Validation data : keystone to assess performance of state-space models for movement

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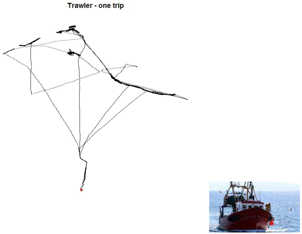
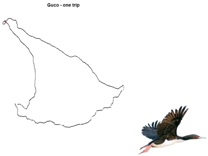
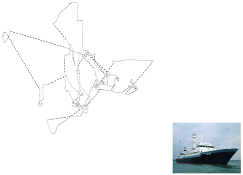
Plan

Inferring behavior from tracking data

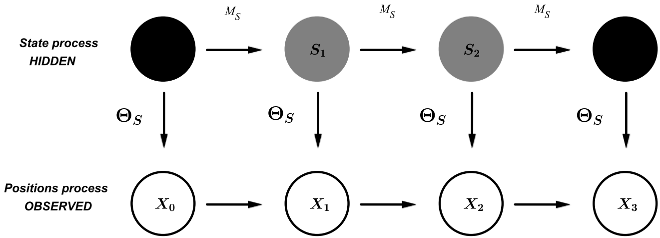




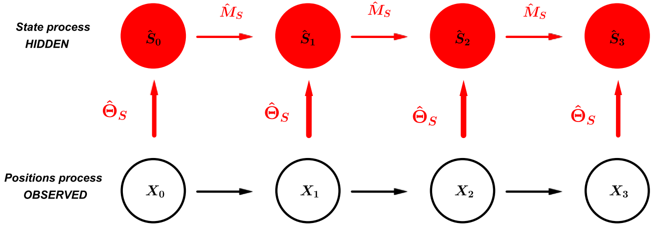


- Learning individual behavior along trajectory from movement
- Observations : positions at regular time step
- Behavior : fishing / not fishing, diving / not diving

Selecting a state space model

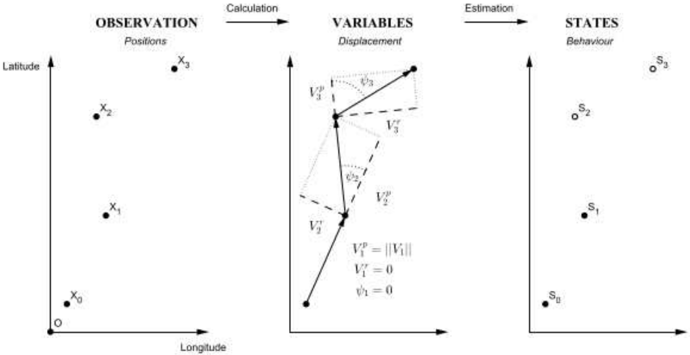


Selecting a state space model



Estimation : $\hat{\Theta}_S, \hat{M}_S$ and hidden states sequence$(\hat{S}_i))_i$

Selecting a state space model



...required assumptions

1. Observed positions process $X_{t+1} = D_t + X_t + \epsilon_t$

assuming a piecewise linear path with

Uncorrelated process : $V_t|(S_t) = f_V(\Theta_V)$ and $\Psi_t|(S_t) = f_\Psi(\Theta_\Psi)$

Uncorrelated model (Vermard et al 2010, Walker and Bez 2010, Joo et al 2013)

Correlated process : $V^p_{t+1}|(S_{t+1} = i) = \eta_{p,i} + \mu_{p,i} V^p_t + \sigma_{p,i}\epsilon_{p,t}$

$$V^r_{t+1}|(S_{t+1} = i) = \eta_{r,i} + \mu_{r,i} V^r_t + \sigma_{r,i}\epsilon_{r,t}$$

Autoregressive Model (Gloaguen et al 2014)

2. Hidden states process $S_{t+1} = F((S_1, ..., S_t), M_S)$

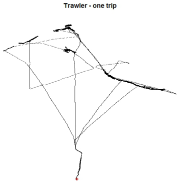
Markov Chain : $S_{t+1} = F(S_t, M_S)$

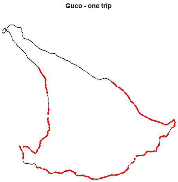
Semi Markov : $(S_{t_k}, T_{t_k})_{t_k}$ and $\tau_{t_k} = T_{t_k+1} - T_{t_k}$

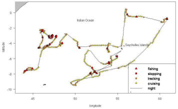
$$(S_{t_k+1}, \tau_{t_k+1}) = F((S_{t_1}, T_{t_1}, ..., S_{t_k}, T_{t_k}), M_S) = F(S_{t_k}, M_S)$$

High resolution trajectories with validation data

- Vessels and birds paths monitored **regularly** (with a **smaller time step** than usual)
- At each position, the state (fishing or not for vessels, diving or not for birds) is observed







High resolution trajectories with validation data

Learning from data and models fitting

- are models assumptions violated ?
- are inferred behaviors robust to model assumptions ?
- are the answers sensitive to observations time step ?

Performance of state space models : experiment

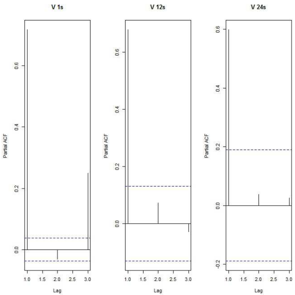
Degrading the observations time step,

1. we explore
   - Positions process : is it correlated ? PACF analyses (H_0 : uncorrelated)
   - State process : is it Markov ? Residence time analyses (H_0 : geometric distribution)
2. we estimate model parameters independantly (maximum likelihood)
3. we predict the most likely sequence of states using Viterbi algorithm

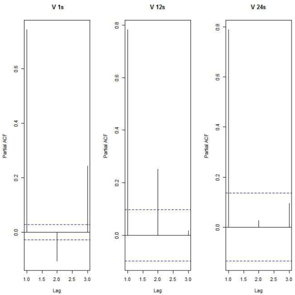
Positions process : $H_0 = V$ uncorrelated

Partial autocorrelation of V at lag 1, 2 and 3 for several δ_t

Diving



Not Diving



Autocorrelated ?

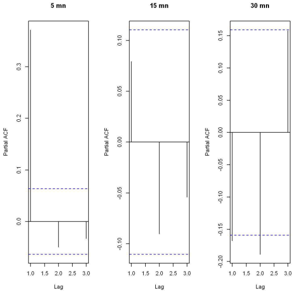
Diving, Not Diving : V, V_p, V_r first(or second) order correlated

δ_t : V, V_p, V_r first order correlated whatever δ_t

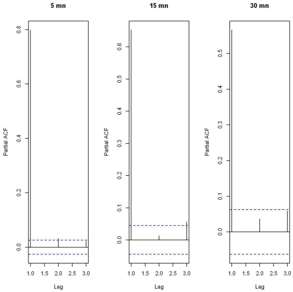
Positions process : $H_0 = V$ uncorrelated

Partial autocorrelation of V at lag 1, 2 and 3 for several δ_t

Fishing



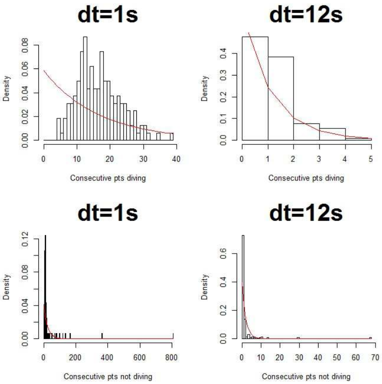
Not Fishing



Autocorrelated ?

Fishing, Not Fishing : V, V_p, V_r first (or second) order correlation whatever $\delta_t = 15min, 1h$

Behavior process : H_0 = Residence time $\sim$ geometric distribution



δ_t	pval fish	pval steam
1s	0.01	0.28
12s	0.000	0.000

test de χ_2 : geometric (p = empiric mean)

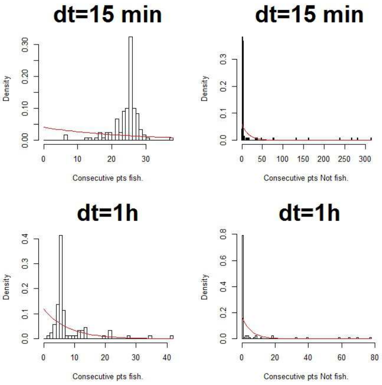
number of consecutive positions

Markov ?

Diving : not relevant - better should be semi-Markov

Not Diving : Markov

Behavior process : H_0 = Residence time $\sim$ geometric distribution



δ_t	pval fish	pval steam
15min	0.002	0.000
1h	0.000	0.000

test de χ_2 : geometric (p = empiric mean)

number of consecutive positions

Markov ?

Fishing : not relevant - better should be semi-Markov

Not Fishing : Markov

Fisheries Modelling experiment

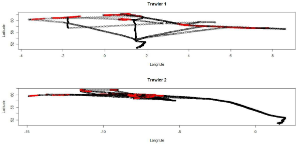
Assumptions	Uncorrelated, (V, Ψ)	Autoregressive, (V_p, V_r)
Markov	X	X
Semi-Markov	X	X

Steps of the experiment

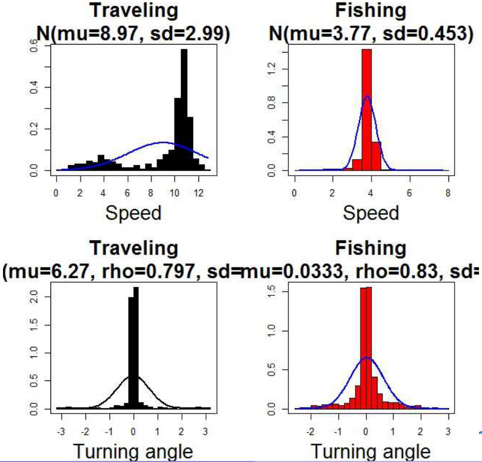
1. Split the dataset into a learning dataset and a testing dataset
2. With the learning dataset : estimate the model parameters
   - speed and turning angle distributions, correlations
   - residence time for transition matrix
3. With the remaining dataset :
   - simulating the most likely sequence of states using the Viterbi algorithm
   - estimating the performance of the model : confusion matrix

The most likely sequence of states- Uncorrelated, (V, Ψ)

Analysis performed using learning dataset for two trawlers operating in the English Channel (5 and 13 trips)



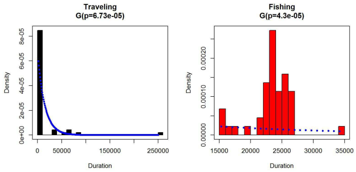
For trawler 1 with $\delta_t = 15min$ estimates of Θ_V and Θ_Ψ



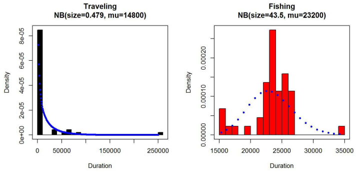
The most likely sequence of states - Uncorrelated, (V, Ψ)

For trawler 1 with $\delta_t = 15min$ estimates of M_S

Markov



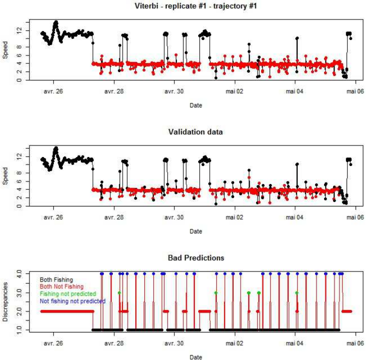
Semi Markov



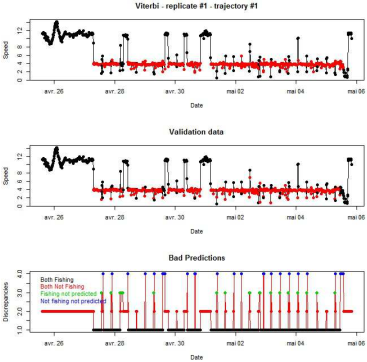
The most likely sequence of states - Uncorrelated, (V, Ψ)

Using the Viterbi algorithm with the estimated parameters Θ_V, Θ_Ψ and M_S

Markov

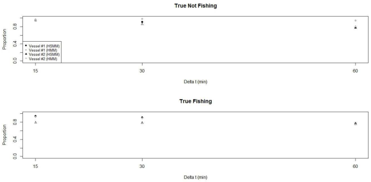


Semi Markov

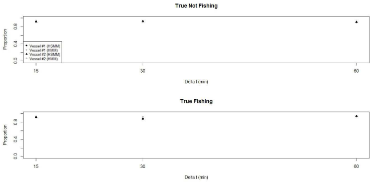


The most likely sequence of states - summary of the whole experiment

Uncorrelated Model



Autocorrelated Model



Performance of AR model and Drift model

Best fit for vessel 1

Robust to Markov assumption

Small degradation with δ_t

Conclusions

- are models assumptions violated ?
  - fisrt order correlation rarely taken into account (fisheries)
  - Markov only confirmed for not fishing or not diving state
- are inferred behaviors robust to model assumptions ?
  - Uncorrelated and AR models are robust to state process assumptions
  - but fitted Θ distributions not satisfactory
- are the answers sensitive to observations time step ?
  - increasing time step increases autocorrelation for birds'speed
  - increasing time step decreases autocorrelation for vessels'speed
  - but does not influence the performance of AR and uncorrelated model

Conclusions

- Ecology - Fisheries : differences ?
- Time step : a limitation for fishing sequence identification but not for inferring behavior
- Speed is not observed - computing average speed required assumptions on the path between two positions - monitor instantaneous speed
- AR model or Drift Model ? the simplest Drift-Markov model
- Apropriate approach for trajectories with validation data
- Next step : what is the influence of the learning step on conclusions ?
  - performance of the autocorrelated model are known to be lower than those of the uncorrelated
  - to be compared with an integrated estimation procedure (like with not observed behavior)
- another track : segmentation of path (using path chracteristics, patterns ...), continuous model