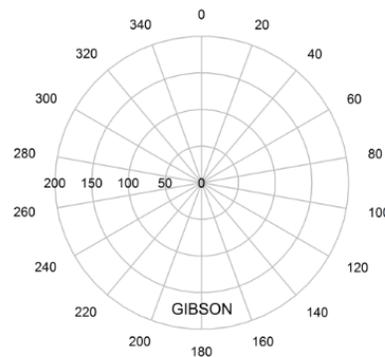
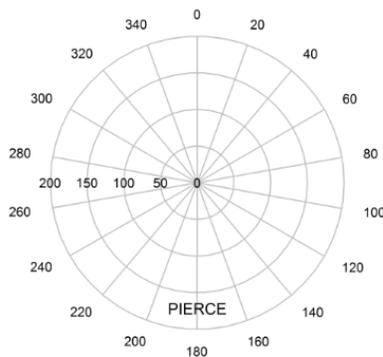
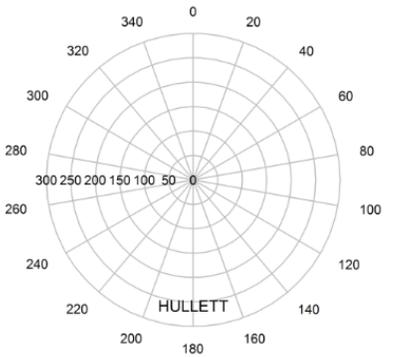
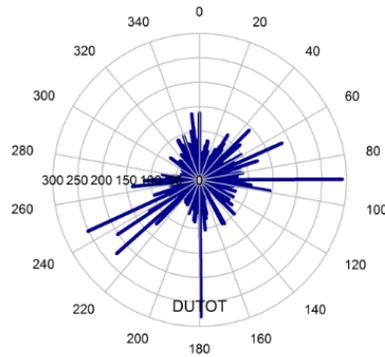
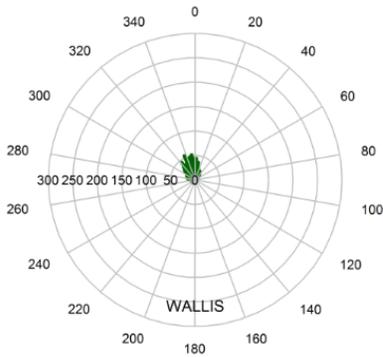
*Flight directions significantly different ($p < 0.05$)



2014-04-19

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 341 ° Number of tracks = 3279
 Mean flight direction = 14 ° Number of tracks = 17478
 Mean flight direction = NA Number of tracks = 0

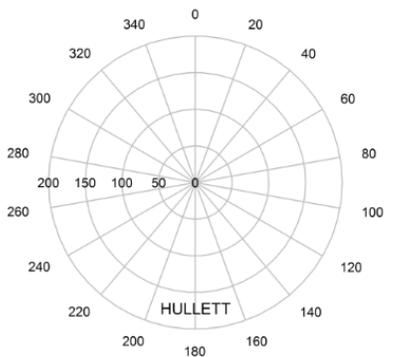
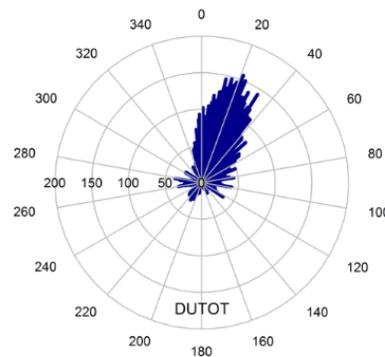
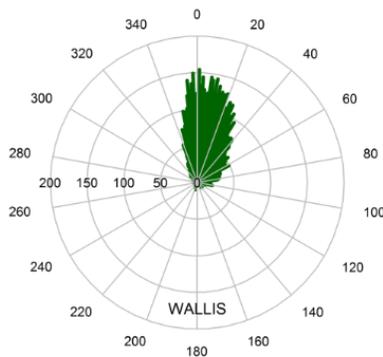
Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 31 ° Wind speed = 3.5 m/s
 Wind direction = 29 ° Wind speed = 3.5 m/s
 Wind direction = NA Wind speed = NA

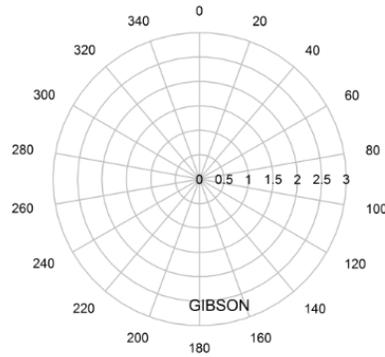
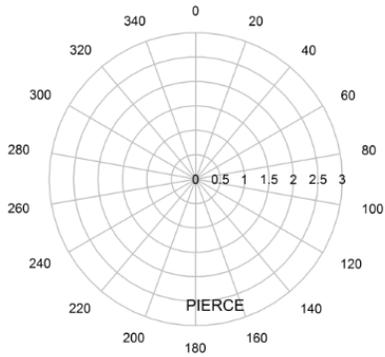


2014-04-20

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 18 ° Number of tracks = 8098
 Mean flight direction = 26 ° Number of tracks = 9720
 Mean flight direction = NA Number of tracks = 0

Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 146 ° Wind speed = 4.7 m/s
 Wind direction = 146 ° Wind speed = 4.7 m/s
 Wind direction = NA Wind speed = NA

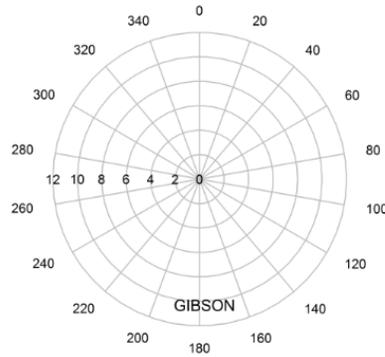
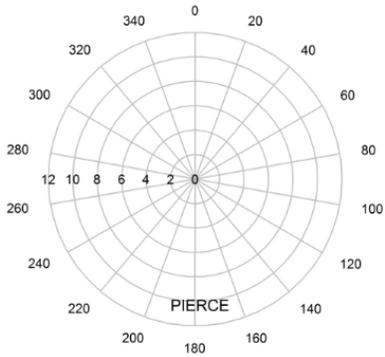
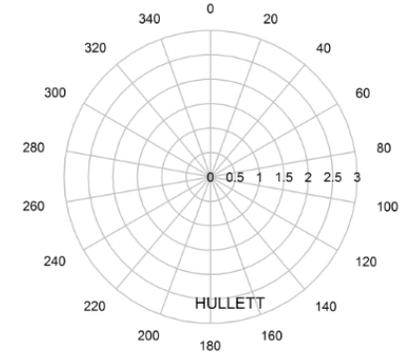
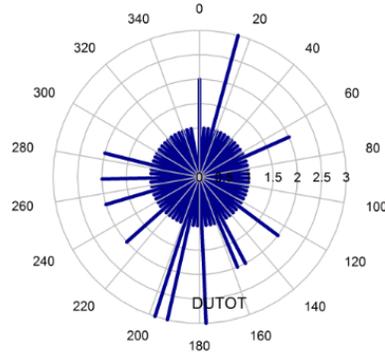
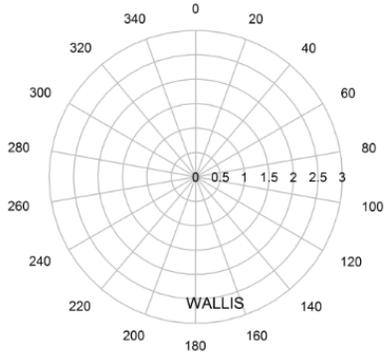




2014-04-22

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 168° Number of tracks = 87
 Mean flight direction = NA Number of tracks = 0

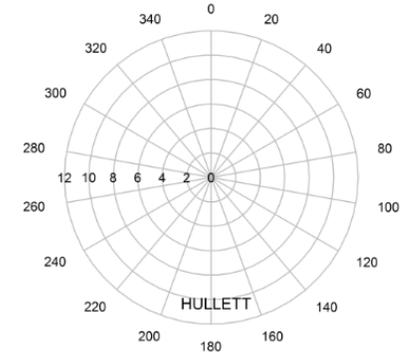
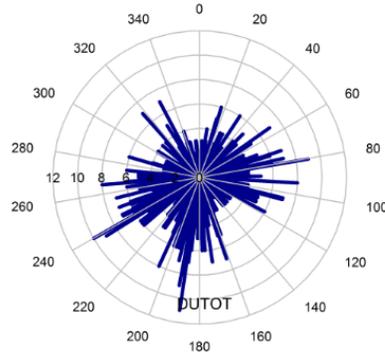
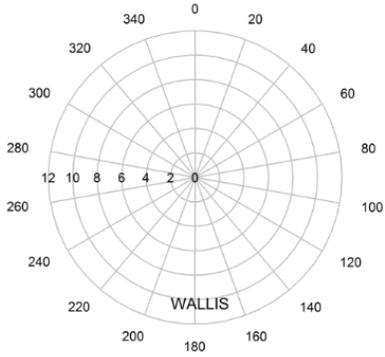
Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 271° Wind speed = 5.7 m/s
 Wind direction = NA Wind speed = NA

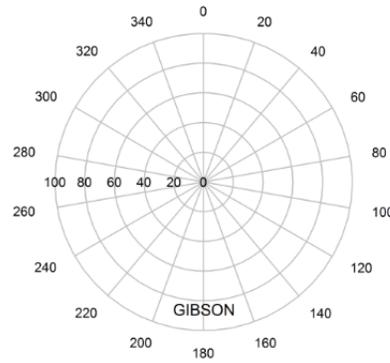
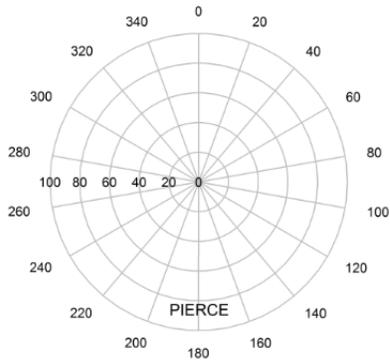


2014-04-23

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 194° Number of tracks = 1035
 Mean flight direction = NA Number of tracks = 0

Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 319° Wind speed = 6.7 m/s
 Wind direction = NA Wind speed = NA

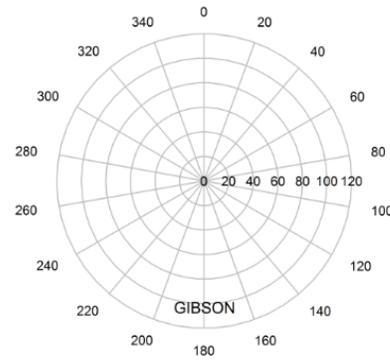
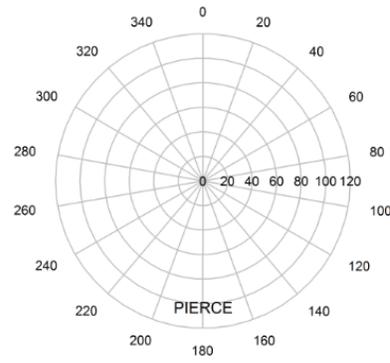
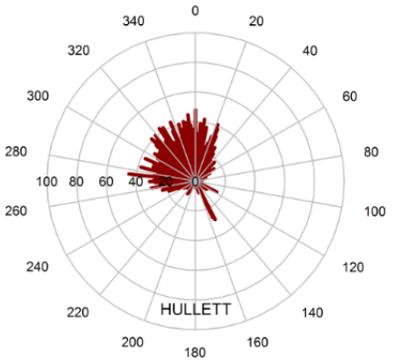
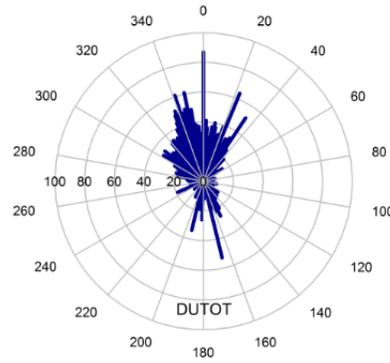
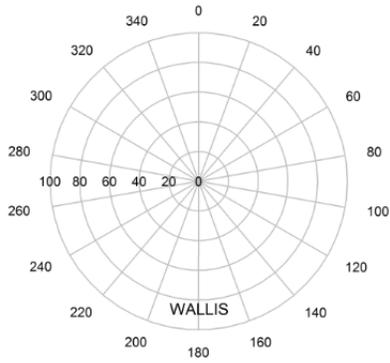




2014-04-24

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 345 ° Number of tracks = 3924
 Mean flight direction = 341 ° Number of tracks = 3212

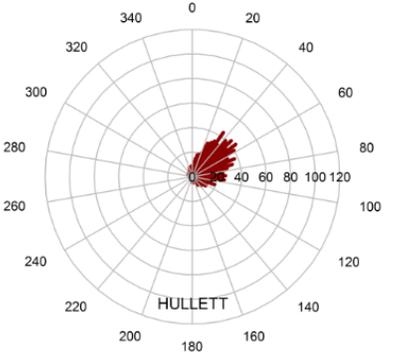
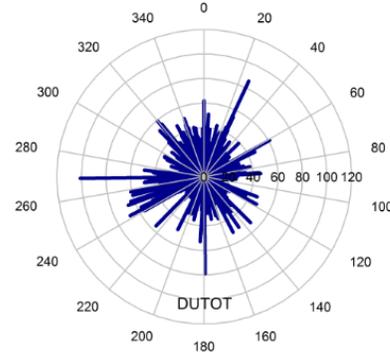
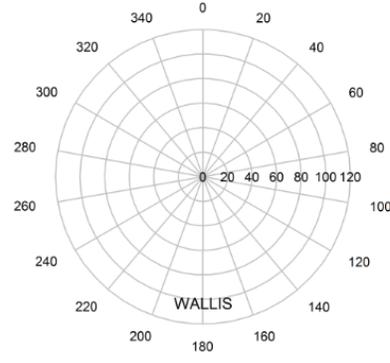
Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 36 ° Wind speed = 3.2 m/s
 Wind direction = 32 ° Wind speed = 3.2 m/s

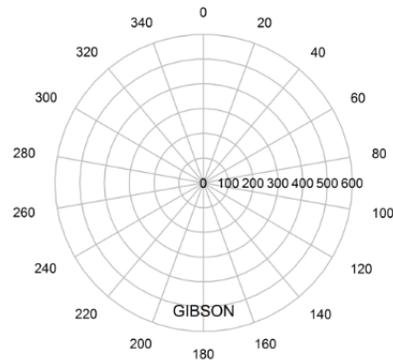
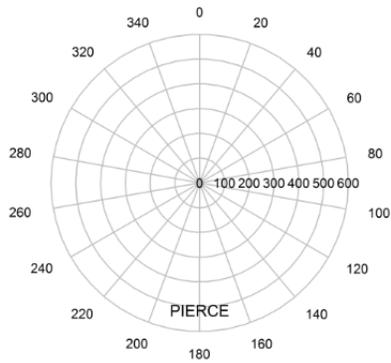


2014-04-25

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 316 ° Number of tracks = 9586
 Mean flight direction = 39 ° Number of tracks = 2147

Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 93 ° Wind speed = 4.3 m/s
 Wind direction = 84 ° Wind speed = 4.9 m/s

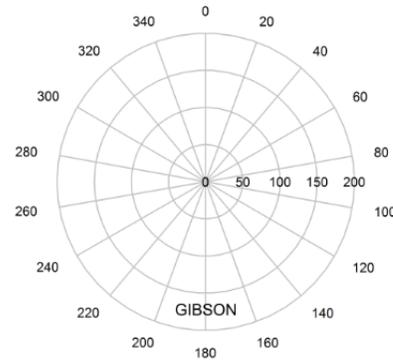
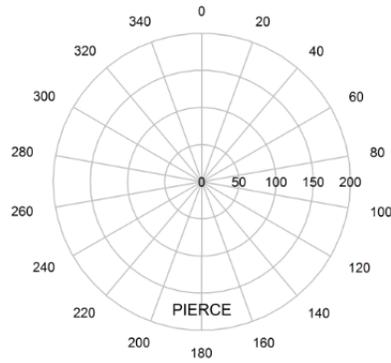
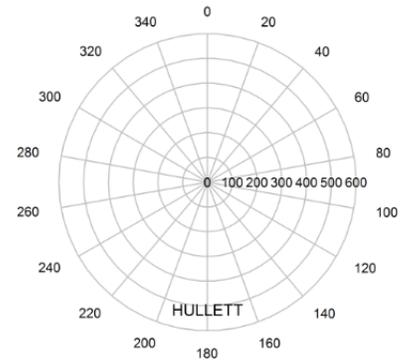
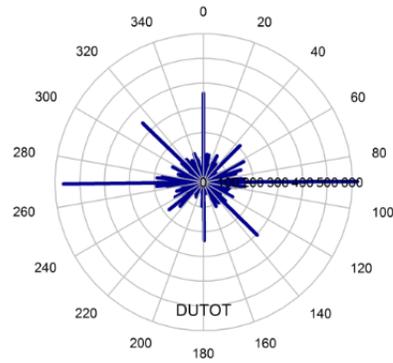
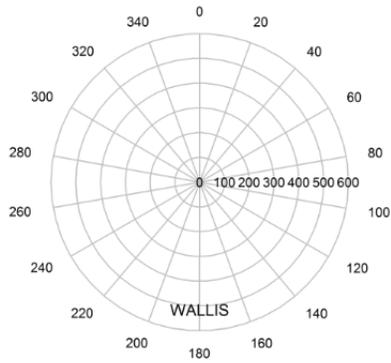




2014-04-26

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 8 ° Number of tracks = 23354
 Mean flight direction = 121 ° Number of tracks = 380

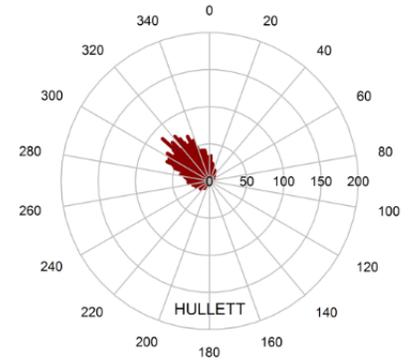
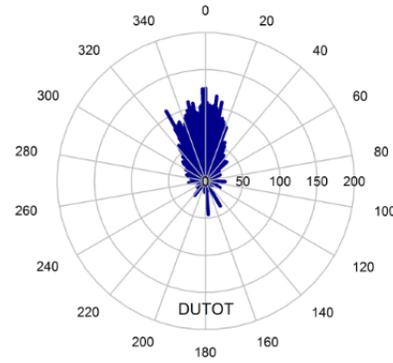
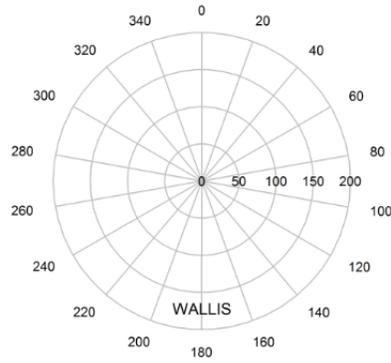
Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 288 ° Wind speed = 5.1 m/s
 Wind direction = 309 ° Wind speed = 4.6 m/s

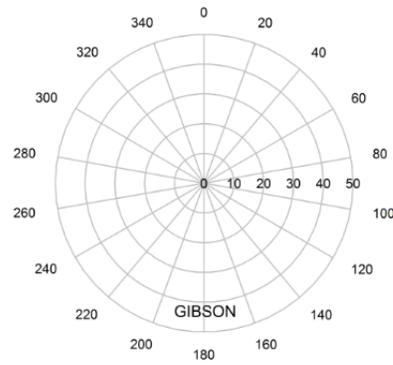
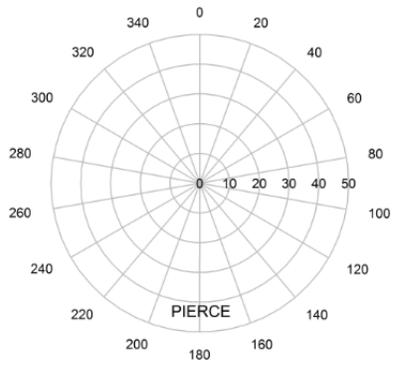


2014-04-27

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 354 ° Number of tracks = 8198
 Mean flight direction = 327 ° Number of tracks = 4080

Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 23 ° Wind speed = 5.2 m/s
 Wind direction = 16 ° Wind speed = 5 m/s

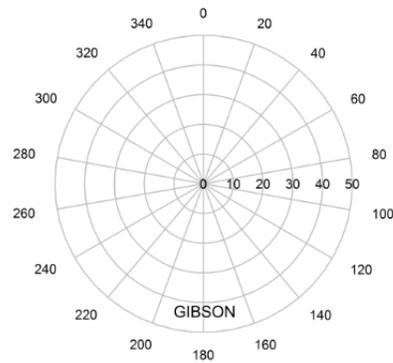
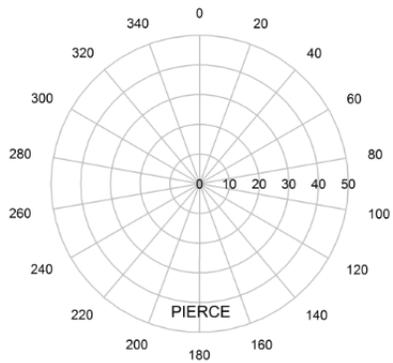
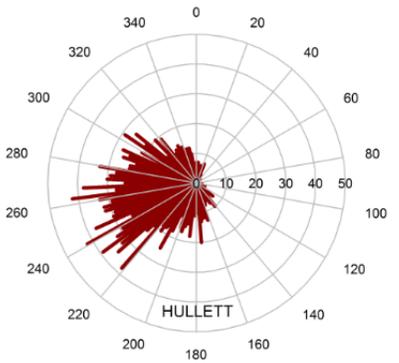
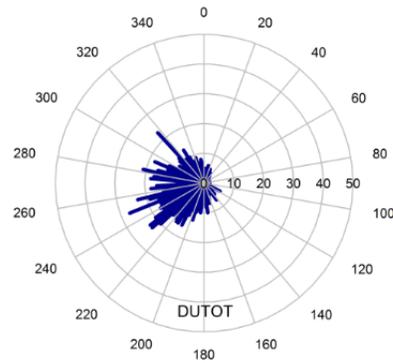
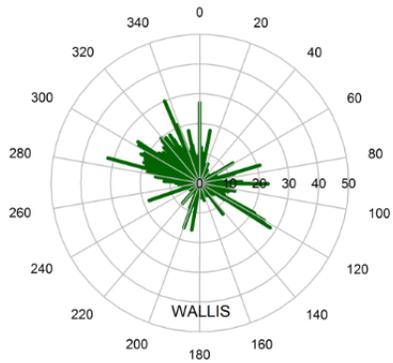




2014-04-28

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 343 ° Number of tracks = 1998
 Mean flight direction = 323 ° Number of tracks = 1021
 Mean flight direction = 318 ° Number of tracks = 1793

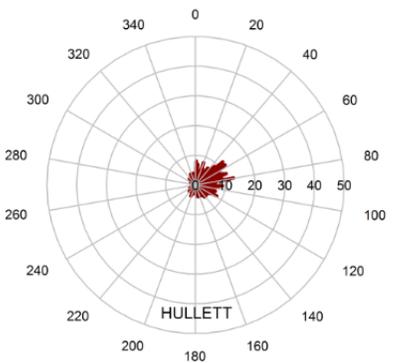
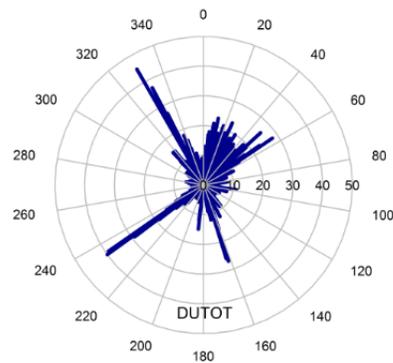
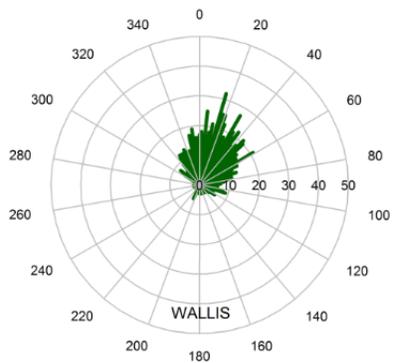
Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 62 ° Wind speed = 6.6 m/s
 Wind direction = 62 ° Wind speed = 6.5 m/s
 Wind direction = 57 ° Wind speed = 6.2 m/s

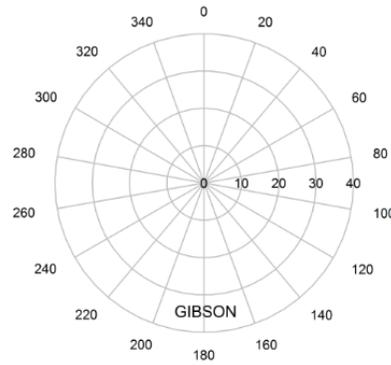
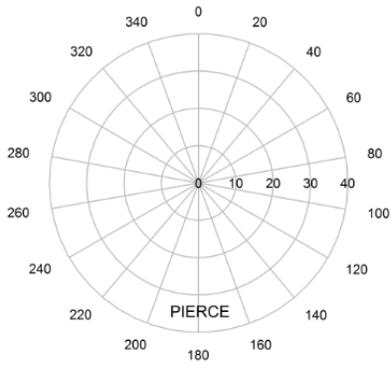


2014-04-30

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 17 ° Number of tracks = 1206
 Mean flight direction = 18 ° Number of tracks = 2523
 Mean flight direction = 41 ° Number of tracks = 569

Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 134 ° Wind speed = 6.2 m/s
 Wind direction = 133 ° Wind speed = 6.2 m/s
 Wind direction = 130 ° Wind speed = 7.2 m/s

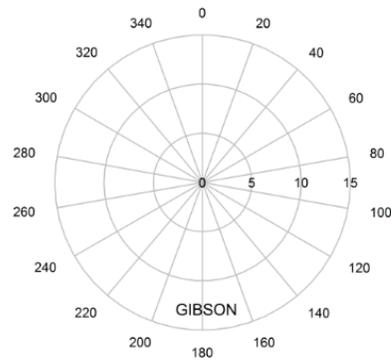
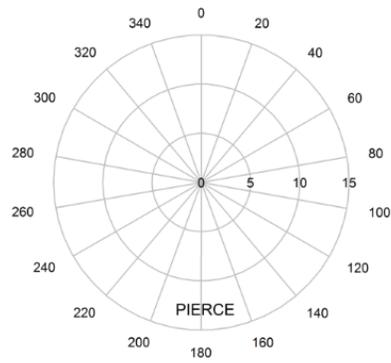
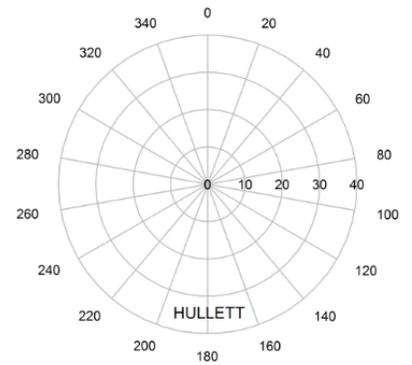
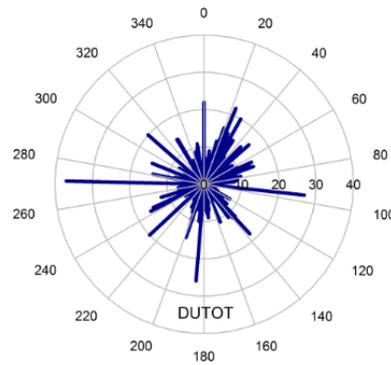
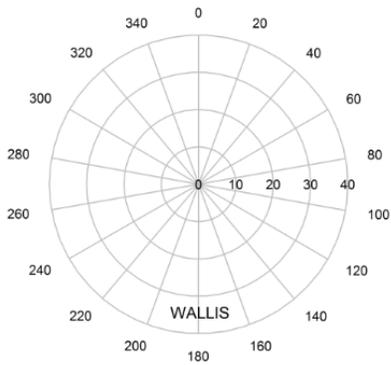




2014-05-01

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 25 ° Number of tracks = 1851
 Mean flight direction = NA Number of tracks = 0

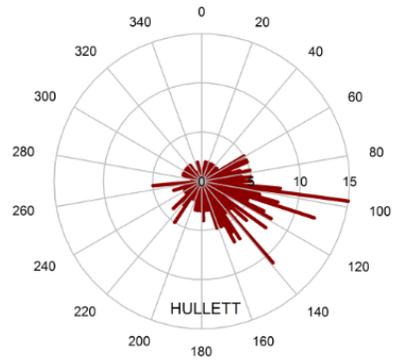
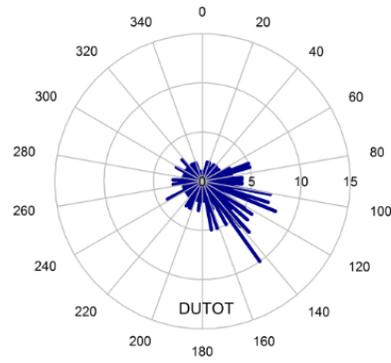
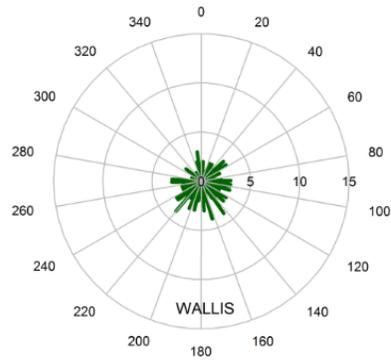
Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 200 ° Wind speed = 4 m/s
 Wind direction = NA Wind speed = NA



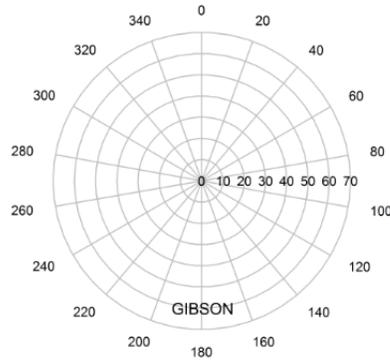
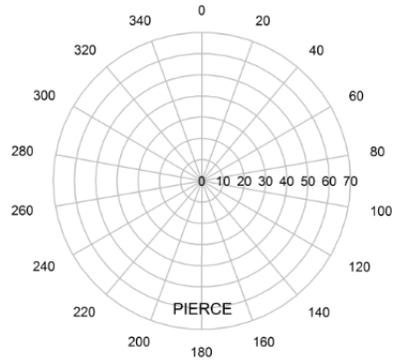
2014-05-03

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 113 ° Number of tracks = 206
 Mean flight direction = 102 ° Number of tracks = 343
 Mean flight direction = 99 ° Number of tracks = 376

Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 218 ° Wind speed = 5.8 m/s
 Wind direction = 217 ° Wind speed = 5.8 m/s
 Wind direction = 213 ° Wind speed = 5.2 m/s



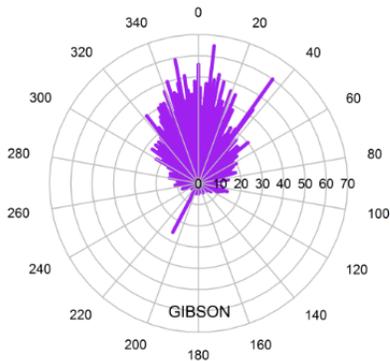
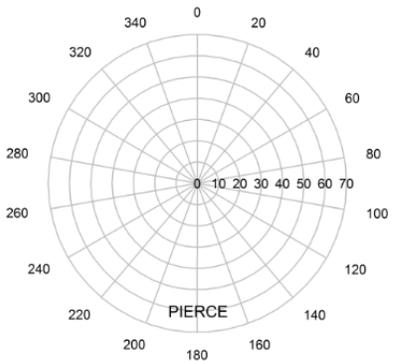
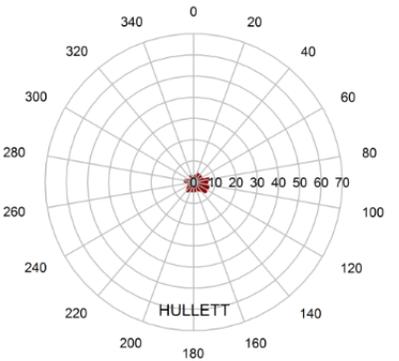
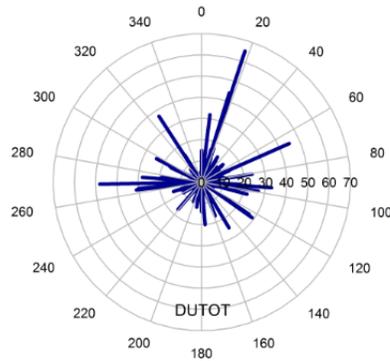
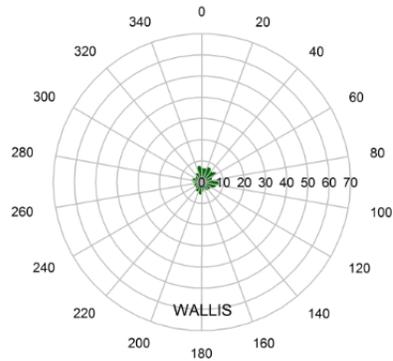
*Flight directions significantly different ($p < 0.05$)



2014-05-04

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 43° Number of tracks = 583
 Mean flight direction = 19° Number of tracks = 1918
 Mean flight direction = 91° Number of tracks = 458

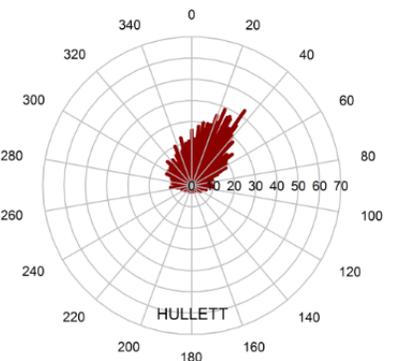
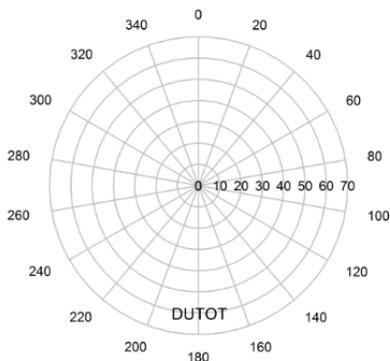
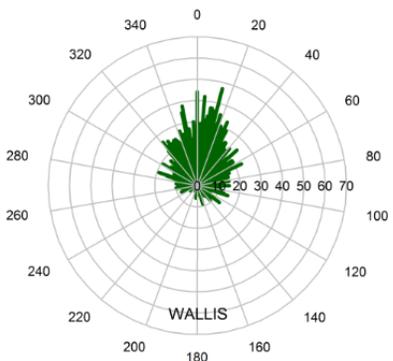
Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 279° Wind speed = 6.2 m/s
 Wind direction = 279° Wind speed = 6.3 m/s
 Wind direction = 281° Wind speed = 5.9 m/s

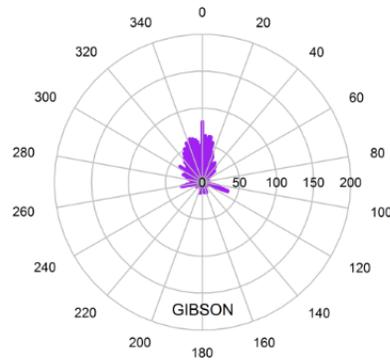
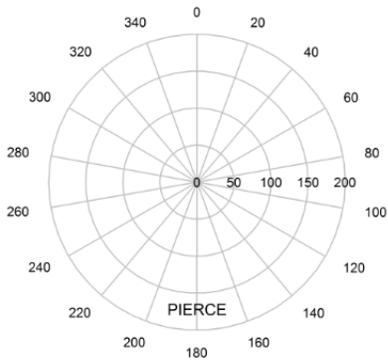


2014-05-05

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 3° Number of tracks = 4660
 Mean flight direction = 8° Number of tracks = 3138
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 10° Number of tracks = 2401

Wind direction = NA Wind speed = NA
 Wind direction = 7° Wind speed = 2.3 m/s
 Wind direction = 1° Wind speed = 2.8 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 351° Wind speed = 2.8 m/s

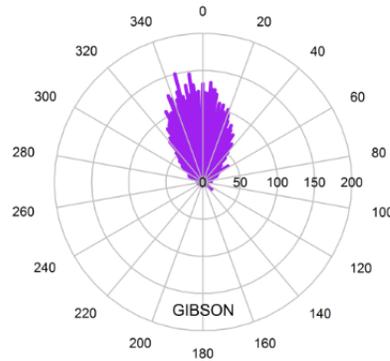
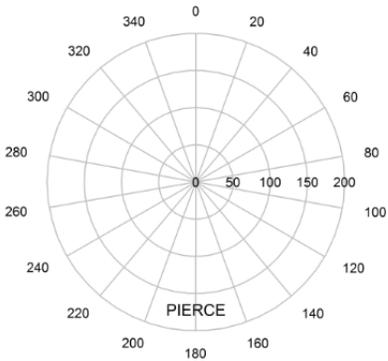
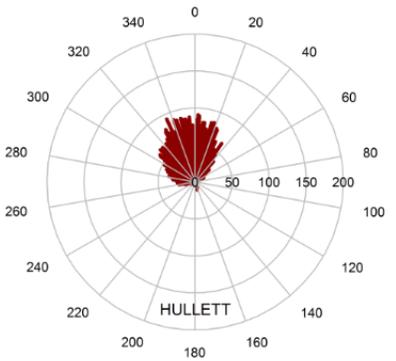
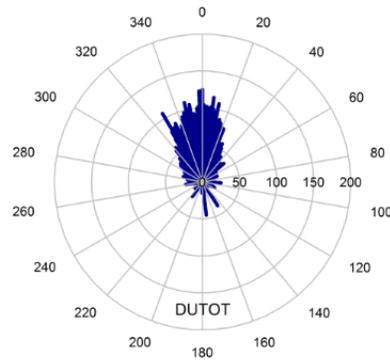
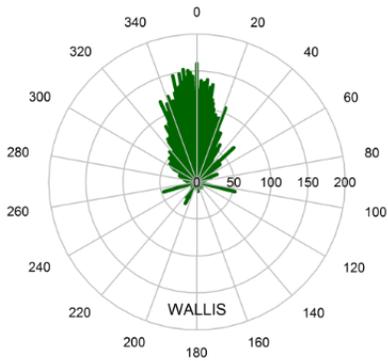




2014-05-06

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 349 ° Number of tracks = 4832
 Mean flight direction = 354 ° Number of tracks = 8576
 Mean flight direction = 354 ° Number of tracks = 8012
 Mean flight direction = 347 ° Number of tracks = 6628

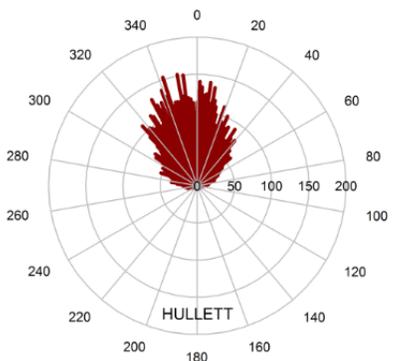
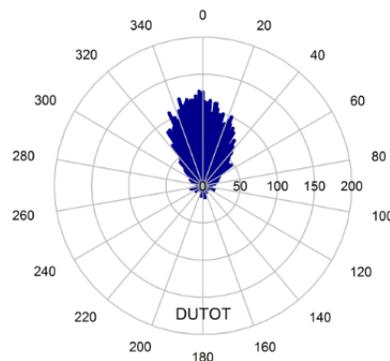
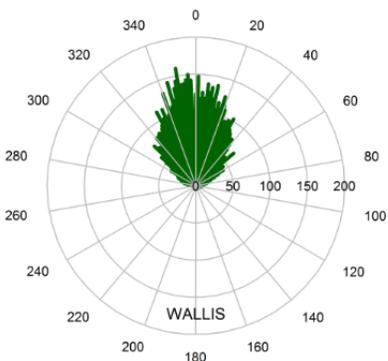
Wind direction = NA Wind speed = NA
 Wind direction = 27 ° Wind speed = 3.6 m/s
 Wind direction = 30 ° Wind speed = 3.7 m/s
 Wind direction = 29 ° Wind speed = 3.7 m/s
 Wind direction = 25 ° Wind speed = 3.6 m/s

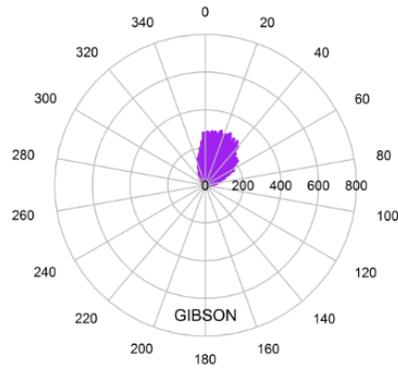
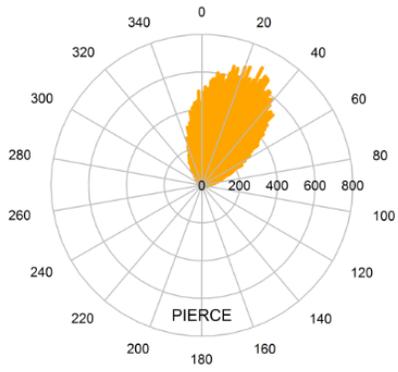


2014-05-07

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 359 ° Number of tracks = 6822
 Mean flight direction = 1 ° Number of tracks = 8382
 Mean flight direction = 3 ° Number of tracks = 8033
 Mean flight direction = 355 ° Number of tracks = 8781

Wind direction = NA Wind speed = NA
 Wind direction = 84 ° Wind speed = 5.8 m/s
 Wind direction = 86 ° Wind speed = 5.6 m/s
 Wind direction = 86 ° Wind speed = 5.6 m/s
 Wind direction = 82 ° Wind speed = 5.9 m/s

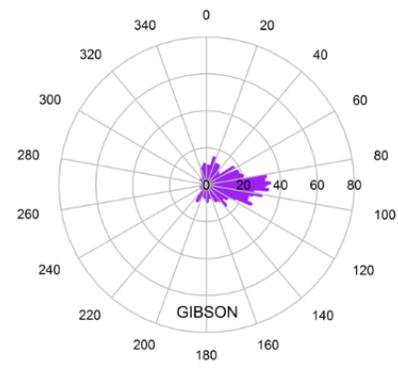
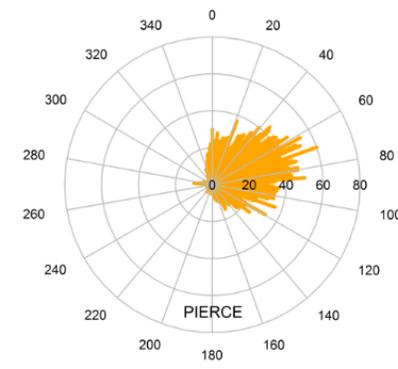
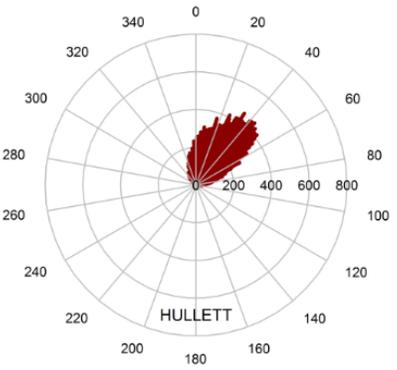
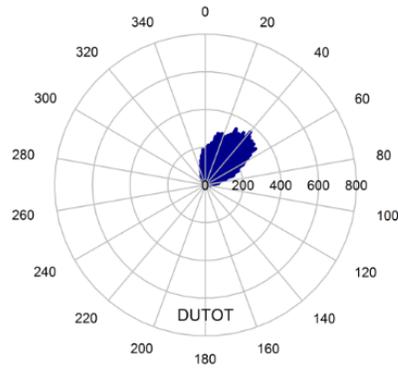
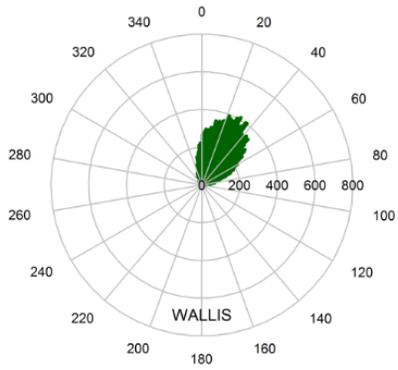




2014-05-08

Mean flight direction = 22 ° Number of tracks = 46096
 Mean flight direction = 20 ° Number of tracks = 19278
 Mean flight direction = 28 ° Number of tracks = 25323
 Mean flight direction = 31 ° Number of tracks = 22825
 Mean flight direction = 29 ° Number of tracks = 29816

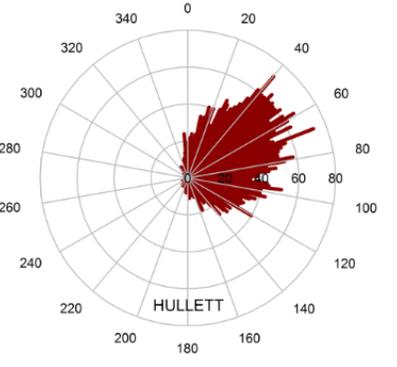
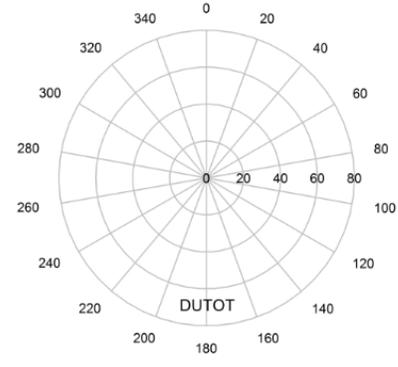
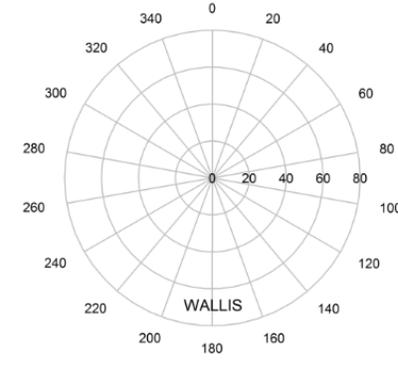
Wind direction = 103 ° Wind speed = 4.4 m/s
 Wind direction = 103 ° Wind speed = 4.3 m/s
 Wind direction = 109 ° Wind speed = 3.9 m/s
 Wind direction = 109 ° Wind speed = 3.8 m/s
 Wind direction = 98 ° Wind speed = 4.8 m/s

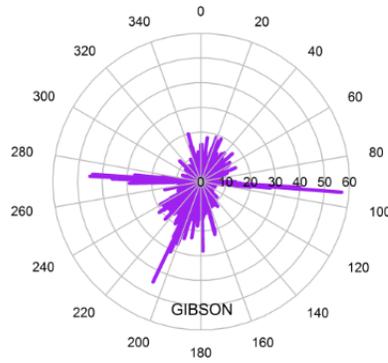
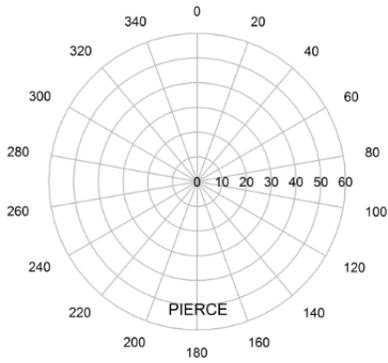


2014-05-09

Mean flight direction = 47 ° Number of tracks = 3595
 Mean flight direction = 55 ° Number of tracks = 1588
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 42 ° Number of tracks = 4014

Wind direction = 168 ° Wind speed = 6.4 m/s
 Wind direction = 168 ° Wind speed = 6.3 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 163 ° Wind speed = 6.4 m/s

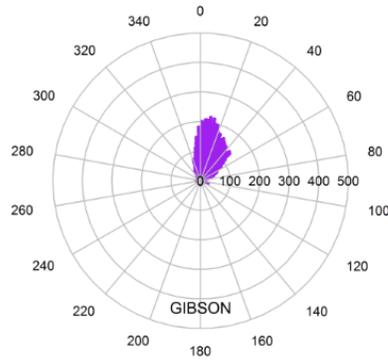
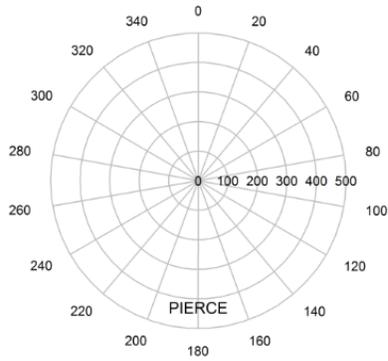
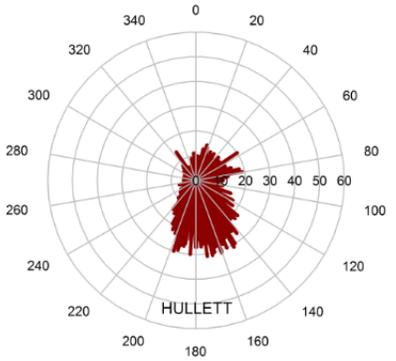
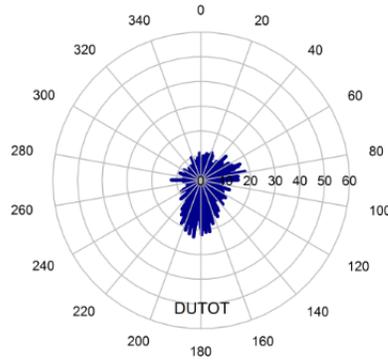
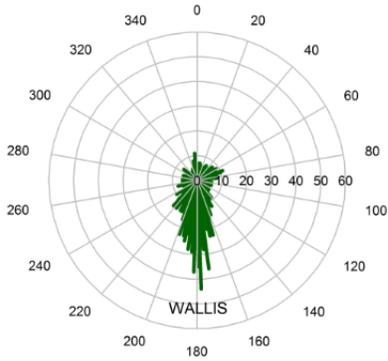




2014-05-10

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 217 ° Number of tracks = 3452
 Mean flight direction = 173 ° Number of tracks = 2137
 Mean flight direction = 148 ° Number of tracks = 2723
 Mean flight direction = 147 ° Number of tracks = 3641

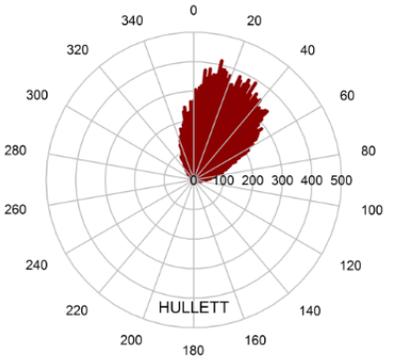
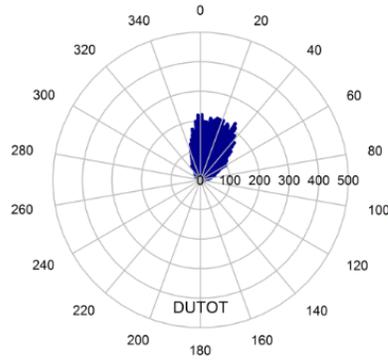
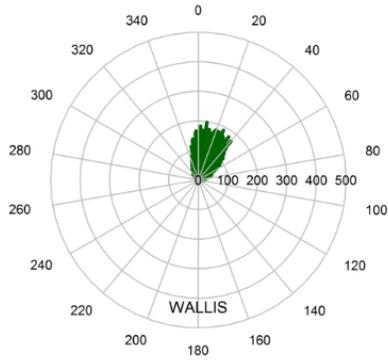
Wind direction = NA Wind speed = NA
 Wind direction = 238 ° Wind speed = 7.1 m/s
 Wind direction = 239 ° Wind speed = 6.7 m/s
 Wind direction = 239 ° Wind speed = 6.7 m/s
 Wind direction = 237 ° Wind speed = 7.5 m/s

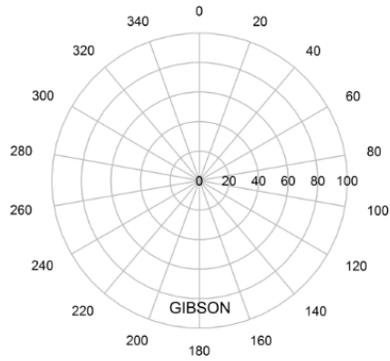
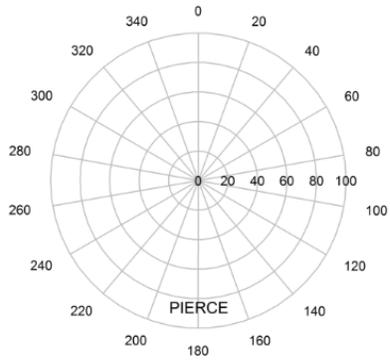


2014-05-11

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 18 ° Number of tracks = 11309
 Mean flight direction = 17 ° Number of tracks = 10955
 Mean flight direction = 17 ° Number of tracks = 13654
 Mean flight direction = 22 ° Number of tracks = 24307

Wind direction = NA Wind speed = NA
 Wind direction = 243 ° Wind speed = 2.6 m/s
 Wind direction = 234 ° Wind speed = 2.3 m/s
 Wind direction = 235 ° Wind speed = 2.3 m/s
 Wind direction = 246 ° Wind speed = 3 m/s

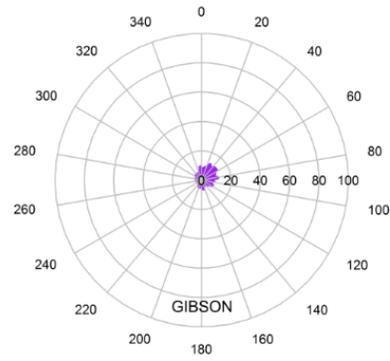
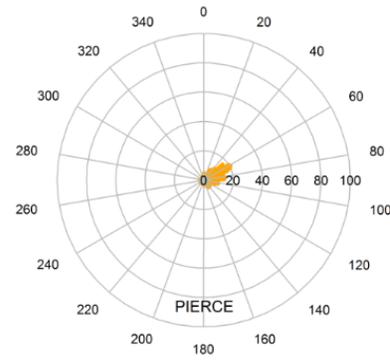
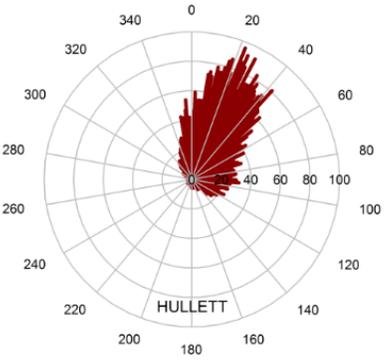
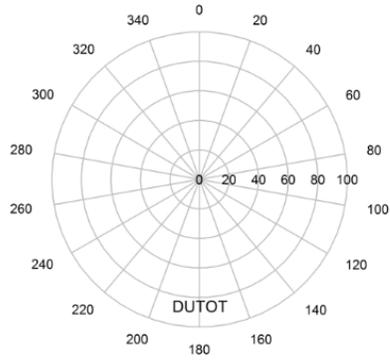
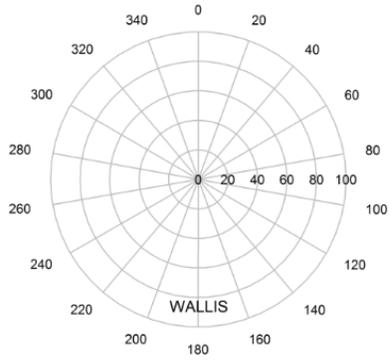




2014-05-13

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 34 ° Number of tracks = 6170

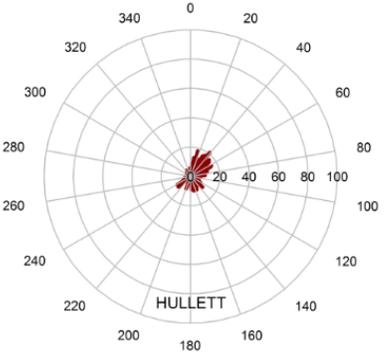
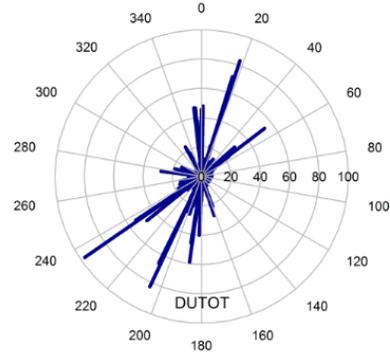
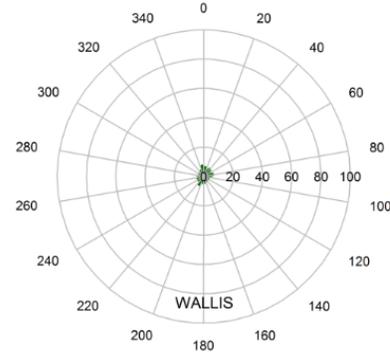
Wind direction = NA Wind speed = NA
 Wind direction = 147 ° Wind speed = 5.2 m/s

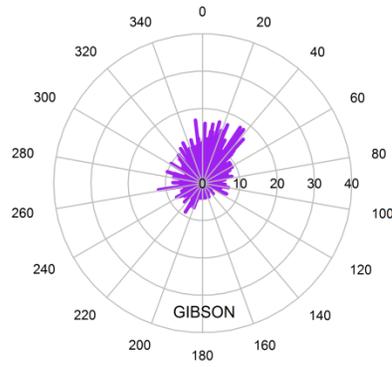
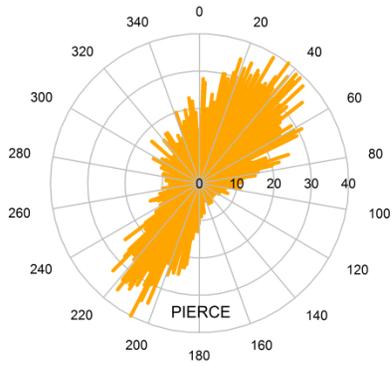


2014-05-15

Mean flight direction = 50 ° Number of tracks = 862
 Mean flight direction = 41 ° Number of tracks = 890
 Mean flight direction = 70 ° Number of tracks = 382
 Mean flight direction = 243 ° Number of tracks = 2960
 Mean flight direction = 66 ° Number of tracks = 1497

Wind direction = 97 ° Wind speed = 3 m/s
 Wind direction = 103 ° Wind speed = 3 m/s
 Wind direction = 121 ° Wind speed = 3.2 m/s
 Wind direction = 123 ° Wind speed = 3.2 m/s
 Wind direction = 81 ° Wind speed = 3 m/s

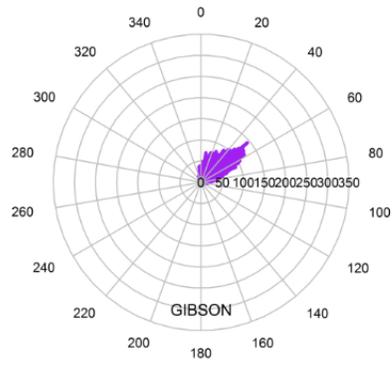
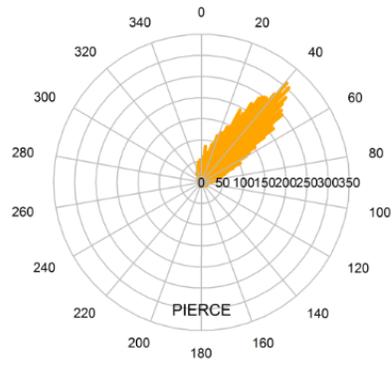
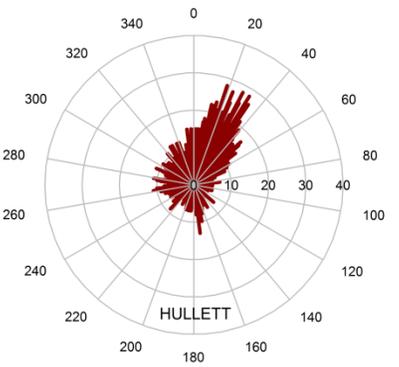
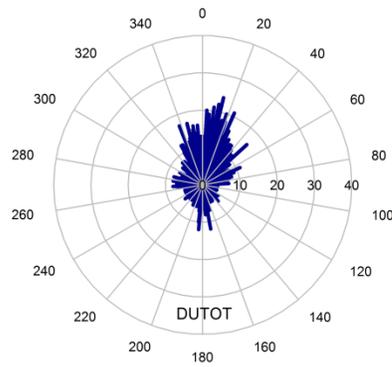
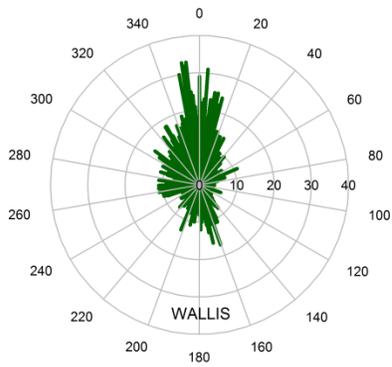




2014-05-16

Mean flight direction = 4 ° Number of tracks = 4933
 Mean flight direction = 360 ° Number of tracks = 1671
 Mean flight direction = 334 ° Number of tracks = 2601
 Mean flight direction = 3 ° Number of tracks = 2031
 Mean flight direction = 2 ° Number of tracks = 2338

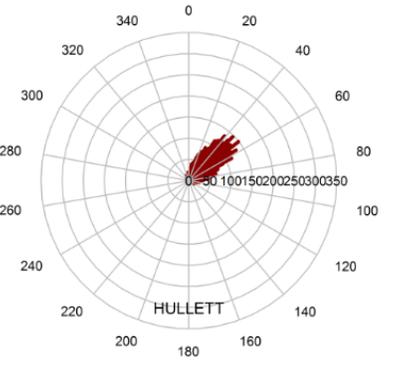
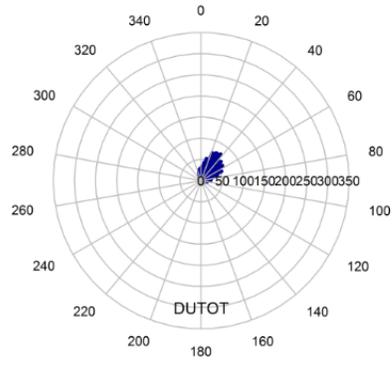
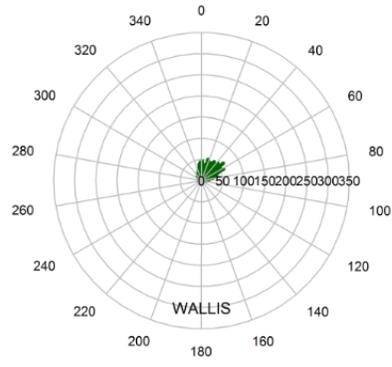
Wind direction = 264 ° Wind speed = 4.6 m/s
 Wind direction = 264 ° Wind speed = 4.6 m/s
 Wind direction = 267 ° Wind speed = 4.5 m/s
 Wind direction = 267 ° Wind speed = 4.5 m/s
 Wind direction = 260 ° Wind speed = 4.6 m/s

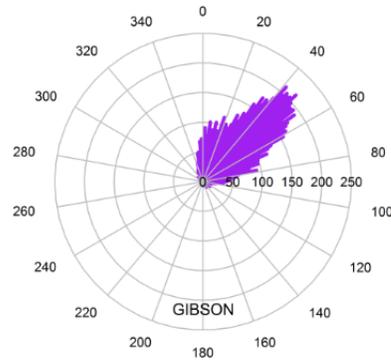
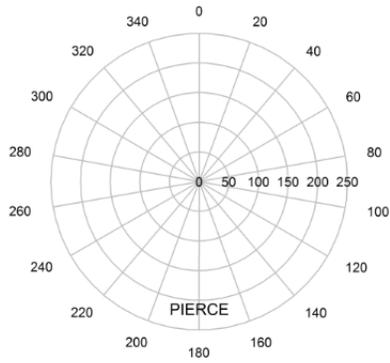


2014-05-17

Mean flight direction = 36 ° Number of tracks = 12416
 Mean flight direction = 32 ° Number of tracks = 5926
 Mean flight direction = 26 ° Number of tracks = 4013
 Mean flight direction = 32 ° Number of tracks = 4422
 Mean flight direction = 36 ° Number of tracks = 6013

Wind direction = 273 ° Wind speed = 2.8 m/s
 Wind direction = 275 ° Wind speed = 2.8 m/s
 Wind direction = 274 ° Wind speed = 2.7 m/s
 Wind direction = 275 ° Wind speed = 2.7 m/s
 Wind direction = 275 ° Wind speed = 2.9 m/s

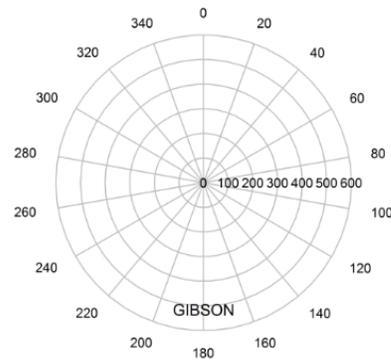
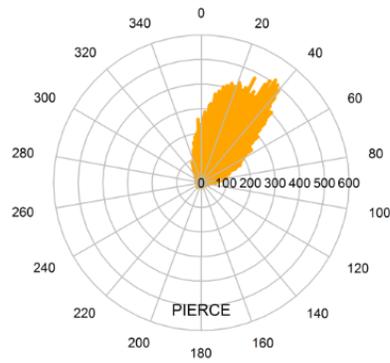
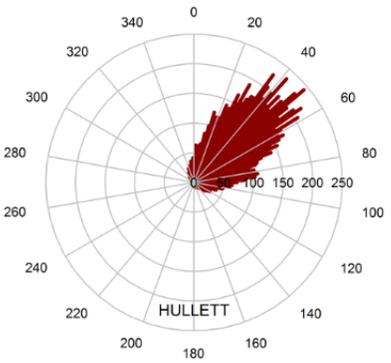
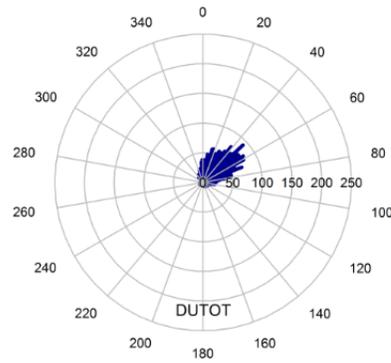
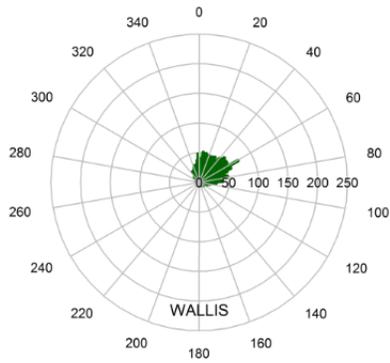




2014-05-18

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 37° Number of tracks = 10861
 Mean flight direction = 32° Number of tracks = 4216
 Mean flight direction = 39° Number of tracks = 5427
 Mean flight direction = 38° Number of tracks = 11156

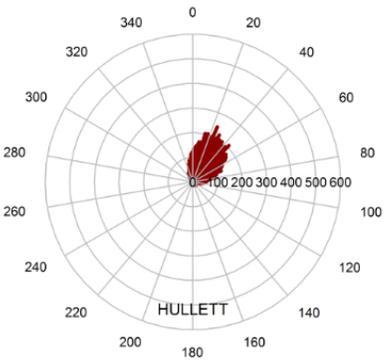
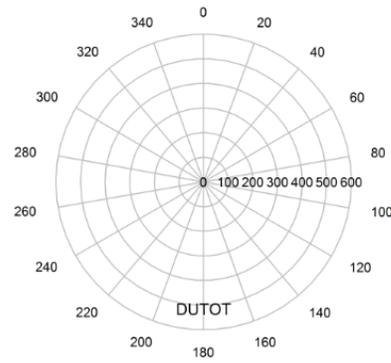
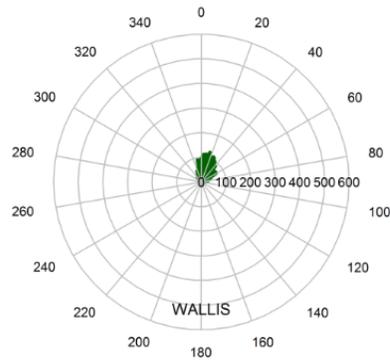
Wind direction = NA Wind speed = NA
 Wind direction = 218° Wind speed = 4.4 m/s
 Wind direction = 222° Wind speed = 4.2 m/s
 Wind direction = 222° Wind speed = 4.2 m/s
 Wind direction = 213° Wind speed = 4.6 m/s

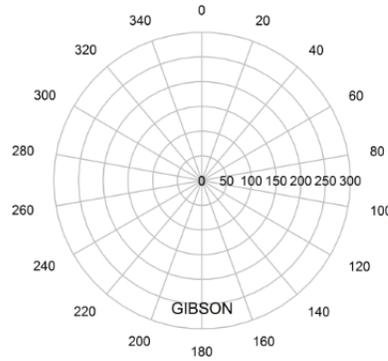
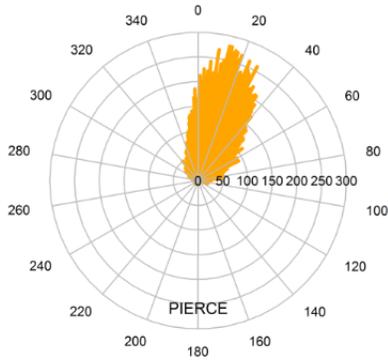


2014-05-19

Mean flight direction = 28° Number of tracks = 32985
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 22° Number of tracks = 8445
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 33° Number of tracks = 15197

Wind direction = 219° Wind speed = 3.6 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 222° Wind speed = 3.7 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 218° Wind speed = 3.4 m/s

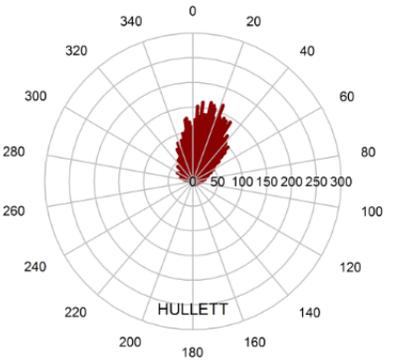
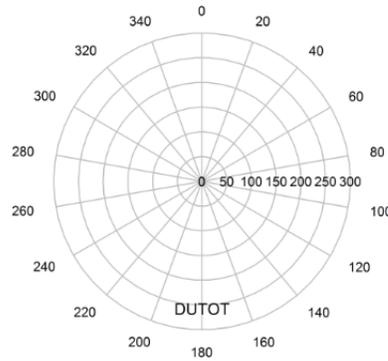
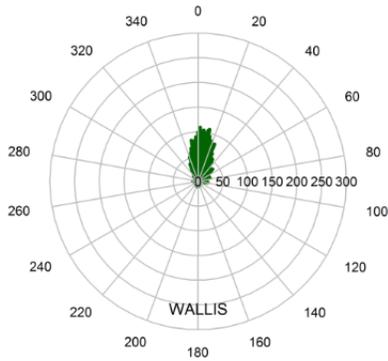




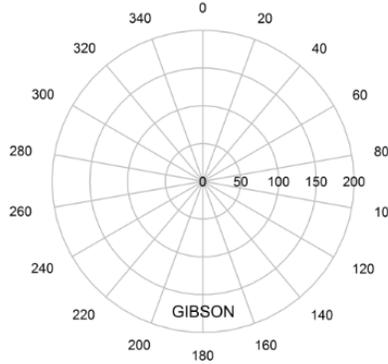
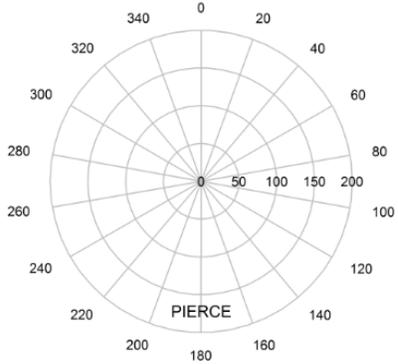
2014-05-20

Mean flight direction = 20 ° Number of tracks = 17078
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 13 ° Number of tracks = 6134
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 12 ° Number of tracks = 9747

Wind direction = 148 ° Wind speed = 4.6 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 149 ° Wind speed = 4.5 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 149 ° Wind speed = 4.5 m/s



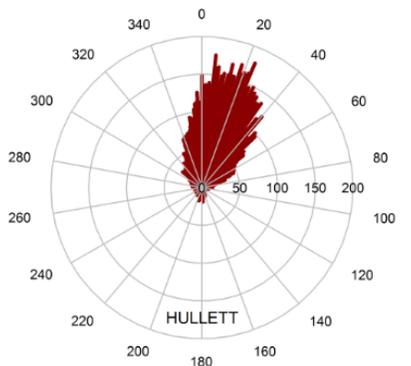
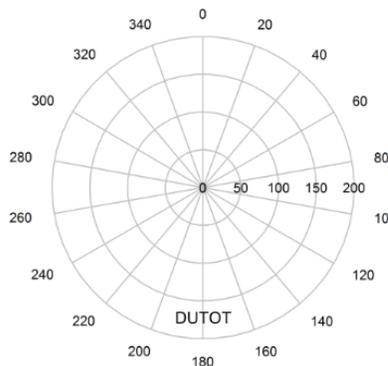
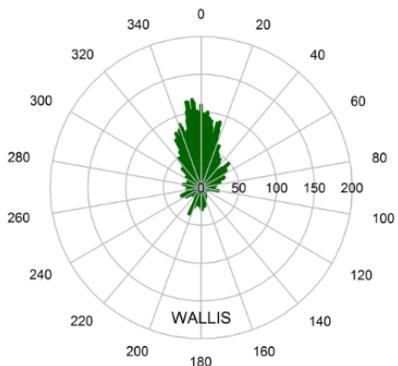
*Flight directions significantly different ($p < 0.05$)

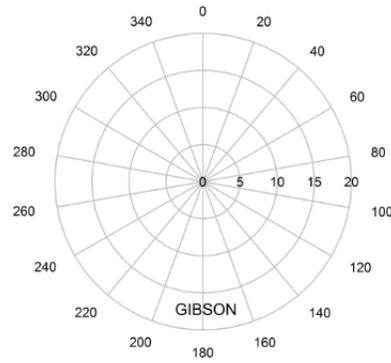
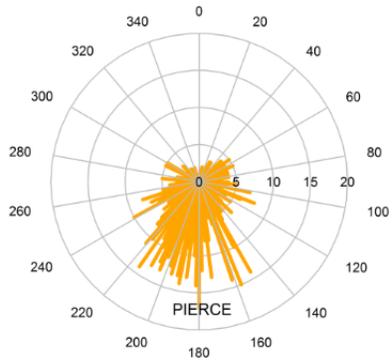


2014-05-21

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 358 ° Number of tracks = 9348
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 14 ° Number of tracks = 12016

Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 174 ° Wind speed = 2.7 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 167 ° Wind speed = 3.1 m/s

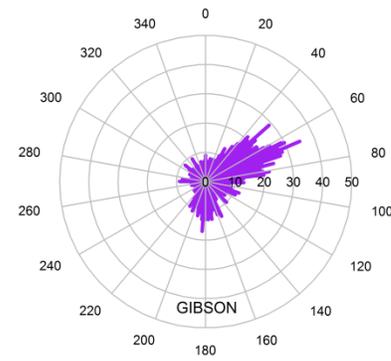
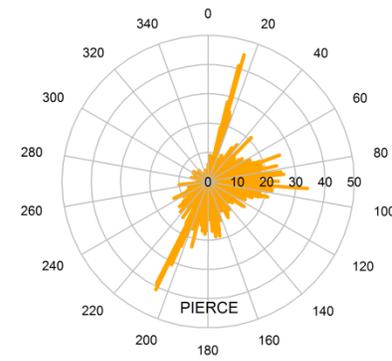
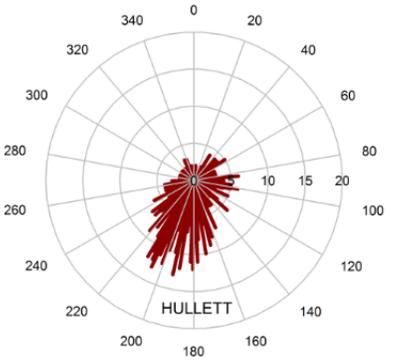
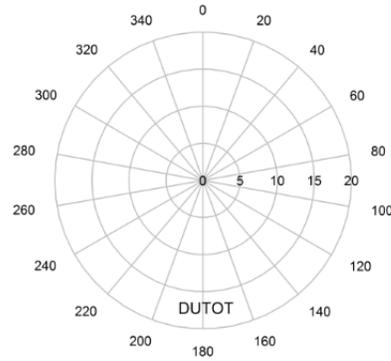
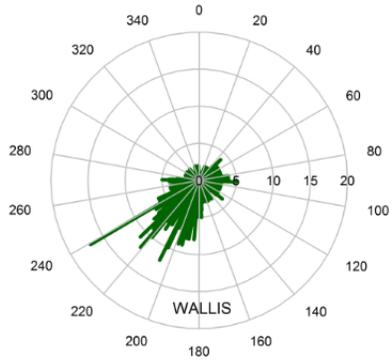




2014-05-22

Mean flight direction = 131 ° Number of tracks = 816
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 172 ° Number of tracks = 611
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 171 ° Number of tracks = 714

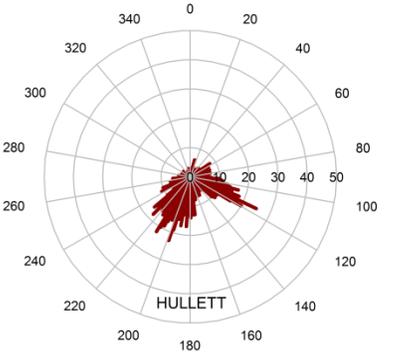
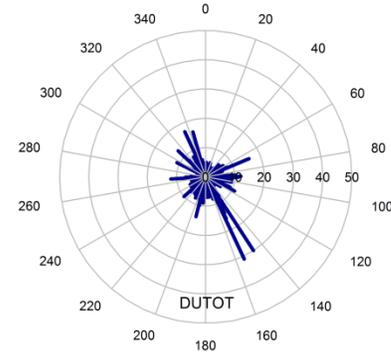
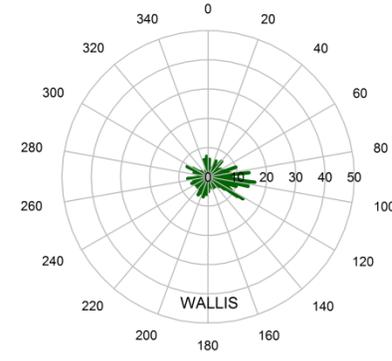
Wind direction = 292 ° Wind speed = 4 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 290 ° Wind speed = 4 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 292 ° Wind speed = 3.9 m/s

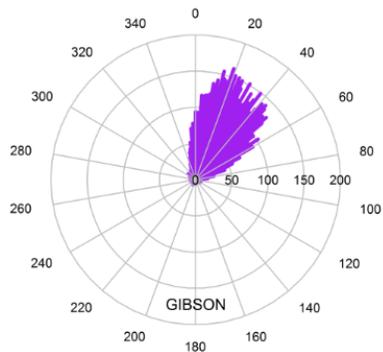
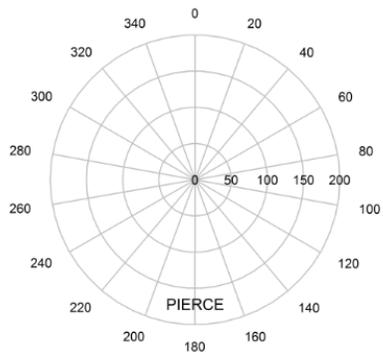


2014-05-23

Mean flight direction = 117 ° Number of tracks = 3214
 Mean flight direction = 78 ° Number of tracks = 2467
 Mean flight direction = 120 ° Number of tracks = 873
 Mean flight direction = 145 ° Number of tracks = 1274
 Mean flight direction = 148 ° Number of tracks = 1599

Wind direction = 301 ° Wind speed = 5.5 m/s
 Wind direction = 301 ° Wind speed = 5.5 m/s
 Wind direction = 300 ° Wind speed = 5.4 m/s
 Wind direction = 300 ° Wind speed = 5.4 m/s
 Wind direction = 301 ° Wind speed = 5.5 m/s

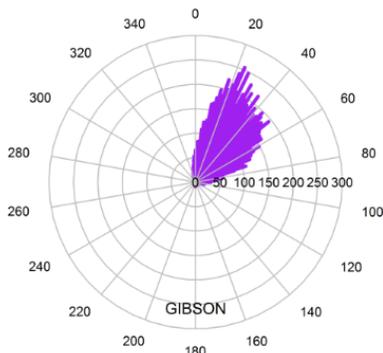
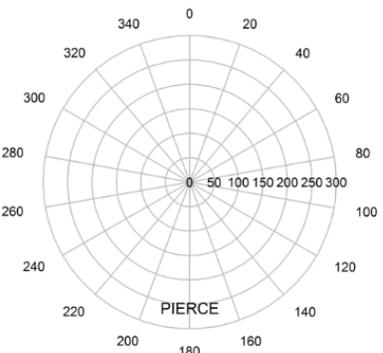
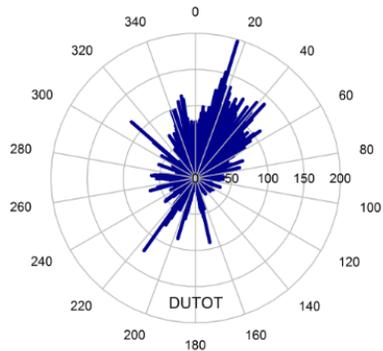
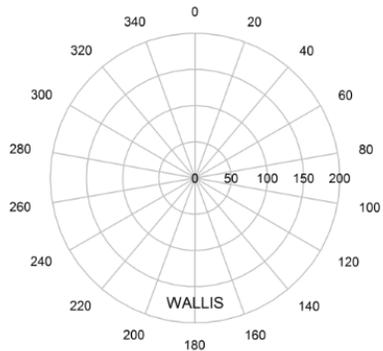




2014-05-24

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 27° Number of tracks = 9507
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 10° Number of tracks = 15083
 Mean flight direction = NA Number of tracks = 0

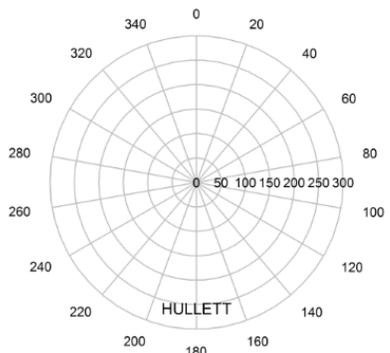
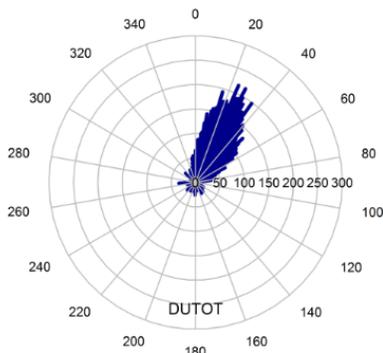
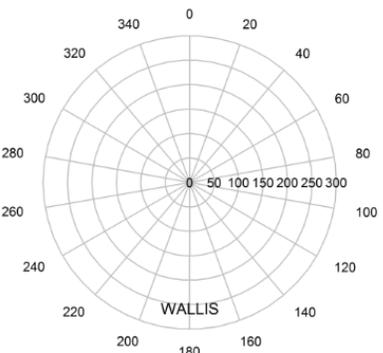
Wind direction = NA Wind speed = NA
 Wind direction = 292° Wind speed = 3.7 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 292° Wind speed = 3.7 m/s
 Wind direction = NA Wind speed = NA

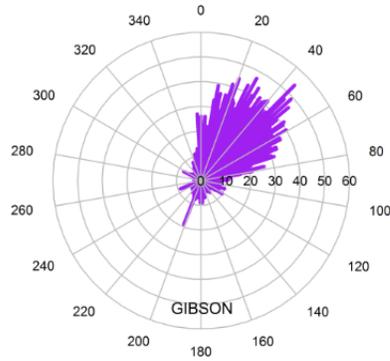
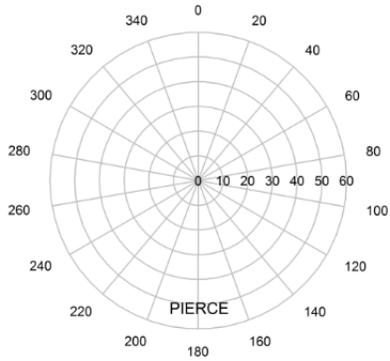


2014-05-25

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 30° Number of tracks = 10901
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 28° Number of tracks = 10801
 Mean flight direction = NA Number of tracks = 0

Wind direction = NA Wind speed = NA
 Wind direction = 269° Wind speed = 3.4 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 274° Wind speed = 3.1 m/s
 Wind direction = NA Wind speed = NA

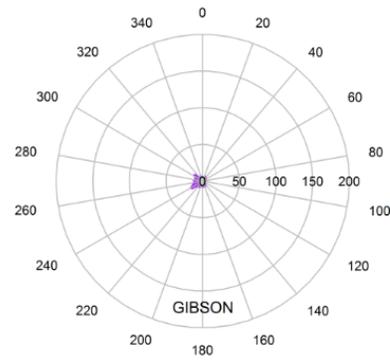
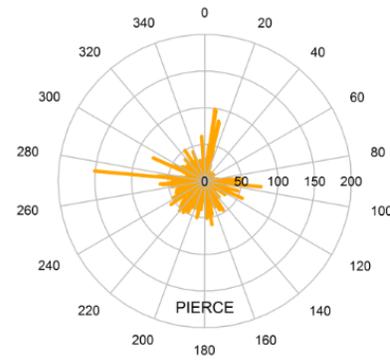
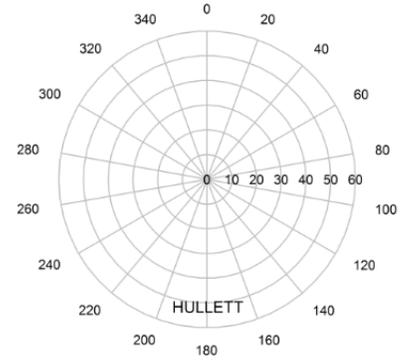
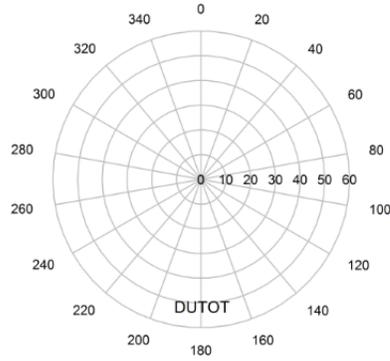
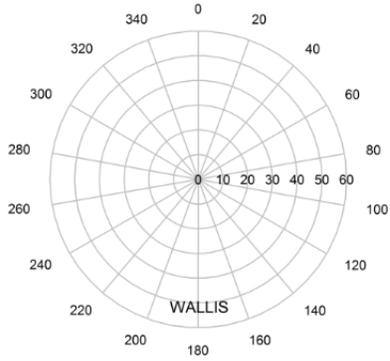




2014-05-26

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 41 ° Number of tracks = 3291
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0

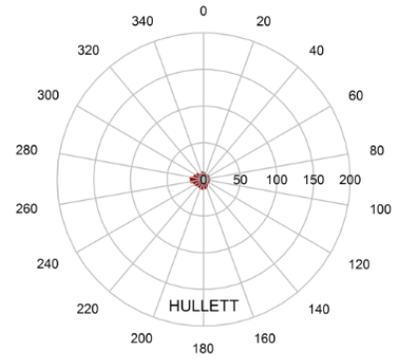
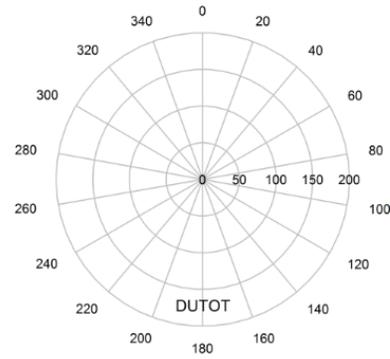
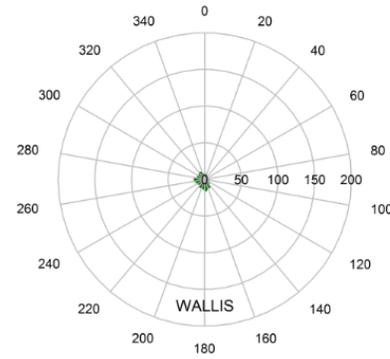
Wind direction = NA Wind speed = NA
 Wind direction = 234 ° Wind speed = 5.1 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA

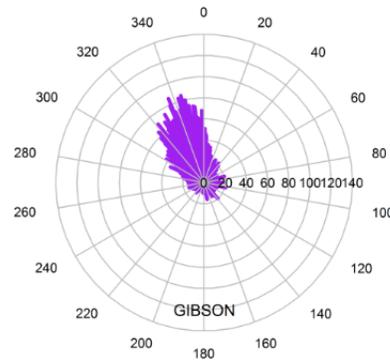
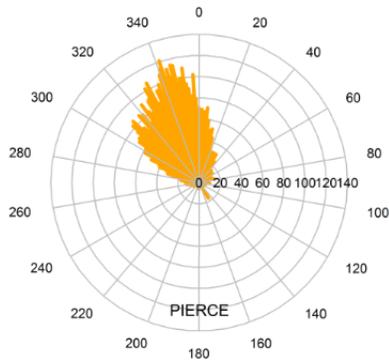


2014-05-27

Mean flight direction = 253 ° Number of tracks = 8716
 Mean flight direction = 262 ° Number of tracks = 1174
 Mean flight direction = 247 ° Number of tracks = 1324
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 242 ° Number of tracks = 1664

Wind direction = 272 ° Wind speed = 3.7 m/s
 Wind direction = 271 ° Wind speed = 3.8 m/s
 Wind direction = 266 ° Wind speed = 4 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 276 ° Wind speed = 3.5 m/s

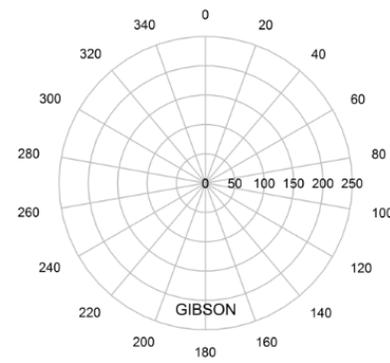
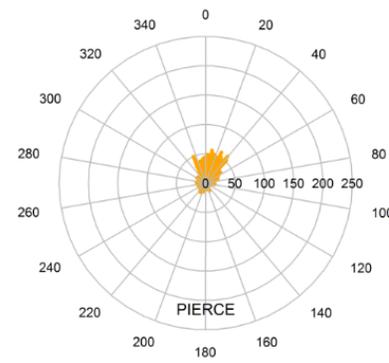
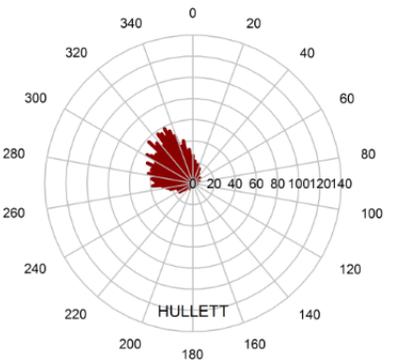
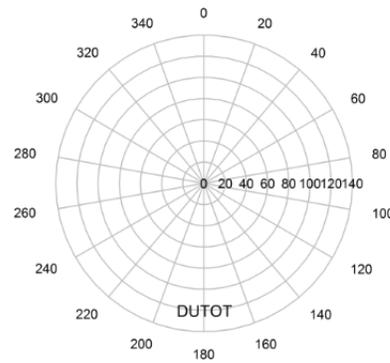
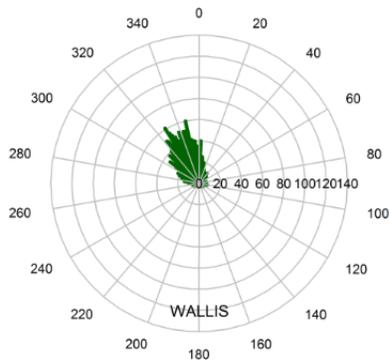




2014-05-28

Mean flight direction = 340 ° Number of tracks = 7669
 Mean flight direction = 341 ° Number of tracks = 6686
 Mean flight direction = 341 ° Number of tracks = 3280
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 333 ° Number of tracks = 3137

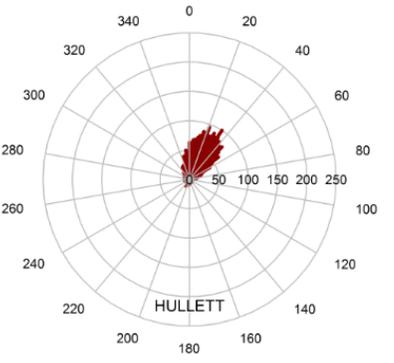
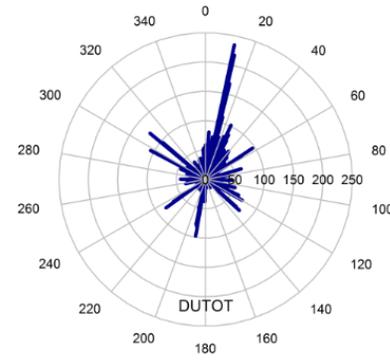
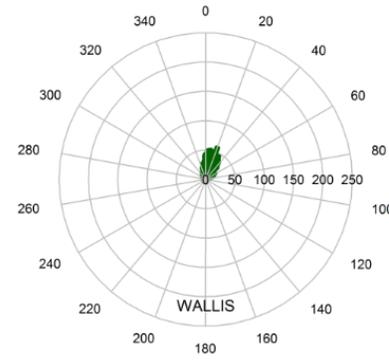
Wind direction = 27 ° Wind speed = 3.5 m/s
 Wind direction = 27 ° Wind speed = 3.4 m/s
 Wind direction = 19 ° Wind speed = 3 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 34 ° Wind speed = 3.9 m/s

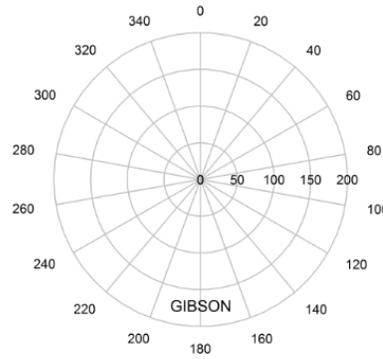
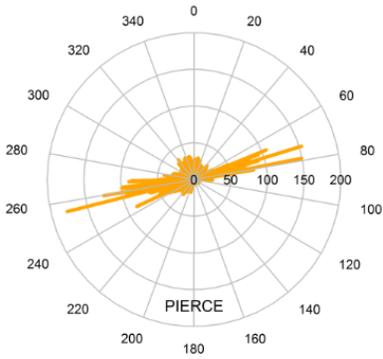


2014-05-29

Mean flight direction = 10 ° Number of tracks = 5401
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 11 ° Number of tracks = 3058
 Mean flight direction = 17 ° Number of tracks = 8717
 Mean flight direction = 19 ° Number of tracks = 5996

Wind direction = 65 ° Wind speed = 2.3 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 59 ° Wind speed = 2.3 m/s
 Wind direction = 59 ° Wind speed = 2.3 m/s
 Wind direction = 71 ° Wind speed = 2.2 m/s

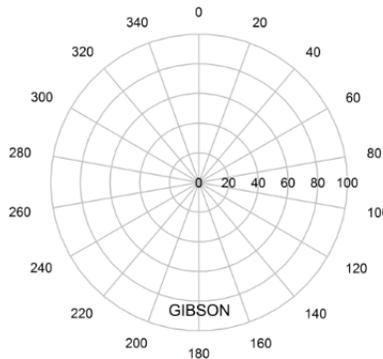
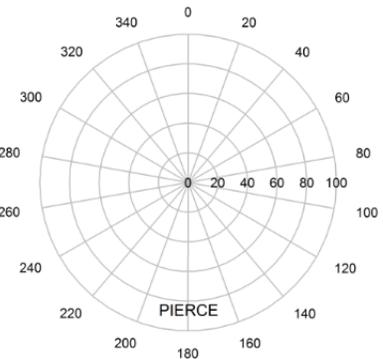
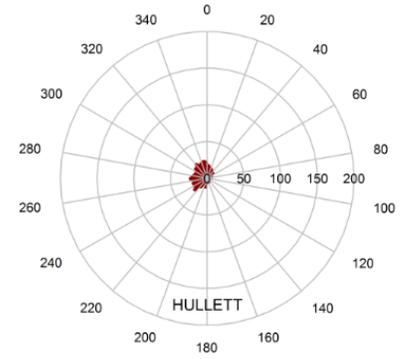
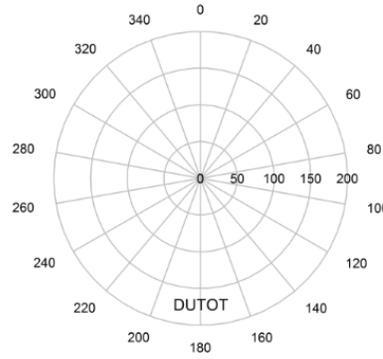
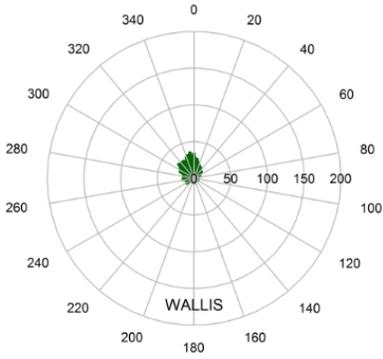




2014-05-30

Mean flight direction = 310 ° Number of tracks = 7534
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 341 ° Number of tracks = 2655
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 311 ° Number of tracks = 2495

Wind direction = 28 ° Wind speed = 2.2 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 24 ° Wind speed = 2.1 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 28 ° Wind speed = 2.2 m/s



2014-05-31

Mean flight direction = NA Number of tracks = 0
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 2 ° Number of tracks = 4321
 Mean flight direction = NA Number of tracks = 0
 Mean flight direction = 348 ° Number of tracks = 5917

Wind direction = NA Wind speed = NA
 Wind direction = NA Wind speed = NA
 Wind direction = 75 ° Wind speed = 2.7 m/s
 Wind direction = NA Wind speed = NA
 Wind direction = 95 ° Wind speed = 2.6 m/s

