STSM Report

The effects of atmospheric conditions on the flight of soaring migrants in Italy recorded by radar

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INTRODUCTION

This is a report for a Short Term Scientific Mission (STSM) in the COST Action ES1305 (European Network for the Radar surveillance of Animal Movement, ENRAM), under working group 4: Significance and Potential of Animal Movement Research.

Host institution: Department of Evolutionary and Environmental Biology at the University of Haifa (Haifa, IL) hosted by Dr. Nir Sapir;

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Purpose: This STSM combined a radar study on bird raptor tracks (mainly Honey Buzzards and Marsh Harriers) recorded by an x-band radar located on the Strait of Messina (Italy) during the 2014 spring with atmospheric data. During this scientific mission I examined how specific meteorological parameters (e.g. wind direction and speed) affect bird flight parameters, namely (i) daily radar tracks density (number of birds), (ii) daily bird gliding speed. Data from two radar stations (Calabria and Sicily) located in two sides of the Strait of Messina were included in this analysis. This STSM was crucial for understanding the effects of atmospheric conditions on the flight of soaring migrants in a migratory bottleneck (the Strait of Messina) while crossing an ecological barrier (the Mediterranean Sea).

MATERIALS & METHODS

The scientific association *Ornis italica* (Rome, Italy) provided the raw data of radar tracks gathered during spring 2014 (09/04-20/05) in two radar stations located in either side and close by to the Strait of Messina, the first in Calabria (Aspromonte mountain, Reggio Calabria) and the second in Sicily (Serro, Messina). These radars collected data as radar echoes that went further processing for extracting the bird tracks. Bird track data included geographic coordinates, time and date. I processed the raw dataset of the Sicily radar station in QGis Desktop 2.8.0 (QGIS Development Team 2015) calculating length, mean direction and mean speed of each bird track. Dr Viviana Stanzione provided the dataset with all track parameters of the Calabria radar station that went through identical processing.

I ran descriptive circular analysis on direction of the Calabrian and Sicilian radar tracks to determine mean bird directions (Fig. 1, 2, 3).

I compared daily means of bird speed and track numbers of the two radar stations with specific meteorological parameters (Table 1) gathered by three weather stations: two of the stations were set close to each radar station in Calabria and Sicily and the other one was the weather station of the Reggio Calabria airport placed in the middle of the Strait of Messina (http://www.wunderground.com/). I transformed wind data (direction and intensity) into two biologically meaningful variables, tailwind assistance (TWA) and crosswind (CRW). TWA and CRW were calculated by the following formulas:

$$TWA = V_W \cdot \cos((\theta_W + 180°) - \theta_b), \quad (1)$$

$$CRW = V_W \cdot \cos((\theta_W + 90°) - \theta_b), \quad (2)$$

where V_W is the measured wind velocity in meter per second, θ_W is wind direction (i.e., the direction from where the wind was blowing) in degrees, and θ_b is the preferred direction of the birds. TWA is simply the tailwind component of wind velocity in meter per second or the wind assistance vector at the presumably preferred direction of the bird, with positive and negative values indicating tailwinds and headwinds, respectively (Sapir *et al*. 2011). CRW is the sideway component of wind velocity in meter per second or the wind vector perpendicular to the preferred direction of the bird, with positive and negative values indicating crosswinds coming from the right and the left of the birds, respectively.

RESPONSE VARIABLES	EXPLANATORY VARIABLES				
Daily n°TRACKS in Calabria (log)	Temperature (°C)	Pressure (hPa)	Humidity (%)	Crosswind (CRW)	Tailwind assistance (TWA)
Daily n°TRACKS in Sicily (log)					
Daily bird SPEED in Calabria (m/s)					
Daily bird SPEED in Sicily (m/s)					

Tab.1 - Variables used for statistical analysis

For statistical analysis I used linear models testing the effects of the explanatory variables on the response variables and circular analysis for the direction of birds. The daily number of tracks in Calabria and Sicily were transformed with natural logarithmic function. The best models were chosen manually removing explanatory variables to the current full models (i.e. SPEED ~ Temperature + Pressure + Humidity + CRW + TWA) obtaining the model with the greatest R^2. I ran 12 models crossing each response variable with the explanatory variables of the three weather stations (Calabria, Sicily and Strait of Messina), removing the variables which decrease the R^2, as explained above. I ran all the analysis using R 3.2 (R Core Team 2014) and its package *circular* for circular analysis.

RESULTS & DISCUSSION

The number of track considered for daily analysis was 14533 for 30 days in Calabria and 1958 for 14 days in Sicily. Simultaneous data from the two radar stations were recorded only during the period between 30/04/2014 and 20/05/2014, the radars did not work every day because sometimes there were bad weather conditions.

The mean direction of the radar tracks (average vector) in Calabria and in Sicily was μ= 42.40° (~ North-East), with *r* as the length of mean vector (Fig. 3; Rayleigh's test: r = 0.8201, P < 0.001). The average vector for Calabria's birds was μ= 39.81° (Fig. 2; Rayleigh's test: N = 32, r = 0.8966, P < 0.001) and for Sicily's birds was μ= 78.17° (Fig. 1; Rayleigh's test: N = 13, r = 0.8059, P < 0.001).

Radar tracks

In the Model 1 (best model: n° TRACKS Calabria (log) ~ CRW + TWA; R^2 = 0.574) I analyzed the relationships between the number of tracks in Calabria and the explanatory variables (CRW and TWA in Calabria).

Best model	CALABRIA	Temperature (°C)			Pressure (hPa)			Humidity (%)			CRW			TWA			R-squared
		Estimate	*t-value*	*p-value*	*Estimate*	*t-value*	*p-value*	*Estimate*	*t-value*	*p-value*	*Estimate*	*t-value*	*p-value*	*Estimate*	*t-value*	*p-value*	
Model 1	n° TRACKS Calabria (log)										0.571	5.061	0.000	-0.353	-3.235	0.003	0.574
Model 2	n° TRACKS Sicily (log)	-0.195	-4.005	0.007	0.032	1.422	0.205	-0.028	-2.292	0.062	-0.767	-4.717	0.003	0.203	2.025	0.089	0.755
Model 3	Bird speed Calabria	-0.133	-3.000	0.006				-0.019	-2.469	0.020				0.621	4.824	0.000	0.524
Model 4	Bird speed Sicily	-0.216	-2.707	0.022													0.365

Best model	SICILY	Temperature (°C)			Pressure (hPa)			Humidity (%)			CRW			TWA			R-squared
		Estimate	*t-value*	*p-value*	*Estimate*	*t-value*	*p-value*	*Estimate*	*t-value*	*p-value*	*Estimate*	*t-value*	*p-value*	*Estimate*	*t-value*	*p-value*	
Model 5	n° TRACKS Calabria (log)				0.038	2.368	0.050				0.392	4.673	0.002				0.695
Model 6	n° TRACKS Sicily (log)																
Model 7	Bird speed Calabria	0.092	1.064	0.323	0.018	0.866	0.415				0.256	2.216	0.062	0.441	1.583	0.157	0.394
Model 8	Bird speed Sicily							0.055	2.801	0.019				0.678	2.003	0.073	0.336

Best model	STRAIT OF MESSINA	Temperature (°C)			Pressure (hPa)			Humidity (%)			CRW			TWA			R-squared
		Estimate	*t-value*	*p-value*	*Estimate*	*t-value*	*p-value*	*Estimate*	*t-value*	*p-value*	*Estimate*	*t-value*	*p-value*	*Estimate*	*t-value*	*p-value*	
Model 9	n° TRACKS Calabria (log)										0.210	4.741	0.000				0.434
Model 10	n° TRACKS Sicily (log)				0.059	2.780	0.024	0.017	1.813	0.107	0.296	1.454	0.184	0.221	1.688	0.130	0.464
Model 11	Bird speed Calabria	-0.118	-1.295	0.208	-0.069	-2.038	0.053	-0.028	-1.613	0.120	-0.478	-2.099	0.047	-0.198	-1.318	0.200	0.278
Model 12	Bird speed Sicily	-0.266	-2.809	0.017													0.365

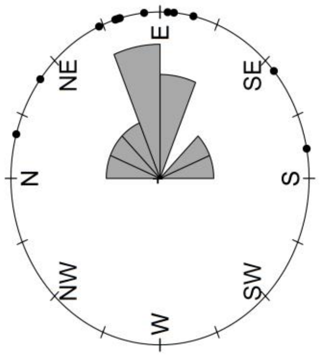


Fig.1 - Rose diagram of bird directions in Sicily

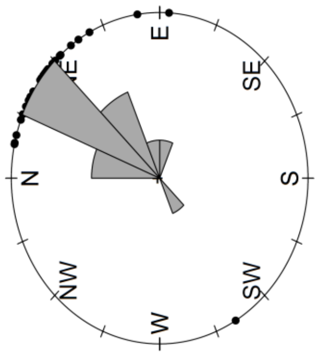


Fig.2 - Rose diagram of bird directions in Calabria

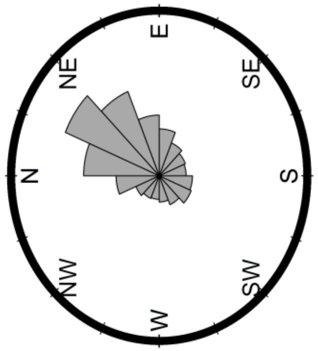


Fig.3 - Rose diagram of mean bird directions among Calabria and Sicily

Tab. 2 - Resuming table with the best model results in the three weather stations.

The number of Calabrian tracks is positively related to the CRW, right-side crosswinds (from left to right side of the mean bird direction) increase the number of migrating birds ($t = 5.061$, $P < 0.001$; Tab. 2; Fig. 4). On the contrary, the TWA is negatively related to the number of birds detected by the radar in the Calabria station ($t = -3.235$, $P < 0.01$; Tab. 2; Fig. 5). This negative relationship is surprising and warrants explanation (see below). The relationship with the CRW probably confirms that many raptors prefer flying with side-winds which support soaring and gliding flight to cover long distances (Agostini *et al*. 2015).

In the Model 2 (best model: n° TRACKS Sicily (log) ~ Temperature + Pressure + Humidity + CRW + TWA; $R^2 = 0.755$) the number of tracks in Sicily are negatively related to the temperature ($t = -4.005$, $P < 0.01$) and CRW (Fig. 6; $t = -4.717$, $P < 0.01$) in Calabria (Tab. 2). The TWA, pressure and humidity have no significant effect on the bird's passage in Sicily. The result concerning the relationship with meteorological variables in Calabria and the bird's movement in Sicily is hard to explain, because during the spring migration the birds move from Sicily to Calabria. Anyway, it seems that right-side crosswinds and high temperature in Calabria negatively affect the number of birds in Sicily.

In the Model 5 (best model: n° TRACKS Calabria (log) ~ Pressure + CRW; $R^2 = 0.695$) the number of tracks in Calabria are positively related to the pressure ($t = 2.368$, $P = 0.05$) and the CRW (Fig. 7; $t = 4.673$, $P < 0.01$) in Sicily (Tab. 2). The latter increase the passage in Calabria because, as explained above, probably the raptor birds migrate when crosswinds are blowing.

The Model 6 is the only linear model that was impossible to run, because there were many missing values.

The last two models concern the interactions between number of tracks in Calabria (Model 9) and Sicily (Model 10), and meteorological variables in the middle of the Strait of Messina. The Model 9 (best model: n° TRACKS Calabria (log) ~ CRW; $R^2 = 0.434$) underline the positive relationships between the number of tracks and the CRW (Fig. 8; $t = 4.741$, $P < 0.001$), and this result is consistent with the positive CRW influence on the numbers of Calabrian tracks in the others two places (Model 1, Model 5). In the Model 10 (best model: n° TRACKS Sicily (log) ~ Pressure + Humidity + CRW + TWA; $R^2 = 0.464$) the only significant related variable is the pressure ($t = 2.780$; $P < 0.05$), whereas the other variables have no effect on the number of Sicilian birds. Tailwinds and crosswinds do not affect Sicilian bird passage (Fig. 9, Fig. 10), this is probably due to the Peloritani Mountains, a geographical barrier located between the Strait of Messina and the Sicilian radar station.

The most important factor affecting the number of tracks in Calabria it seems to be the crosswinds from every station. On the contrary, for the Sicily side it is difficult to estimate the main factor affecting the intensity of bird passage. Probably with finer analysis I will able to find out other factors with an important role in bird migration over the Strait of Messina.

Bird speeds

In the next models I analyzed the relationships between the meteorological variables in the three weather stations considered and the track speeds in Calabria and Sicily. In the Model 3 (best model: Bird speed Calabria ~ Temperature + Humidity + TWA; $R^2 = 0.524$) the bird speed in Calabria is negatively related to the temperature ($t = -3.0$, $P < 0.01$) and humidity ($t = -2.469$, $P < 0.05$) in the same place (Tab. 2). On the contrary, the TWA positively affects the bird speed (Fig. 11; $t = 4.824$, $P < 0.001$). Probably, higher temperatures could increase the soaring flight behaviour in raptor birds and decrease their ground speed. Predictably, the tailwinds raise up the bird speed (Fig. 11).

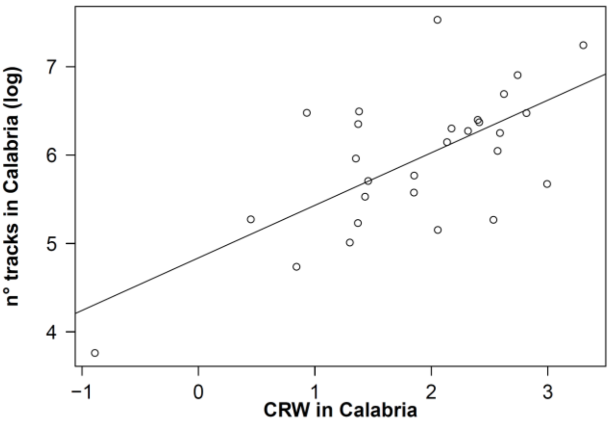


Fig. 4

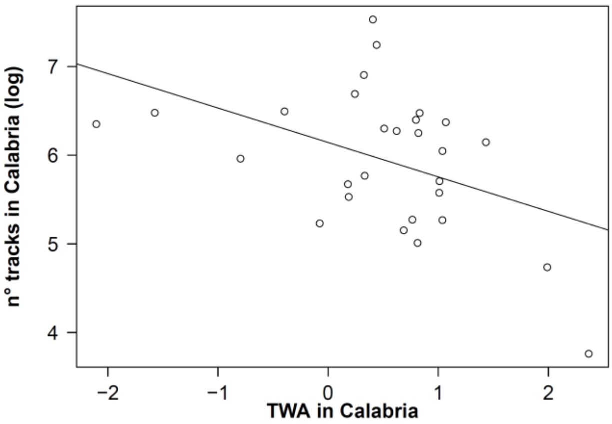
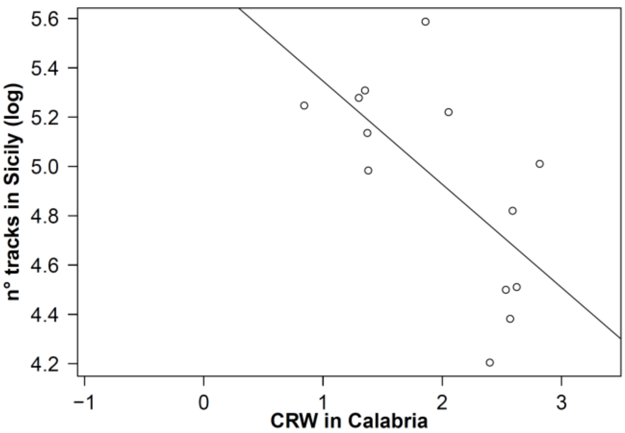


Fig. 5



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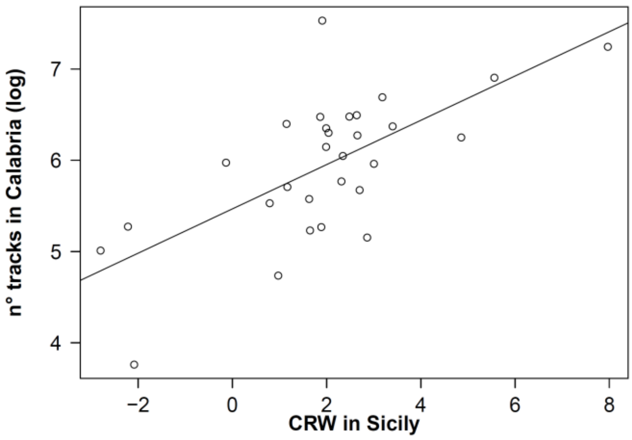

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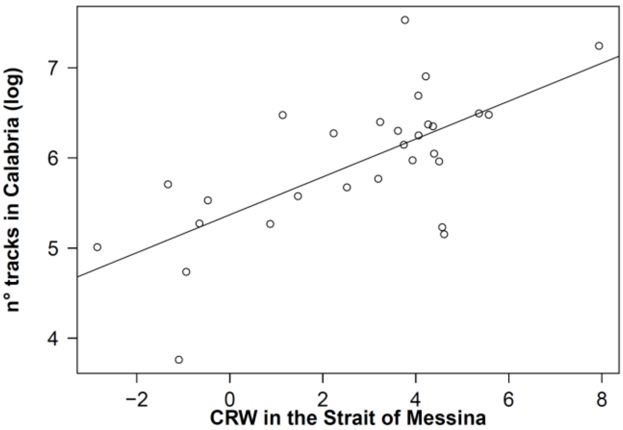

Fig. 8

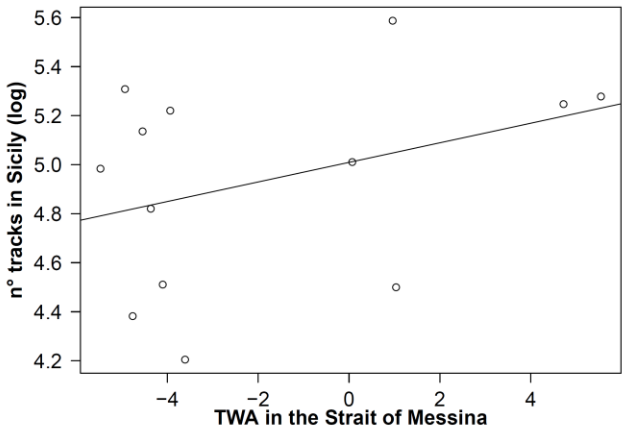

Fig. 9

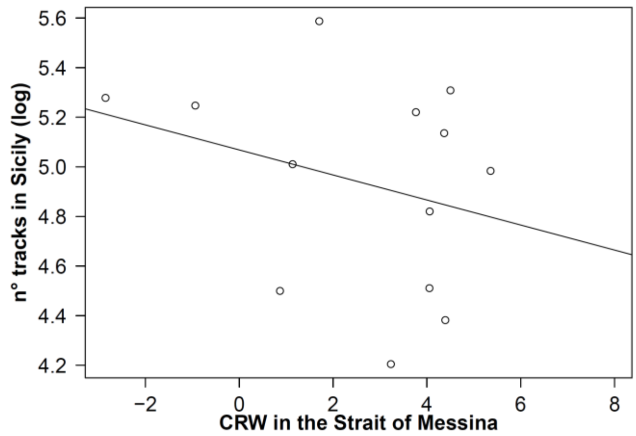

Fig. 10

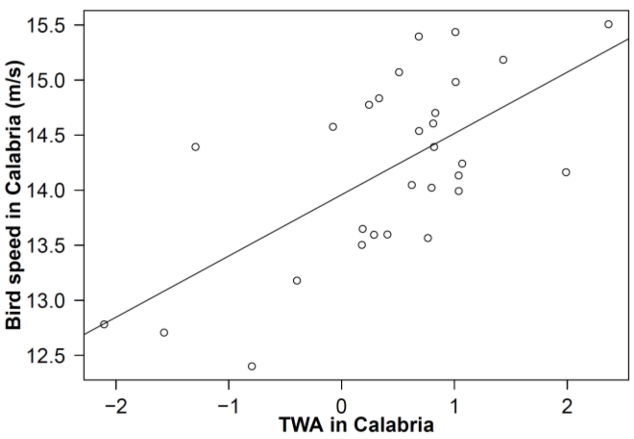

Fig. 11

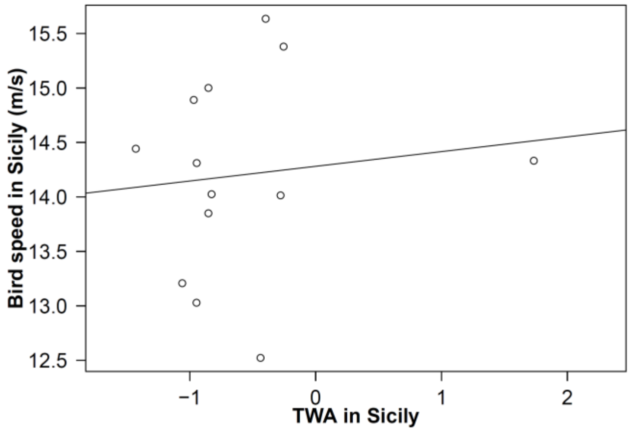

Fig. 12

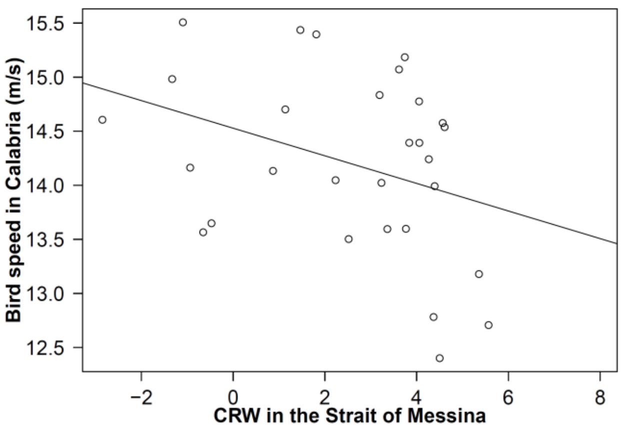

Fig. 13

In the Model 4 (best model: Bird speed Sicily ~ Temperature; $R^2 = 0.365$) there is only a significant negative relationship between bird speed in Sicily and the temperature in Calabria ($t = -2.707$, $P < 0.05$) as it happened in Model 1.

In the Model 7 (best model: Bird speed Calabria ~ Temperature + Pressure + CRW + TWA; $R^2 = 0.394$) the temperature, the pressure, the CRW and the TWA in Sicily have a positive, but no significant, relationship with the bird speed in Calabria (Tab. 2).

In the Model 8 (best model: Bird speed Sicily ~ Humidity + TWA; $R^2 = 0.336$) the humidity have a strong positive relationship with the bird speed in Sicily ($t = 2.801$, $P < 0.05$) and it is present a weak positive relationship between the TWA and bird speed (Fig. 12; $t = 2.003$, $P = 0.073$).

The last two models concern the interactions between the speed of tracks in Calabria (Model 11) and Sicily (Model 12), and meteorological variables in the middle of the Strait of Messina.

The Model 11 (best model: Bird speed Calabria ~ Temperature + Pressure + Humidity + CRW + TWA; $R^2 = 0.278$) shows a weak negative relationships between the pressure ($t = -2.038$, $P = 0.053$), the CRW (Fig. 13; $t = -2.099$, $P = 0.047$) and the bird speed in Calabria. The other variables do not affect the bird speed.

In the Model 12 (best model: Bird speed Sicily ~ Temperature; $R^2 = 0.365$) the temperature have a strong negative effect on bird speed, probably because high temperatures increase the probability to use soaring flight by raptor birds, this flight mode could reduce the bird speed.

The most important factors affecting the speed of birds in Calabria and Sicily seem to be the temperature in negative direction, and the TWA in the positive way. Apparently, atmospheric variables in the Strait of Messina do not affect the speed of Sicilian and Calabrian birds, possibly due to lower temporal resolution of the measurements from this weather station. The next stage of the analysis will try to understand interactions between bird migration and meteorological factors using an analysis that will consider different time scales from minutes to days.

CONCLUSIONS

In order to enhance our understanding of animal movement in general and specifically of bird migration through the exchange of knowledge and methods by researchers in COST ENRAM's working group 4, this STSM has strongly contributed to understanding the ways bird movements, detected using x-band radars, are affected by meteorological factors (Shamoun-Baranes *et al*. 2014). The analysis presented in this work could be considered a basis for understanding the role of atmospheric factors on bird migration over the Strait of Messina. In particular, the strong effects of both tailwinds and crosswinds is relevant on bird migration strategies. Also, is important to consider the geographical context of bird migration, in this case the crossing of wide ecological barriers such as the Mediterranean Sea, as well as more local topographical features like Peloritani Mountains in Sicily, which could nullify the effects of the wind which may evoke a behavioral response of the birds during flight.

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