



British  
Antarctic Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



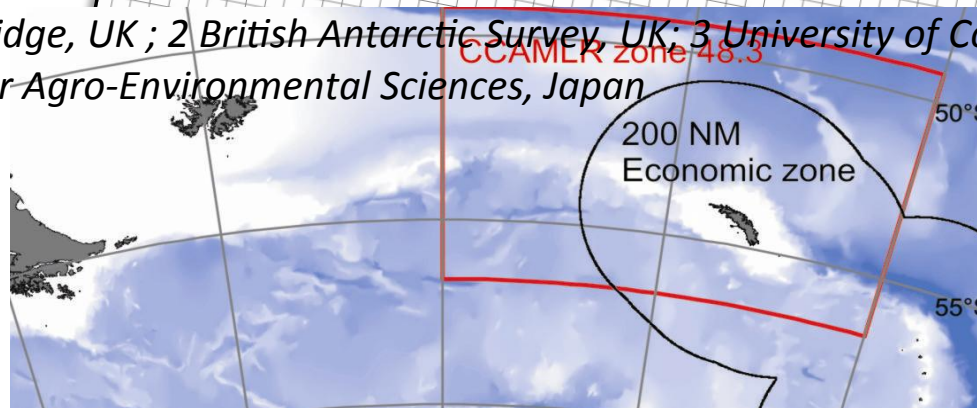
UNIVERSITY OF  
CAMBRIDGE

Conservation Science Group  
Department of Zoology

# Using seabird tracking data for the identification of important marine areas in the Southern Ocean

*Claire Tancell<sup>1,2</sup>, Richard Phillips<sup>2</sup>, Jose Xavier<sup>3</sup>, Tatsuya Amano<sup>4</sup>, Geraint Tarling<sup>2</sup>, William J Sutherland<sup>1</sup>*

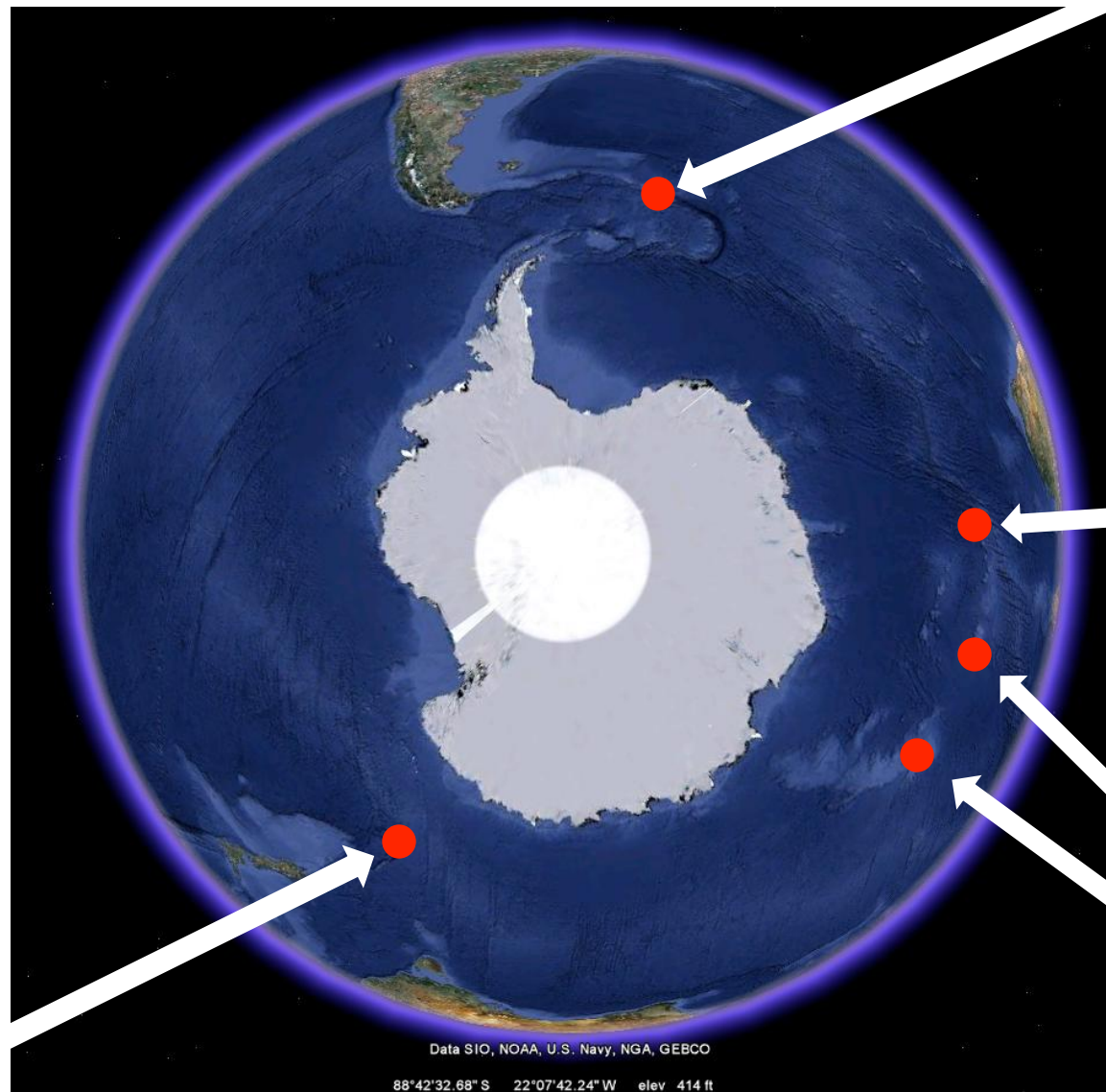
*1 University of Cambridge, UK ; 2 British Antarctic Survey, UK; 3 University of Coimbra, Portugal;  
4 National Institute for Agro-Environmental Sciences, Japan*



# Wandering Albatross



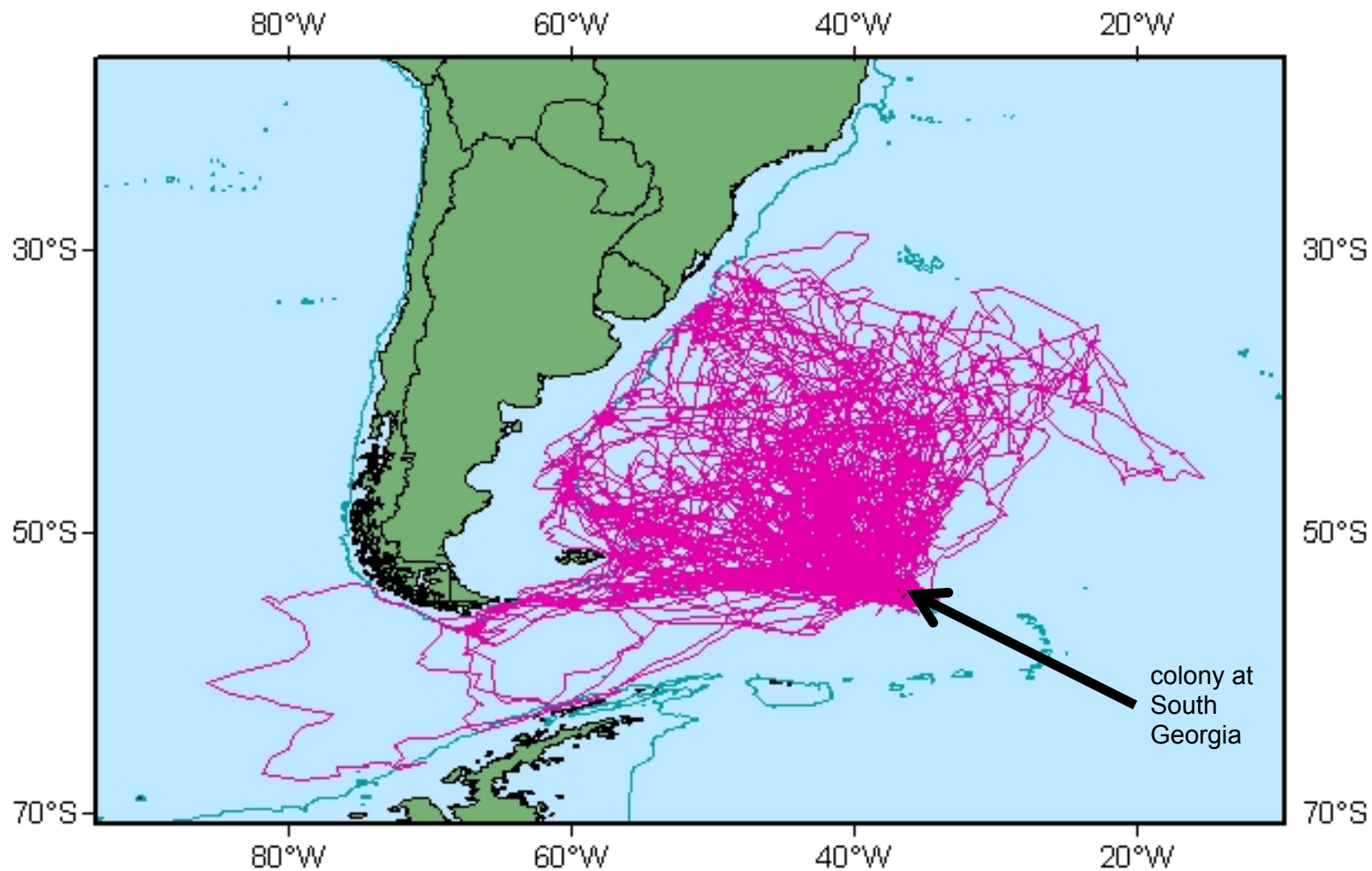
South Georgia

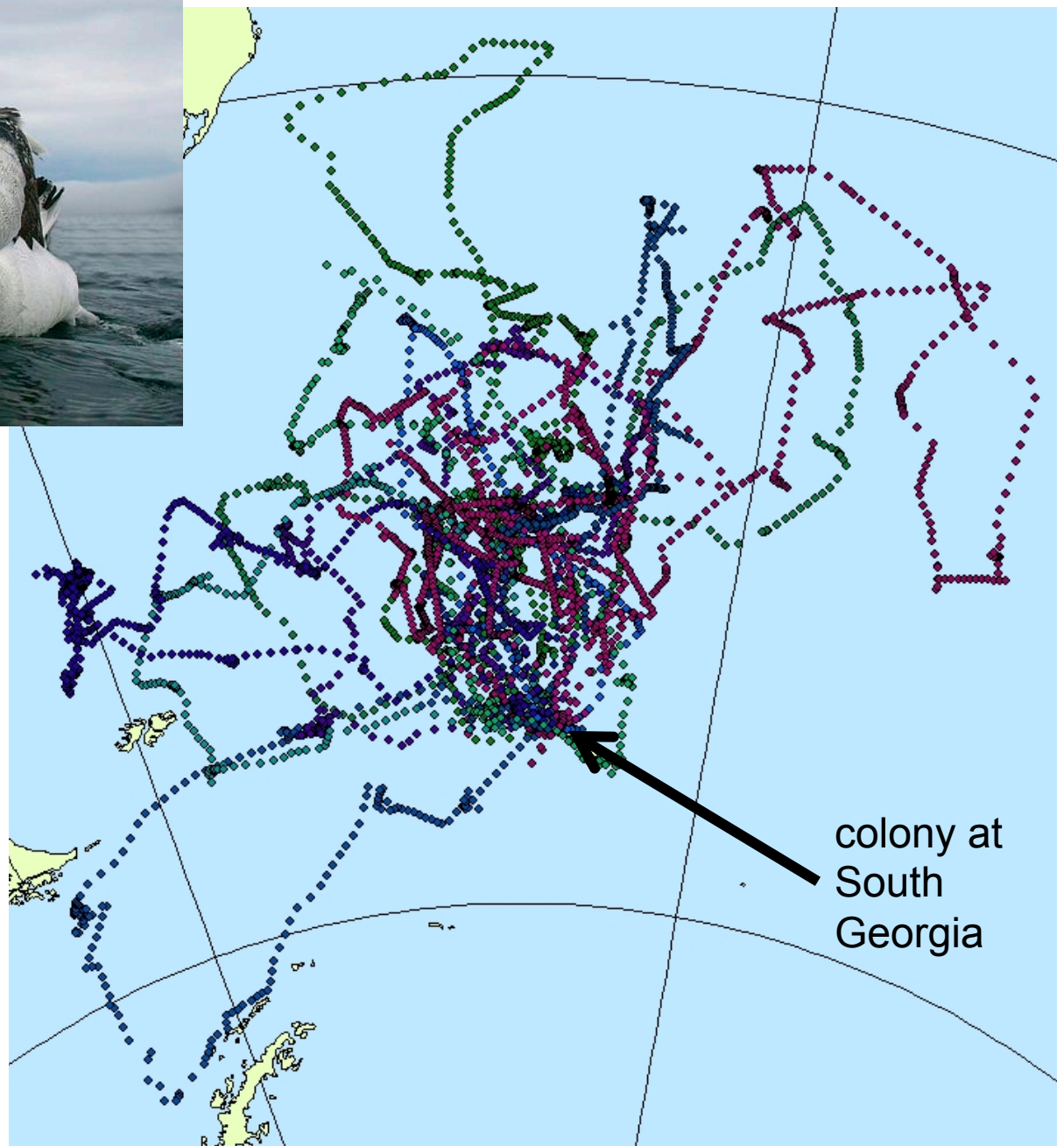
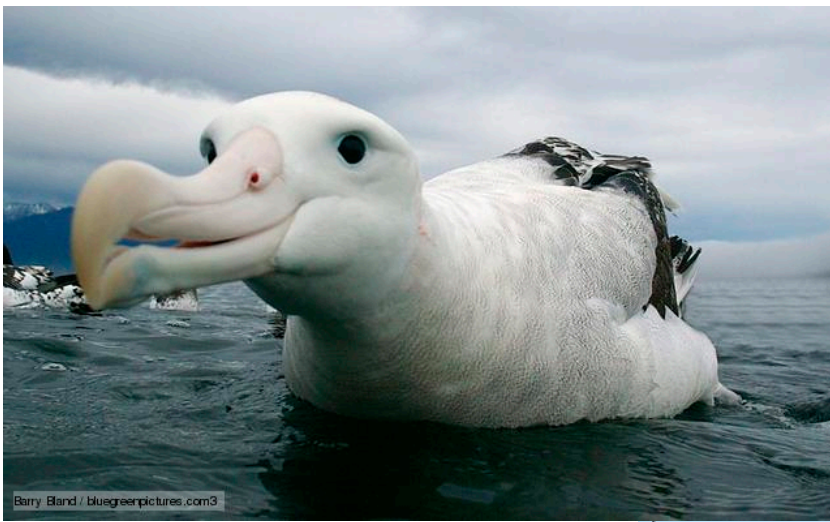


Prince Edward Islands

Crozet and Kerguelen Islands

Macquarie Island





Modeler's choice

4 sets of assumptions  
2000 season

3 established methods

- Keppel
- First-passage time
- State-space model
- Post-brood season
  - both parents at sea

One new method

- Minimum Displacement Rate

## Kernel analysis

$$\hat{f}(x) = \frac{1}{nh} \sum_{i=1}^n K\left(\frac{x - X_i}{h}\right)$$

- high point density = significant

## First-passage time

$$S_{(r)} = \text{Var}[\log t_{(r)}]$$

- slow relative progress along track = area restricted search

## State-space model

$$d_t \sim \gamma T d_{t-1} + N_2(0, \Sigma)$$

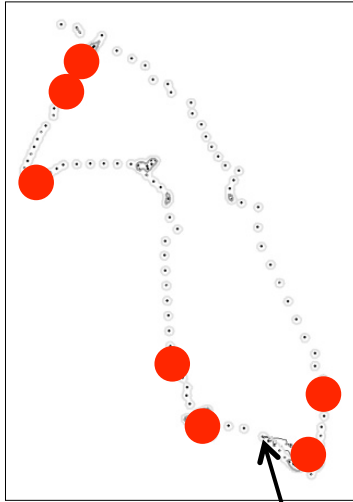
- high turning rate/low speed = foraging

$$y_{t,i} = (1 - j_i)x_{t-1} + j_i x_t + \varepsilon_t$$

## Minimum displacement rate

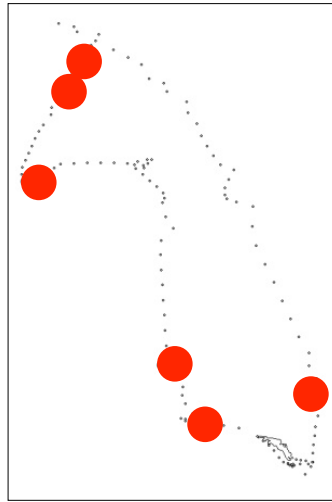
$$\delta_{\min} = (d_{t+24} - d_t)_{\min}$$

- day in which progress away from or towards colony was at a minimum = significant

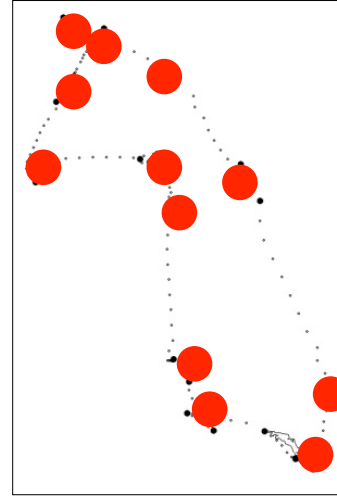


Kernel

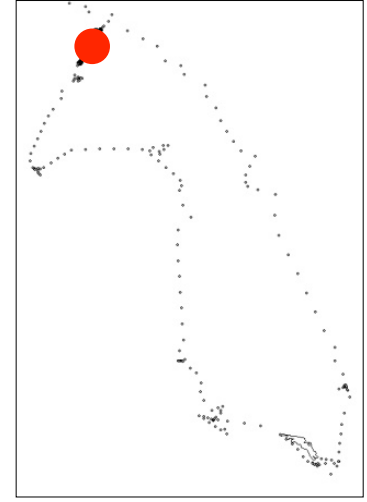
colony at  
South  
Georgia



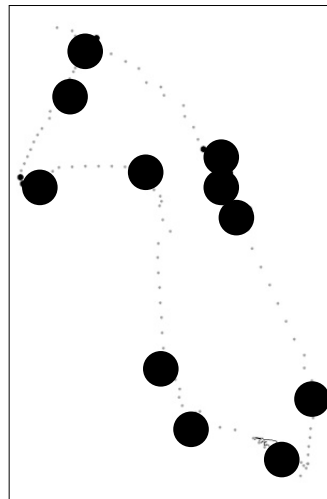
First-passage  
time



State-space  
model



Minimum  
displacement

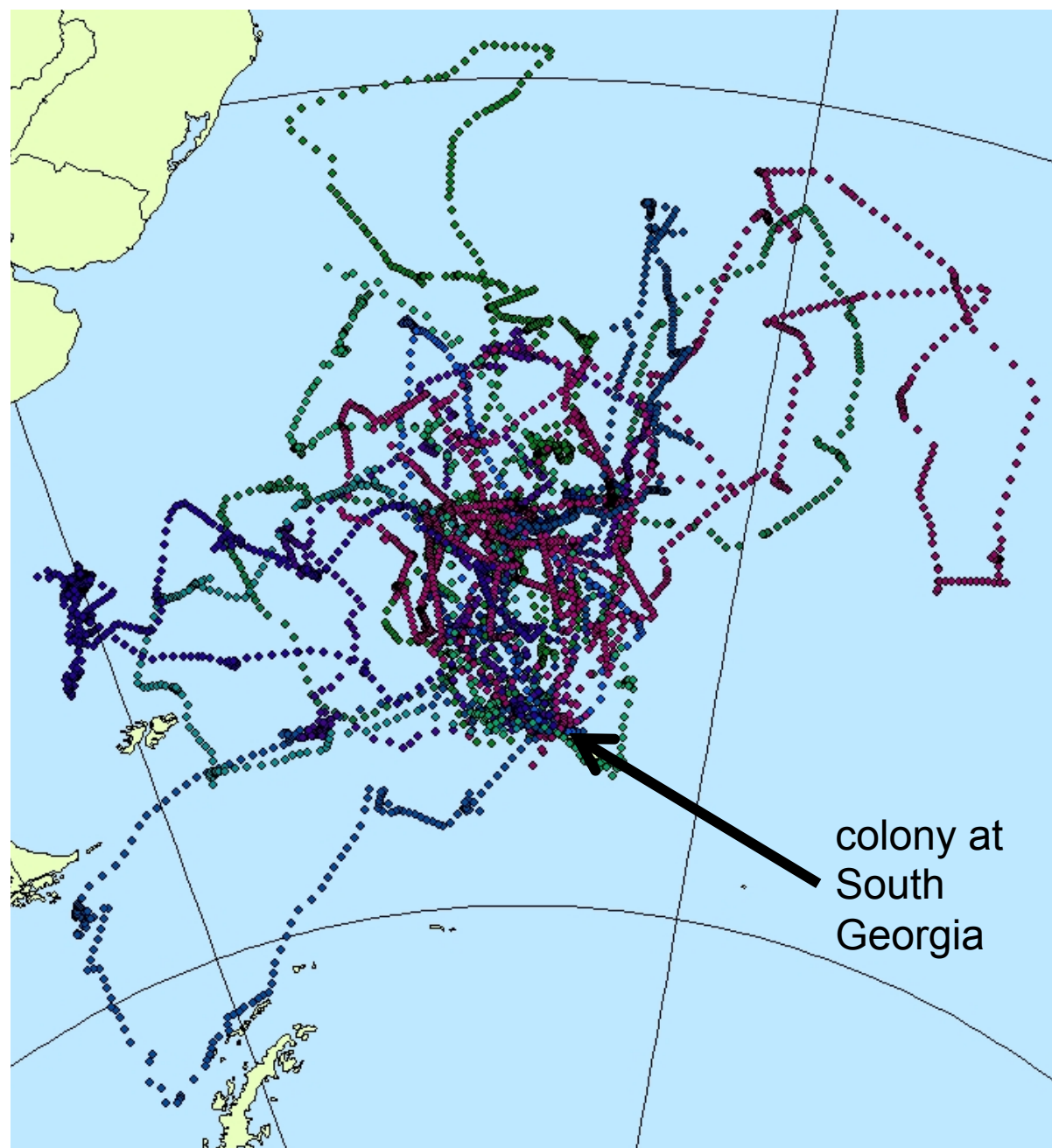


Single randomly  
selected track

Darkness

Kernel  
First-passage  
time  
Minimum  
displacement

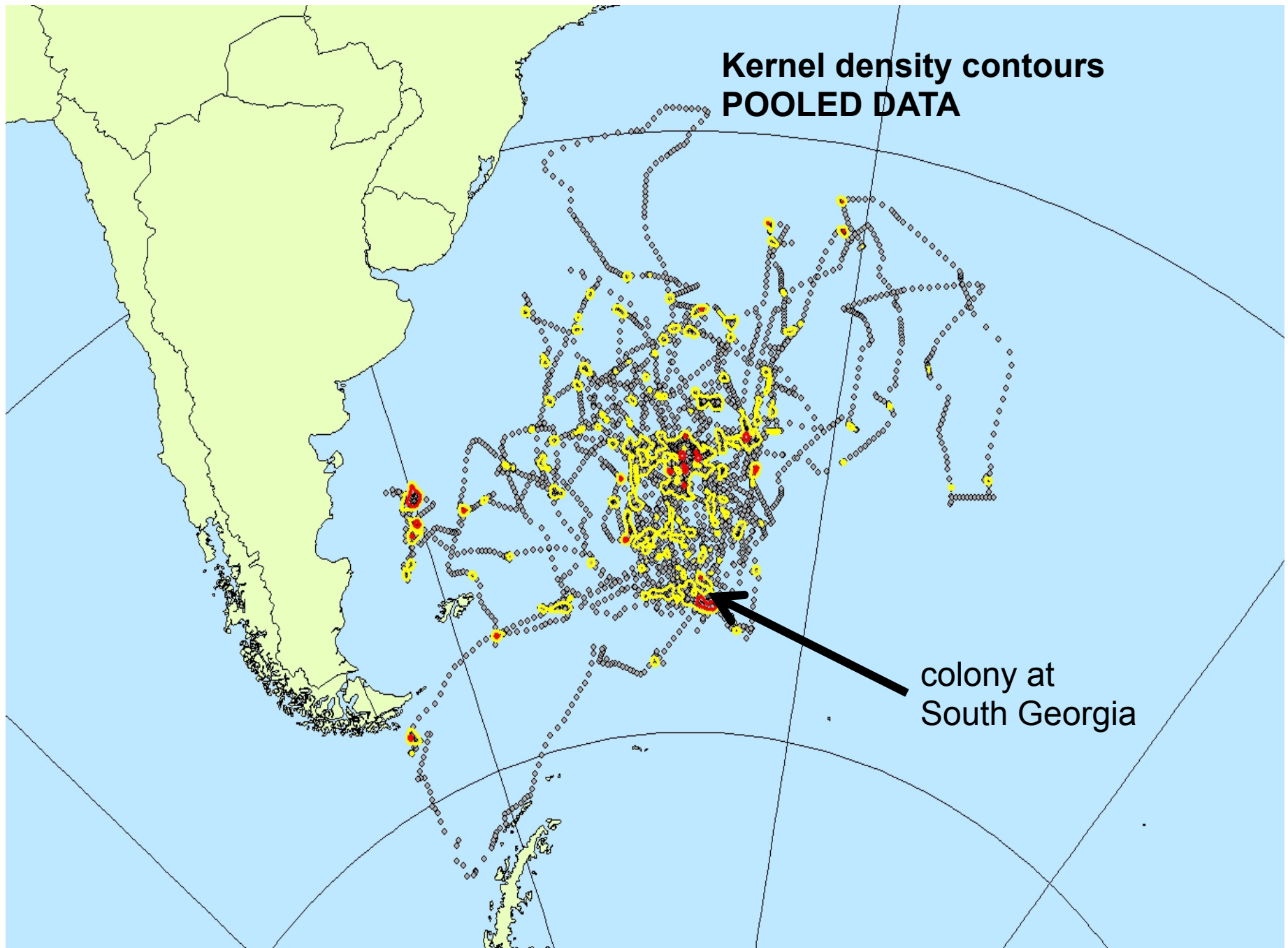
All tracks  
2000 season



colony at  
South  
Georgia

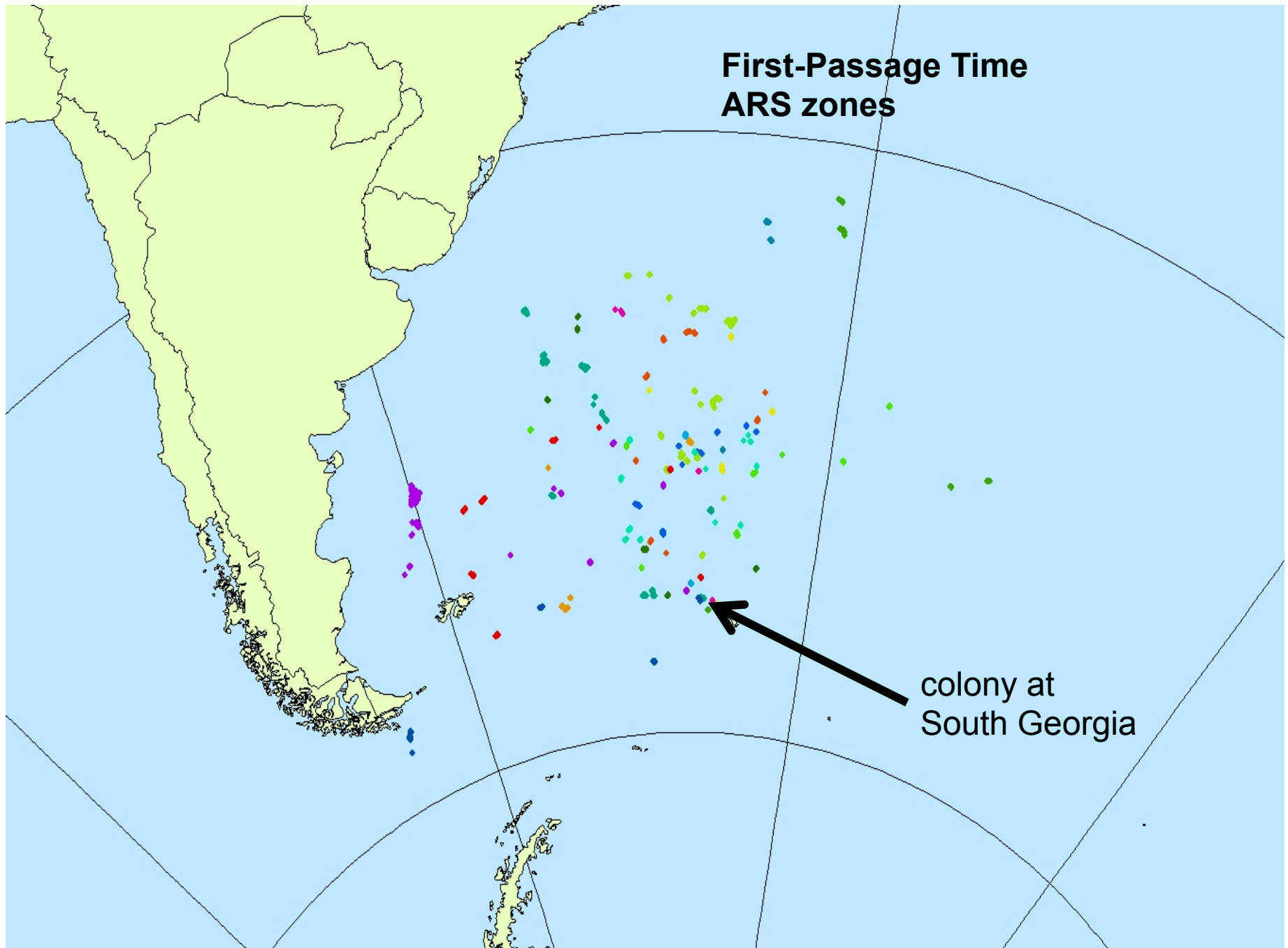
**Kernel density contours  
POOLED DATA**

colony at  
South Georgia

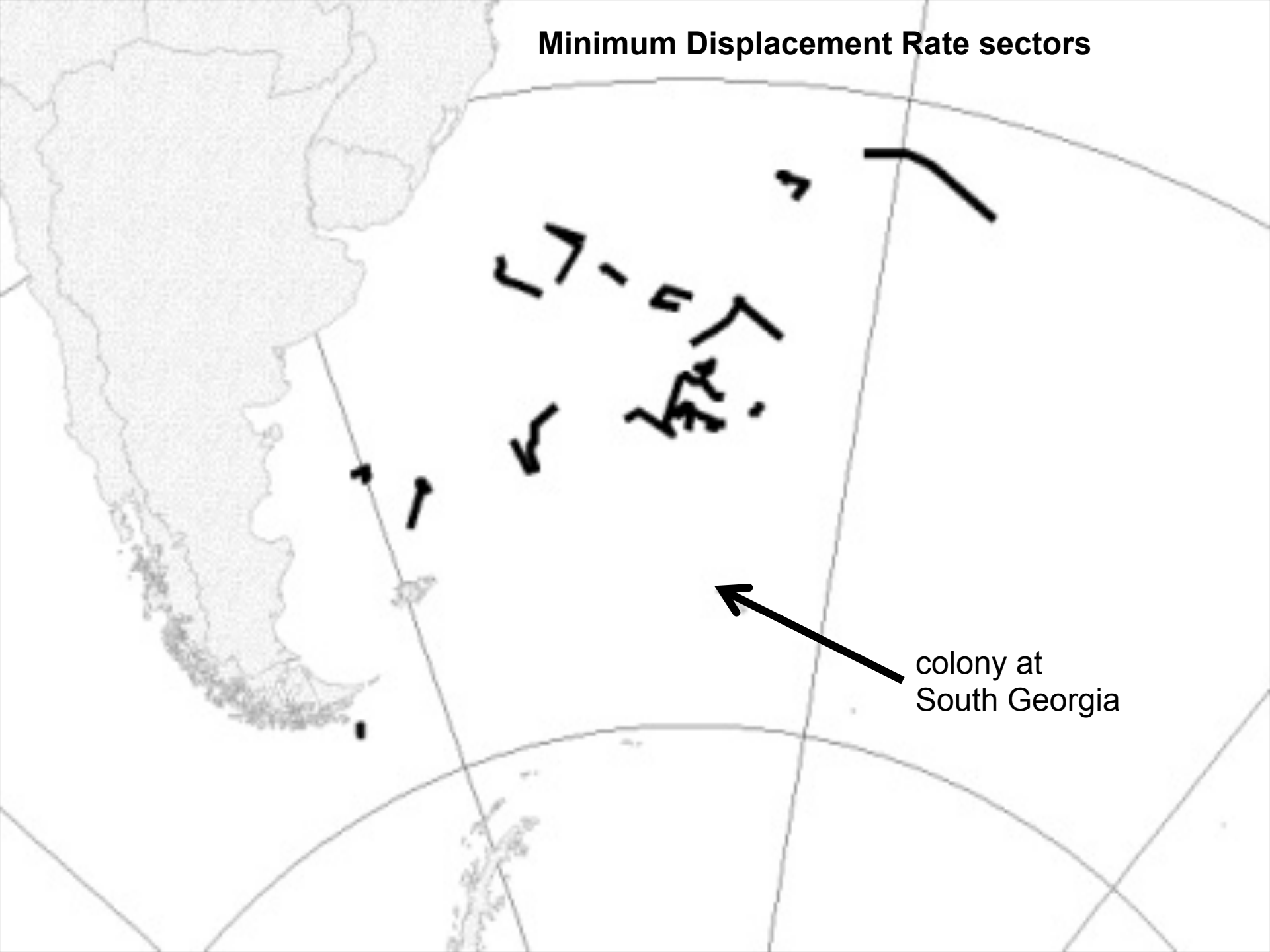


**First-Passage Time  
ARS zones**

colony at  
South Georgia



# Minimum Displacement Rate sectors

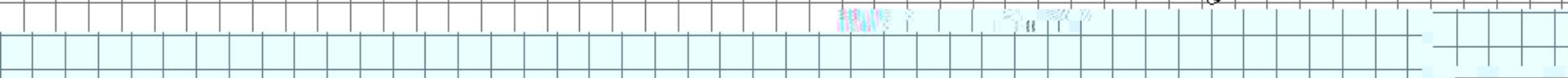


Key:

■ Kernel

□ First-passage time

▨ Minimum displacement



Methods show agreement at this scale despite different assumptions

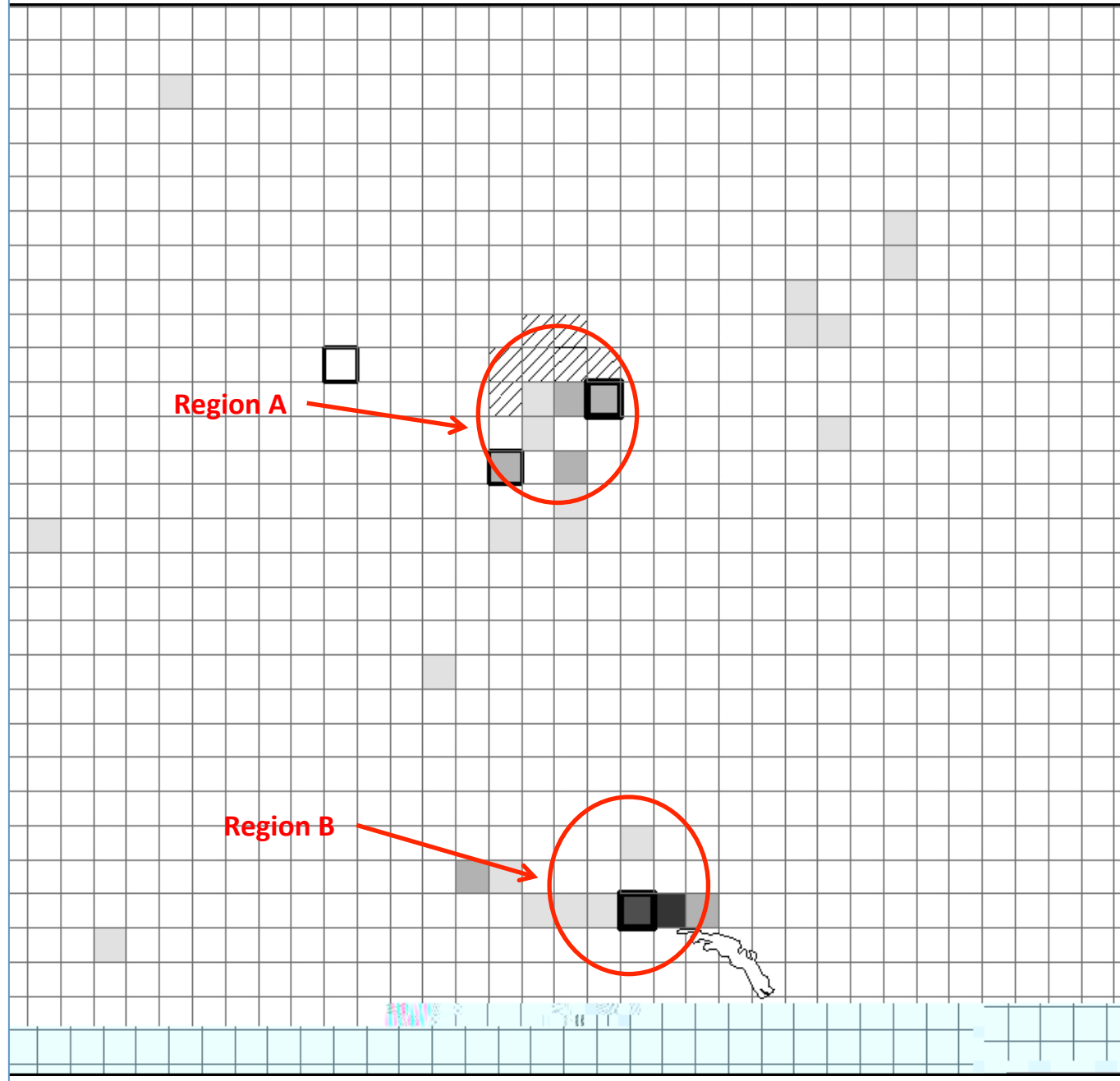
Assumptions robust

Overlap method reduces method specific biases

Gridding = accessible summary of sophisticated statistical techniques

Region A:  
Oceanographic feature  
Mesoscale eddy?  
Mobile?

Region B:  
Known to be important during chick-rearing  
Consistent during post-brood



## Region A

Significant

High Seas

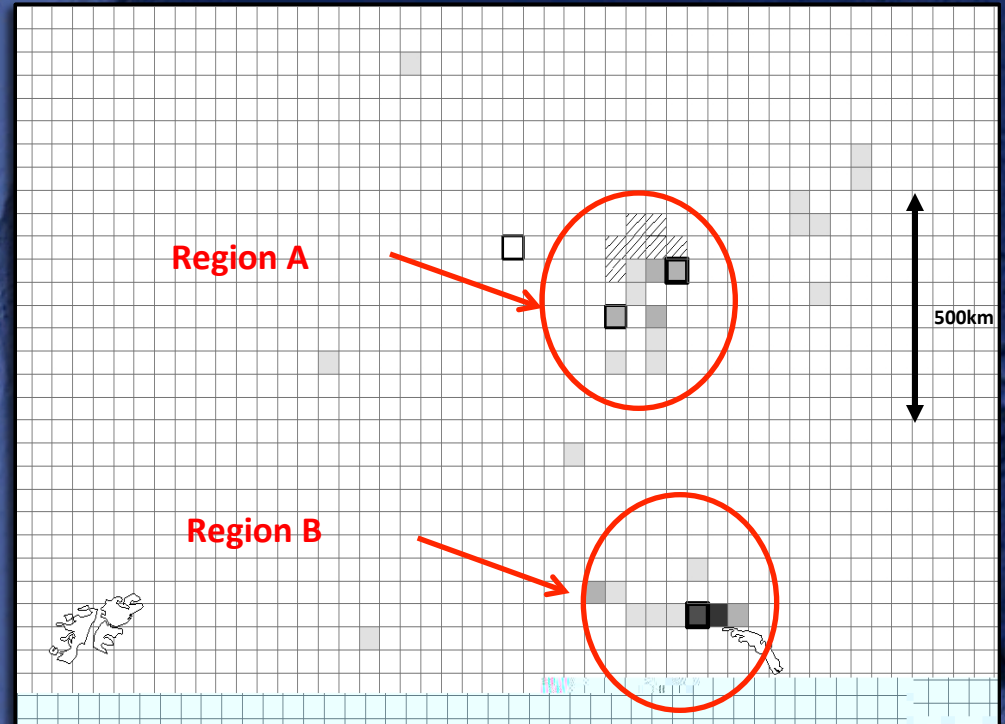
Diffuse management

Regional Fisheries Management

Organisations requires multi-

party agreement

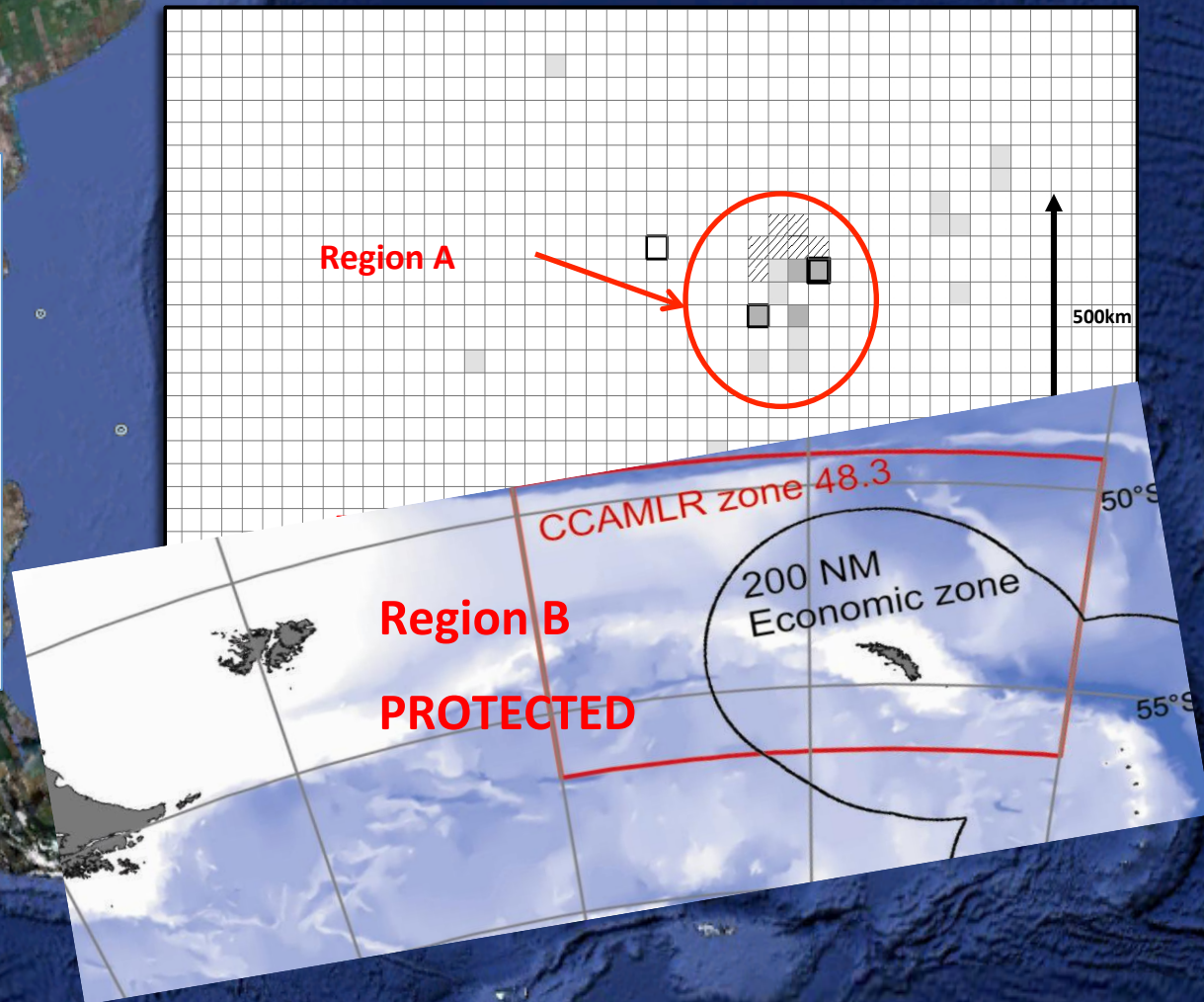
Mobile system



Fishing banned within 12nm

Fishery closed Oct – Mar  
(breeding season for all  
other species)

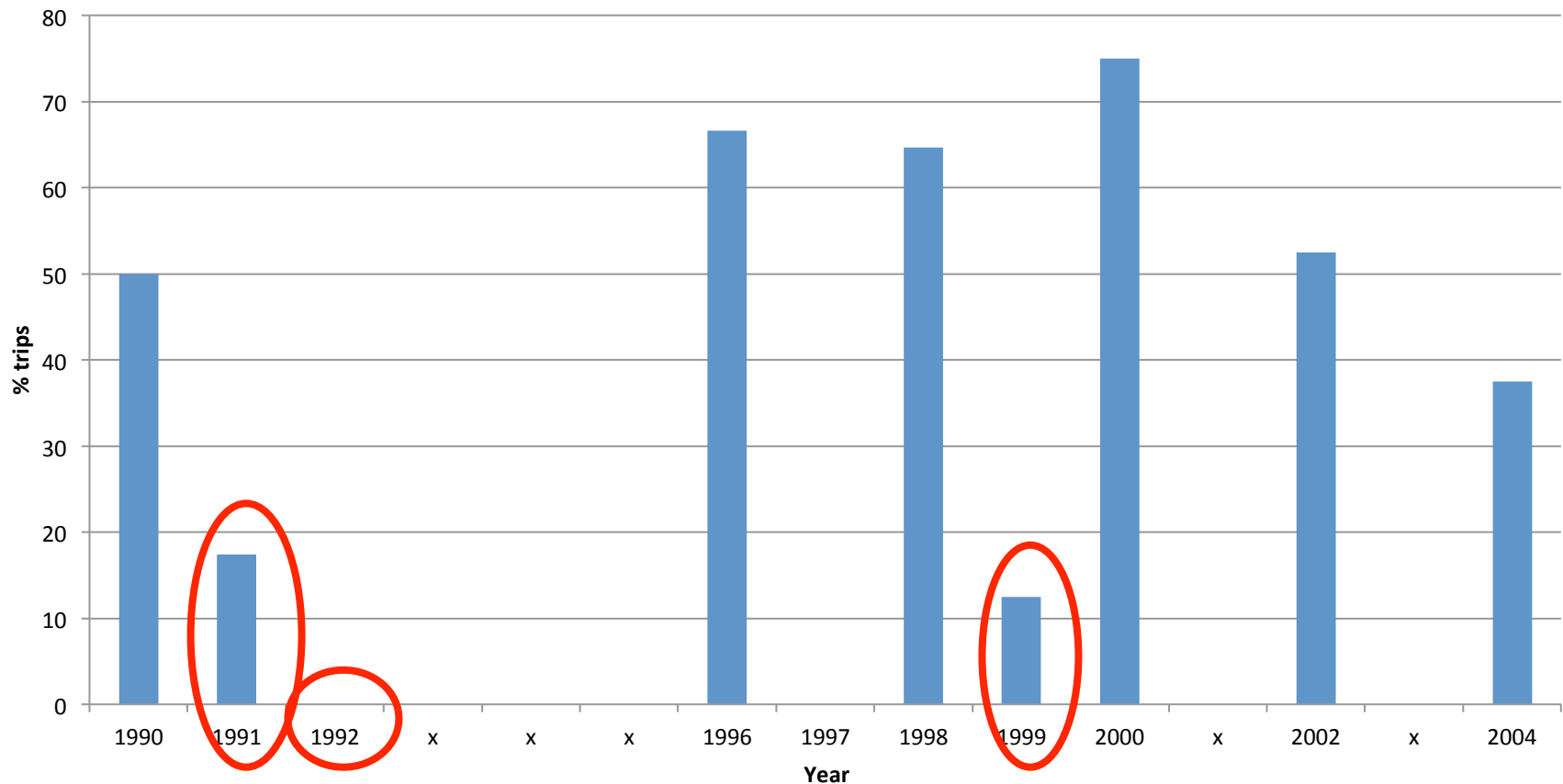
Night-setting, streamer-  
lines, line weighting,  
observers



In most years Region B important in **chick-rearing** period for Wandering Albatross

- trip destination
- period of fishery closure only covers incubation of Wandering Albatross
- mitigation methods crucial

### Percentage of chick-rearing trips entirely within protected area (males)



Ongoing research.....

Apply gridded method across

- Years
- Species
- Breeding stages

Test consistency of these regions

Next steps.....

Identify destination in years  
when Region B is under-used

Predictability

Ongoing research.....

Apply gridded method across

- Years
- Species
- Breeding stages

Test consistency of these regions

Next steps.....

Identify destination in years  
when Region B is under-used

Predictability

- Ongoing research.....
- Apply gridded method across
- Years
  - Species
  - Breeding stages
- Test consistency of these regions
- Next steps.....
- Identify destination in years  
when Region B is under-used
- Predictability

Ongoing research.....

Apply gridded method across

- Years
- Species
- Breeding stages

Test consistency of these regions

Next steps.....

Identify destination in years  
when Region B is under-used

Predictability

Ongoing research.....

Apply gridded method across

- Years
- Species
- Breeding stages

Test consistency of these regions

Next steps.....

Identify destination in years  
when Region B is under-used

Predictability

Ongoing research.....

Apply gridded method across

- Years
- Species
- Breeding stages

Test consistency of these regions

Next steps.....

Identify destination in years  
when Region B is under-used

Predictability

Ongoing research.....

Apply gridded method across

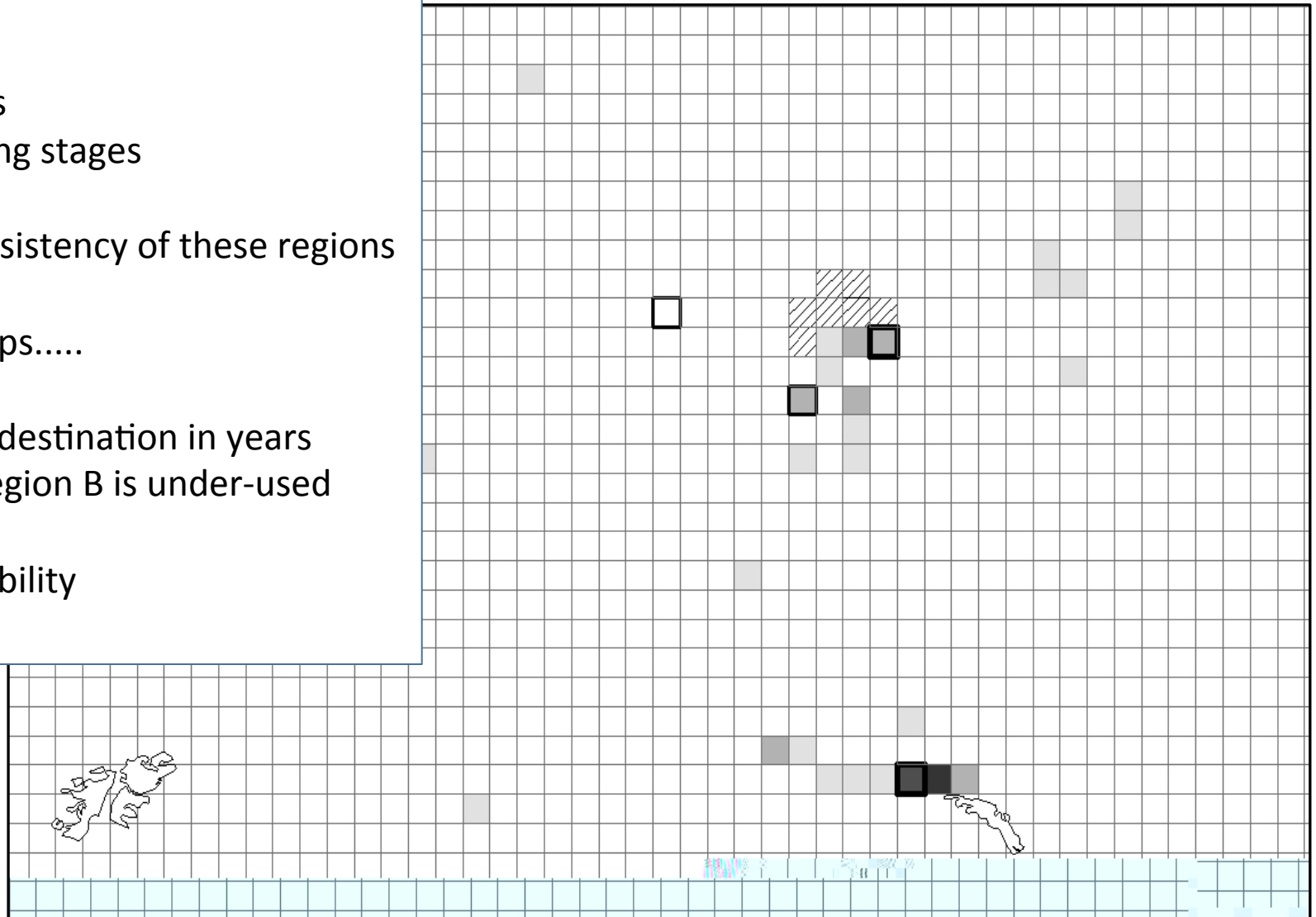
- Years
- Species
- Breeding stages

Test consistency of these regions

Next steps.....

Identify destination in years  
when Region B is under-used

Predictability





**British  
Antarctic Survey**

NATURAL ENVIRONMENT RESEARCH COUNCIL

SIGHT



PRINCE ALBERT II OF MONACO  
FOUNDATION

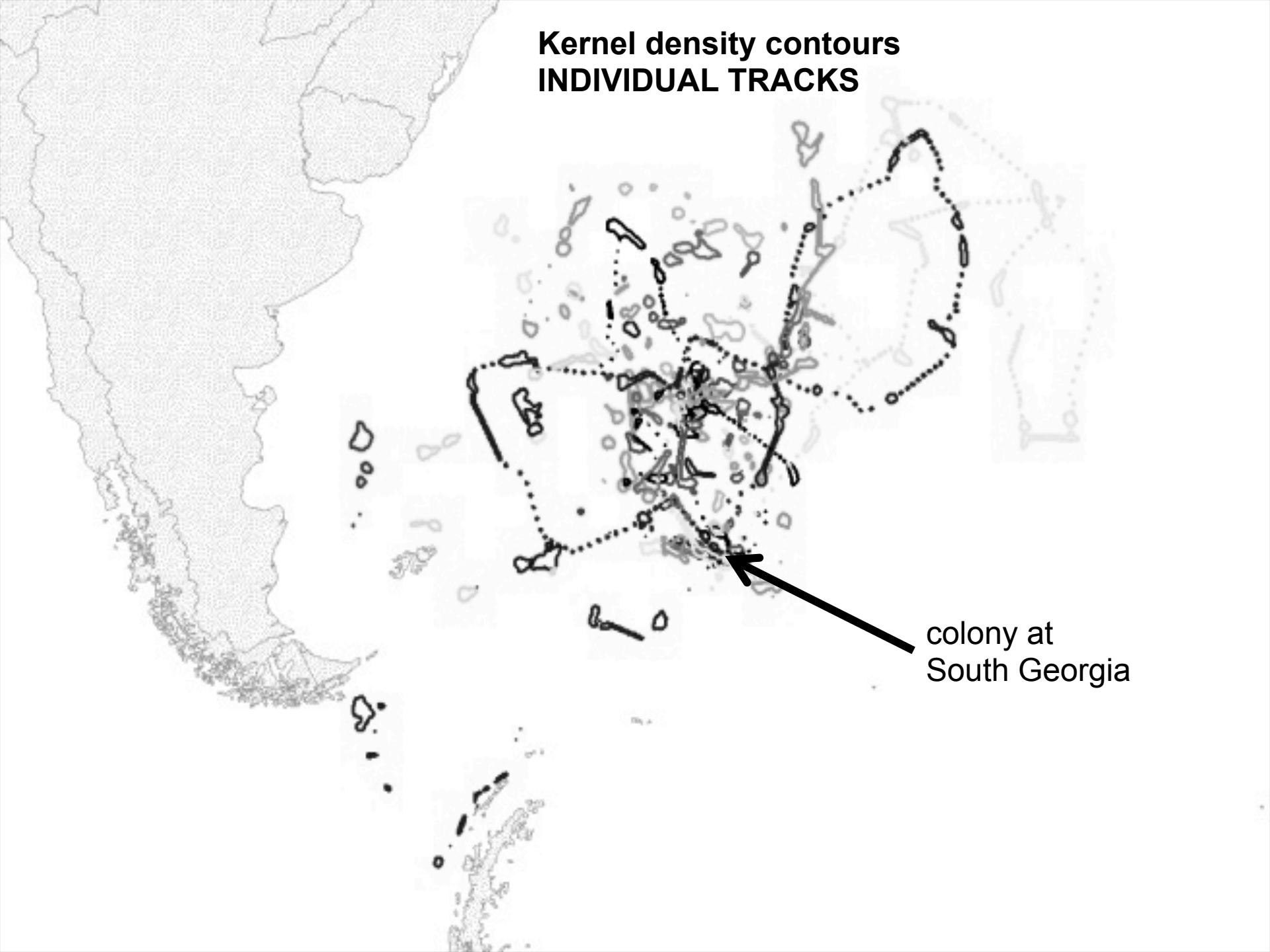
Conservation Science Group  
Department of Zoology



UNIVERSITY OF  
CAMBRIDGE



**Kernel density contours  
INDIVIDUAL TRACKS**

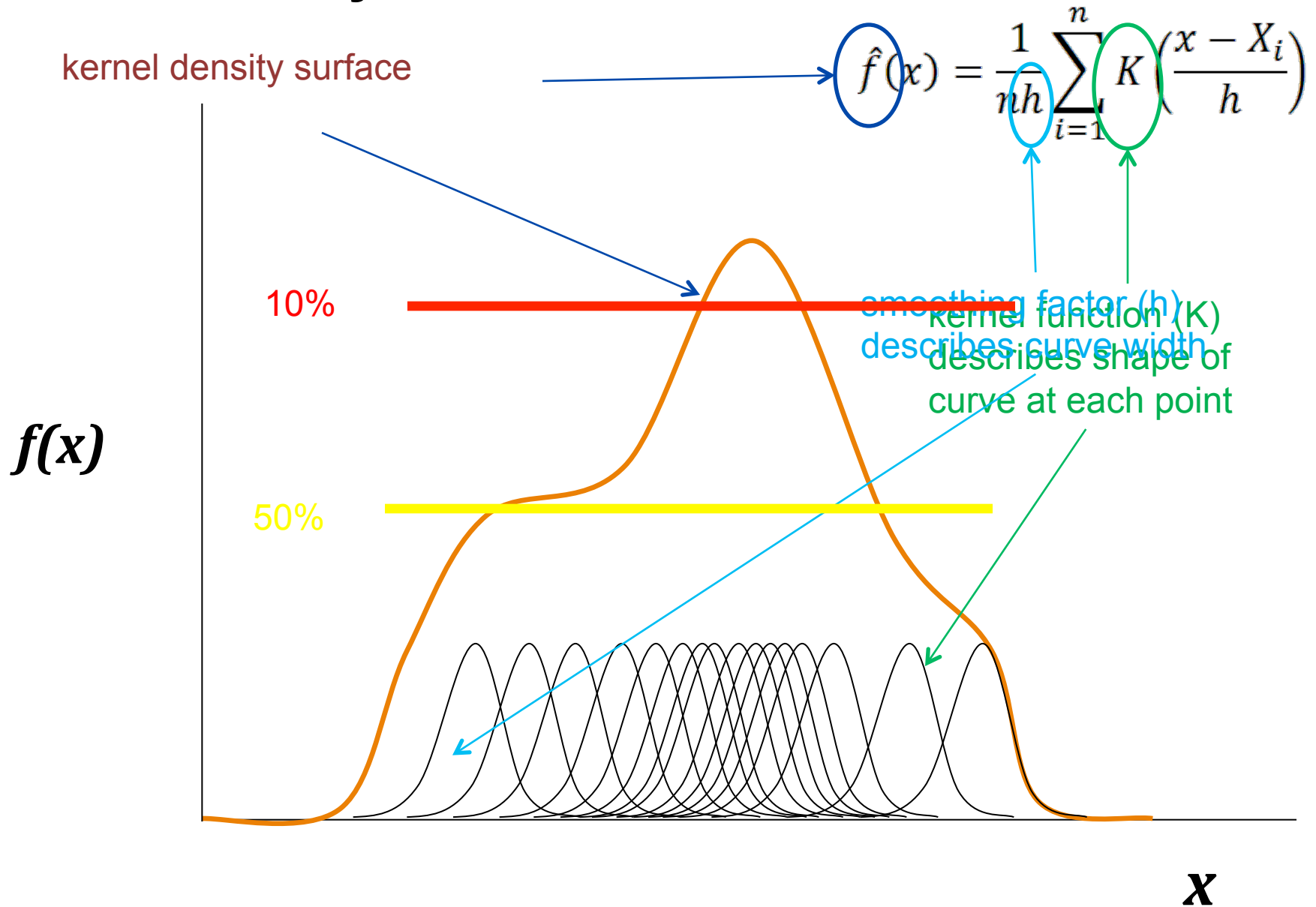


colony at  
South Georgia



# Kernel Analysis

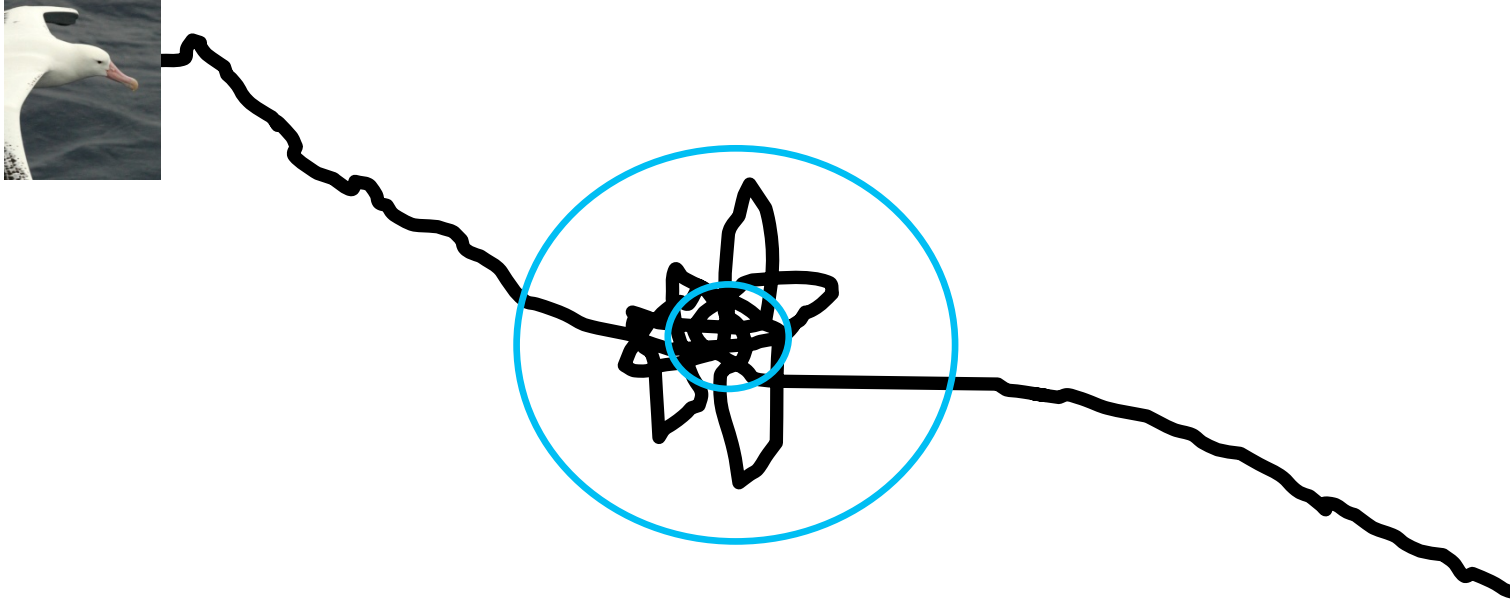
(Rosenblatt 1956; Silverman 1986)



# First-Passage Time Analysis

(Fauchald and Tverraa 2003)

Definition: time required for an animal to cross a circle with a given radius



$$S_{(r)} = \text{Var}[\log t(r)]$$

radius of the circle

# First-passage Time

relative variance in first-passage  
time for all points along the path

makes  $S_{(r)}$  independent of  
magnitude of  
mean first-passage time

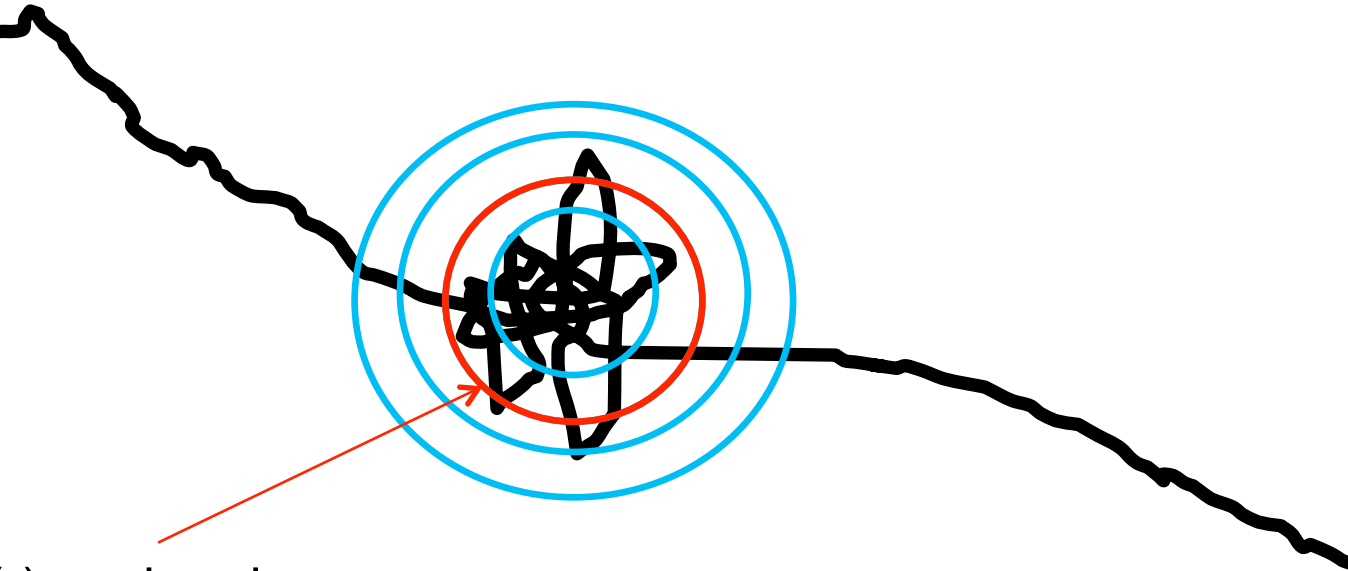
The equation  $S_{(r)} = \text{Var}[\log t(r)]$  is shown with several annotations. A blue circle highlights  $S_{(r)}$ , with a blue arrow pointing to it from the text 'relative variance in first-passage time for all points along the path'. A red circle highlights  $(r)$ , with a red arrow pointing to it from the text 'radius of the circle'. A green circle highlights  $\log$ , with a green arrow pointing to it from the text 'makes  $S_{(r)}$  independent of magnitude of mean first-passage time'. An orange circle highlights  $t(r)$ , with an orange arrow pointing to it from the text 'time lag between first-passage time forwards and first-passage time backwards'.

$$S_{(r)} = \text{Var}[\log t(r)]$$

radius of the circle

time lag between first-passage time forwards  
and first-passage time backwards

# First-Passage Time Analysis



$S(r)$  peaks when  
 $r$  corresponds to  
search radius

Area Restricted Search Zone (ARS)

# State Space Model

(Jonsen et al 2005)

Transition equation:



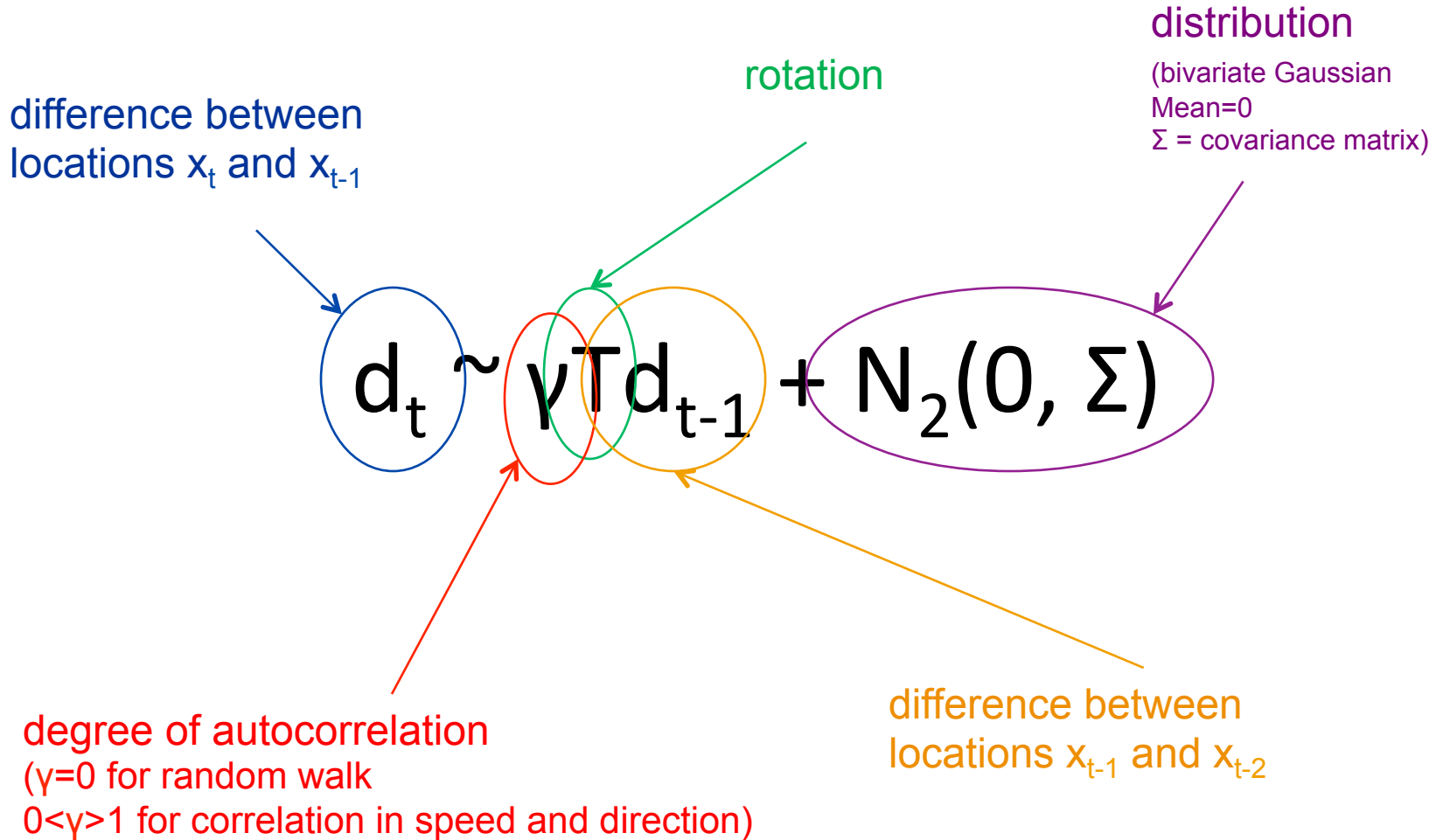
- Describes how the individual's movement evolves through time
- Predicts individual's position when not observed

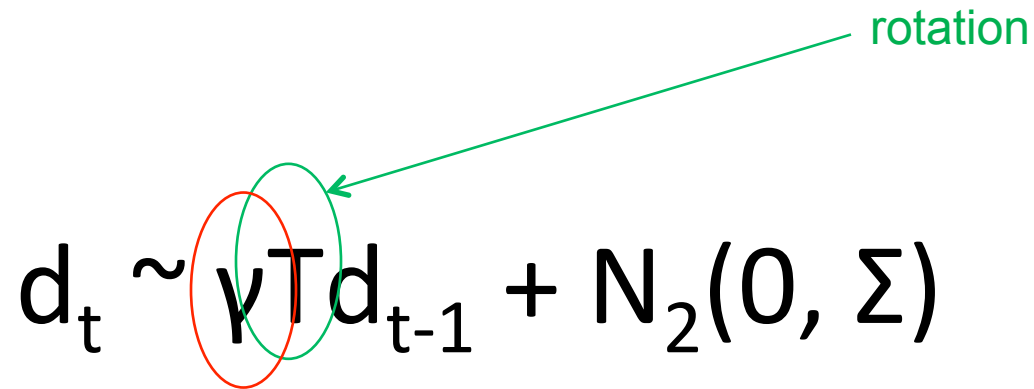
Measurement equation:



- Relates observed positions to those predicted in the transition equation
- Interpolates where observations are irregular
- Includes different degrees of error for each observation

Transition equation:  
**First-difference correlated random walk**



$$\mathbf{d}_t \sim \gamma \mathbf{T} \mathbf{d}_{t-1} + N_2(0, \Sigma)$$


degree of autocorrelation  
( $\gamma=0$  for random walk  
 $0 < \gamma < 1$  for correlation in speed and direction)

Behavioural mode 1: low  $\gamma$  and high  $\mathbf{T}$  represents **foraging**

Behavioural mode 2: high  $\gamma$  and low  $\mathbf{T}$  represents **commuting**

## Measurement equation

interpolated location  
between position at  
time  $t$  and the  $i^{\text{th}}$   
observation between  
 $t$  and  $t+1$

variable estimation error  
dependant on data quality

$$y_{t,i} = (1 - j_i)x_{t-1} + j_i x_t + \varepsilon_t$$

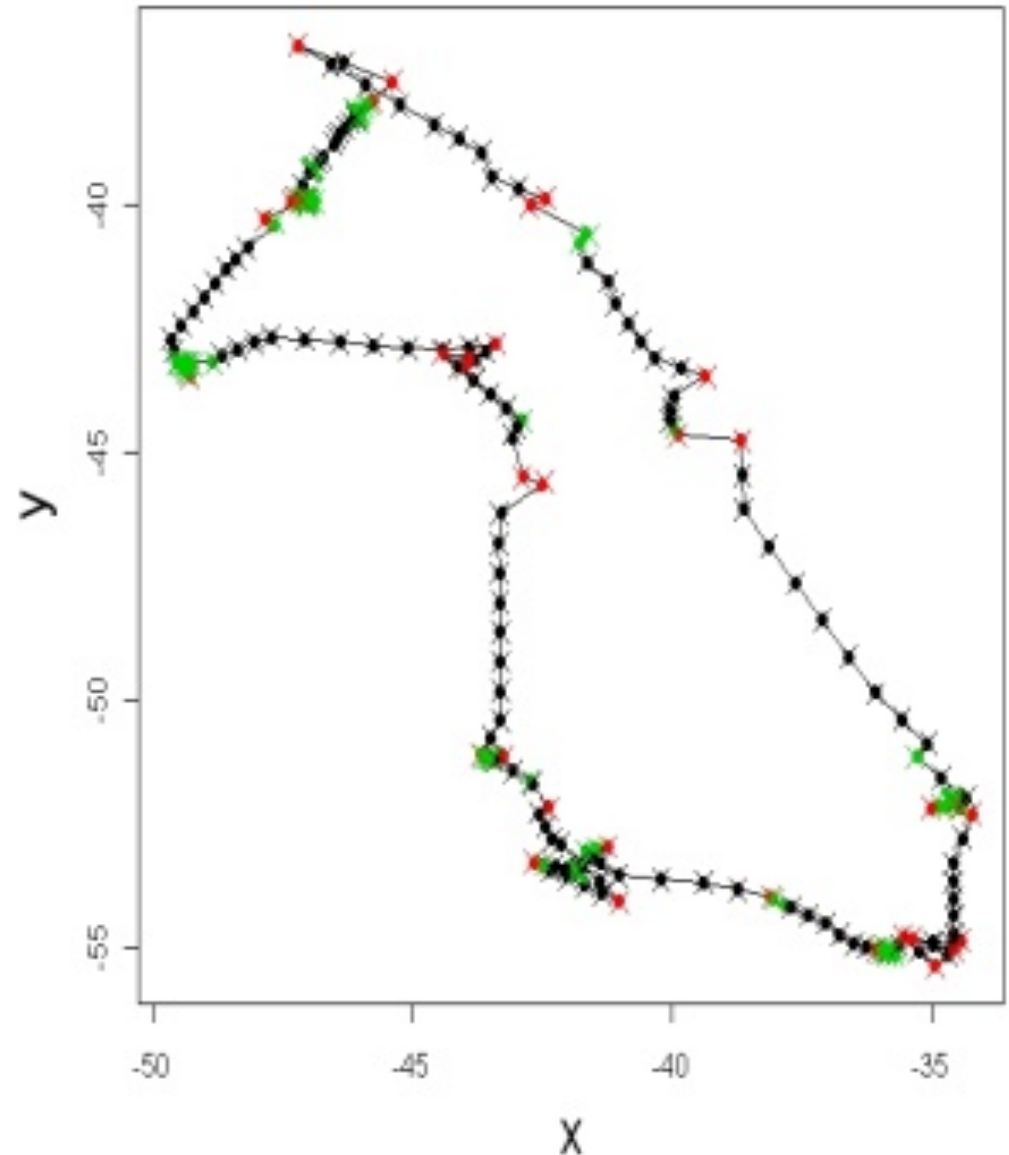
proportion of the  
regular time interval  
between  $x_{t-1}$  and  $x_t$   
at which the  $i^{\text{th}}$  observation  
is made

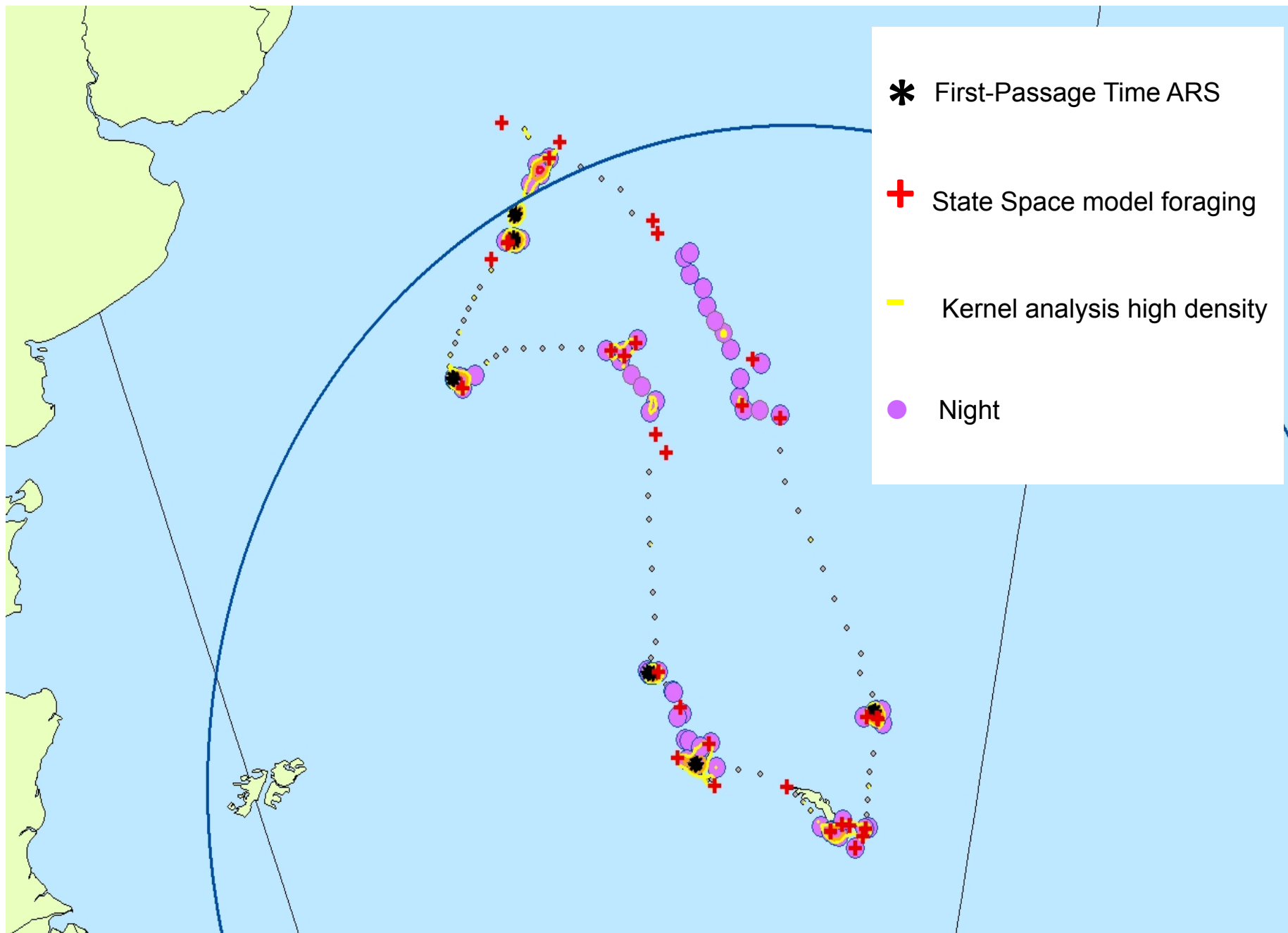
# State Space Model output - single track

**X** Foraging

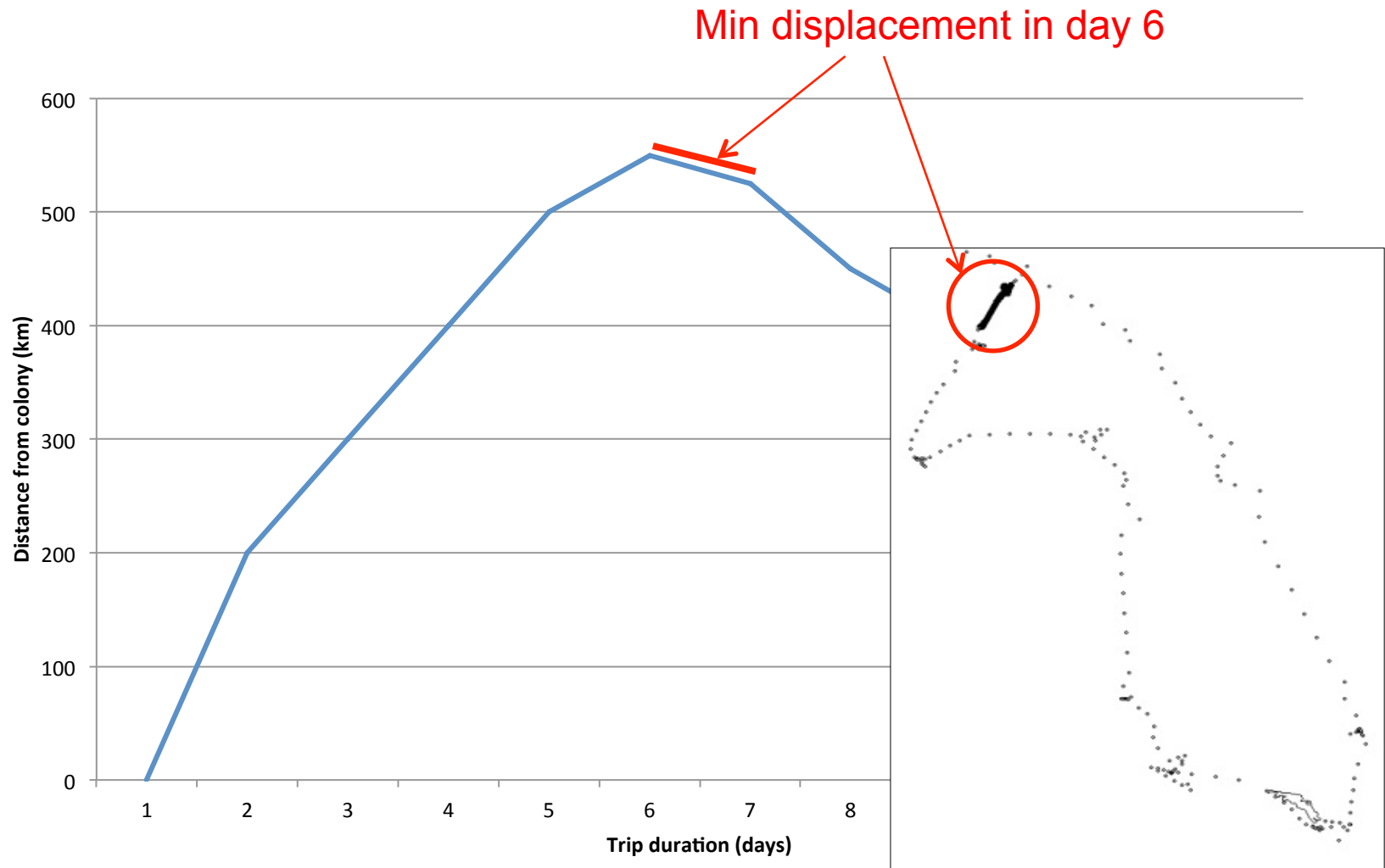
**X** Commuting

**X** not differentiated





# Minimum Displacement-Rate Analysis





Bottom trawling  
in CCAMLR sul



**Marine Stewardship Council**  
Certified sustainable seafood

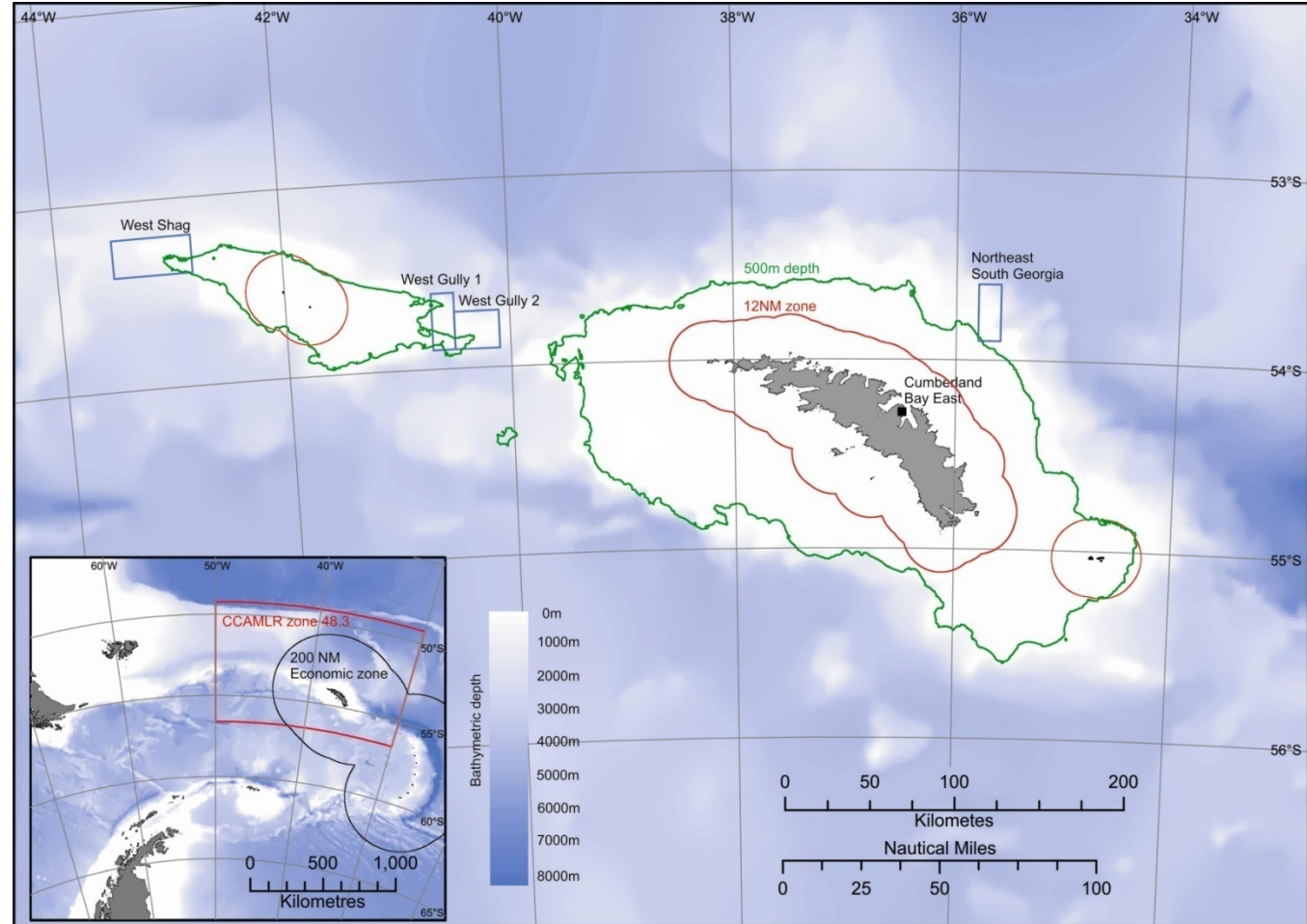
**measures**

Bottom fishing banned at  
depths < 500m  
South Georgia

All fishing banned within  
Government of South  
Georgia and the South  
Sandywich Islands  
by-catch reduced  
(by 99%) only permitted  
at Cumberland Bay East

Three Restricted Impact  
As)

fishing licensed  
at depths > 500m under  
Commission for the  
Conservation of Marine  
Living Resources  
(CCAMLR)  
34 Nations



2000 season

PTT

Post-brood season

