University of Hawaii

Sloping Towards the Holy Grail

Combining Conventional Tagging and Tracking Data

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Shhh!

- Conventional tagging data only rarely used directly in stock assessment.
  - MULTIFAN-CL and SS3 best examples.
  - May be used to estimate mortality for incorporation in assessment in non-integrated analyses.
- Tracking data are never directly used in stock assessment.
  - May be used indirectly to "standardize" longline fishing effort.
  - May be used qualitatively to identify habitats of particular interest.

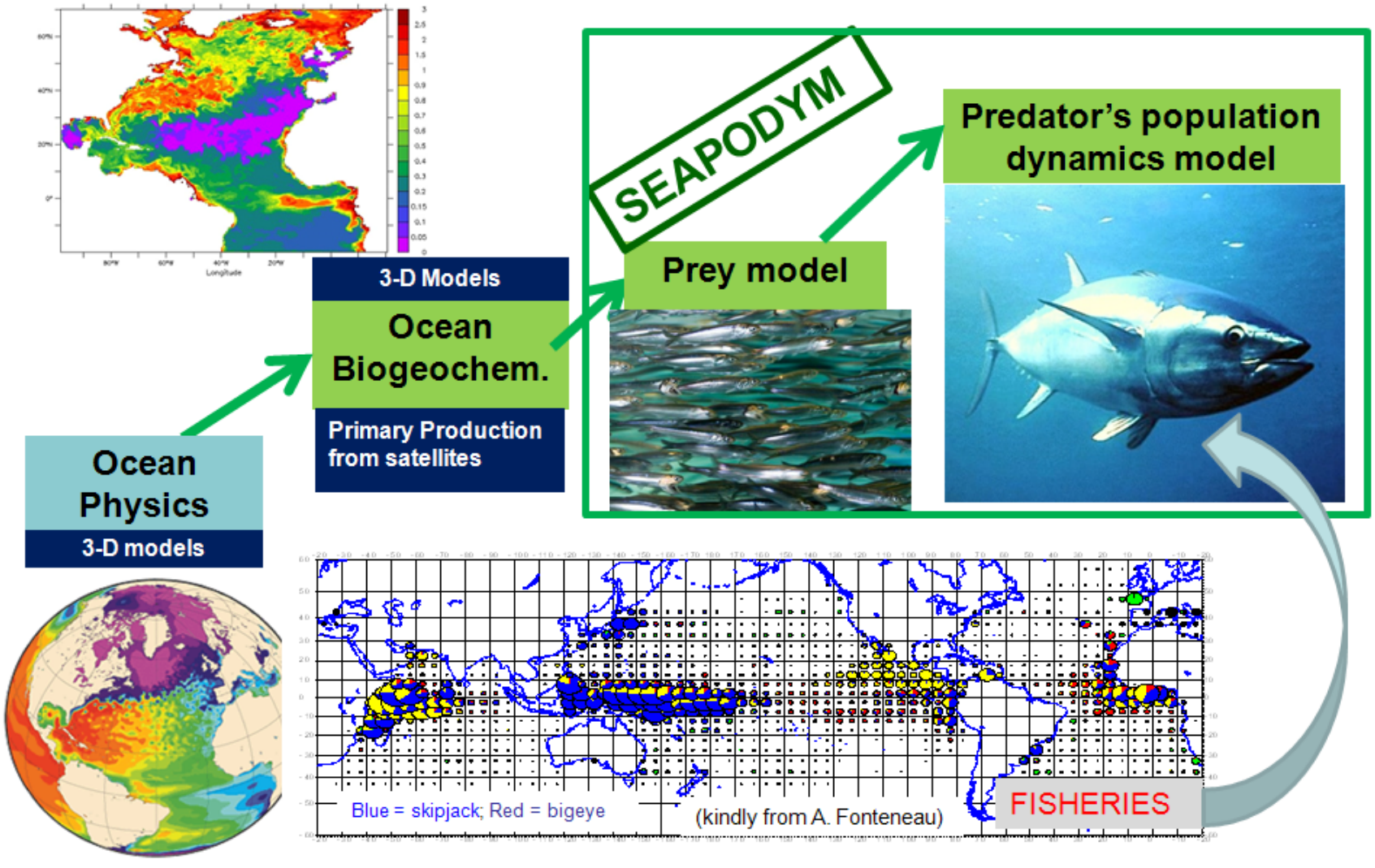
- Need more data.
- Need appropriate models.

Spatial Models for Tagging and Tracking

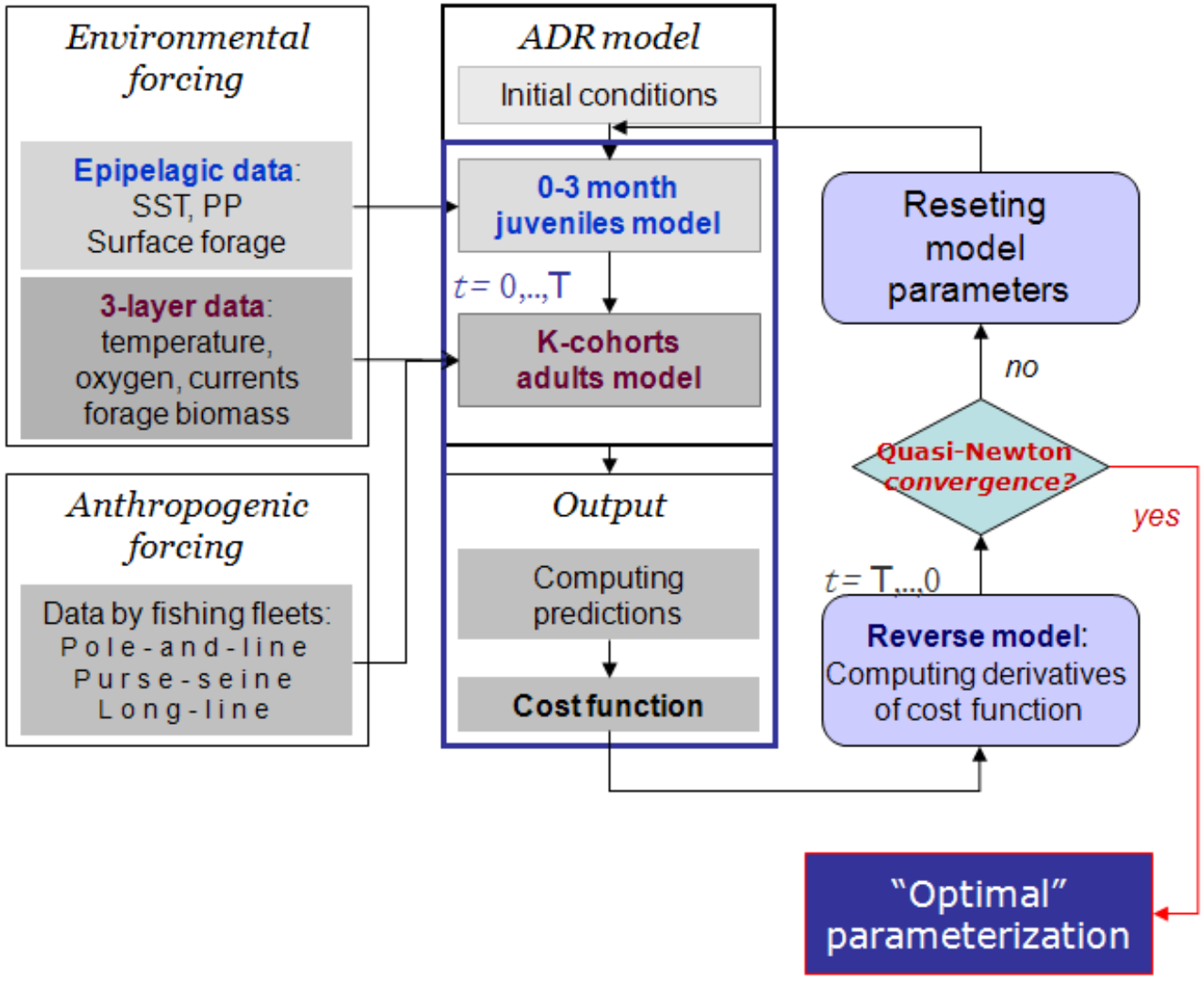
- Advection-diffusion-reaction models for tuna populations since 1990 — “Eulerian”.
- State space Kalman filter models for individual fish since 2000 — “Lagrangian”.
- Really the same model with the same parameters.
- Maximum likelihood estimation of model parameters.

- (animation)
- Is it feasible to integrate the Lagrangian models of individual fish movement into Eulerian model of fish populations?

SEAPODYM — General Overview

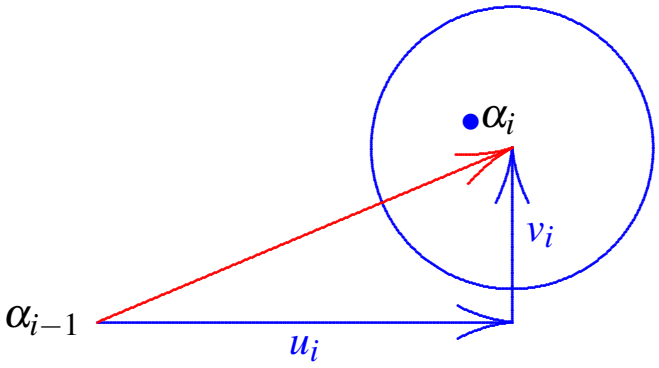


SEAPODYM — Optimal Parameterization

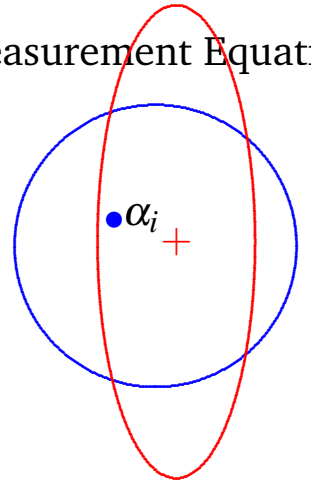


State Space Model

Transition Equation



Measurement Equation



$$\alpha_{ki} = \alpha_{ki-1} + c_i + \eta_i; \quad i = 1, \ldots, T_k$$

$$c_i = \begin{pmatrix} u_{xy} \\ v_{xy} \end{pmatrix} \qquad \eta_i = N(0, Q_i)$$

$$Q_i = \begin{pmatrix} 2D_{xy} & 0 \\ 0 & 2D_{xy} \end{pmatrix}$$

$$y_{ki} = z(\alpha_{ki}) + d_{ki} + \varepsilon_{ki}; \quad i = 1, \ldots, T_k$$

$$d_{ki} = \begin{pmatrix} b_{xk} \\ b_{yk} \\ b_{\tau k} \end{pmatrix} \qquad \varepsilon_{ki} = N(0, H_{ki})$$

$$H_i = \begin{pmatrix} \sigma_{xk}^2 & 0 & 0 \\ 0 & \sigma_{yki}^2 & 0 \\ 0 & 0 & \sigma_{\tau k}^2 \end{pmatrix}$$

Aggregate Model: SEAPODYM + State Space

Negative aggregate log likelihood

$$\ell_A = -\left(w_\ell \cdot \log L_T + (1 - w_\ell) \cdot \frac{1}{n} \cdot \sum_k^n \log L_k\right)$$

Parameter Estimates

$$\widehat{\Phi_I, \Phi_S} = \underset{\Phi_I, \Phi_S}{\operatorname{argmin}}\, \ell_A$$

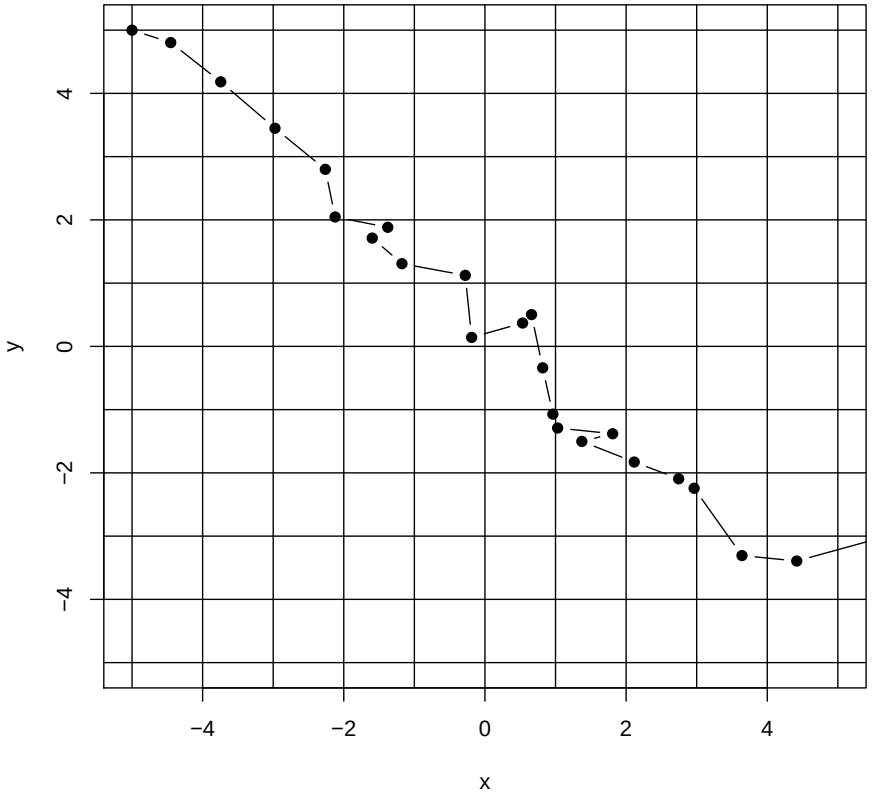
SEAPODYM-TAGEST

$$L_T\left(F, I, C_{obs} | \Phi_I, \Phi_F, \Phi_M\right) = \prod \left[\frac{C_{obs}^{C_{pred}} e^{-C_{obs}}}{C_{obs}!}\right]$$

Unscented Kalman filter likelihood

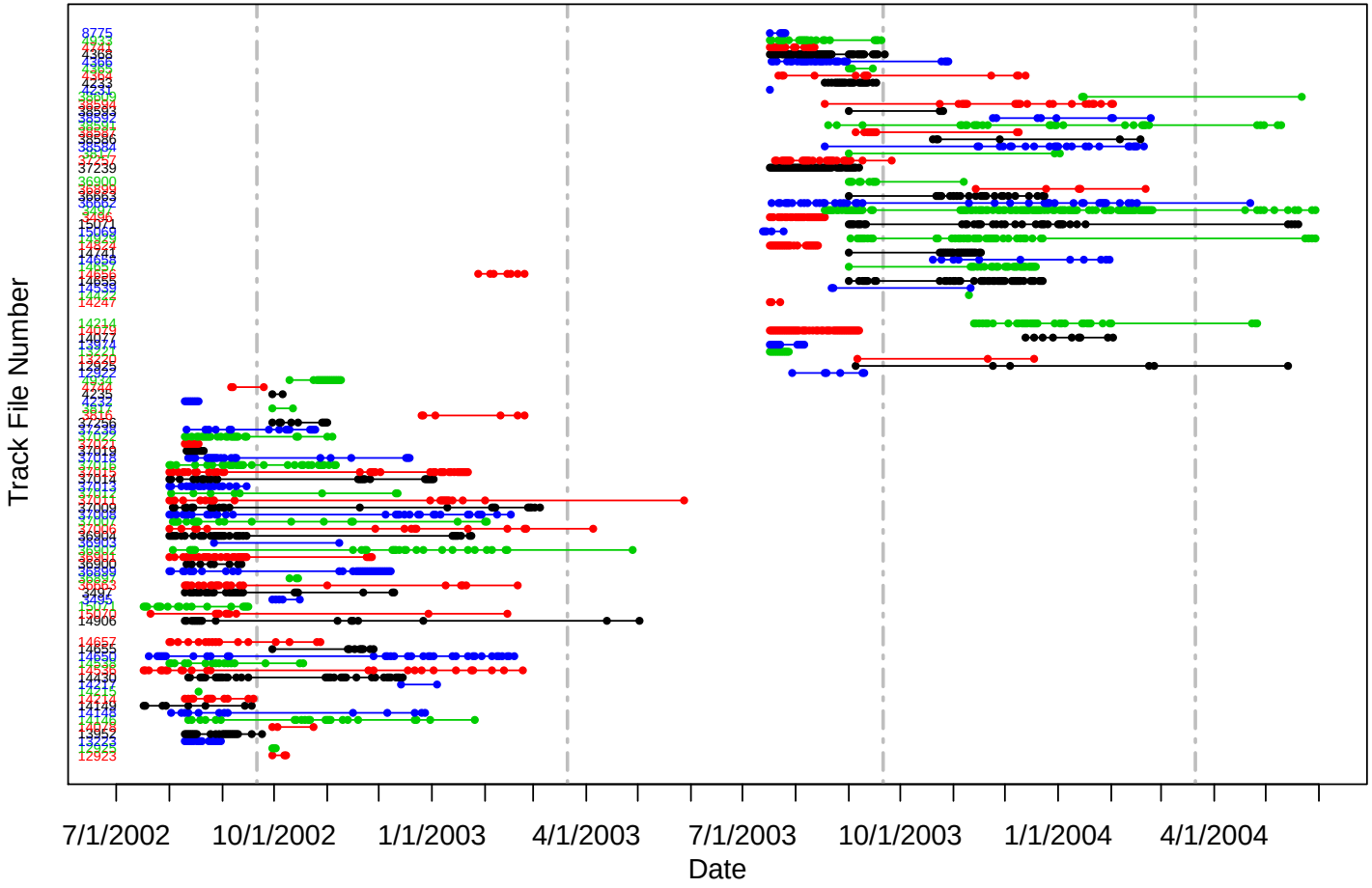
$$L_k\left(Y_k | \Phi_{Sk}\right) \quad k = 1, 2, \ldots, n; \quad \Phi_{Sk} = \left(b_{xk}, b_{yk}, b_{\tau k}, \sigma_{xk}, \sigma_{yk}, \sigma_{\tau k}, a_{0k}, b_{0k}\right)$$

First problem: scale incompatibilities

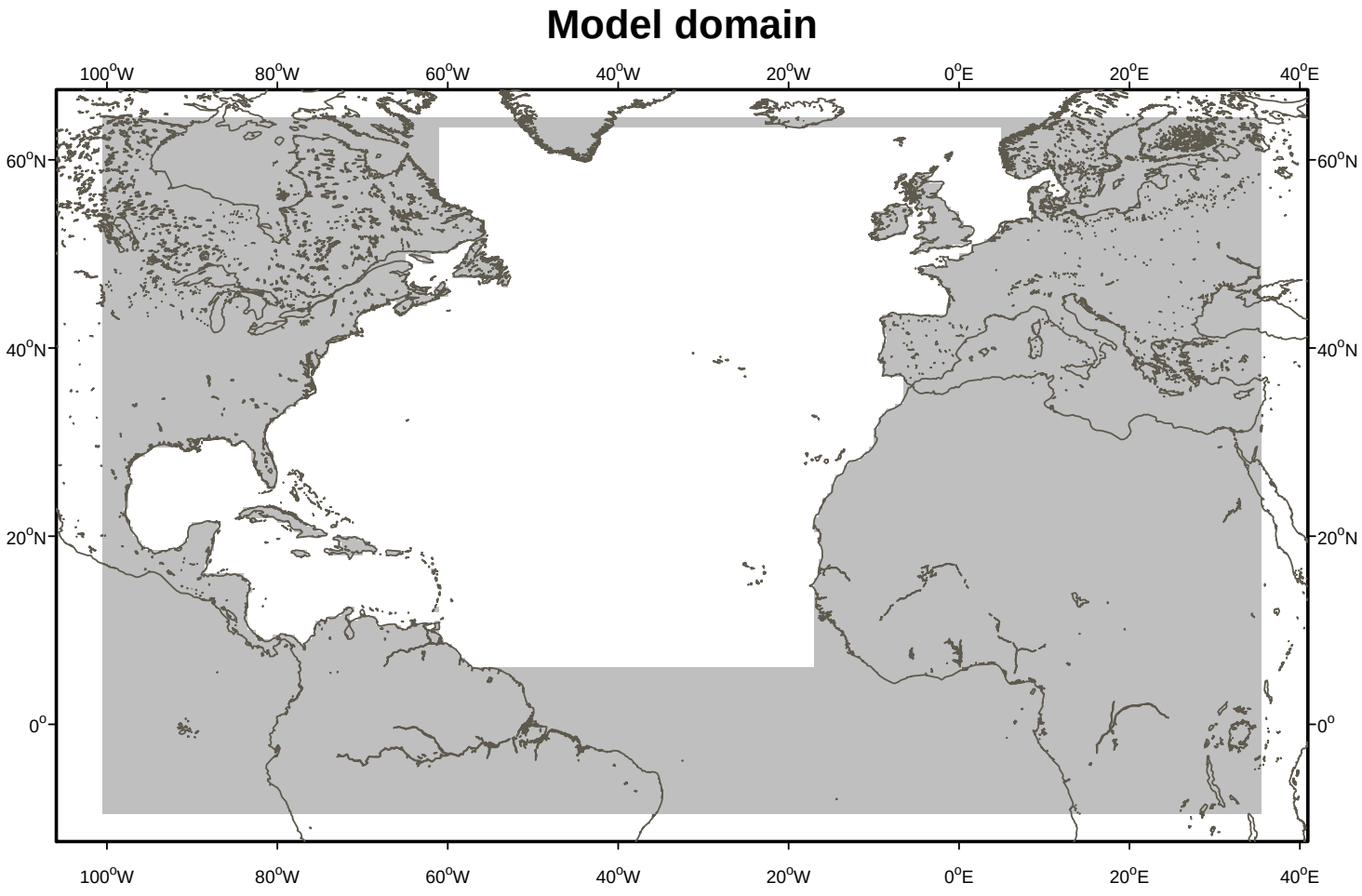


- SEAPODYM:
  - 0.5° grid
  - Monthly time steps
  - Grid-scale variability in u, v, D
- uKfSST:
  - Continuous in space
  - Daily time steps (sort of).

Second problem: “gappy” data.



Third problem: boundaries.



Fourth problem: automatic differentiaton

- Need to connect state space model transition equation to the parameters of the habitat model though the chain rule.
- Matrix subscript operators are not differentiable with respect to the indices; i. e., $\frac{\partial z_{ij}}{\partial i}$ and $\frac{\partial z_{ij}}{\partial j}$ undefined.
- Bilinear interpolation might work;
  $z_{xy} \approx f\left(z_{i,j}, z_{i+1,j}, z_{i,j+1}, z_{i+1,j+1}\right)$

Solutions

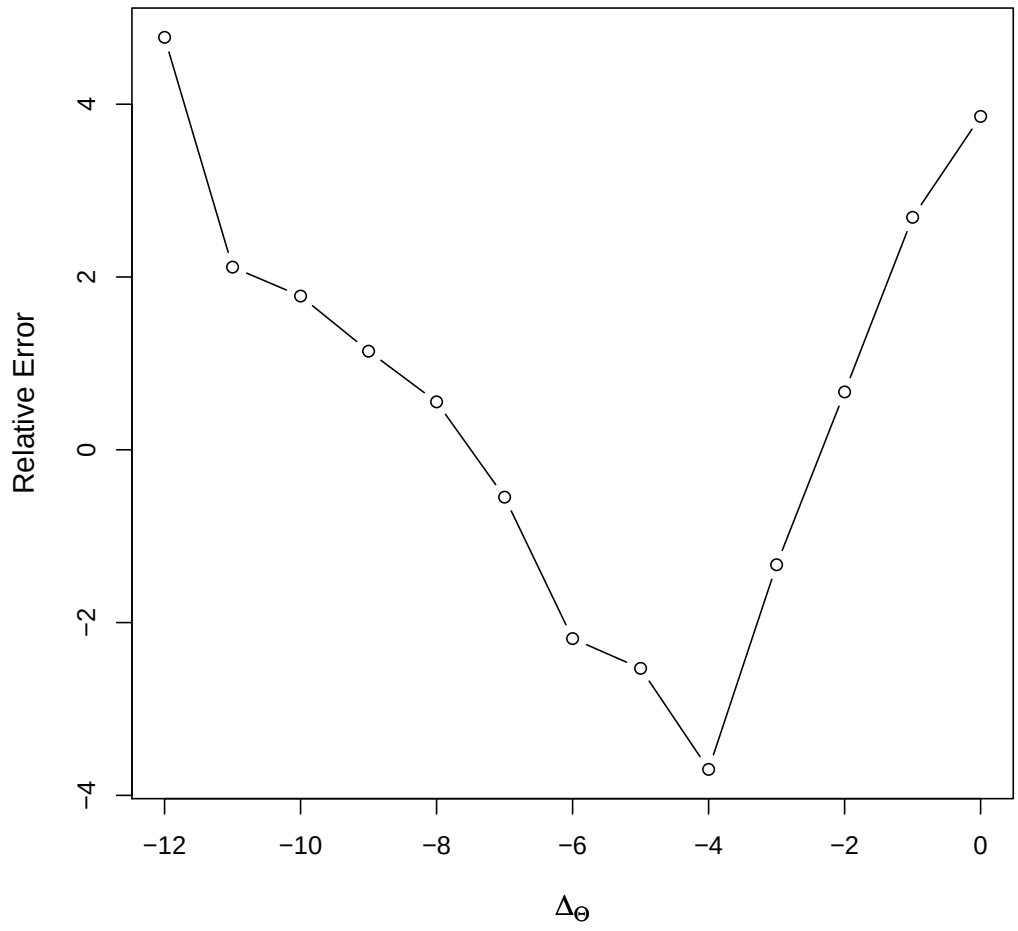
1. Scale incompatibilities:
   bilinear interpolation between computational elements;
   daily time steps in state-space model between SEAPODYM iterations.

2. “Gappy” data:
   use reconstructed tracks from Royer’s ensemble Kalman filter.

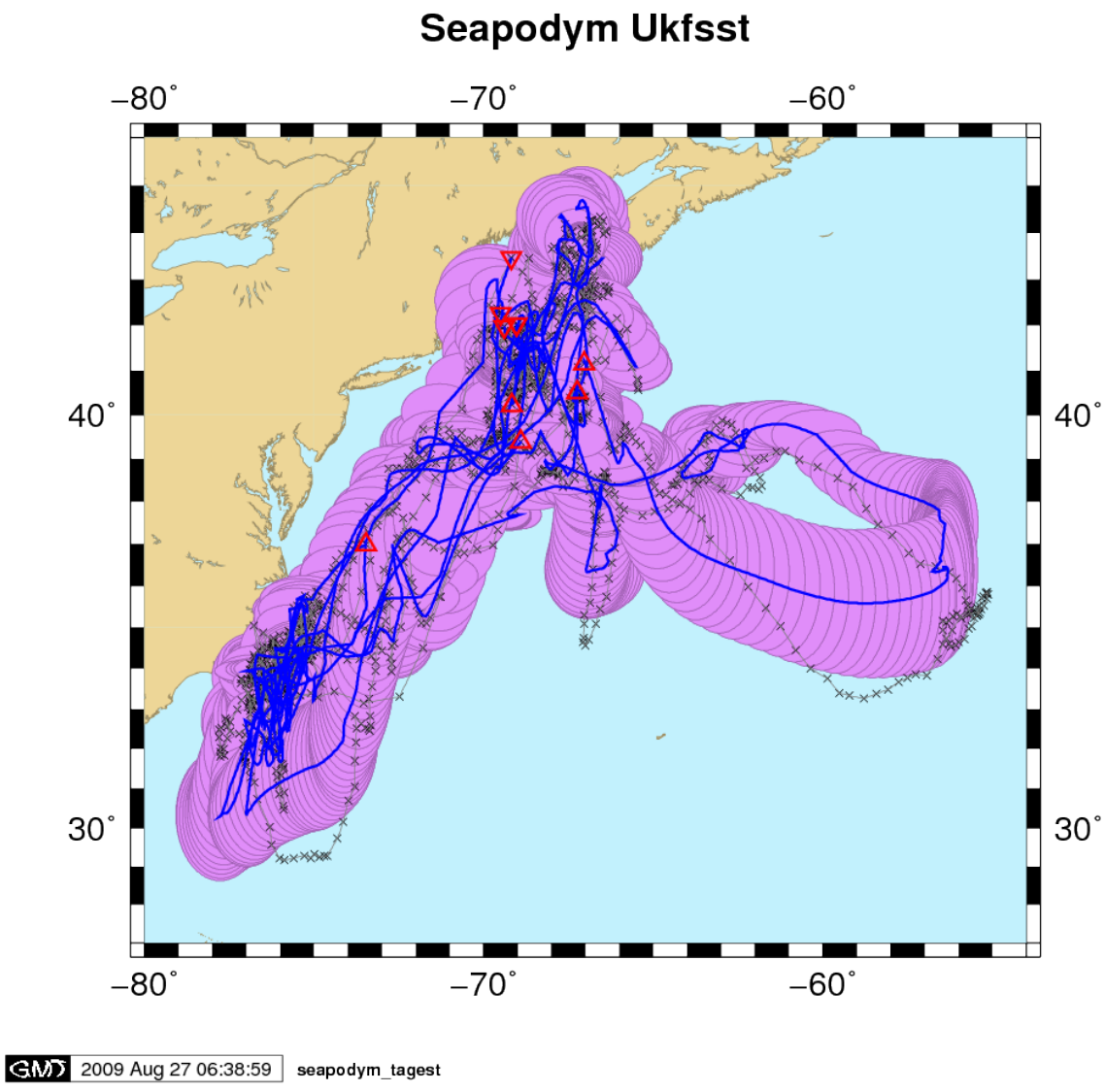
3. Boundaries:
   reflect tags away from boundaries;
   penalize likelihood for violation of boundaries.

4. Differentiability:
   the interpolation and reflection operations may be inherently non-differentiable.
   But ...

Differentiability?



Preliminary results — 5 tracks



Preliminary results — 5 tracks

Estimated Parameters

Parameter	Starting Value	Composite "Optimum"	Previous Optimum
σ_a	4.00	3.05	2.26
T	15.0	16.7	16.0
α_{oxy}	0.001	0.087	0.100
$\widehat{O}$	1.00	0.263	1.26
MSS	0.5	0.118	0.600

Preliminary Conclusions

Feasibility of combined model

- Model is sensitive to data and appears to shift parameter estimates in sensible directions.
- Model is computationally feasible. Minimization requires about 20 minutes 2.2GHz laptop.

Next Steps

- Improve reflective boundaries.
- Devise differentiable way of spatial interpolation.
- Relax constraint on identical errors for all tags.

Thanks

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- Anders Nielsen, Chi Lam — for implementing and sharing uKfSST.