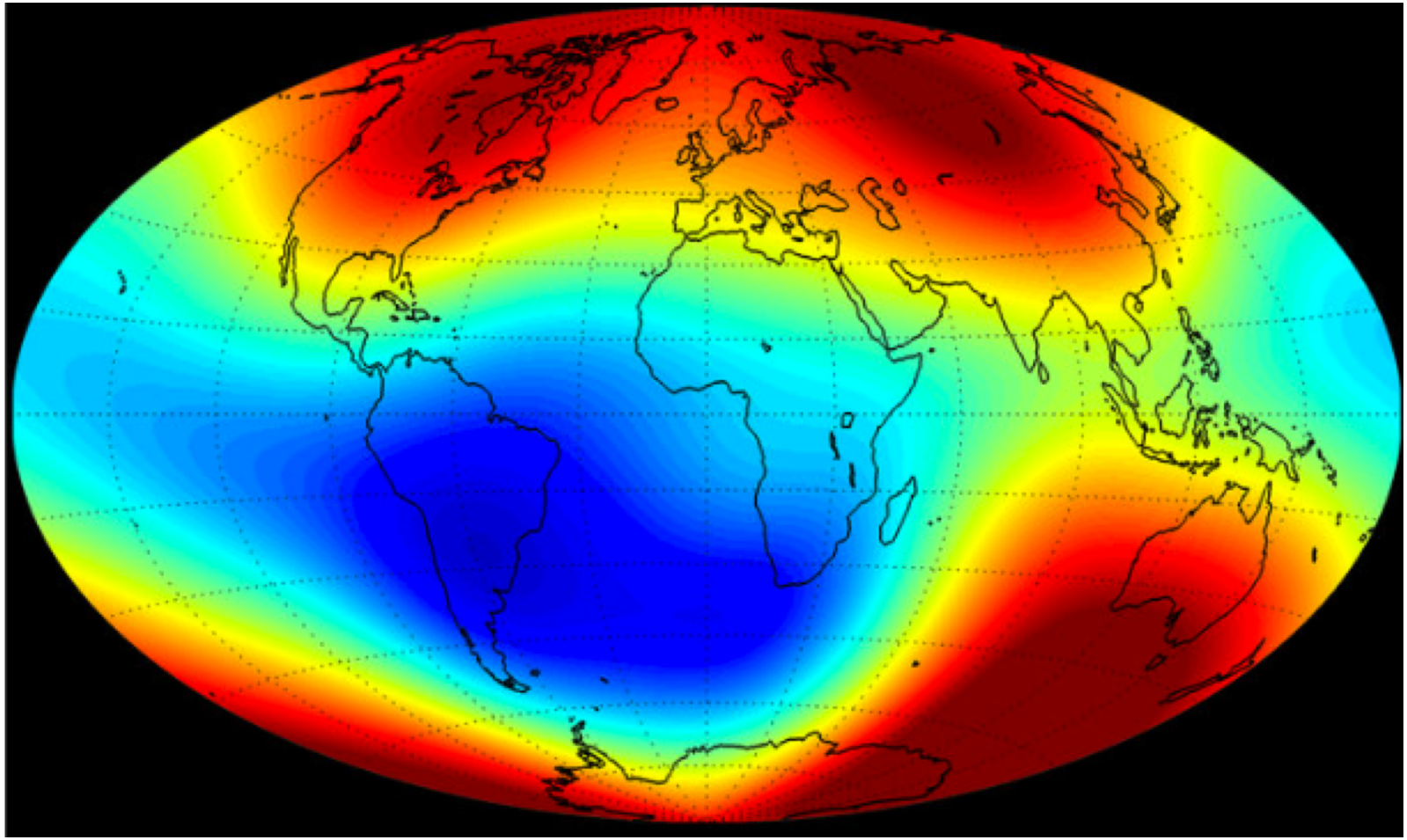
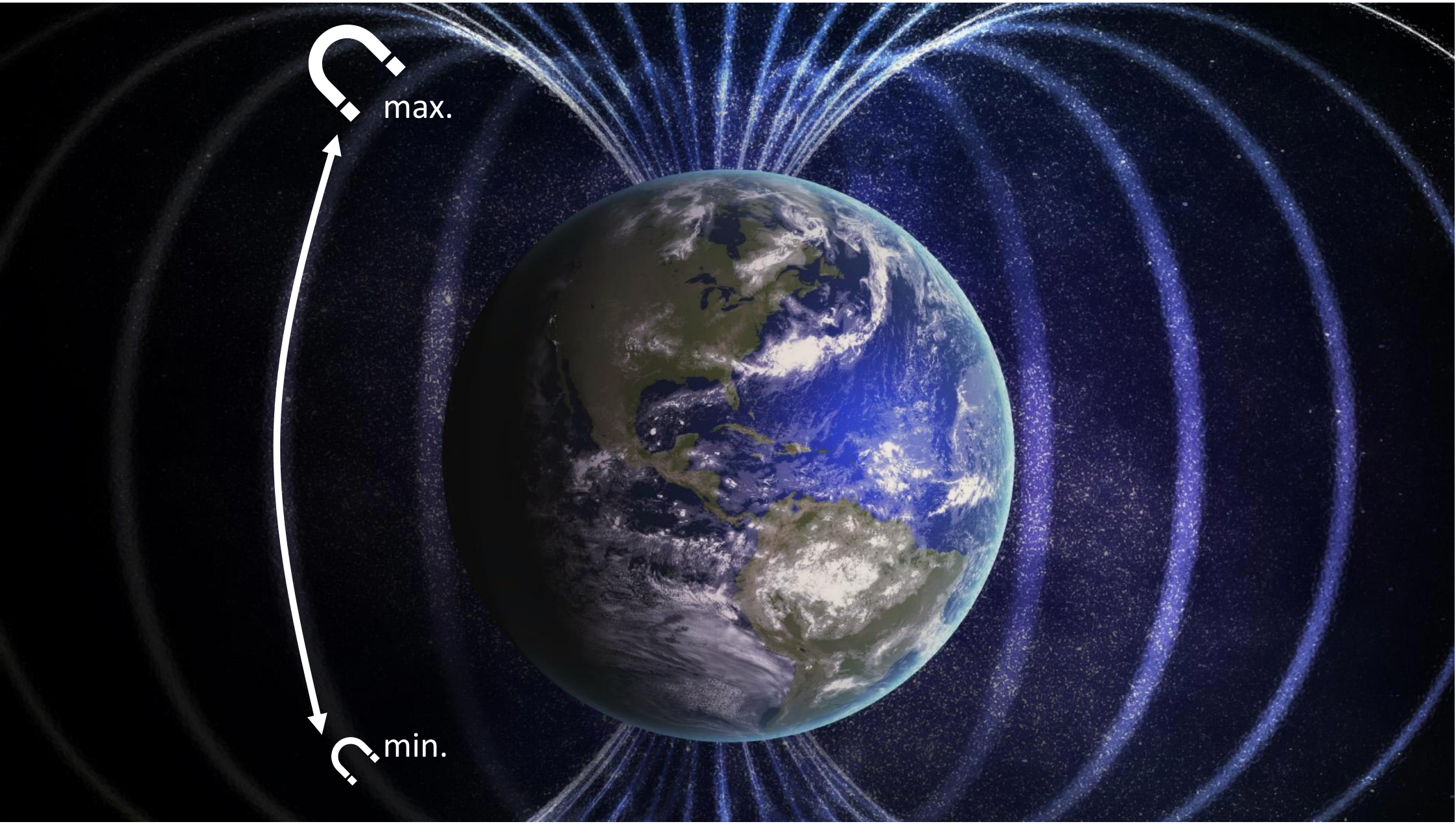
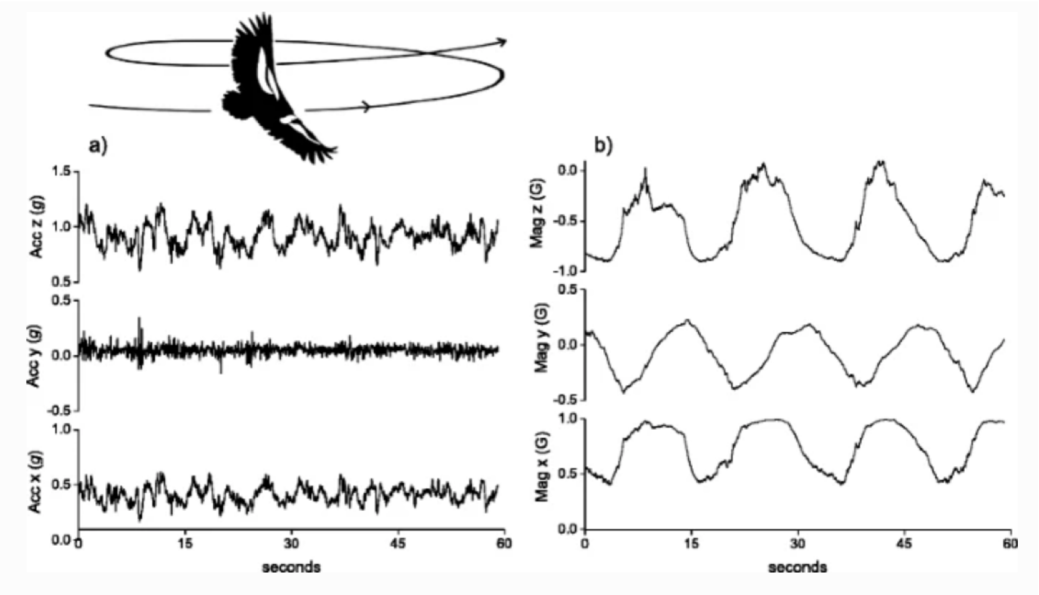
Tri-axial MAGNETOMETER

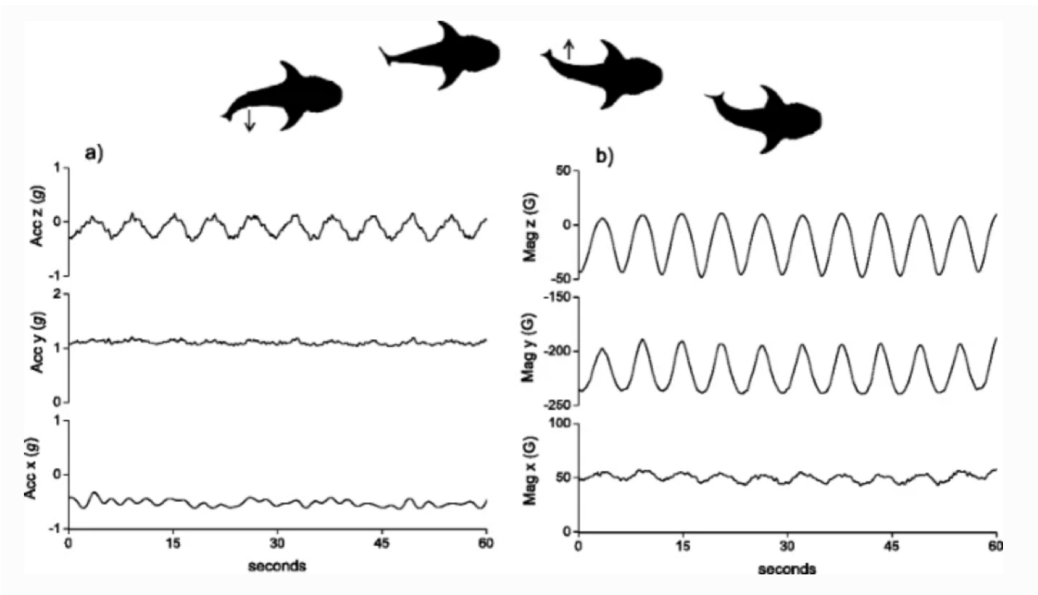



max.
min.

Angular rotation → Orientation

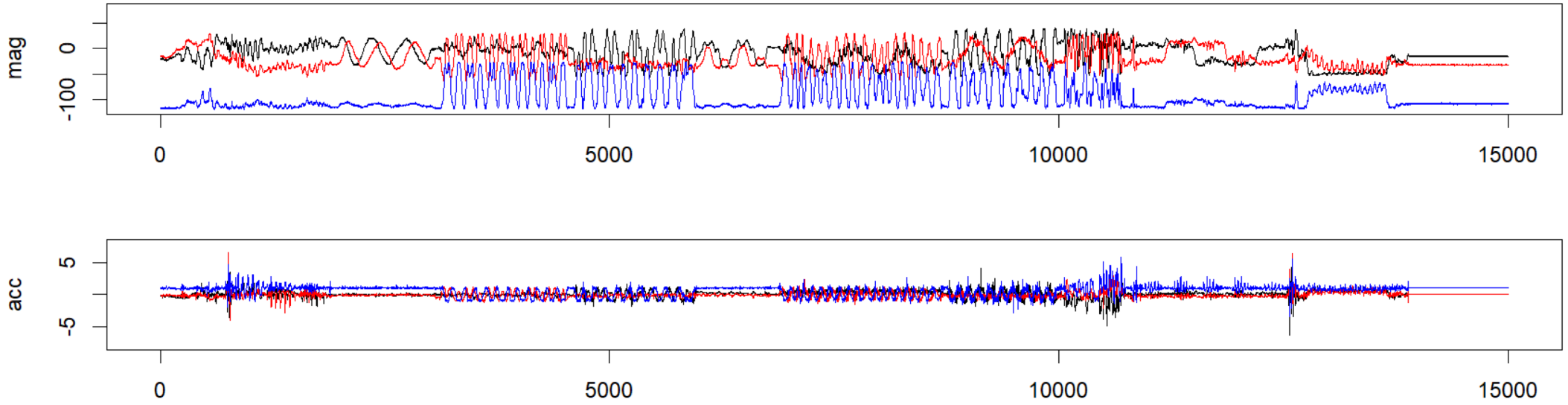
- tri-axial sensors that are capable of recording orientation in relation to the Earth's magnetic field (Gauss)
- Given this sensitivity, there is great potential for such systems to help elucidate animal behaviour based on angular rotation.





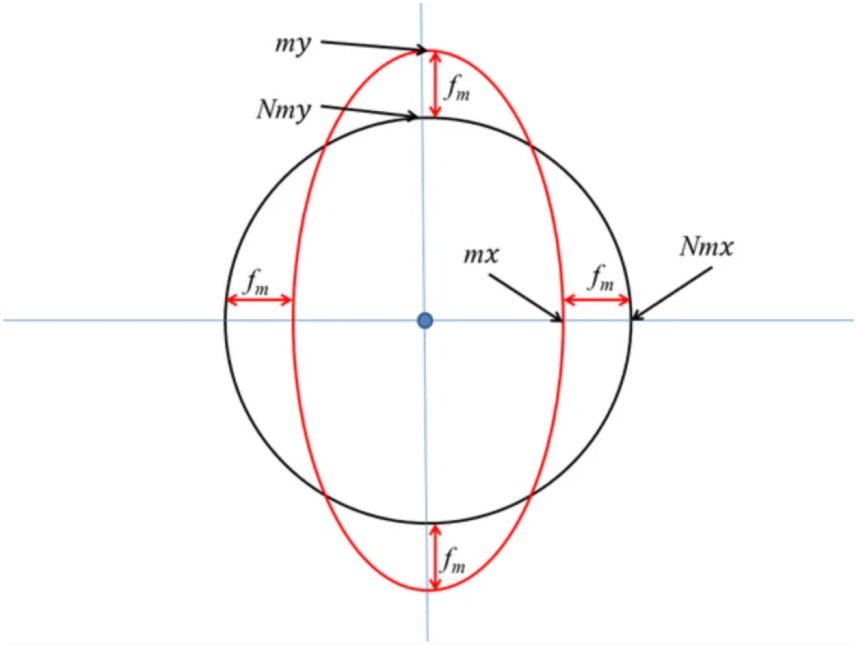
Williams et al (2017) Movement Ecology

Resolving orientation with magnetic and configuration calibrations

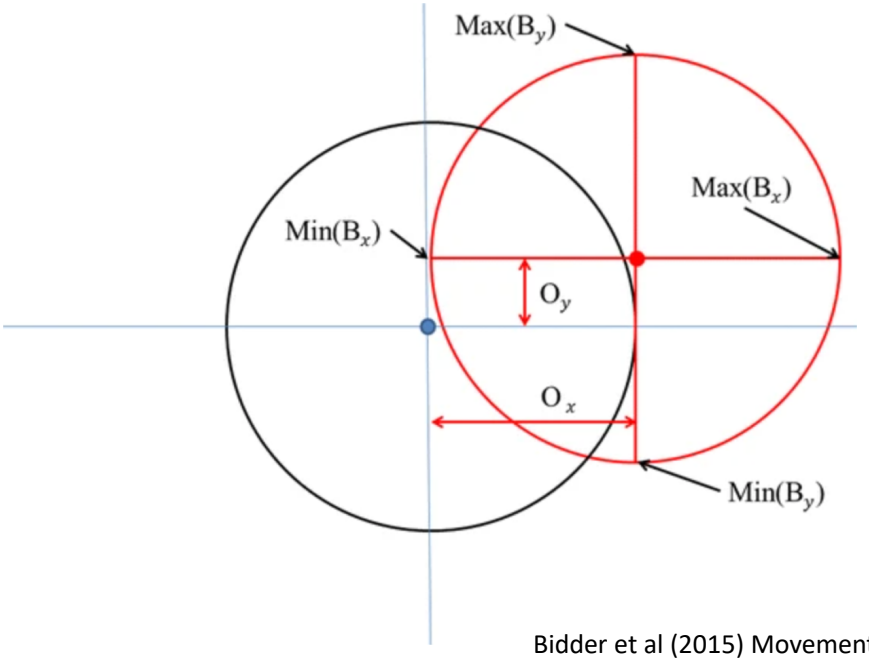


Resolving orientation with magnetic and configuration calibrations

Soft iron



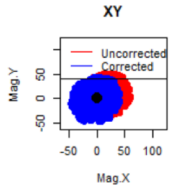
Hard iron

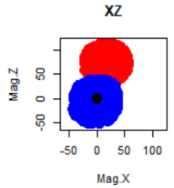


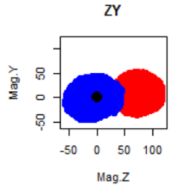
Bidder et al (2015) Movement Ecology

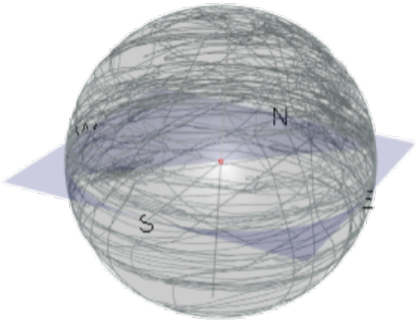
```
Gundog.compass = function(mag.x, mag.y, mag.z, acc.x, acc.y, acc.z, ME,
pitch.offset = 0, roll.offset = 0, yaw.offset = 0, method = 3, plot=TRUE)
```

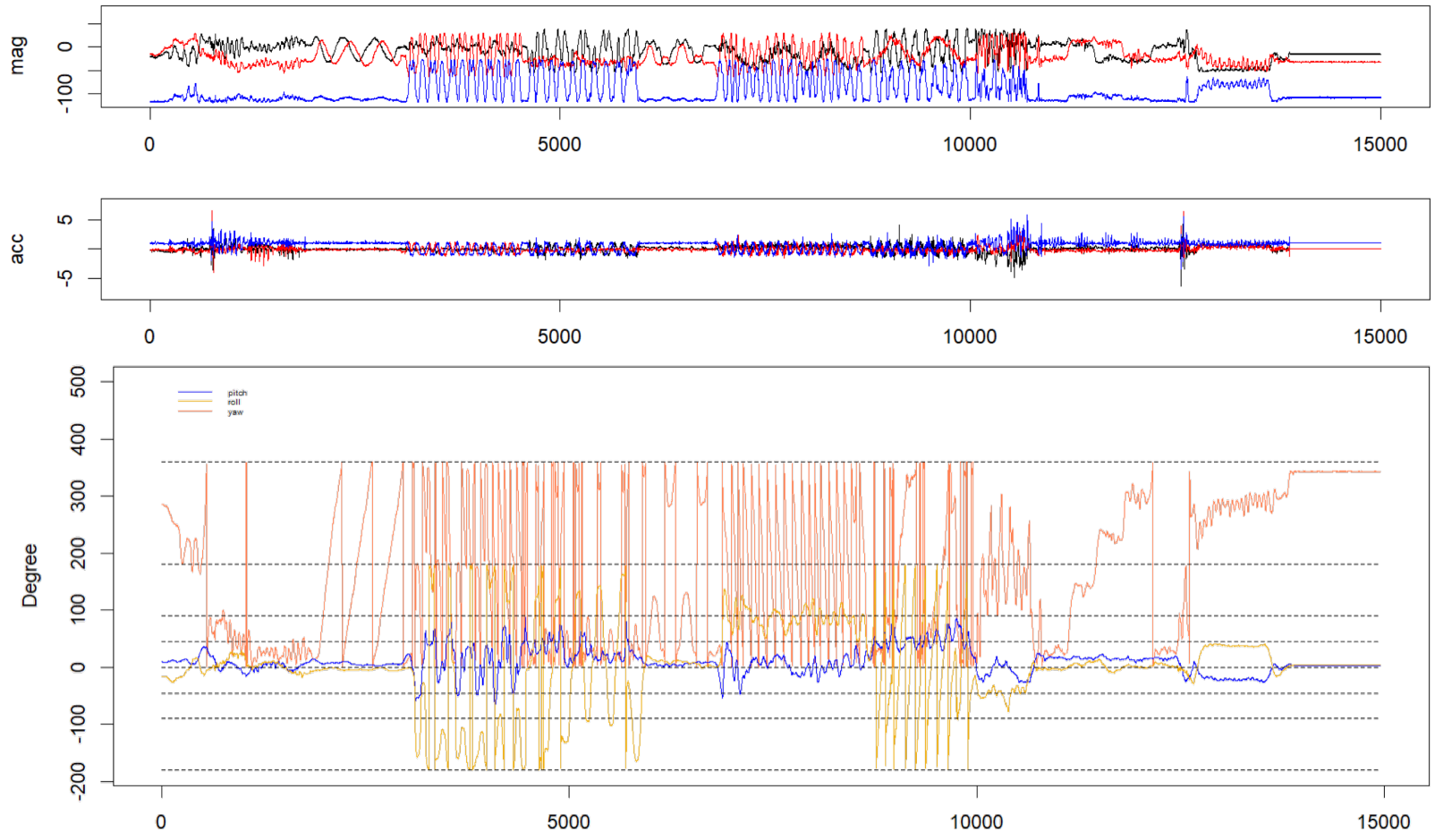
Resolving orientation with magnetic and configuration calibrations

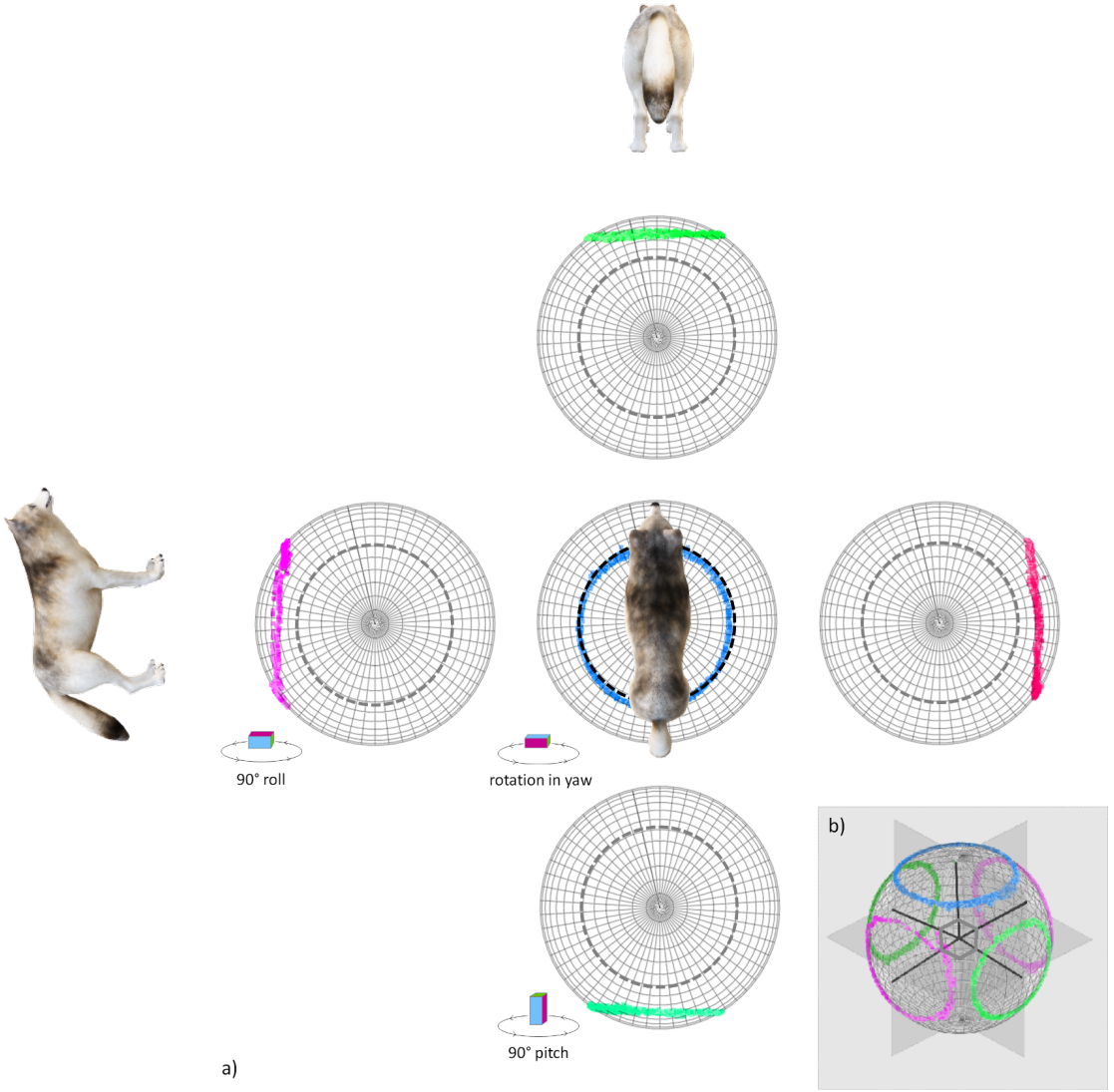






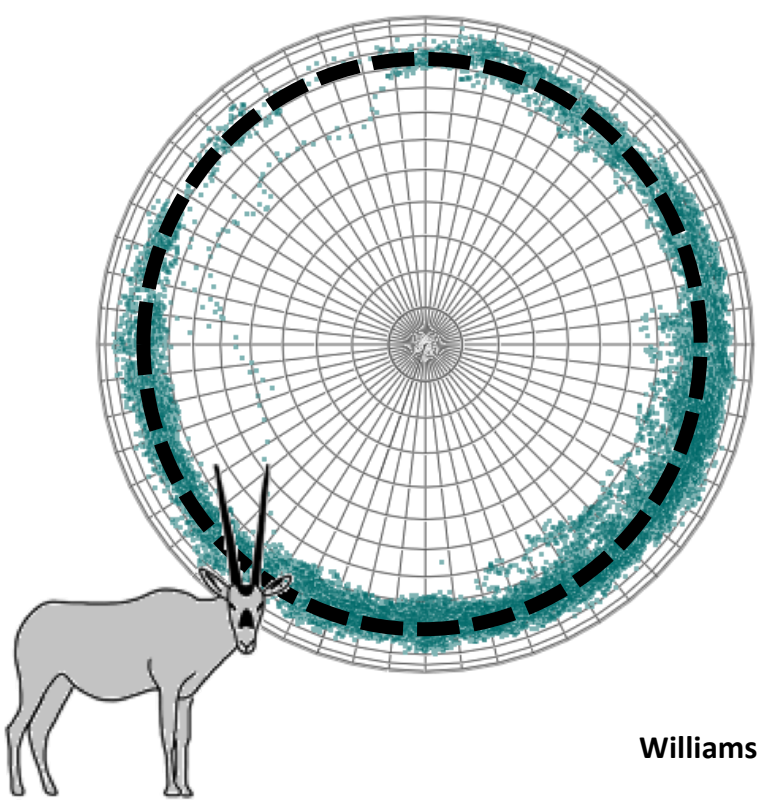


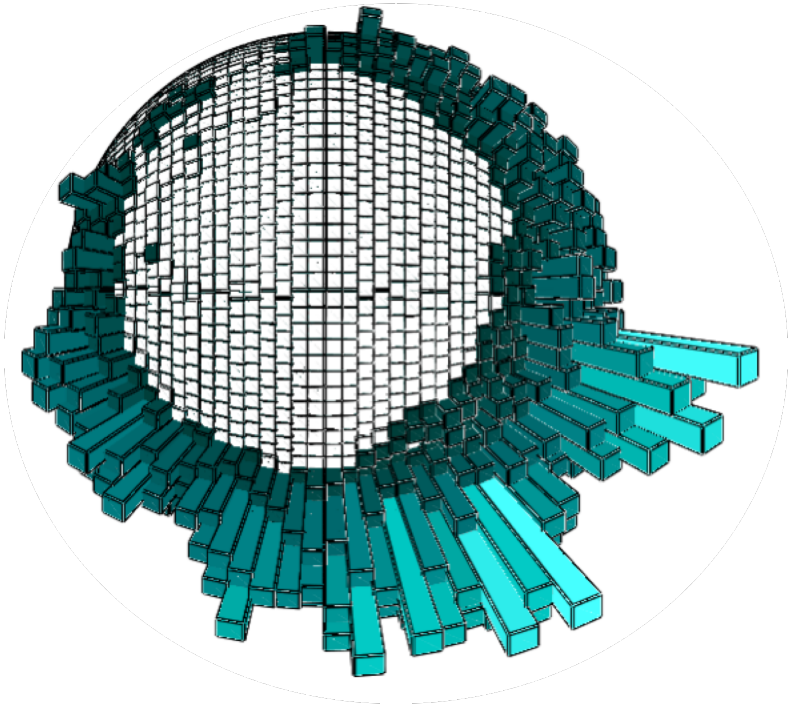




Normal Operational Plane

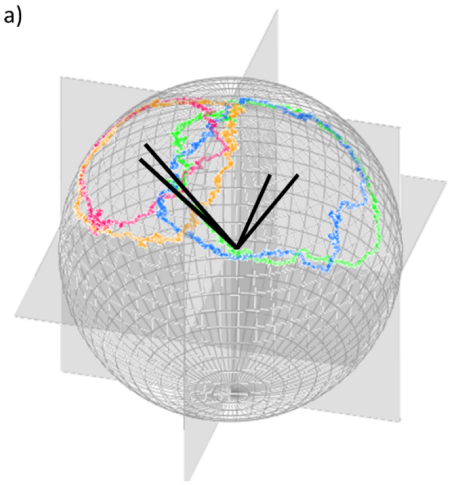
Adds directionality to behaviour to examine interactions, vigilance and responsivness

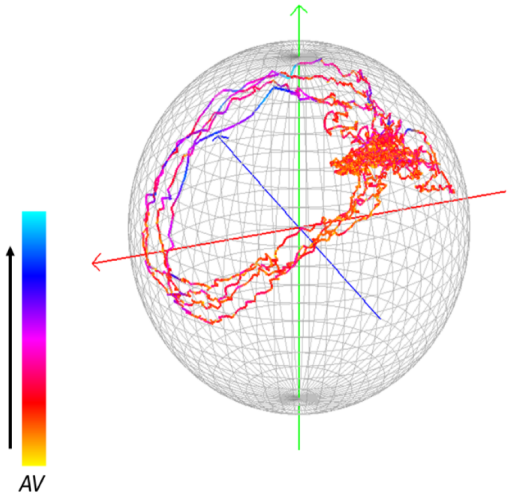


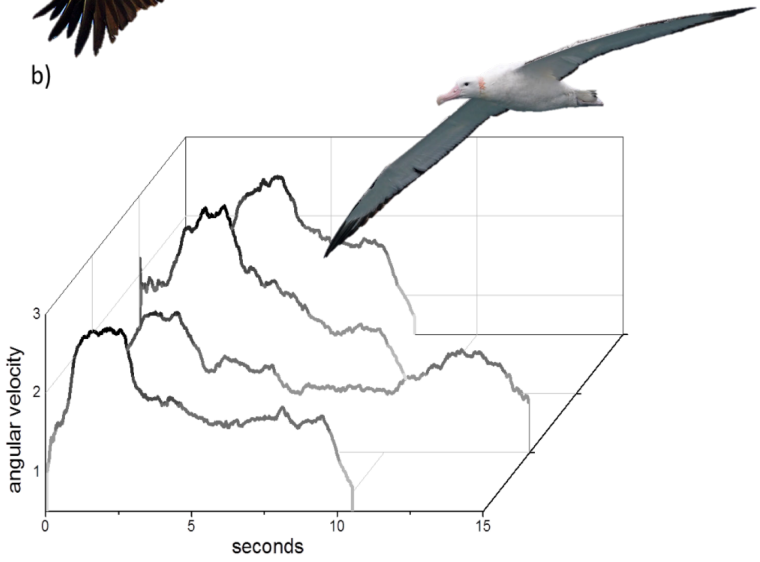


Williams et al. 2017 Identification of animal movement patterns using tri-axial magnetometry. Movement Ecology

‘M-prints’ to define behaviour!







Posture, Activity, Behaviour from IMU

Detailed metadata

Partition static and dynamic

Convert to DBA

Magnetometry corrections

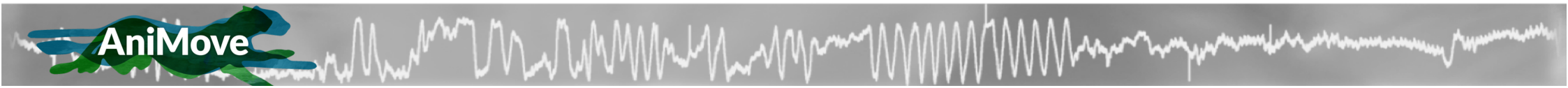
Preprocessing & subsampling

Visualise

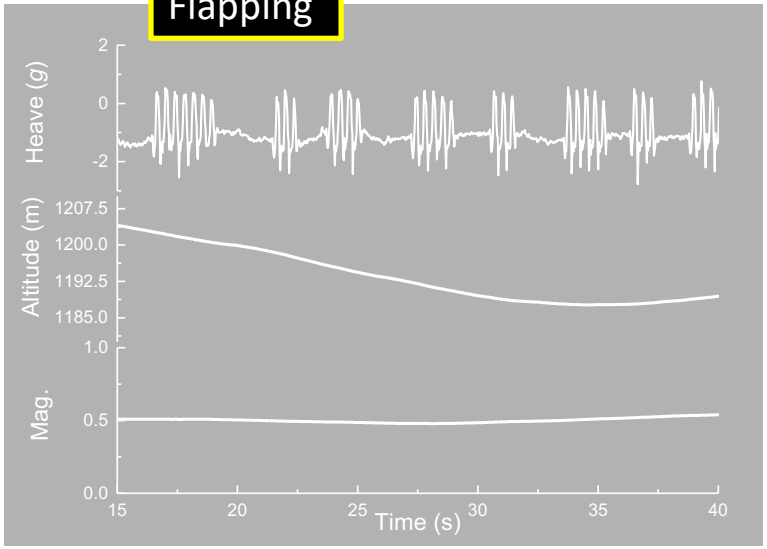
Behavioural classificiation

Dead-reckoning

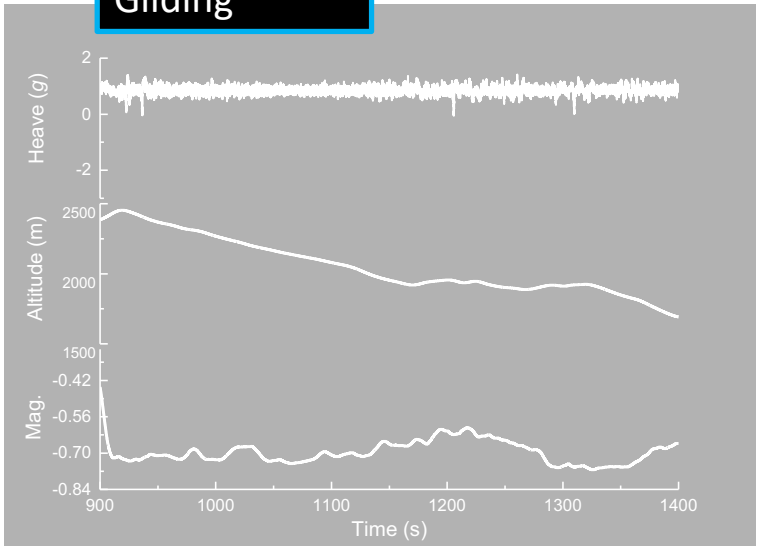
- detailed metadata on the attachment type and position on the animal of the loggers, as otherwise, establishing a close relationship between the output from sensor data (such as tri-axial accelerometer) and the heading and posture of the animal will be near impossible.
- Partition the static and dynamic components
- then converted to DBA (ideally correlated with energy or oxygen in lab)
- Magnetometry corrections
- Pre-processing should be per-formed before subsampling (in the case of autocorrelation)
- visualize and display quantitative information



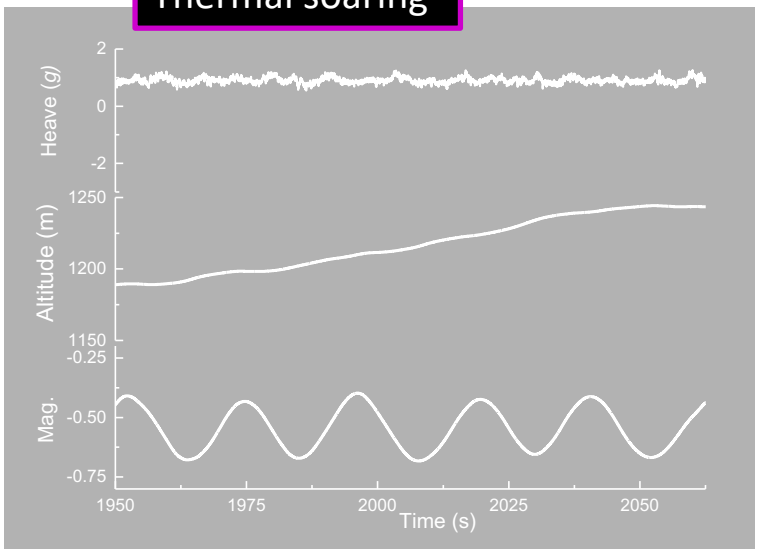
Flapping



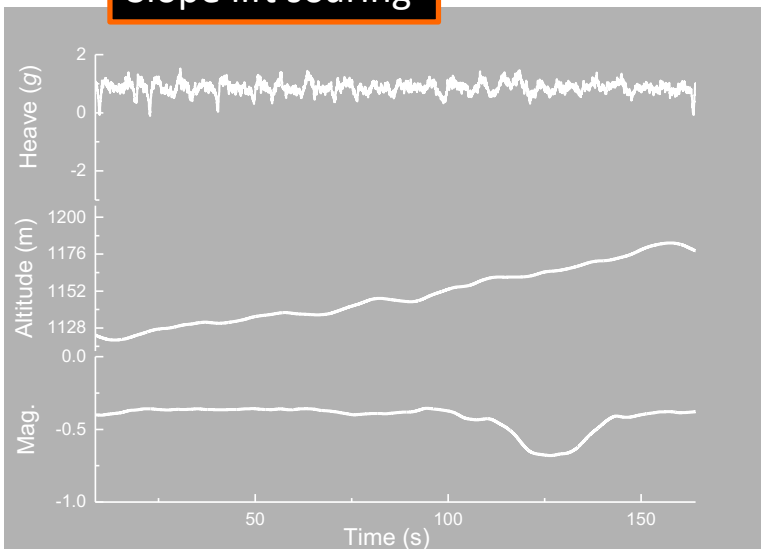
Gliding



Thermal soaring



Slope lift soaring



Behavioural Classification

Behaviour-linked thresholds

such as an increase in pressure to indicate diving, but more commonly will involve consideration of multiple data streams

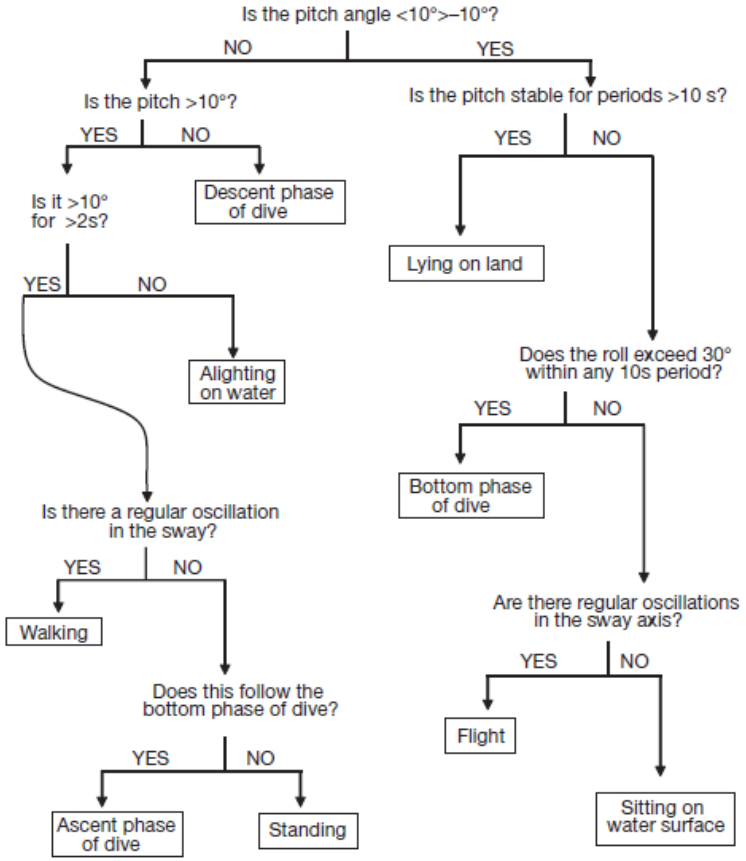


Fig. 6. *Phalacrocorax atriceps*. Simplistic diagram to show how behaviour of an imperial cormorant (cf. Fig. 5) can be resolved using data from a tri-axial accelerometer

Wilson et al (2020) JAE

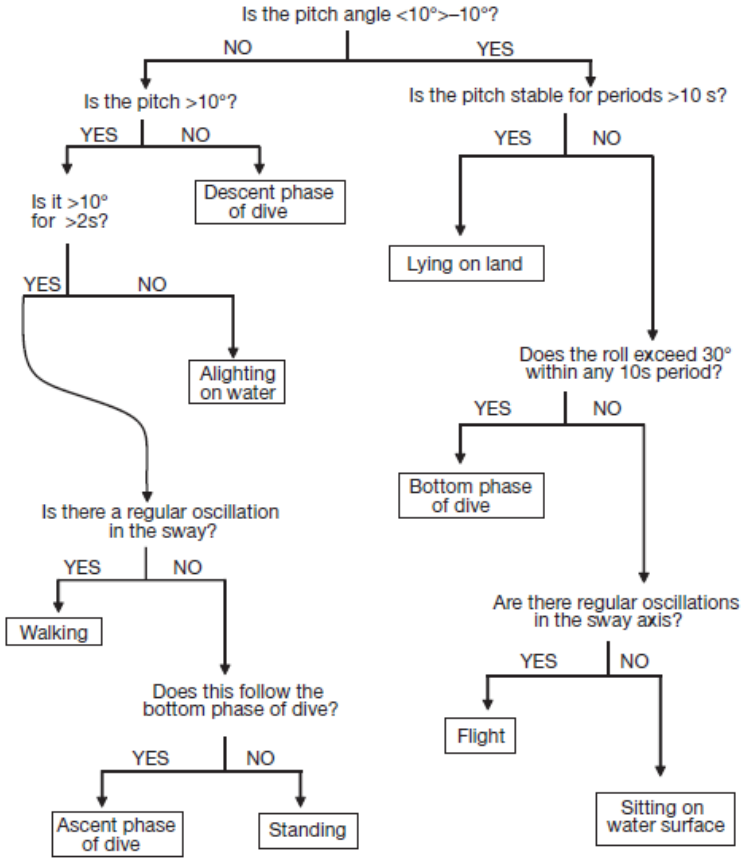
Behavioural Classification

Behaviour-linked thresholds

such as an increase in pressure to indicate diving, but more commonly will involve consideration of multiple data streams

Machine-learning algorithms:

- K-nearest neighbour [KNN]
- support vector machines [SVMs]
- classification and regression trees [CART]
- artificial neural networks [ANNs])
- hidden Markov models (HMMs)



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Wilson et al (2020) JAE

Behavioural Classification

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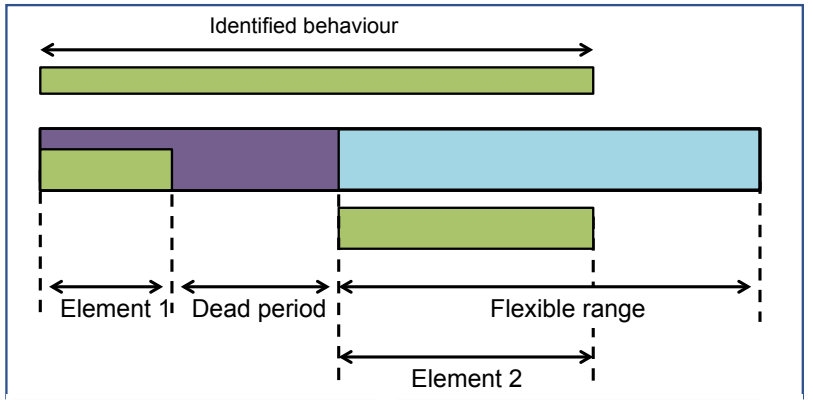
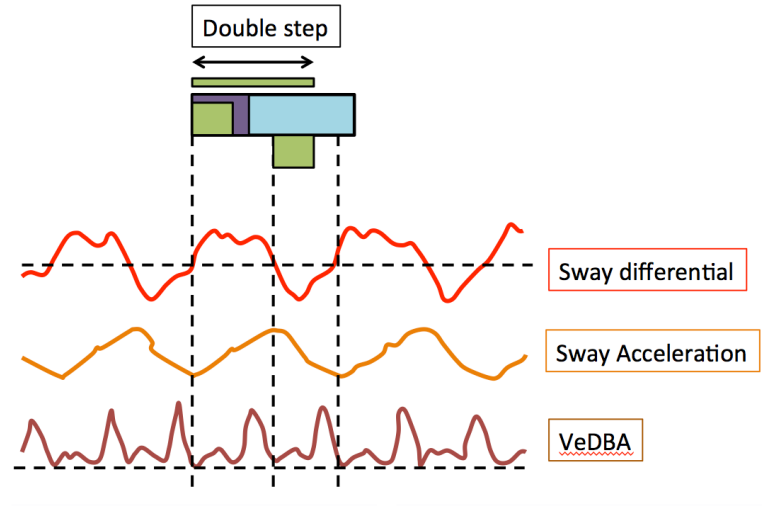
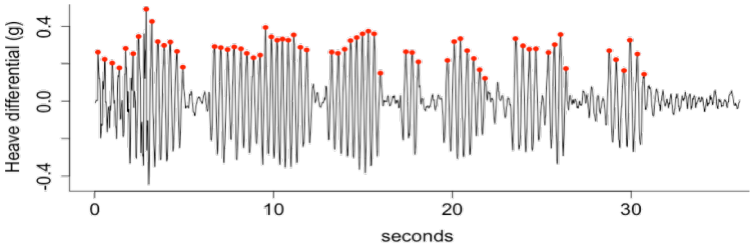
Boolean framework and requires that the researchers have enough specialist knowledge to be able to pick out a sequence of features in behaviours

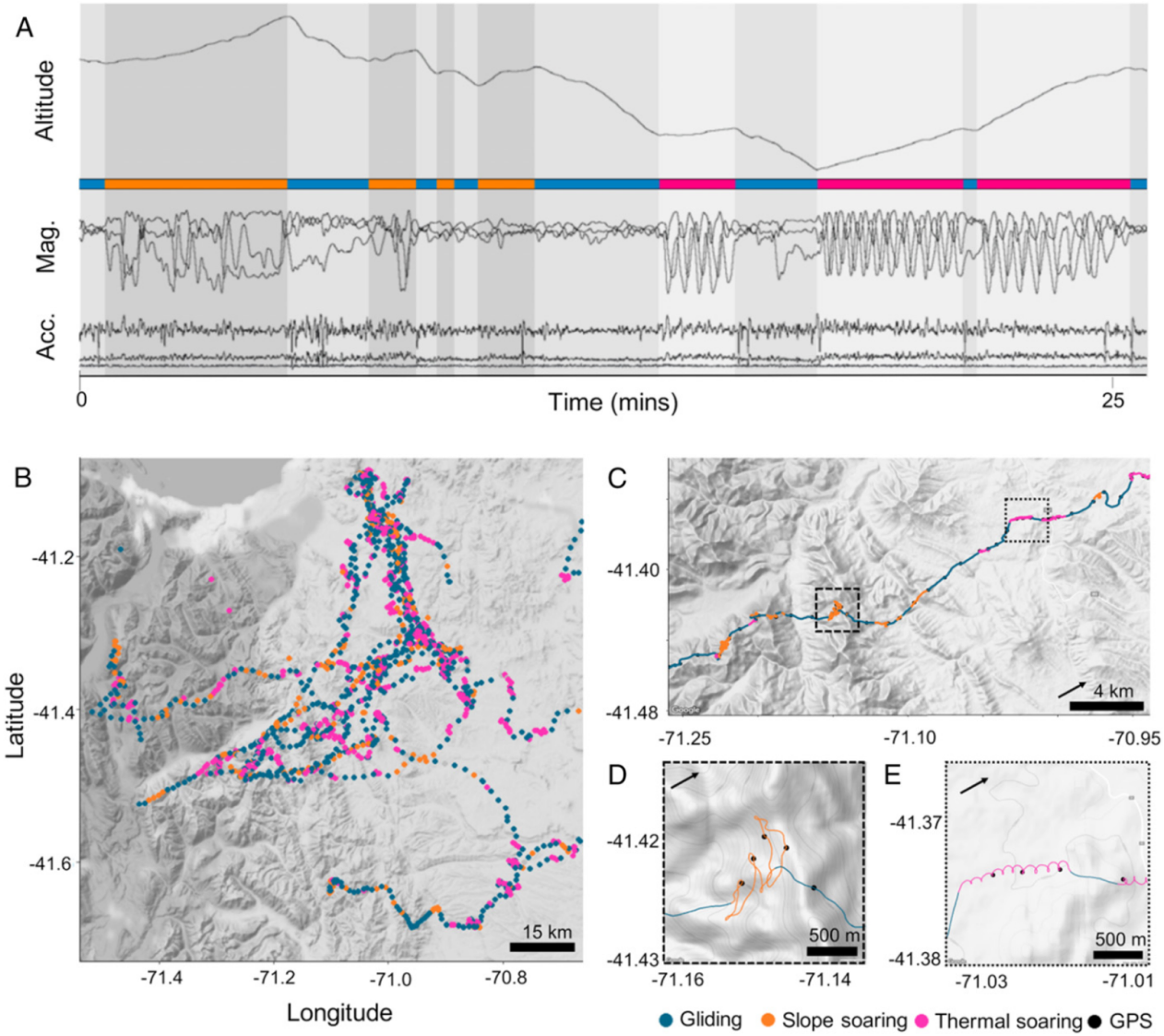




Wilson et al (2020) JAE

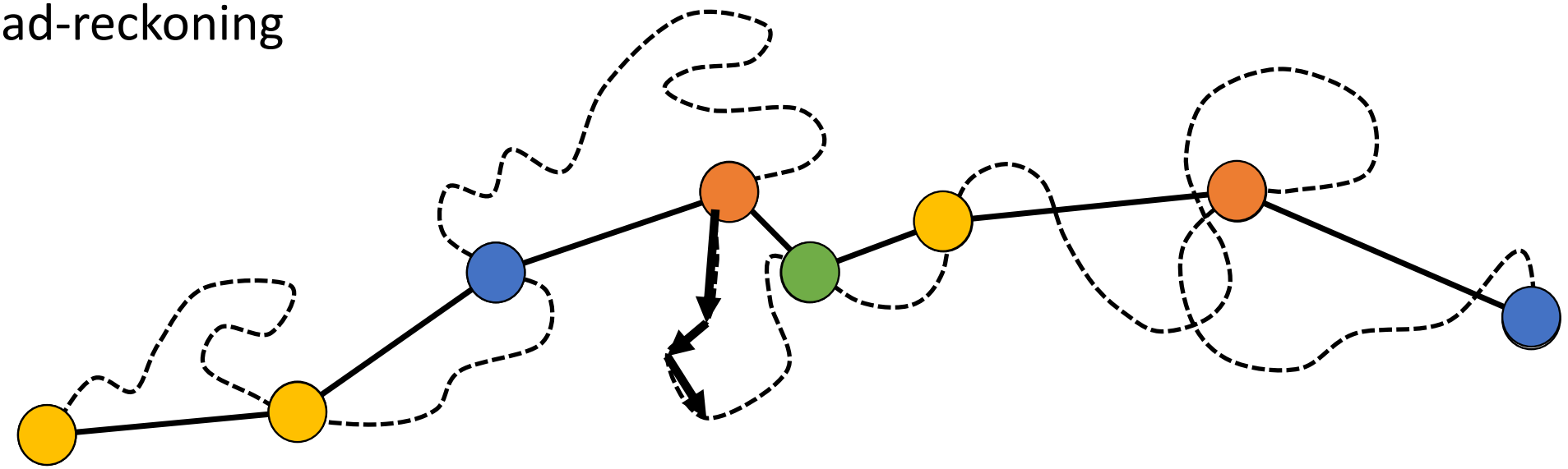
Andean Condors (*Vultur gryphus*)
Bariloche, Argentina, 2013-2018
8 Juveniles
9.5-13.9 kg
freely flying for 8 days of data collection
DD 40 Hz, GPS 0.1 Hz



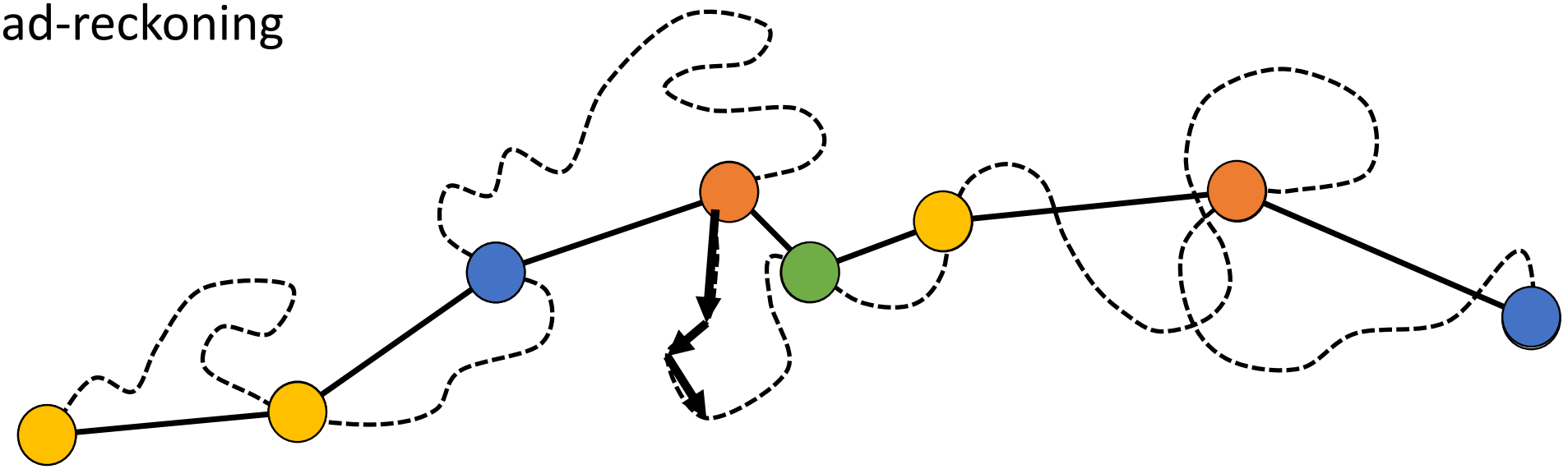


Williams &Shepard et al (2021)

Dead-reckoning



Dead-reckoning

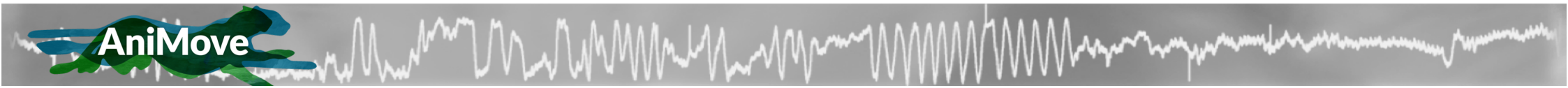


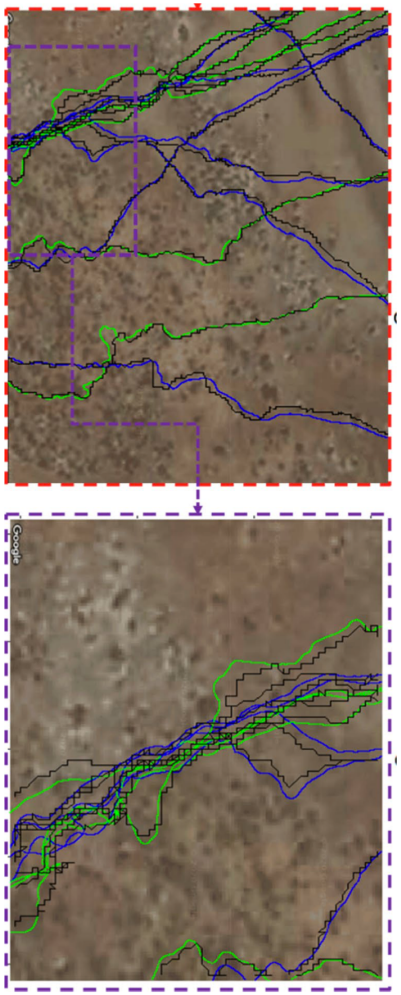
- ✓ Limitations of telemetry devices
- ✓ Properly identify true turn-points in the data
- ✓ Connect behaviour to landscape ecology and population dynamics with increased confidence
- ✓ embrace optimality approach - incorporate the energetic costs and benefits derived from detailed biologging data
- ✓ the bio-energetic reasons behind animal movement choices, rather than simply describing landscape aspects that covary with animal movement

Dead-reckoning

DBA speed proxy	- More recently, dynamic body acceleration has been validated as a linear proxy of speed for terrestrial animal (such as from treadmill tests or using GPS- derived speed)
Peak periodicity distance proxy	- peak periodicity (and amplitude) may be used as a proxy of distance moved by providing a distance per step estimate
Linear drift correction vector	- Ground-truthing dead-reckoned tracks typically involves the linear drift correction method to provide a correction vector that is applied linearly between time point one and time point two
Correction coefficients	- correction coefficients for both heading and distance are calculated
VPC	- Verified position correction

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





Gunner et al 2021

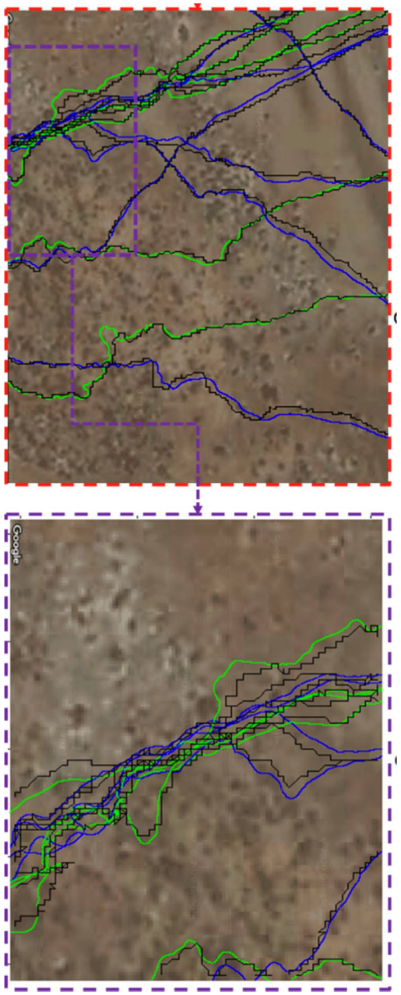
Dead-Reckoning procedure

Device orientation is expressed in terms of a sequence of Euler angle [roll (Φ), pitch (ϑ), yaw (Ψ)] rotations about the *x*-, *y*- and *z*-axes, respectively, relative to the (inertial) Earths fixed frame of reference

For the correct computation of heading, these two channels need to be aligned parallel to To the Earth's surface

Taken together then, in R, pitch and roll are computed according to, ($R_{24:25}$) with outputs within the range of – 90° to + 90° for pitch and – 180° to + 180° for roll, and this is the formula we use in the tilt-compensated method

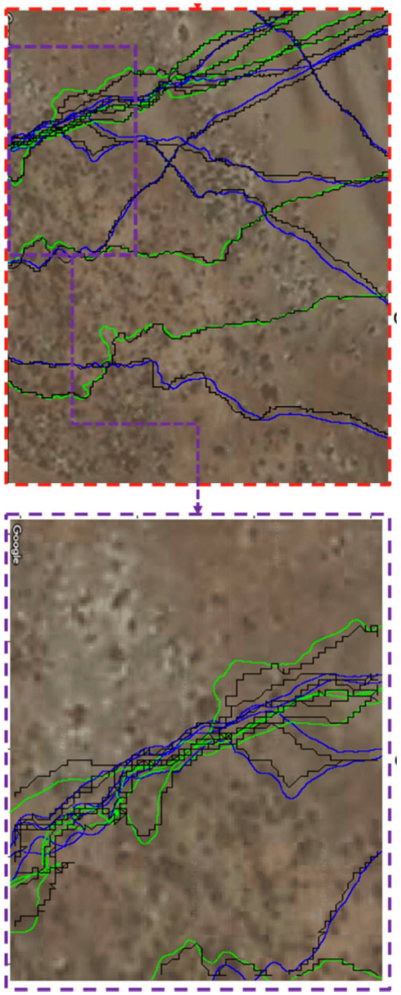
```
Pitch = atan2(-NGbx, sqrt(NGby^2 + NGbz^2)) * 180/pi
Roll = atan2(NGby, sign * sqrt(NGbz^2 + mu * NGbx^2)) * 180/pi
```



Gunner et al 2021

Dead-Reckoning procedure

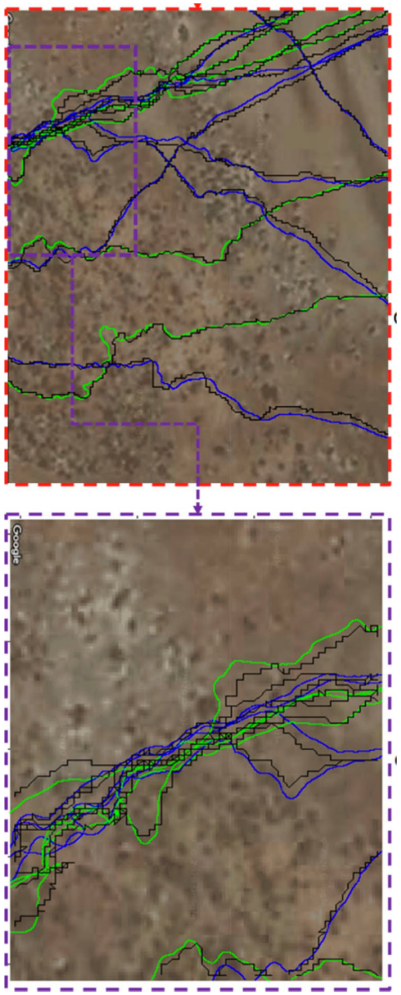
1. Magnetometer calibration, rotation correction and deriving of yaw
2. The magnetic vector of the device is then de-rotated to the Earth frame (tilt-corrected) by pre-multiplying by the product of the inverse roll multiplied by inverse pitch rotation matrix
3. Speed estimate e.g. VedBA, DBA, step frequency - distance per step
4. Convert speed to distance
5. Compute coordinates
6. Integrate current vectors



Gunner et al 2021

Verified Position Correction (VPC) procedure

- ✓ Reconstruct continuous, fine-scale 2-/3-D movement paths, irrespective of the environment and at higher resolution than any VP system
- ✓ Reduces the recording frequency of GPS locations, extending battery life and/or reducing deployment bulk/weight.
- ✓ Limits positional noise (‘jitter’) of ‘high-res’ (e.g., ≥ 1 Hz) GPS datasets, which is most apparent during non-moving behaviours such as rest and in highly heterogenous environments where radio signal can be easily obstructed

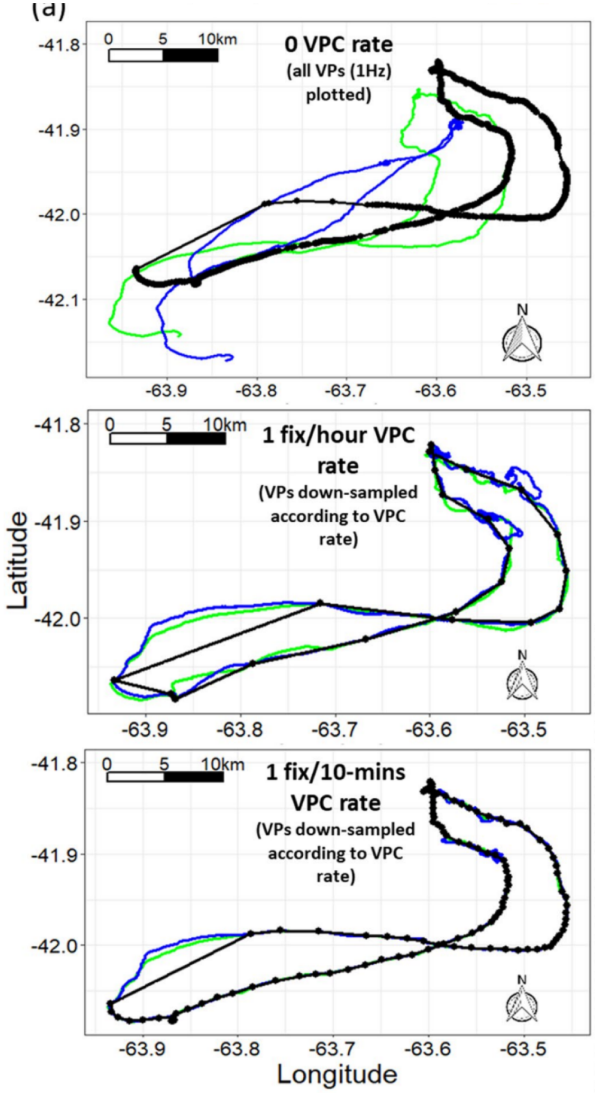


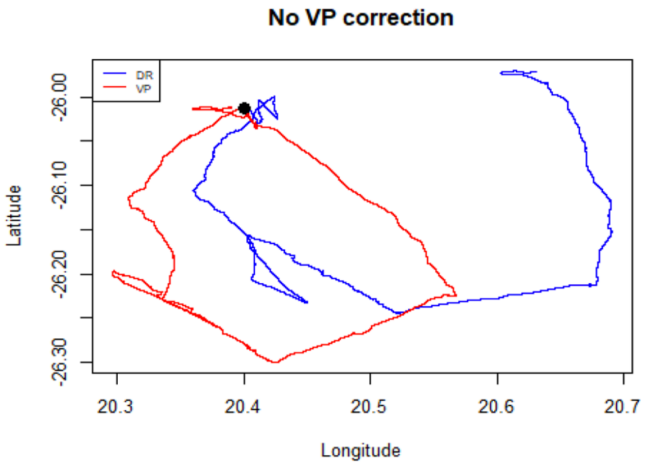
Gunner et al 2021

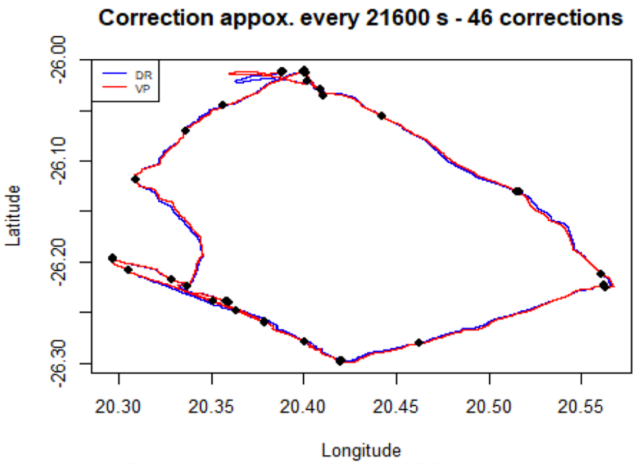
Verified Position Correction (VPC) procedure

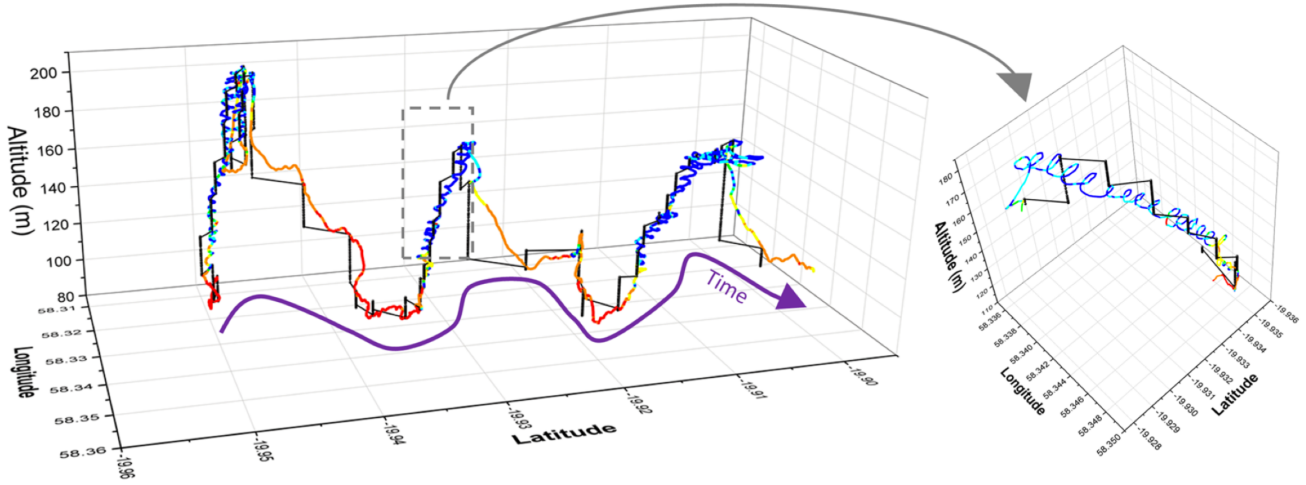
Haversine distance (net error; great-circle distance) and bearing (from true North; great circular bearing) between consecutive VPs and the corresponding time-matched dead-reckoned track positions.

1. Index row number with NA for non-VPs
2. Under sampled data frame time-matched DR tracks
3. Distance correction factor = VP distance / DR distance
4. Heading correction factor = VP head - DR head
5. Merged back to the main data frame
6. Updated coefficients are substituted into DR formular and process repeated iteratively


(d)
0 VPC rate
(all VPs (1Hz) plotted)
1 fix/hour VPC rate
(VPs down-sampled according to VPC rate)
1 fix/10-mins VPC rate
(VPs down-sampled according to VPC rate)
0 5 10km
N
Latitude
Longitude
-41.8
-41.9
-42.0
-42.1
-63.9
-63.8
-63.7
-63.6
-63.5


No VP correction
DR
VP
Latitude
Longitude
-26.00
-26.10
-26.20
-26.30
20.3
20.4
20.5
20.6
20.7


Correction appox. every 21600 s - 46 corrections
DR
VP
Latitude
Longitude
-26.00
-26.10
-26.20
-26.30
20.30
20.35
20.40
20.45
20.50
20.55


Altitude (m)
Longitude
Latitude
Time
200
180
160
140
120
100
80
58.31
58.32
58.33
58.34
58.35
58.36
-19.96
-19.95
-19.94
-19.93
-19.92
-19.91
-19.90

Barometric pressure sensor

$$\text{Altitude(m)} = 44,330 \times \left[1 - \left(\frac{P}{P_o}\right)^{\frac{1}{5.255}}\right]$$

where P is the smoothed pressure and P_o is a daily constant pressure at sea level

Home > Animal Biotelemetry > Article

How to improve the accuracy of height data from bird tracking devices? An assessment of high-frequency GPS tracking and barometric altimetry in field conditions

Methodology | Open access | Published: 04 August 2023
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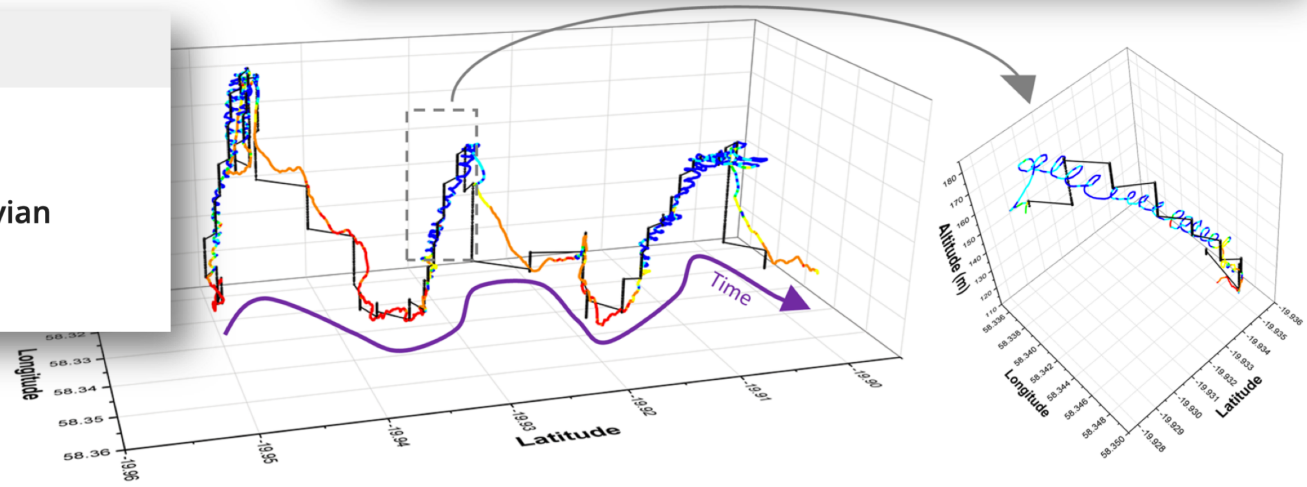
RESEARCH ARTICLE

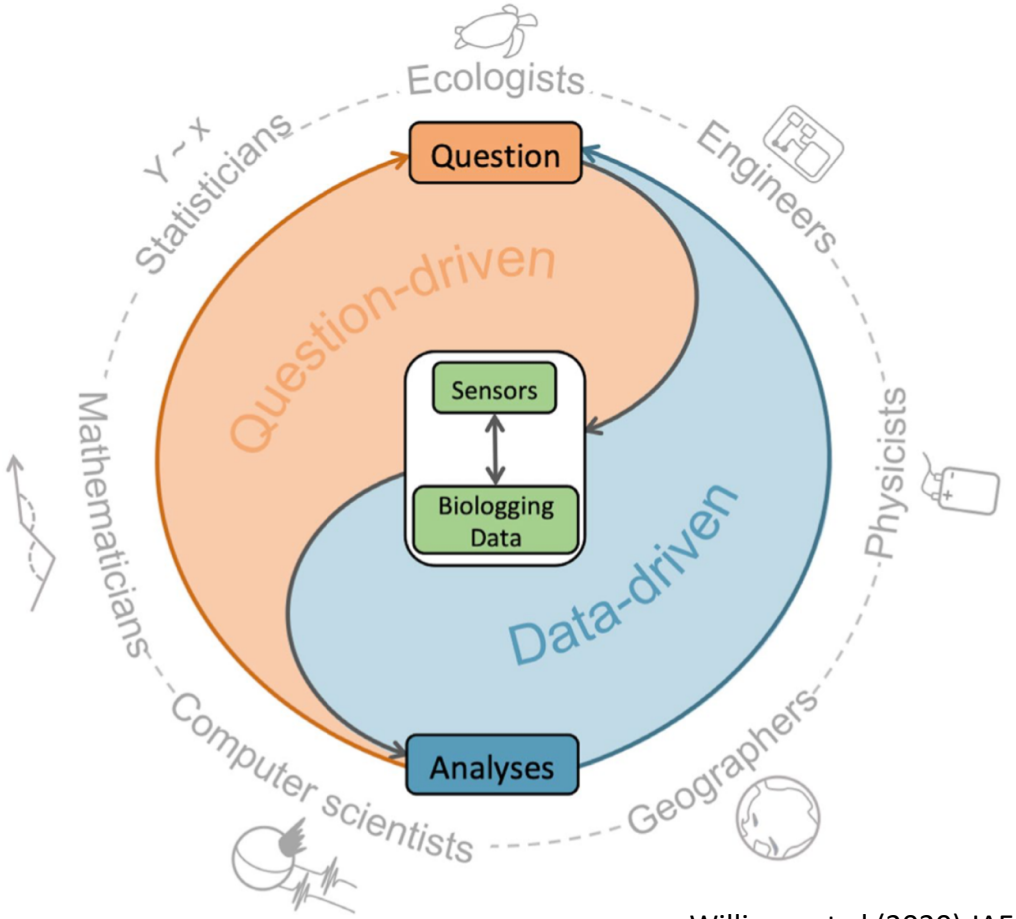
Assessing the accuracy of altitude estimates in avian biologging devices

Kimberly A. Lato, Julia E. F. Stepanuk, Eleanor I. Heywood, Melinda G. Conners, Lesley H. Thorne

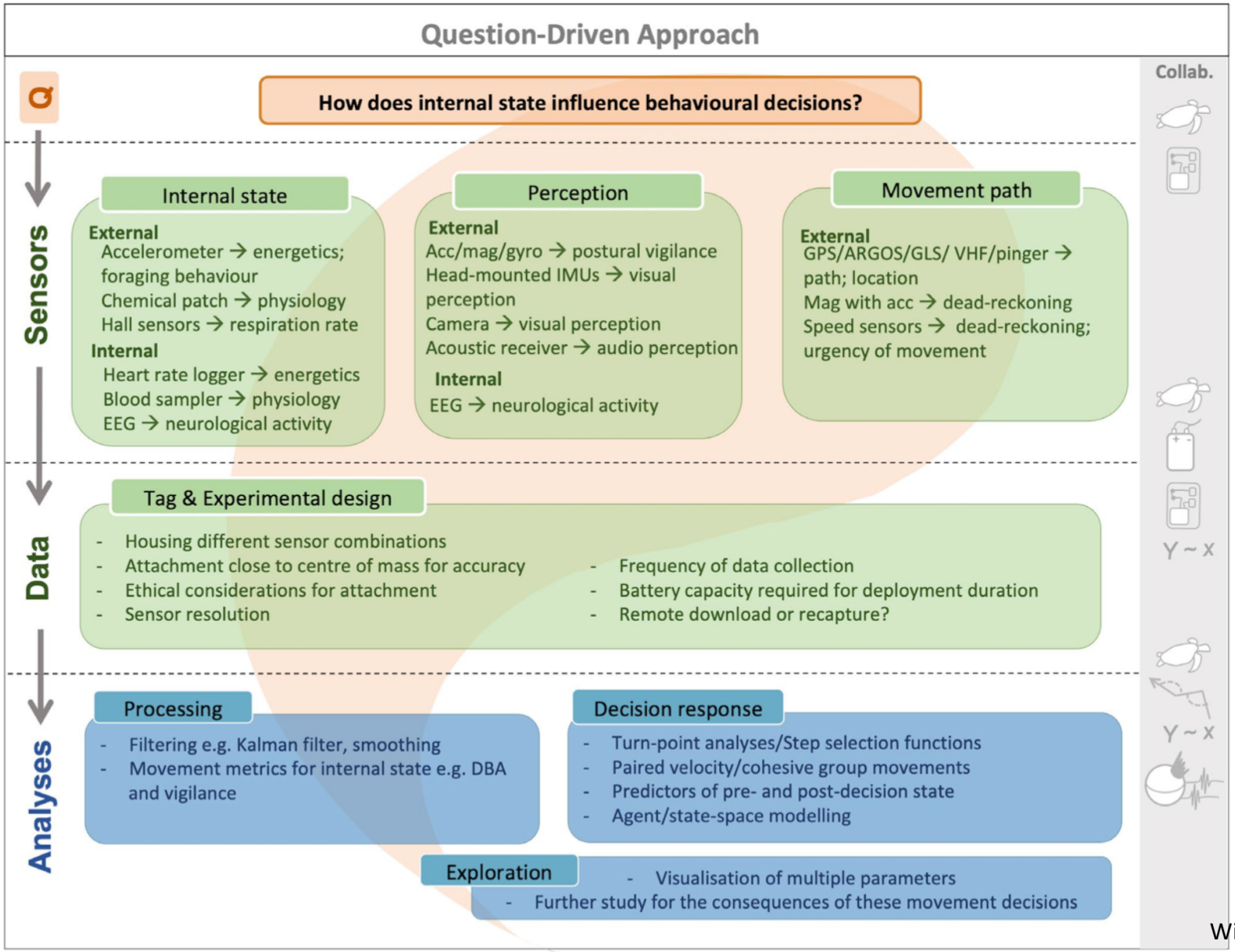
Published: October 26, 2022 • https://doi.org/10.1371/journal.pone.0276098



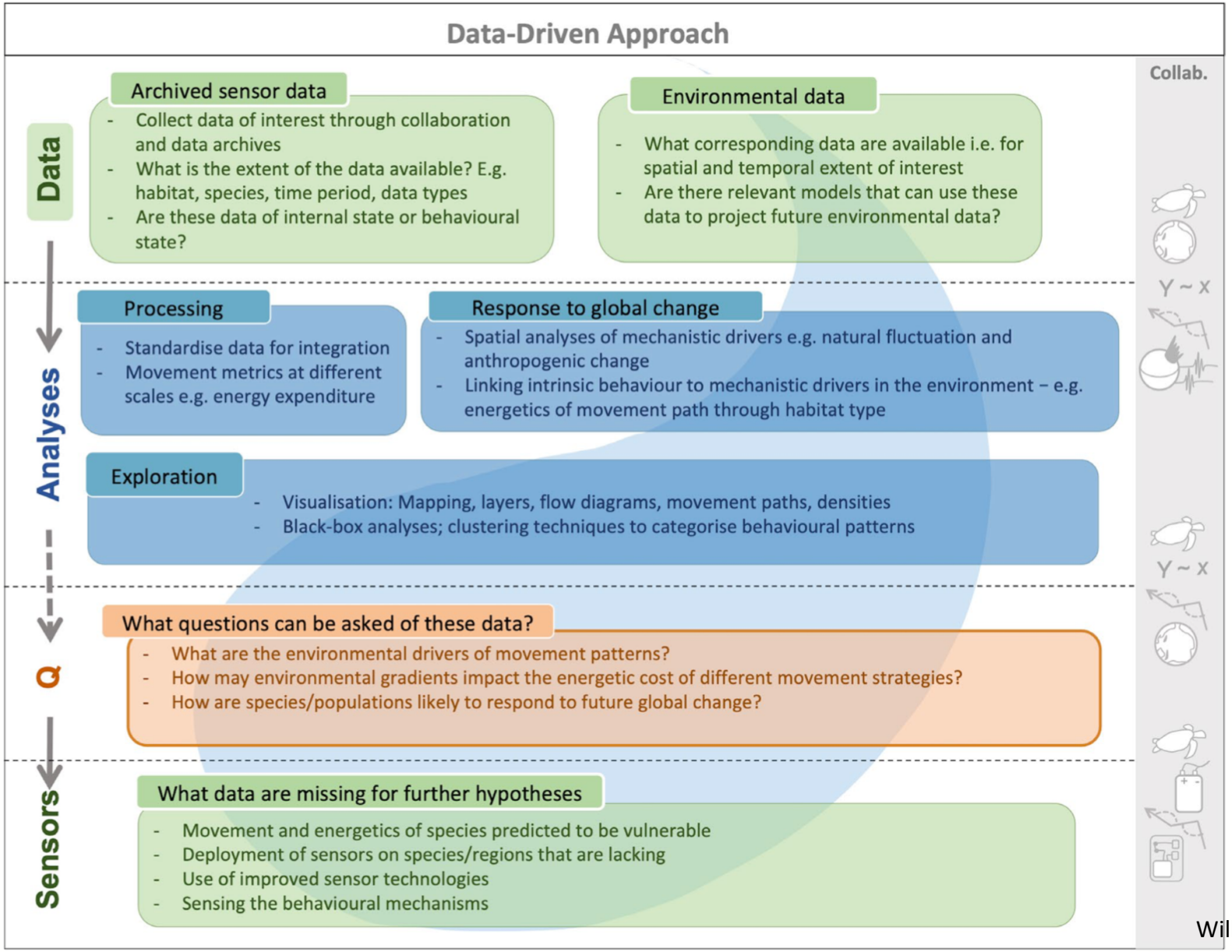
Optimising use of multisensory bio-loggers



Williams et al (2020) JAE



Williams et al (2020) JAE



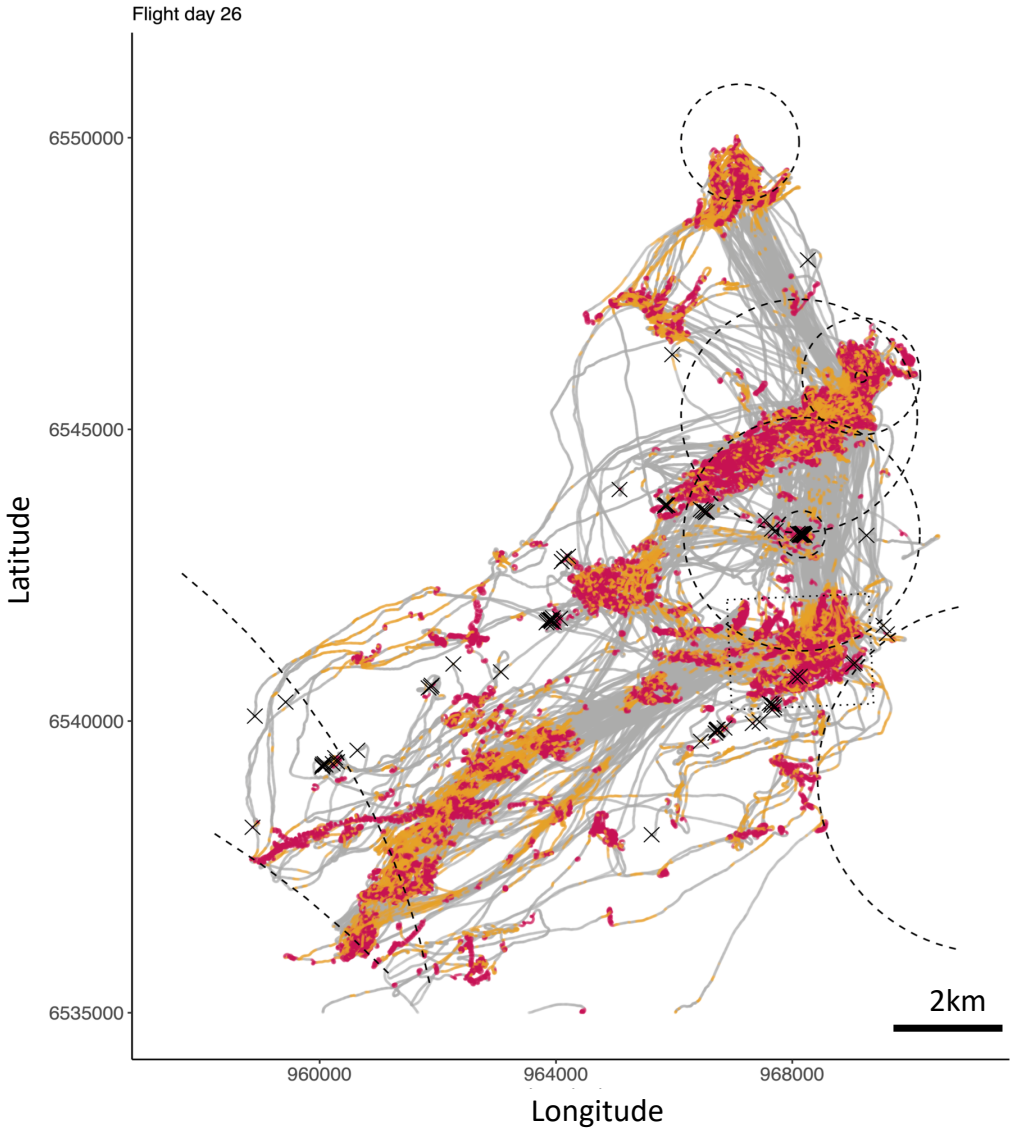
Williams et al (2020) JAE

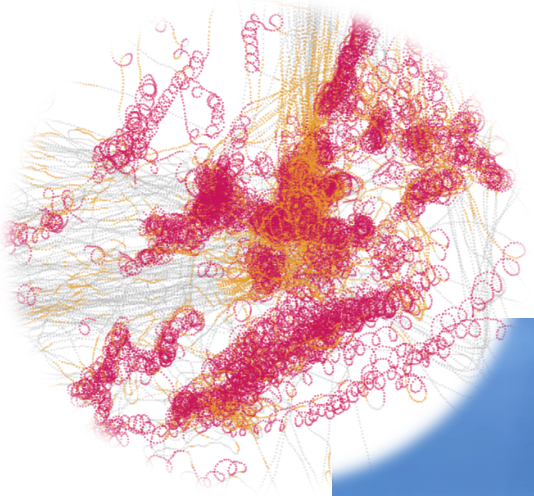
A Case Study: soaring flight

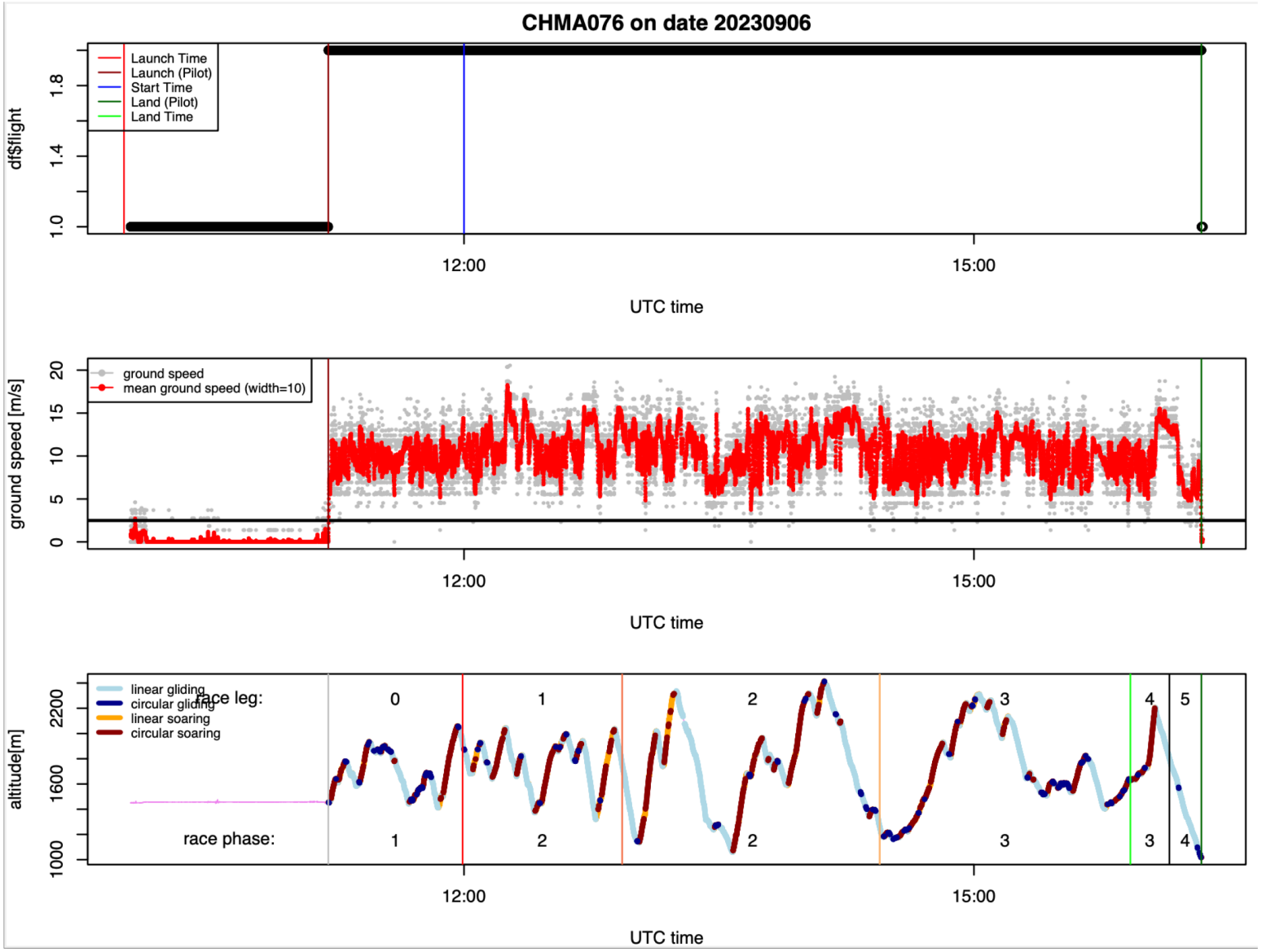
AniMove

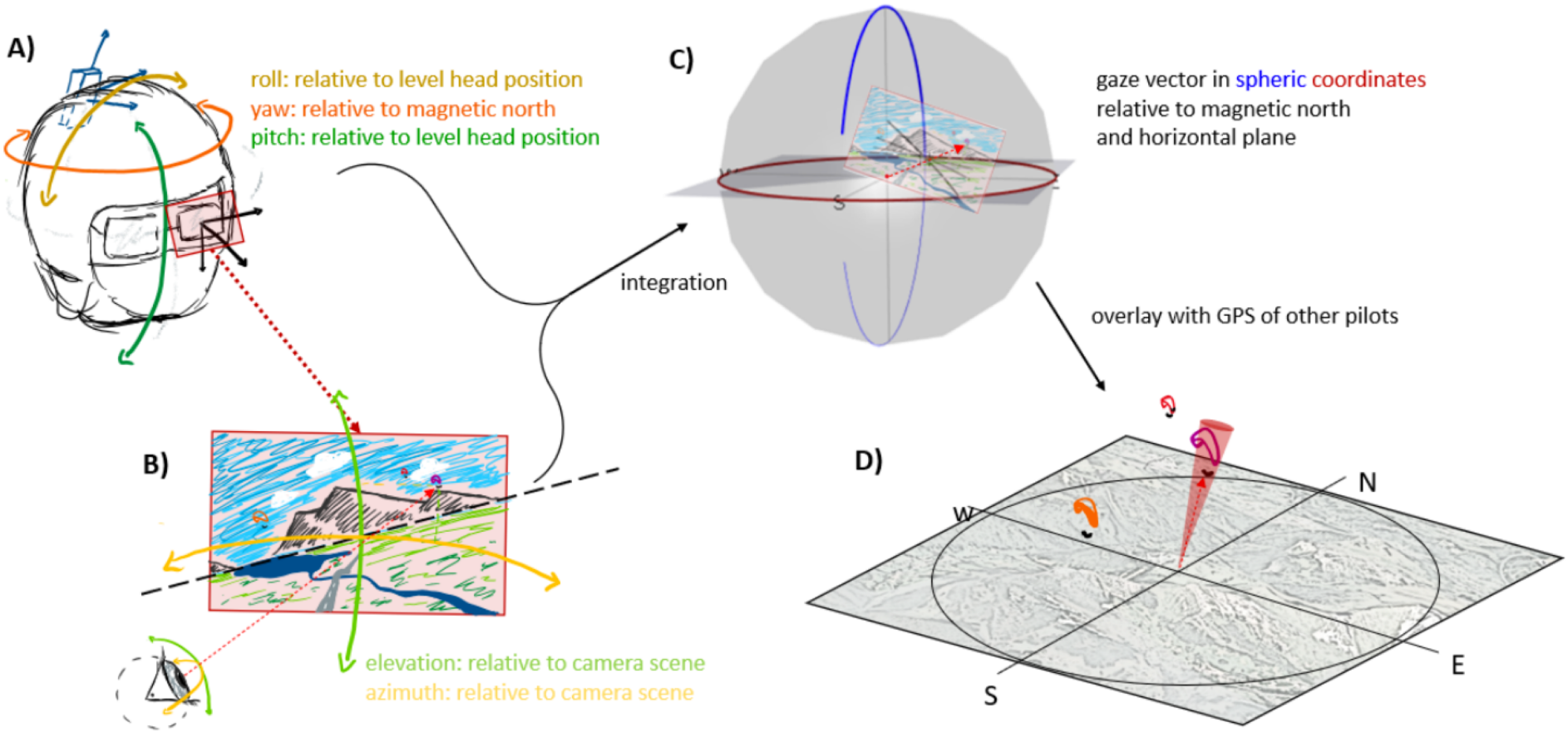
EIGEIST
FELLOWSHIP DER VOLKSWAGENSTIFTUNG

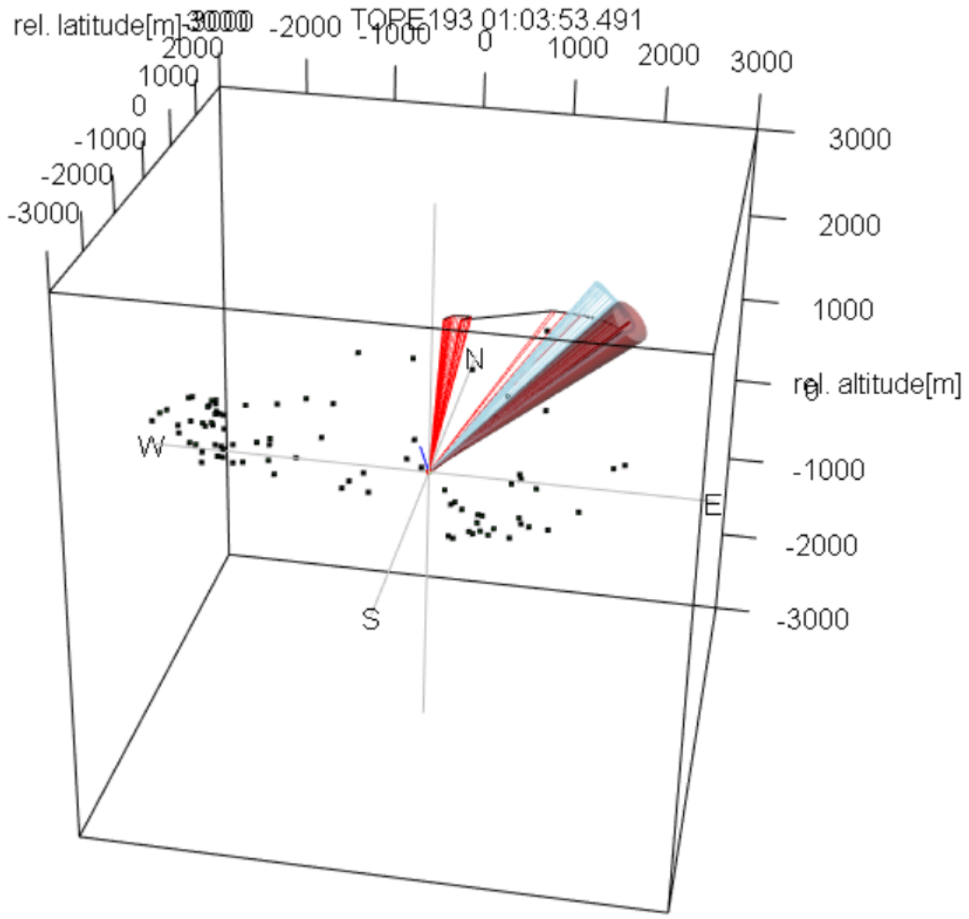
Move
inFormation


Flight day 26
6550000
6545000
6540000
6535000
Latitude
960000
964000
968000
Longitude
2km


Behaviour
circular
linear.soaring


CHMA076 on date 20230906
Launch Time
Launch (Pilot)
Start Time
Land (Pilot)
Land Time
df$flight
1.0
1.4
1.8
12:00
15:00
UTC time
ground speed
mean ground speed (width=10)
ground speed [m/s]
0
5
10
15
20
12:00
15:00
UTC time
linear gliding
circular gliding
linear soaring
circular soaring
race leg:
0
1
2
3
4
5
race phase:
1
2
2
3
3
4
altitude[m]
1000
1600
2200
12:00
15:00
UTC time


A)
roll: relative to level head position
yaw: relative to magnetic north
pitch: relative to level head position
B)
elevation: relative to camera scene
azimuth: relative to camera scene
integration
C)
gaze vector in spheric coordinates
relative to magnetic north
and horizontal plane
overlay with GPS of other pilots
D)
N
W
E
S


TOPE193 01:03:53.491
rel. latitude[m]
-3000
-2000
-1000
0
1000
2000
3000
rel. altitude[m]
N
W
E
S

Resolving behavior with auxiliary sensors