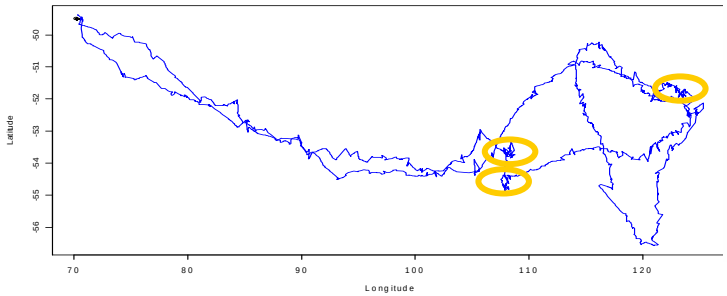
Centre d'Études Biologiques de Chizé

Marine predators team

Southern Elephant Seal Foraging Behaviour
Influences of Oceanographic Conditions

Anne-Cécile Dragon [1,2]



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[2] MAP 5-CNRS, France

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Chize, 16 September 2011

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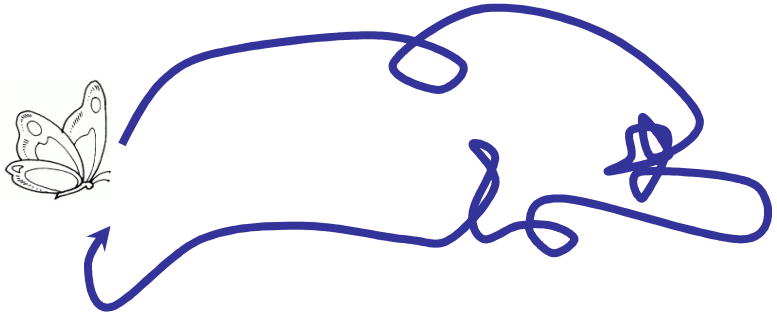


Seasonal migrations

Avoiding predators

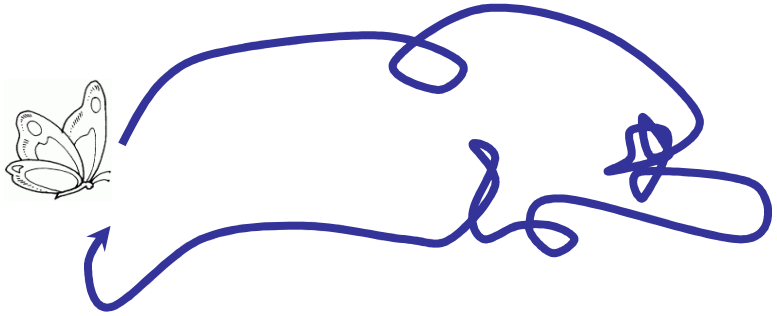
Foraging

Animal movement

Finding mates

Aggressive interactions

Optimal Foraging



Seasonal migrations

Avoiding predators

Foraging

Animal movement

Finding mates

Aggressive interactions

Optimal Foraging Theory

Mac Arthur & Pianka 1966 ; Emlen 1966 ; Pyke et al. 1977 etc.

→ animals forage in ways maximizing their fitness

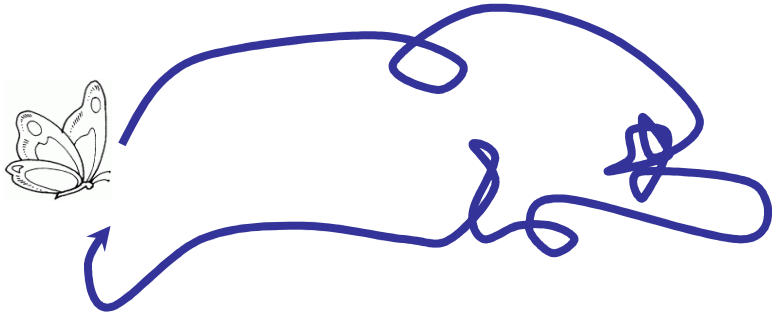
→ evolutionary favorable strategies that optimise resource acquisition

Field measurements

In the field,

observations / measurements of

- **feeding events**



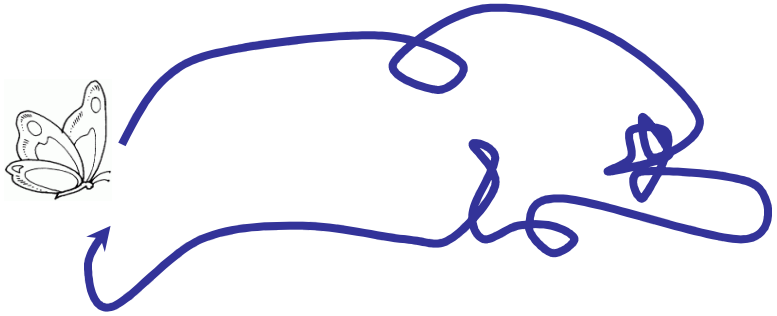
feeding events

Field measurements

In the field,

observations / measurements of

- **feeding events**
- **body condition**



feeding events

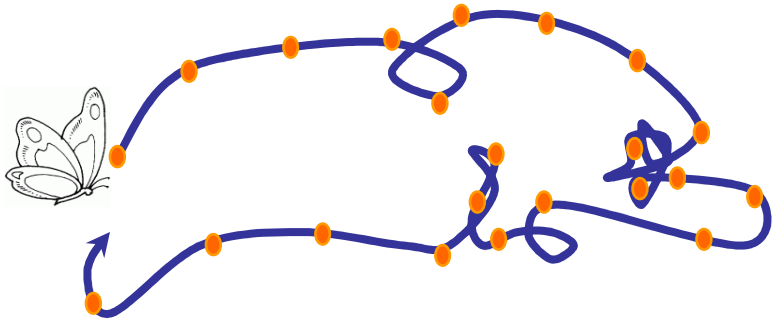
body condition

Field measurements

In the field,

observations / measurements of

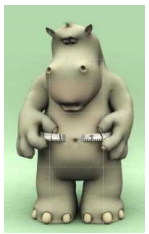
- **feeding events**
- **body condition**
- **trajectory**

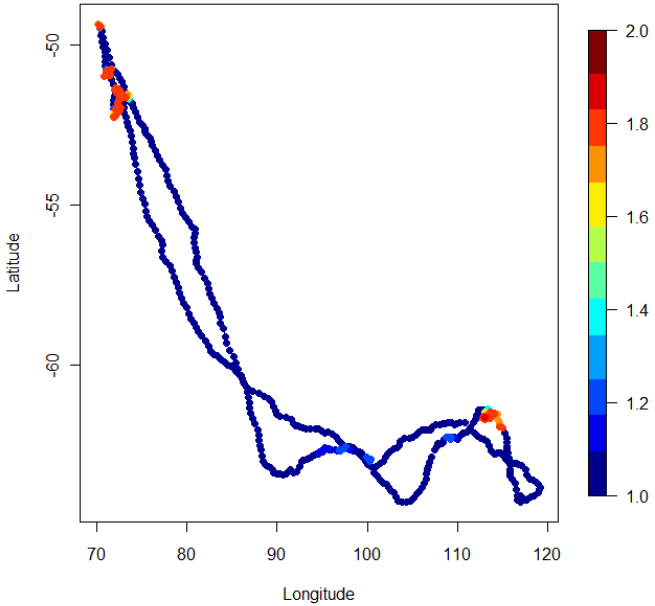


trajectory

feeding events

body condition





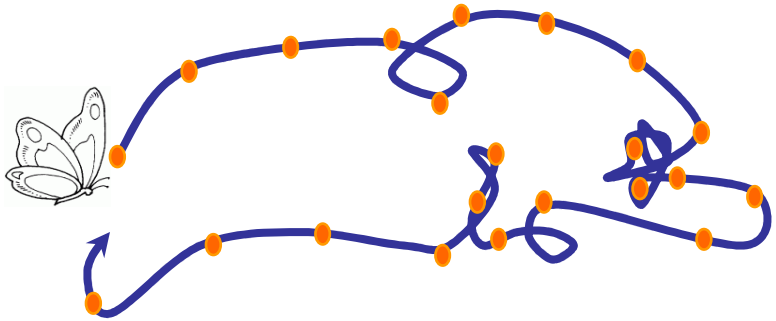
Field measurements

In the field,

observations / measurements of

- **feeding events**
- **body condition**
- **trajectory**

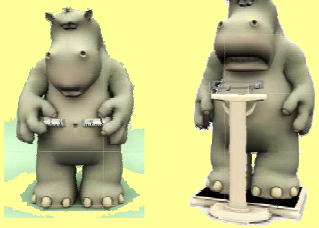
} ***proxies***

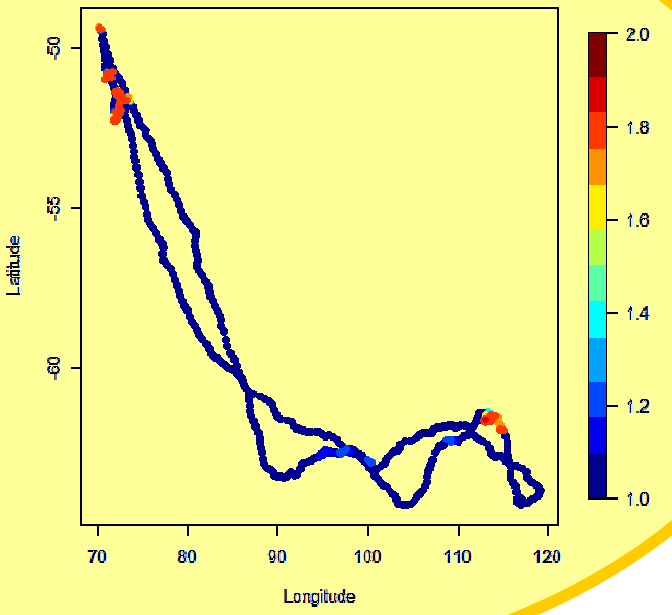


feeding events

trajectory

body condition





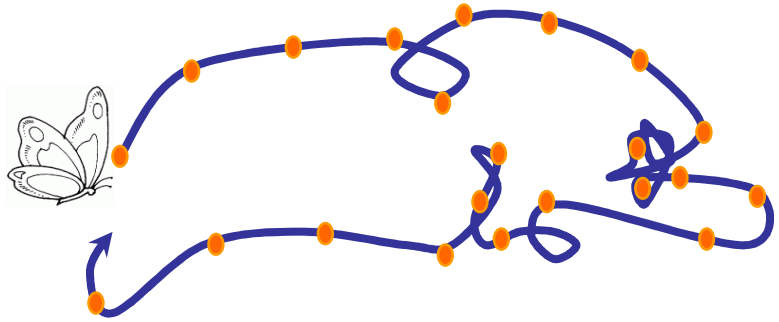
Trajectory

Movement

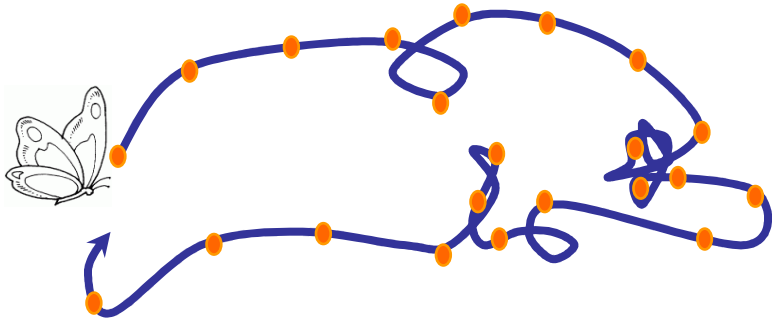
→ continuous process

∀t decision to change behaviour

or not



Trajectory



Movement

→ continuous process

∀t decision to change behaviour

or not

Moving animal,

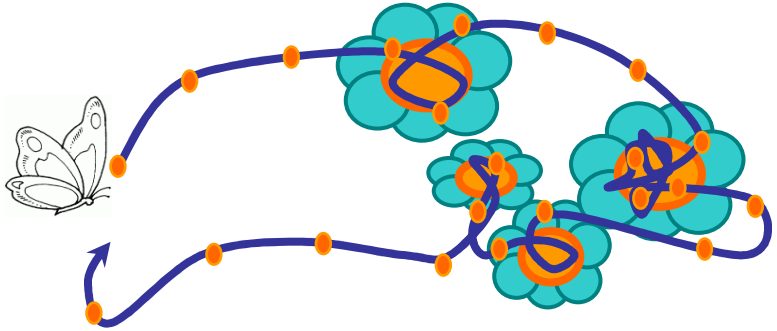
→ must decide to continue moving,

to change direction,

speed of movement

etc.

Trajectory



Movement

→ continuous process

∀t decision to change behaviour

or not

Patch =

High trophic value area

Moving animal,

→ must decide to continue moving,

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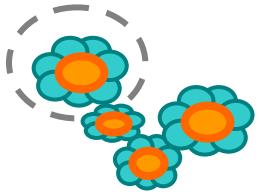
etc.

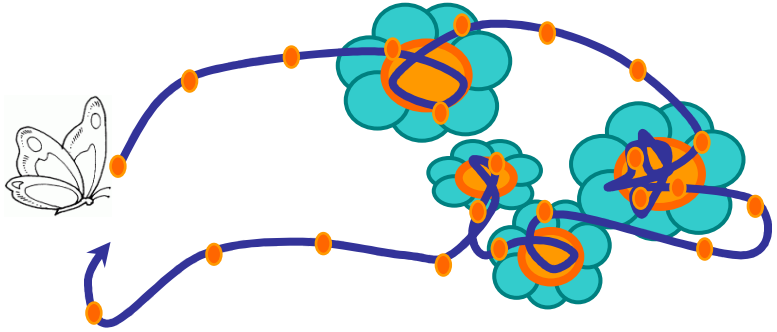


temporal & spatial scales

in a patchy environment

→ within-patch movements

Trajectory



Movement

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Moving animal,

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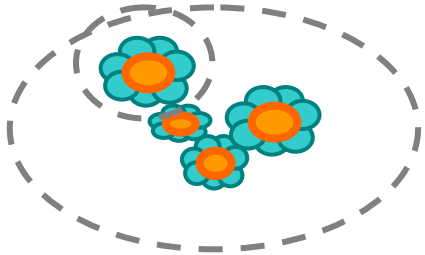
etc.

Patch =

High trophic value area

& Different patch sizes



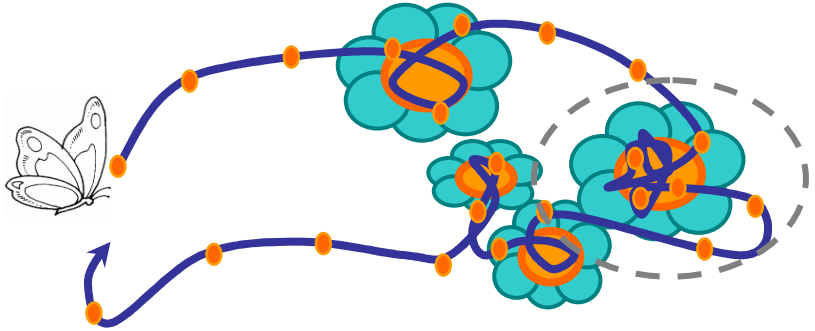
temporal & spatial scales

in a patchy environment

→ within-patch movements

→ between patches

Foraging Detection in Predators



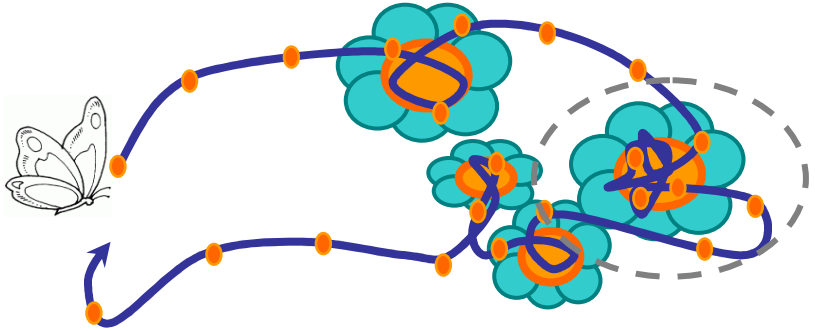
- Detection of **intensive foraging zones**

→ Area Restricted Search (ARS)

Kareiva & Odell 1987

→ *with **aggregated** prey items, search **intensification***

Foraging Detection in Predators



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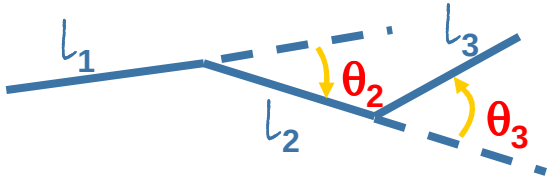
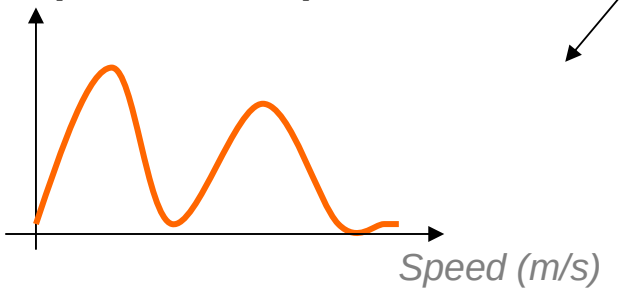
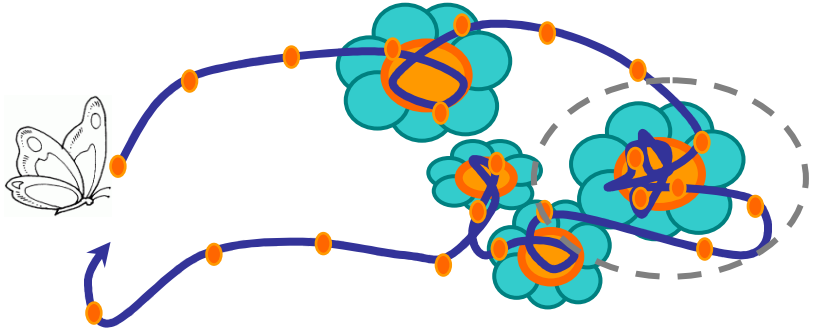
⇗ **Turning angles**



⇘ **Displacement speed**



Foraging Detection in Predators



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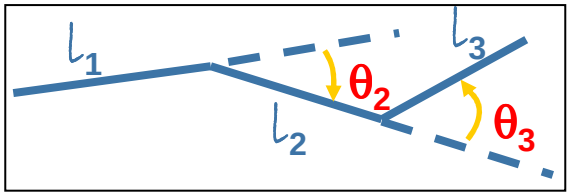

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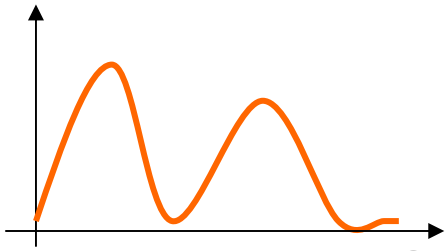


Speed (m/s)

Intensive search ⇔ ARS

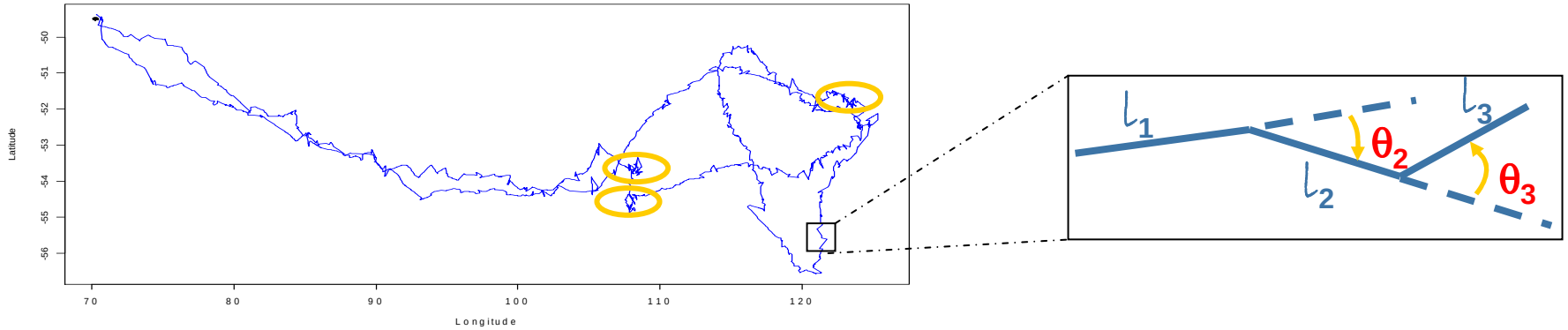
- *low speed*
- *strong sinuosity*

Extensive search ⇔ travelling

- *high speed*
- *small sinuosity*

Detection Methodology

➢Goal: **identify foraging behaviour** from **displacement parameters**

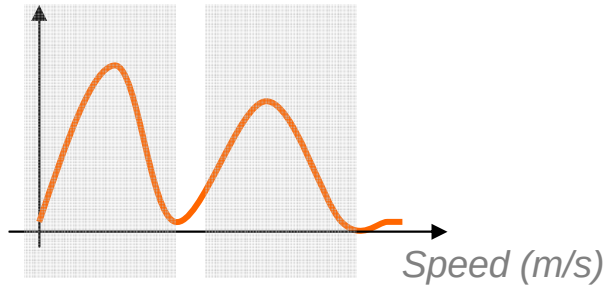


- empirical descriptors ***Benhamou & Bovet 1989***

pathlength, speed, turning angles etc.

Hyp: displacement ⇔ foraging behaviour

bimodal distribution → 2 behavioural modes



Detection Methodology

➢Goal: **identify foraging behaviour** from **displacement parameters**

- empirical descriptors
- analytical methods

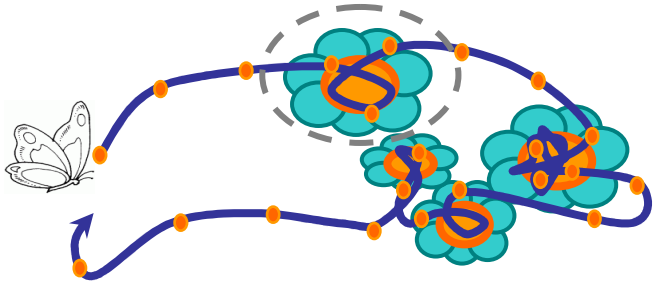
fractal dimension, first-passage-time etc. ***Fauchald & Tveraa 2003***

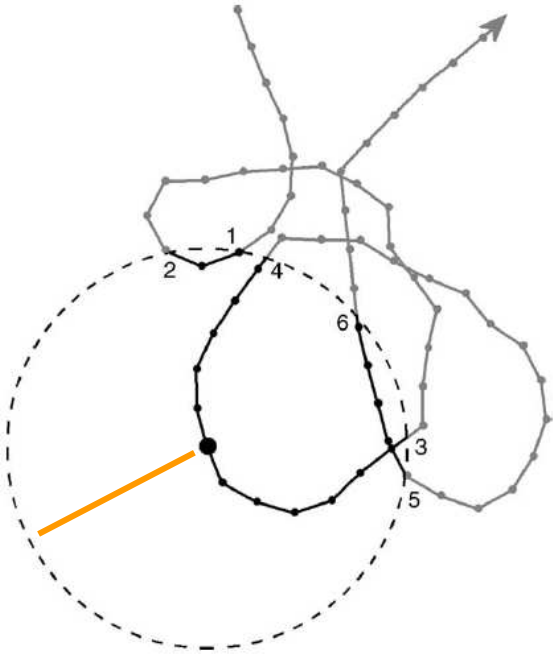
First-Passage-Time (FPT)

= **crossing duration** in a virtual circle with a given radius *d* centered on the *ith* path location

$$FPT = t_6 - t_1$$

radius d ~ patch scale





Detection Methodology

➢Goal: **identify foraging behaviour** from **displacement parameters**

- empirical descriptors
- analytical methods
- process-based models

Double Switch Model:

X = behaviour — ***discrete hidden variable***

Y = path length — ***observed variable***

Jonsen et al. 2003, Moralès et al. 2004, Jonsen et al. 2007, Patterson et al. 2008

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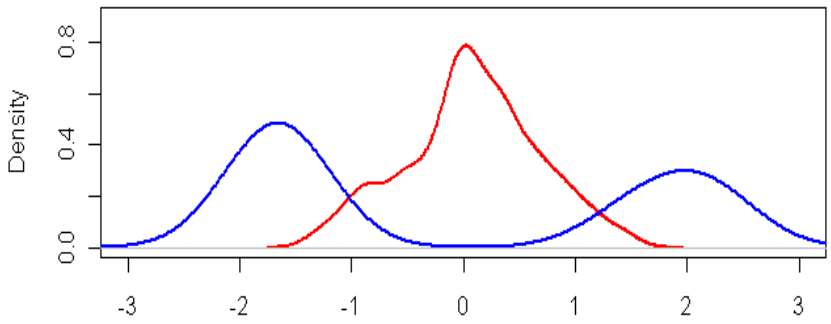
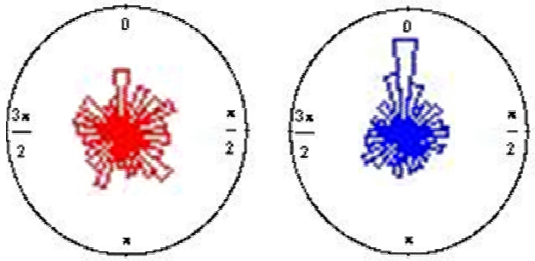
bimodal distribution → 2 behavioural modes





$\theta_1 \sim 56{,}26°$ $\theta_2 \sim -3{,}58°$

$l_1 \sim 10{,}3$ km $l_2 \sim 25{,}9$ km

Jonsen et al. 2003, Moralès et al. 2004, Jonsen et al. 2007, Patterson et al. 2008

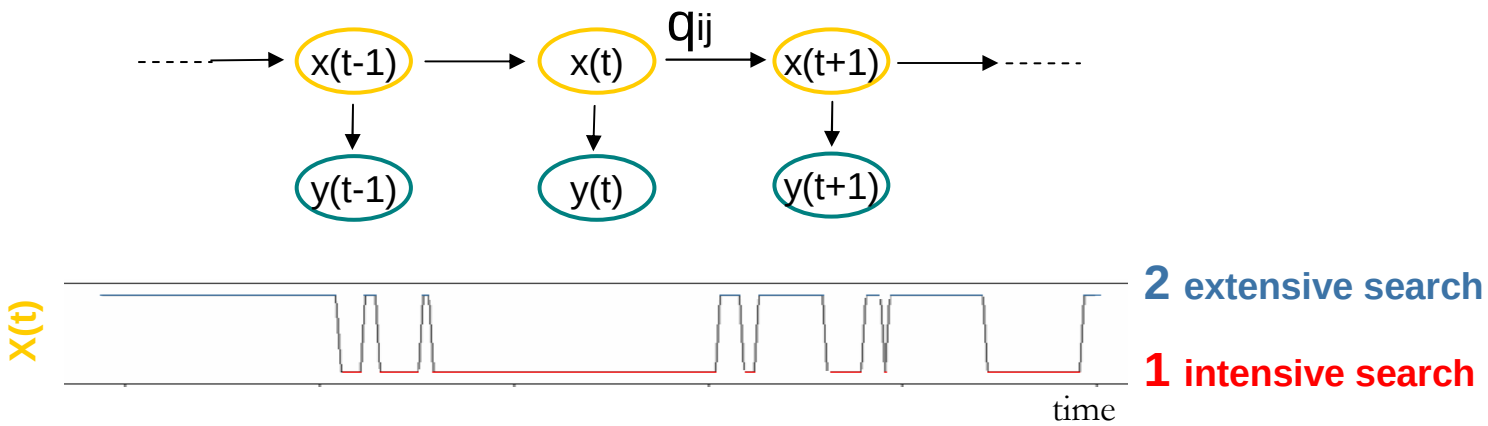
Detection Methodology

➢Goal: **identify foraging behaviour** from **displacement parameters**

- empirical descriptors
- analytical methods
- process-based models

q_{ij} = **probability** of being in the **behavioural mode** *i* at the time *t+1*
knowing that the individual was in mode *j* at the time *t*

$[i,j] \in \{1,2\}^2 \rightarrow$ estimation of q_{11}, q_{12}, q_{21}, q_{22}



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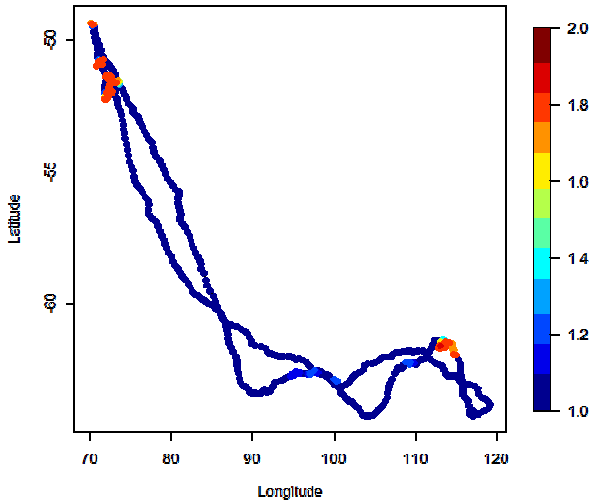

→ Behaviour estimation from movement variables

\+ environmental covariate to help in estimation

→ **¿ Behavioural transitions ⇔ Environmental Changes ?**

Jonsen et al. 2003, Moralès et al. 2004, Jonsen et al. 2007, Patterson et al. 2008

Movement & Environment

- Detection of **intensive foraging zones** along tracks

→ Area-restricted Search ***Kareiva & Odell, 1987***

→ detection at **different scales** that will match the **patch sizes**

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Movement & Environment

- Detection of **intensive foraging zones** along tracks

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But are they **successful** foraging zones ?

→ detection at **different scales** that will match the **patch sizes**

¿ What are the additional challenges in the marine environment ?

Movement & Environment

- Detection of **intensive foraging zones** along tracks

  → Area-restricted Search *Kareiva & Odell, 1987*

→ detection at **different scales** that will match the **patch sizes**

¿ What are the additional challenges in the marine environment ?

o fluid & dynamic & wide environment

Movement & Environment

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¿ What are the additional challenges in the marine environment ?

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o difficulty of observation

Movement & Environment

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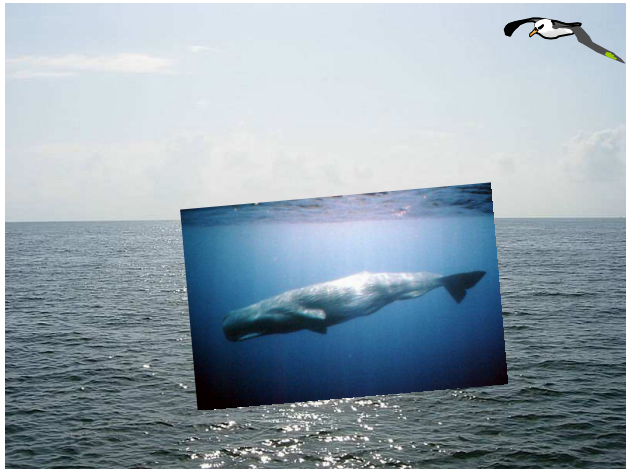
→ + detection at **different scales** that will match the **patch sizes**

¿ What are the additional challenges in the marine environment ?

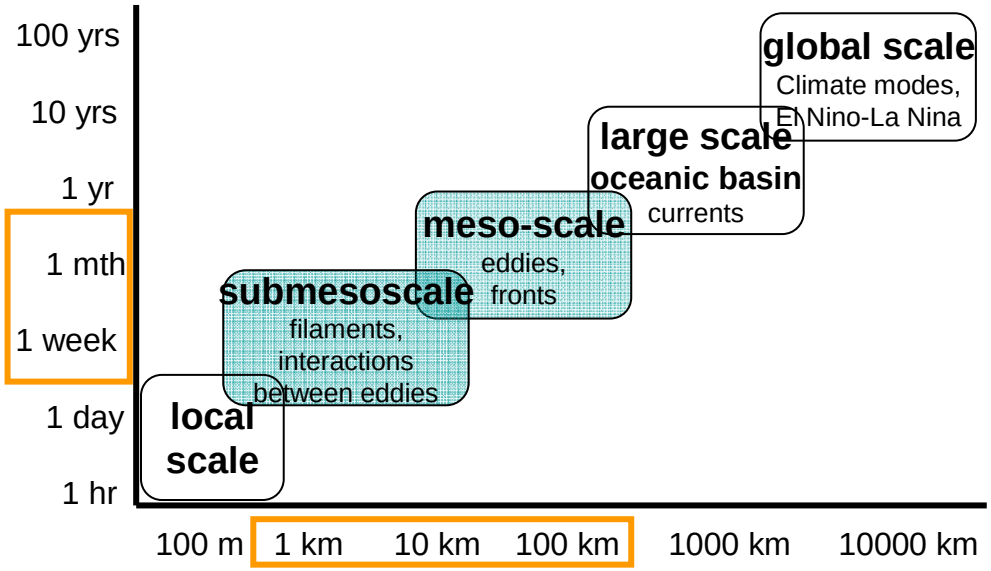
- o fluid & dynamic & wide environment
- o difficulty of observation
- o vertical dimension



Meso-scale Structuration

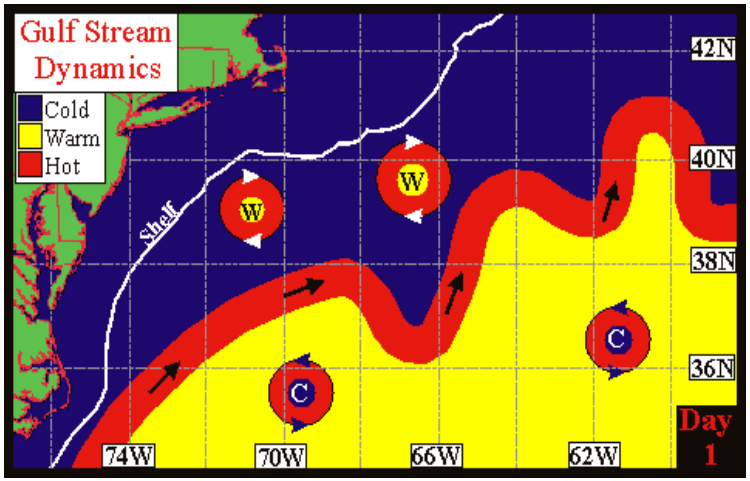
Climate

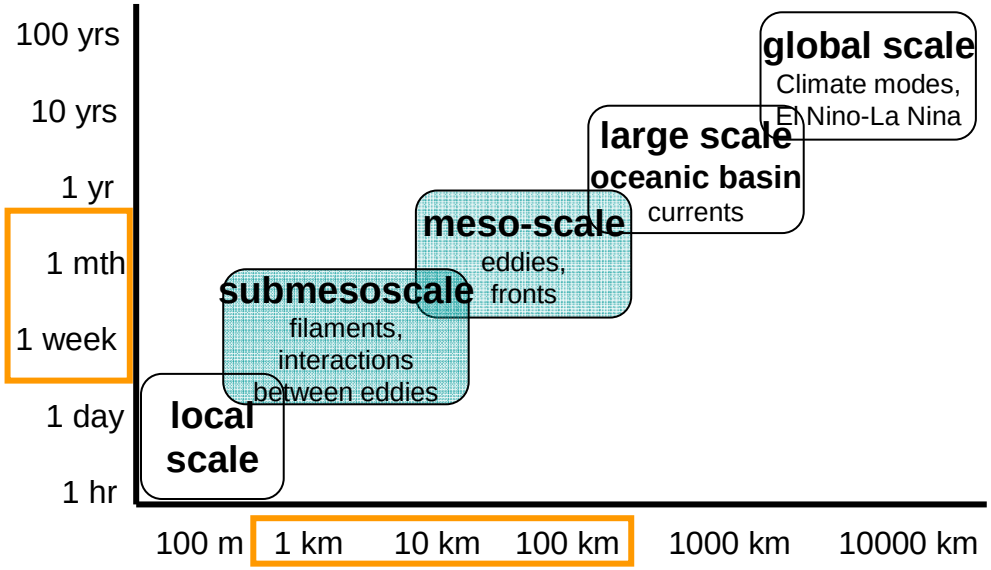
→ Oceanographic Conditions



Meso-scale Structuration

Climate
→ Oceanographic Conditions





Meso-scale Structuration

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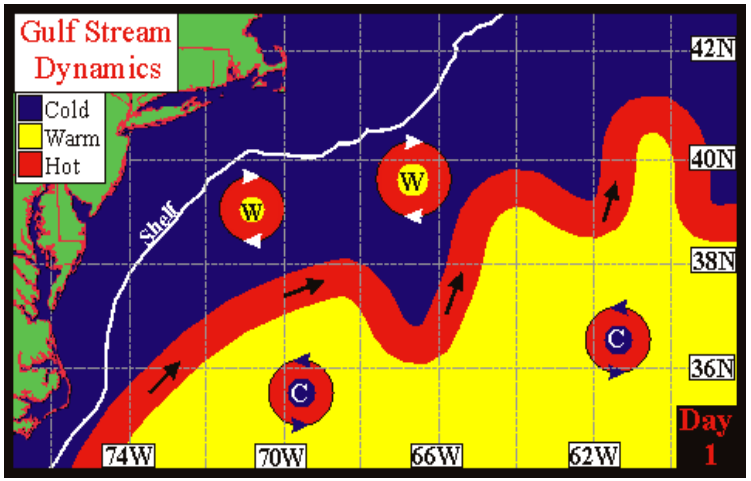
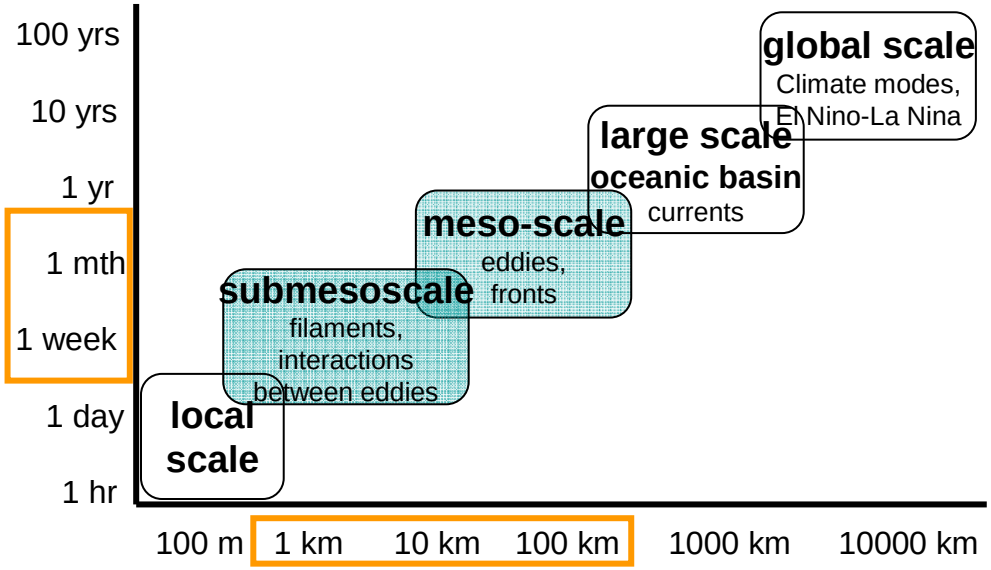
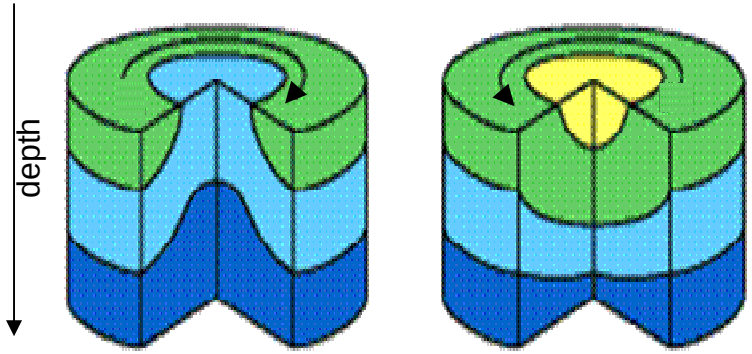






Meso-scale Structuration

Climate
→ **Oceanographic Conditions**

Lower trophic levels

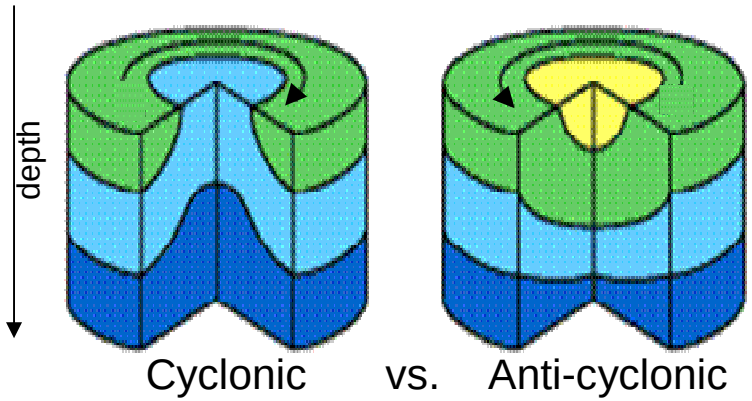
phytoplankton blooms stimulation
in sub- & mesoscale structures

→ resources **aggregation**

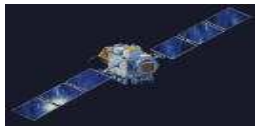
in the eddies & filaments

for higher trophic levels

Wheeler et al. 2003, Bakun 2006, Bost 2009



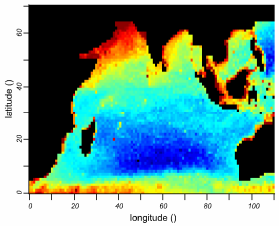
Proxies of Biological Richness



Climate

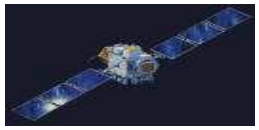
→ Oceanographic Conditions

Lower trophic levels



Medium trophic levels

Proxies of Biological Richness



Climate

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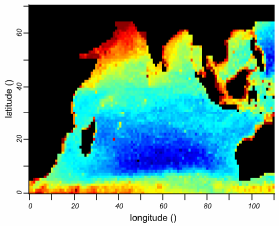
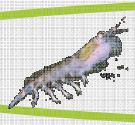
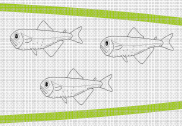
Lower trophic levels



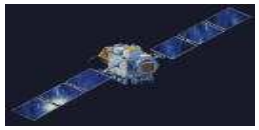


Medium trophic levels



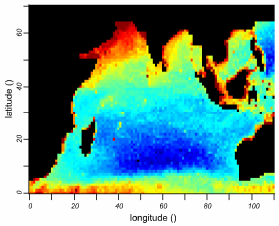
?

Biologging & Top-Predators



Climate

→ Oceanographic Conditions



Lower trophic levels

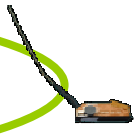
Medium trophic levels

?

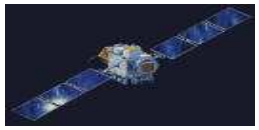
Biologging

Movements of **upper trophic levels**

Foraging of top-predators

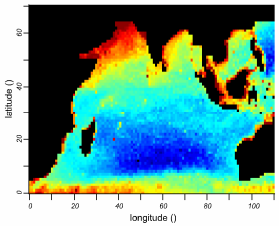


Biologging & Top-Predators



Climate

→ Oceanographic Conditions



Lower trophic levels

Medium trophic levels

?

?

Biologging

Movements of upper trophic levels

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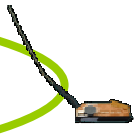


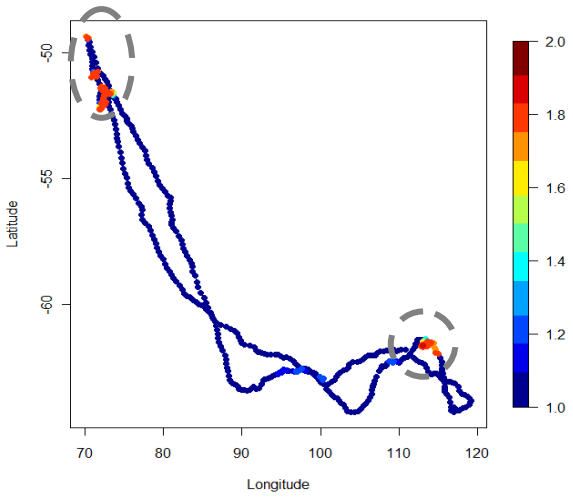
Goals of this PhD

- Detect **successful foraging behaviour**

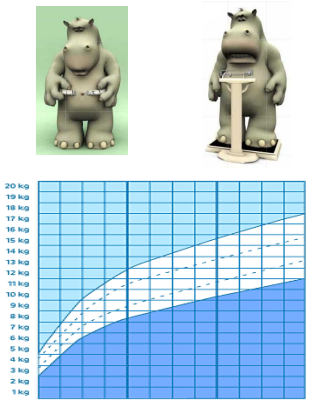
horizontal dimension

¿ Which data resolution ?

¿ Which methodology ?



⇔



Hyp: **intensive foraging related to ⇗ body condition**

Goals of this PhD

- Detect **successful foraging behaviour**

horizontal dimension

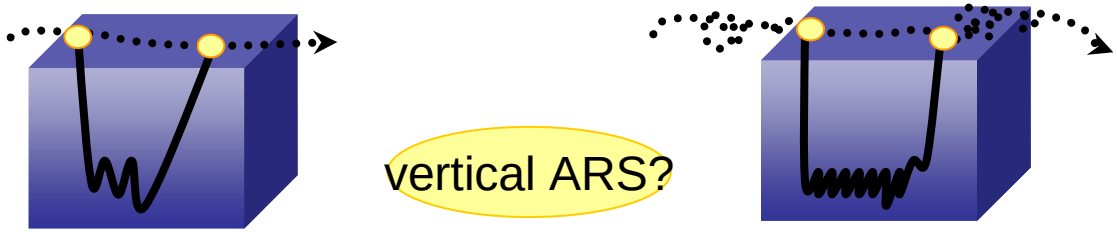
vertical dimension

¿ Which data resolution ?

¿ Which methodology ?

For **diving predators**,

with movements in **horizontal + vertical dimensions**



Extensive Foraging

Intensive Foraging

***Hyp:* diving behaviour related to horizontal ARS**

Goals of this PhD

- Detect **successful foraging behaviour**

  horizontal dimension

  vertical dimension

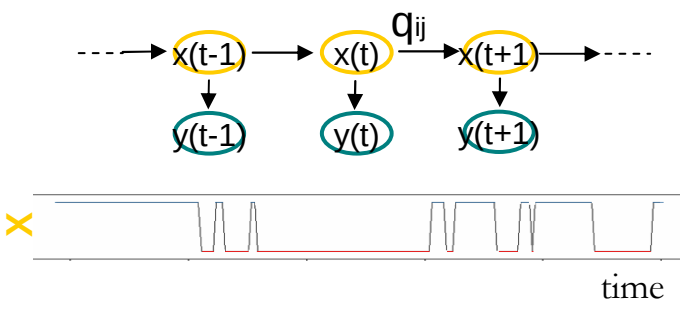
  ¿ Which data resolution ?

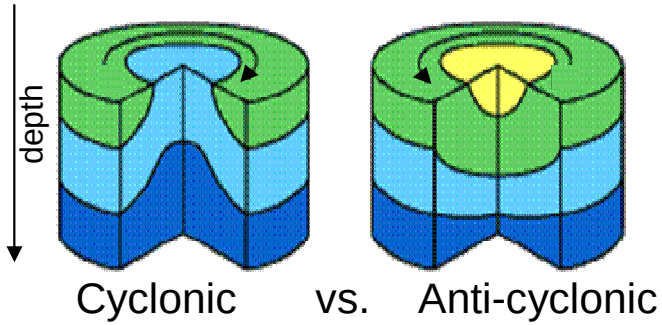
  ¿ Which methodology ?

- Establish how **oceanographic conditions** affect the foraging behaviour

  ¿ Behavioural transitions ⇔ Oceanographic Changes ?

  ¿ Influence of Eddies ?





Hyp: **intensive foraging related to eddies**

Goals of this PhD

- Detect **successful foraging behaviour**

  horizontal dimension

  vertical dimension

  ¿ Which data resolution ?

  ¿ Which methodology ?

- Establish how **oceanographic conditions** affect the foraging behaviour

  ¿ Behavioural transitions ⇔ Oceanographic Changes ?

  ¿ Influence of Eddies ?

→ *According to various **spatial & temporal scales***

→ *In a **wild animal** in a **dynamic environment***

Southern Elephant Seal

Content

Introduction

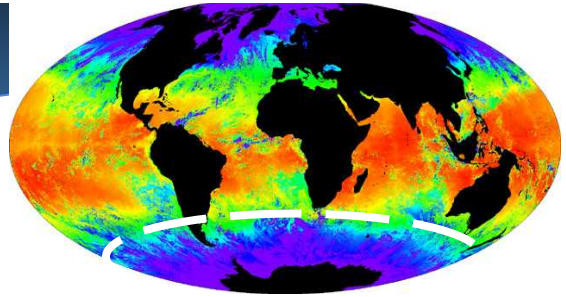
Study site & model species

Scale-related patterns: Detection of Foraging Behaviour
Foraging & Oceanographic Conditions

Synthesis

Perspectives

Southern Ocean

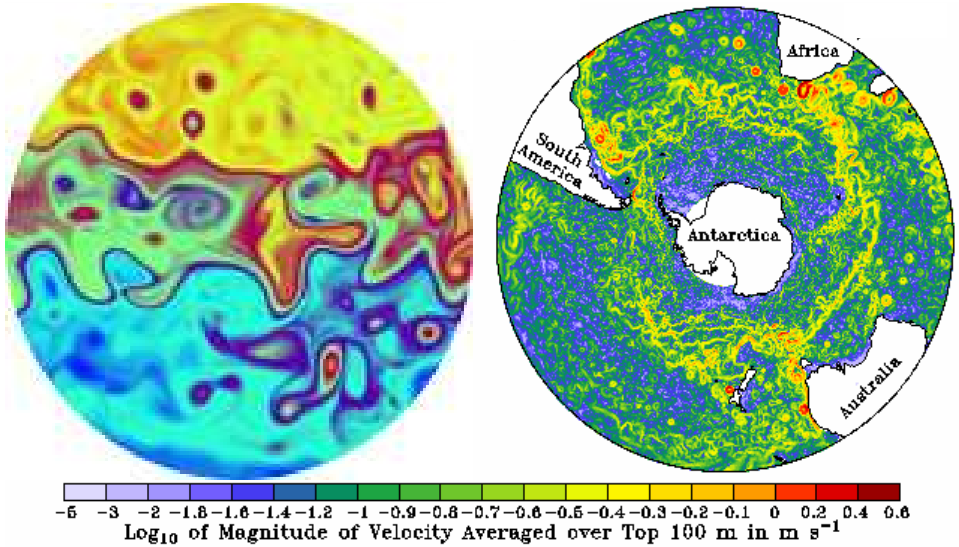


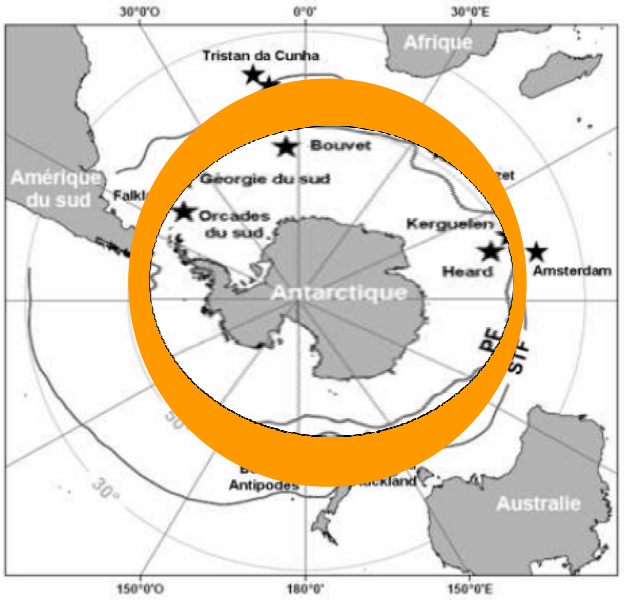
numerous eddies in the **interfrontal zone**

→ HNLC but local primary production

→ enhancement

→ prey aggregation





PF = Polar Front

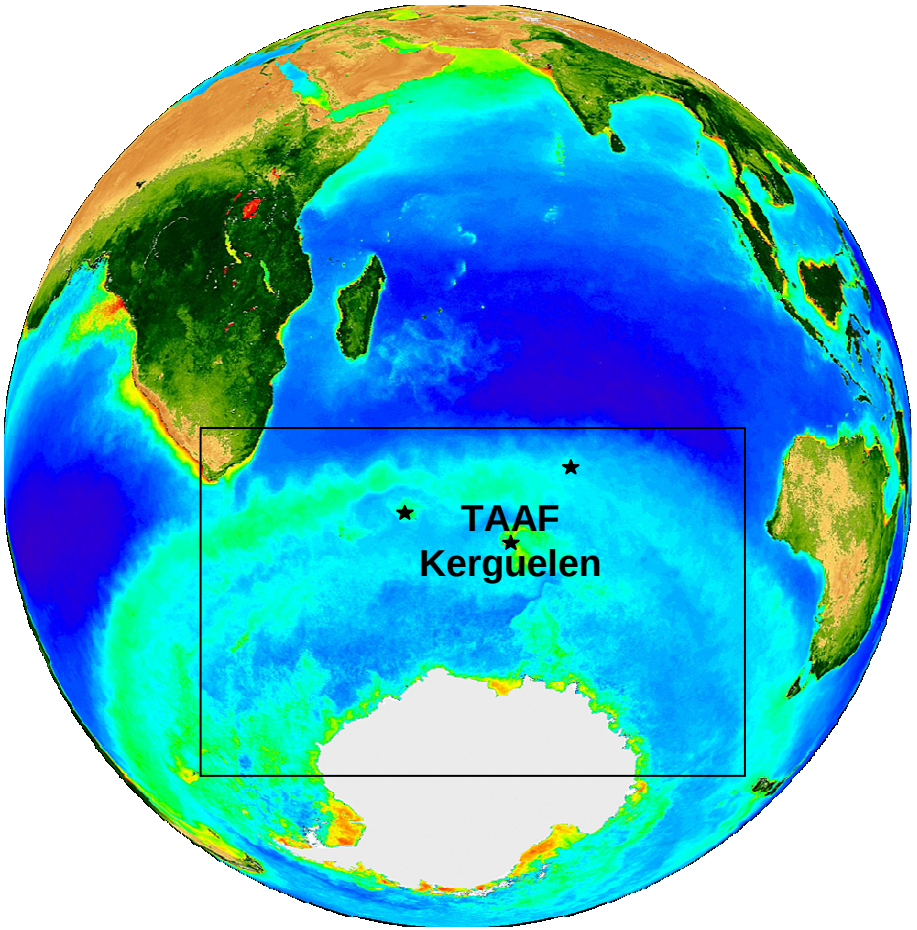
SAF = Sub-Antarctic Front

STF = Sub-Tropical Front

Ainley & DeMaster 1990, Polovina et al. 2004

Southern Indian Ocean

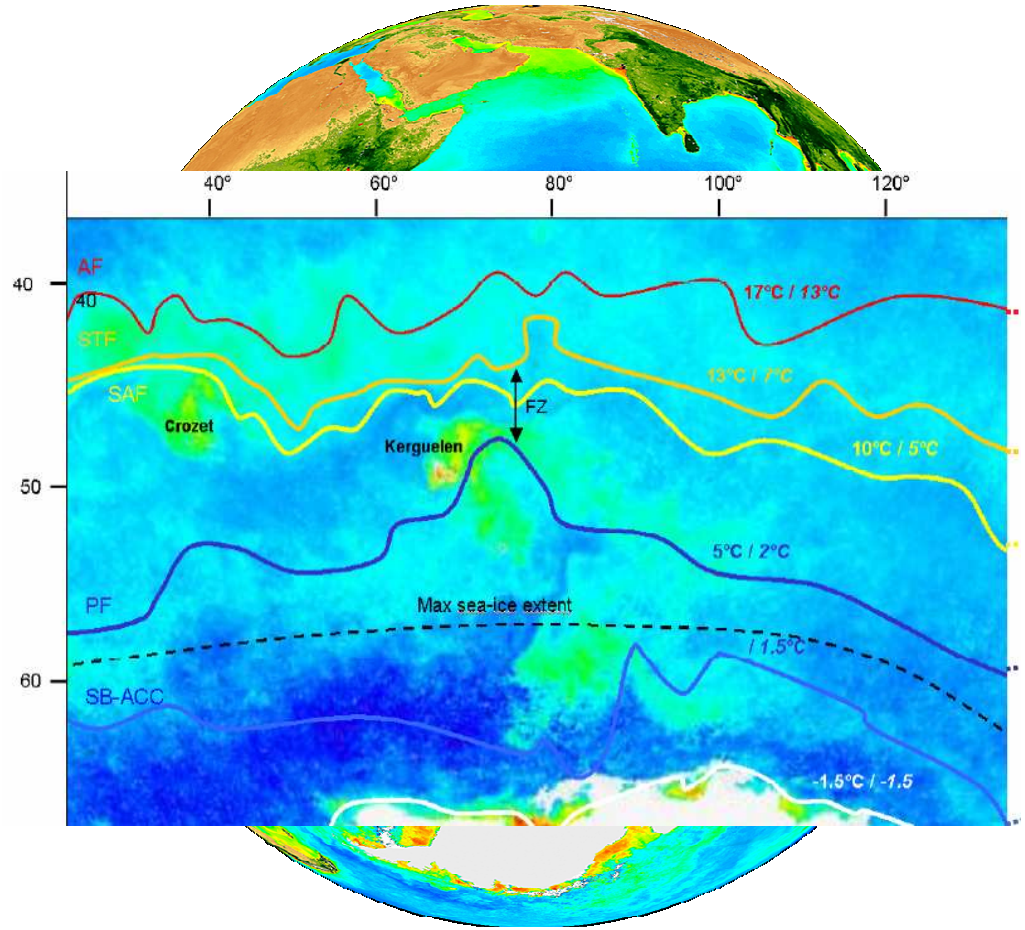




- Numerous top-predators

Southern Indian Ocean



- Numerous top-predators
- Very productive waters during southern summer *Dragon et al. 2011 Cybium*

Southern Elephant Seal

Southern Elephant Seal

Order: Pinnipeds *Biggest Phocid*

Important Sexual Dimorphism

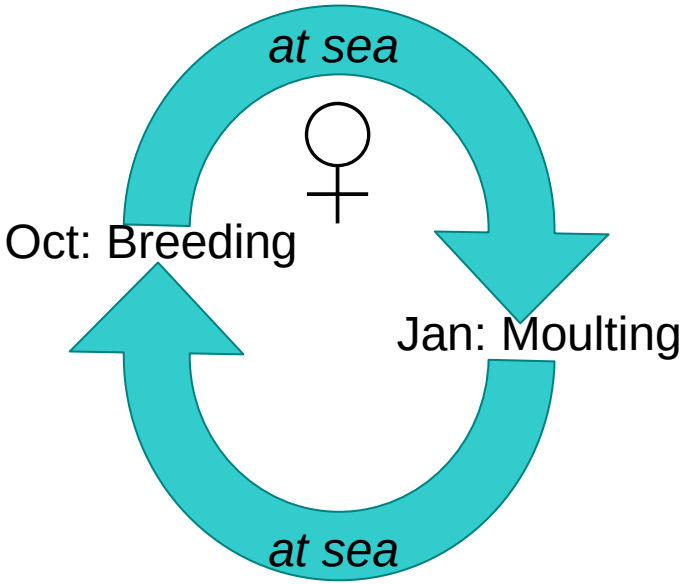
Life cycle: 2 months on land / year

Post-breeding Foraging trip:

3 - 4 months

Post-moulting Foraging trip:

6 - 7 months



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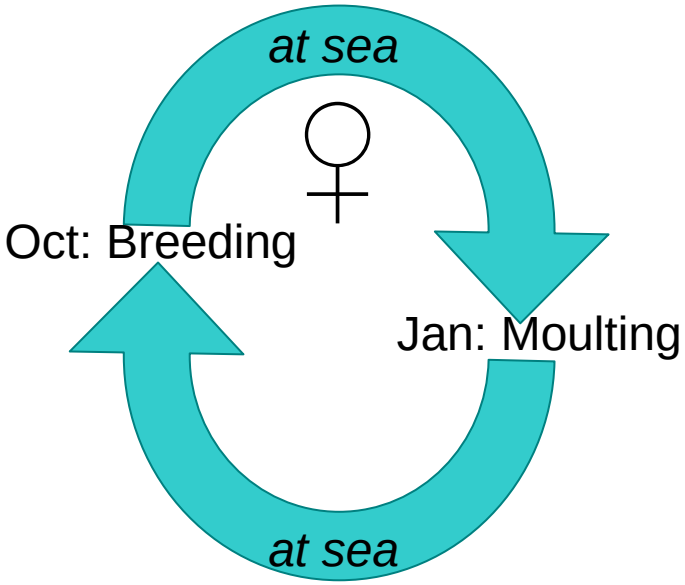
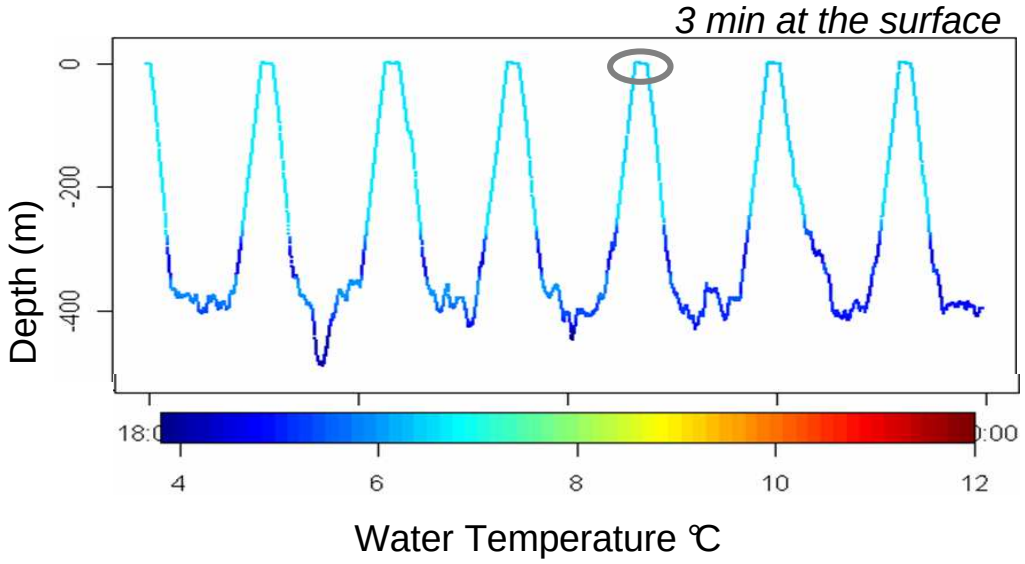
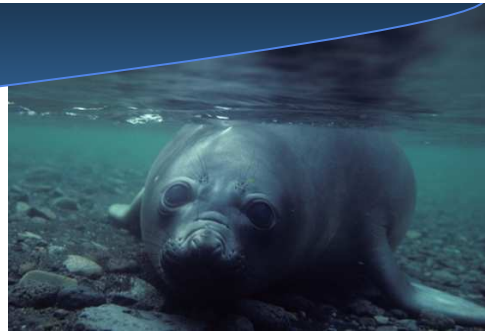


Continuous Deep Diving

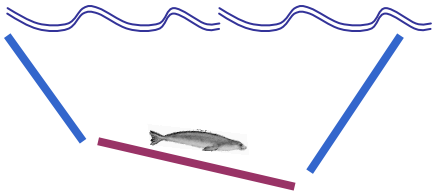


	Depth	Dive duration
Mean	**500-600 m**	**20-30 min**
Maximal	**2000 m**	**~ 80 min**

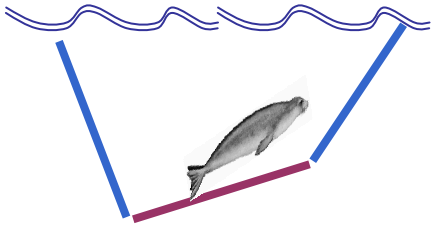
Southern Elephant Seal



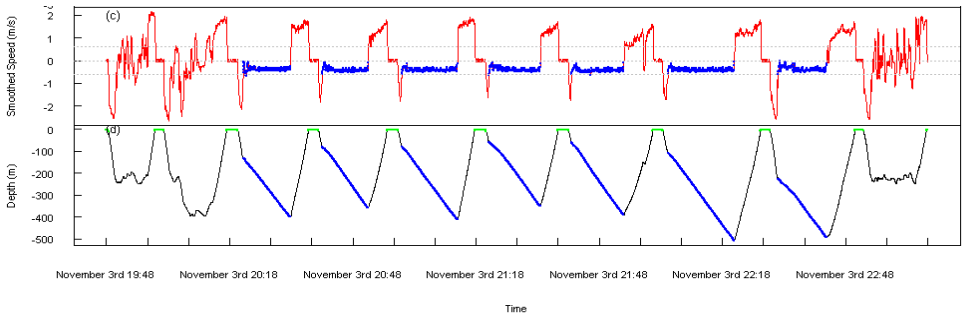
+ specific diving behaviour **Passive Drift Dives**



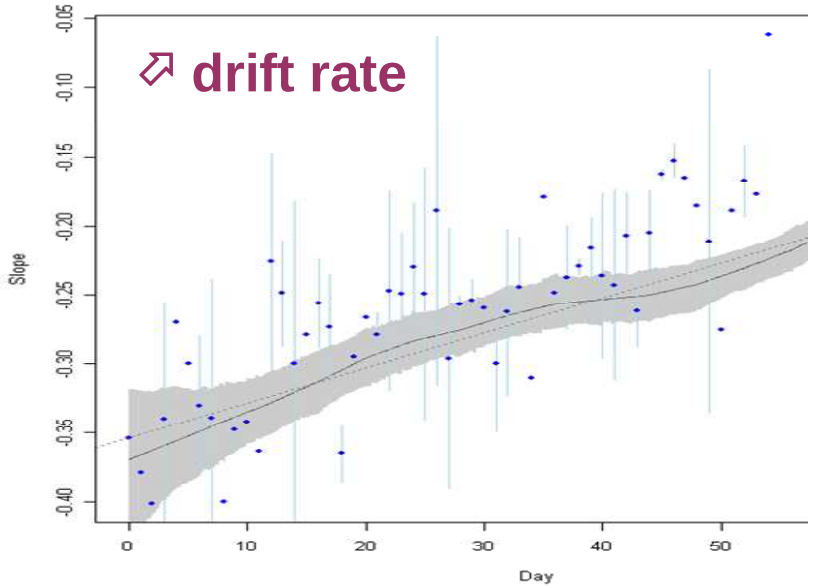
Negative vs. Positive



Crocker et al. 1997
Biuw et al. 2003



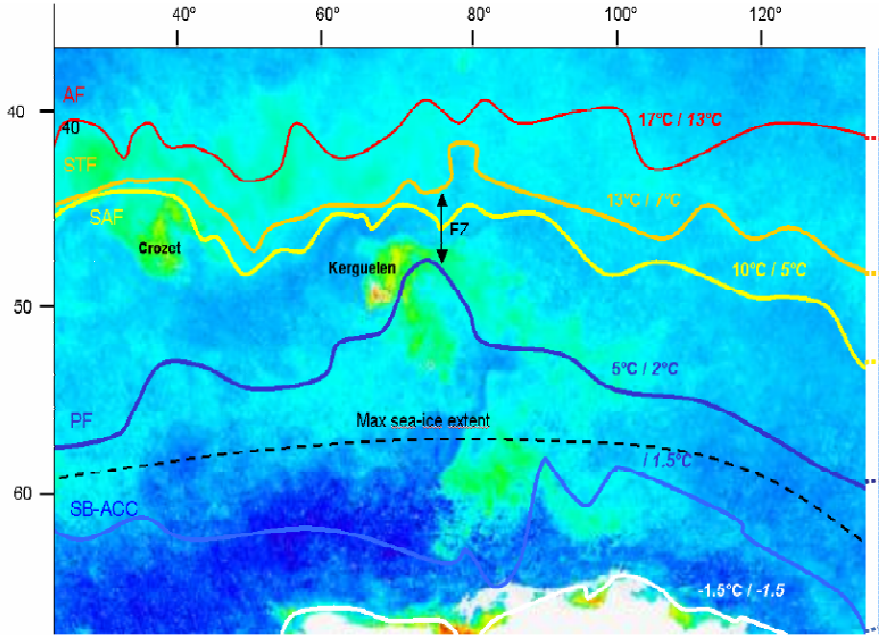
⇗ Drift rate = ⇗ body condition
At-sea proxy of foraging success

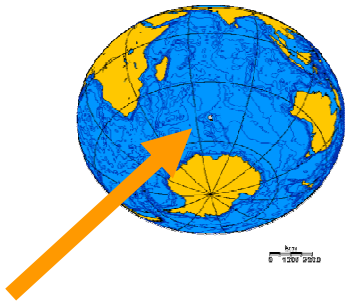


Previous Studies

At-sea distribution ?

Tagging since 2003 in Kerguelen





Previous Studies

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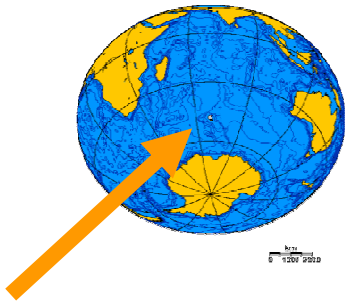
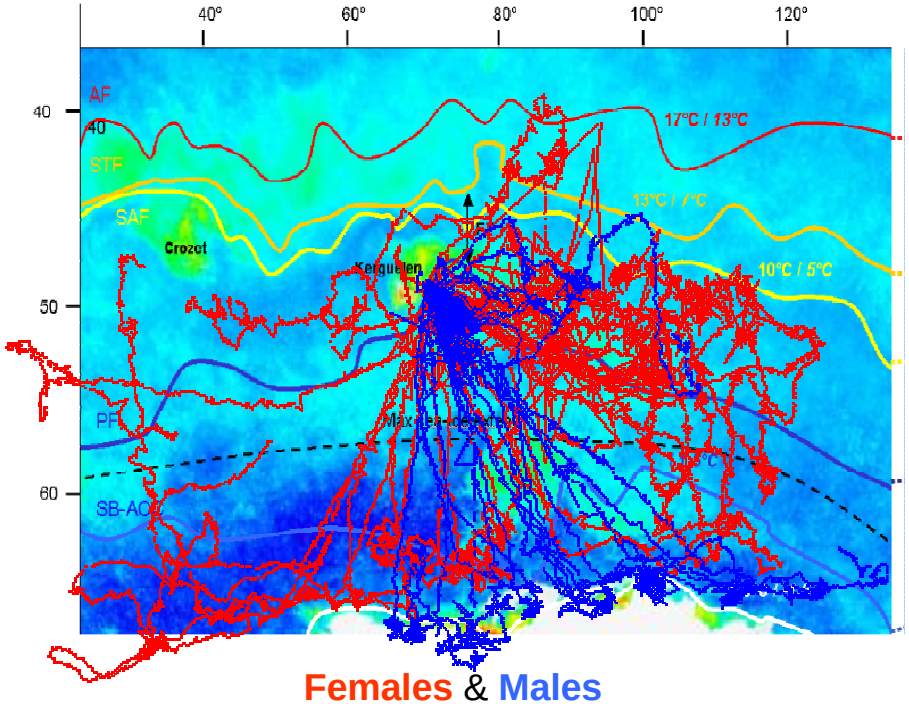
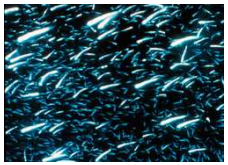




Females & **Males**

Previous Studies

→ **Intersexual & Inter-ages differences**

	Tagging	Indirect Studies (Isotopes etc.)
Juveniles (♀ & ♂)	**pelagic**: interfrontal zone	
Females (> 4 yrs)	**pelagic**: - Interfrontal zone - Marginal Ice Zone	Meso-pelagic prey ***Myctophids***  
Males (> 4 yrs)	**benthic**: - Kerguelen Plateau - Peri-Antarctic Plateau	benthic prey 

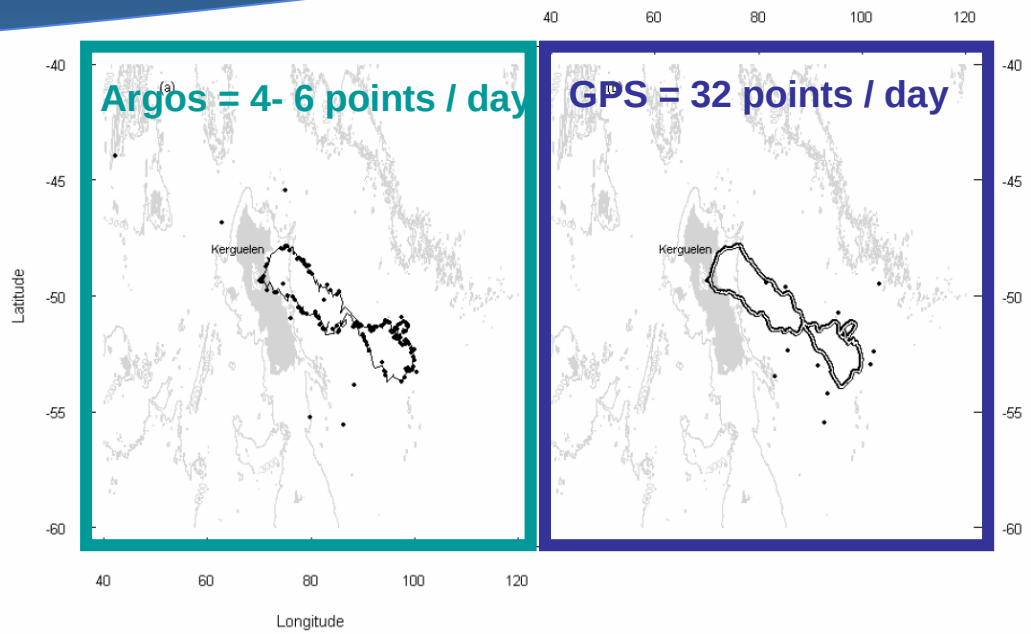
→ **several geographic foraging strategies**

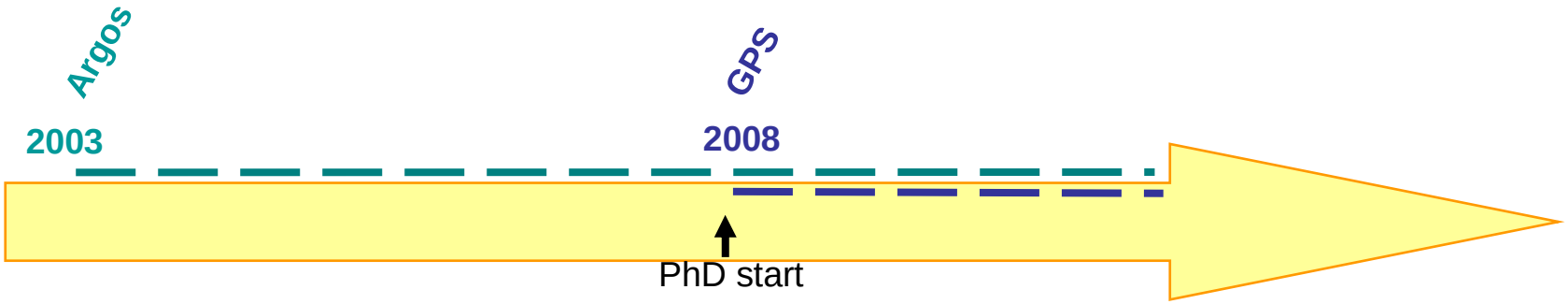
Ducatez et al. 2008 Mar Biol, Cherel et al. 2008 MEPS, Bailleul F. et al 2010. Ecography

this PhD DATA

Tagging data

- **Argos** & **GPS** tracks (Lon, Lat)



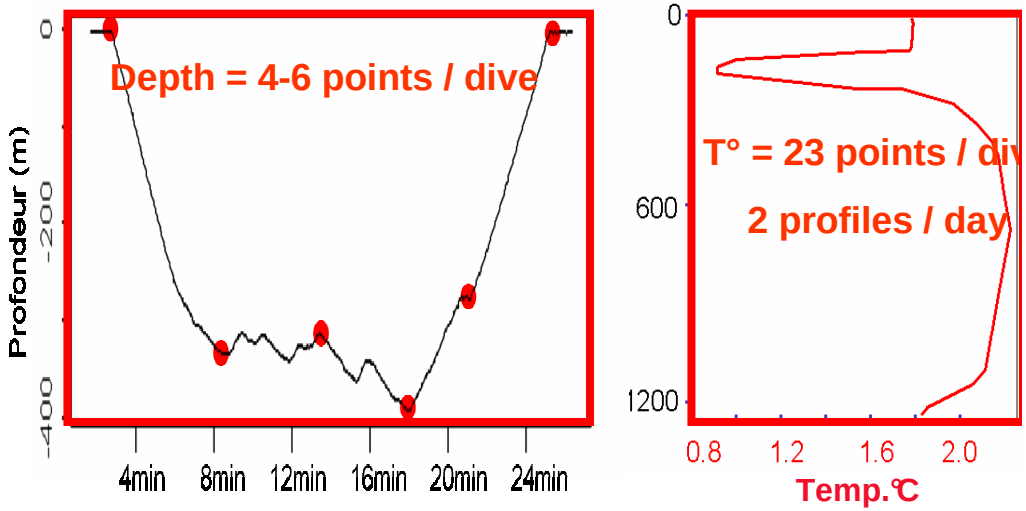


this PhD DATA

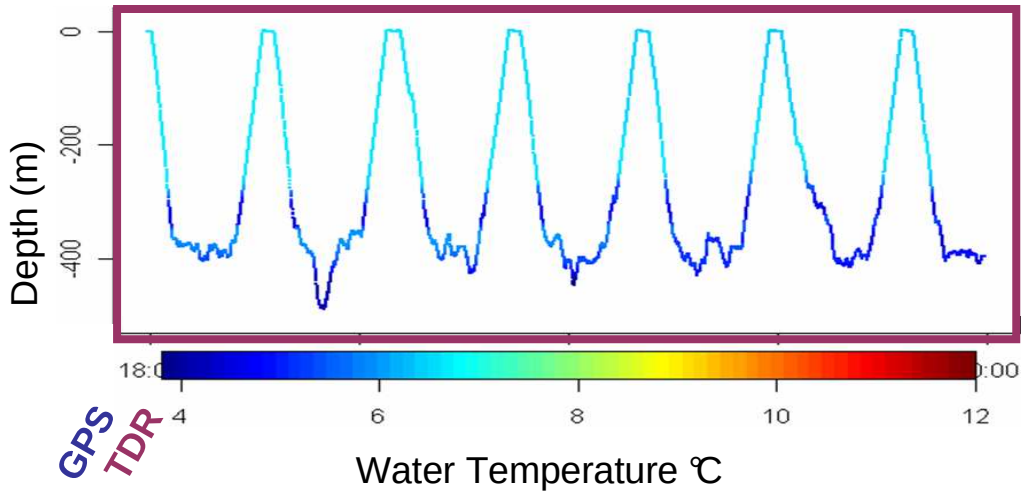
Tagging data

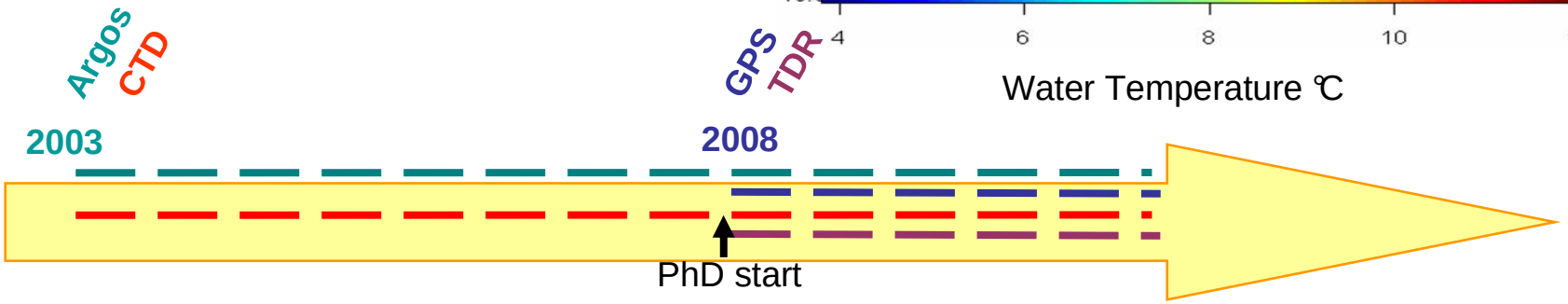
- **Argos** & **GPS** tracks (Lon, Lat)
- **CTD** (Conductivity, T°, Depth)
- **TDR** (T°, Depth)

along the water column



TDR = every 2 sec





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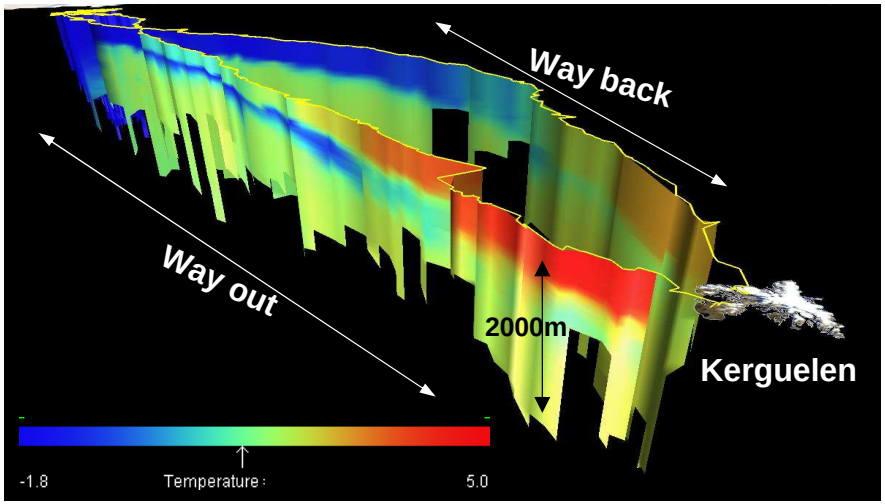
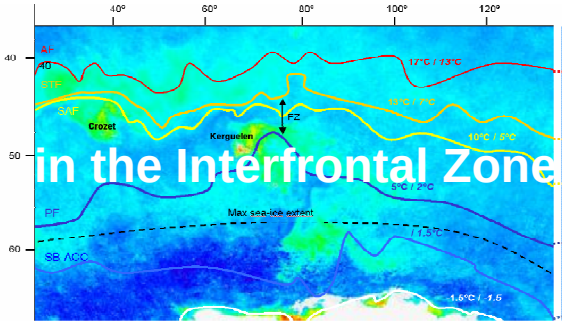
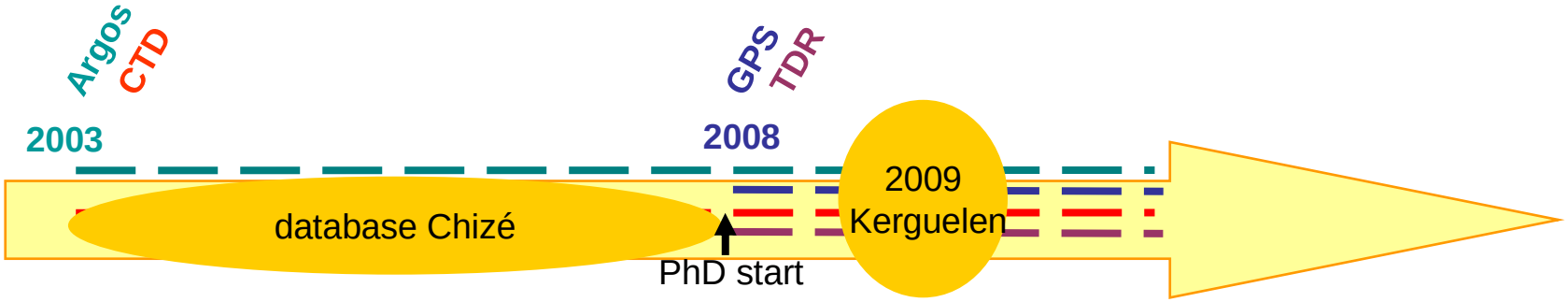


2003 - 2010

- **35 ♀ Argos + CTD**
- **6 ♀ GPS**
- **9 ♀ TDR**





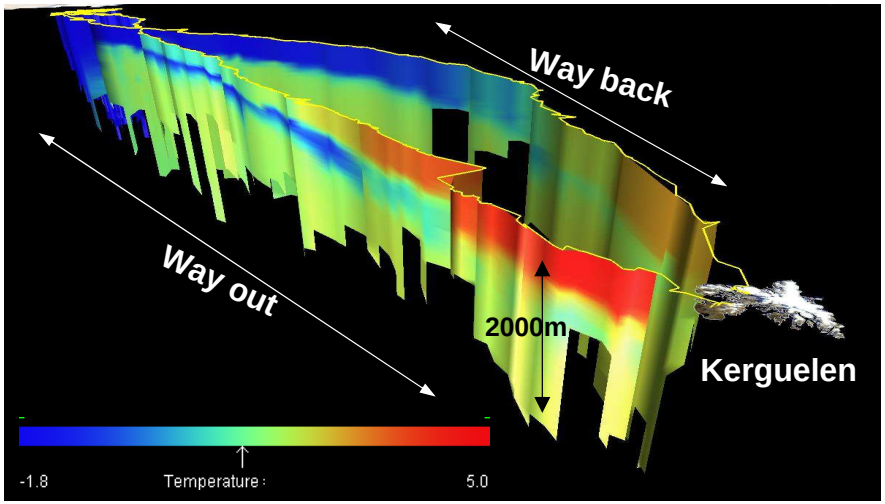
this PhD DATA

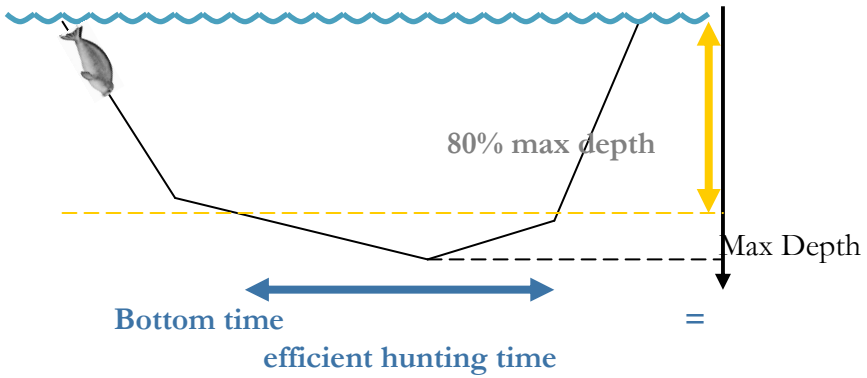
Tagging data

- **Argos** & **GPS** tracks (Lon, Lat)
- **CTD** (Conductivity, T°, Depth)
- **TDR** (T°, Depth)

Diving behaviour variables:

- Diving duration, bottom-time
- Max depth, pathlength





this PhD DATA

Tagging data

- **Argos** & **GPS** tracks (Lon, Lat)
- **CTD** (Conductivity, T°, Depth)
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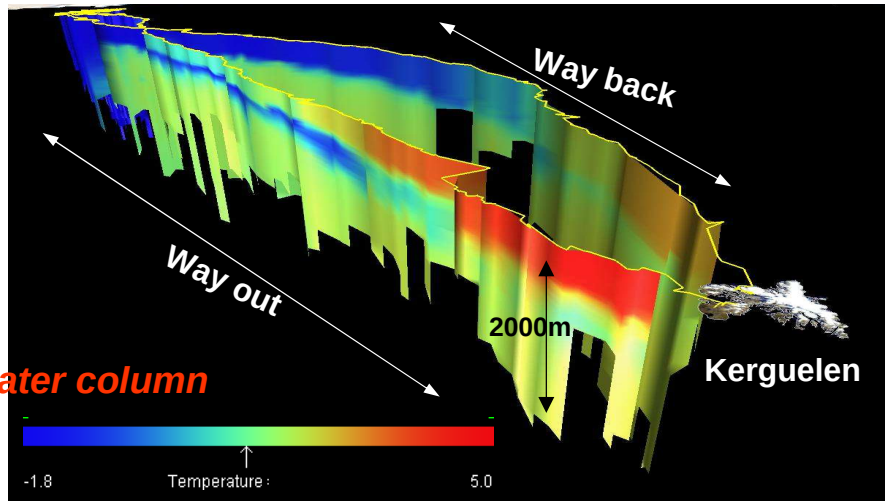
along the water column



Diving behaviour variables:

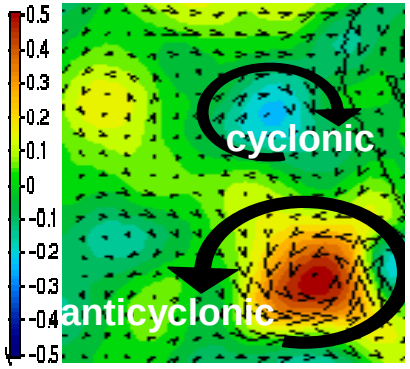
- Diving duration, bottom-time
- Max depth, pathlength

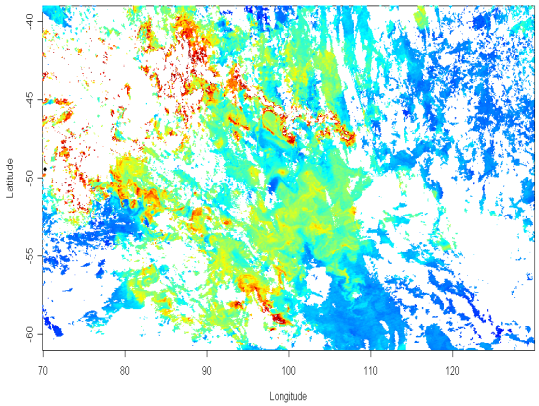
Satellital data

weekly & monthly maps

- Sea Level Anomalies **SLA** (1/3°)
- Water Colour (1/25°) → **[chlorophyll A]**

Sea Level Anomalies (m)





Content

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Foraging Detection

to detect successful foraging areas,

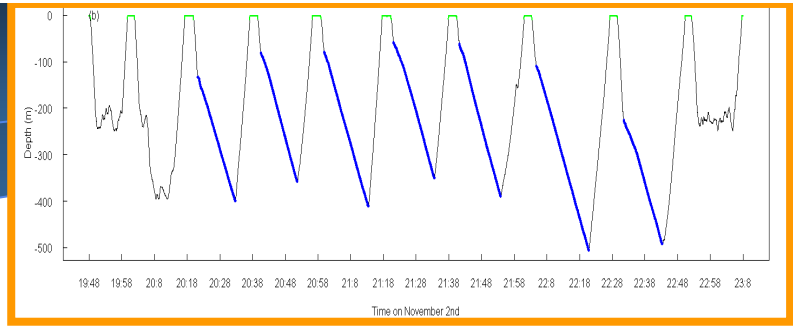
1) successful = ***increase in body condition***

in the *horizontal dimension*,

2) **which method** & **data** is the most appropriate ?

Foraging Detection

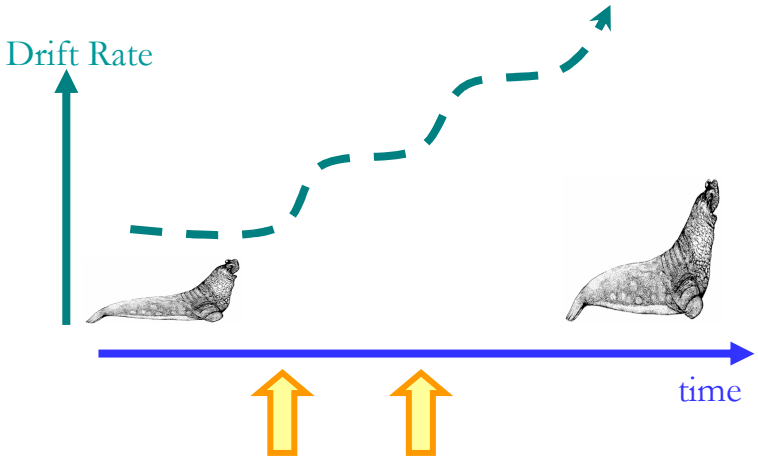
1) Increase in body condition ?



Foraging success from the drift rate index

⇗ Drift rate over time = ⇗ body condition

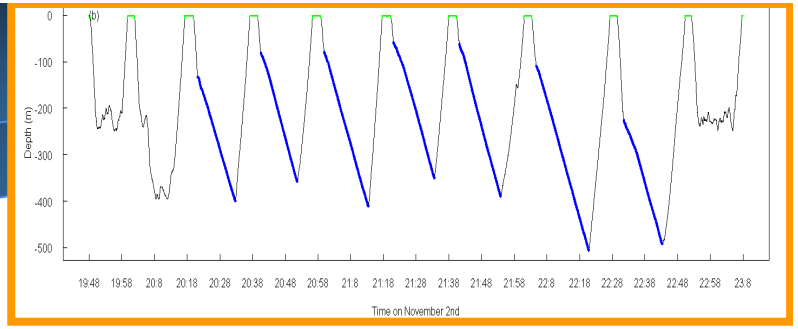
Crocker et al. 1997, Biuw et al. 2003



Argos + GPS + TDR, n = 6 ♀

Foraging Detection

1) Increase in body condition ?



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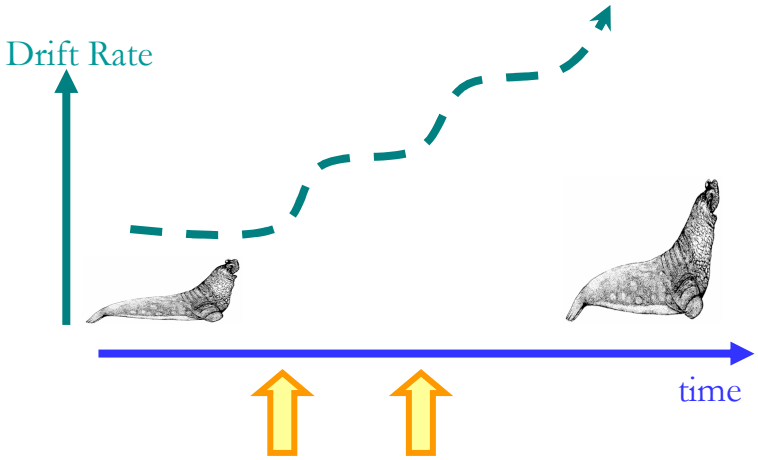
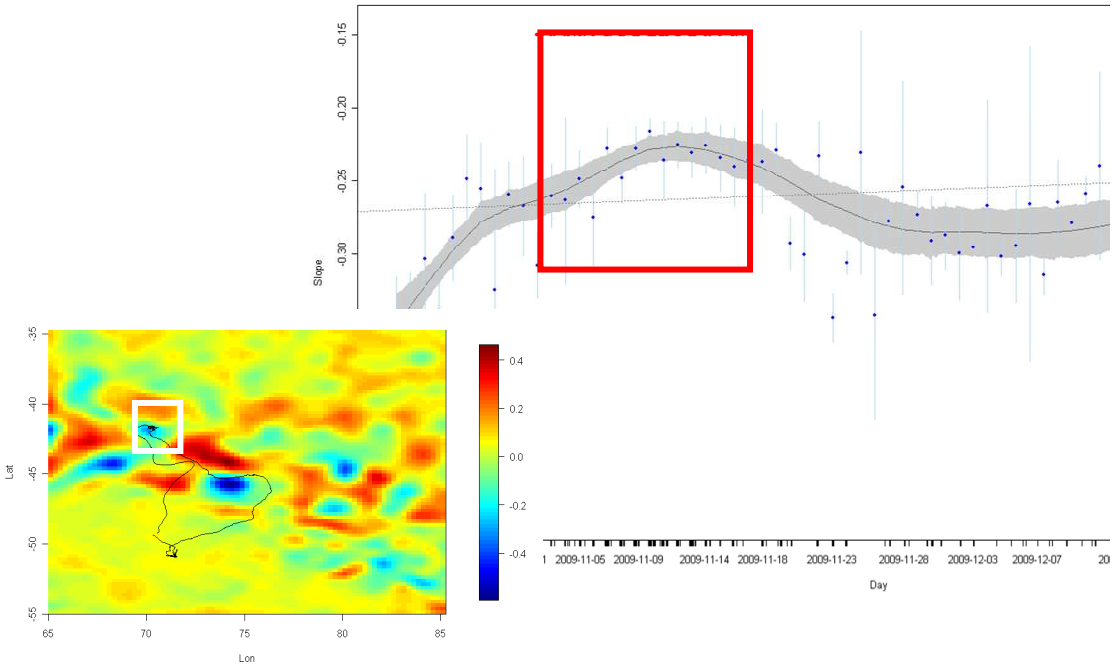
⇗ Drift rate over time = ⇗ body condition

Crocker et al. 1997, Biuw et al. 2003

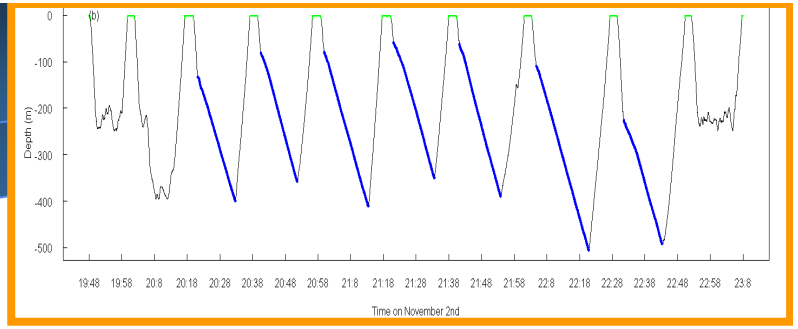




Argos + GPS + TDR, n = 6 ♀

Foraging Detection

1) Increase in body condition ?



Foraging success from the drift rate index

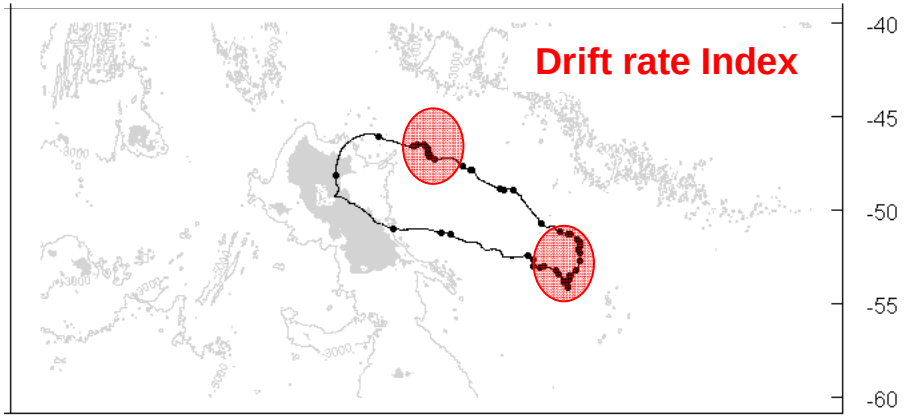
⇗ Drift rate over time = ⇗ body condition

Crocker et al. 1997, Biuw et al. 2003

Main successful foraging areas

including a 4 day metabolisation lag

Rosen et al. 2007, Thums et al. 2008



Argos + GPS + TDR, n = 6 ♀

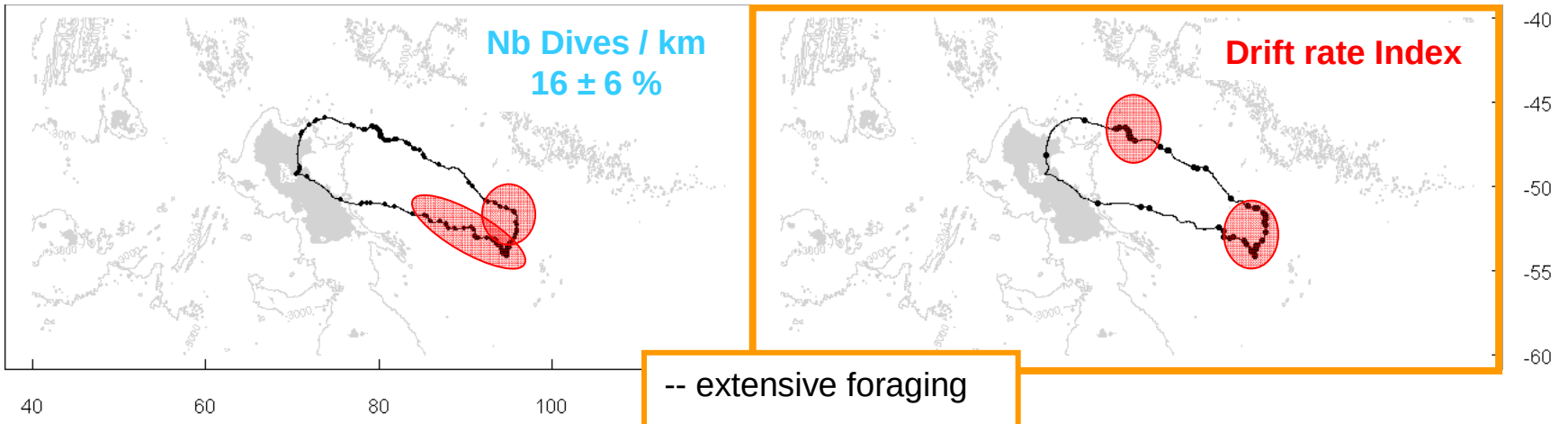
Dragon et al. in revision MEPS

Foraging Detection
2) which method & data ?

Similarity** between* • ***empirical descriptors

• ***analytical methods***

• ***process-based models***



Argos + GPS + TDR, n = 6 ♀

-- extensive foraging

intensive foraging

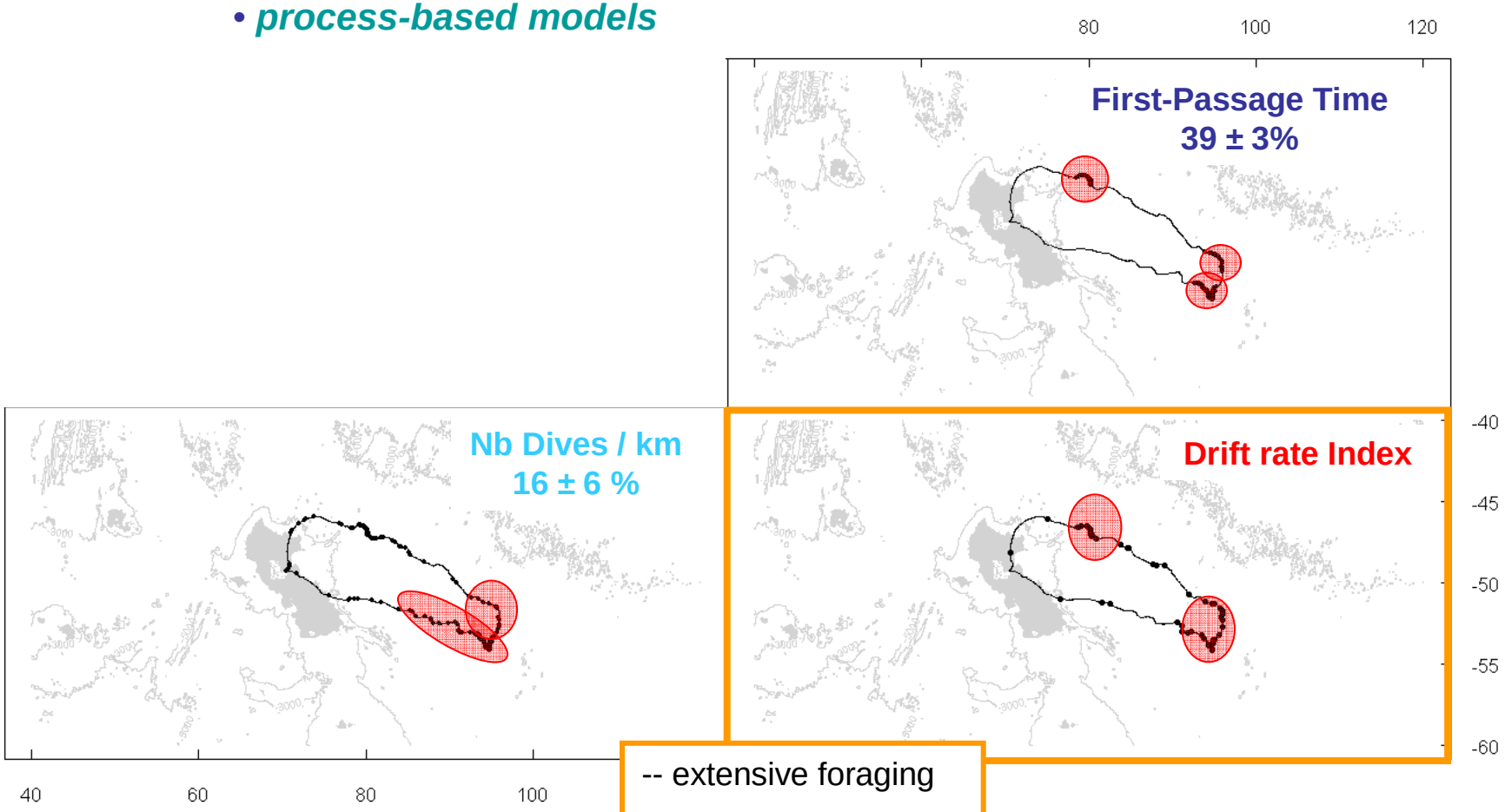
Dragon et al. in revision MEPS

Foraging Detection
2) which method & data ?

Similarity** between* • ***empirical descriptors

• ***analytical methods***

• ***process-based models***



-- extensive foraging

intensive foraging

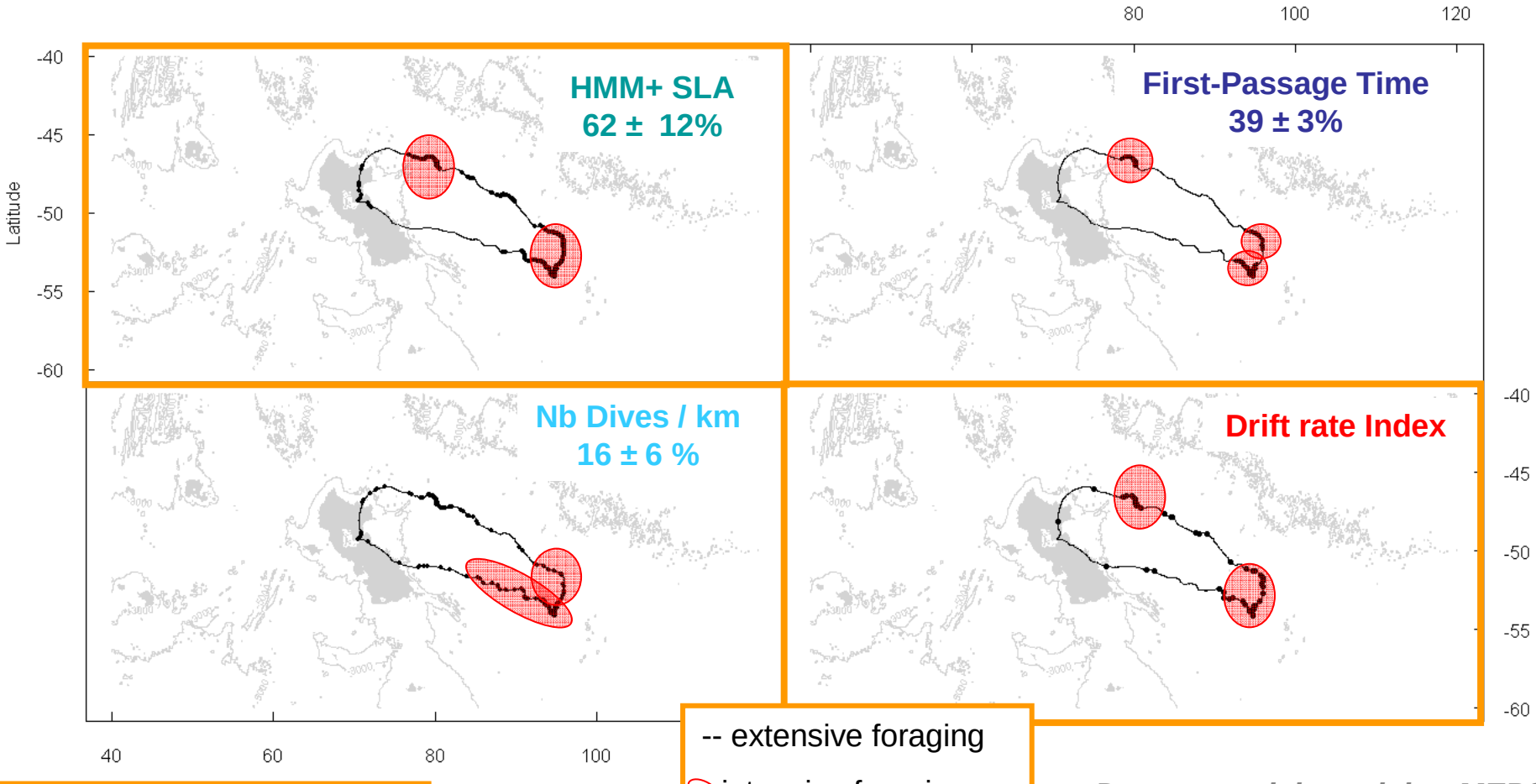
Argos + GPS + TDR, n = 6 ♀

Dragon et al. in revision MEPS

Foraging Detection
2) which method & data ?

Best similarity between

process-based models & ⇗ Body Condition



-- extensive foraging

intensive foraging

Argos + GPS + TDR, n = 6 ♀

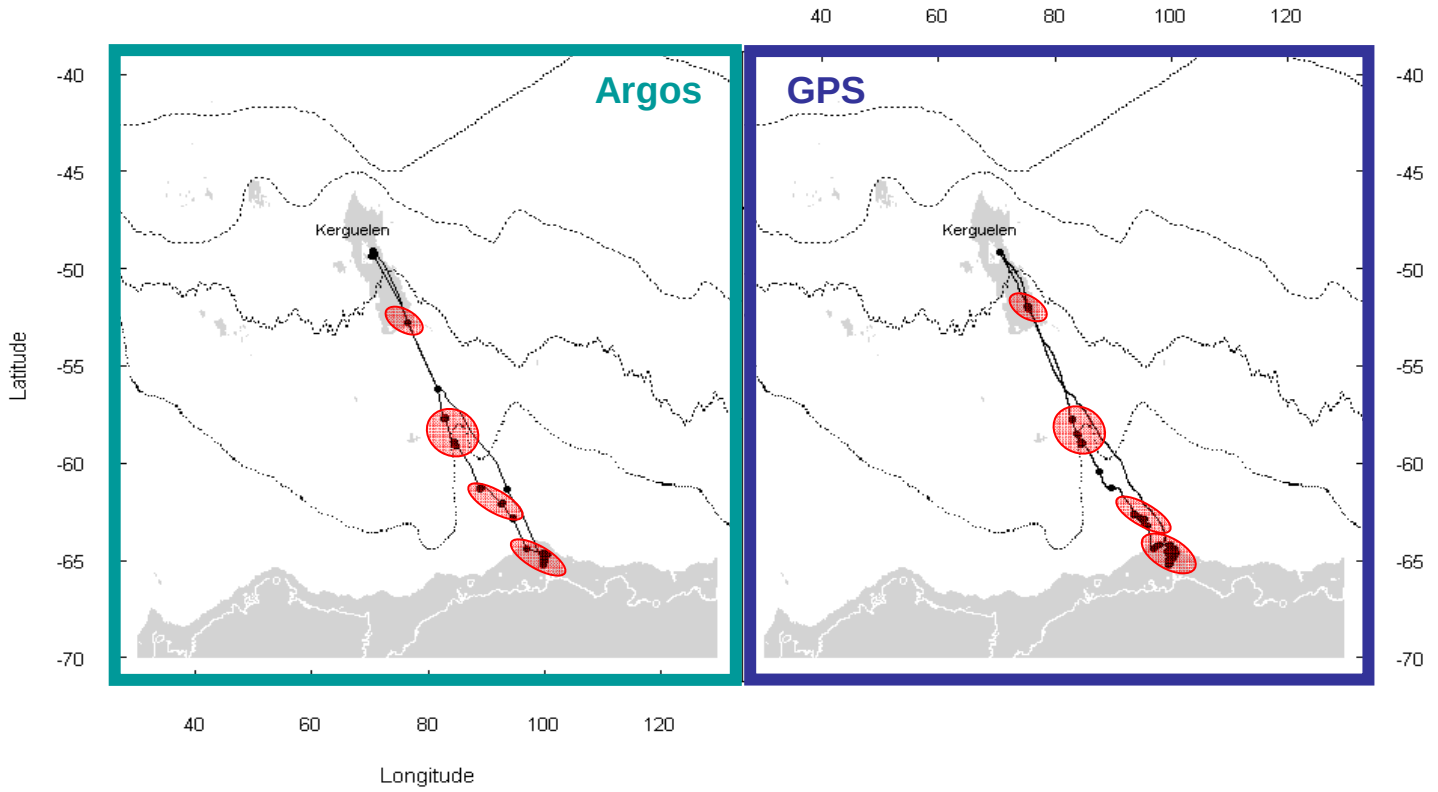
Dragon et al. in revision MEPS

Foraging Detection
2) which method & data ?

Good similarity between Argos & GPS (39 ± 6 %)

for **process-based models**

→ *little effect of data resolution*



Argos + GPS + TDR, n = 6 ♀

Dragon et al. in revision MEPS

Foraging Detection

to detect successful foraging areas,

1) successful = ***increase in body condition***

in the *horizontal dimension*,

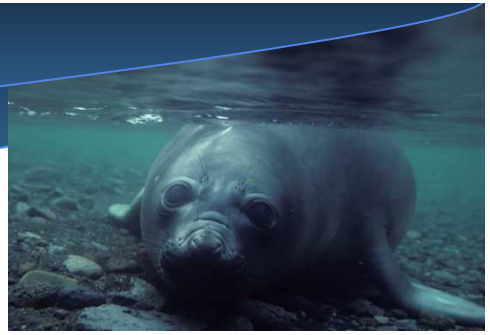
2) **which method** & **data** is the most appropriate ?

in the *vertical dimension*,

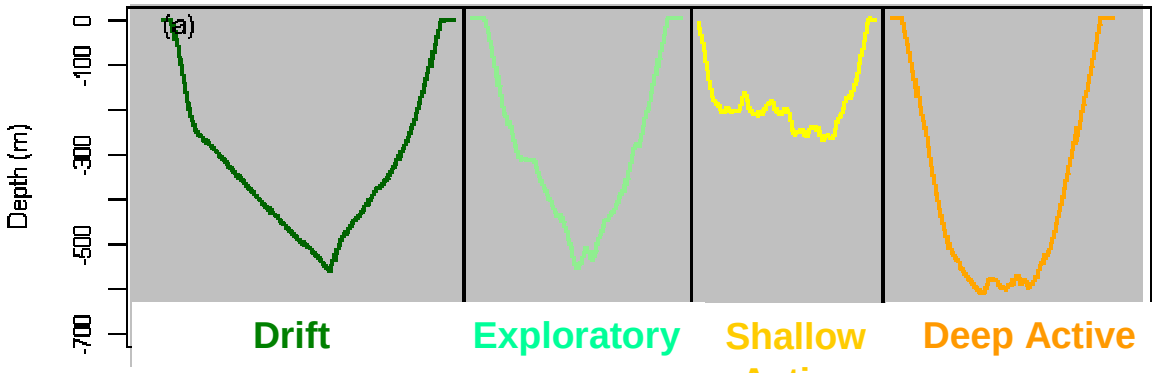
3) are the seals displaying **vertical ARS** ?

Foraging Detection

3) vertical ARS ?



Identification of 4 dive classes *(PCA & cluster)*



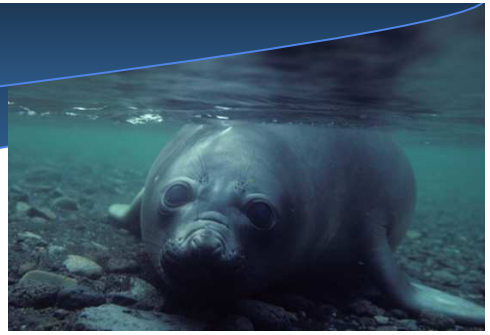
Hindell et al. 1991
Fedak et al. 2001
Schreer et al. 2001
Thums et al. 2008

Argos + GPS + TDR, n = 9 ♀

Dragon et al. accepted MEPS

Foraging Detection

3) vertical ARS ?



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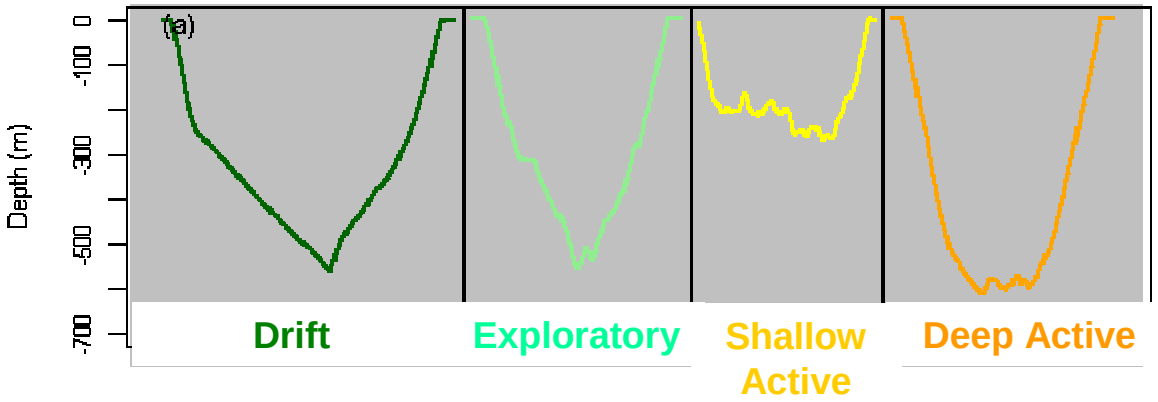


Hindell et al. 1991
Fedak et al. 2001
Schreer et al. 2001
Thums et al. 2008

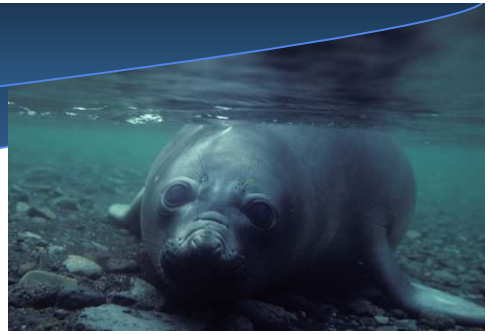
	Sinuosity	Bott.Time	Pathlength	Depth
Drift	**0**	**++**	**--**	**-**
Explo	**-**	**-**	**++**	**+**
Shal. Active	**++**	**+**	**--**	**-**
Deep. Active	**+++**	**--**	**---**	**++**

Intensification of the foraging activity
→ vertical ARS

Argos + GPS + TDR, n = 9 ♀

Dragon et al. accepted MEPS

Foraging Detection
3) vertical ARS ?

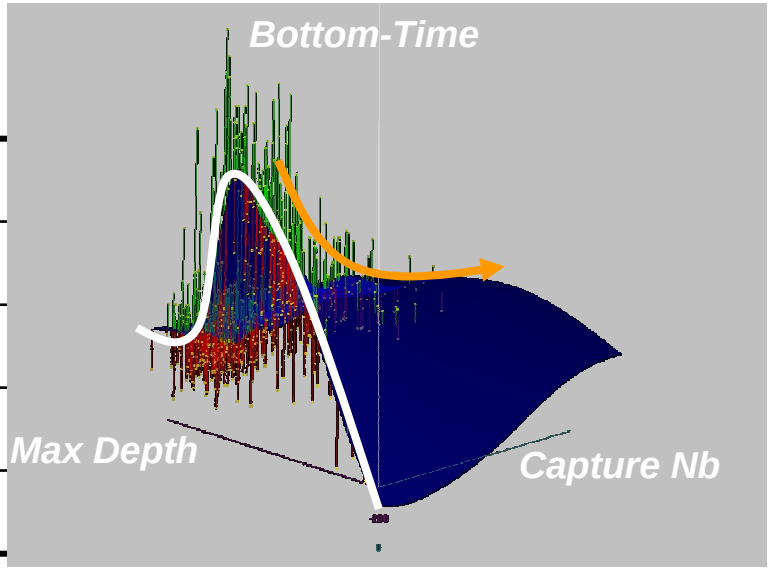


Bottom -Time adaptation according to depth

- Shallow diving: optimisation of bottom time *Bailleul et al. 2007b,*
- Deep diving: energetic cost

→ **quadratic relation** *Bessigneul et al. in prep.*

	Sinuosity	Bott.Time
Drift	**0**	**++**
Explo	**-**	**-**
Shal. Active	**++**	**+**
Deep. Active	**+++**	**--**



Argos + GPS + TDR, n = 9 ♀

Dragon et al. accepted MEPS

Foraging Detection

to detect successful foraging areas,

1) successful = *local* ***increase in body condition***

in the *horizontal dimension*,

2) **which method** & **data** is the most appropriate ?

in the *vertical dimension*,

3) are the seals displaying **vertical ARS** ?

in *both dimensions*,

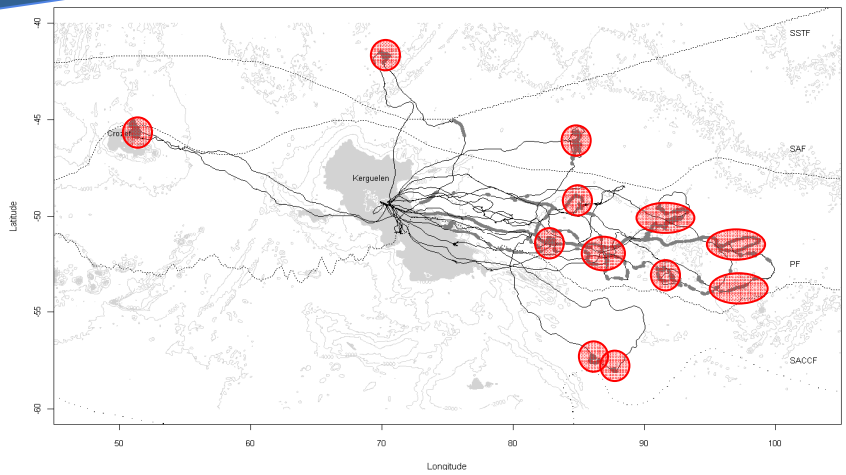
4) **consistence** between increase in body condition and horizontal & vertical ARS ?

Foraging Detection

4) horizontal & vertical consistency ?

Process-based models & Drift rate index:

→ Localisation of the main successful foraging areas



Argos + GPS + TDR, n = 9 ♀

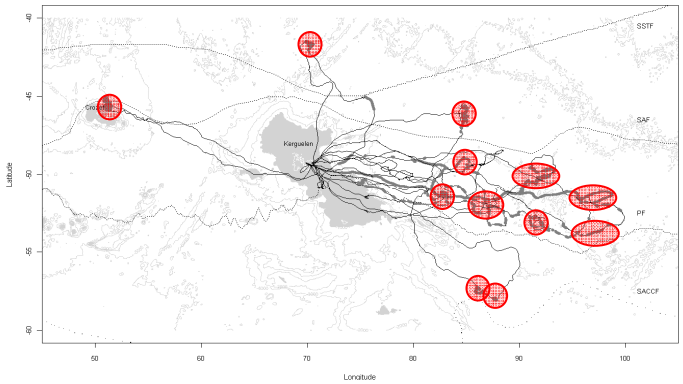
Dragon et al. accepted MEPS

Foraging Detection

4) horizontal & vertical consistency ?

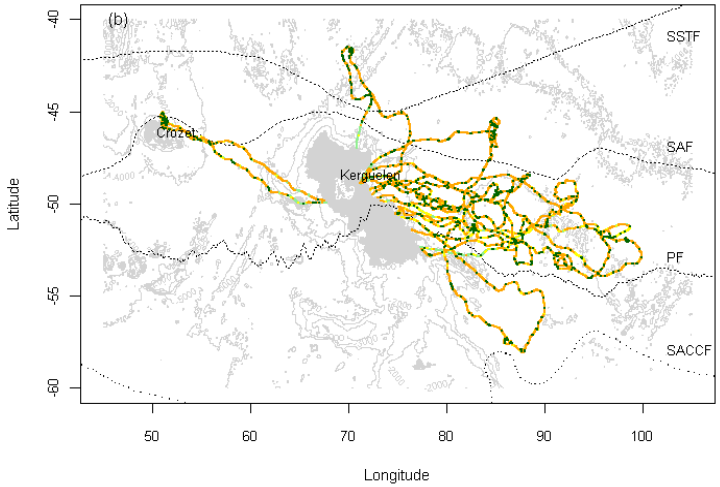
Process-based models & Drift rate index:

→ Localisation of the main successful foraging areas



Active dives & vertical ARS *all along the tracks*

→ Localisation of the **foraging dives**



Deep Active Dive
Shallow Active Dive
Exploratory Dive
Drift Dive

Argos + GPS + TDR, n = 9 ♀

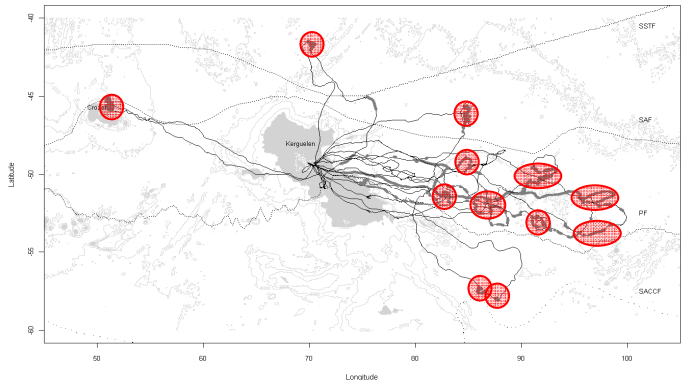
Dragon et al. accepted MEPS

Foraging Detection

4) horizontal & vertical consistency ?

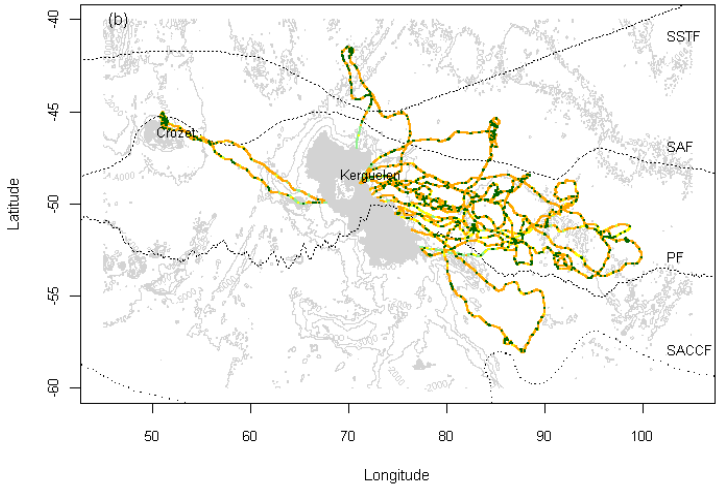
Process-based models & Drift rate index:

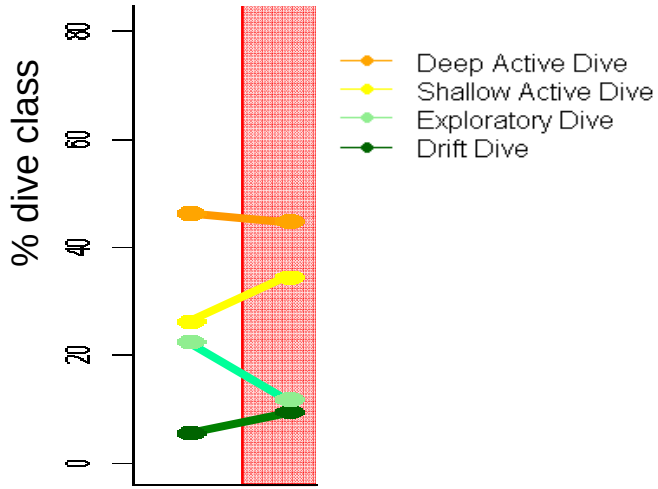
→ Localisation of the main successful foraging areas



Active dives & vertical ARS *all along the tracks*

→ Localisation of the **foraging dives**





Extensive Foraging vs. **Intensive Foraging**

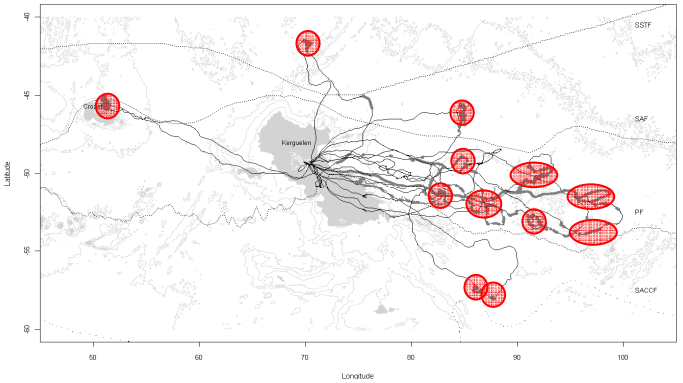
Variations in dive proportions depending on the horizontal behavioural mode

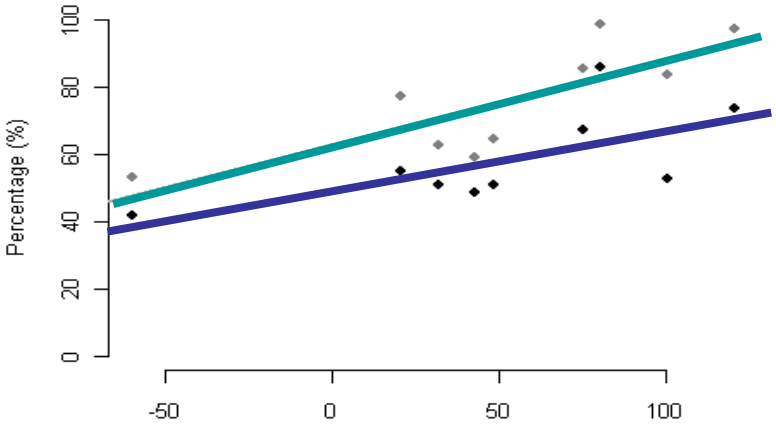
⇗ **Active dives when intensive foraging**

Dragon et al. accepted MEPS

Foraging Detection

4) horizontal & vertical consistency ?





Mass Gain (kg)
global body condition

% time in ARS

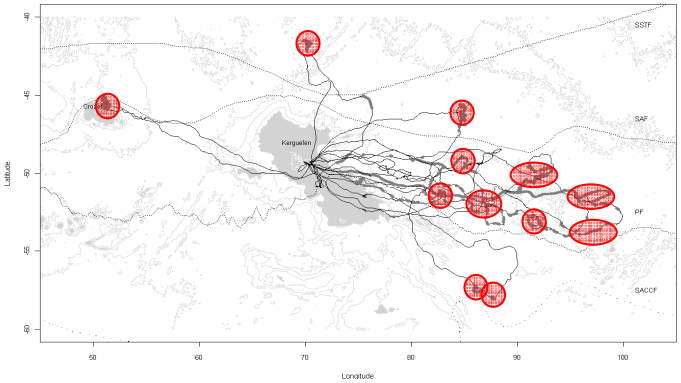
ρ=0.67, p.value < 0.05

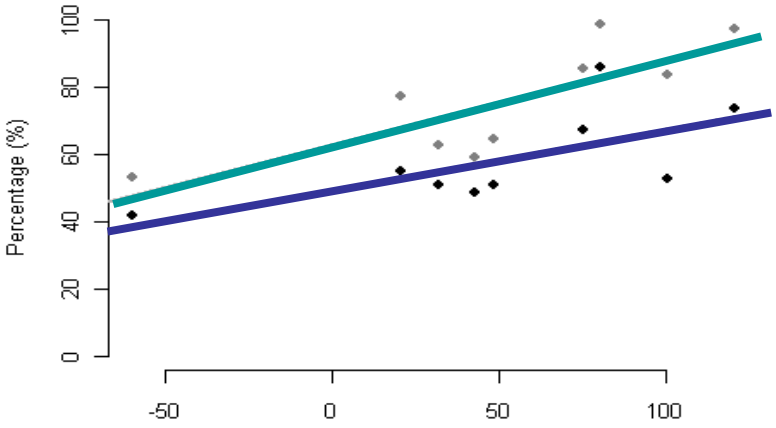
Argos + GPS + TDR, n = 9 ♀

Dragon et al. accepted MEPS

Foraging Detection

4) horizontal & vertical consistency ?





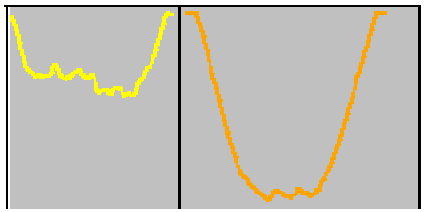
Mass Gain (kg)
global body condition

% time in ARS

ρ=0.67, p.value < 0.05

% Active dives

ρ = 0.80, p.value < 0.01



Shallow Active **Deep Active**

⇗ Mass Gain when ⇗ foraging intensification

Argos + GPS + TDR, n = 9 ♀

Dragon et al. accepted MEPS

Foraging Detection

4) horizontal & vertical consistency ?

→ foraging & ⇗ in body condition *all along the tracks*

→ but, main successful foraging localised in very favourable areas

→ localisation of main foraging areas from horizontal tracking data

= good proxy of foraging success

even for a diving predator

Argos + GPS + TDR, n = 9 ♀

Dragon et al. accepted MEPS

Foraging Detection

to detect successful foraging areas,

in the *horizontal dimension*,

1) **increase in body condition**

Main successful foraging areas = ARS
4-day lag for an increase in body condition

2) **which method** & **data** is the most appropriate ?

Process-based models (HMM, SSM etc.)
either on Argos or GPS tracking data

Dragon et al. under review MEPS

Foraging Detection

to detect successful foraging areas,

in the *vertical dimension*,

3) are the seals displaying **vertical ARS** ?

intensification of foraging in deep & shallow active dives

occurring all along the foraging trip

in both dimensions,

4) **consistence** between increase in body condition and horizontal & vertical ARS ?

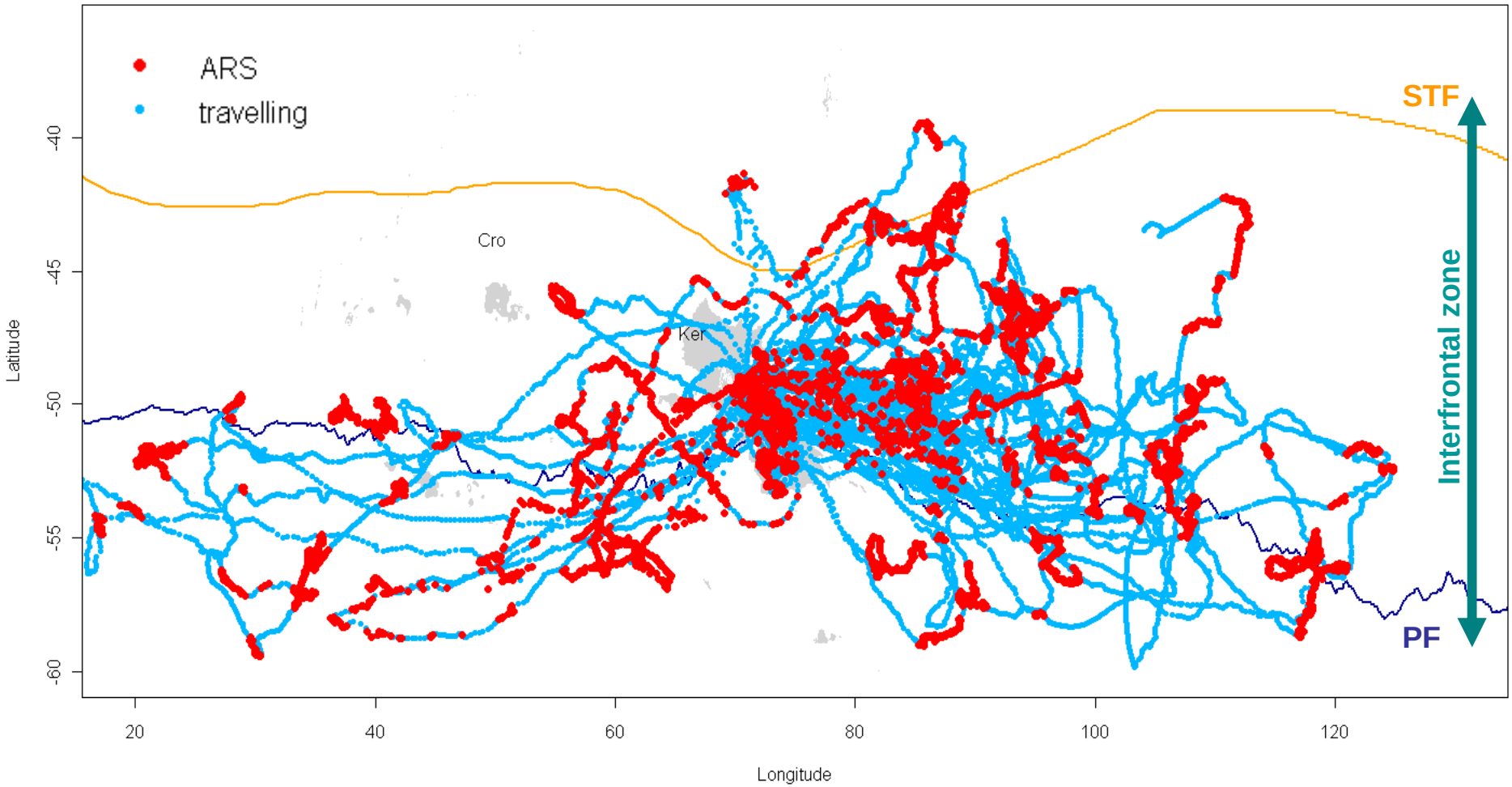
⇗% active dives when horizontal ARS

⇗% active dives & ⇗% horizontal ARS ~ ⇗ gain mass

horizontal ARS = good predictor of foraging success

Dragon et al. accepted MEPS

Foraging Detection



Favourable foraging areas

→ how can we characterise their distribution ?

Content

Introduction

Study site & model species

Scale-related patterns: Detection of Foraging Behaviour
Foraging & Oceanographic Conditions

Synthesis

Perspectives

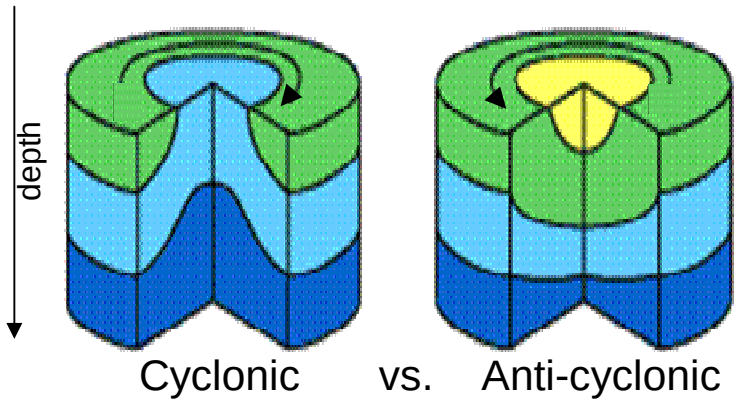
Foraging & Oceanographic Conditions

1) Do the seals **adapt their foraging behaviour** according to specific **oceanographic conditions ?**

¿ Behavioural transitions ⇔ Oceanographic Changes ?

2) Are **successful foraging areas** related to **eddies ?**

if yes, which type of eddies ?



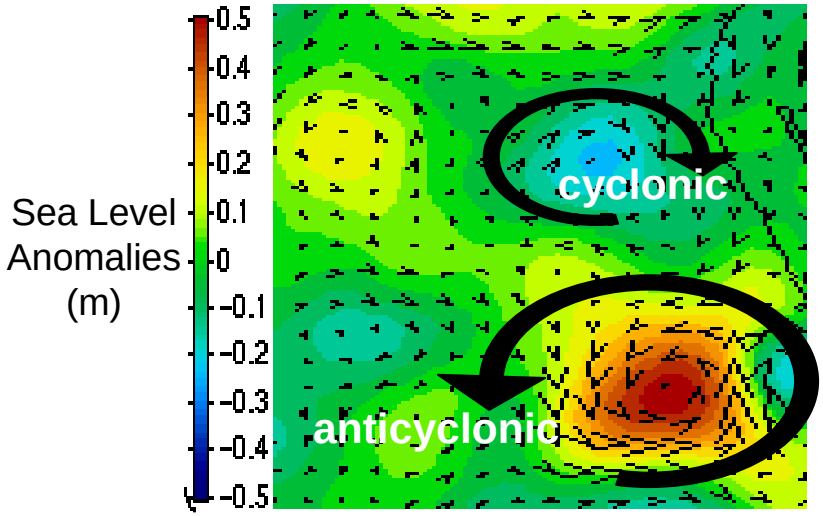
Foraging & Oceanographic Conditions

1) Oceanographic conditions at track scale?

→ in process-based models,

improvement of behavioural mode estimation

with the use of an environmental covariate : *Sea Level Anomalies*



GPS, n = 6 ♀

Dragon et al. in revision MEPS

Foraging & Oceanographic Conditions

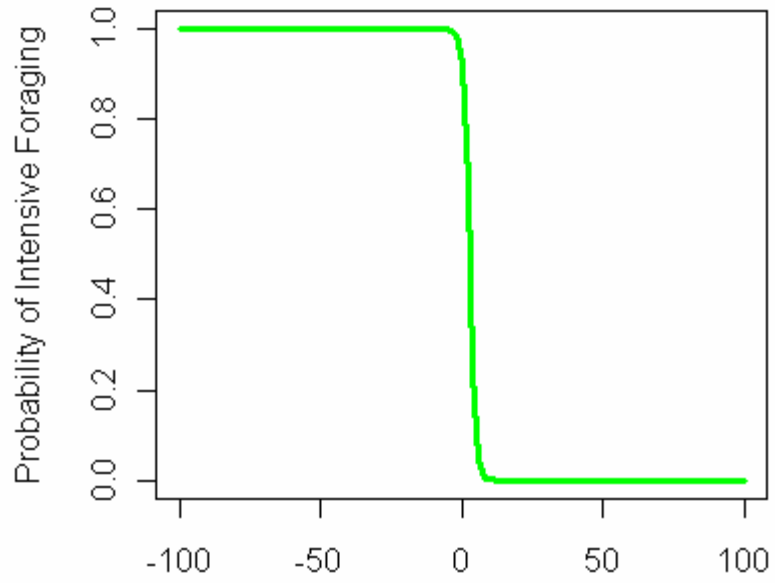
1) Oceanographic conditions at track scale?

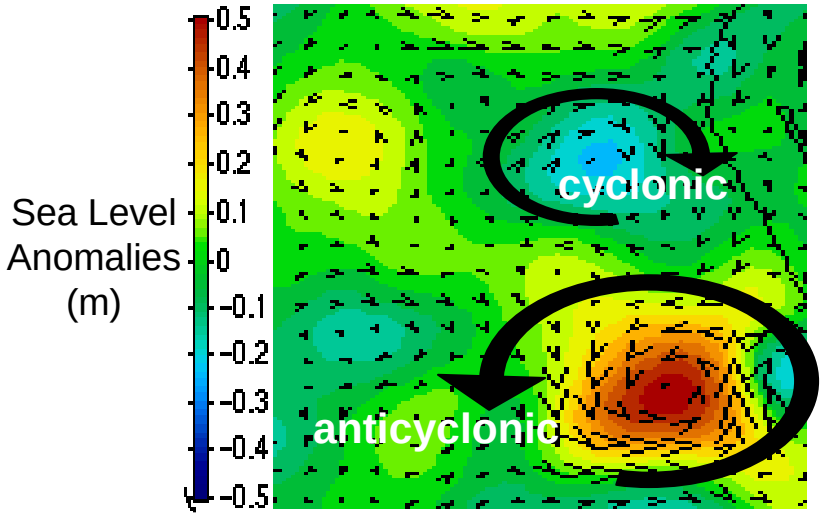
→ in process-based models,

improvement of behavioural mode estimation

with the use of an environmental covariate : *Sea Level Anomalies*

Logit(P[switching to intensive foraging]) = - 2.52 + 0.92 * SLA





GPS, n = 6 ♀

Dragon et al. in revision MEPS

Foraging & Oceanographic Conditions

2) Eddies & Foraging ?

→ Significant correlations between behaviour & oceanographic environment

	Nb Dive/km	Bottom Time	Depth	Pathlength
SLA ↘	↗	↗		
[Chl a] ↗	↗	↗	↘	↘
Temp ↘			↘	↘

Argos + CTD, n = 22 ♀

Dragon et al. 2010 Prog in Ocean

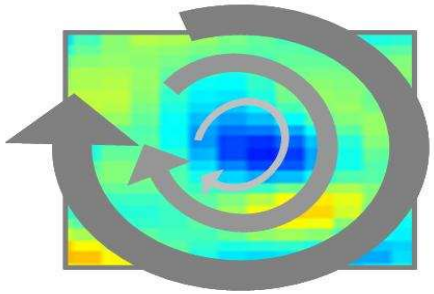
Foraging & Oceanographic Conditions

3) Eddies & Foraging ?

If an oceanographic structure presents …

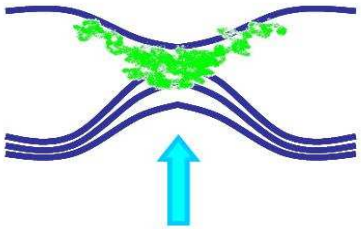
Low **SLA**

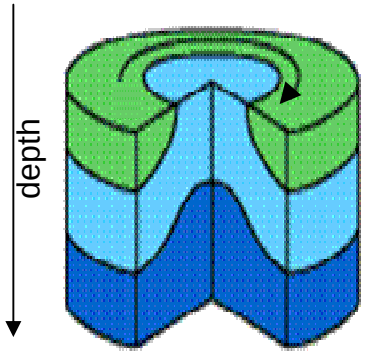
Low AbGeoVel



High **[Chl a]**

Low **Temperatures**





Cyclonic

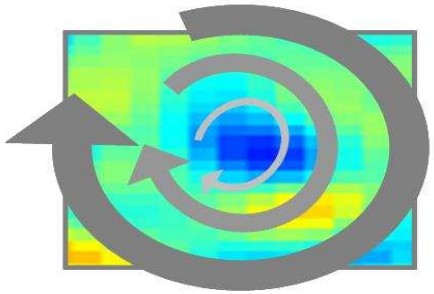
Argos + CTD, n = 22 ♀

Foraging & Oceanographic Conditions

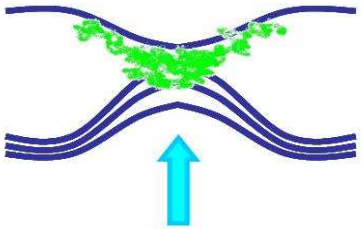
3) Eddies & Foraging ?

If an oceanographic structure presents …

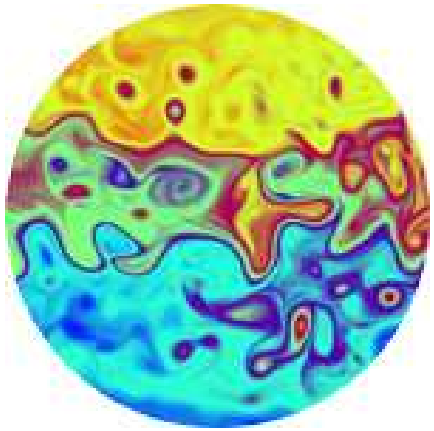
Low **SLA**
Low AbGeoVel

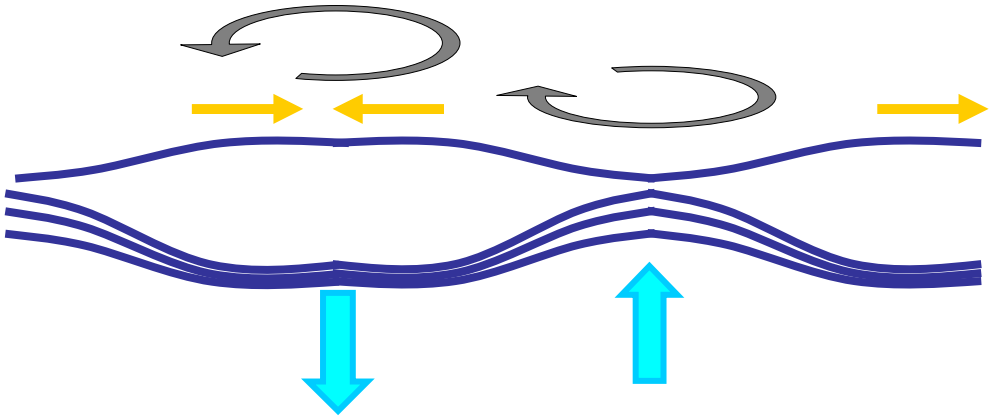


High **[Chl a]**
Low **Temperatures**



in a dynamic environment,





Cyclonic & Anti-Cyclonic eddies are adjacent

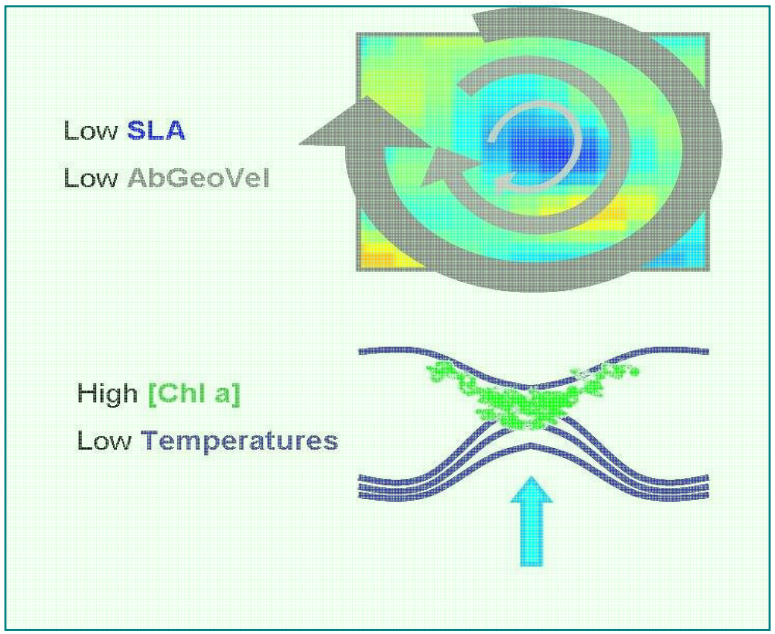
Argos + CTD, n = 22 ♀

Park et al. 2002, Bakun 2006

Foraging & Oceanographic Conditions

3) Eddies & Foraging ?

If an oceanographic structure presents …



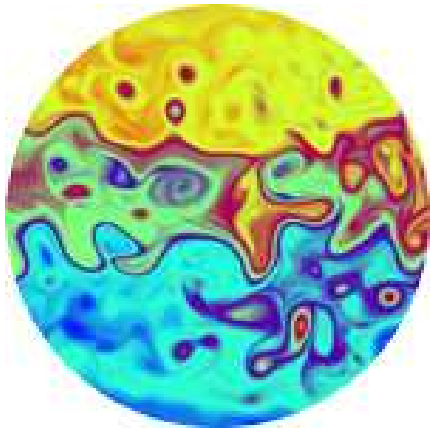
common characteristics between

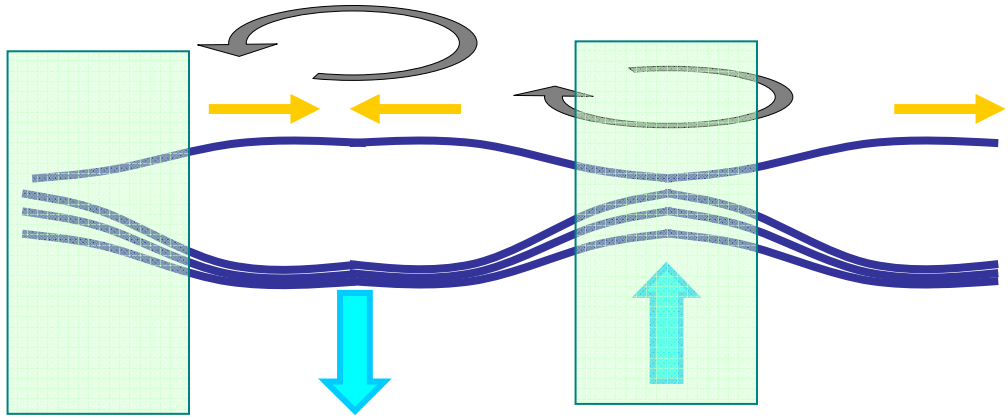
Anti-Cyclonic edges

& **Cyclonic cores**

Argos + CTD, n = 22 ♀

in a dynamic environment,





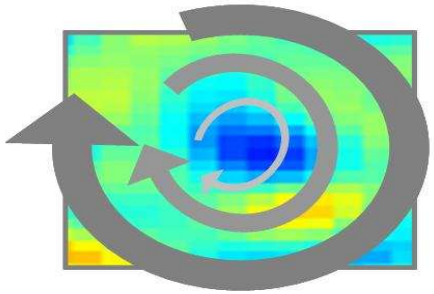
Cyclonic & Anti-Cyclonic eddies are adjacent

Eddies' edges present **bouncing effects**

Foraging & Oceanographic Conditions

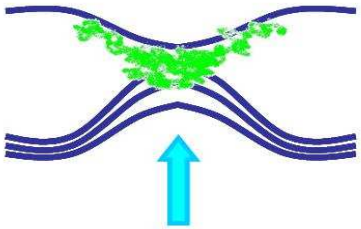
3) Eddies & Foraging ?

If an oceanographic structure presents …



Low **SLA**

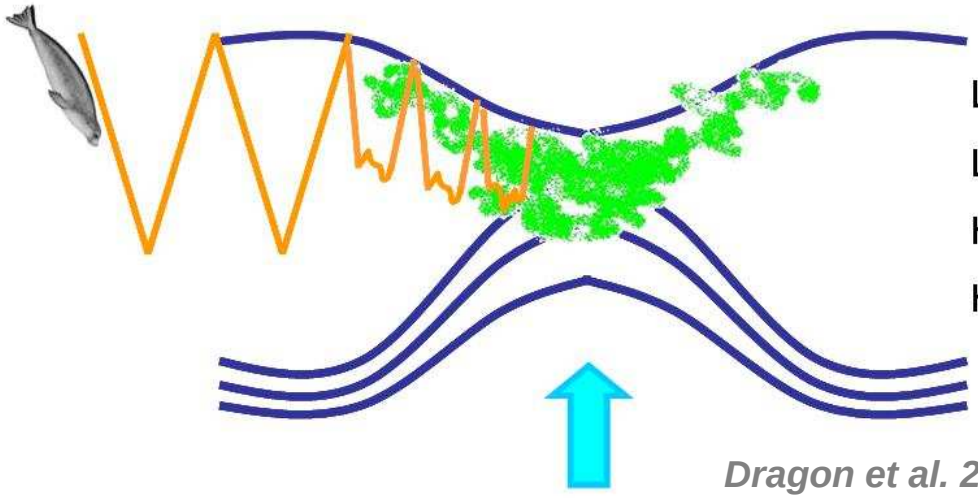
Low **AbGeoVel**



High **[Chl a]**

Low **Temperatures**

***… then the behaviour* intensifies**



Low **Pathlength**

Low **Max Depth**

High **Bottom Time**

High **Nb Dives/km**

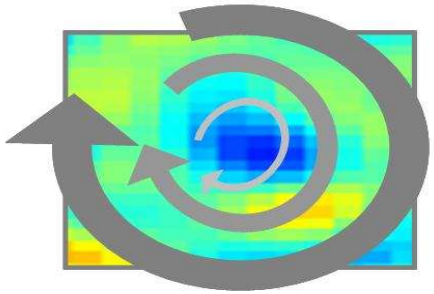
Argos + CTD, n = 22 ♀

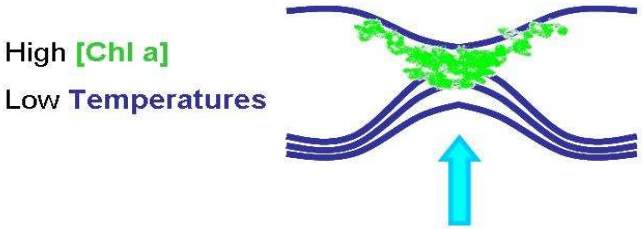
Dragon et al. 2010 Prog in Ocean

Foraging & Oceanographic Conditions

3) Eddies & Foraging ?

If an oceanographic structure presents …



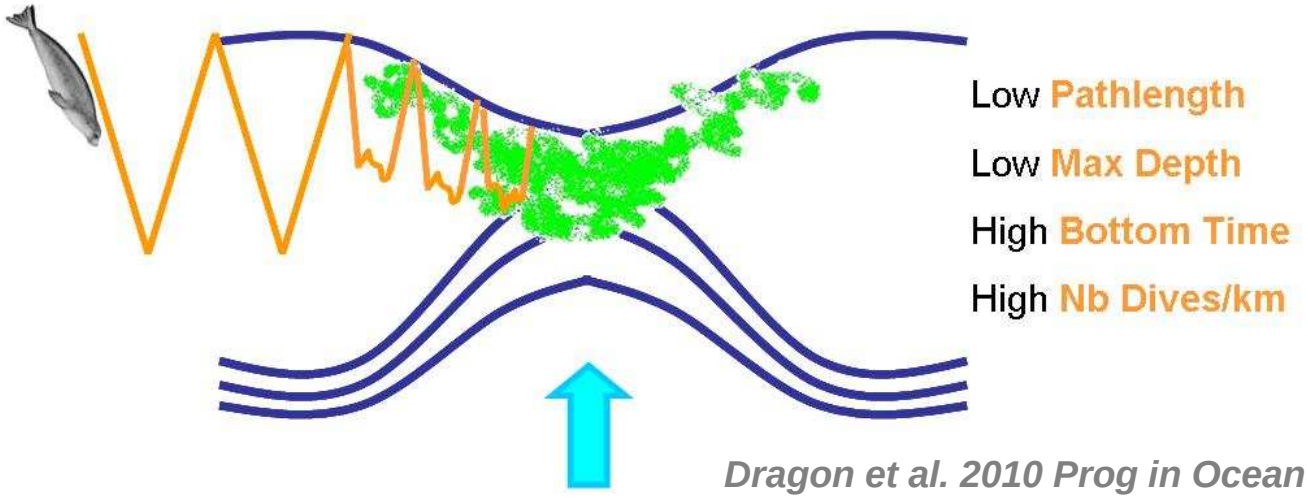


Cyclonic cores

& Anticyclonic edges

→ intensification of the foraging behaviour

… then the behaviour intensifies



Argos + CTD, n = 22 ♀

Dragon et al. 2010 Prog in Ocean

Foraging & Oceanographic Conditions

→ **Foraging related to specific oceanographic structures**

Do the seals adapt their foraging behaviour according to specific oceanographic conditions ?

YES

Are successful foraging areas related to eddies ?

YES

if yes, which type of eddies ?

cyclonic cores & anti-cyclonic edges

Dragon et al. 2010 Prog in Ocean, Dragon et al. in revision MEPS

Content

Introduction

Study site & model species

Scale-related patterns: Detection of Foraging Behaviour
Foraging & Oceanographic Conditions

Synthesis

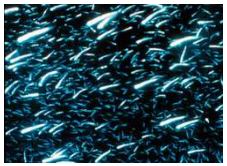
Perspectives

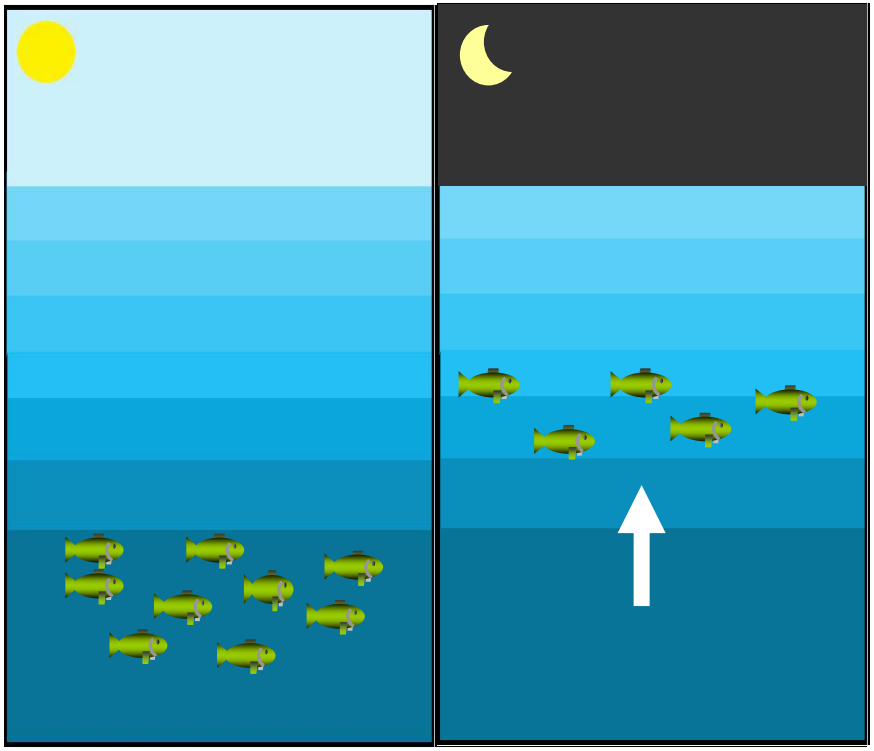
Intensification of Foraging Behaviour

Myctophids = nyctemeral migrations

↘ depth of cryptic prey

↘ forager depth





Pusch et al. 2004, Loots et al. 2007

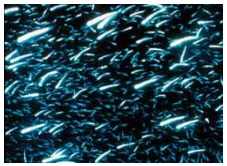
Intensification of Foraging Behaviour

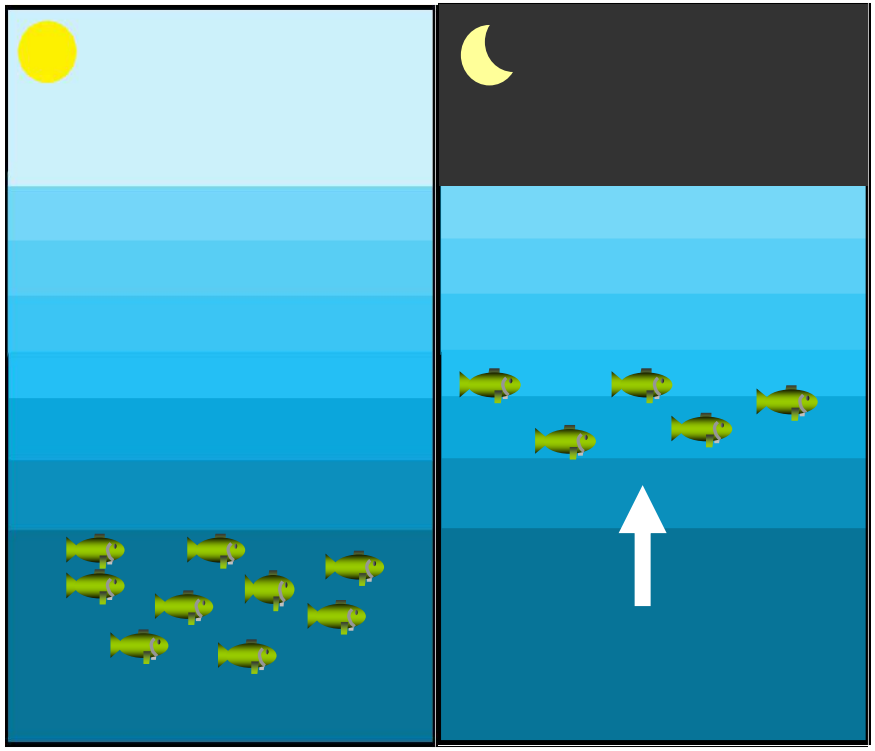
Contraints & Species Biology

Myctophids = nyctemeral migrations

⇘ depth of cryptic prey

⇘ forager depth





Dive by night

depth ~ 80m

Dive by day

depth ~ 200m

Dive by day & night

depth ~ 500m

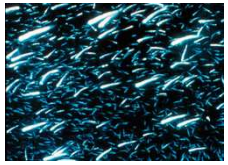
Depth

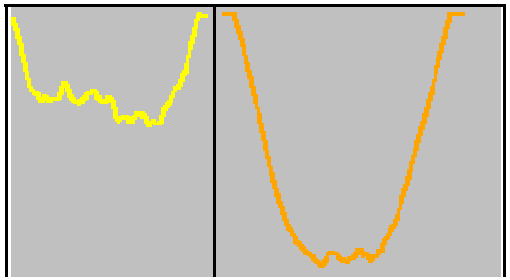
Intensification of Foraging Behaviour

Myctophids = nyctemeral migrations

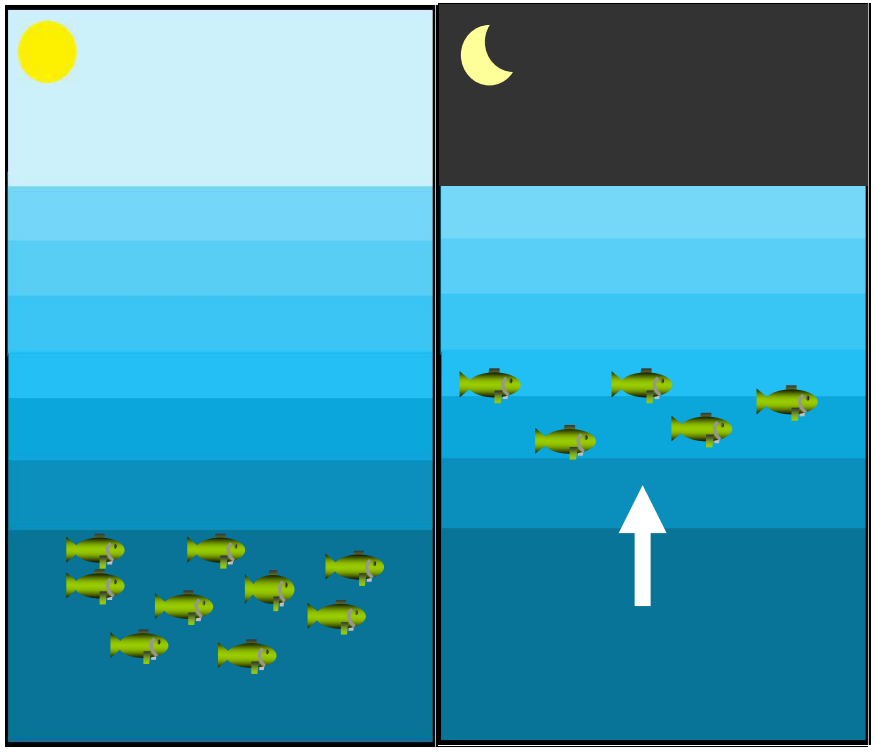
↘ depth of cryptic prey

↘ seal depth





Shallow Active **Deep Active**



Dragon et al. accepted MEPS

Intensification of Foraging Behaviour

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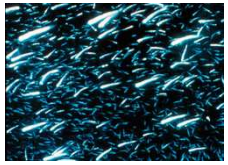

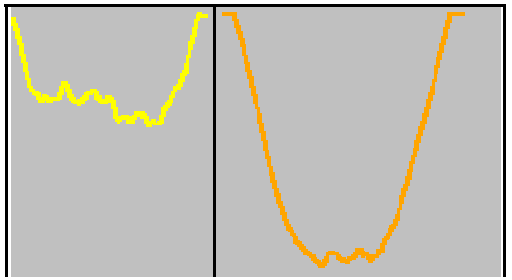

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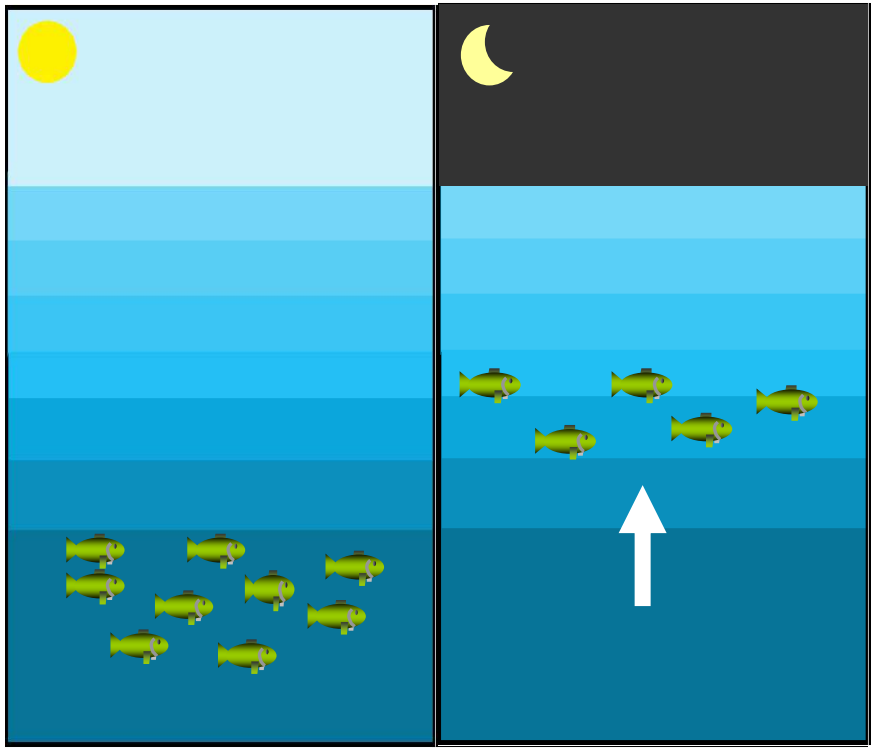


But

both **active dives** displayed by

day & night time

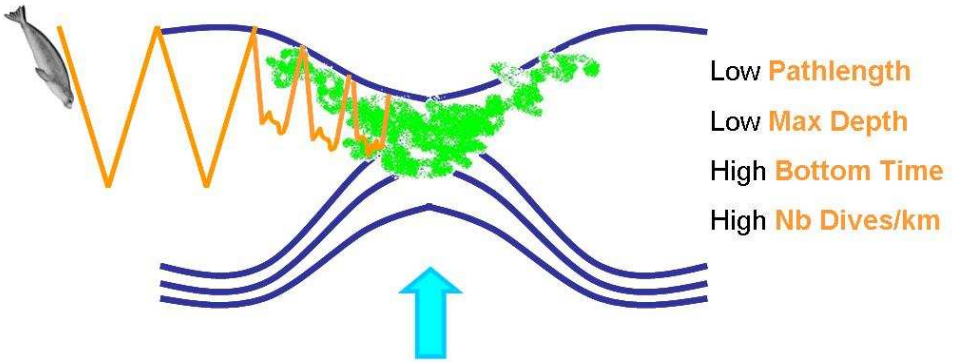
Dragon et al. accepted MEPS

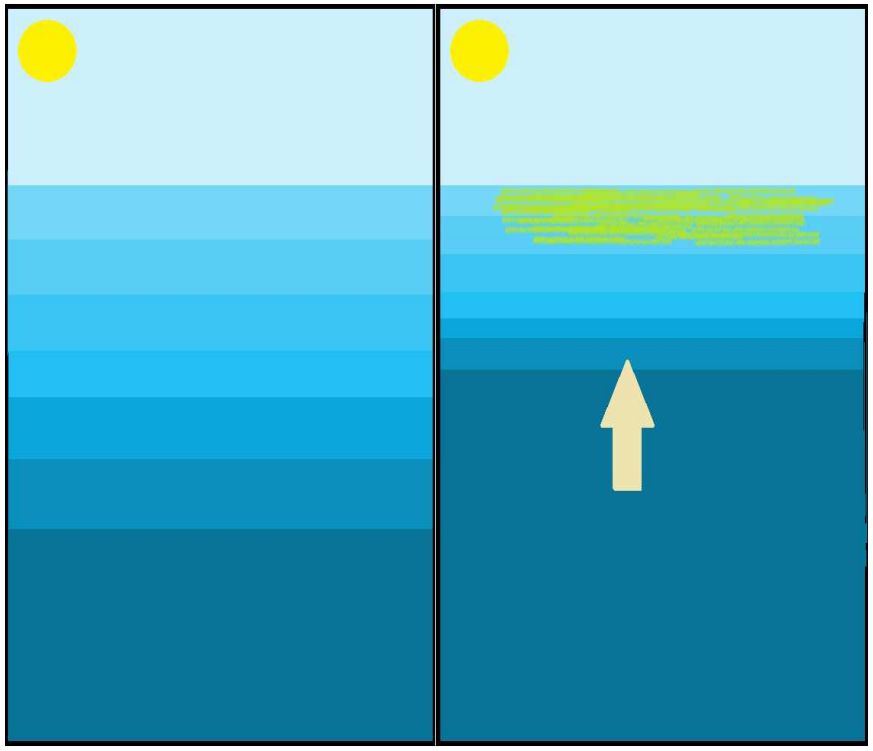
Intensification of Foraging Behaviour

Cyclonic cores

& Anticyclonic edges

→ intensification of the foraging behaviour





⇗[phytoplankton]

⇗ light attenuation

Dragon et al. 2010 Prog in Ocean

Jaud et al. in prep.

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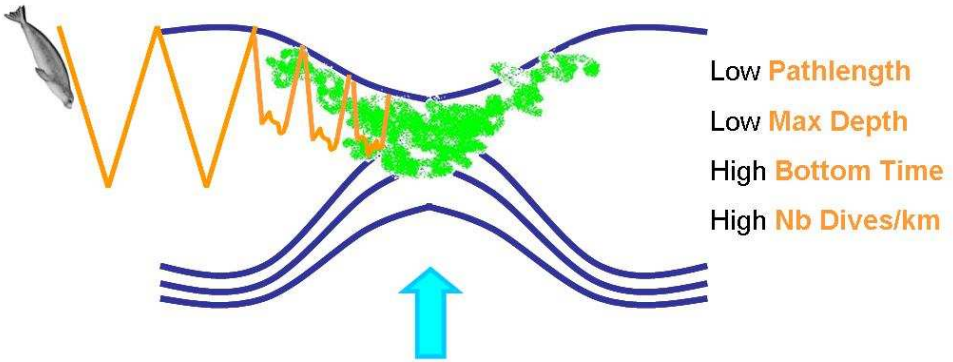
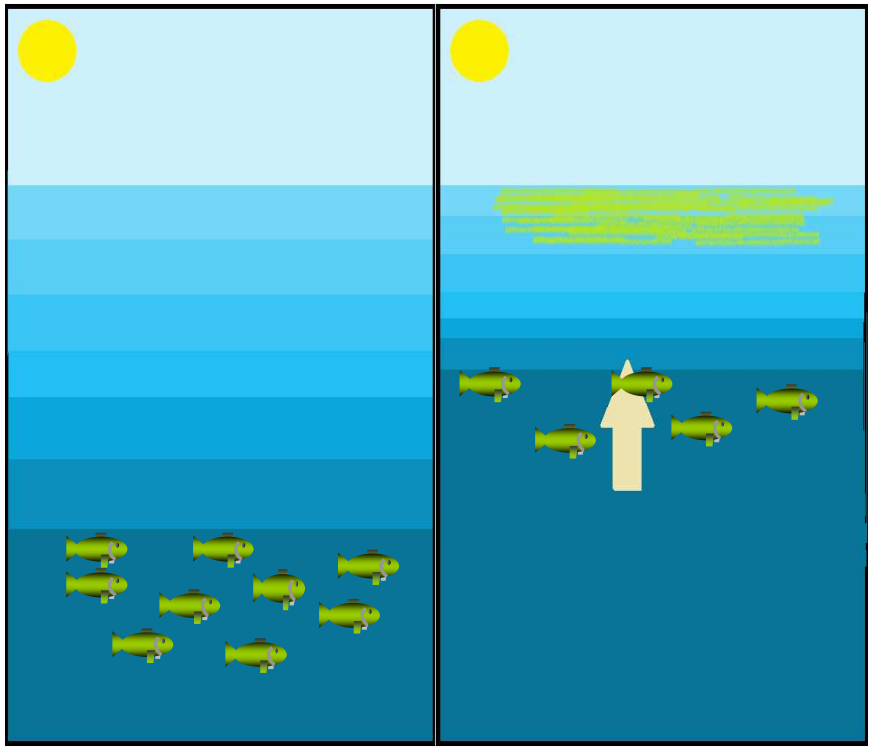
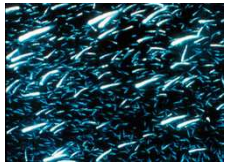




⇗[phytoplankton]

⇗ light attenuation

⇘ depth of cryptic prey



Dragon et al. 2010 Prog in Ocean

Jaud et al. in prep.

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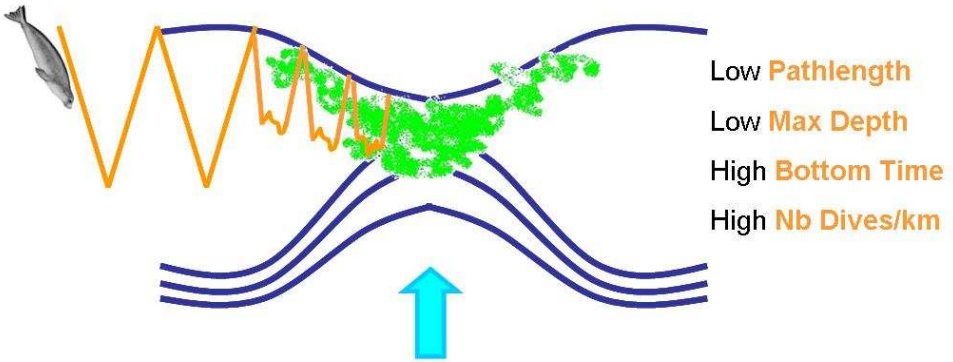

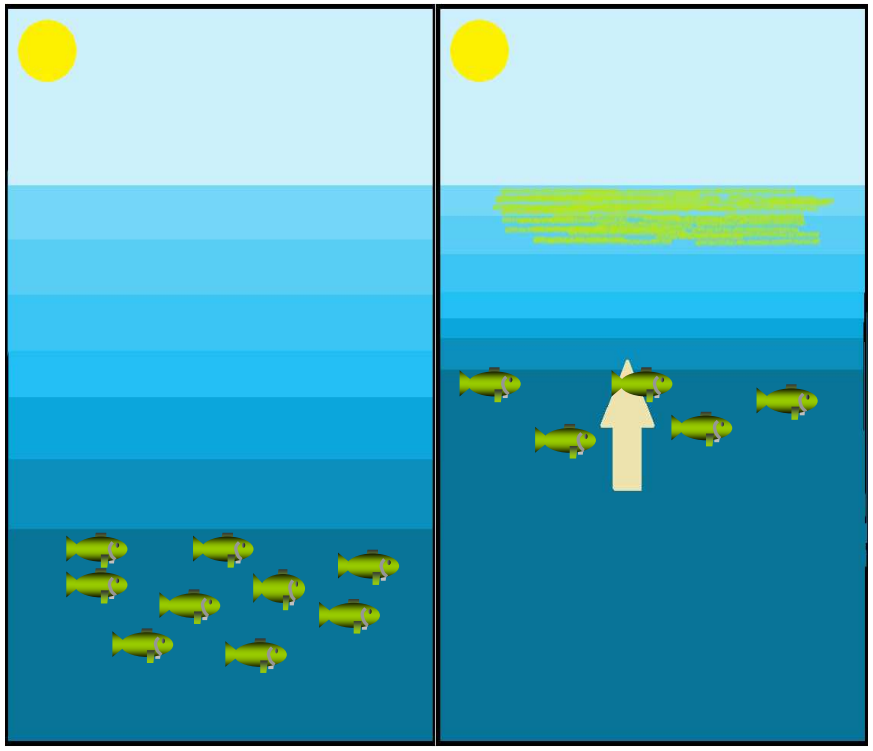

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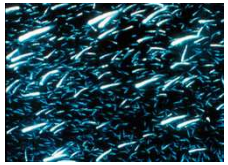

⇘ depth of cryptic prey

⇘ seal depth

Dragon et al. 2010 Prog in Ocean

Jaud et al. in prep.

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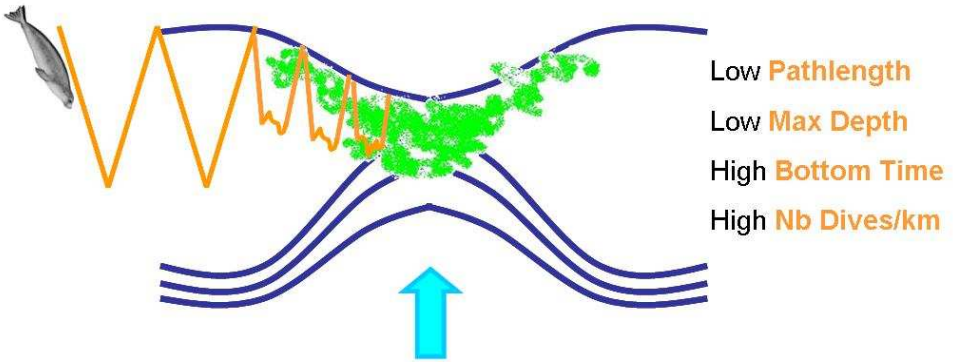

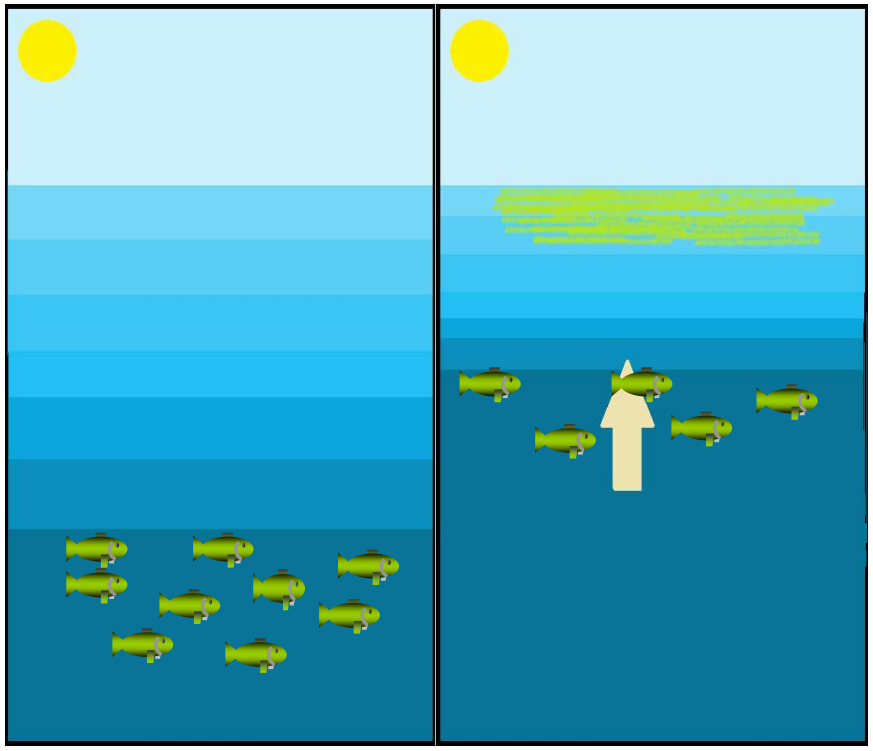

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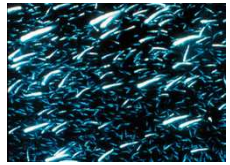

⇘ depth of cryptic prey

⇘ seal depth

►Sub-surface Fluorescence study

Guinet et al. in prep.

Dragon et al. 2010 Prog in Ocean

Jaud et al. in prep.

Intensification of Foraging Behaviour

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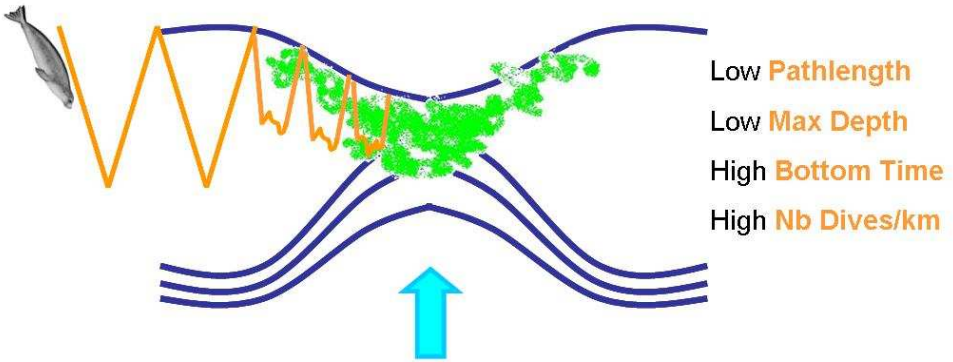
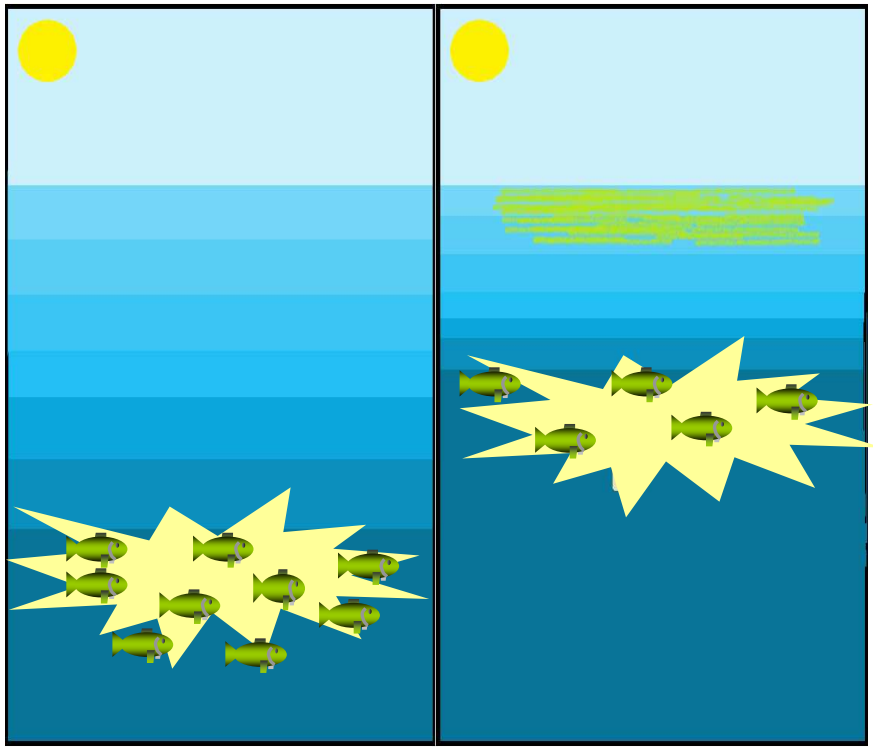
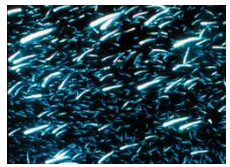




⇗[phytoplankton]



⇗ light attenuation

⇘ depth of cryptic prey

⇘ seal depth

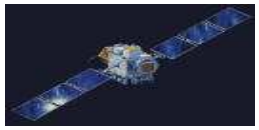
►Bioluminescent study

Vacquie et al. submitted

Dragon et al. 2010 Prog in Ocean

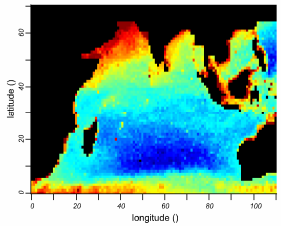
Jaud et al. in prep.

Biologging & Top-Predators



Climate

→ Oceanographic Conditions



Lower trophic levels

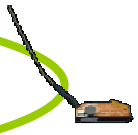
Medium trophic levels

?

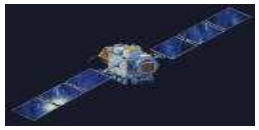
Biologging

Movements of **upper trophic levels**

Foraging of top-predators



Biologging & Top-Predators



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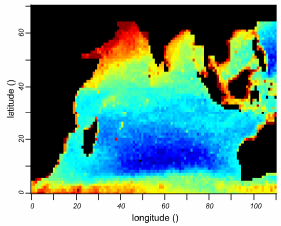

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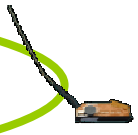

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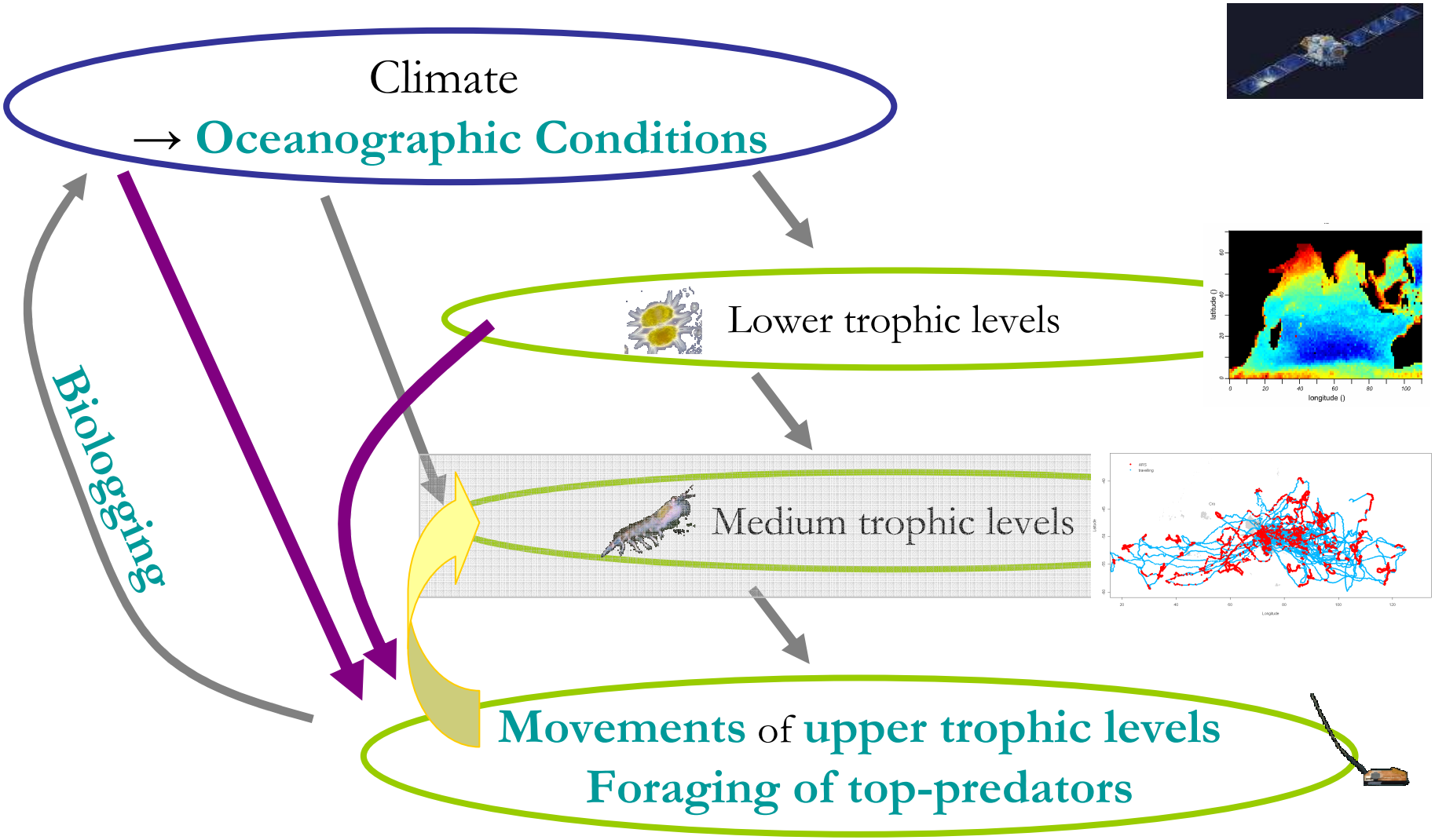
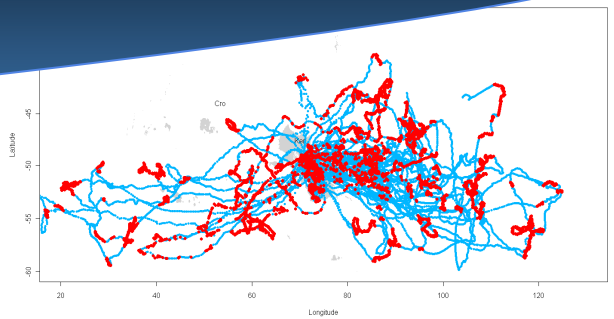


Foraging Detection



Animals forage & feed all along their tracks, but …

Favourable foraging areas

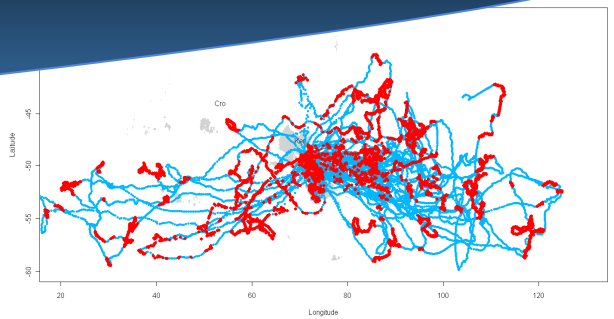
Fine scale

→ ARS display

→ body condition increase

→ diving activity intensification (esp. shallow active dives)

Foraging Detection



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► *to be confirmed for other top-predator species*

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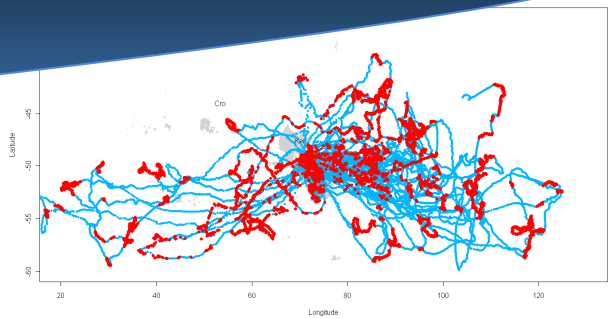

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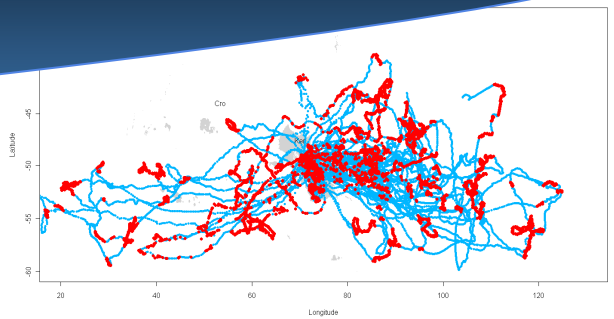
sea level anomalies, sea ice, bathymetry etc.





Foraging Detection



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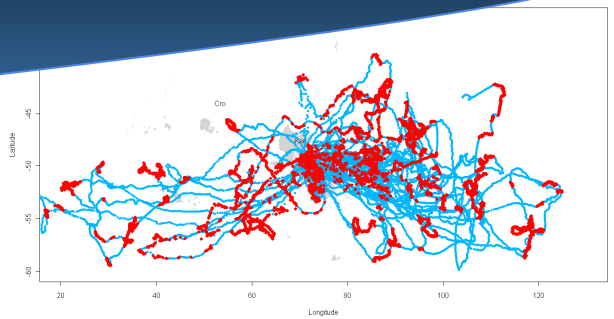
3) Validation by very fine scale data

Foraging Detection



Favourable foraging areas

Fine scale

→ ARS display

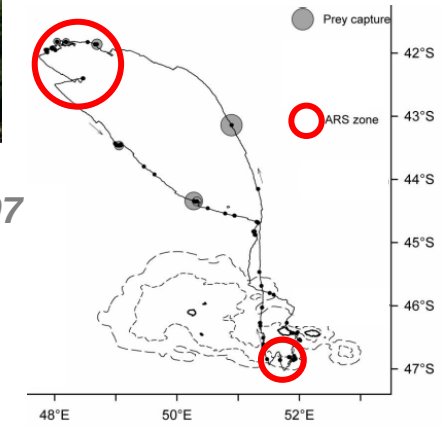
→ body condition increase

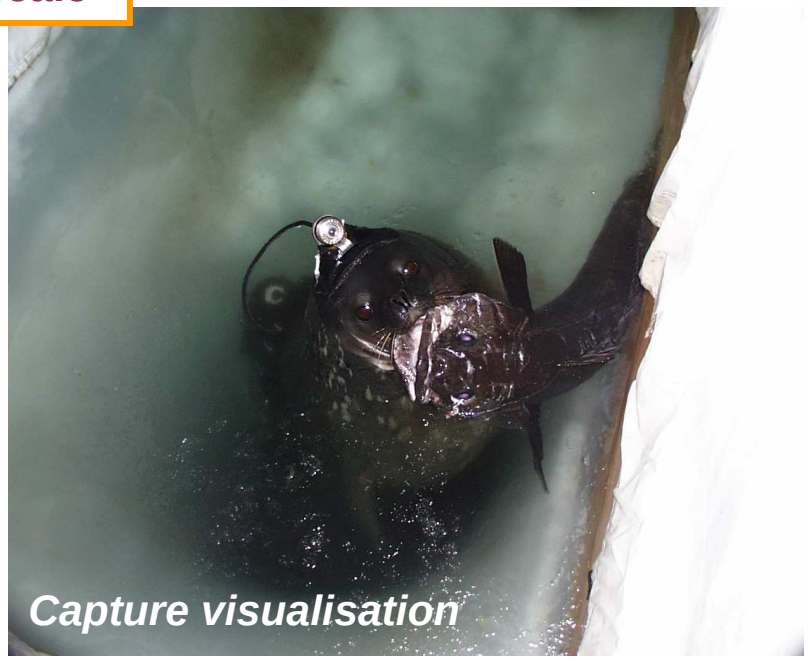
→ diving activity intensification (esp. shallow active dives)

→ ¿ feeding events increase ?

Very Fine scale

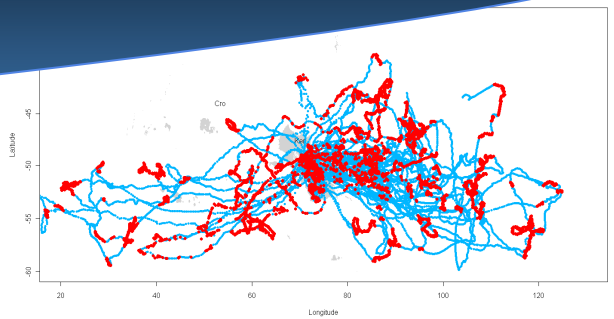
Weimerskirch et al. 2007





Bowen et al. 2002, Hooker et al. 2002, Davis et al. 2003

Foraging Detection



Favourable foraging areas

→ ARS display

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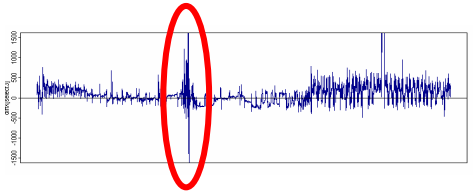
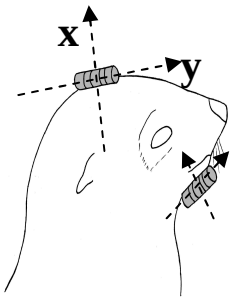
→ ¿ feeding events increase ? **Very Fine scale**

Capture attempt

= proxy of foraging success

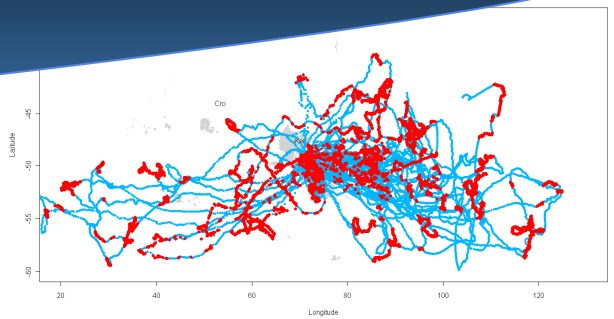




Naito et al. 2007, Viviant et al. 2010

Bowen et al. 2002, Hooker et al. 2002, Davis et al. 2003

Foraging Detection



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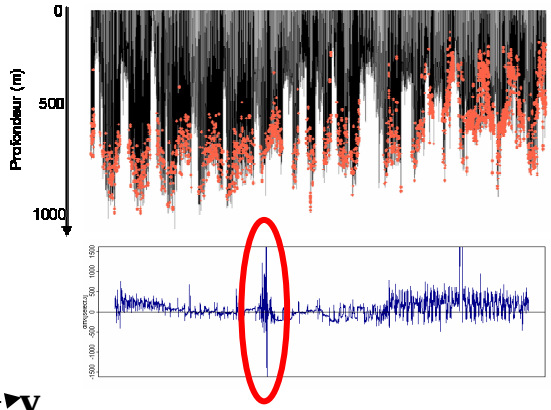
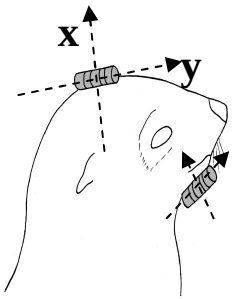
→ ¿ feeding events increase ? **Very Fine scale**

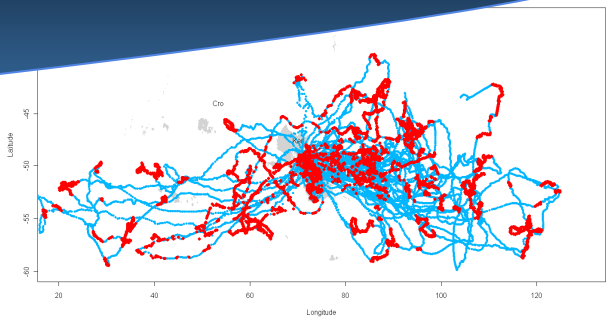




Naito et al. 2007, Viviant et al. 2010

Bowen et al. 2002, Hooker et al. 2002, Davis et al. 2003

Foraging Detection



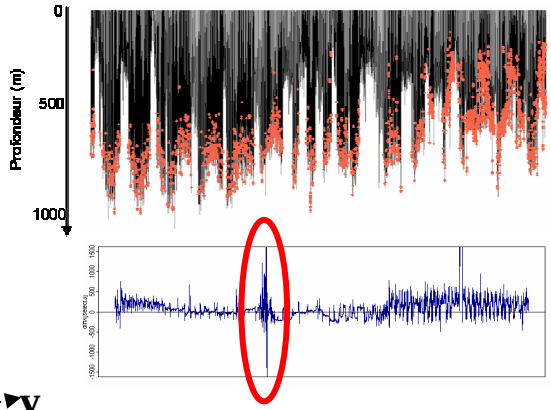
Favourable foraging areas

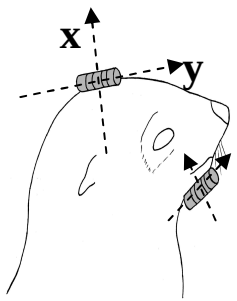
→ ARS display

→ body condition increase

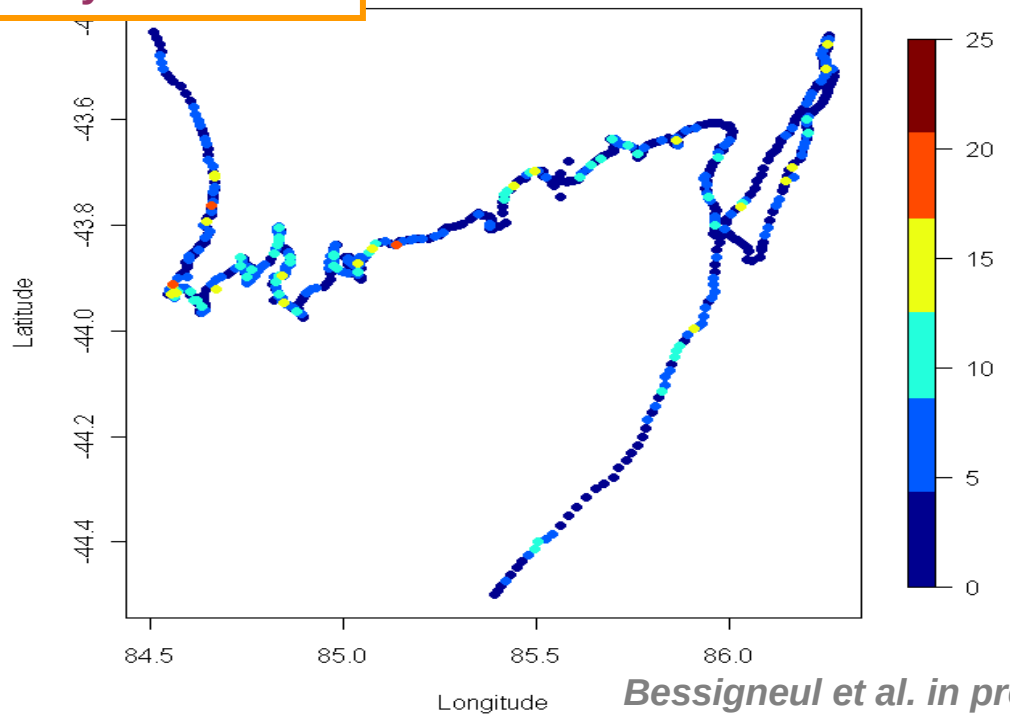
→ diving activity intensification (esp. shallow active dives)

→ ¿ feeding events increase ?



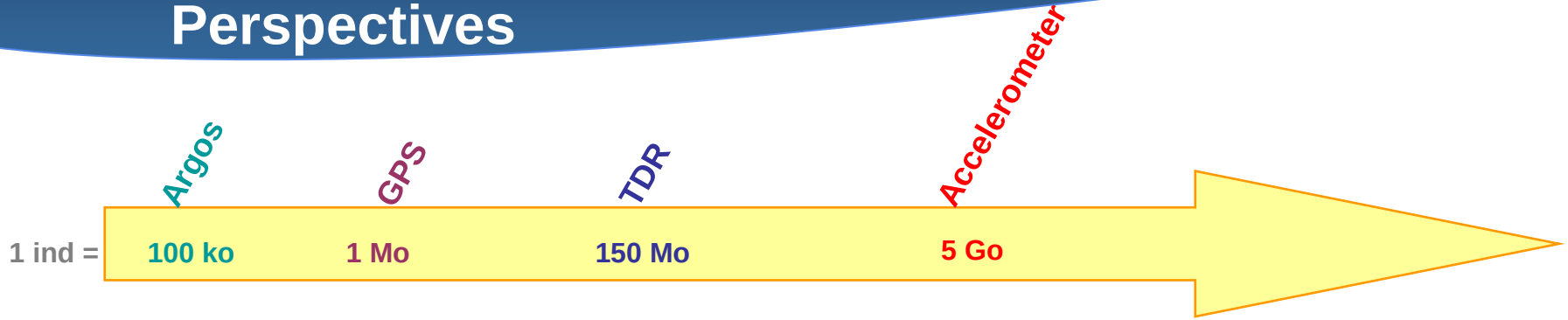


Very Fine scale



Bessigneul et al. in prep.

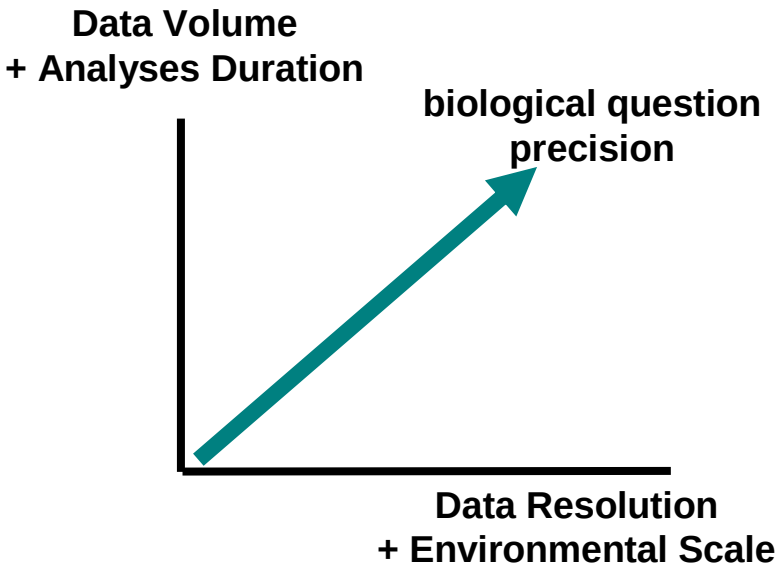
Perspectives



In the last decades,

Exponential increase in **data quality** & **quantity**

+ complexification of **methodology**



∀ Study Species

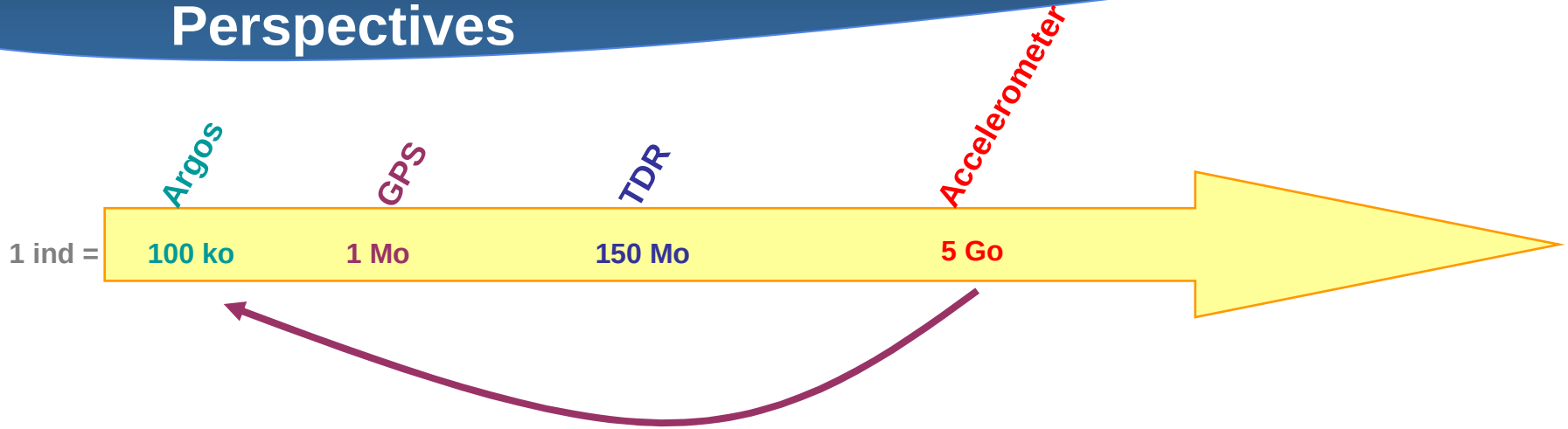
Given a biological question,

► best foraging predictor ?

► most optimal methodology ?

Population Study (n > 30)

Perspectives



Given a biological question,

► validation of best foraging predictor with few individuals

Application to long-term tracking datasets

►Inter-annual Study

Natural experiment for inter-annual variations

Perspectives

Global Warming

Abiotic effects
Origin & Number of Eddies
Mixing–Layer Depth

Biotic effects
Primary Production
Secondary Production

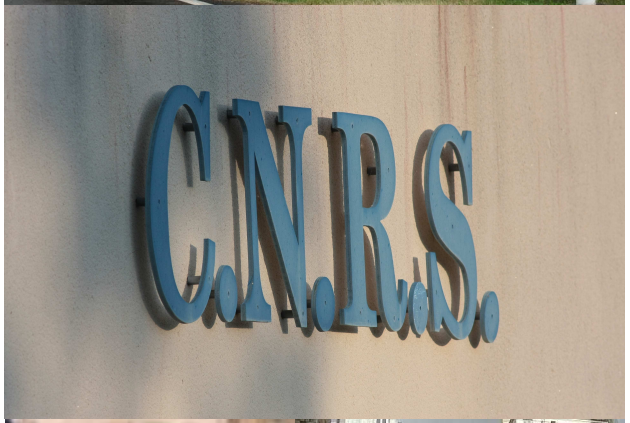
Over the years,

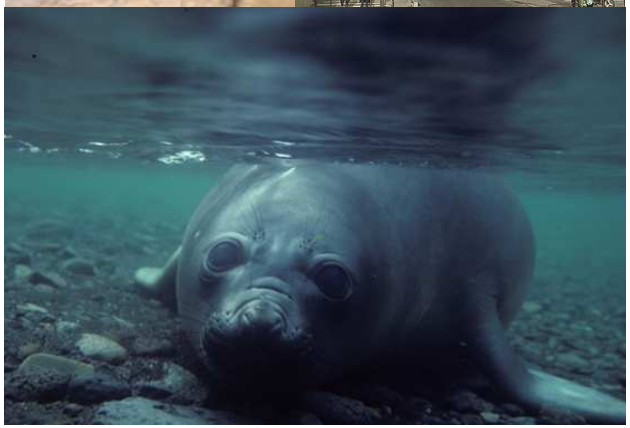
⇗ thermocline depth ~ ⇗ **predators foraging depth**

⇗ eddies ~ ⇗ **biological richness**

► impact on top-predators **population dynamics** ?


Thank you for your attention





Special Thanks to …

Defence committee

Chizé's team

Paris's team

Kerguelen's team

Friends & Family

Arnaud

Publications

Refereed Journal Publications

Dragon, A-C., Monestiez, P., Bar-Hen, A. and C. Guinet. Linking foraging behaviour to physical oceanographic structures: Southern Elephant Seals and mesoscale eddies east of Kerguelen Island. *Progress in Oceanography*, 87 (2010) 61-71.

Dragon, A-C., Marchand, S., Authier, M., Cotté, C., Blain, S. and C. Guinet. Insights into the spatio-temporal distribution of productivity in the indian southern ocean provided by satellite observations. *Cybium*, in press.

Dragon, A-C., Bar-Hen, A., Monestiez, P. and C. Guinet. Horizontal Area-Restricted-Search and Vertical Diving Movements to Predict Foraging Success in a Marine Top-Predator. *Marine Ecology Progress Series*. 2011. *Accepted*.

Publications

Submitted Journal Publications

Patterson, T., Bravington, M., Biuw, M., Hindell, M., Foster, S., Fedak, M., **Dragon, A-C.**, Guinet, C. and D. Costa. Ocean-scale analysis, population-level comparisons ans spatial-prediction of foraging marine top-predators: a global comparison of foraging strategies in four sub-populations of southern elephant seals (*Mirounga leonina*). *Ecological Monographs.* 2011. *In Revision.*

Dragon, A-C., Bar-Hen, A., Monestiez, P. and C. Guinet. Comparative analysis of methods for inferring successful foraging areas from Argos and GPS tracking data *Marine Ecology Progress Series.* 2011. *In Revision.*

Authier, M., **Dragon, A-C.**, Richard, P., Cherel, Y. and C. Guinet. O' mother where wert thou ? Maternal strategies in the southern elephant seal: a stable isotope investigation. *Proceedings of the Royal Society of London, B.* 2011. *Under Review.*

Vacquie-Garcia, J., Royer, F., **Dragon, A-C.**, Viviant, M. and Bailleul, F. and C. Guinet. Foraging in the darkness of the Southern Ocean: influence of bioluminescence on a deep diving predator. *PloS One. Under Review.*

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Dragon, A-C., Bar-Hen, A., Monestiez, P. and C. Guinet. Temperature and Temperature Gradient as Predictors of Top-Predators' Fine Foraging Decisions: Southern Elephant Seals Adapting their Diving Behaviour in the Polar Frontal Zone off Kerguelen Islands. *Deep-Sea Research, Part II.* submission in November 2011.

Dragon, A-C., Viviant, M., Bar-Hen, A., Monestiez, P. and C. Guinet. Adapting state-space models to predator's biology: the detection of area-restricted search on antarctic fur seals' tracks. *Marine Ecology Progress Series.* submission in December 2011.

Dragon, A-C., Cotté, C., Walker, E., Phillips, H., Bar-Hen, A., Monestiez, P. and C. Guinet. Horizontal and vertical characterisation of a polar mesoscale structure: from ecological and oceanographical points of view. *Proceedings of the Royal Society of London, B.* submission in December 2011.

Authier, M., **Dragon, A-C.**, Cherel, Y. and C. Guinet.Changing your Habits: where's the gain? Females sticking to their foraging strategy have larger mass gain in Southern Elephant Seals. *Ecology.* submission in October 2011.

Cotté, C., d'Ovidio, F., **Dragon, A-C.**, Lévy, M. and C. Guinet. Biophysical identification of eddies of ecological interest from a marine predator outlook. *Royal Society Interface.* submission in October 2011.

Martin, A., Thiebot, J-B., **Dragon, A-C.**, Cherel, Y. and C-A. Bost. Sexual differences in foraging strategies of macaroni penguins in relation to austral oceanographic structures and diet. *Polar Biology.* submission in October 2011.