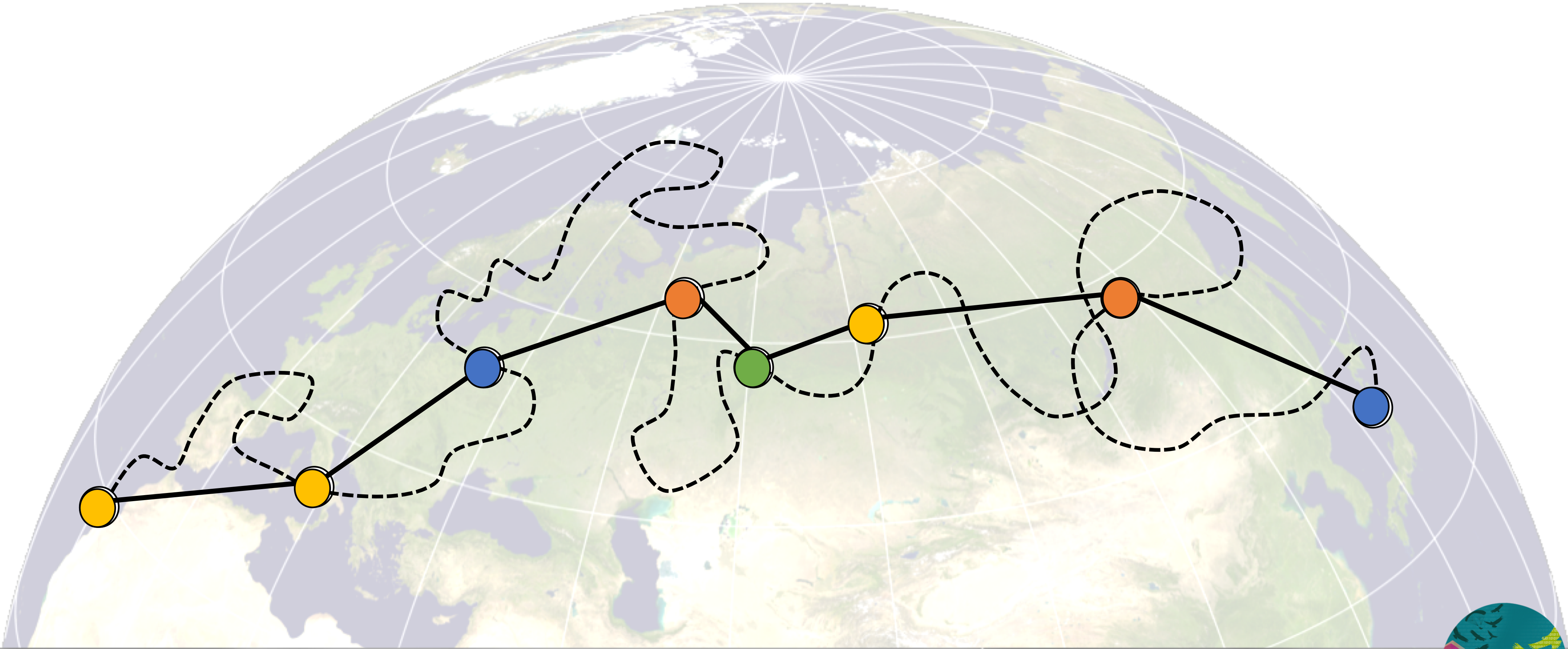
Resolving behavior with auxiliary sensors

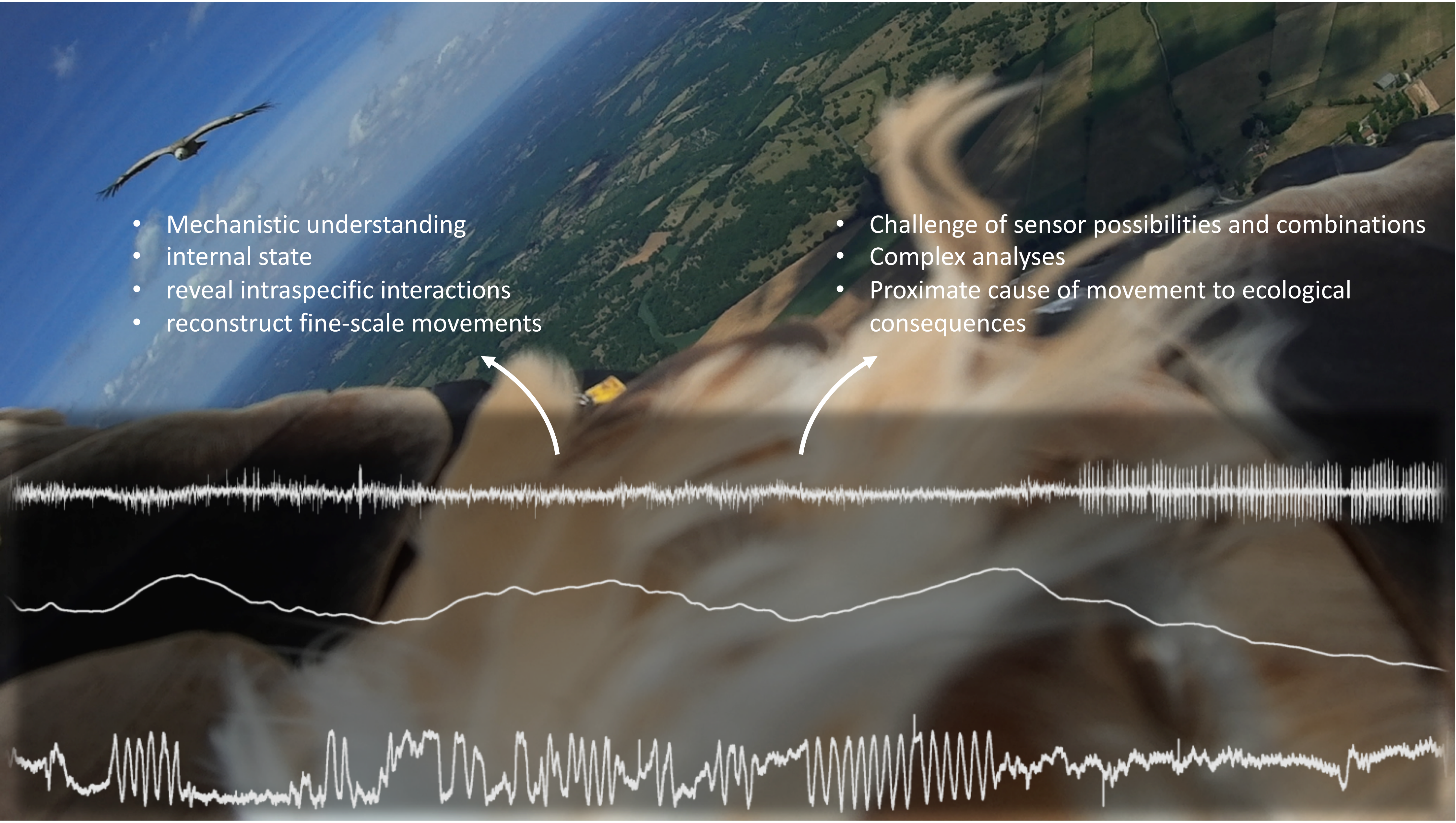


How can we resolve behaviour remotely?

Vulture recording by Hannah Williams

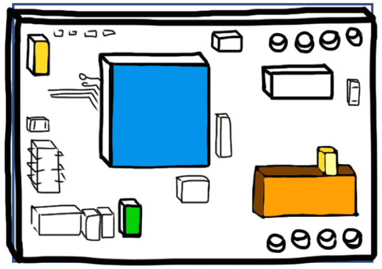
Penguin recording by Rory Wilson

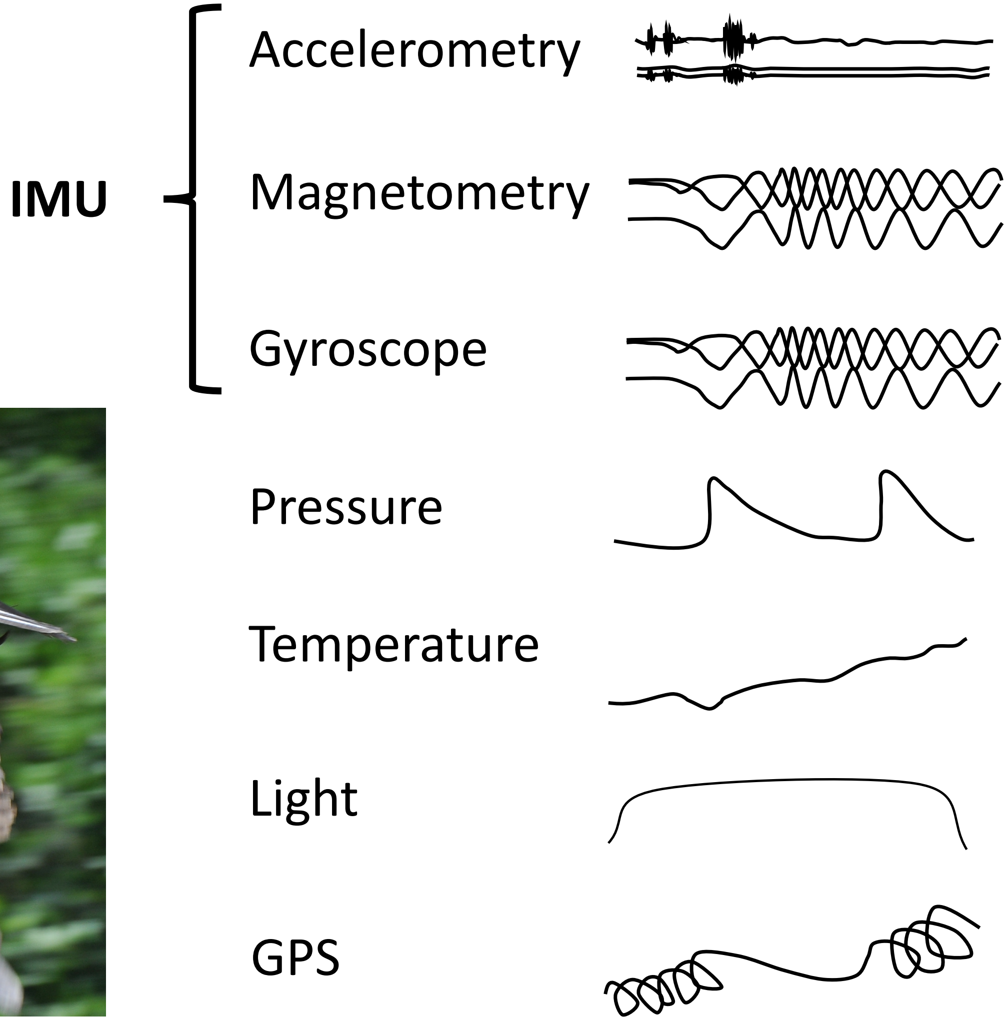
AniMove



• Mechanistic understanding
• internal state
• reveal intraspecific interactions
• reconstruct fine-scale movements
• Challenge of sensor possibilities and combinations
• Complex analyses
• Proximate cause of movement to ecological consequences

Auxiliary sensors





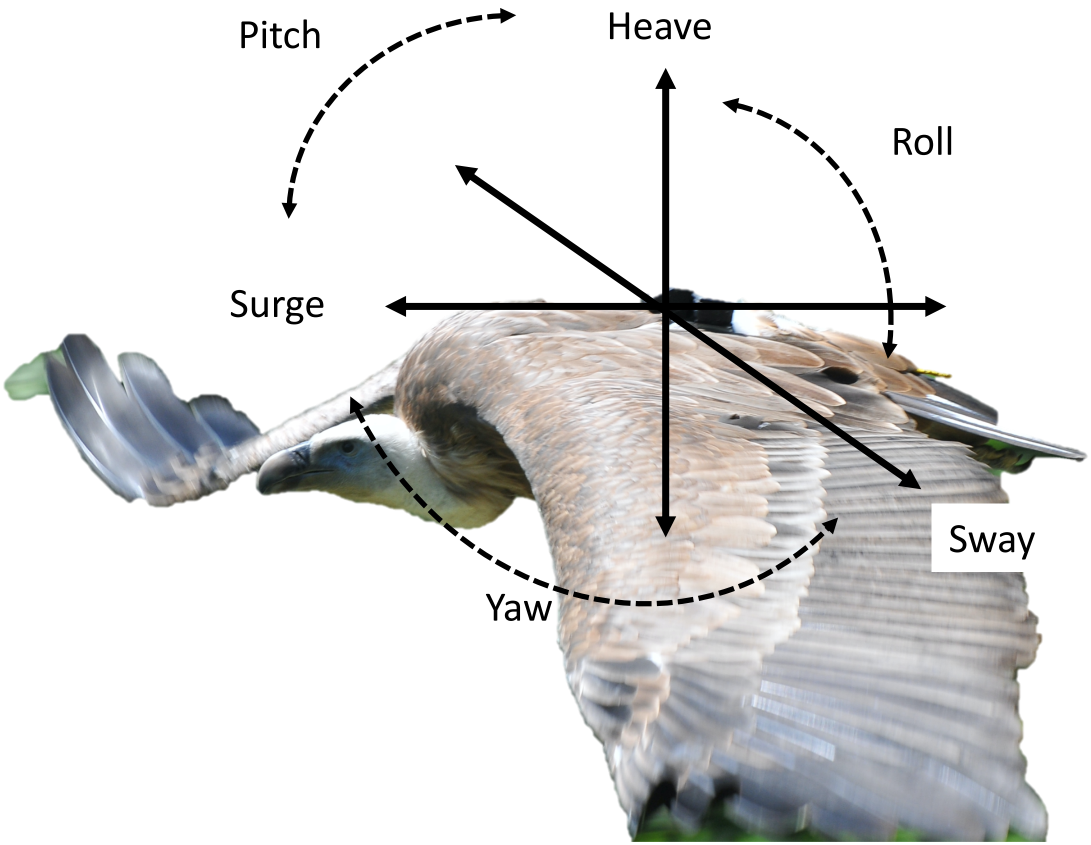
Auxiliary sensors

- Annotate position data with behavior data
- Matching sensor combinations to specific biological questions
- Analyses of high-frequency multivariate bio-logging data

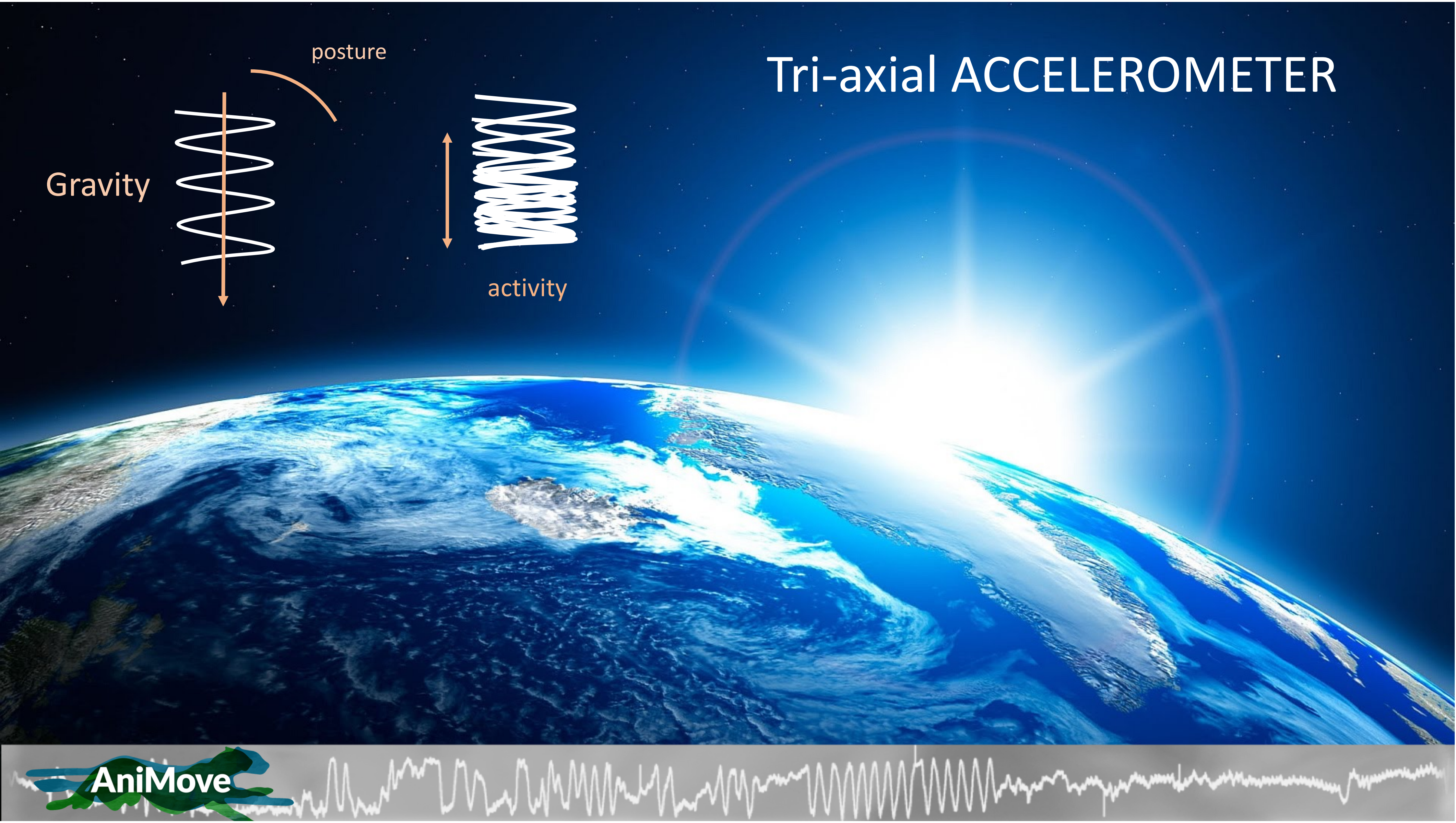
https://github.com/trichl/WildFiOpenSource

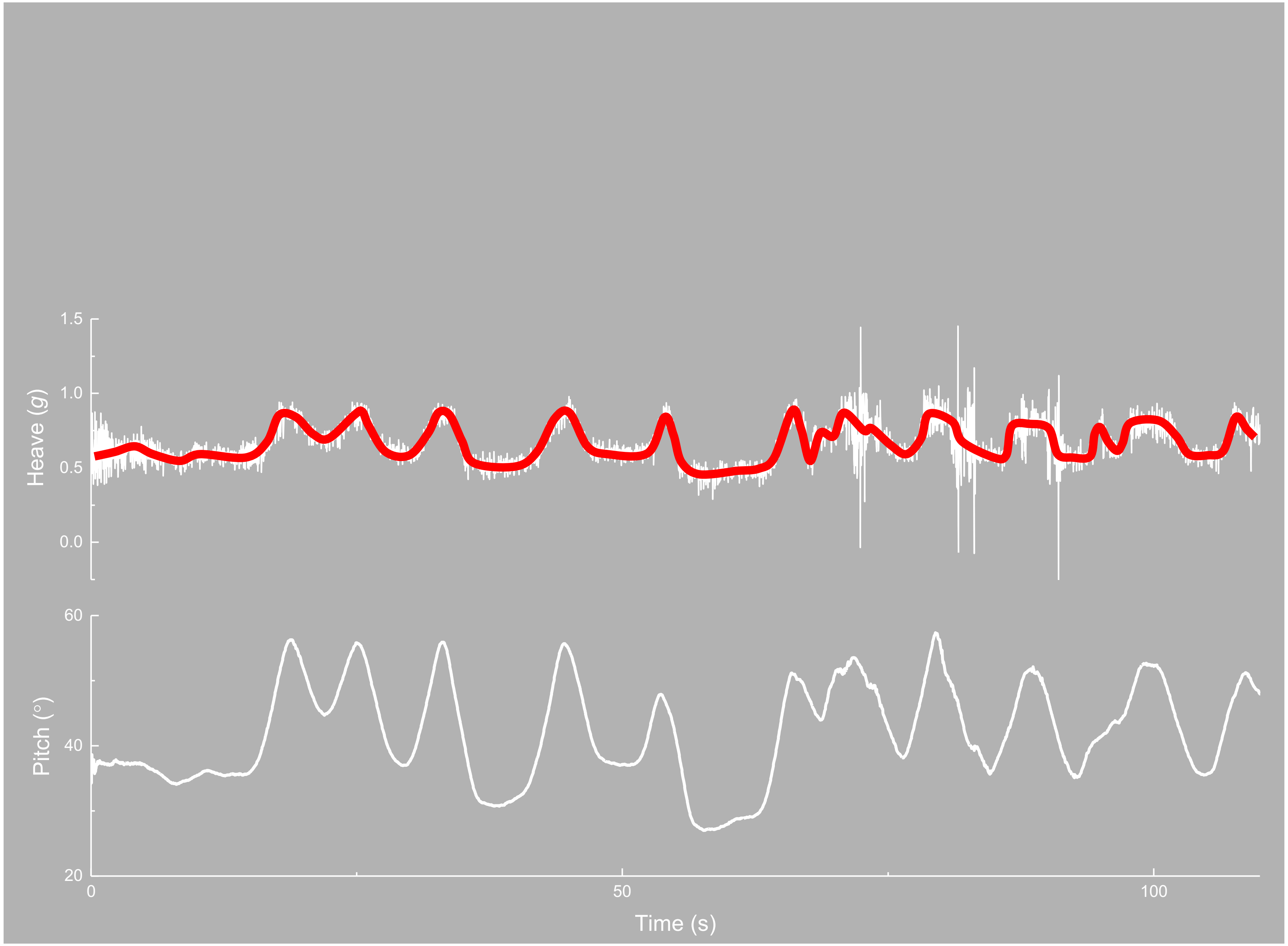
https://github.com/Richard6195/Dead-reckoning-animal-movements-in-R

Inertial Measurement Unit

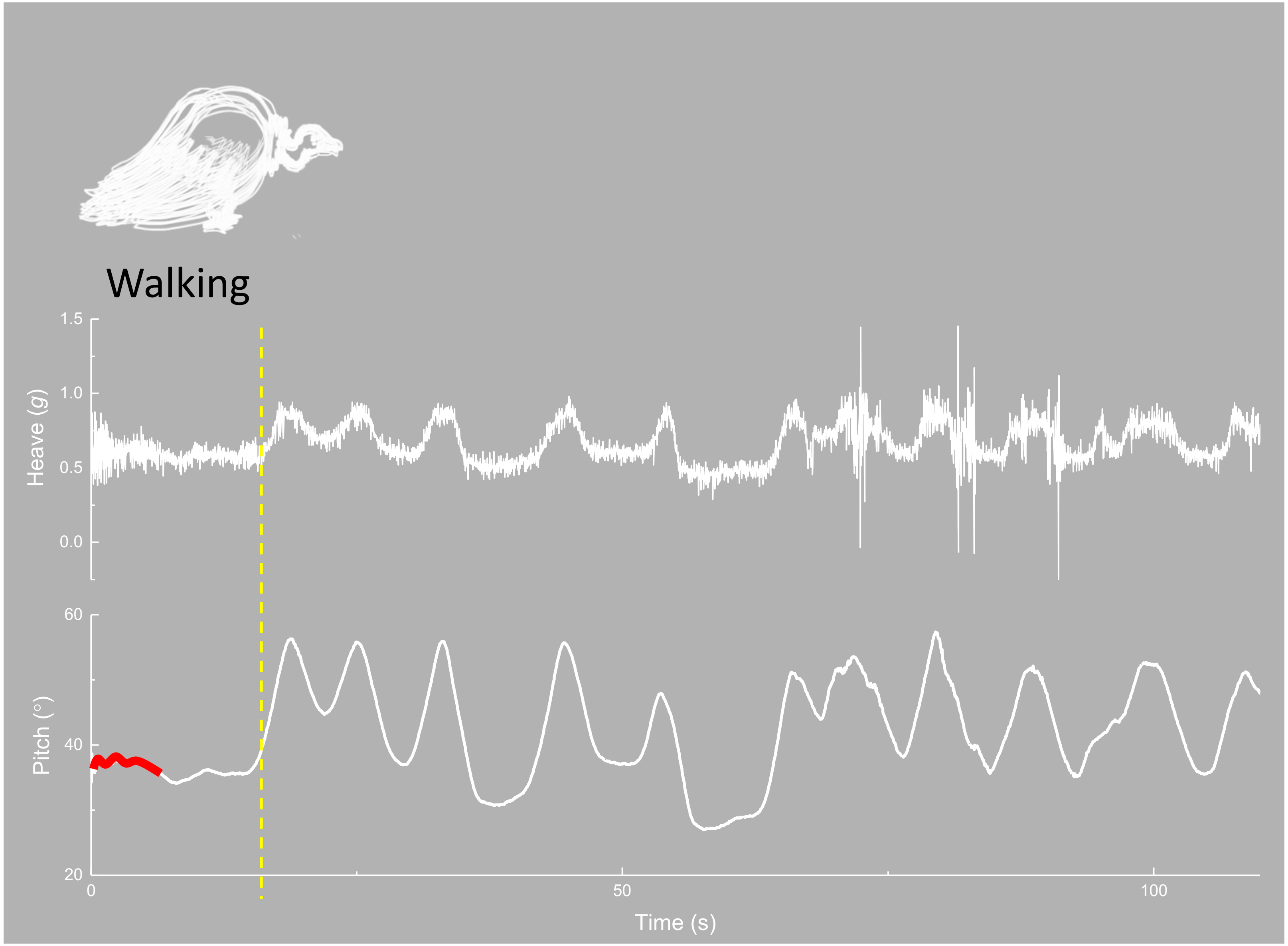


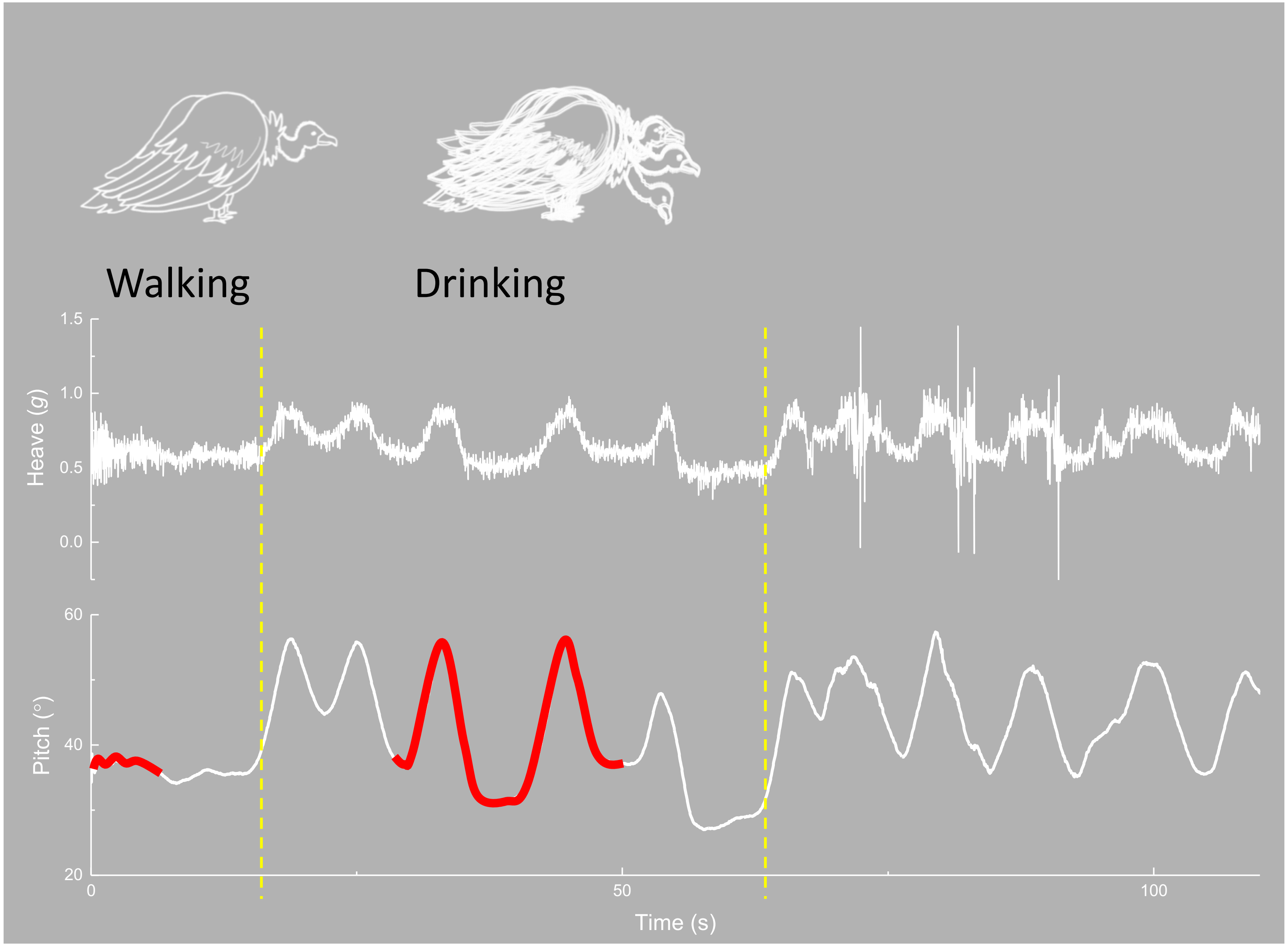
Tri-axial ACCELEROMETER



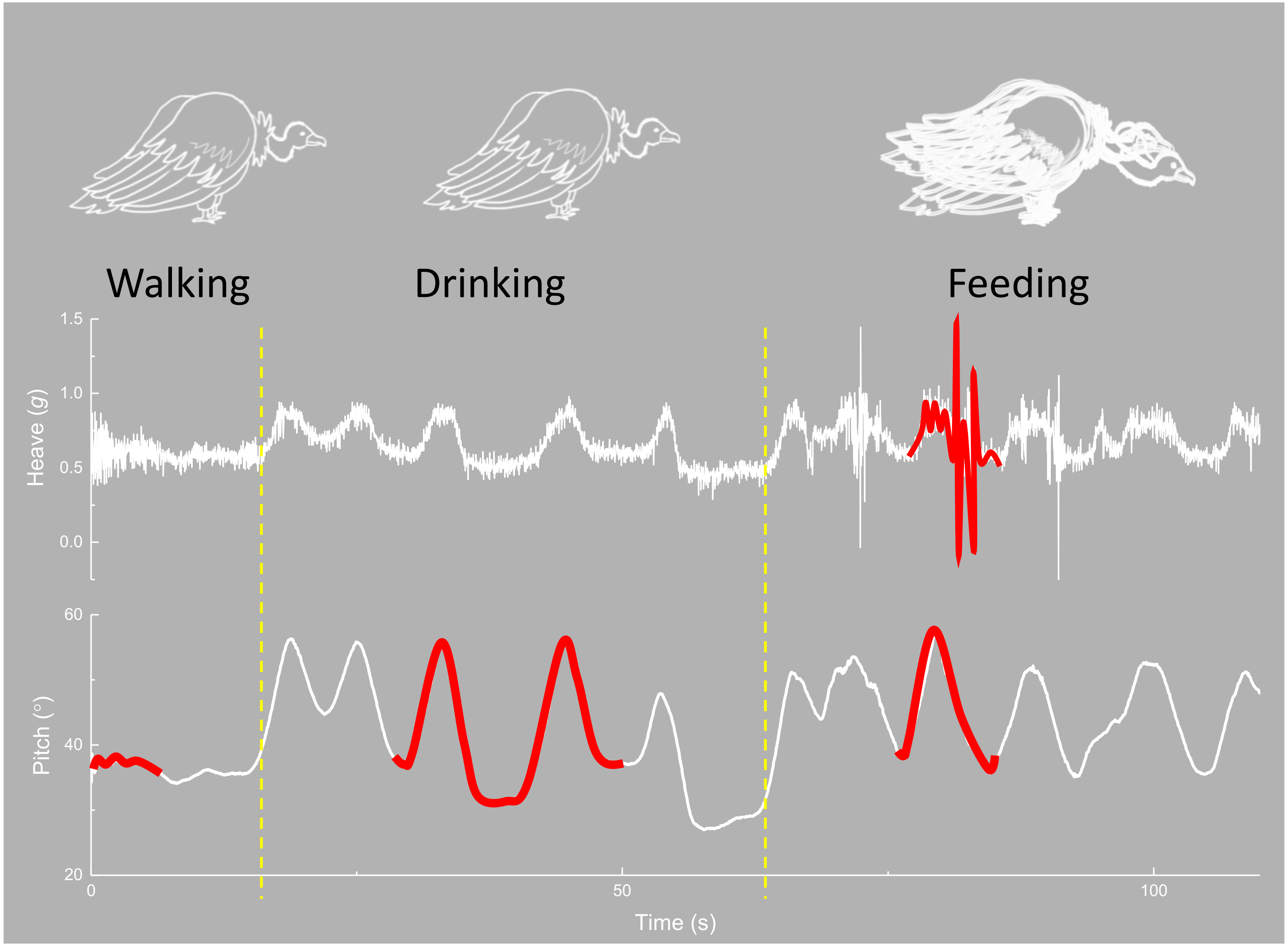


1.5
1.0
0.5
0.0
Heave (g)
60
40
20
Pitch (°)
0
50
100
Time (s)


Walking
Heave (g)
1.5
1.0
0.5
0.0
Pitch (°)
60
40
20
0
50
100
Time (s)



Walking
Drinking
Heave (g)
1.5
1.0
0.5
0.0
Pitch (°)
60
40
20
0
50
100
Time (s)


Walking
Drinking
Feeding
1.5
1.0
0.5
0.0
Heave (g)
60
40
20
Pitch (°)
0
50
100
Time (s)

Activity and energy expenditure

Behaviour is manifest by movement so we should 'measure' movement

the accelerometry technique has the potential to provide information about how animals partition their use of both time and energy

Energy expenditure is the key link between behaviour and overall fitness

Extract the static and dynamic acceleration components

Nyquist theorem

Sensor bit resolution

Measurement range

Recording frequency

Data smoothing

Validation

- Nyquist or sampling theorem - sampling frequency (temporal or spatial) should be at least twice the fastest frequency of interest
- sensor bit resolution- e.g., 8-bit resolution, meaning the sensor can obtain an absolute resolution given by the maximum resolution range divided by 256.
- Measurement range of the sensor. – e.g., accelerometer which records up to 8 g will miss any data of animals moving more dynamically (e.g., head impacts) default should be at least 16 g for initial studies for terrestrial systems (a lower range may be sufficient for aquatic systems as, due to friction, movement speed may change less fast)
- But highly prescribed, low-frequency sampling may miss serendipitous observations of importance.
- High-frequency recording of raw data (>20 Hz) may be necessary to compute animal posture and DBA
- Data smoothing by a running mean ; a Fast-Fourier transformation; a high-pass filter ; a Kalman-filter
- ‘validated’ in level terrain will produce markedly different acceleration offsets if it normally lives in mountains because body pitch

WildFi IMU/GPS Units

prefixDataType	tagId	utcTimestamp	utcDate	milliseconds	lastErrorId	lat	lon	hdop
12345A	NA	NA	NA	NA	NA	NA	NA	NA
12345A	NA	NA	NA	NA	NA	NA	NA	NA
12345A	EC50	1694163712	2023-09-08 09:01:52	0	0	42.04591	0.746720	1.1
12345A	NA	NA	NA	NA	NA	NA	NA	NA
12345A	NA	NA	NA	NA	NA	NA	NA	NA
12345A	NA	NA	NA	NA	NA	NA	NA	NA
12345A	NA	NA	NA	NA	NA	NA	NA	NA
12345A	NA	NA	NA	NA	NA	NA	NA	NA
12345A	NA	NA	NA	NA	NA	NA	NA	NA
12345A	NA	NA	NA	NA	NA	NA	NA	NA
12345A	NA	NA	NA	NA	NA	NA	NA	NA
12345A	NA	NA	NA	NA	NA	NA	NA	NA
12345A	NA	NA	NA	NA	NA	NA	NA	NA
12345A	NA	NA	NA	NA	NA	NA	NA	NA
12345A	NA	NA	NA	NA	NA	NA	NA	NA

WildFi IMU/GPS Units

accXinG	accYinG	accZinG	magXinUT	magYinUT	magZinUT	hall	gyroXinDPS	gyroYinDPS	gyroZinDPS
0.04467773	-0.07739258	1.022949	16.6875	39.0625	-118.0625	6957	-0.0228	-0.0494	0.11
0.04516601	-0.07714844	1.019531	17.0625	38.3125	-116.5000	6957	-0.0190	-0.0646	0.10
0.04125976	-0.07812500	1.026367	17.4375	39.4375	-118.0625	6956	-0.0190	-0.0608	0.10
0.04785156	-0.07714844	1.024658	17.8125	38.3125	-117.3125	6957	-0.0076	-0.0646	0.11
0.04711914	-0.07958984	1.023926	16.6875	38.6875	-117.3125	6956	-0.0076	-0.0418	0.11
0.04516601	-0.07177734	1.022949	17.0625	38.6875	-117.3125	6956	-0.0190	-0.0494	0.09
0.04711914	-0.07519531	1.024170	17.4375	39.8125	-116.1250	6957	-0.0342	-0.0532	0.11
0.04248047	-0.07788086	1.020752	17.0625	39.4375	-116.9375	6955	-0.0266	-0.0494	0.11
0.04443359	-0.07812500	1.020996	16.3750	39.8125	-117.3125	6956	-0.0266	-0.0418	0.11
0.04663086	-0.07763672	1.024170	17.0625	39.4375	-116.9375	6957	-0.0266	-0.0380	0.09
0.04443359	-0.07397461	1.026123	17.0625	39.4375	-117.6875	6958	-0.0190	-0.0494	0.11
0.04028320	-0.07641601	1.023682	16.6875	37.9375	-117.3125	6956	-0.0152	-0.0608	0.14
0.04589844	-0.07861328	1.020752	16.6875	40.1875	-117.6875	6956	-0.0114	-0.0380	0.14
0.04858398	-0.07446289	1.023682	17.4375	38.3125	-116.9375	6955	-0.0114	-0.0418	0.11
0.04614258	-0.07641601	1.021484	16.6875	38.6875	-117.7500	6955	-0.0190	-0.0532	0.10
0.04492187	-0.07592773	1.023926	16.6875	40.1875	-118.4375	6957	-0.0304	-0.0646	0.1

E-obs IMU/GPS Units

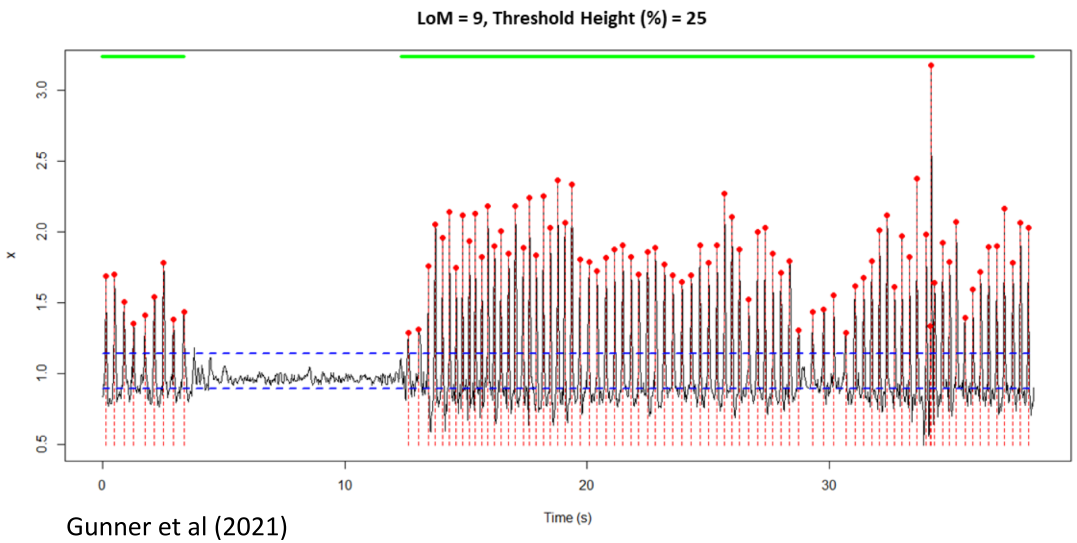
type	tag.serial.number	burst.start.timestamp	eobs_acceleration_axes	eobs_acceleration_sampling_frequency_per_axis	eobs_accelerations_raw
acc	0	2021-08-24 18:45:09.000	XYZ	10	2017 1833 1593 2022 1846
acc	0	2021-08-24 20:00:09.000	XYZ	10	2017 1903 1558 2032 1908
acc	0	2021-08-24 17:05:08.000	XYZ	10	2022 1994 1459 2067 2001
acc	0	2021-08-24 09:20:08.000	XYZ	10	2026 1983 1520 2040 2030
acc	0	2021-08-24 19:45:09.000	XYZ	10	2028 1894 1572 2029 1895
acc	0	2021-08-24 12:50:08.000	XYZ	10	2028 2028 1485 2109 2004
acc	0	2021-08-24 18:30:09.000	XYZ	10	2029 1804 1596 2022 1819
acc	0	2021-08-24 19:15:09.000	XYZ	10	2029 1821 1600 2027 1824
acc	0	2021-08-24 11:20:08.000	XYZ	10	2030 2001 1516 2057 2008
acc	0	2021-08-24 06:00:09.000	XYZ	10	2030 2146 1612 1994 2044
acc	0	2021-08-24 19:30:09.000	XYZ	10	2031 1812 1608 2033 1814
acc	0	2021-08-24 19:00:09.000	XYZ	10	2033 1849 1603 2043 1816
acc	0	2021-08-24 16:35:08.000	XYZ	10	2034 1986 1403 2036 2038
acc	0	2021-08-24 02:15:09.000	XYZ	10	2035 1892 1575 2033 1889
acc	0	2021-08-24 04:45:09.000	XYZ	10	2039 1863 1624 2125 1673
acc	0	2021-08-24 08:30:09.000	XYZ	10	2041 1815 1598 2036 1814
acc	0	2021-08-24 16:50:08.000	XYZ	10	2043 1983 1500 2031 1976
acc	0	2021-08-24 15:50:08.000	XYZ	10	2044 1893 2016 2089 2013
acc	0	2021-08-24 17:45:09.000	XYZ	10	2045 1882 1582 2054 1873
acc	0	2021-08-24 02:30:09.000	XYZ	10	2047 1963 1557 2048 1965
acc	0	2021-08-24 10:05:08.000	XYZ	10	2048 1981 1572 2088 2003
acc	0	2021-08-24 02:45:09.000	XYZ	10	2049 1916 1567 2048 1914
acc	0	2021-08-24 15:05:08.000	XYZ	10	2050 1877 2222 2081 2105

...

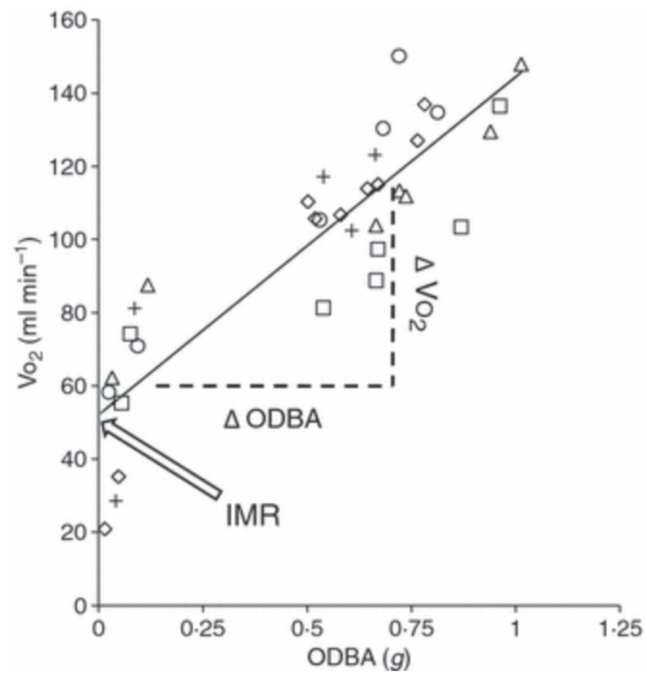
	acc.odba	acc.xmean	acc.ymean	acc.zmean	acc.activity
1853 1590	692.85	2023.575	1858.775	1582.825	7.572650
1891 1568	522.20	2026.425	1895.950	1571.375	4.940171
1975 1457	4188.75	2066.950	1991.450	1506.875	50.264957
2021 1430	5714.35	2073.725	1998.300	1453.375	45.068376
1885 1574	238.35	2030.025	1887.575	1574.475	2.555556
1968 1423	3647.90	2059.150	1989.250	1495.100	28.435897
1805 1595	909.85	2026.200	1820.650	1599.875	8.153846
1849 1594	412.30	2027.775	1830.675	1596.200	2.940171
1976 1493	1813.00	2065.725	1998.125	1505.350	18.213675
1962 1562	4151.40	2068.750	2061.200	1559.050	36.376068
1822 1601	212.55	2035.000	1817.175	1601.700	1.709402
1878 1584	1428.15	2035.550	1854.375	1588.425	10.623932
1963 1475	3297.95	2067.350	1999.650	1483.825	32.085470
1899 1571	293.60	2030.500	1890.800	1573.050	3.452991
1959 1662	9757.40	2079.125	1886.525	1580.425	119.863248
1935 1574	5696.80	2062.850	1886.400	1580.925	40.897436
1998 1459	3660.65	2072.975	1995.700	1508.350	26.547009
1982 1506	4622.80	2064.025	1975.550	1522.675	51.179487
1795 1511	4221.85	2077.625	1887.525	1573.400	38.196581
1962 1557	199.80	2047.300	1963.775	1555.800	1.572650
1955 1373	13380.35	2058.675	1965.375	1486.250	162.803419
1915 1566	132.30	2048.975	1913.800	1566.525	1.230769
1994 1581	3906.10	2065.150	1980.775	1554.725	37.307692

DBA → ODBA/VeDBA

The rate at which this mechanical work is conducted (and therefore energy used) is the mechanical power (*P*). The ability of DBA to act as a proxy for energy expenditure depends, in part, on the link between acceleration produced by muscular contraction and mechanical power.

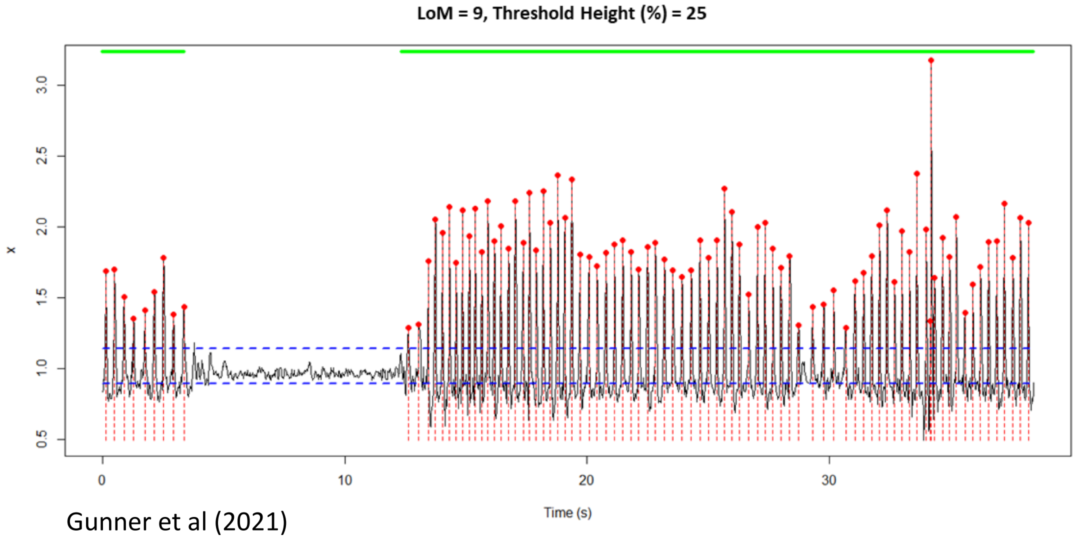


Gunner et al (2021)



Gleiss et al (2011) MEE

DBA → ODBA/VeDBA



Gunner et al (2021)

Gundog.peaks

locates peaks based on local signal maxima, using a given rolling window, with each candidate peak filtered according to whether it surpassed a threshold height

MoveACC

The *ACCwave* function uses a FFT (Fast Fourier Transformation) to extract the wave of the acceleration data, with a PCA (principal components analysis) on the 3 axis to calculate wingbeat frequency on the dominant frequency of the burst

Extract the static and dynamic acceleration components

```
#Required libraries
install.packages("zoo") ; install.packages("dplyr")
library(zoo) ; library(dplyr)

#Note, currently, scripts are composed of base R syntax, using data frames. Code can be optimized further to become more efficient at computing larger data sets
#For example, note the time difference between the 'data.frame' and 'data.table' versions of implementing a running mean:
library(data.table)
df <- data.frame(Ax=sample(1:1000,10000000, replace=T),
                 Ay=sample(1:1000,10000000, replace=T),
                 Az=sample(1:1000,10000000, replace=T))
w=40
# data.frame / zoo solution
system.time({
  df$Gx = zoo::rollapply(df$Ax, width=w, FUN=mean, align="center", fill="extend")
  df$Gy = zoo::rollapply(df$Ay, width=w, FUN=mean, align="center", fill="extend")
  df$Gz = zoo::rollapply(df$Az, width=w, FUN=mean, align="center", fill="extend")
})
# data.table solution
system.time({
  dt <- setDT(df)[, c("Gx","Gy", "Gz") := lapply(.SD,function(x) frollmean(x, n = w, align="center", adaptive=F)),
                  .SDcols = c("Ax", "Ay", "Az")]
})
View(dt[40:140,])
```

We use a centre-aligned index (compared to the rolling window of observations), with “extend” to indicate repetition of the leftmost or rightmost non-NA value

DBA → ODBA/VeDBA

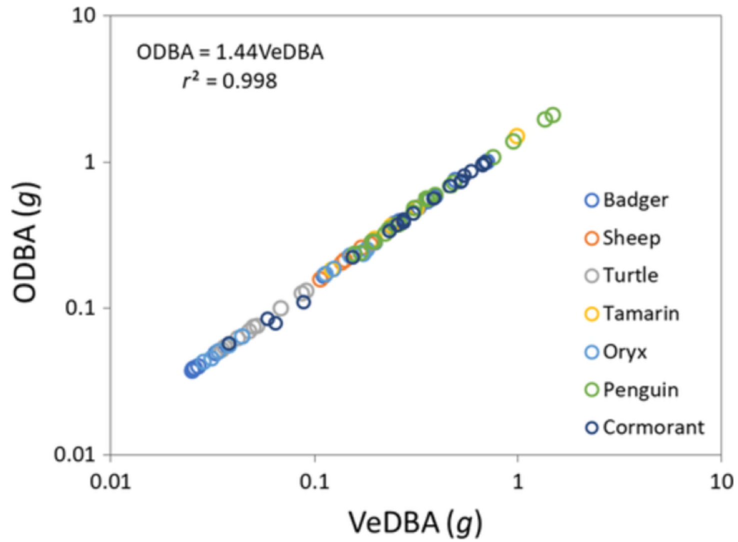
2.2 Derivation of DBA – VeDBA and ODBA

Having removed the Earth's gravitational field from each of the recorded acceleration axes, these should now be summed to provide a measure of DBA. Mathematically, this follows the approach given in Equation 1 where the vectorial sum (Vectorial sum of the Dynamic Body Acceleration, VeDBA) is;

$$\text{VeDBA} = (DAx^2 + DAy^2 + DAz^2)^{0.5} \tag{2}$$

where the "*D*" term refers to the dynamic acceleration stemming from the subtraction of the smoothed acceleration data from the raw. This expression for DBA has been tested against rate of oxygen consumption ($\dot{V}O_2$) on numerous occasions across taxa (e.g. Wright, Metcalfe, Hetherington, & Wilson, 2014; Bidder et al., 2017) and found to be a powerful predictor. However, its formulation is at odds with the first proposition for DBA, that of Overall Dynamic Body Acceleration (ODBA – Wilson et al., 2006) which was simply based on the non-vectorial sum of the absolute dynamic acceleration values from the three acceleration axes following;

$$\text{ODBA} = |DAx| + |DAy| + |DAz| \tag{3}$$

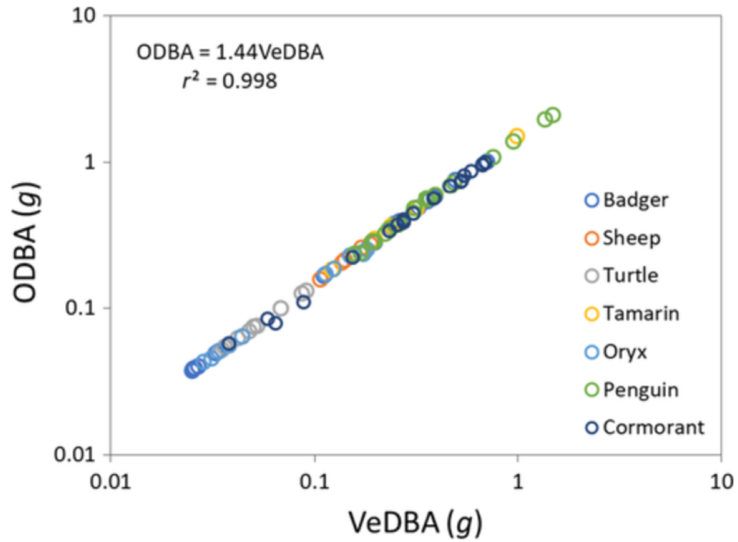


Wilson et al (2020) JAE

DBA → ODBA/VeDBA

Those requiring the absolute best fit between DBA and $\dot{V}O_2$ may prefer to use ODBA while those seeking to describe animal motion without the energetic component may prefer VeDBA.

- Vectorial and additive DBA metrics are proportional to each other.
- Either can be used as a proxy for energy and summed to estimate total energy expended over a given period, or divided by time to give a proxy for movement-related metabolic power.
- ODBA is statistically marginally better at predicting oxygen consumption
- VeDBA may prove more appropriate when behaviours other than locomotion occur over less predictable orientation planes, & account forerrors associated with device orientation in relation to the plane of muscular contraction
- Researchers should use the term DBA generally, but be specific about its derivation at the outset.



Wilson et al (2020) JAE

DBA → ODBA/VeDBA

```
#7) Calculate VeDBA (assuming DBA~speed within Gundog.Tracks is desired. Also post-smooth VeDBA (2 s used here)
df$VeDBA = sqrt((df$Acc_x - df$Acc_x.sm)^2 + (df$Acc_y - df$Acc_y.sm)^2 + (df$Acc_z - df$Acc_z.sm)^2)
df$VeDBA.sm = rollapply(df$VeDBA, width=80, FUN=mean, align="center", fill="extend")
```

Factors affecting DBA metrics

Tag position

Tag stability

Environmental DBA

VO_2 ~ ODBA

Pulling-g

Negligible DBA

Relative measures

- Tag position – impossible to orthogonally orientate it in line with main axis of movement to remove angular inadequacies of the ODBA metric
- Tag stability
- Environmental DBA
- Nature of the general relationship between ODBA and VO_2
- Pulling g – where the animal experience increased inertial acceleration in additional to the force of gravity, and the vectorial sum of the smoothed channels may not equal 1
- negligible DBA signal in slowly moving animals such as many invertebrates and some ectotherms – use rates of change of body pitch, roll or yaw which, although not accelerations, may code for metabolic rate since the animal is still exerting forces to move the body
- All of the above are specifc to a tag and individual attachment thus we can only compare acc/DBA values if they are relative e.g. rate of change of pitch or centred VEDBA

AniMove