

SPATIALLY-EXPLICIT INDIVIDUAL-BASED MODEL OF MARINE MAMMAL MOVEMENTS USING THE PATTERN-ORIENTED MODELING APPROACH

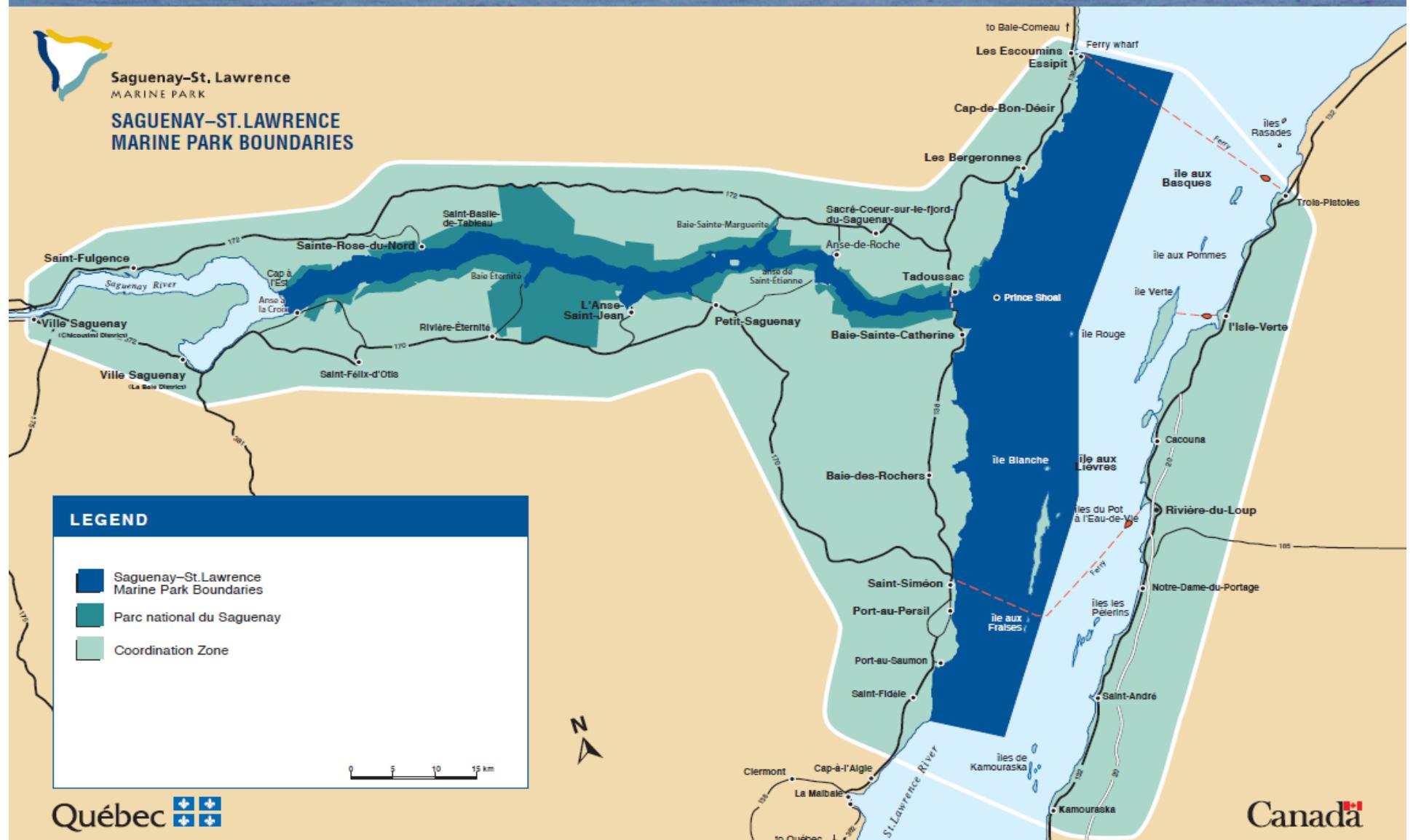
by Philippe Lamontagne

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ISEM October 2009

The Saguenay-Saint Lawrence Marine Park



Project overview

Problematic

- 1-Project overview**
- 2-Patterns extraction**
- 3-Validation process**
- 4-Model development**
- 5-Conclusion**

It is difficult to understand and quantify the exposure of marine mammals resulting from whale watching activities

- During the tourist season, fin whales are highly exposed to whale watching boats : (averaging 6.4 boats at once; radius of 2000m, 1995) (Michaud and Girard, 1997a).
- Exposure of these mammals alters behavior in deep diving and is likely to result in significant energy costs (Michaud and Girard, 1997b).
- The St. Lawrence River beluga is an aquatic specie at risk. It has been suggested that the whale-watching industry may have a negative impact on it.

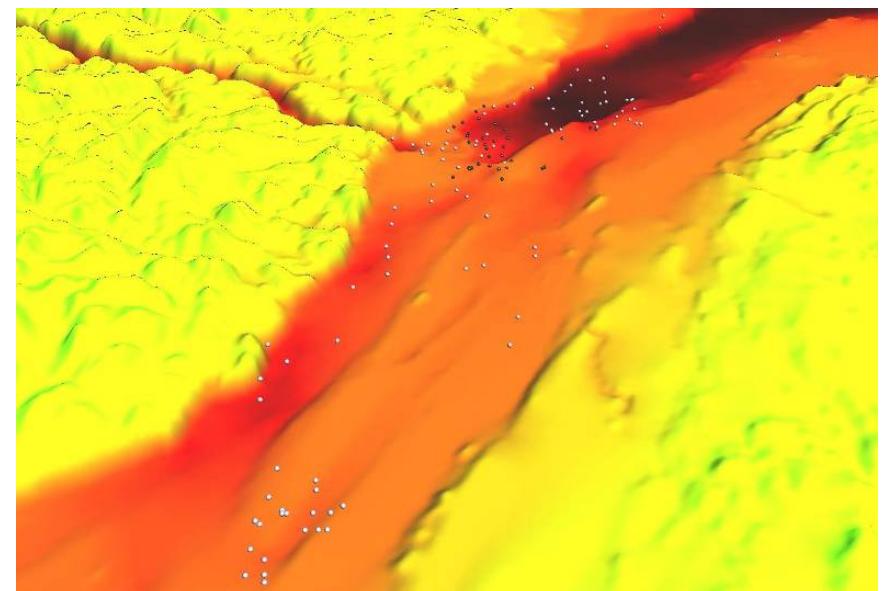


Project overview

Proposed solution

- 1-Project overview**
- 2-Patterns extraction**
- 3-Validation process**
- 4-Model development**
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- We proposed a model to help understand and quantify the exposure of marine mammals to whale watching boats.
- Model can be used as a decision support system to explore a diversity of management solutions
 - Test various zoning scenarios
 - Test regulatory scenarios

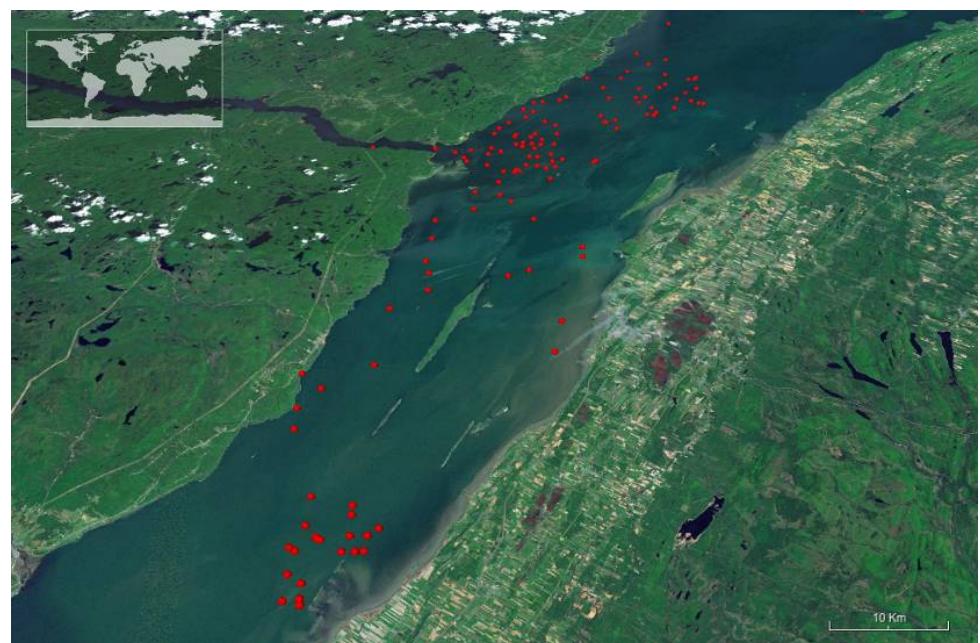


Project overview

Whale sub-model

- 1-Project overview**
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- Main objective : Develop a spatially-explicit model of whale movements
 - Easy to understand for biologists and managers
 - Generic for all species (6 species)
 - Strictly based on already existing data
- Important patterns selected :
 - Movement components
 - Speed, duration, length, turning angle
 - Spatial distribution
 - Group size

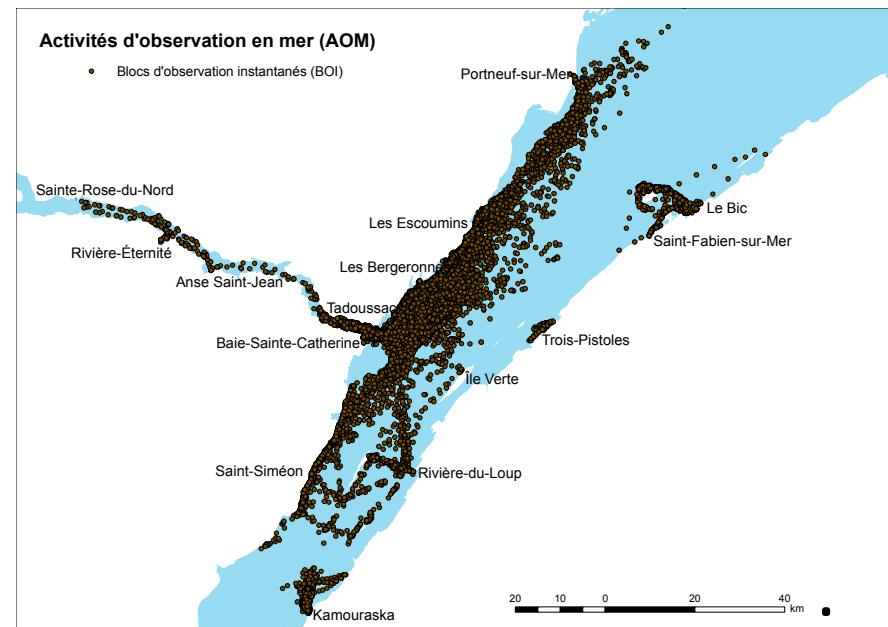
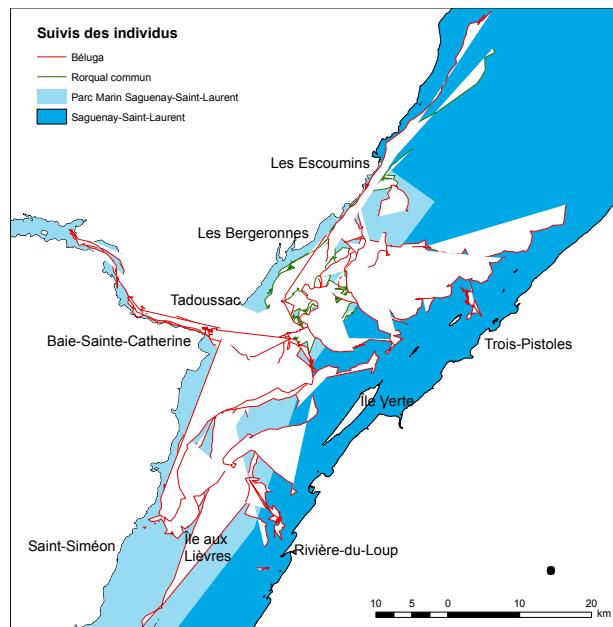


Patterns extraction

Data sources

- 1-Project overview**
- 2-Patterns extraction**
- 3-Validation process**
- 4-Model development**
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- 80 whales tracked by VHF (3256 observations for 330+ hours)
- 32,000+ mammal observations (from whale watching excursions)

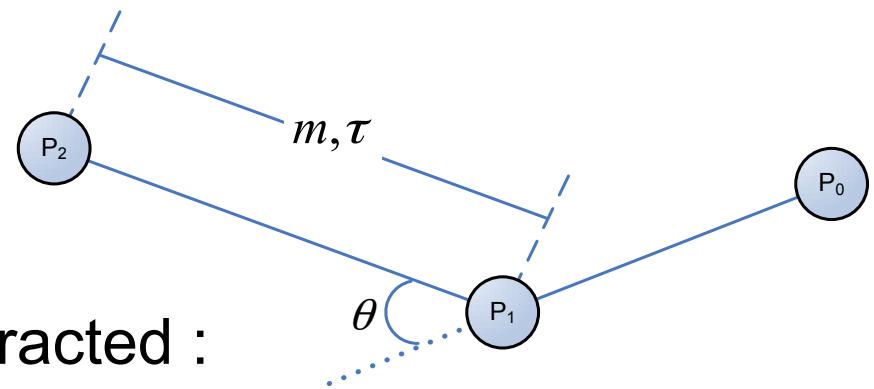


Patterns extraction

Move components

- 1-Project overview**
- 2-Patterns extraction**
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- Data used :
 - 80 whale tracks
 - 25 tracks of fin whale
 - 55 tracks of belugas
- Movement components extracted :
 - Turning angle
 - Duration
 - Length
 - Speed

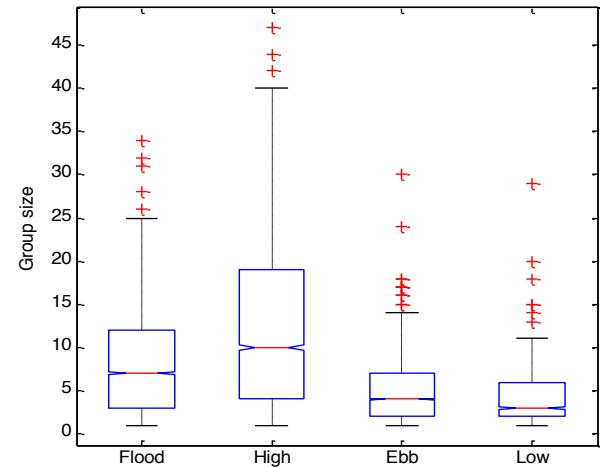


Patterns extraction

Group size

- 1-Project overview**
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- Data used
 - 32,000+ mammal observations from whale watching boats.
- Social behavior : Fin whale
 - Fin whale group size is influenced by the tide, according to statistics (ANOVA)
- Social behavior : Beluga
 - The group size pattern of belugas is not significantly influenced by the tide



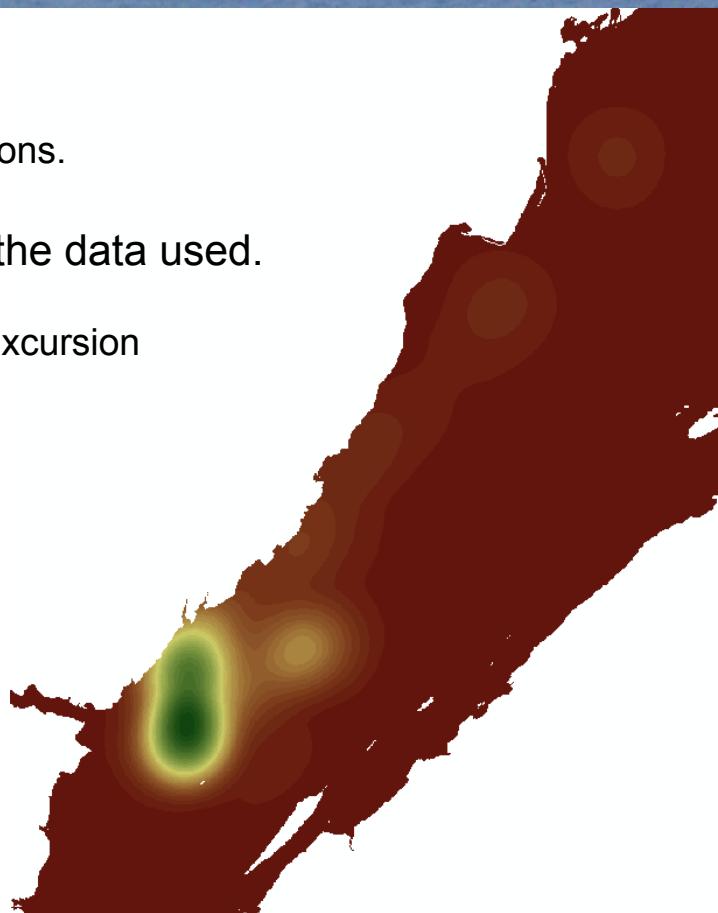
Specie	Tide	n_g	\bar{g}_{int}
Fin whale	Flood	6390	8.68
	High	8939	12.64
	Ebb	3574	5.62
	Low	3038	4.31
Beluga	*	2644	7.91



Patterns extraction Spatial distribution

- 1-Project overview**
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- Data used
 - 32,000+ mammal observations from whale watching excursions.
- The spatial distribution pattern is biased by the nature of the data used.
 - Whale watching boats target specific species
 - A whale may be sampled more than once during the same excursion
 - The sampling effort is not identical for all ports
- Strategies used to reduce sampling bias :
 - Using observation of targeted species only
 - Using median observation only
 - Weighting by the sampling effort of ports



Validation process

Metrics used

- 1-Project overview**
- 2-Patterns extraction**
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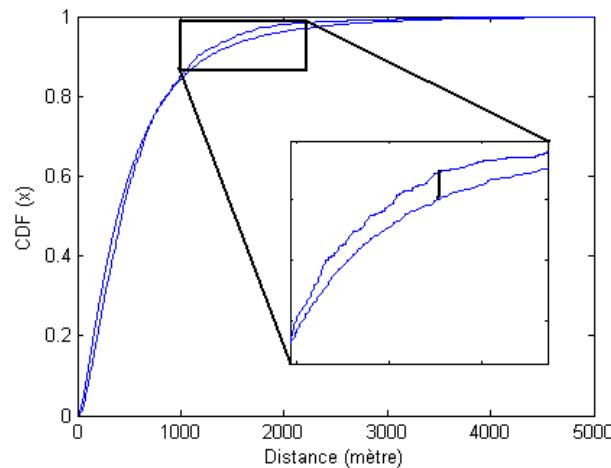
- Metrics used to compare observed and simulated patterns

Kolmogorov-Smirnov (KS) = 0.0623

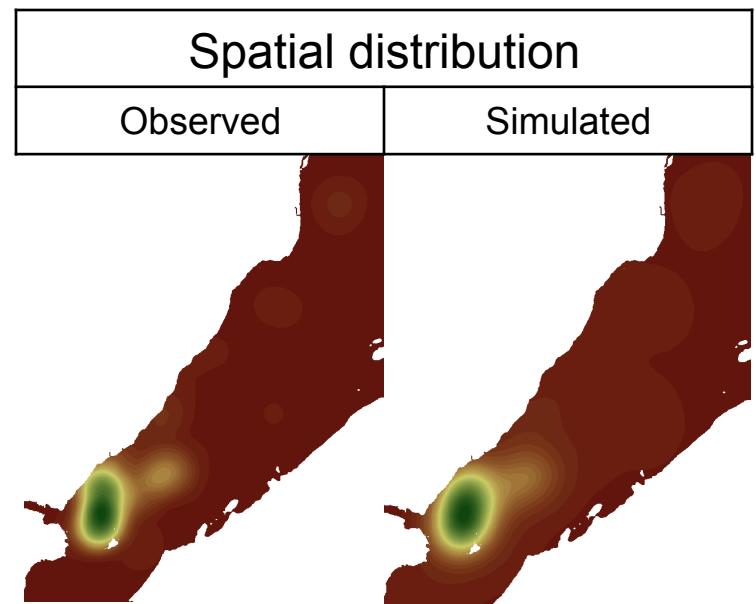
NMAE = 3.57%

Model Efficiency (EM) = 0.95

Move components (length)	
Observed	Simulated



Group size (low tide)	
Observed	Simulated
4.32	4.16



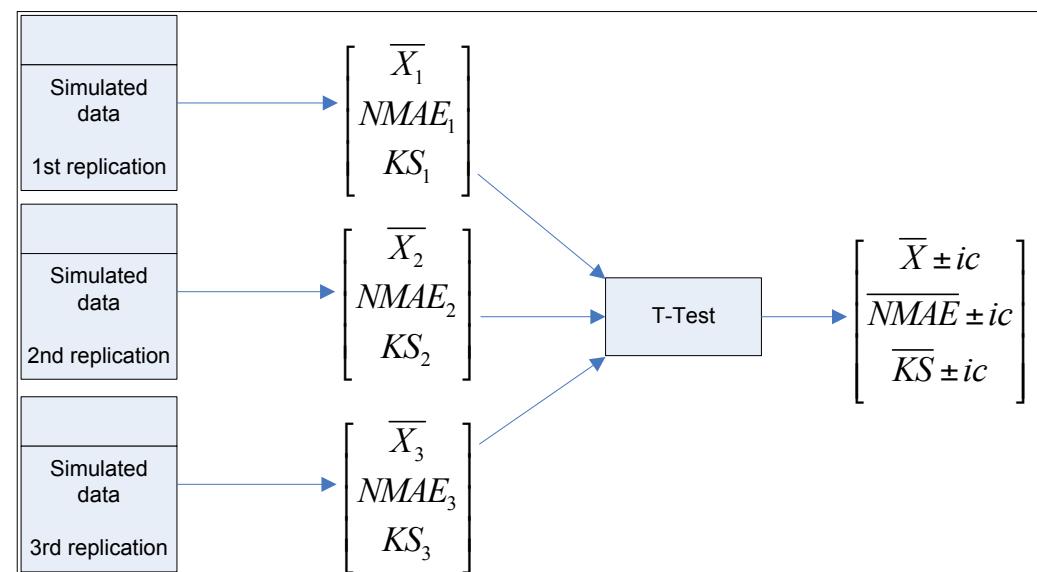
Validation process

Experimental protocol

- 1-Project overview**
- 2-Patterns extraction**
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- Experimental protocol :

- Number of replications : 24
- Duration : 30 days
- Time step : 1 minute
- Number of individuals :
 - 100 belugas
 - 35 fin whales

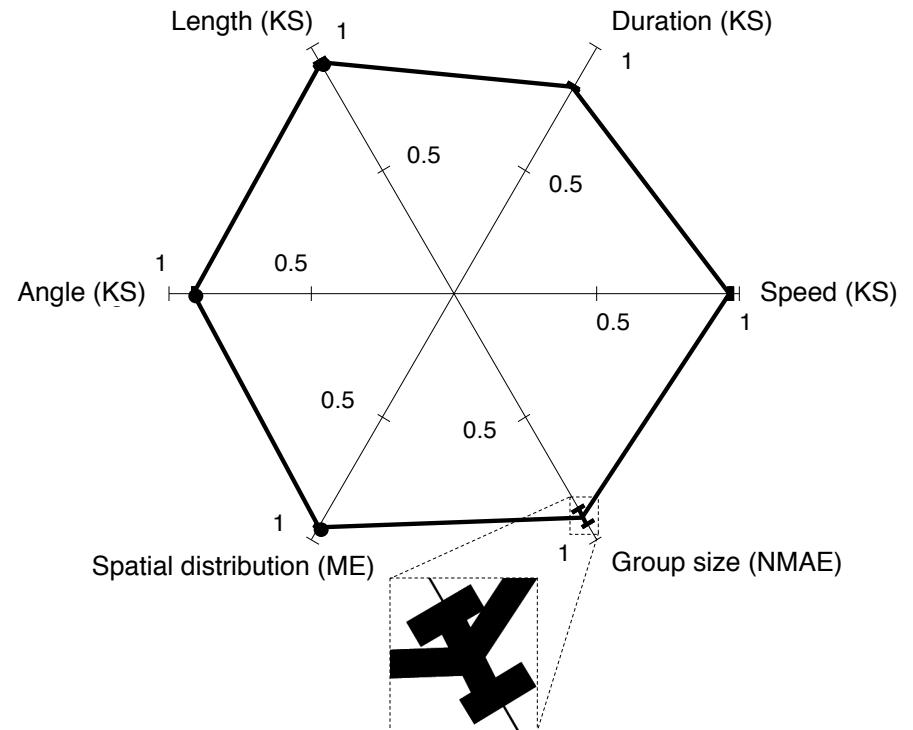


Validation process

Display results

- 1-Project overview**
- 2-Patterns extraction**
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- Display model results
 - 6 axis radar plot
 - With confidence interval
 - Axis normalized :
 - 1=identical
 - 0=different

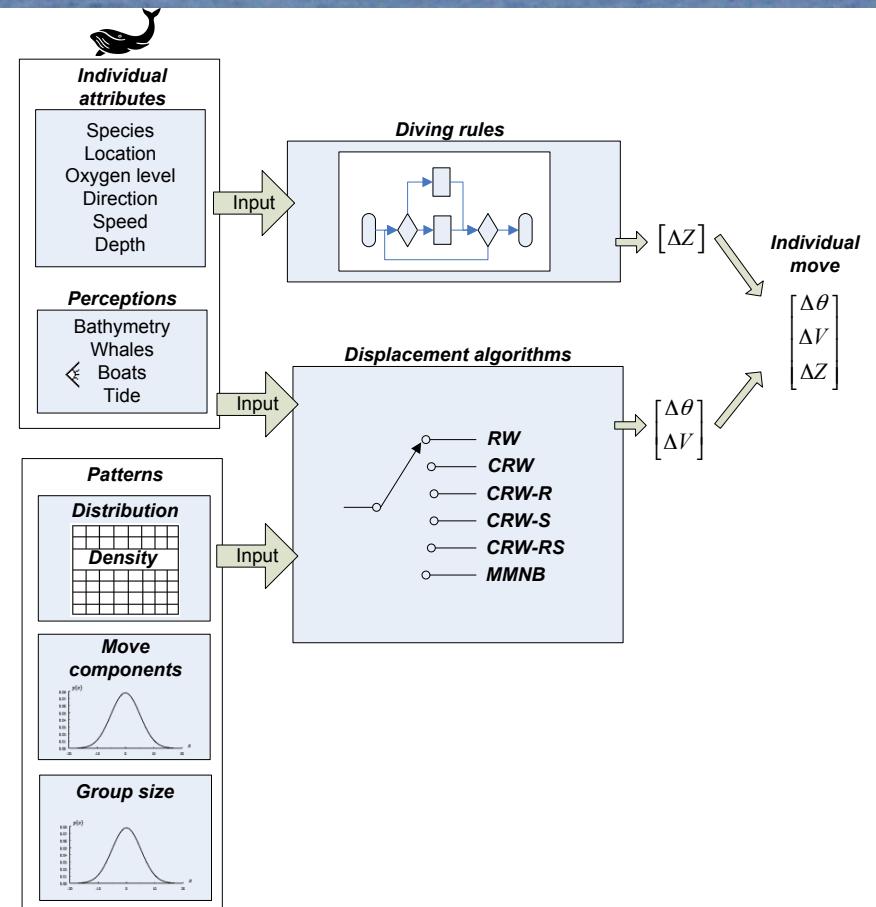


Model development

Conceptual model

- 1-Project overview**
- 2-Patterns extraction**
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- Displacement algorithms implemented :
 - Random walk (RW)
 - Correlated random walk (CRW)
 - CRW with residence index
 - (Turchin, 1998)
 - CRW with social interaction
 - (Couzin and al., 2005)
 - CRW with residence index and social interaction
 - (Turchin, 1998; Couzin and al., 2005)
 - MMNB : Minimum Mean Normalized Bias



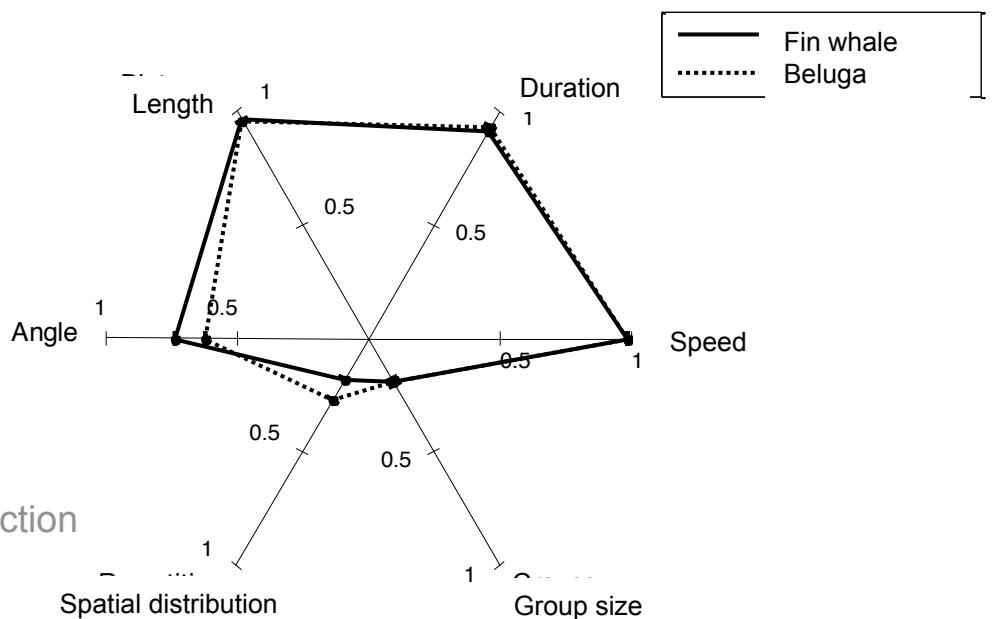
Model development

Displacement algorithm

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- Displacement algorithms used:

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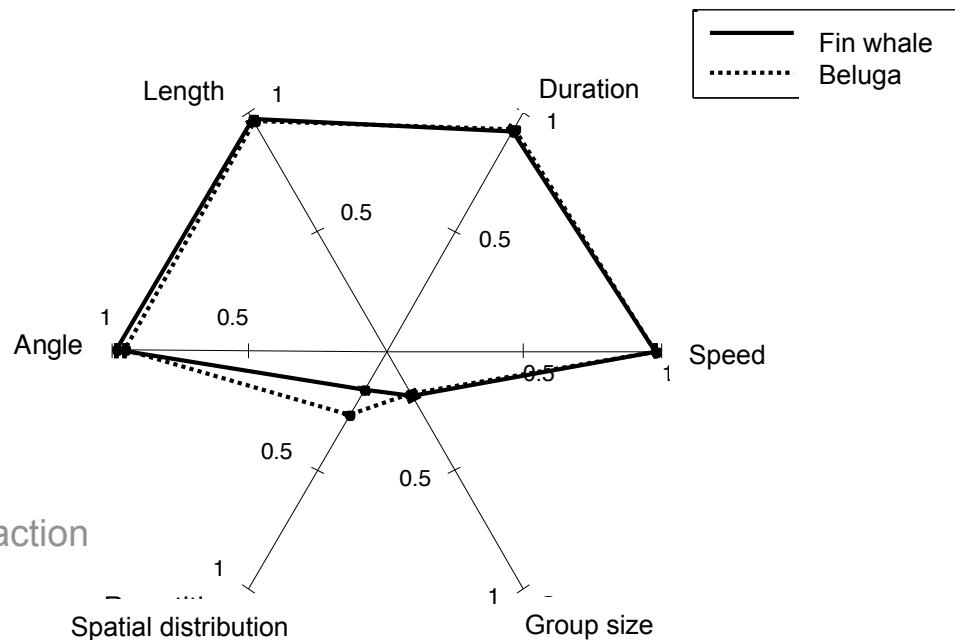
Model development

Displacement algorithm

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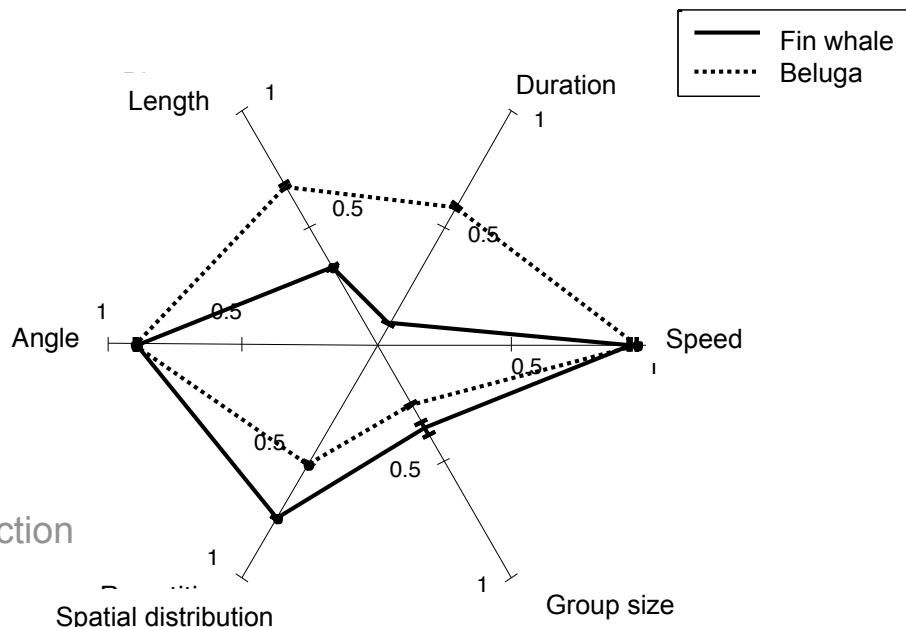


Model development

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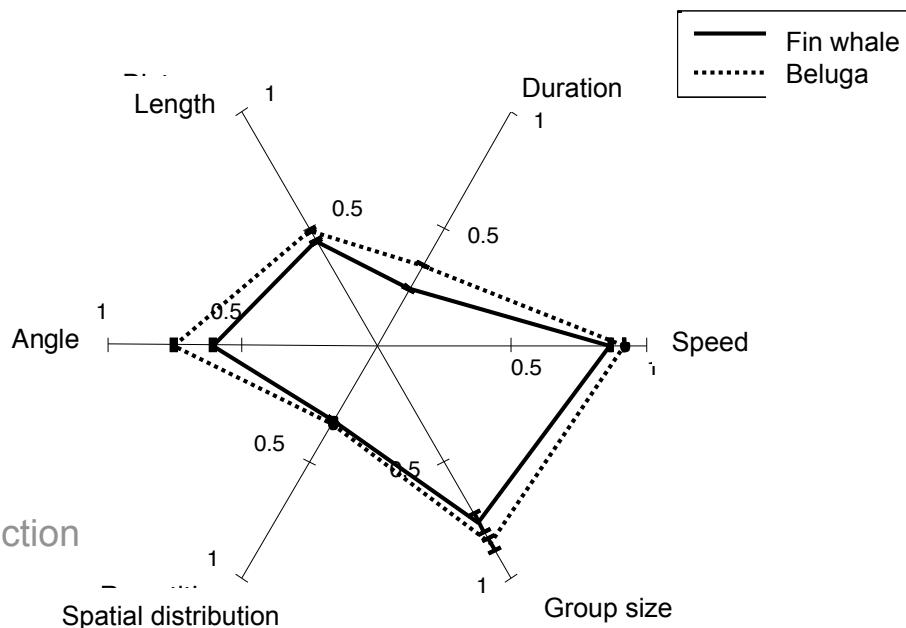


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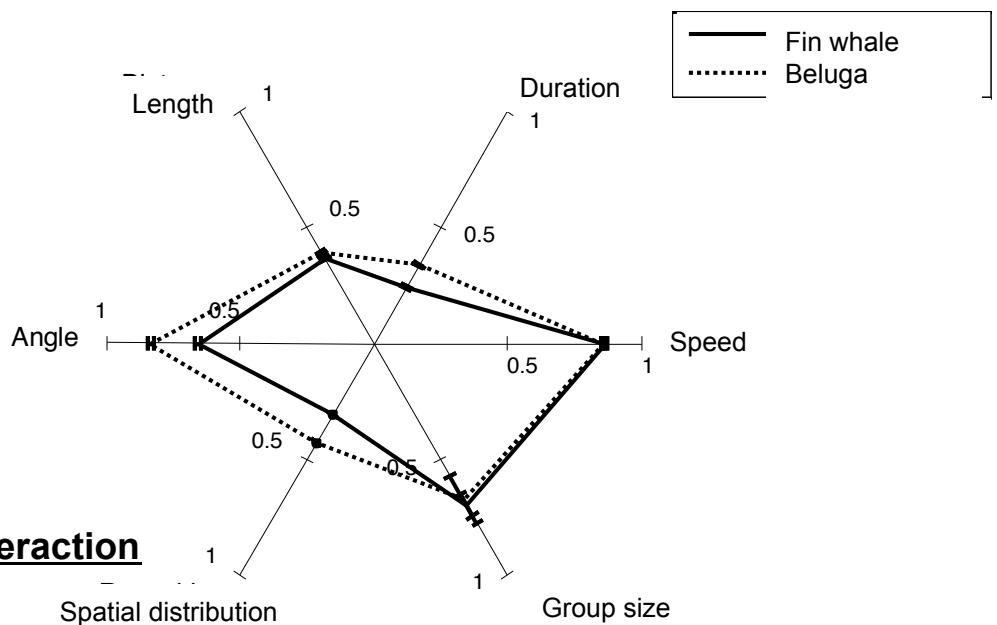


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Model development

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Model development

MMNB Algorithm

- 1-Project overview**
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- MMNB uses a single aggregate objective function that minimizes the bias between simulated and observed patterns
 - Turning angle
 - Group size
 - Spatial distribution

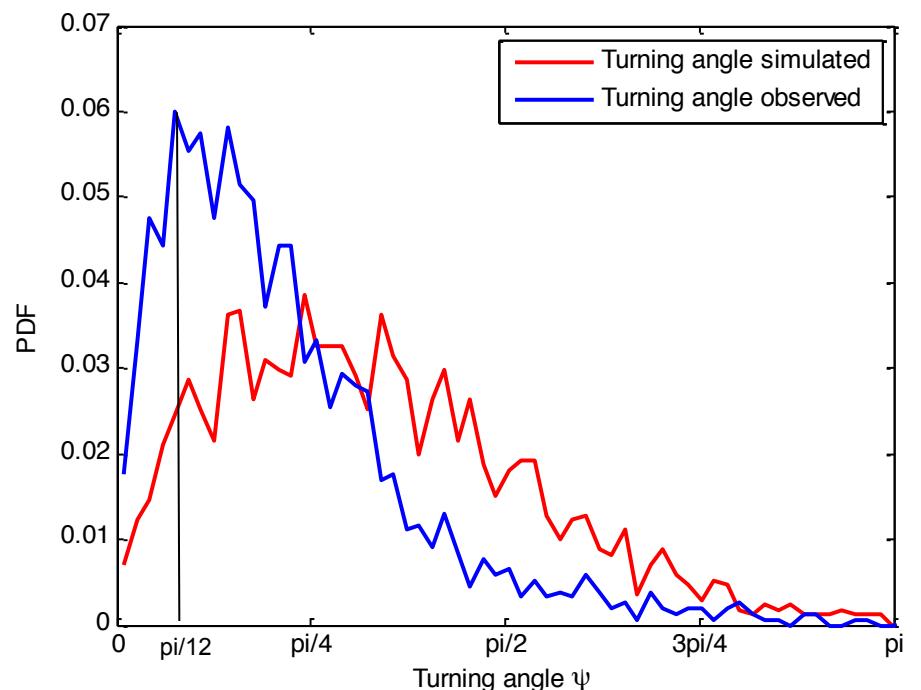
$$\text{Minimize } E(\theta) = w_\psi B_\psi(\theta) + w_u B_u(\theta) + w_g E_g(\theta)$$

$B_\psi(\theta)$: Turning angle bias

$B_u(\theta)$: Spatial distribution bias

$E_g(\theta)$: Group size error

$$Bias_\psi = PDF(\psi)_{\text{SIMULATED}} - PDF(\psi)_{\text{OBSERVED}}$$

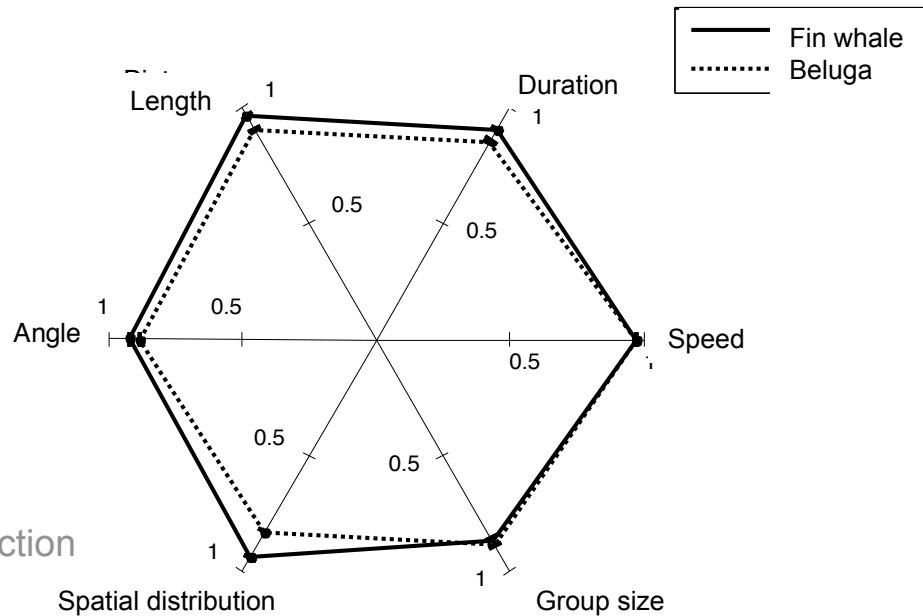


Model development

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➤ **MMNB : Minimum Mean Normalized Bias**

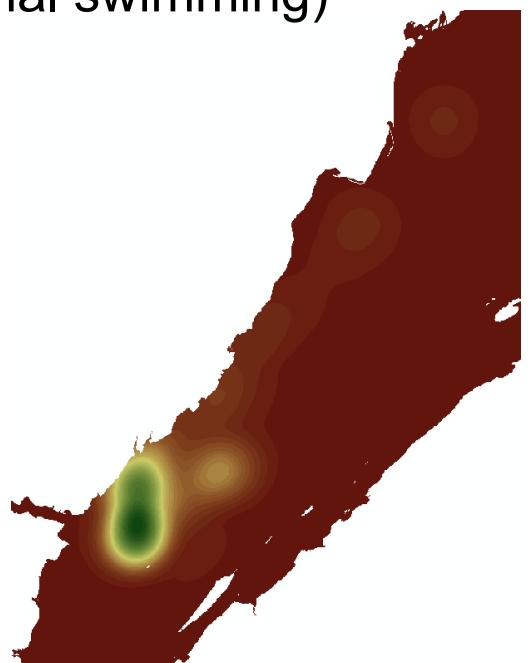


Conclusion

Further work

- 1-Project overview**
- 2-Patterns extraction**
- 3-Validation process**
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- Add features to the whale sub-model
 - Add interaction between whales and boats
 - Create behavior classes (feeding, milling, directional swimming)
- Extract knowledge from the simulation
 - Whales exposition from whale watching boats
 - Maps of problematic zones
 - High concentrations of boats around whales
 - Statistics on risks of collision

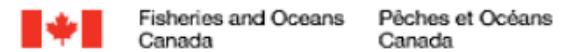


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Pêches et Océans
Canada



Model validation

Metrics used

- Typical results with MMNB algorithm
 - 35 fin whales, 5 replications, 60 days

Patron	Moy.	Err.	KS.	EF.	Moy.ic	Err.ic	KS.ic
Vitesse	1.34	0.0128	0.0274	0	0.0017	0.00128	0.000633
Duree	451	0.102	0.163	0	1.56	0.0031	0.00279
Distance	589	0.0204	0.0623	0	2.28	0.00395	0.00213
Angle braquage	0.252	0.285	0.0813	0	0.00293	0.00831	0.00186
Groupe_maree_0	7.49	0.137	0.254	0	0.207	0.0239	0.00795
Groupe_maree_1	10.6	0.164	0.278	0	0.427	0.0338	0.00496
Groupe_maree_2	5.44	0.0321	0.312	0	0.149	0.0264	0.0313
Groupe_maree_3	4.16	0.0357	0.337	0	0.066	0.0153	0.0212
Groupe	6.92	0.0922	0.295	0	1.17	0.0297	0.0166
Observed density				0.95			



Model development

MMNB Algorithm

$$\text{Minimize } E(\theta) = w_\psi B_\psi(\theta) + w_u B_u(\theta) + w_g E_g(\theta)$$

$B_\psi(\theta)$: Turning angle bias

$B_u(\theta)$: Spatial distribution bias

$E_g(\theta)$: Group size error

$$Bias_\psi(\theta) = PDF(\theta)_{\text{SIMULATED}} - PDF(\theta)_{\text{OBSERVED}}$$

$$Bias_u(\theta) = \frac{1}{T} \sum_{t=1}^T \frac{u_{p(t),sim} - u_{p(t),obs}}{\overline{u_{obs}}} = \frac{1}{T} \sum_{t=1}^T \frac{\frac{n_{p(t),sim}}{n_{sim}} - u_{p(t),obs}}{\frac{1}{size_{SIGHAP}}} = \frac{size_{SIGHAP}}{T} \sum_{t=1}^T \left(\frac{n_{p(t),sim}}{n_{sim}} - u_{p(t),obs} \right)$$

$$E_g(\theta) = \frac{\left| \left(\frac{1}{T} \sum_{a \in A} \sum_{t=1}^T d(a, t) \right) - \overline{g_{obs,maree}} \right|}{\overline{g_{obs,maree}}} \mid d(a, t) = \begin{cases} 1 & \sqrt{(x(t) - a_x(t))^2 + (y(t) - a_y(t))^2} < r \\ 0 & \text{Sinon} \end{cases}$$