Climate Change and Upper Trophic Levels

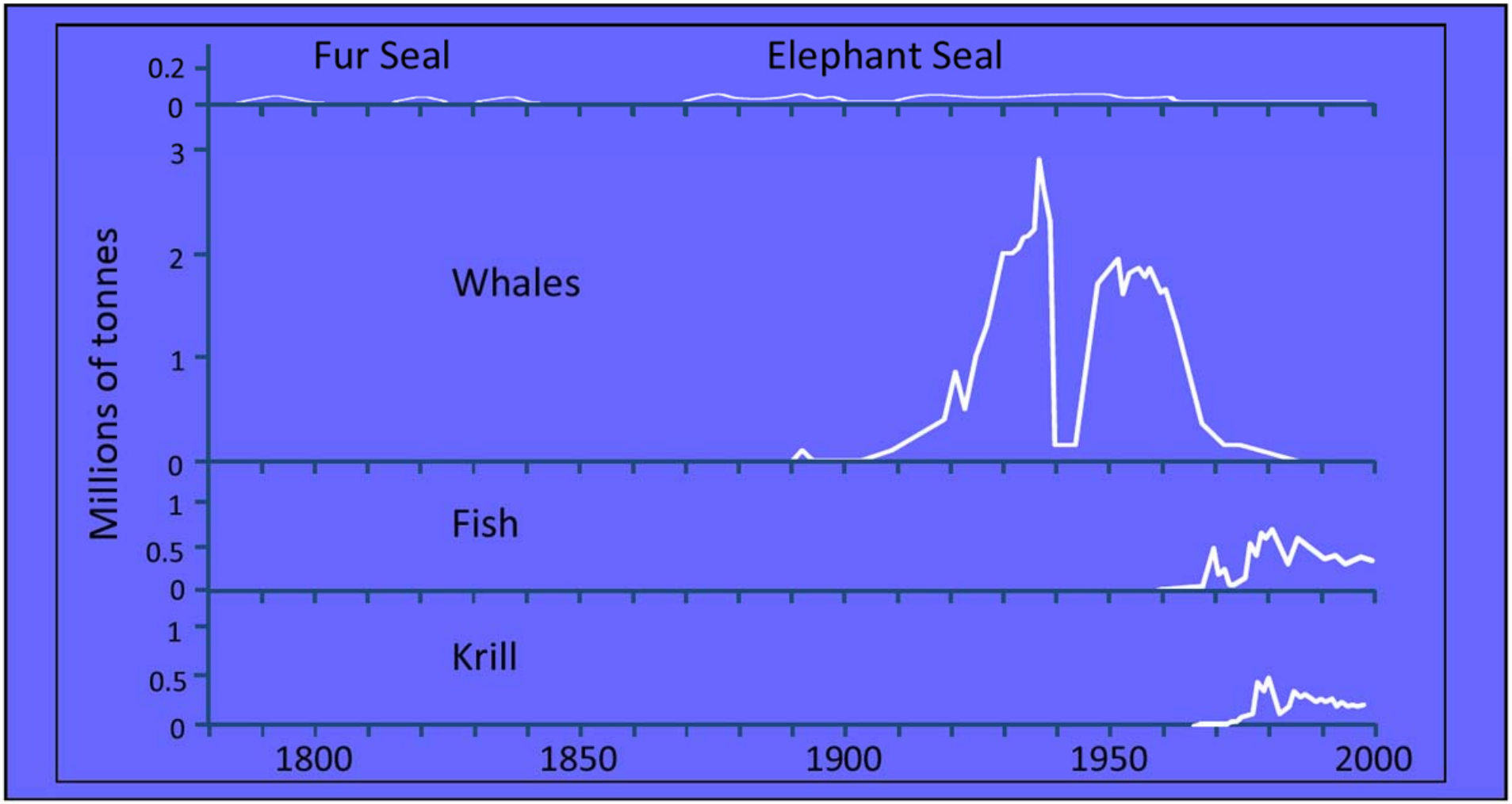
Dan Costa
University of California Santa Cruz

Outline

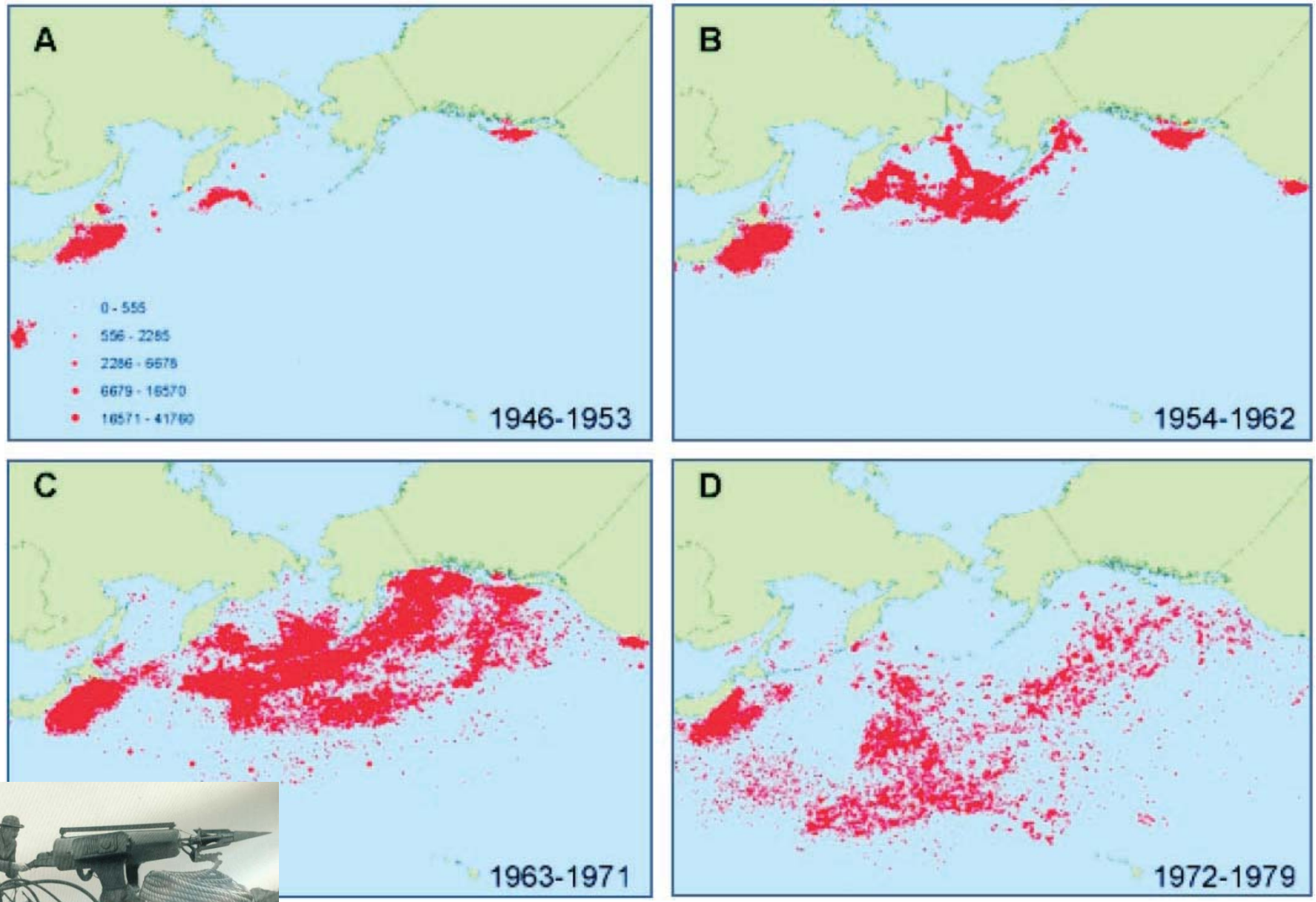
- Role of Top Predators to Marine Ecosystems
  - Top Down Processes
  - Biogeochemical cycles
- Response to Environmental Variability
  - Modern
  - Holocene
- Defining habitat characteristics
- Predicting habitat change
- Using animals to measure a changing habitat
- Research Questions

Outline

- Role of Top Predators to Marine Ecosystems
  - Top Down Processes
  - Biogeochemical cycles
- Response to Environmental Variability
  - Modern
  - Holocene
- Defining habitat characteristics
- Predicting habitat change
- Using animals to measure a changing habitat
- Research Questions

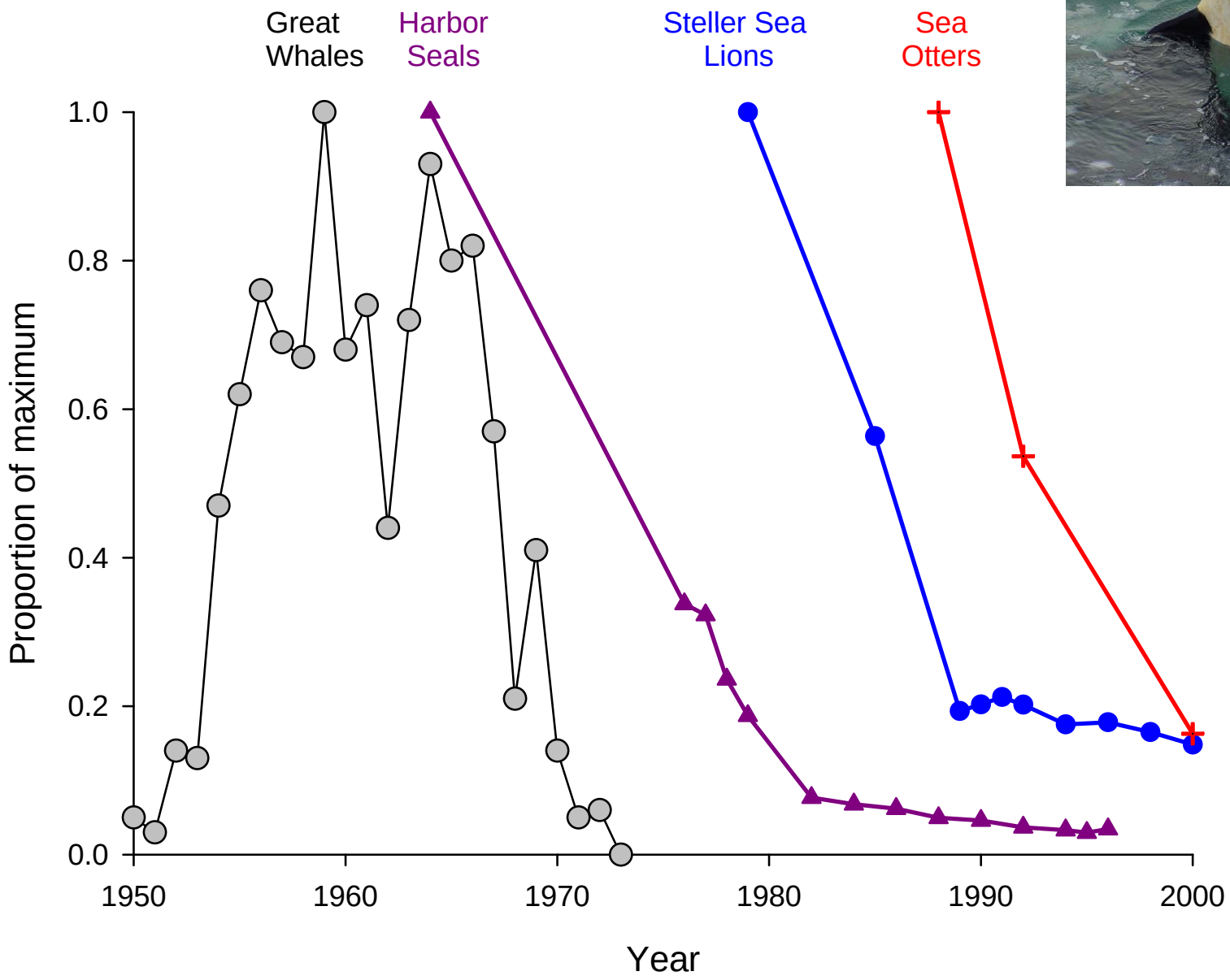

Fur Seal
Elephant Seal
Millions of tonnes
0.2
0
3
2
1
0
Whales
1
0.5
0
Fish
1
0.5
0
Krill
1800
1850
1900
1950
2000

Whale Harvest in North Pacific

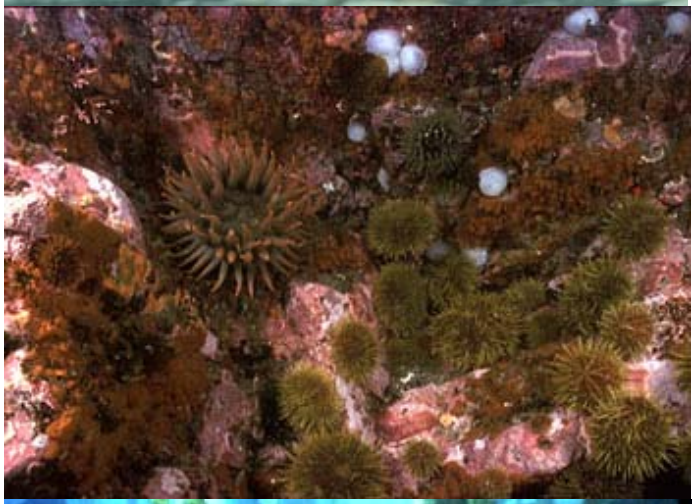


Springer et al 2003 PNAS

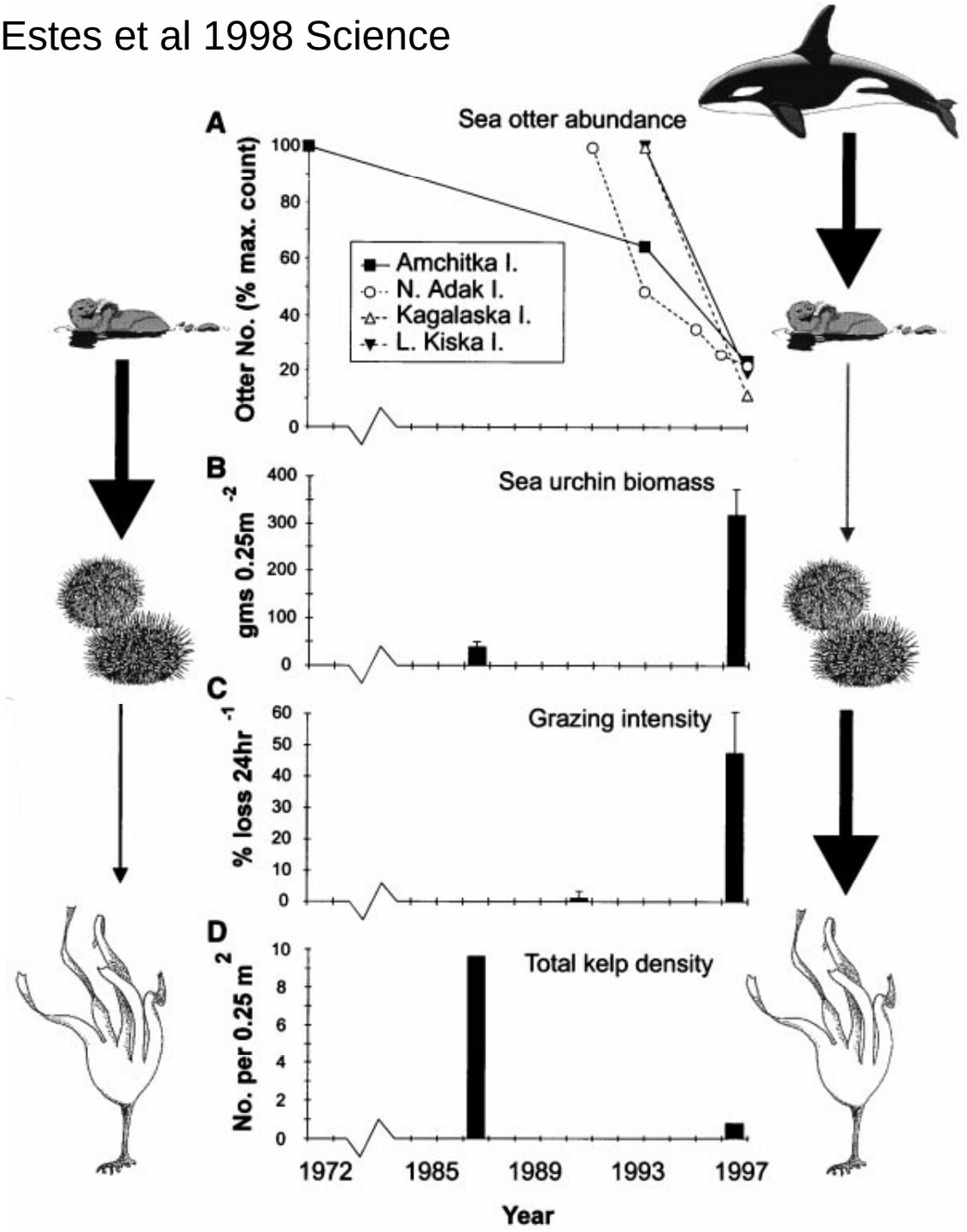
Sequential Megafaunal collapse



Springer et al 2003 PNAS



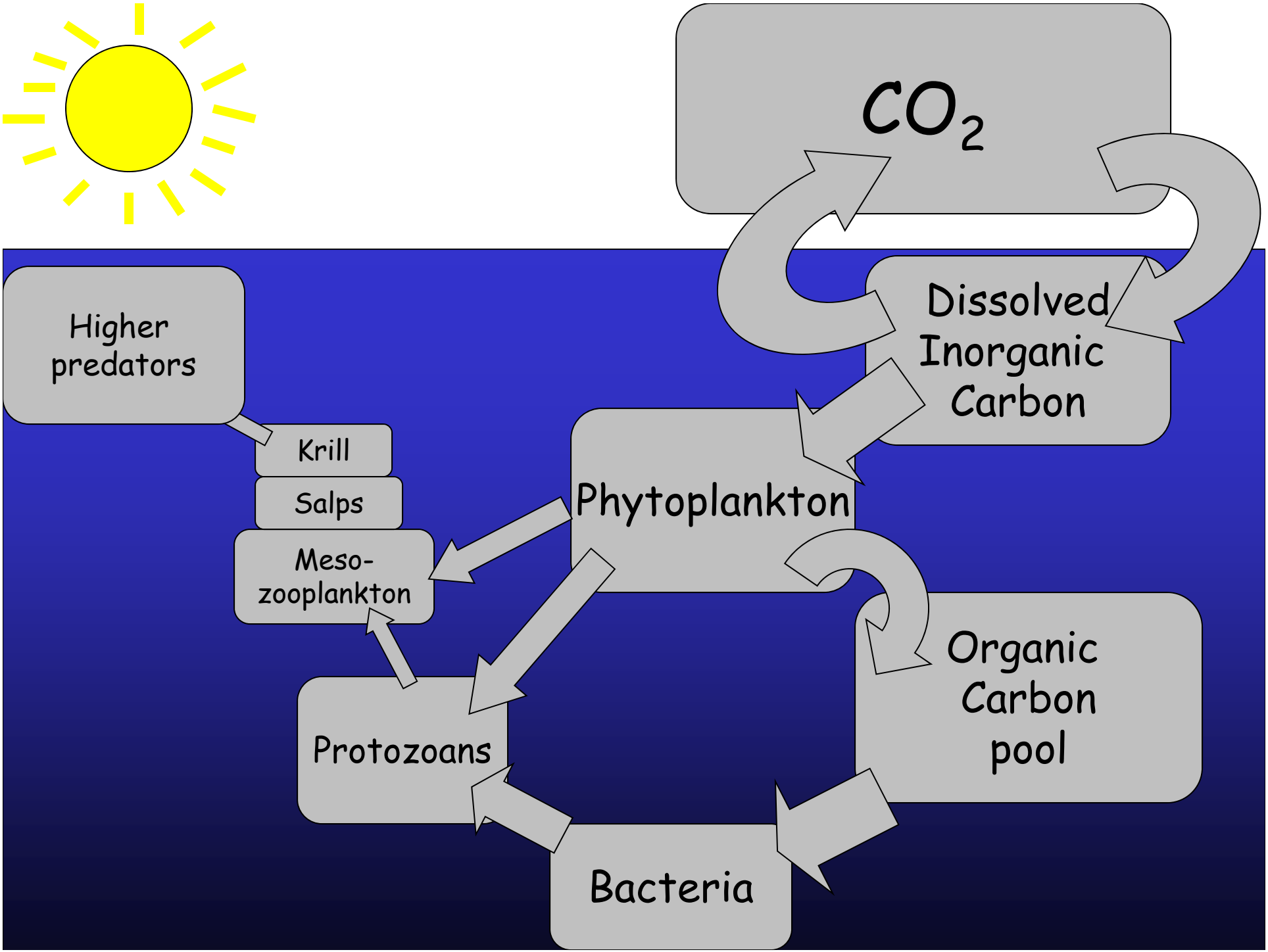
Estes et al 1998 Science



Top Down Control in the Southern Ocean?

Outline

- Role of Top Predators to Marine Ecosystems
  - Top Down Processes
  - Biogeochemical cycles
- Response to Environmental Variability
  - Modern
  - Holocene
- Defining habitat characteristics
- Predicting habitat change
- Using animals to measure a changing habitat
- Research Questions


CO_2
Dissolved Inorganic Carbon
Higher predators
Krill
Salps
Meso-zooplankton
Phytoplankton
Organic Carbon pool
Protozoans
Bacteria

Marine Mammals Fertilize the Ocean

icebergs flatulence whale excretion

Photo by Dr. Nick Gales, AAD

- Ocean is stratified
- Whales excrete waste at the surface
- Whale excretion is liquid and nutrient rich

Trish J Lavery, Laurent Seuront, James G Mitchell

Flinders University of South Australia

Present abundance of great whales in Southern and Indian Oceans

Species	Body mass (t)[2]	Abundance[2,3]	Biomass (t)
Blue whale	103	2,300	236,900
Pygmy blue wh			515,000
Fin whale			4,771,200
Sei whale			184,620
Brydes whale			1,424,000
Minke whale			5,327,000
Humpback wha			1,260,000
Southern right whale	23	7,500	172,500
Sperm whale	27	209,000	5,643,000
TOTAL		**1,211,860**	**19,534,220**

Prey consumption = 4% of body weight per day

Faecal nutrient content

Krill, Salps, Cephalopods[4,5,6,7]

N = 20 mg g^{-1}

Fe = 1 mg g^{-1}

Southern right whale

Consumes[8] 1 tonne d^{-1}

N = 20,000 g

Fe = 1,000 g

Excretes[9]

17,000 g N d^{-1}

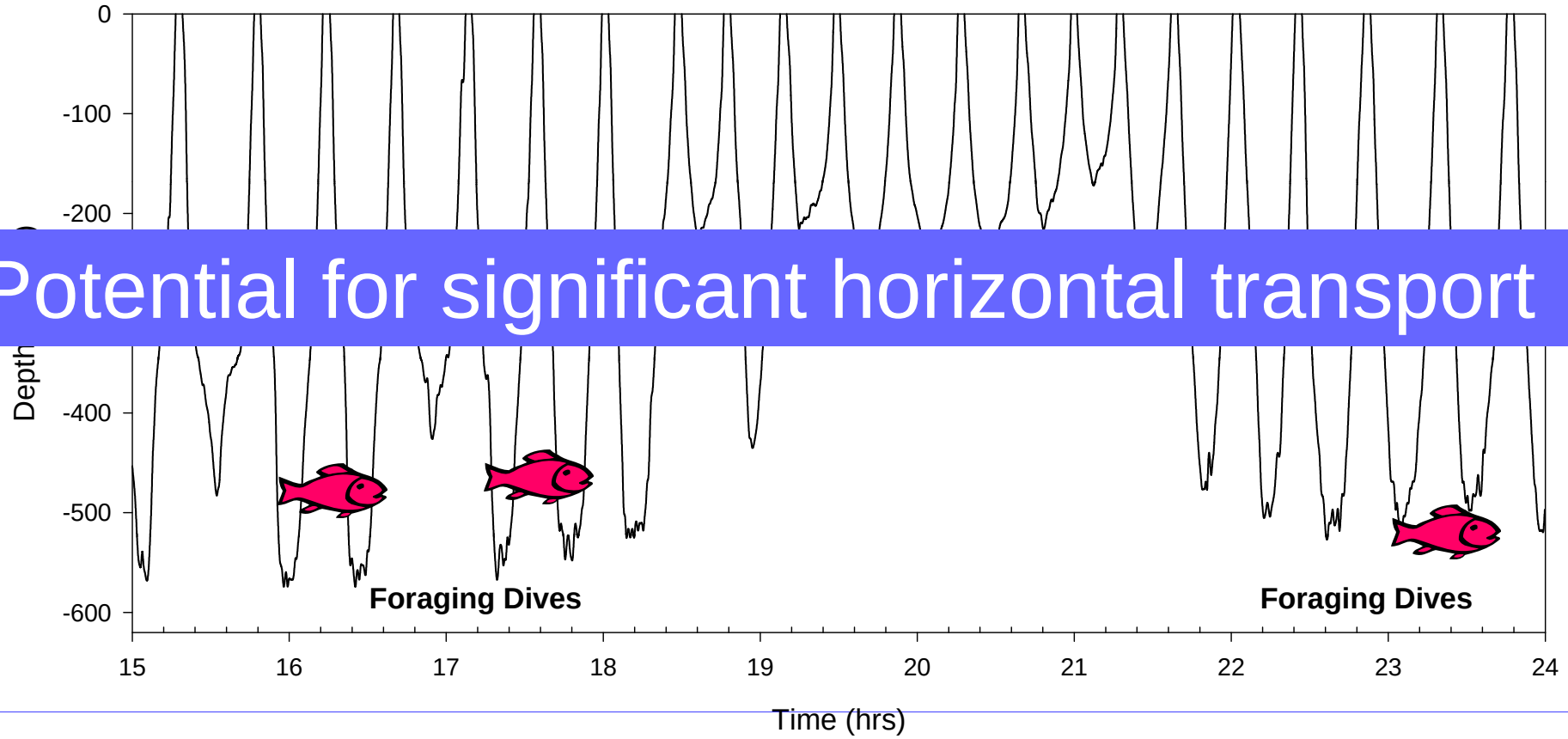
850 g Fe d^{-1}

20 million tonnes whales = 6,000,000 tonnes N $year^{-1}$

300,000 tonnes Fe $year^{-1}$

Vertically Transport Nutrients

Elephant Seal Diving Pattern

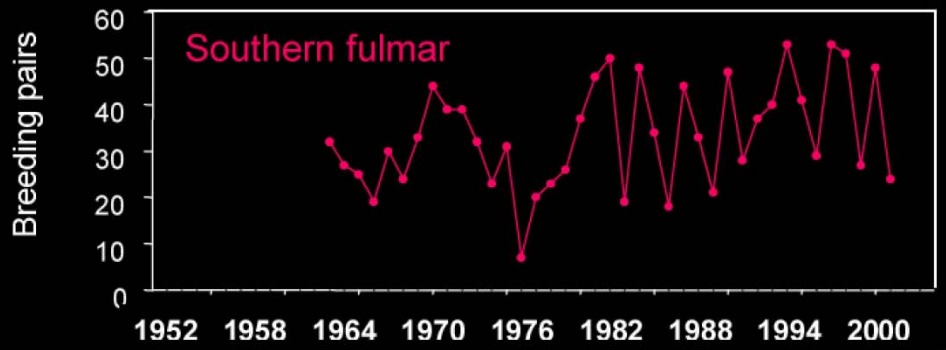


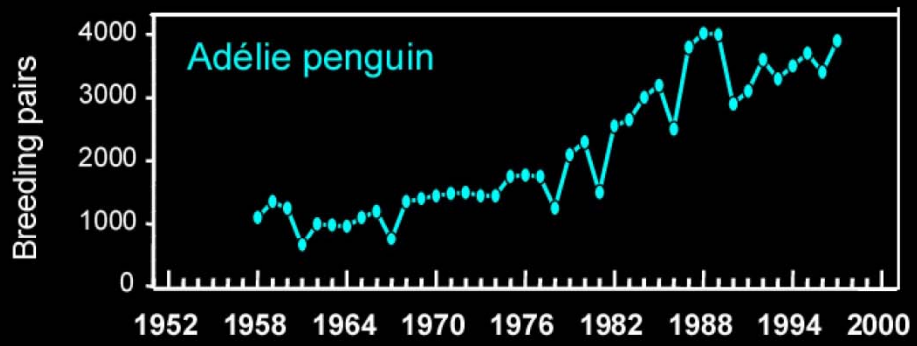
Potential for significant horizontal transport

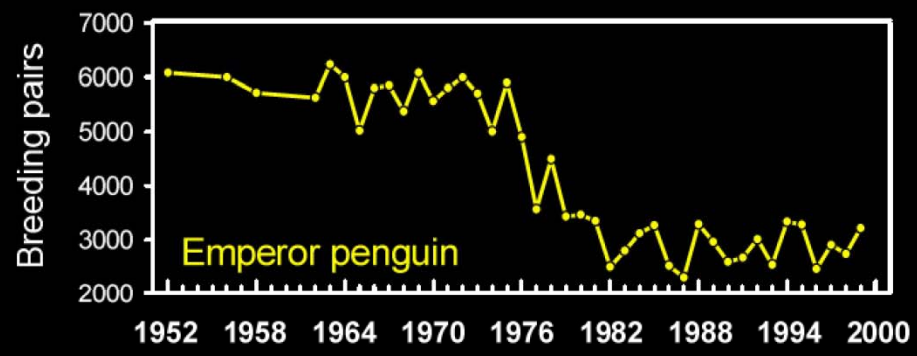
Outline

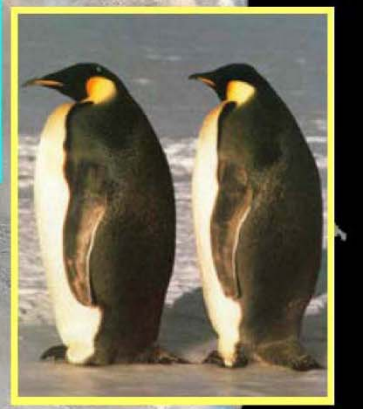
- Role of Top Predators to Marine Ecosystems
  - Top Down Processes
  - Biogeochemical cycles
- Response to Environmental Variability
  - Modern time series
  - Holocene
- Defining habitat characteristics
- Predicting habitat change
- Using animals to measure a changing habitat
- Research Questions

Colony Dynamics French Antarctic Bases

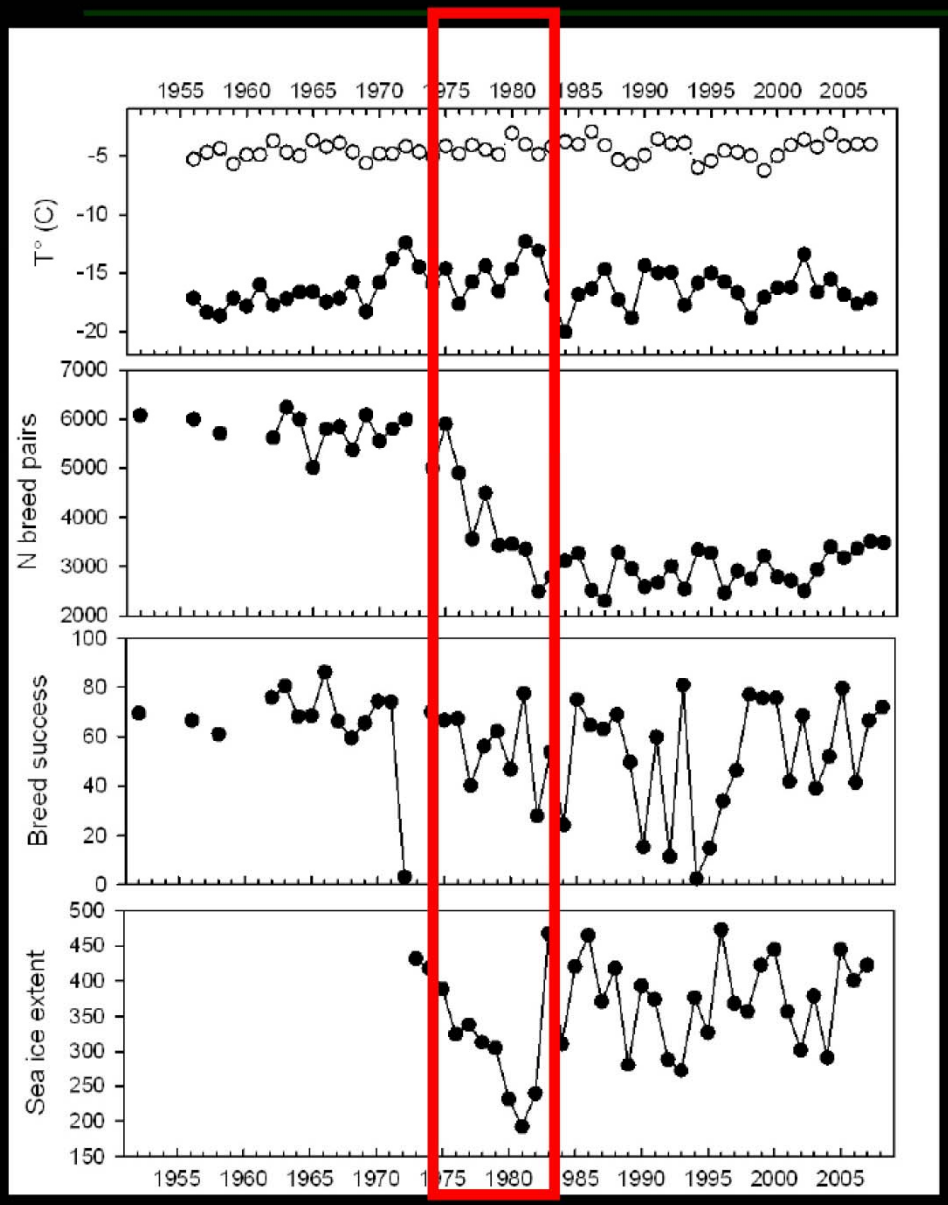


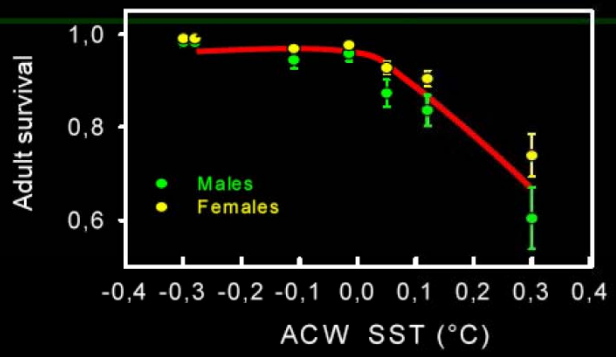


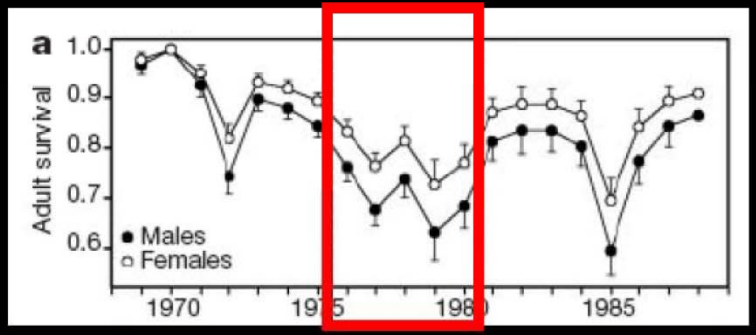


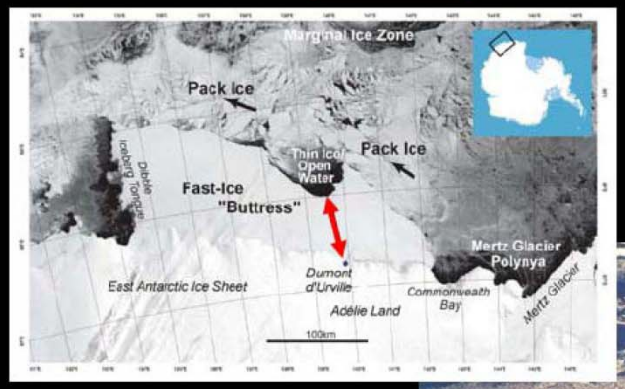


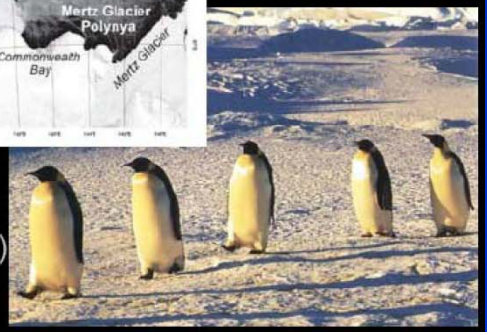
Emperor Penguin Demographic Changes







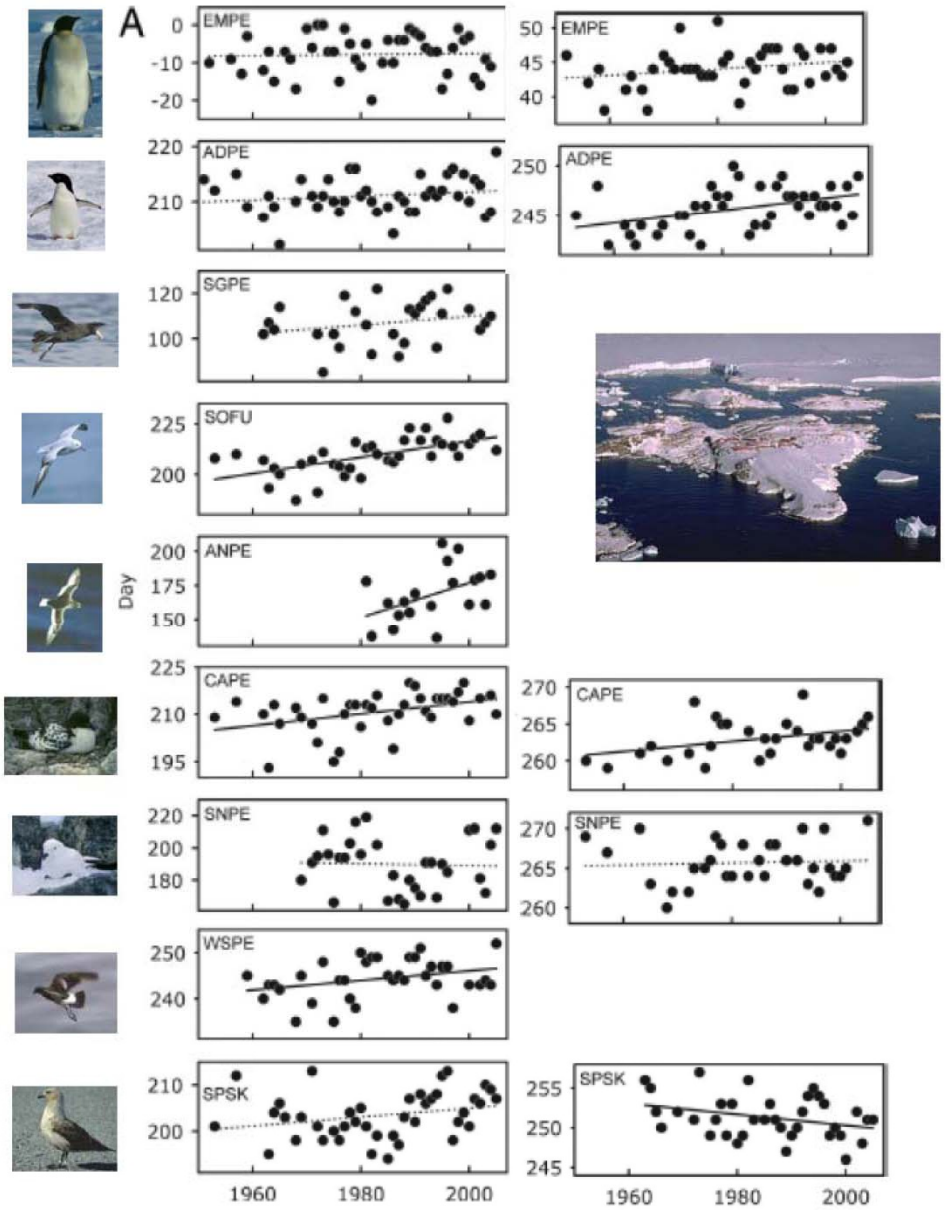


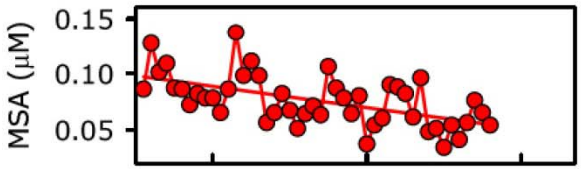


Barbraud & Weimerskirch (2001)
Massom et al. 2008

Phenological changes and sea ice extent

First arrival Egg laying



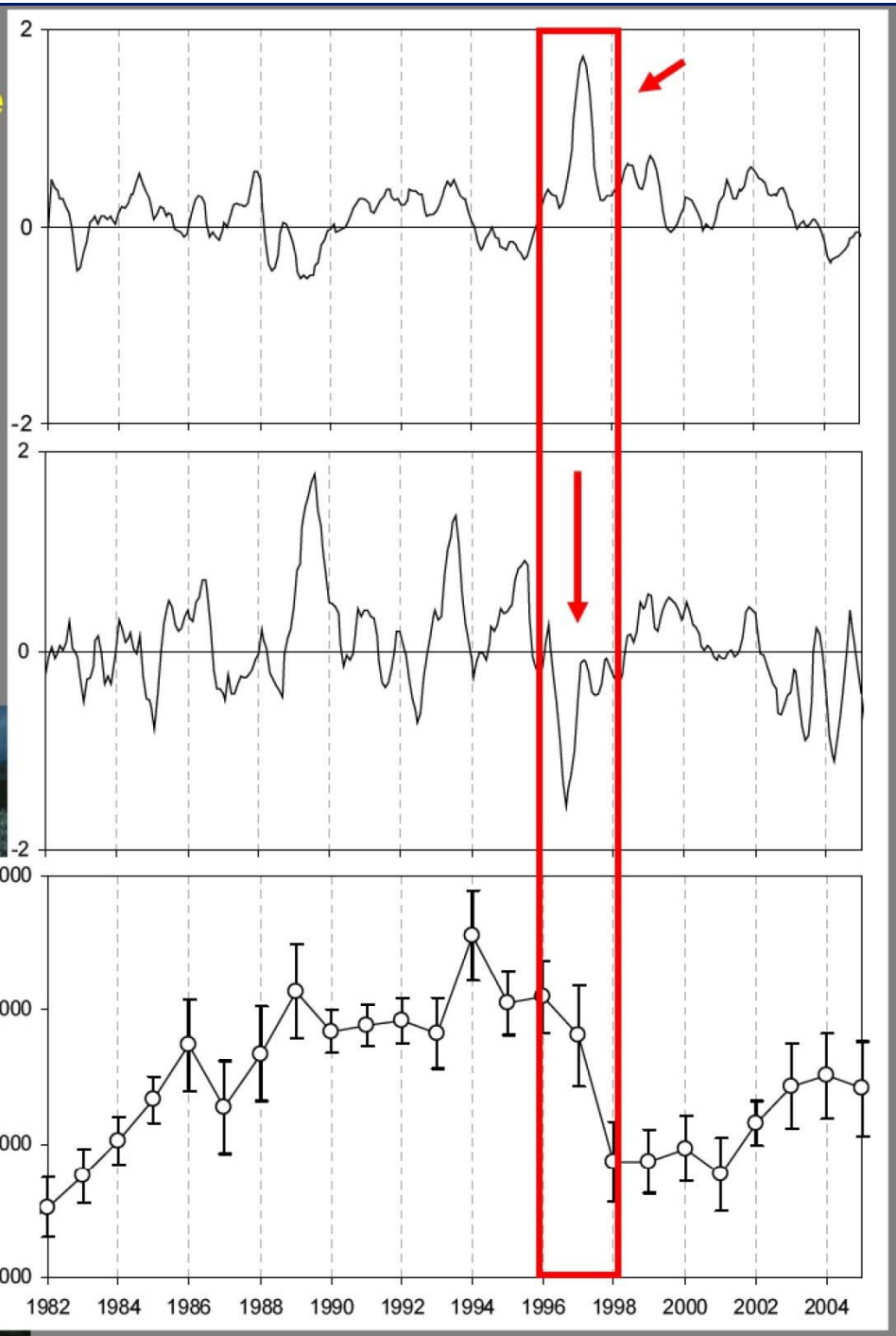


Decrease in sea ice extent

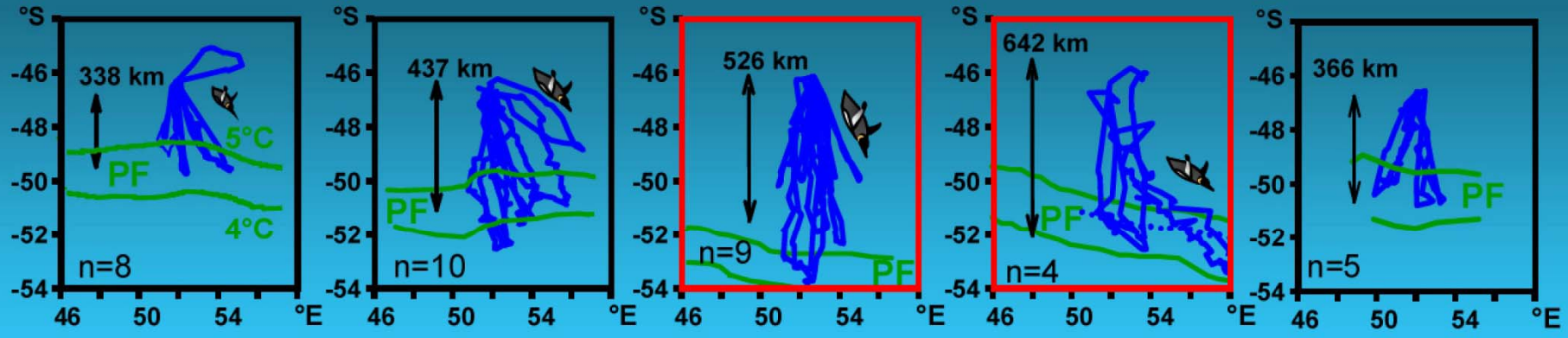
Barbraud & Weimerskirch PNAS (2006)

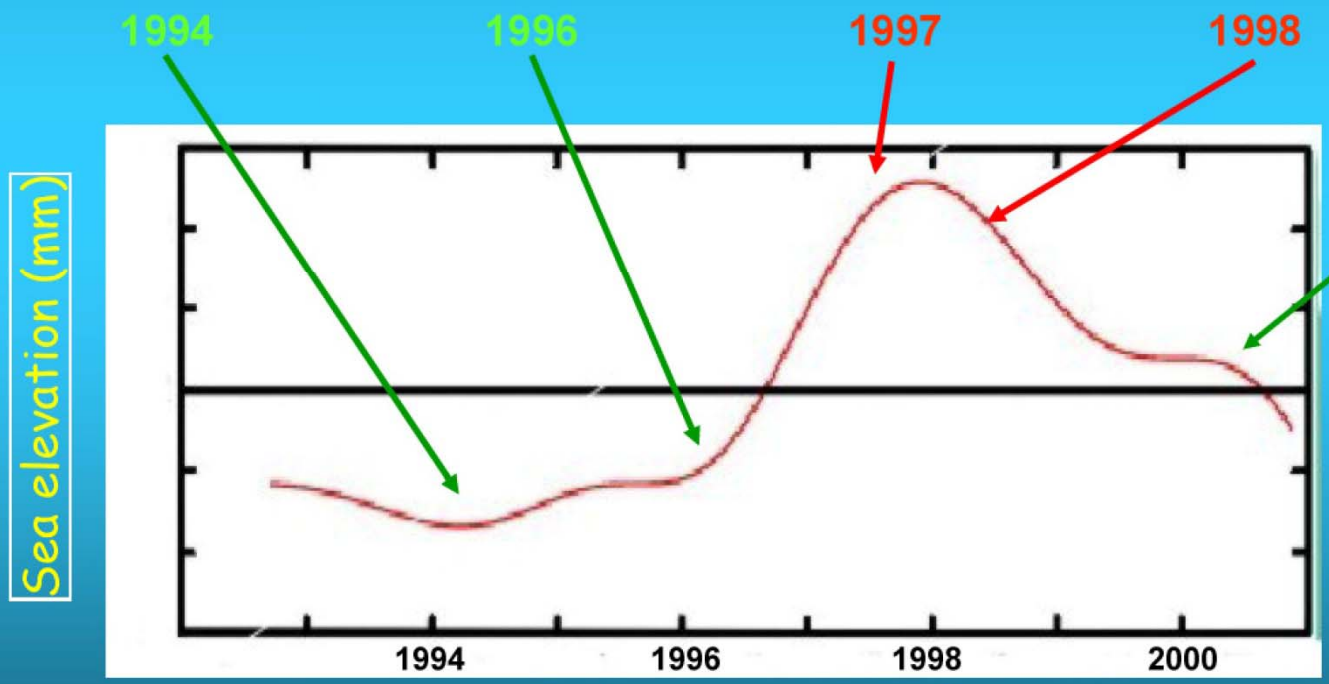
Sea surface temperature anomaly (°C)

Sea ice extent anomaly (°C) (35-65°E)



Inter annual changes: effects on at-sea distribution of king penguins





Inter annual changes in Sea elevation

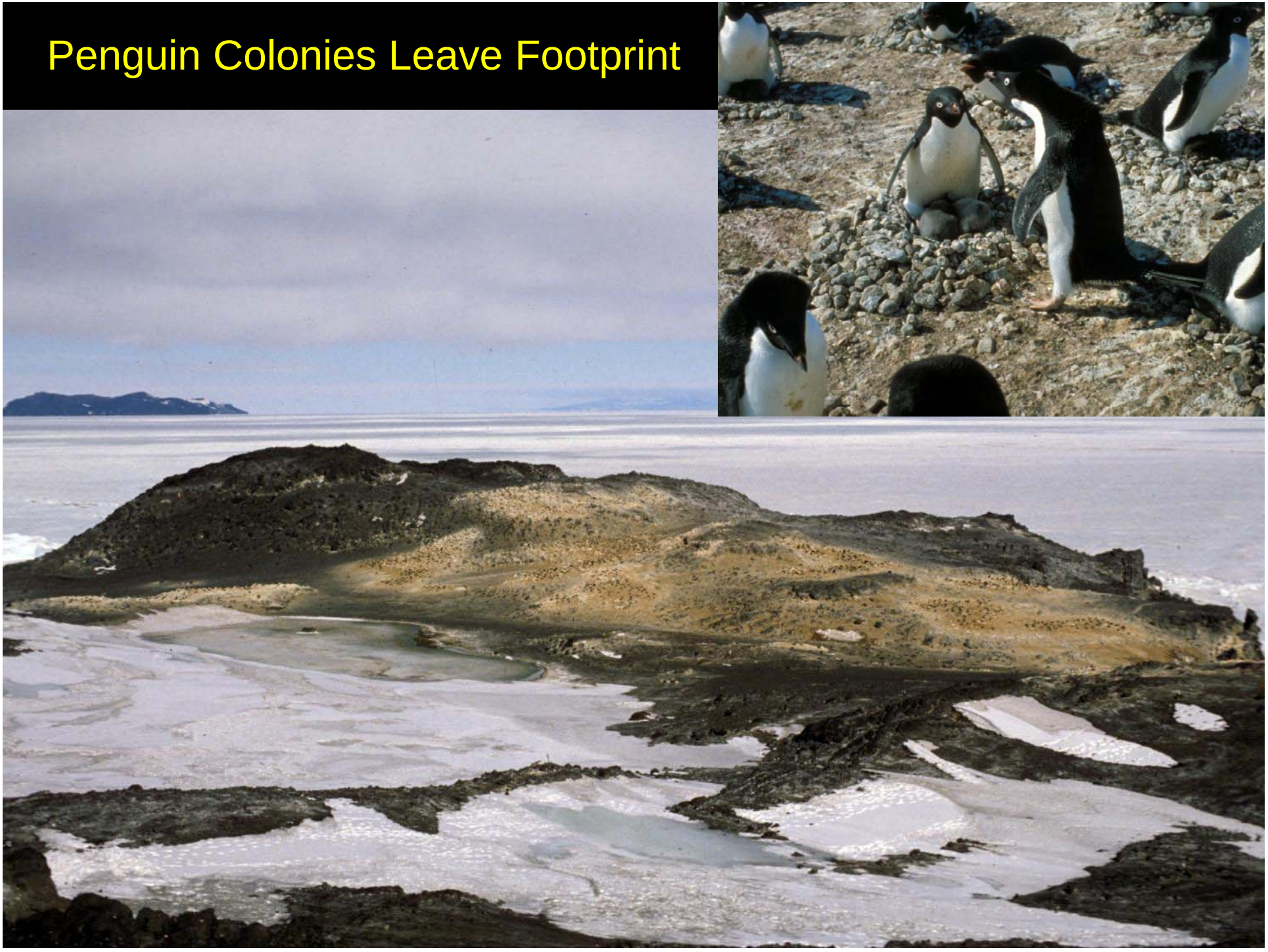
(South Indian Ocean)

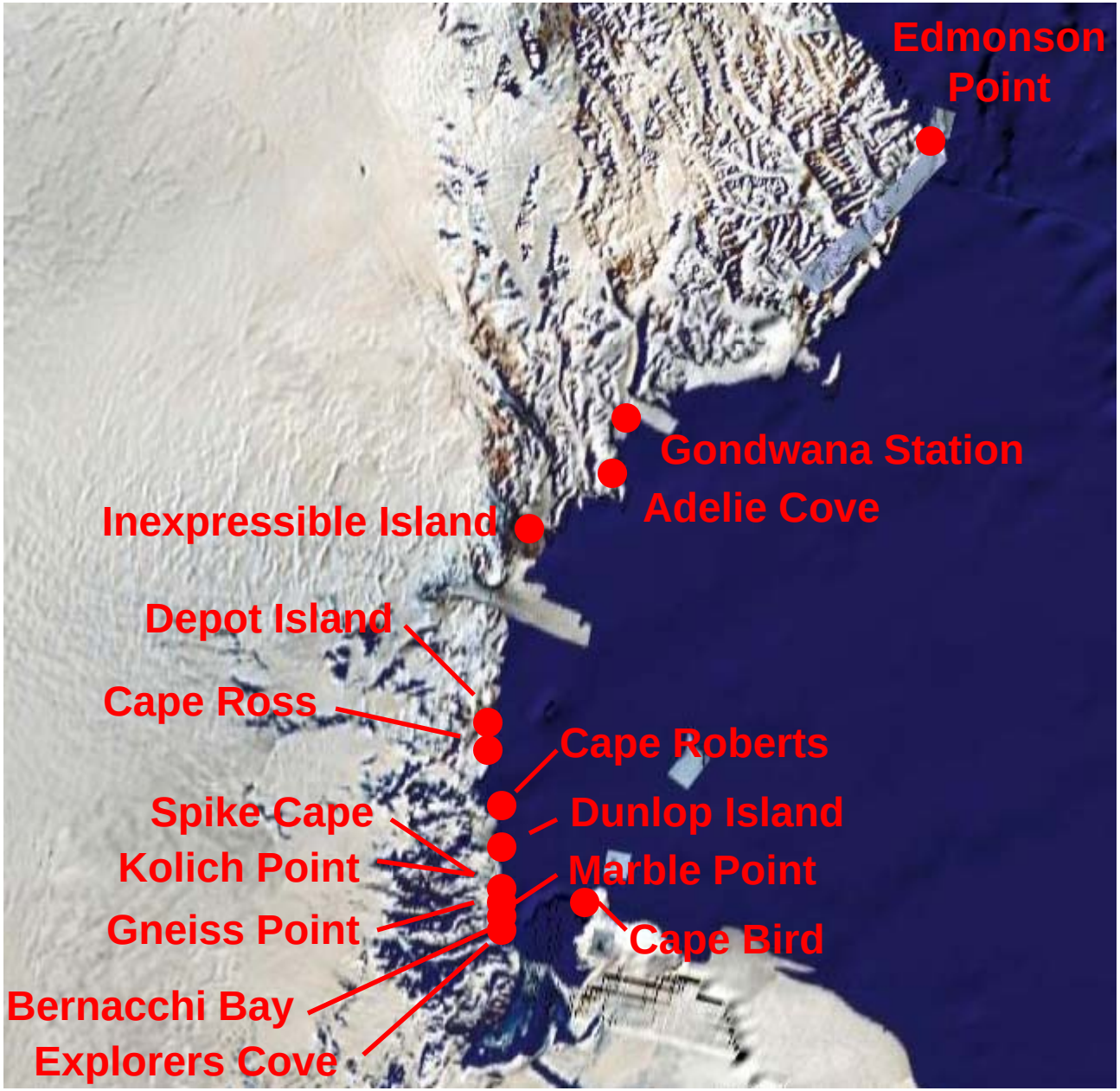
From Bost et al., in prep

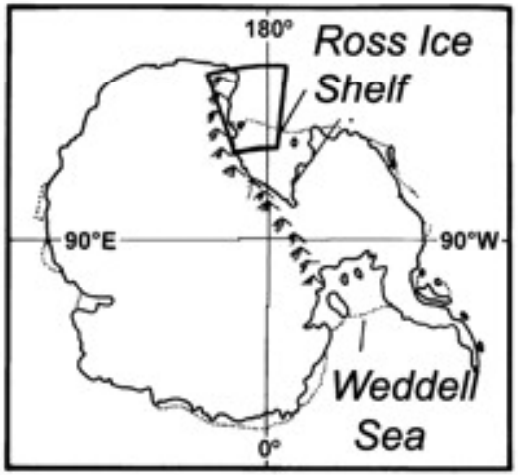
Outline

- Role of Top Predators to Marine Ecosystems
  - Top Down Processes
  - Biogeochemical cycles
- Response to Environmental Variability
  - Modern time series
  - Holocene
- Defining habitat characteristics
- Predicting habitat change
- Using animals to measure a changing habitat
- Research Questions

Penguin Colonies Leave Footprint

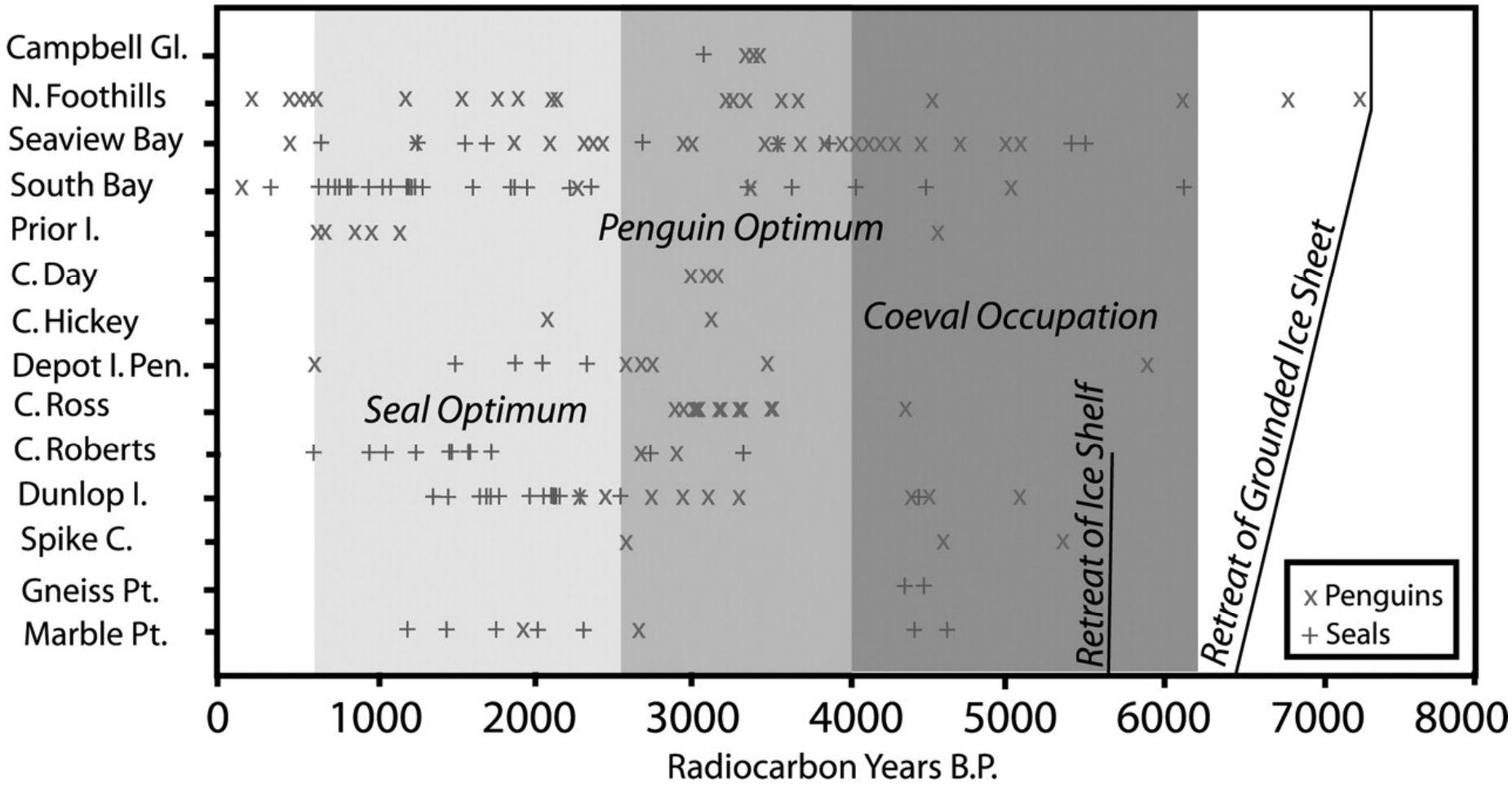






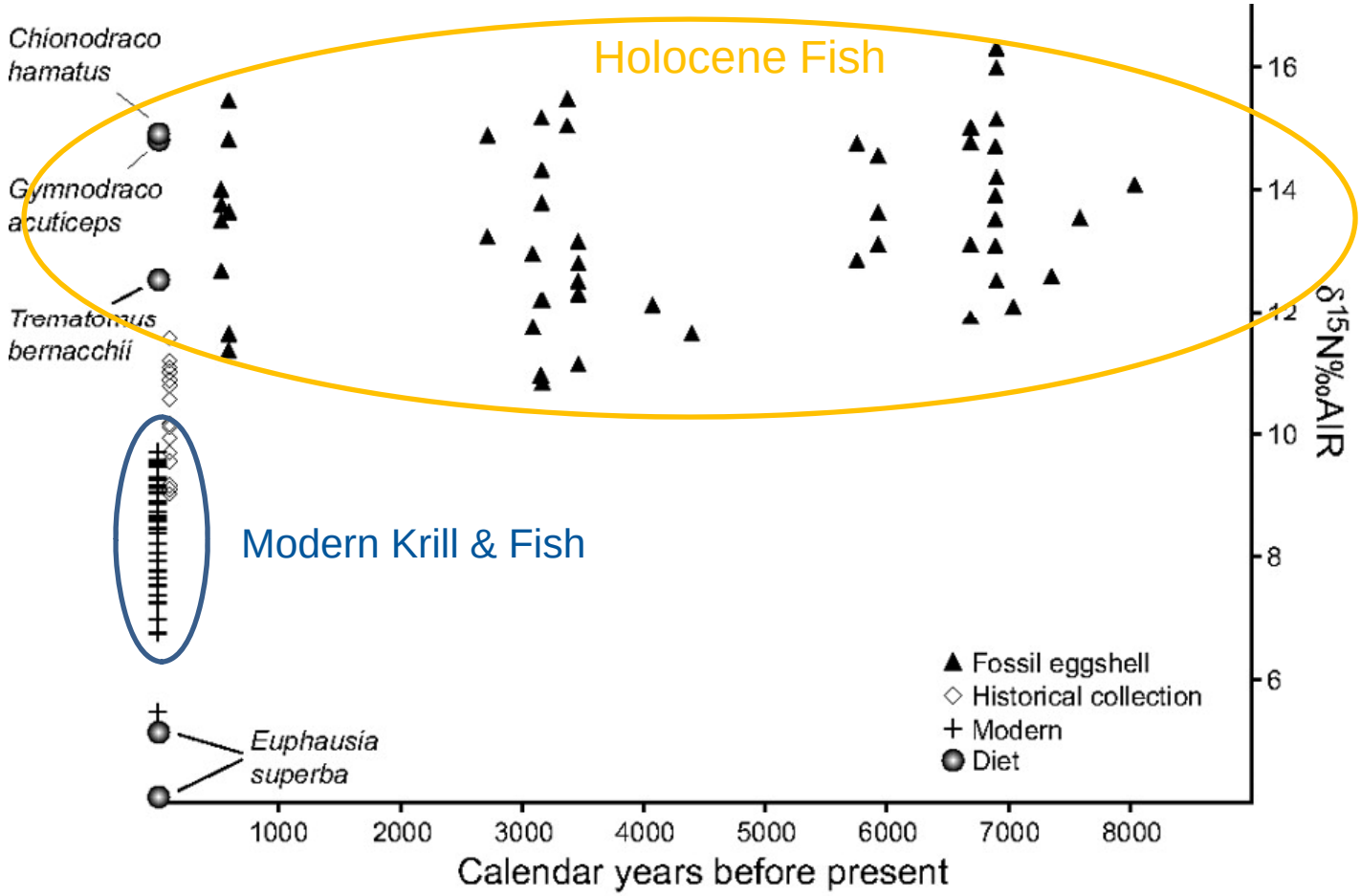
Paul Koch, U. C. Santa Cruz, Brenda Hall, Univ. of Maine,
Carlo Baroni, Univ. di Pisa, Maria C. Salvatore, Univ. di Roma

Diagram showing the distribution of radiocarbon dates for elephant seal (“+”) and Adélie penguin (“×”) samples from each site listed from south (bottom) to north (top).



Hall B. L. et.al. PNAS 2006;103:10213-10217

An ~8,000 year record of $\delta^{15}N$ values of Adélie penguin eggshell from Antarctica



Emslie and Patterson (2007) PNAS

Outline

- Role of Top Predators to Marine Ecosystems
  - Top Down Processes
  - Biogeochemical cycles
- Response to Environmental Variability
  - Modern time series
  - Holocene
- Defining habitat characteristics
- Predicting habitat change
- Using animals to measure a changing habitat
- Research Questions

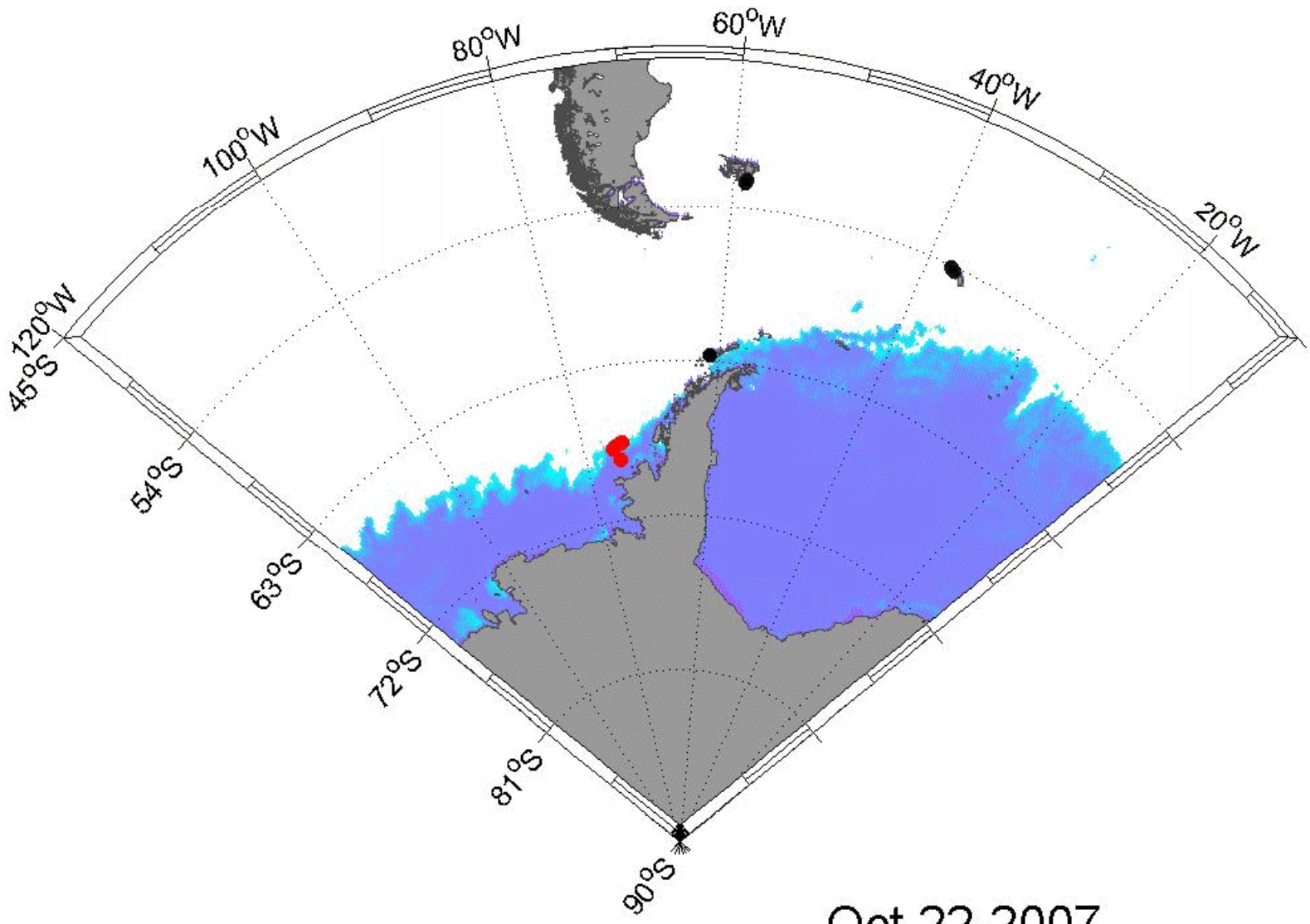
Habitat Utilization of Three Antarctic Seals

Elephant seal

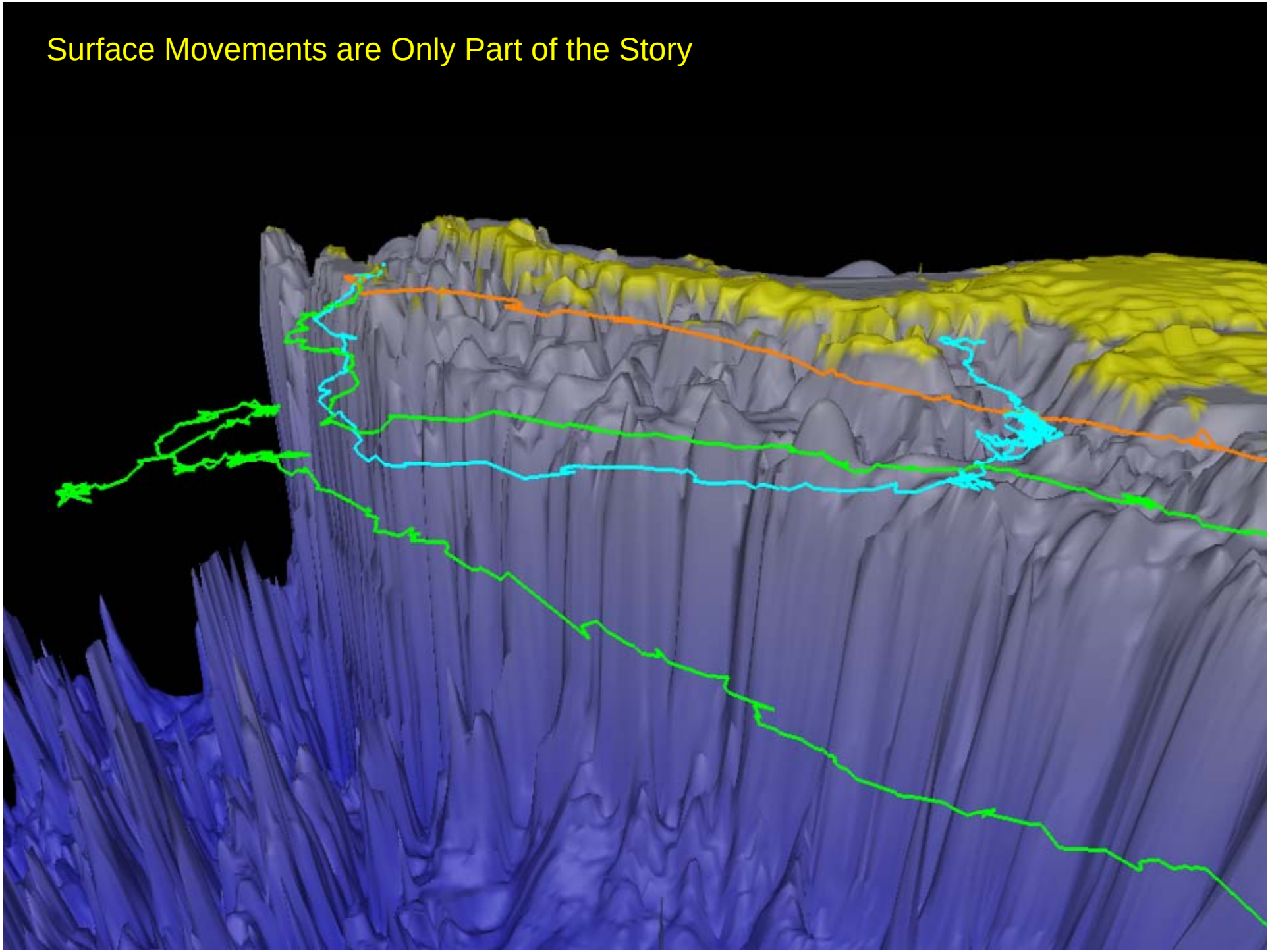
Crabeater seal

Weddell seal

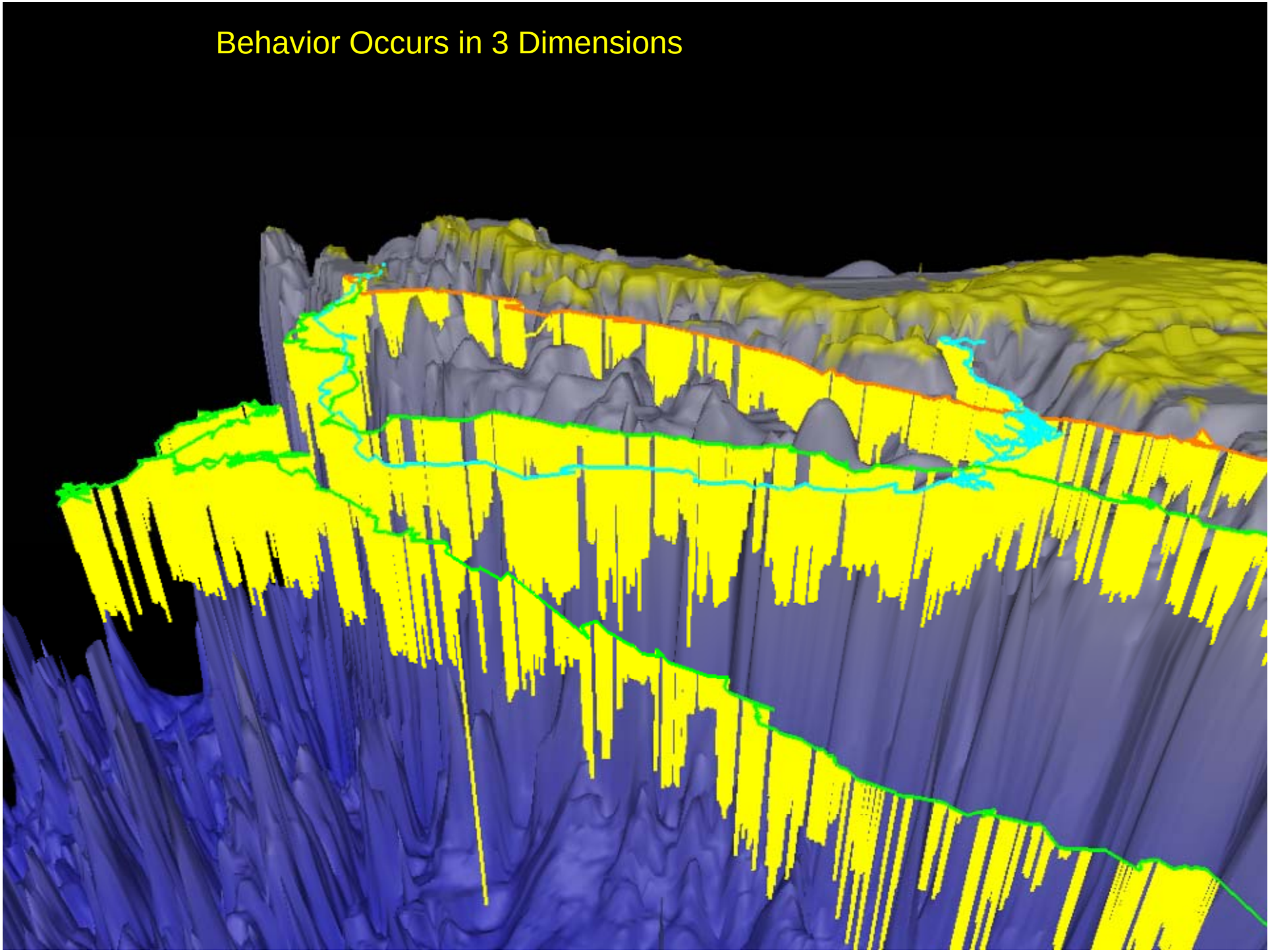
Animation


120°W
100°W
80°W
60°W
40°W
20°W
45°S
54°S
63°S
72°S
81°S
90°S
Oct-22-2007

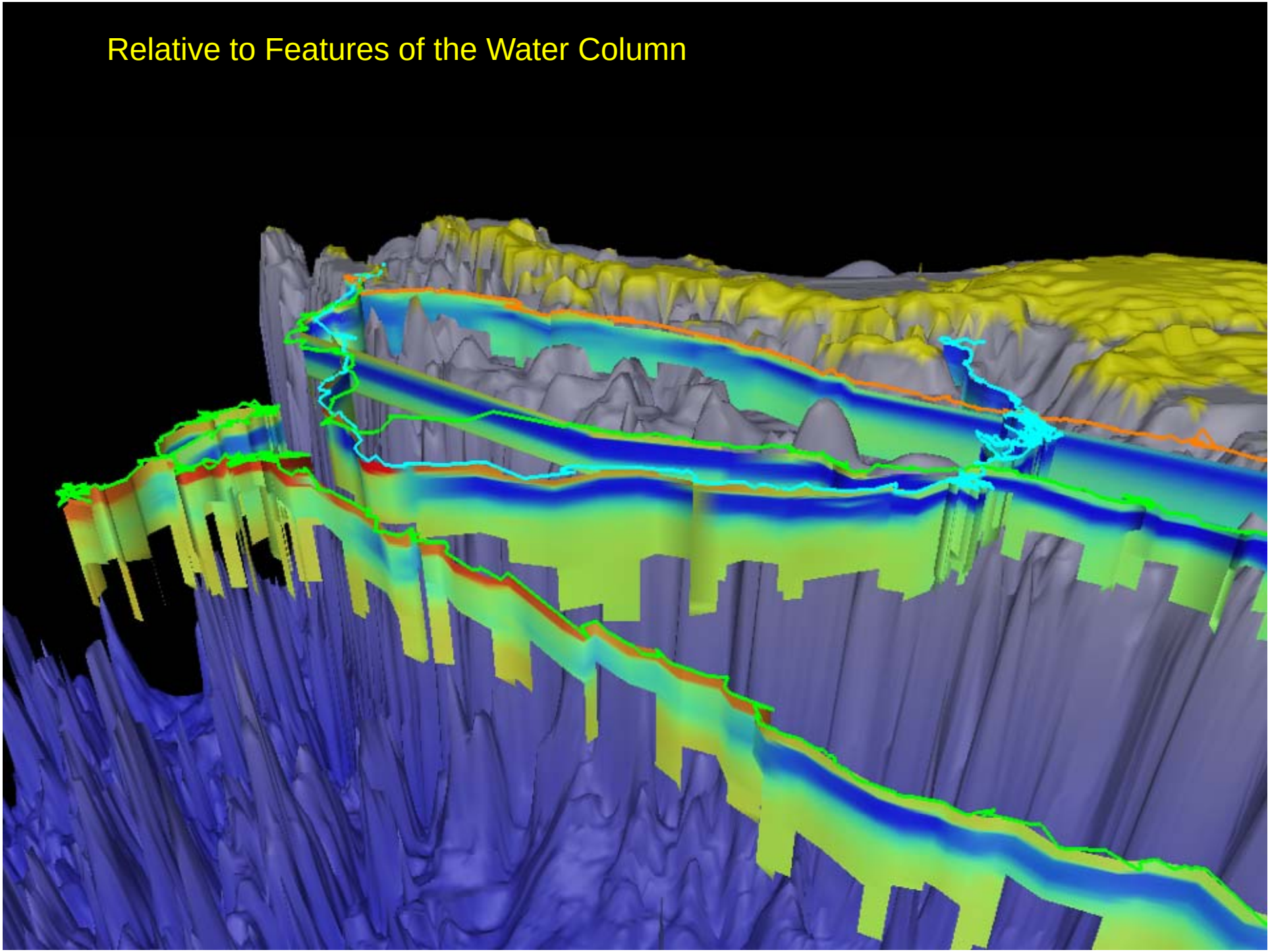
Surface Movements are Only Part of the Story

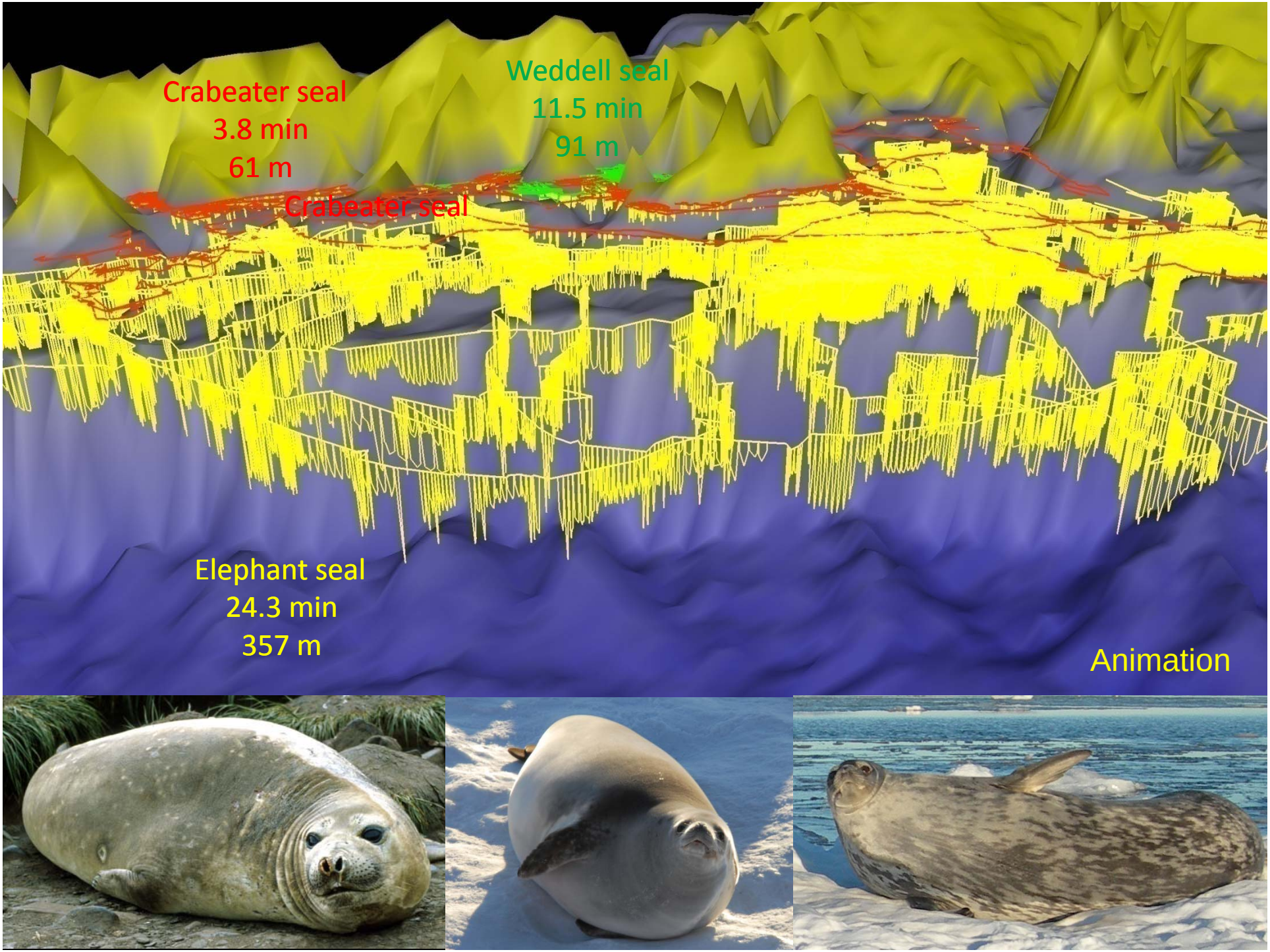


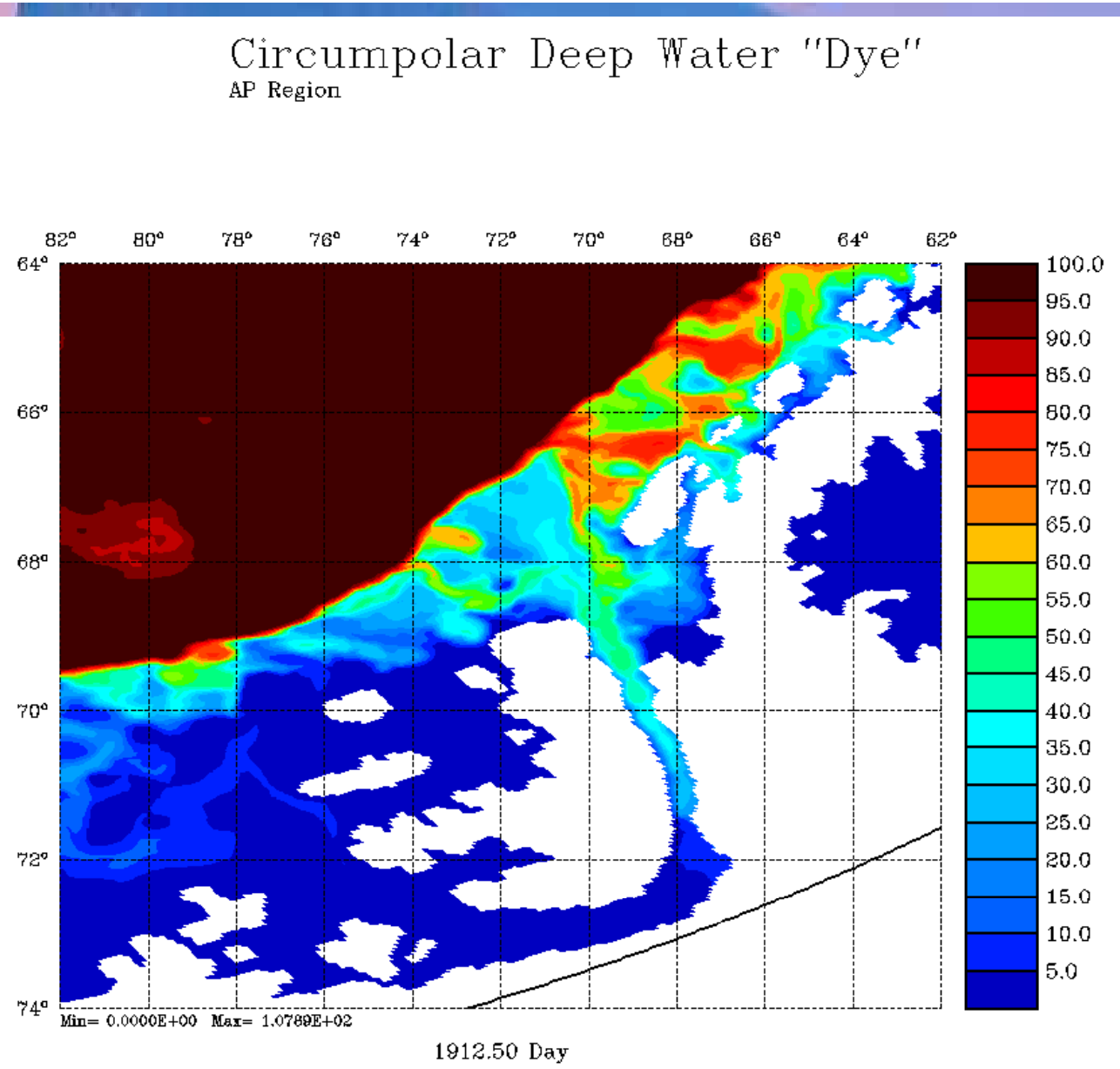
Behavior Occurs in 3 Dimensions



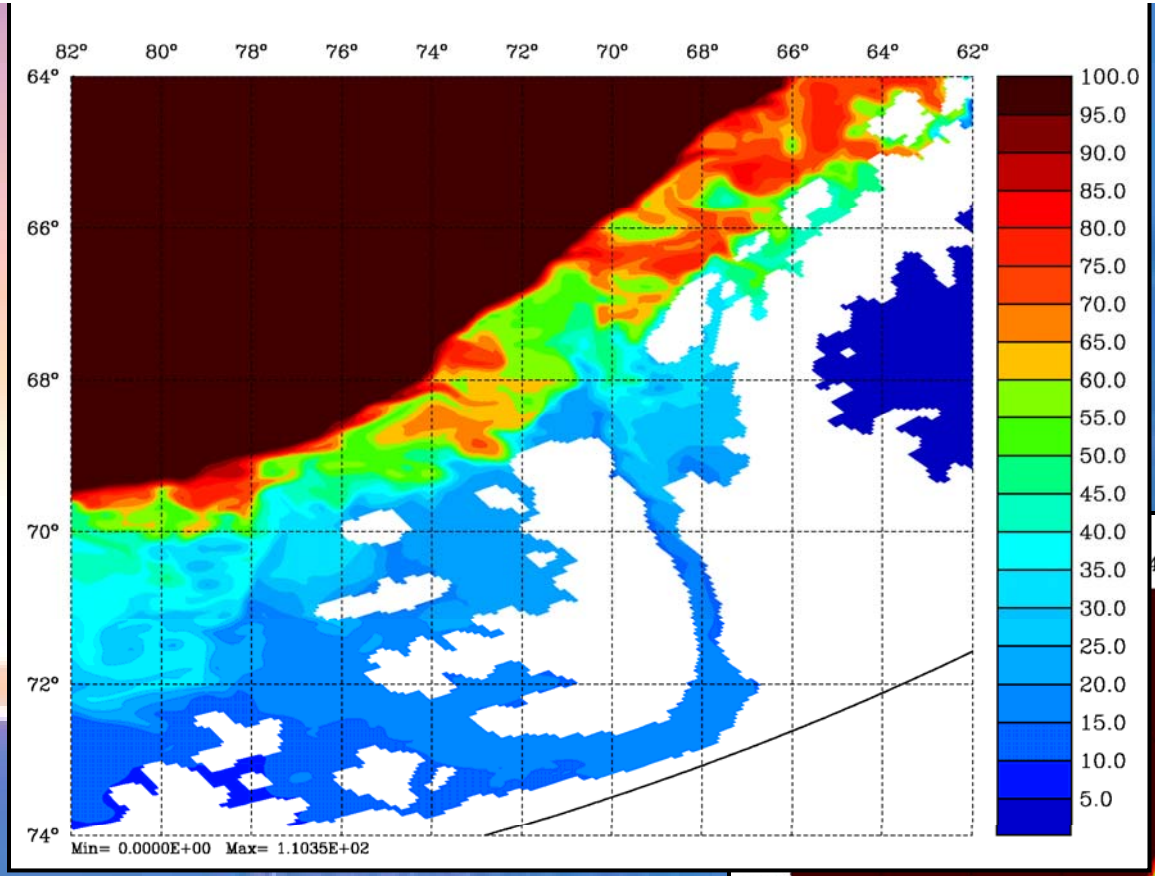
Relative to Features of the Water Column



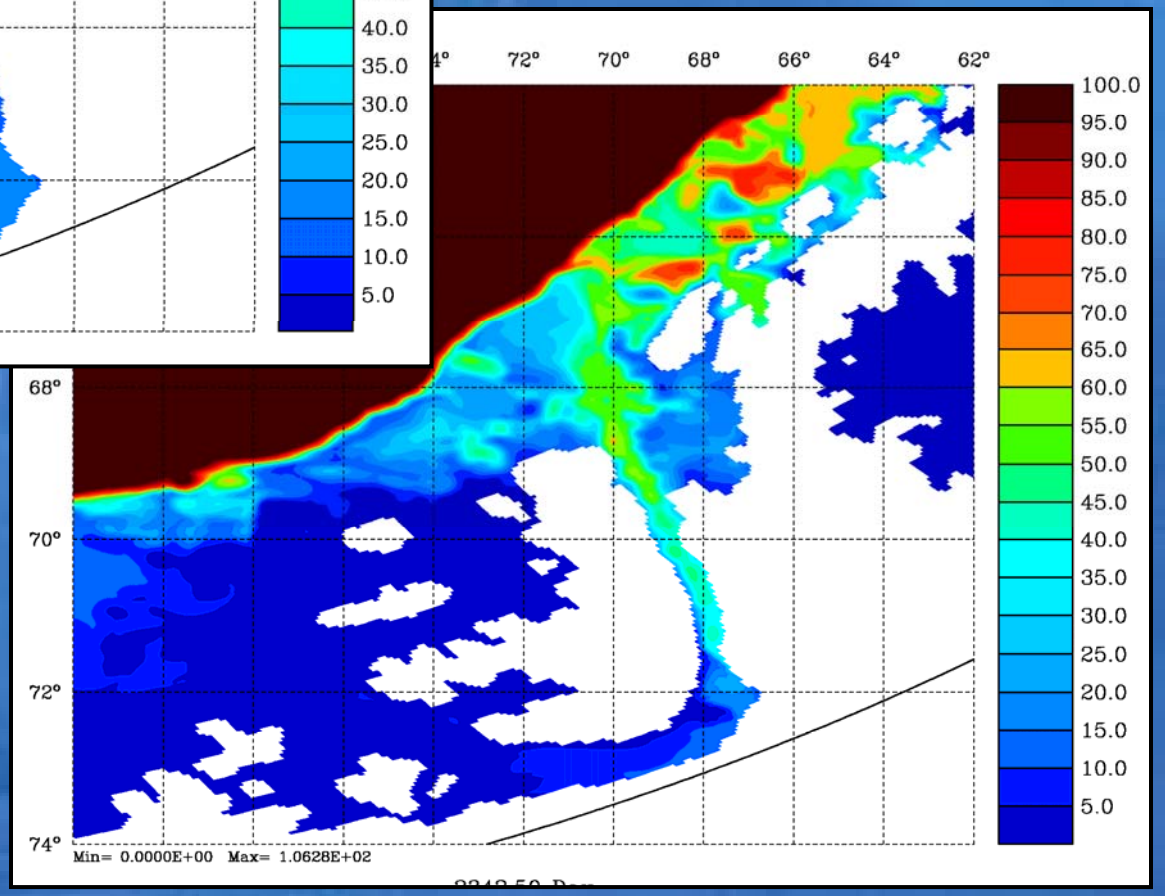

Crabeater seal
3.8 min
61 m
Weddell seal
11.5 min
91 m
Crabeater seal
Elephant seal
24.3 min
357 m
Animation



Dye distribution for current conditions - February
Level of CDW (210-420 m)



50% increase in wind speed

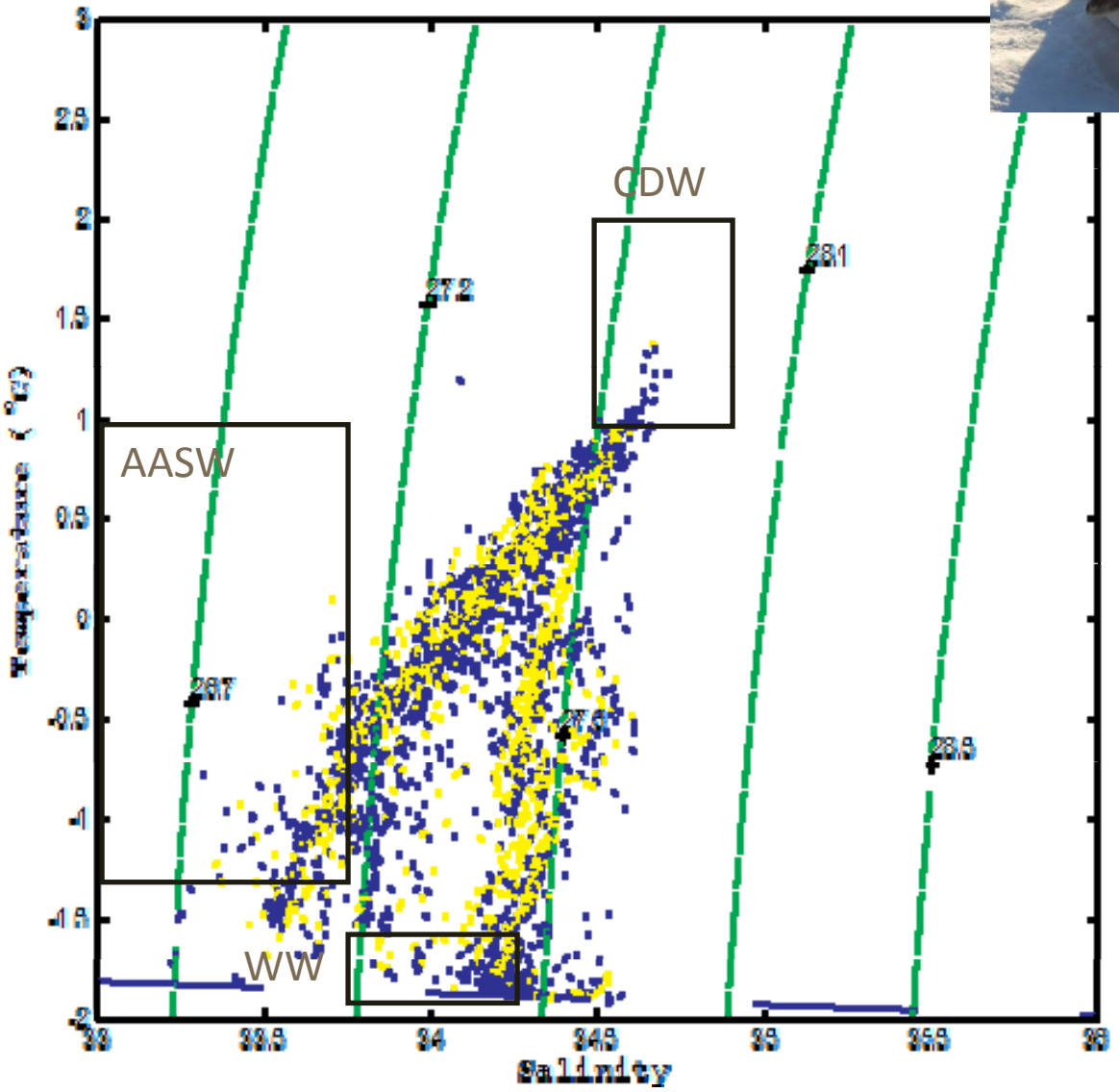


20% decrease in wind speed

ARS zones and Water Masses
Crabeater Seals



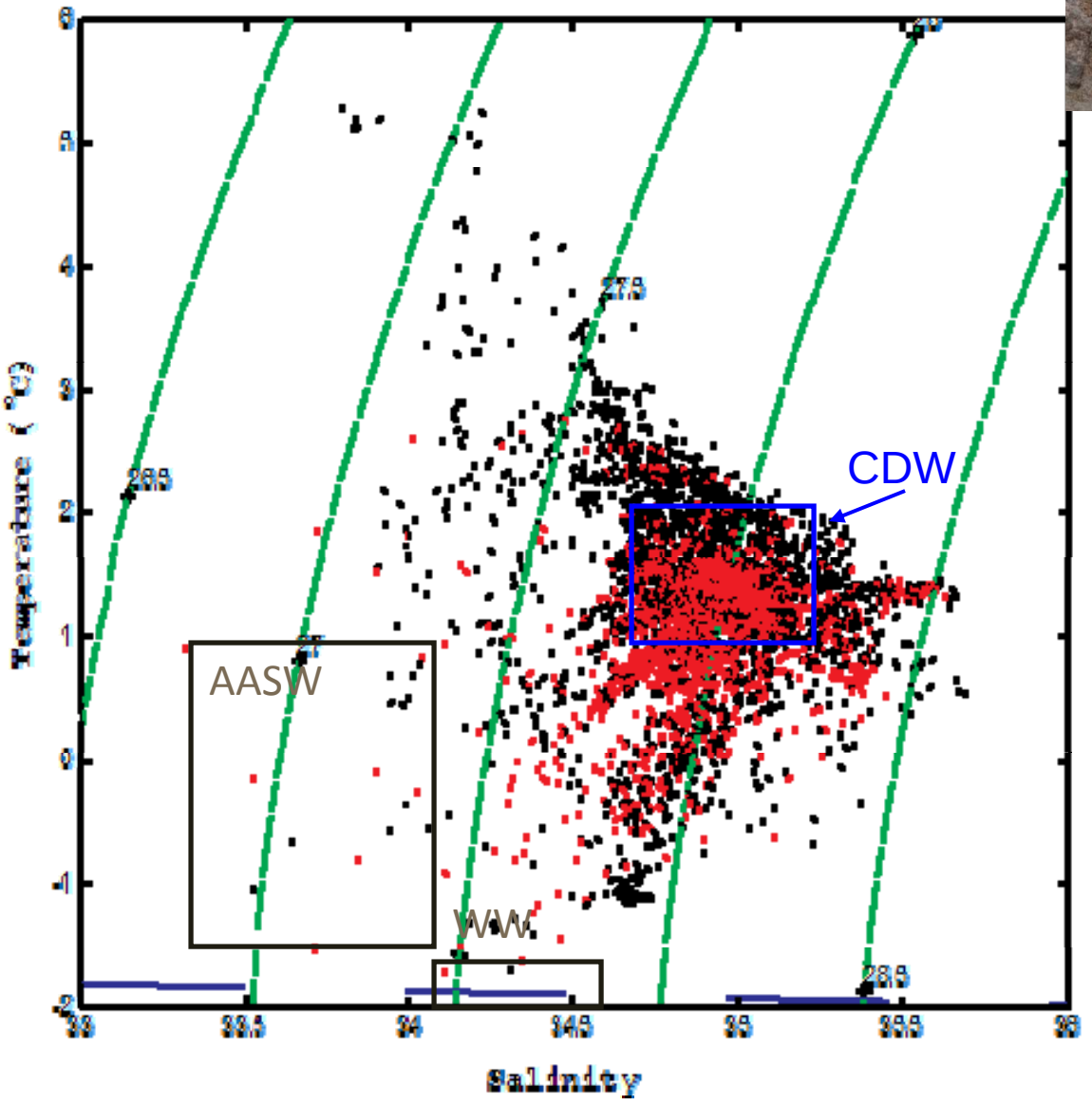


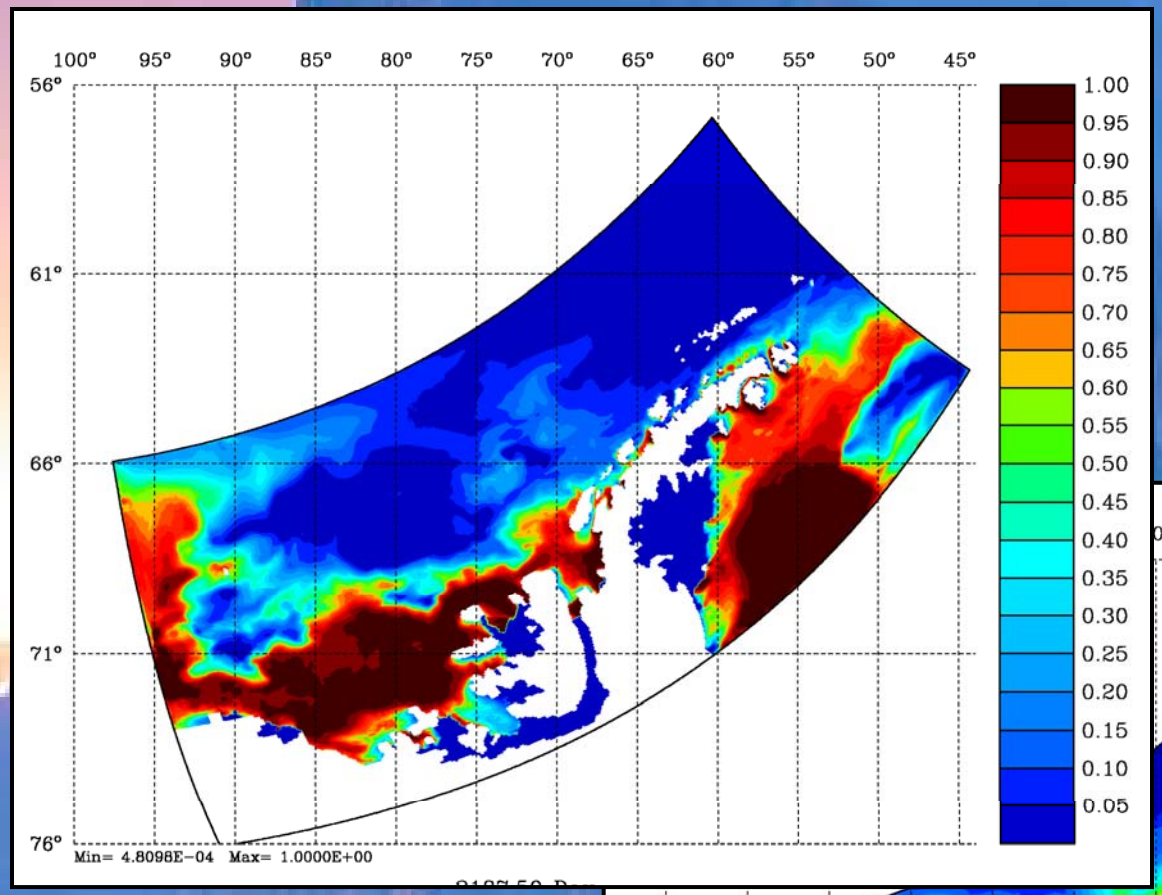



ARS zones – Mixed Layer Depth
Southern Elephant Seals



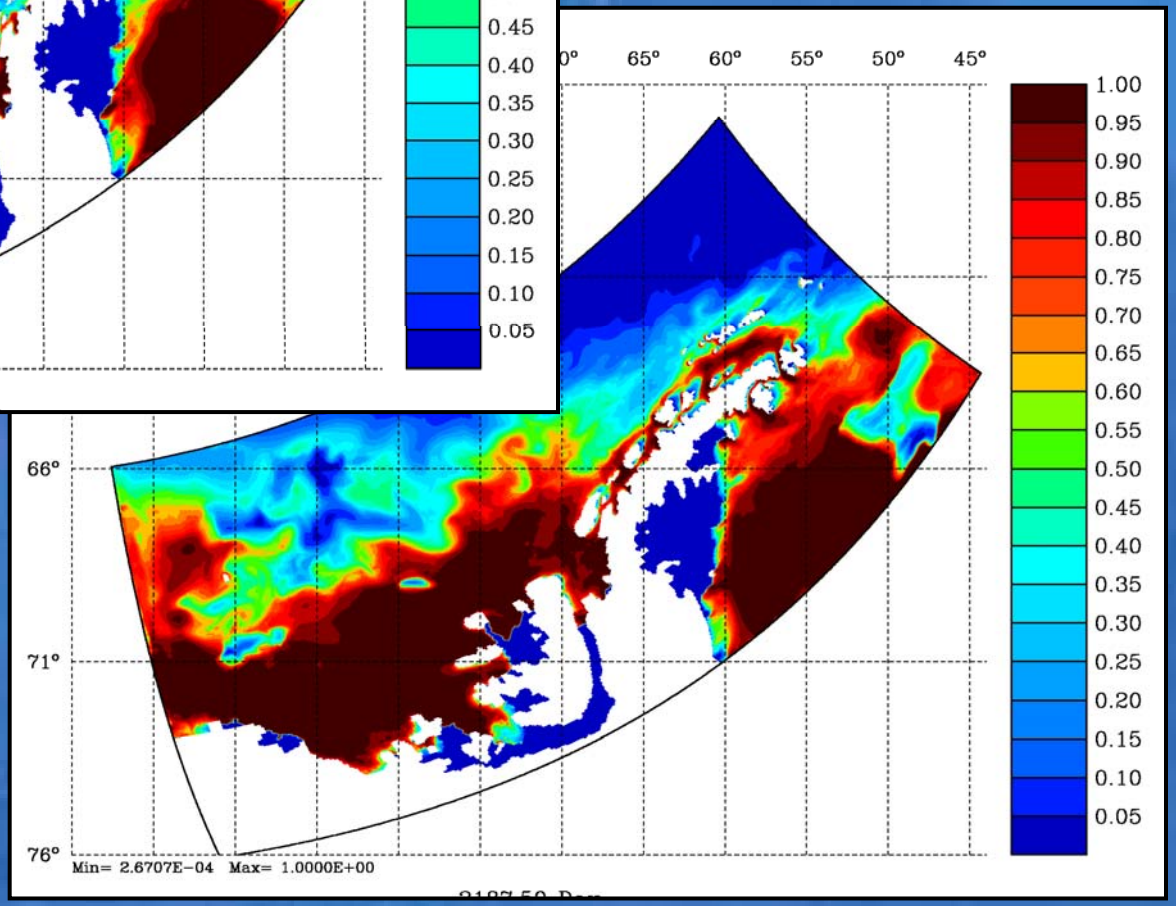




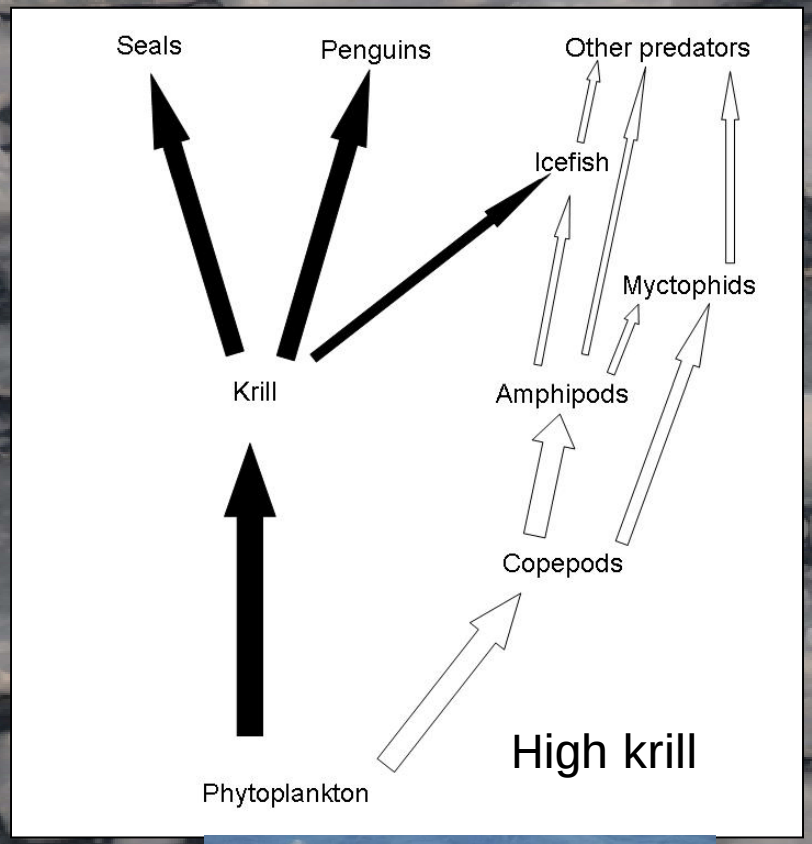
Winter sea ice distribution

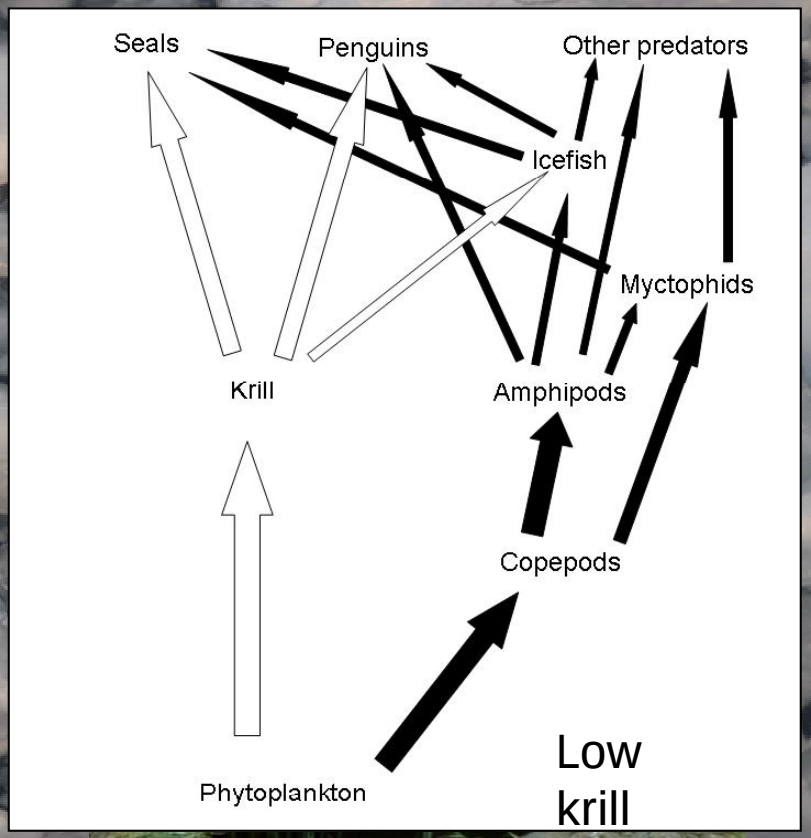
50% increase in wind speed



Current conditions

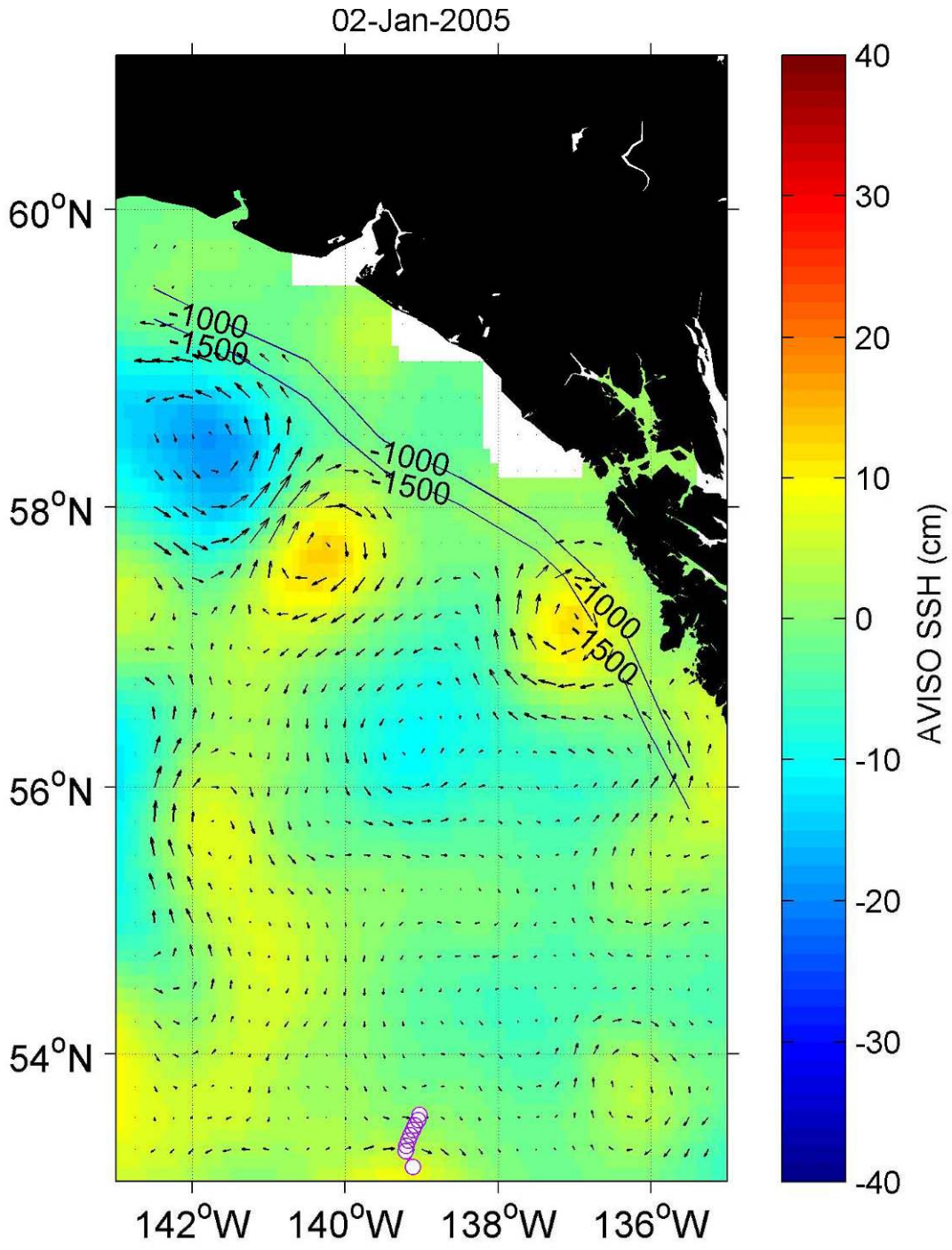
Alternative Food Web Pathways

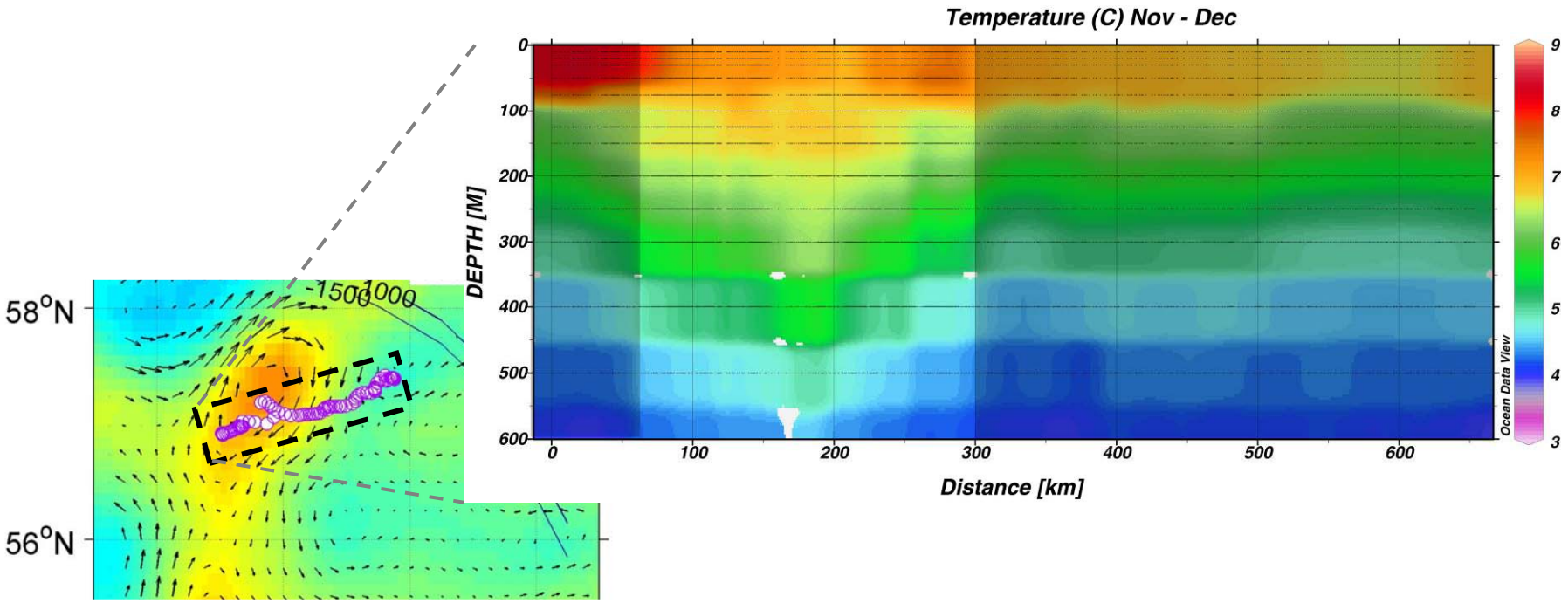




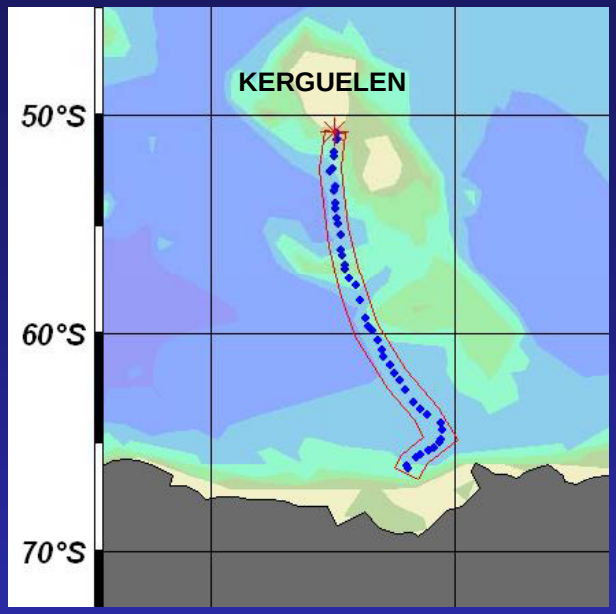
Outline

- Role of Top Predators to Marine Ecosystems
  - Top Down Processes
  - Biogeochemical cycles
- Response to Environmental Variability
  - Modern time series
  - Holocene
- Defining habitat characteristics
- Predicting habitat change
- Using animals to measure a changing habitat
- Research Questions

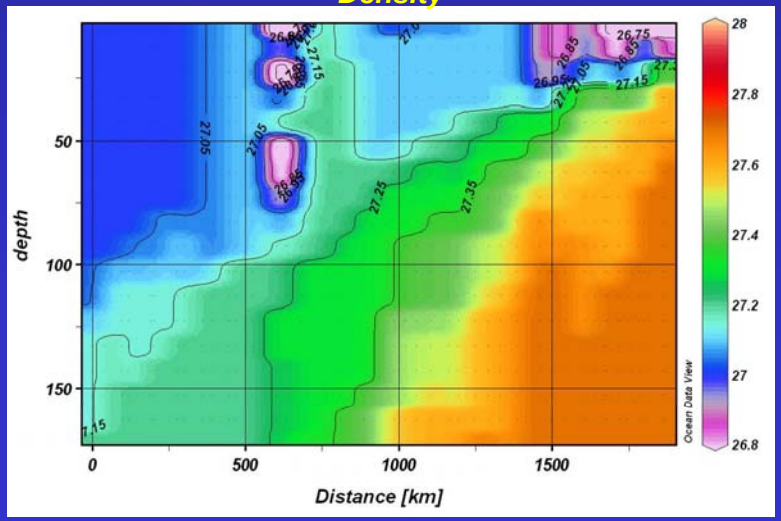

02-Jan-2005
60°N
58°N
56°N
54°N
142°W
140°W
138°W
136°W
-1000
-1500
-1000
-1500
-1000
-1500
40
30
20
10
0
-10
-20
-30
-40
AVISO SSH (cm)


Temperature (C) Nov - Dec
DEPTH [M]
0
100
200
300
400
500
600
Distance [km]
0
100
200
300
400
500
600
9
8
7
6
5
4
3
Ocean Data View
58°N
56°N
-1500
-1000

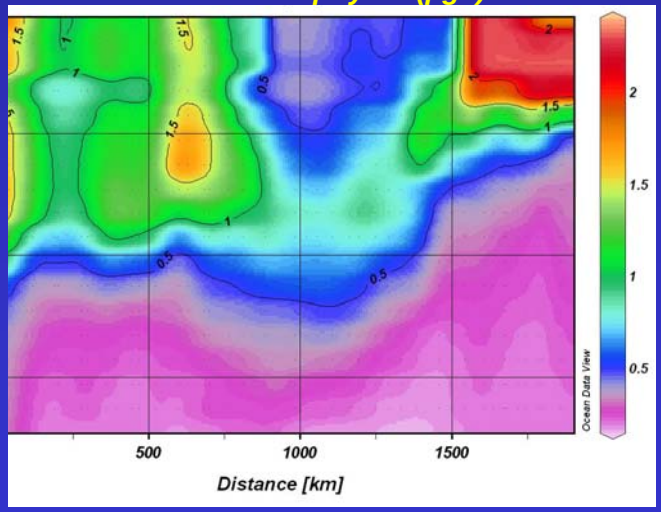
SMRU CTD-Fluorescence Tag



Density



Chlorophyll-a (µg/l)



Guinet *et al.* in prep

Merging Datasets

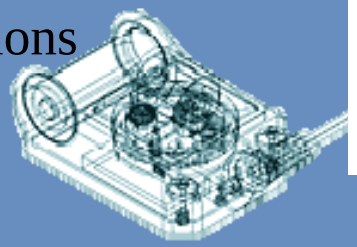
Argo

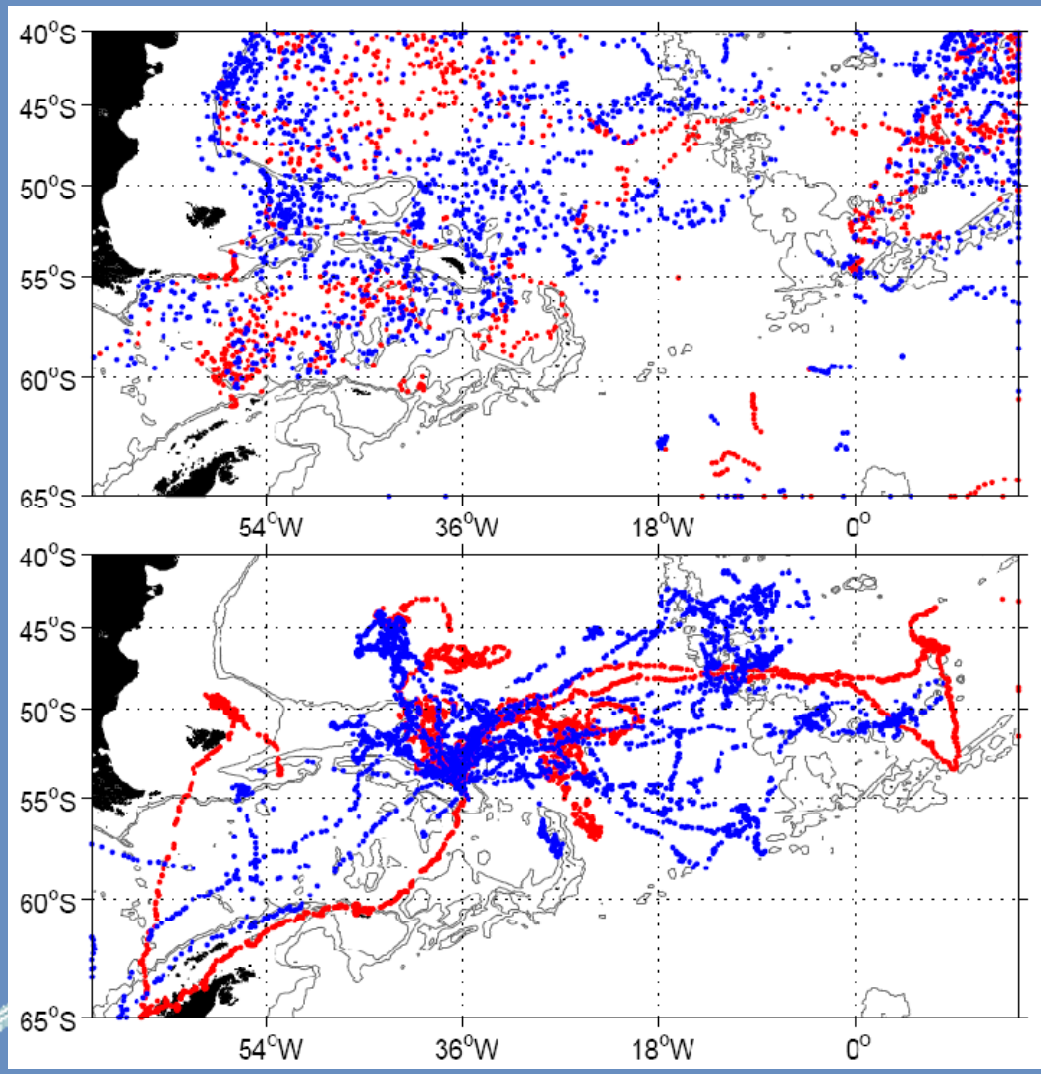
- higher accuracy
- higher vertical resolution
- every 10 days
- freely drifting
- down to 2000 dbar

SEaOS

Southern Elephant Seals as Oceanographic Samplers

- higher temporal resolution (daily)
- higher spatial resolution (<50km)
- along animal migrations
- down to 2000 dbar



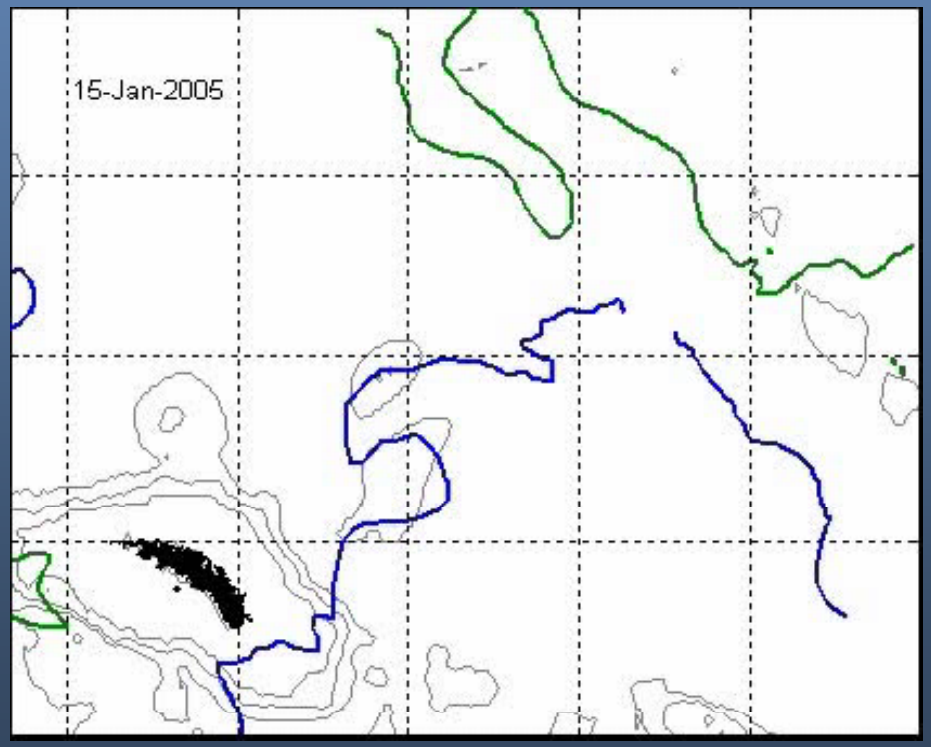


* 2004 * 2005

Temporal variability of ocean fronts

Merging SEaOS data with more traditional provides better temporal resolution.

48ºS



56ºS

39ºW

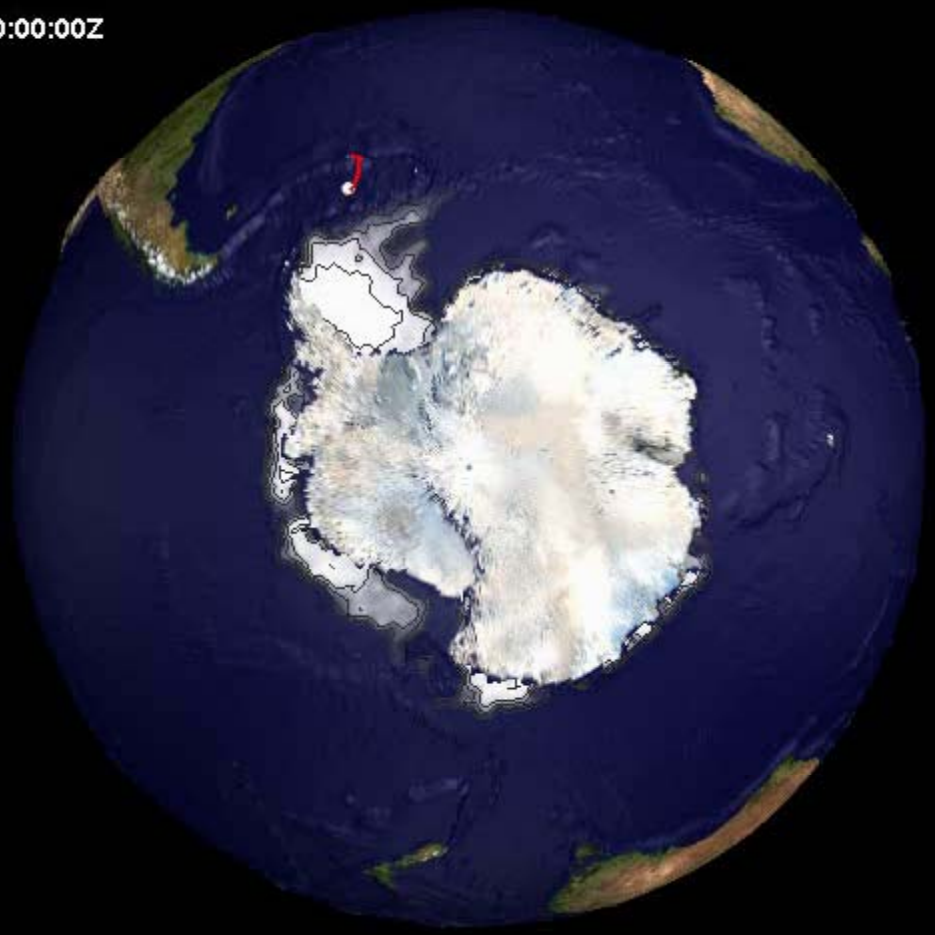
24ºW

This is not a model. It is created from *in-situ* data!

Lars Boehme

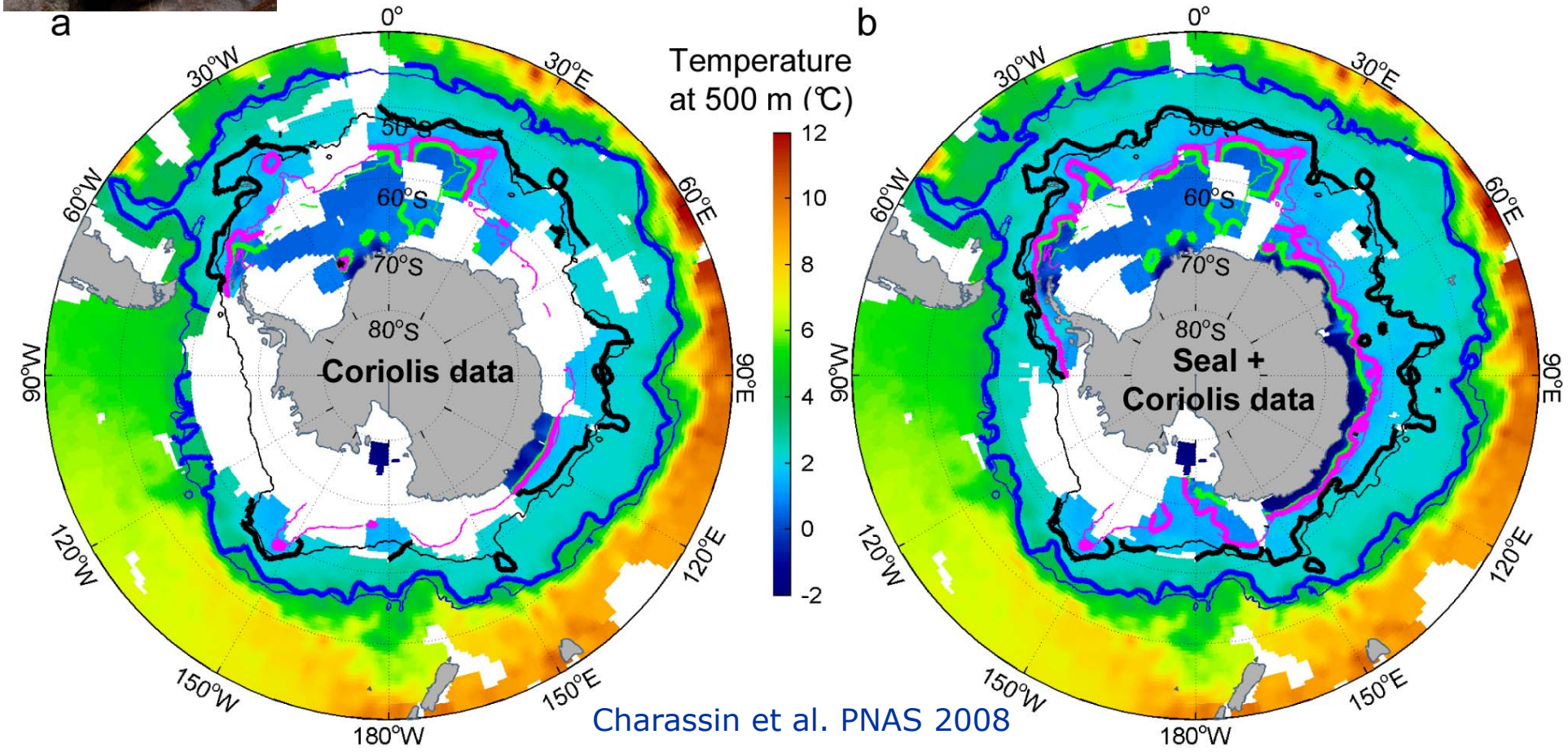
SEaOS

2004-01-20 00:00:00Z
Tail 21 days



SEAOS

Using Seals to Identify Global Physical Habitat



Charassin et al. PNAS 2008

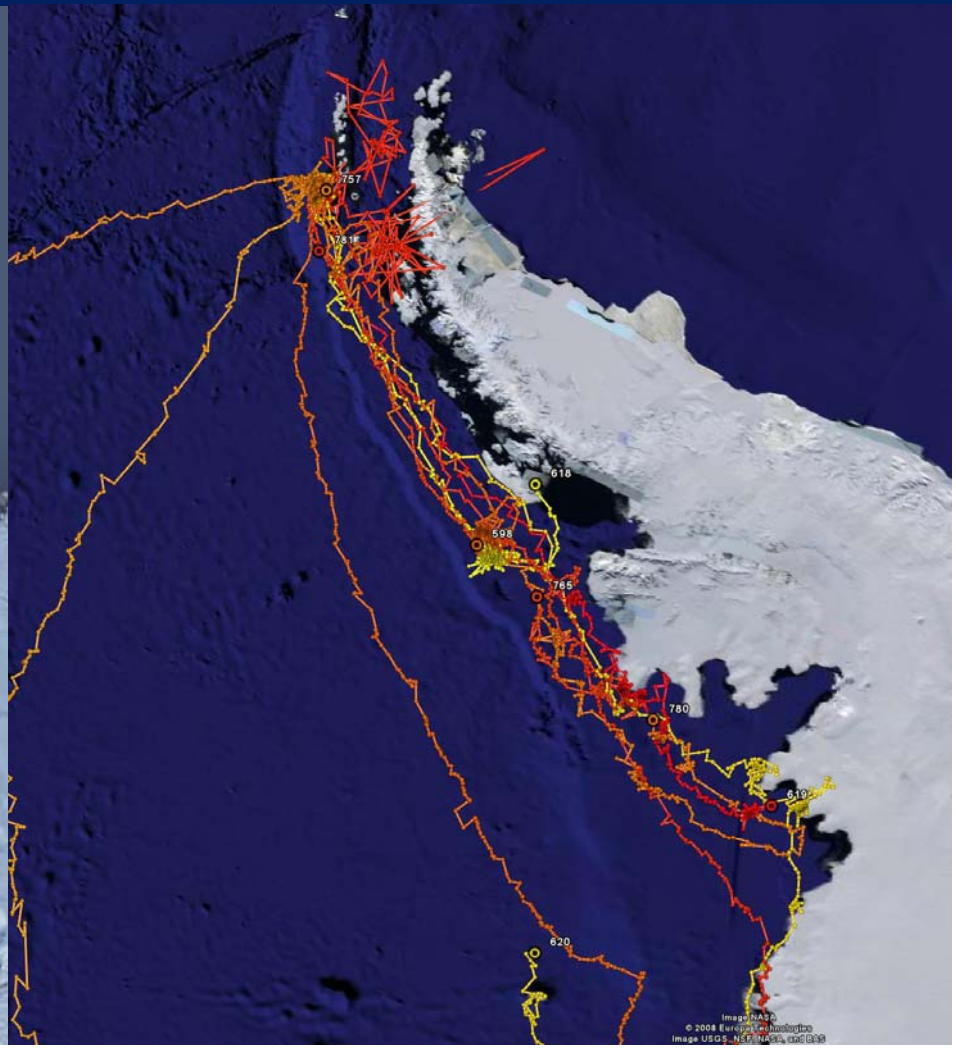
From Coriolis data:
- Bdy
- sACCF
- PF
- SAF

From altimetry:
- Bdy
- sACCF
- PF
- SAF

From seal and Coriolis data:
- Bdy
- sACCF
- PF
- SAF

Seal Collected CTD profiles Collapse of Wilkins Ice Shelf

Padman et al GRL in review

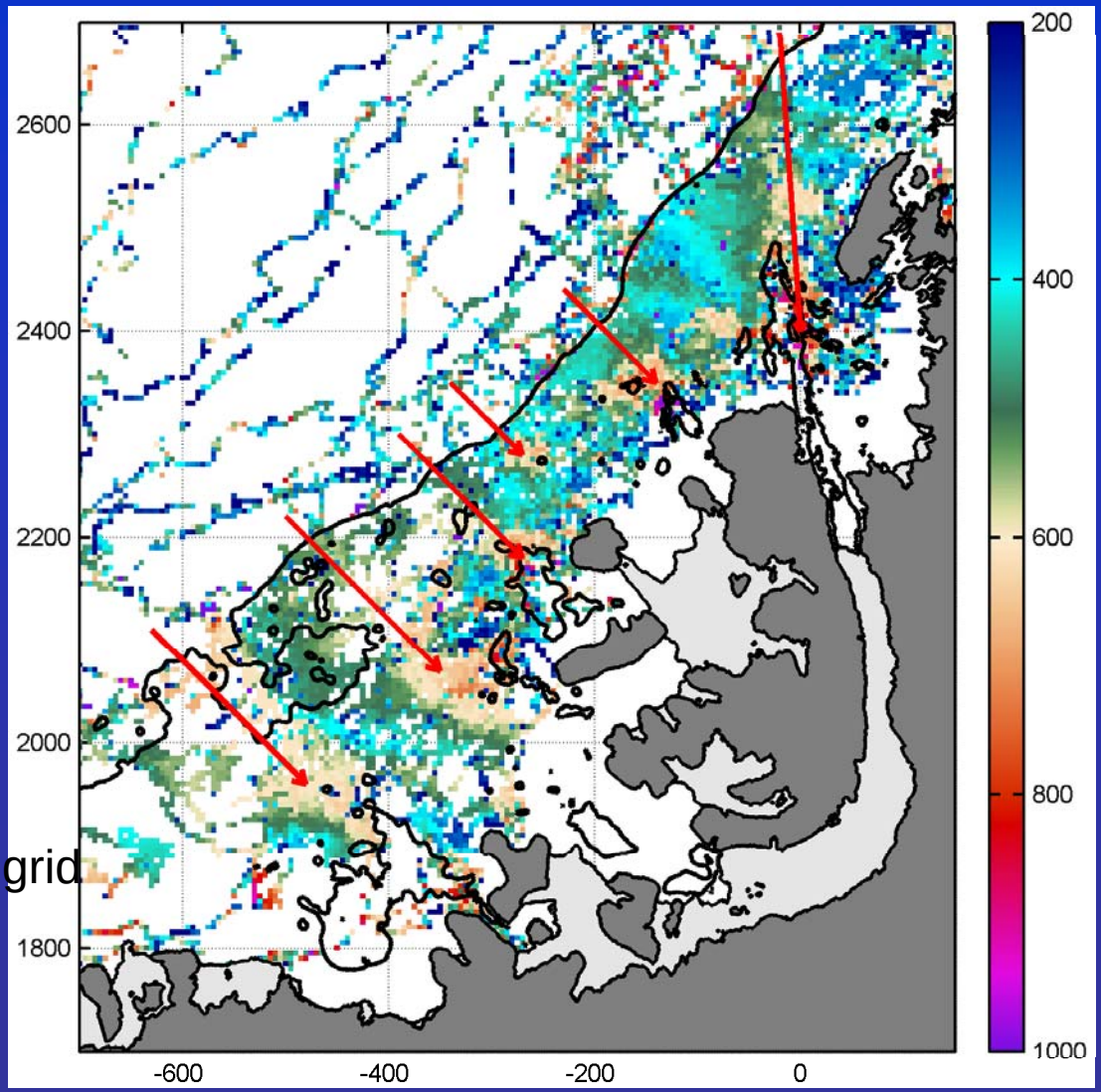


"Bathymetry"

Maximum dive depth

Binned in 5 km boxes

Troughs identified by seal Dives



Black contour = 700 m isobath
Global Predicted Bathymetry V11.1 grid

Maximum ocean temperature (UCDW)

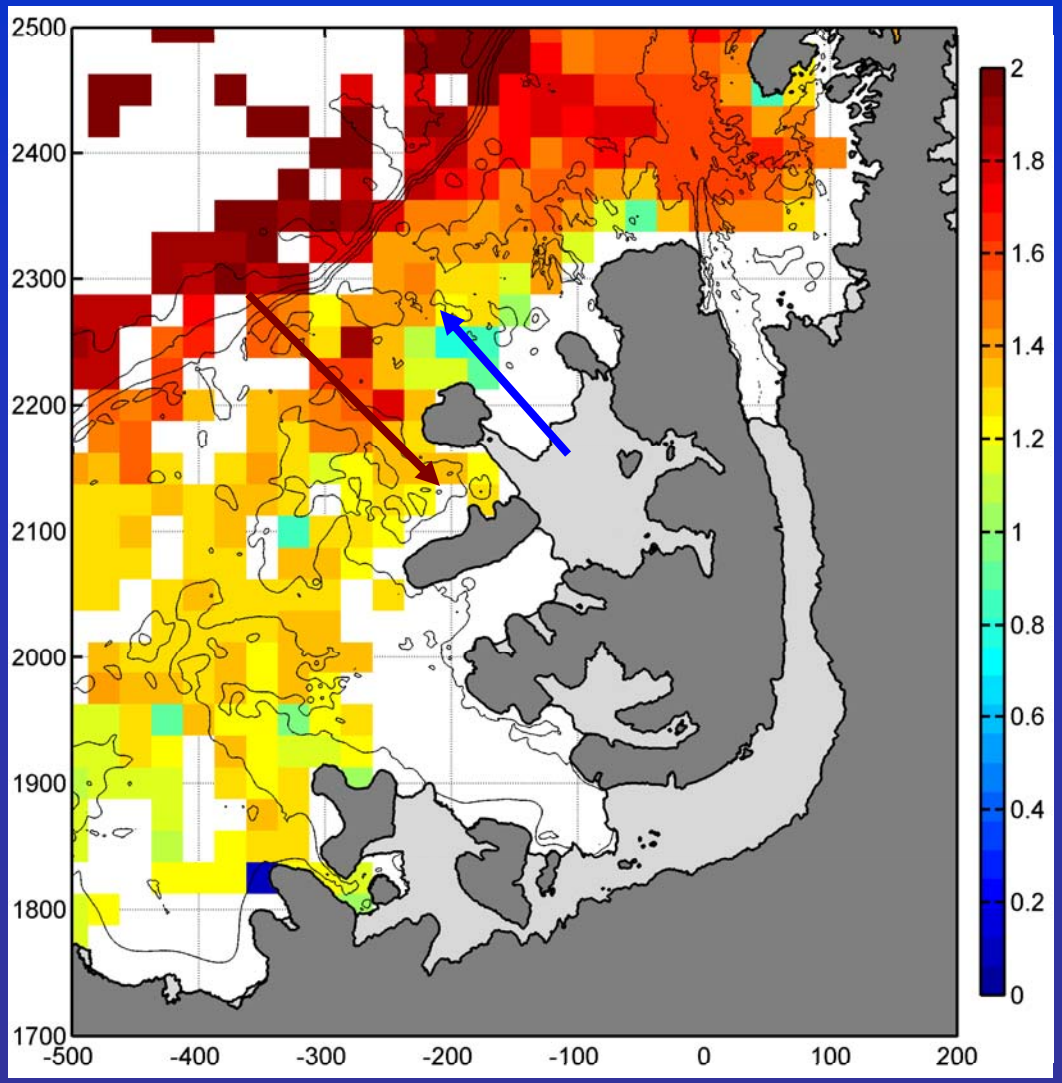
2007 & 2008 seal dive data

Binned in 25 km boxes

Only for z>300 m

Warm water comes inshore along troughs

Cooled water exits WIS to north



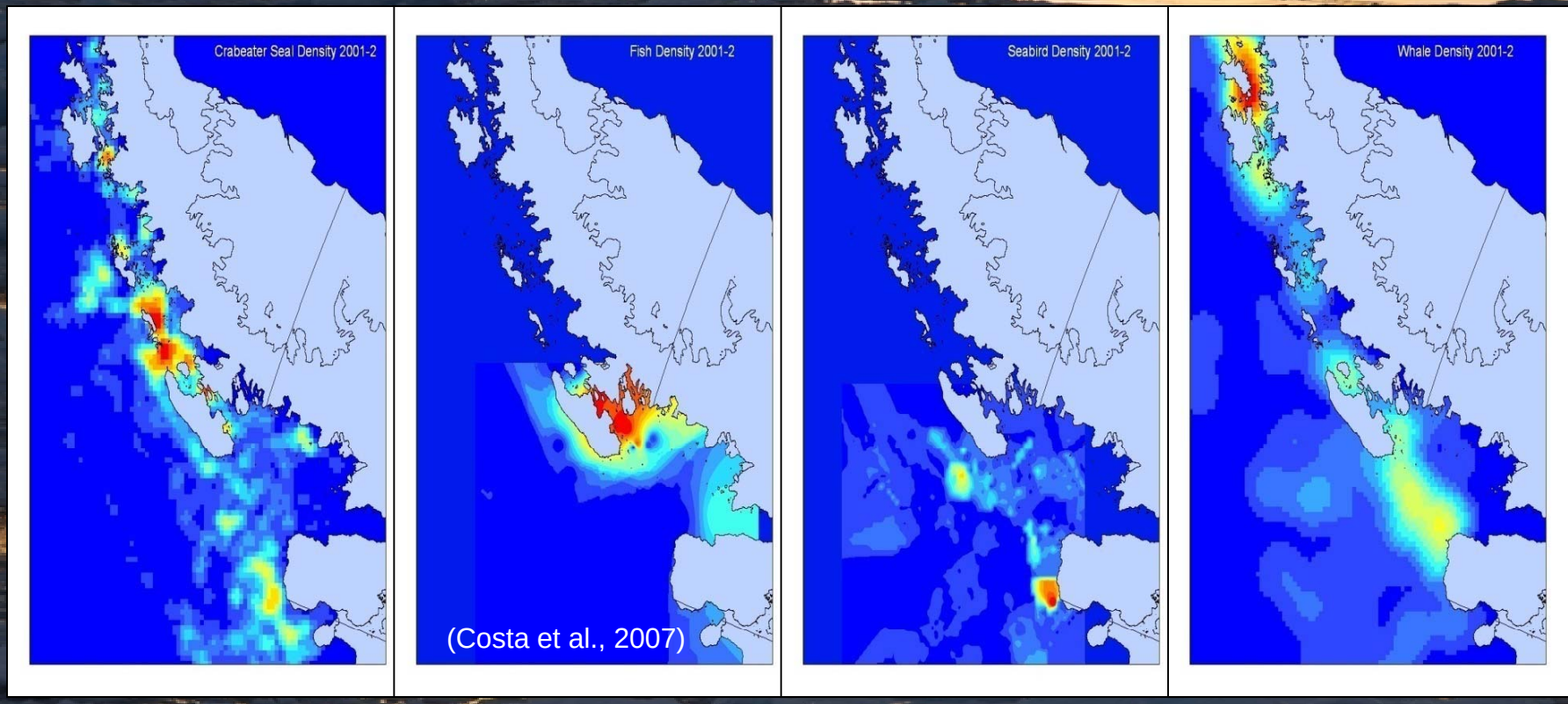
Outline

- Role of Top Predators to Marine Ecosystems
  - Top Down Processes
  - Biogeochemical cycles
- Response to Environmental Variability
  - Modern time series
  - Holocene
- Defining habitat characteristics
- Predicting habitat change
- Using animals to measure a changing habitat
- Research Questions

Research Questions

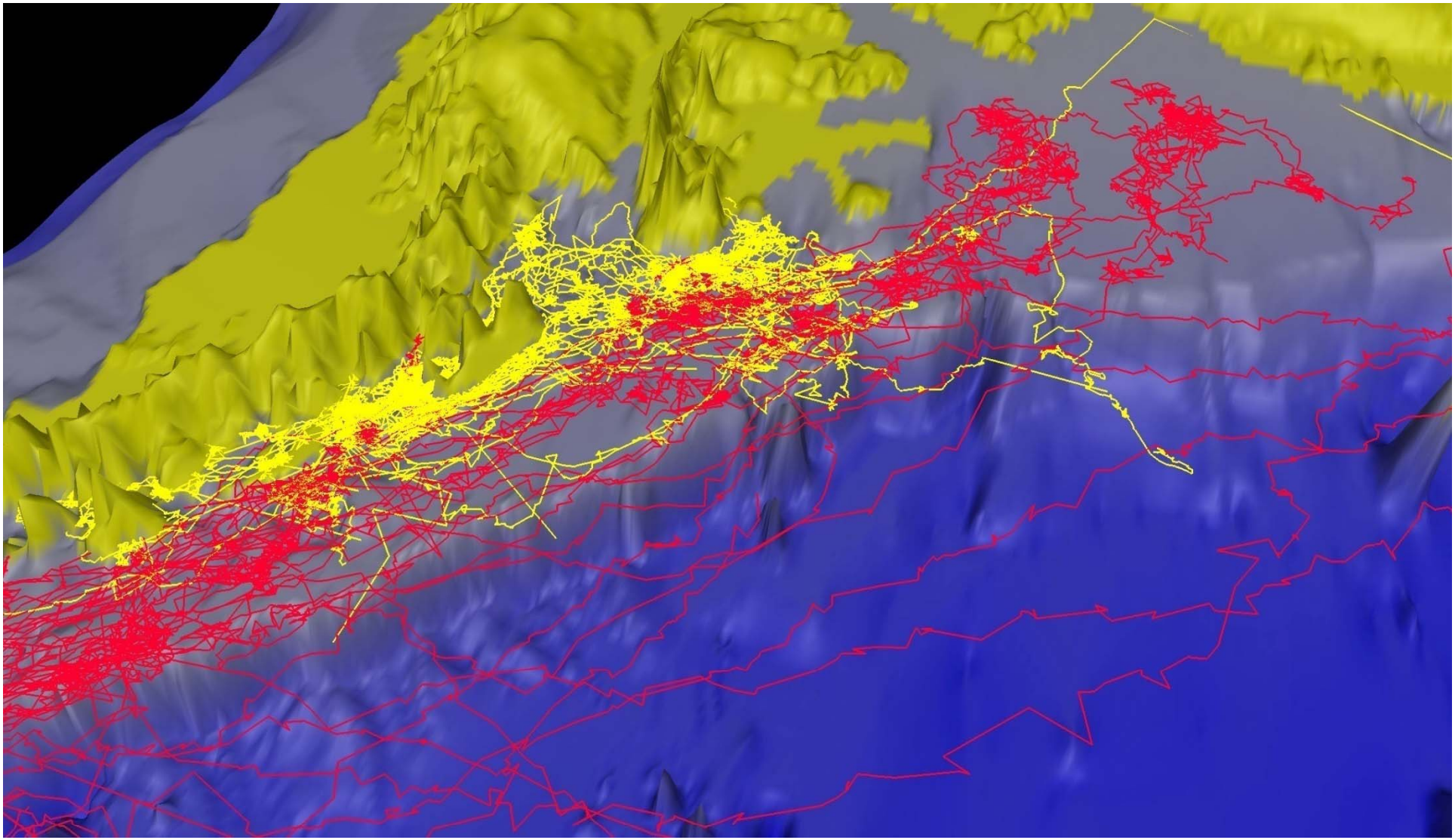
- What are the habitat requirements and foraging behaviors of top predators
  - Oceanographic characteristics
  - How does foraging behavior affect demography?
  - Breeding; non-breeding
  - Functional Response
  - What about non-colony species?
    - Crabeater seals and Cetaceans
- Do top predators have a role in the Carbon cycle?
  - Nutrient recycling or liberation
- What makes a hotspot?

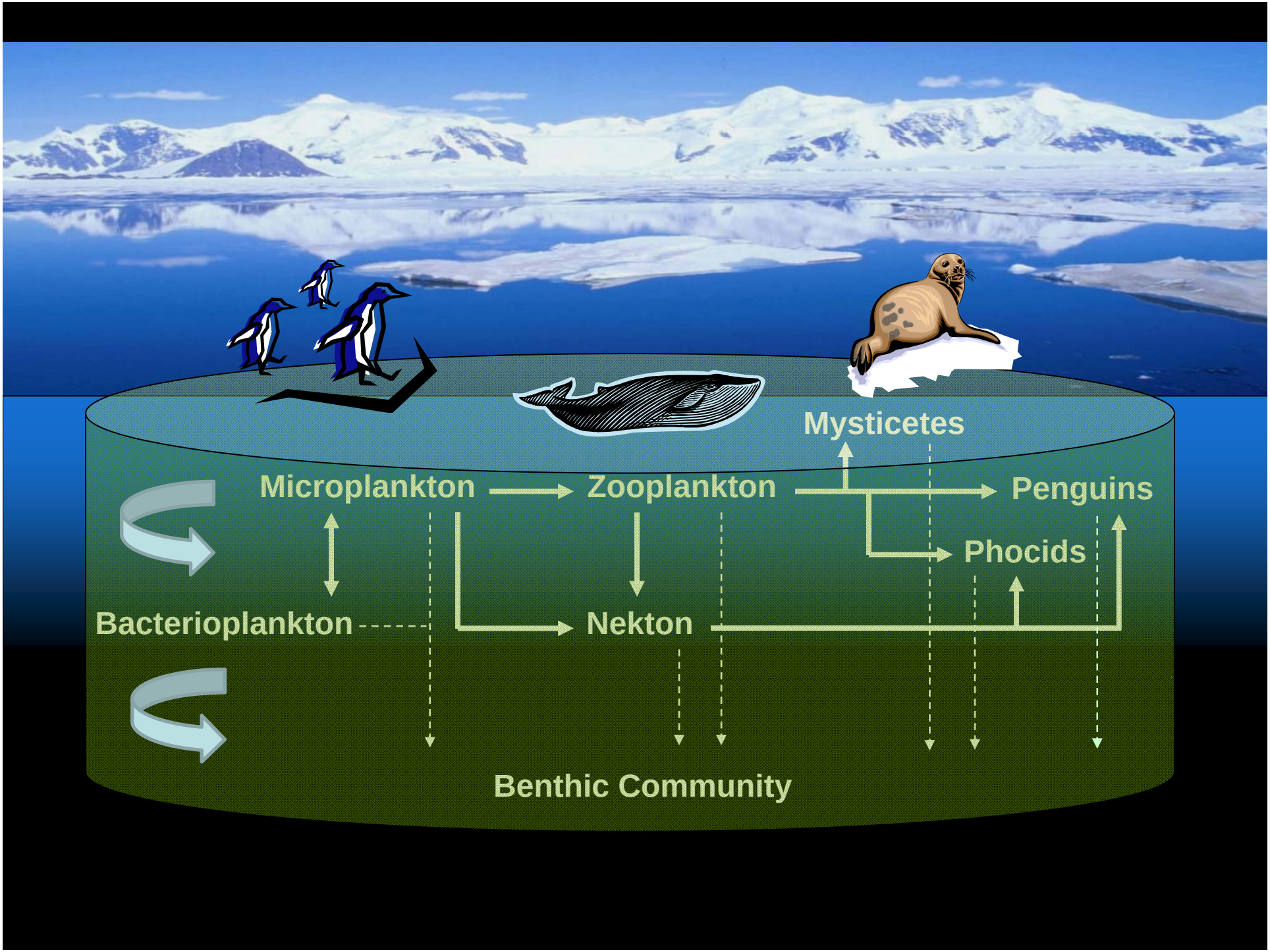
Biological Hot Spots



Not all parts of the shelf are biologically similar

Elephant seals and crabeaters




Mysticetes
Microplankton
Zooplankton
Penguins
Phocids
Bacterioplankton
Nekton
Benthic Community

THANK YOU!

National Science Foundation
WHERE DISCOVERIES BEGIN