Palmer LTER Site Review

Introduction to the Palmer LTER

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Palmer LTER:
Antarctic Marine Ecosystem:
An Ice-Dominated System

- **Outline**
  - Long-term ecological research
  - Antarctic Marine Ecosystem
    - brief overview
    - conceptual diagram of trophic structure
    - seasonal time line
  - Palmer LTER (PAL) Central Hypotheses
    - seasonal linkages & sea ice
    - new perspectives
  - Paleohistory of Western Antarctic Peninsula (WAP)
  - Ecological response to climate variability
  - Satellite estimation of primary productivity
  - Summary & Introduction to co-PIs

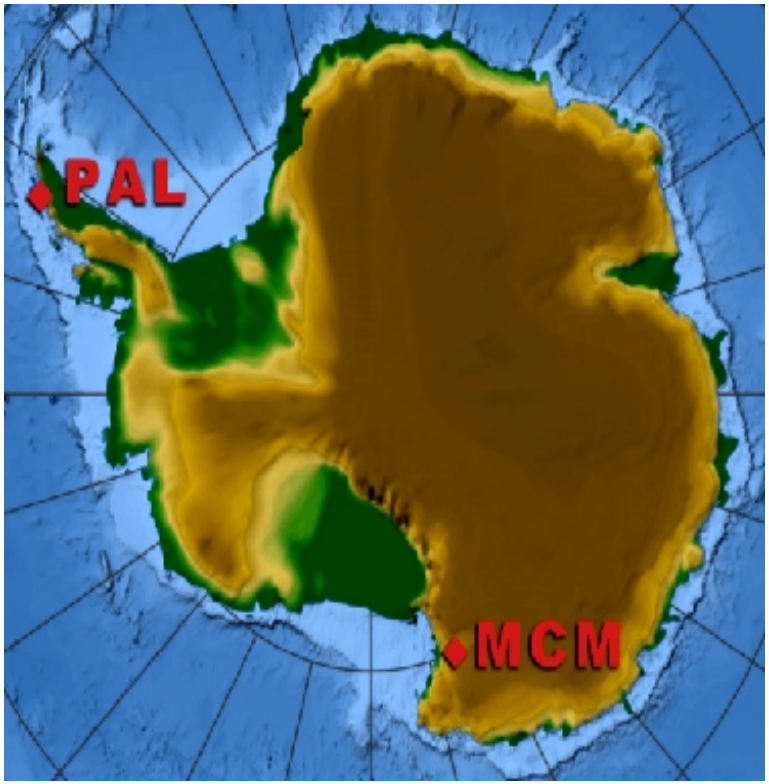
General References

- **Palmer LTER Web Site**
  - http://www.icess.ucsb.edu/lter
- **General References**
  - Smith et. al., The Palmer LTER: A Long-Term Ecological Research Program at Palmer Station, Antarctica. Oceanography, Vol. **8**, 77-86 (1995)
  - Ross, Hofmann & Quetin, Foundations for Ecological Research West of the Antarctic Peninsula. Antarctic Research Series, Vol. **70**, Amer. Geophysical Union (1996)

LTER - brief history

- **Founded by NSF in 1981**
- **currently 21 sites**
- **core data at most sites include:**
  - primary productivity
  - nutrient concentrations & cycling rates
  - organic matter transport
  - trophic interactions
  - effects of natural & anthropogenic disturbances
- **LTER network fosters**
  - cross-site analysis & synthesis
  - integration of data
  - communication among LTER sites
  - interaction with larger scientific community

The LTER Network



PALMER Long Term Ecological Research

LTER Long Term Ecological Research

LONG-TERM RESEARCH important for:

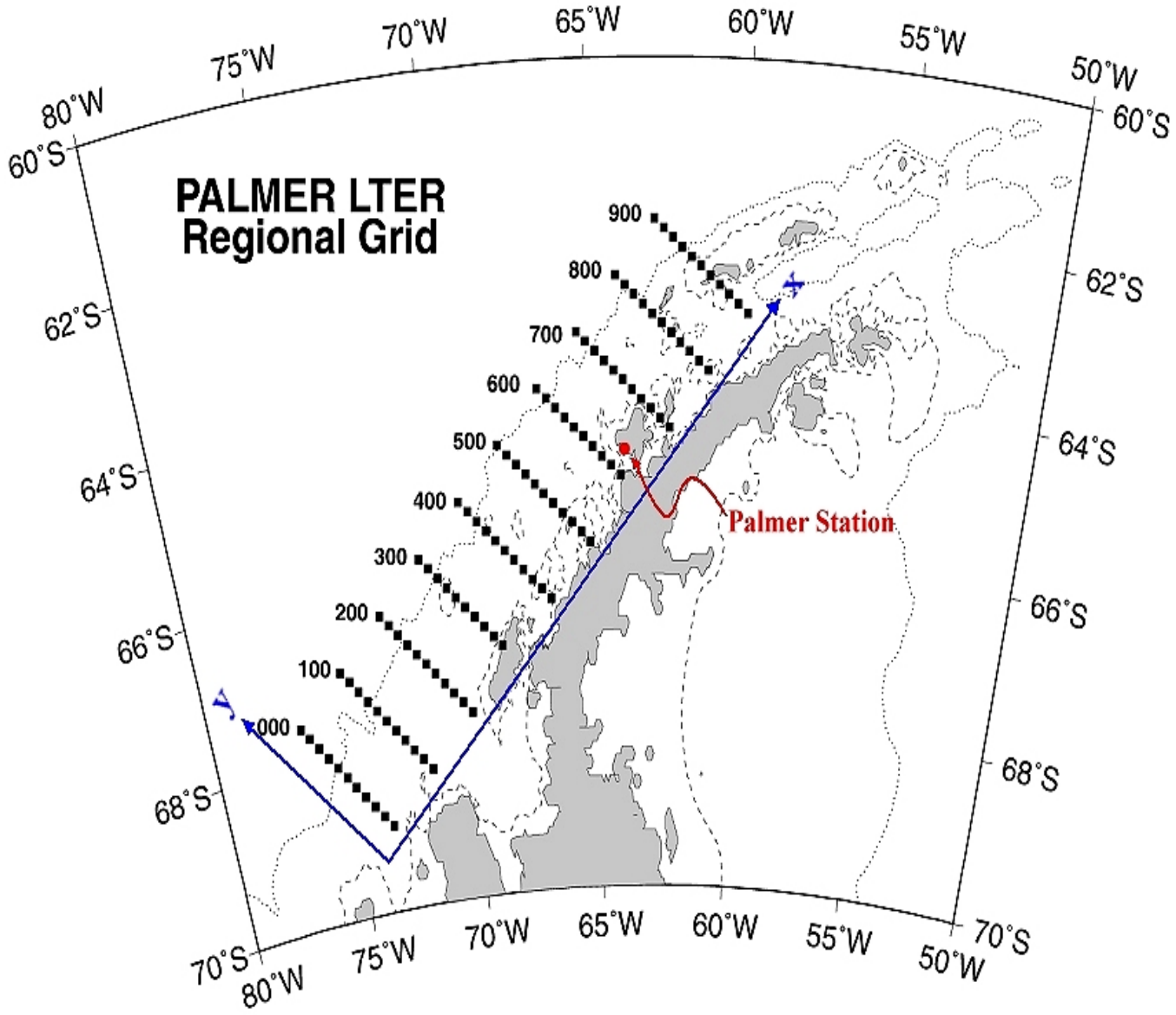
- **Slow processes,** e.g.,
  - long life cycles of key species
  - ecological response to climate change
- **episodic phenomena,** e.g.,
  - relatively rare & intense forcing
  - ENSO
- **processes with high year-to-year variability,** e.g.,
  - climate in polar regions
- **elusive &/or complex processes,** e.g.,
  - where it is difficult to distinguish meaningful patterns from random events

LTER - brief history (con't)

- being part of the LTER network offers both **opportunities & responsibilities**
- **Palmer LTER founded in 1990**
  - funded by NSF Office of Polar Programs
  - first marine site (coastal to pelagic) in the LTER network
  - seek to study the Antarctic Marine Ecosystem within the context, philosophy, and common goals of the LTER Network

Antarctic Marine Ecosystem

- **the assemblage of plants, animals, ocean, & sea ice components south of the Antarctic Convergence**
- **is among the largest readily defined ecosystems on Earth**
  - bounded on the south by Antarctica
  - bounded on the north by the Polar Front
- **ecosystem characterized by:**
  - extreme seasonality
  - very high interannual variability
  - strong winds & broken seas
  - presence/absence of sea ice & related habitats
  - relatively 'simple' food web with krill an important species
  - upper level predators, some of whom (sea birds), breed on land & are thus amenable to observation
- **Palmer LTER study area representative of the Antarctic Marine Ecosystem**
- **Western Antarctic Peninsula (WAP) is a unique location for long term research**



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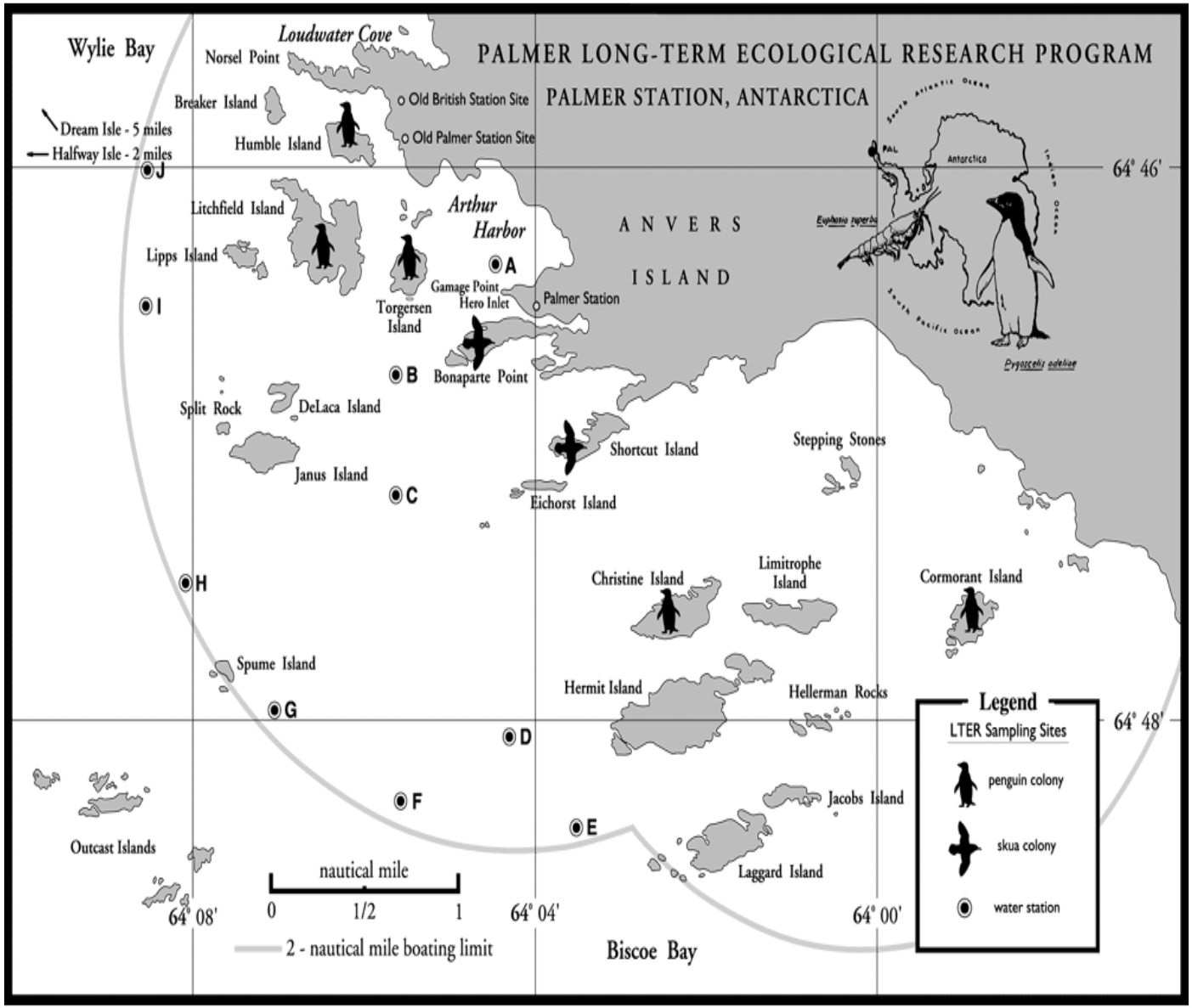
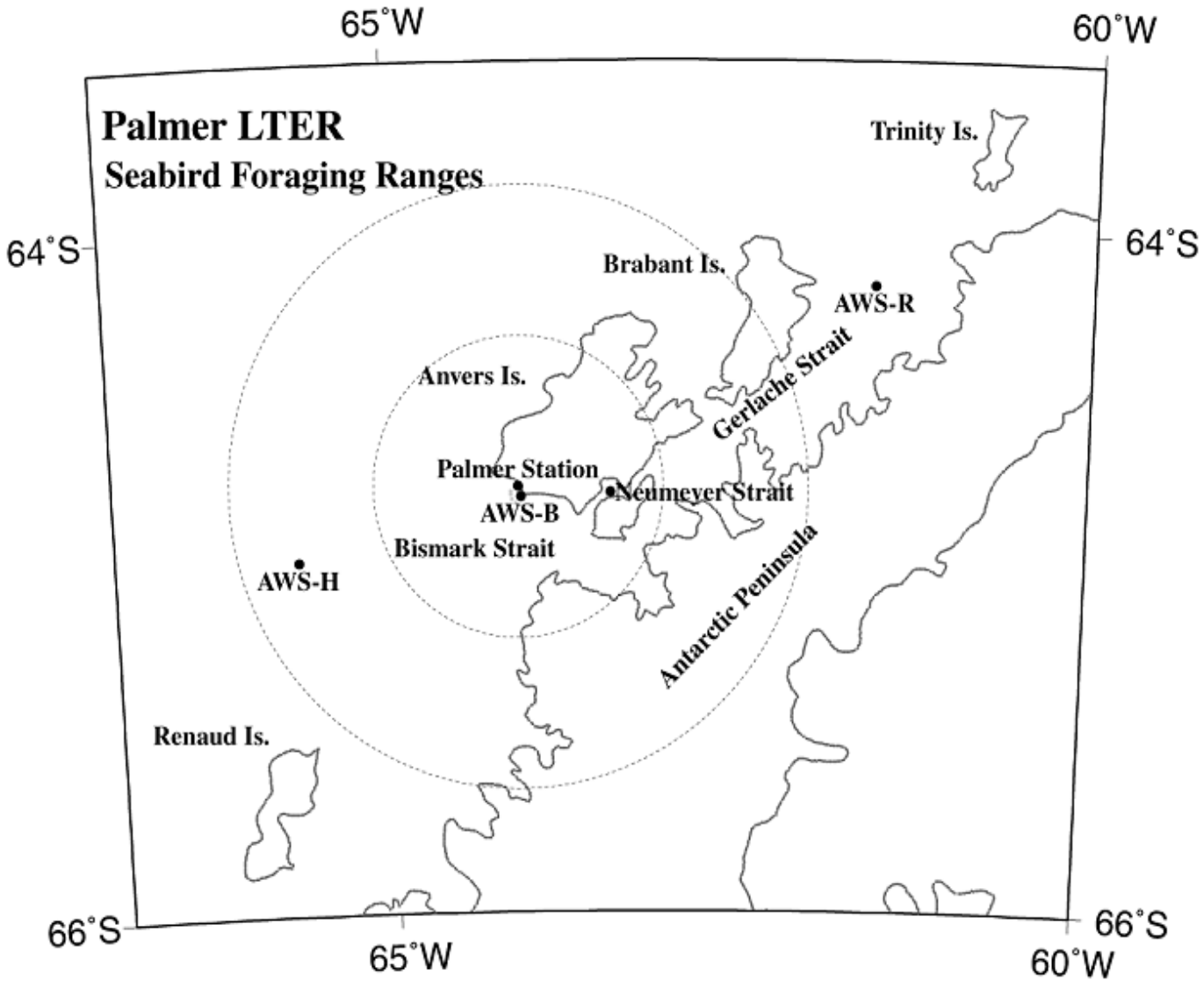

PALMER LONG-TERM ECOLOGICAL RESEARCH PROGRAM
PALMER STATION, ANTARCTICA
Wylie Bay
Loudwater Cove
Norsel Point
Breaker Island
Humble Island
Old British Station Site
Old Palmer Station Site
Dream Isle - 5 miles
Halfway Isle - 2 miles
Litchfield Island
Lipps Island
Arthur Harbor
ANVERS ISLAND
Gamage Point
Hero Inlet
Palmer Station
Torgersen Island
Bonaparte Point
Split Rock
DeLaca Island
Janus Island
Shortcut Island
Eichorst Island
Stepping Stones
Christine Island
Limitrophe Island
Cormorant Island
Spume Island
Hermit Island
Hellerman Rocks
Jacobs Island
Laggard Island
Outcast Islands
Biscoe Bay
64° 46'
64° 48'
64° 08'
64° 04'
64° 00'
nautical mile
0 1/2 1
2 - nautical mile boating limit
Legend
LTER Sampling Sites
penguin colony
skua colony
water station
Antarctica
Euphausia superba
Pygoscelis adeliae


Palmer LTER
Seabird Foraging Ranges
65˚W
60˚W
64˚S
66˚S
Trinity Is.
Brabant Is.
AWS-R
Gerlache Strait
Anvers Is.
Palmer Station
AWS-B
Neumeyer Strait
Bismark Strait
AWS-H
Antarctic Peninsula
Renaud Is.

PALMER LTER

Annual Monthly distribution of LTER cruises & field season

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
90/91	-	-	I	*	*	-	-	-	-	-	-	-
91/92	-	-	-	x	Nov91	x	x	x	-	-	-	-
92/93	-	-	-	x	Nov92	x	Jan93	x	Mar93	*	*	
93/94	-	Aug93	*	I	*	x	Jan94	x	x	-	-	-
94/95	-	-	-	x	x	Dec95	Jan95	x	-	-	-	-
95/96	-	-	-	x	x	x	Jan96	x	x	-	-	-
96/97	-	-	-	-	x	T	Jan97	x	x	-	-	-
97/98	-	-	-	-	x	-	Jan98	x	x	-	-	-
98/99	-	-	-	-	x	-	Jan99	x	x	-	-	Jun99
99/00	*	-	-	-	x	-	Jan00	x	x	-	-	-
00/01	-	-	Sep01	-	x	-	Jan01	x	x	-	-	-
01/02	-	-	-	x	x	-	Jan02	x	x	-	-	-

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WHY ANTARCTICA?

- Oceanic, atmospheric, and biogeochemical processes within this system are **globally significant**
  - deep water formation
  - ENSO teleconnections
  - Carbon fluxes
    - transition zone strong CO2 sink
    - export production is high but erratic
    - large repository of unused surface nutrients
- Cold waters dominate our planet but microbial & other **processes are poorly understood**
- Strong climate gradient, feedback processes & potential amplification of environmental change make **Antarctic a "natural laboratory"**
- Susceptible to global **environmental change**
  - greenhouse gas-induced warming
  - chlorofluorocarbon-induced atmospheric ozone depletion
  - resource management (krill, tourism, …)

Biogeochemical Provinces of the Southern Ocean

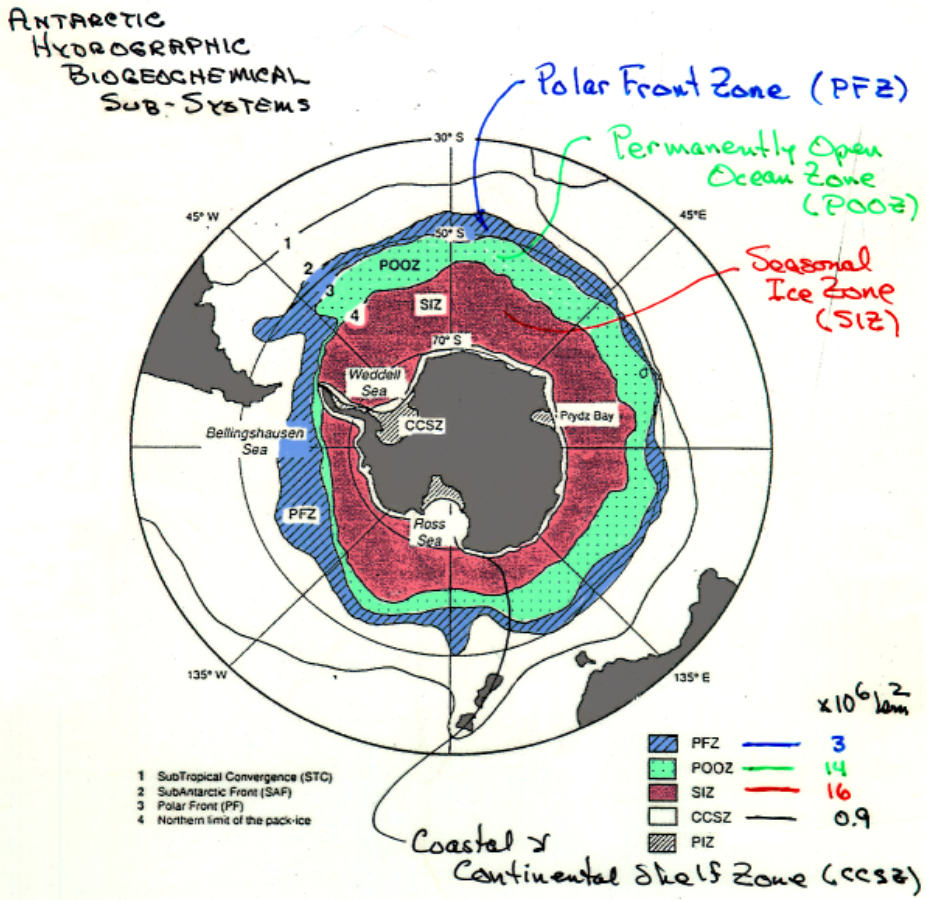

Fig. 1. The Southern Ocean: the four main sub-systems in the Southern Ocean; frontal zones and limits in surface waters. Permanent-ice zone (*hatched zone*); shelf-break (*continuous line*). *1* Subtropical convergence; *PFZ* between *2* and *3*; *POOZ* between *3* and *4*; *SIZ* between *4* and the shelf break; *CCSZ* ice-free part of the continental shelf

Tréguer & Jacques (1992)

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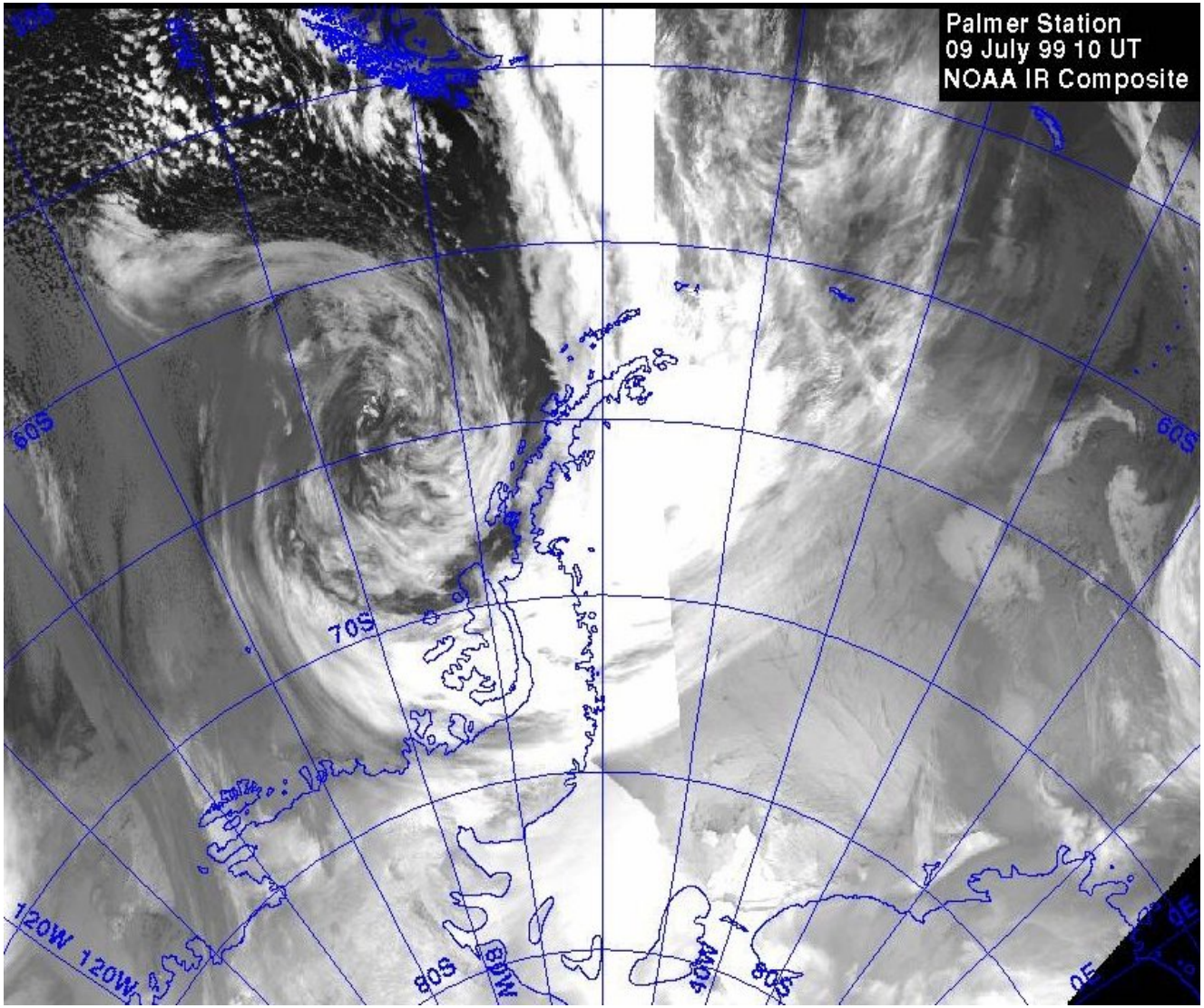

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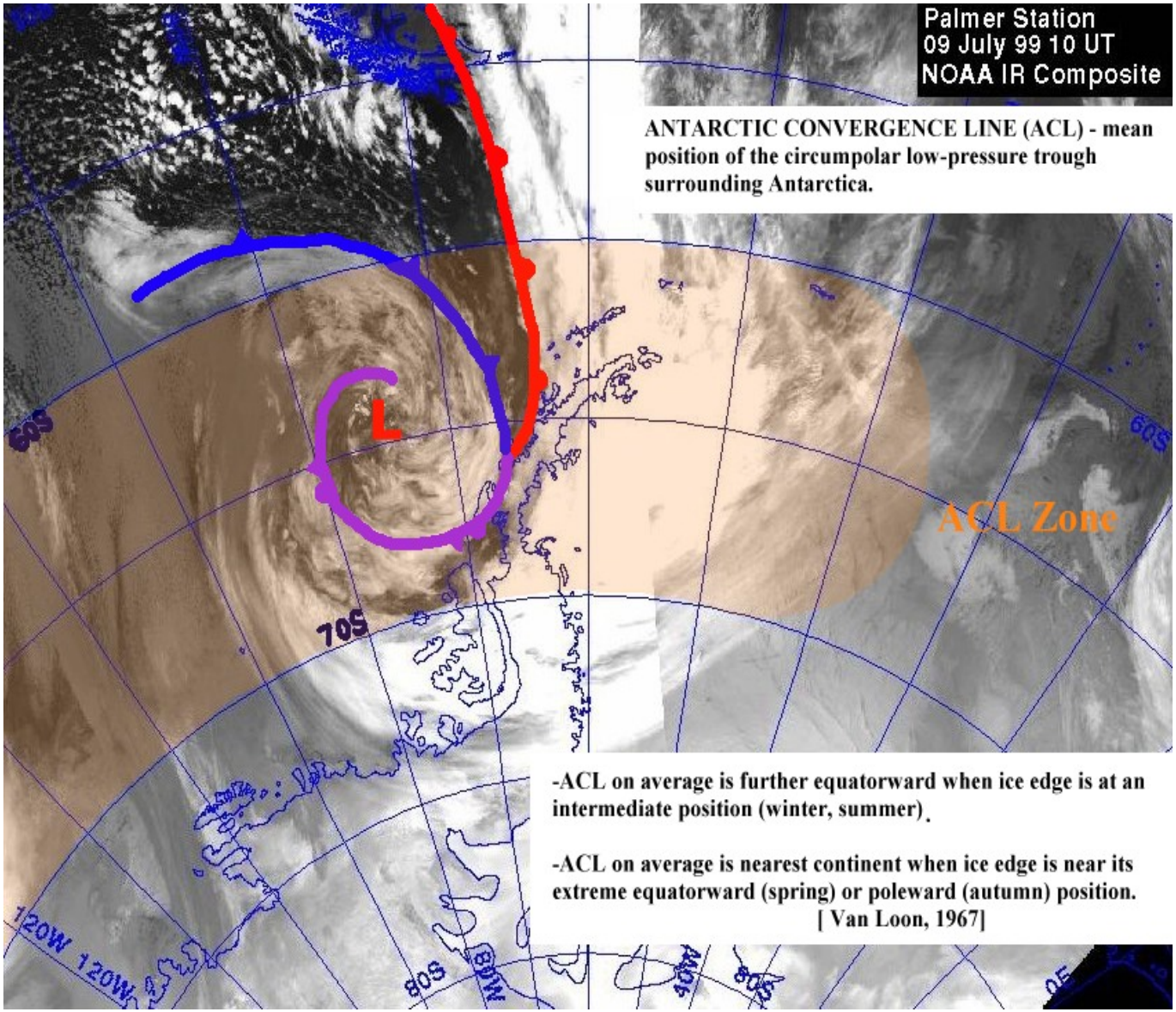
Palmer Station
09 July 99 10 UT
NOAA IR Composite
ANTARCTIC CONVERGENCE LINE (ACL) - mean position of the circumpolar low-pressure trough surrounding Antarctica.
L
60S
70S
ACL Zone
-ACL on average is further equatorward when ice edge is at an intermediate position (winter, summer).
-ACL on average is nearest continent when ice edge is near its extreme equatorward (spring) or poleward (autumn) position.
[Van Loon, 1967]
120W 120W
80S
80W
80S
0E

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Conveyor-like circulation (Stommel, 1961; Broecker, 1991)

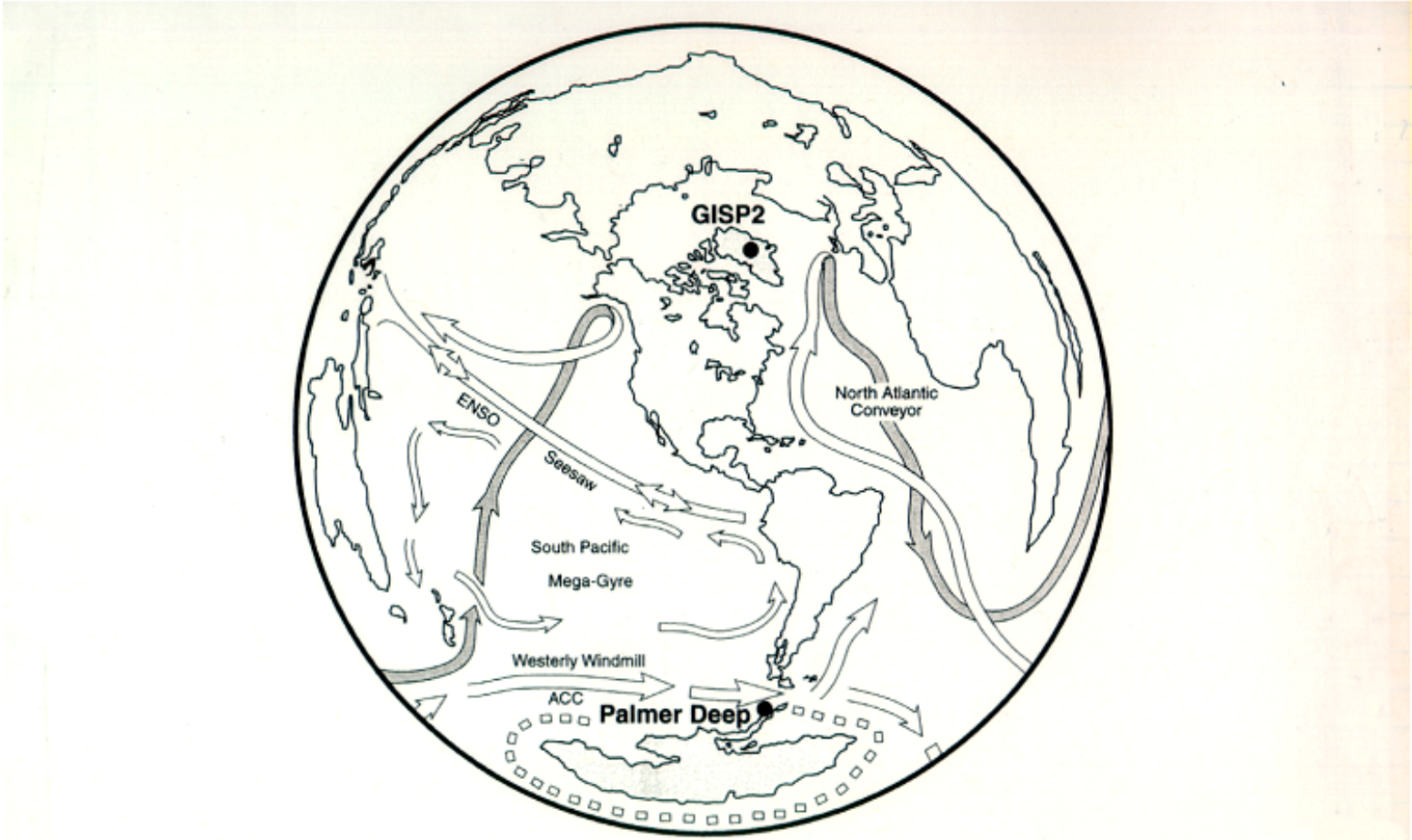


Figure 1 Global view of ocean systems and location of Greenland ice core (GISP2) and marine sediment core in Palmer Deep. Arrows depict circulation patterns and dashes indicate the approximate maximum limit of sea ice. The El Niño Southern Oscillation (ENSO) and the Antarctic Circumpolar Current (ACC) are also shown.

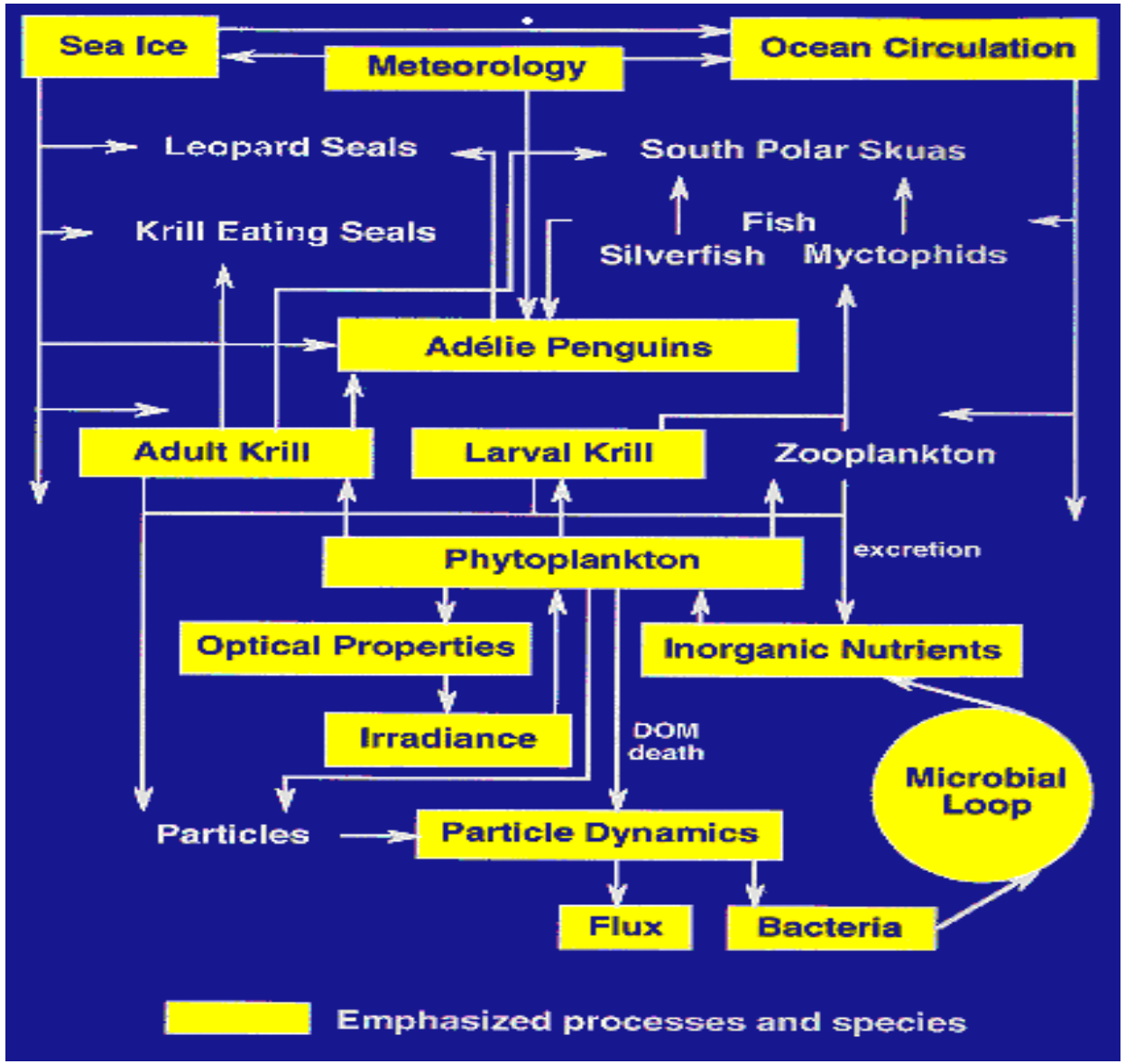
Domack & Mayewski (1999)

Central Hypothesis for PAL research is:

- **that interannual variations in physical processes..**
  - .. Like
    - atmospheric forcing,
    - oceanic circulation,
    - the extent of sea ice
  - affect all levels of the food web of the Antarctic Marine Ecosystem

- **We evaluate testable hypotheses linking sea ice to:**
  - timing & magnitude of seasonal primary production
  - carbon & oxygen dynamics, microbial loops & particle sedimentation
  - krill abundance, distribution & recruitment
  - breeding success & survival of apex predators
  - large scale atmospheric, oceanic & cryogenic interactions

- **A Primary objective is to understand the underlying natural variability in this marine ecosystem**



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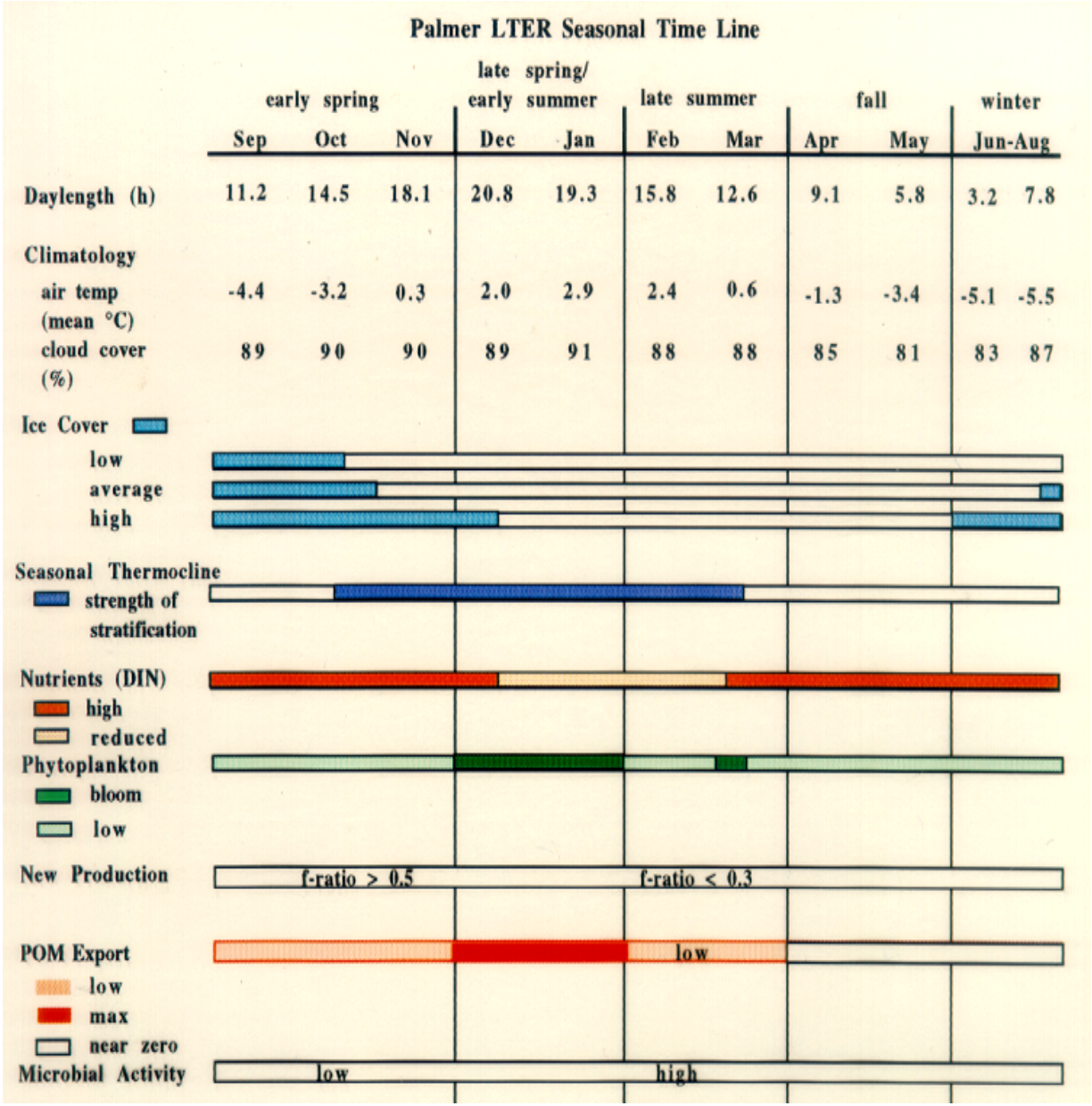
Palmer LTER Seasonal Time Line



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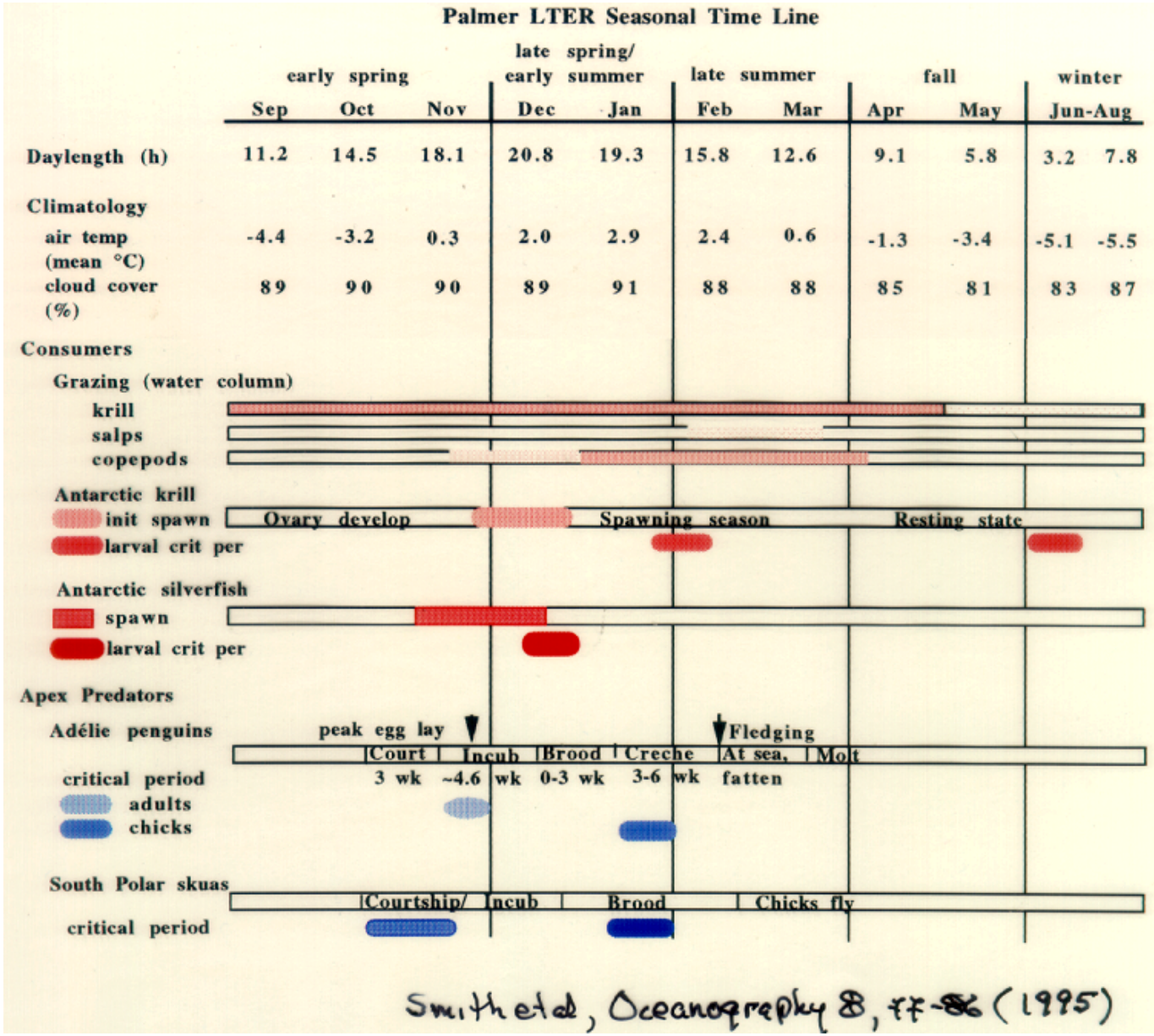
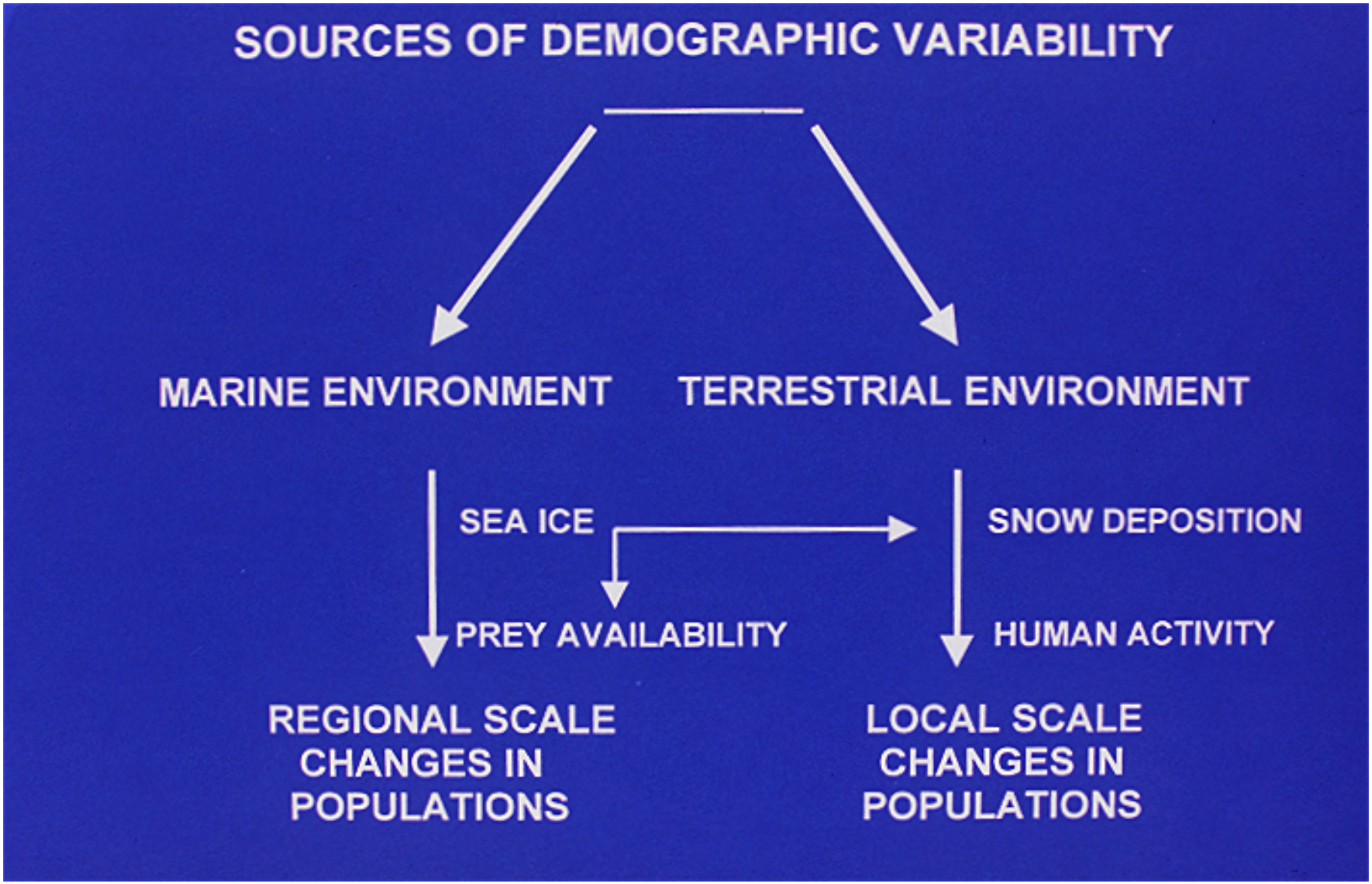
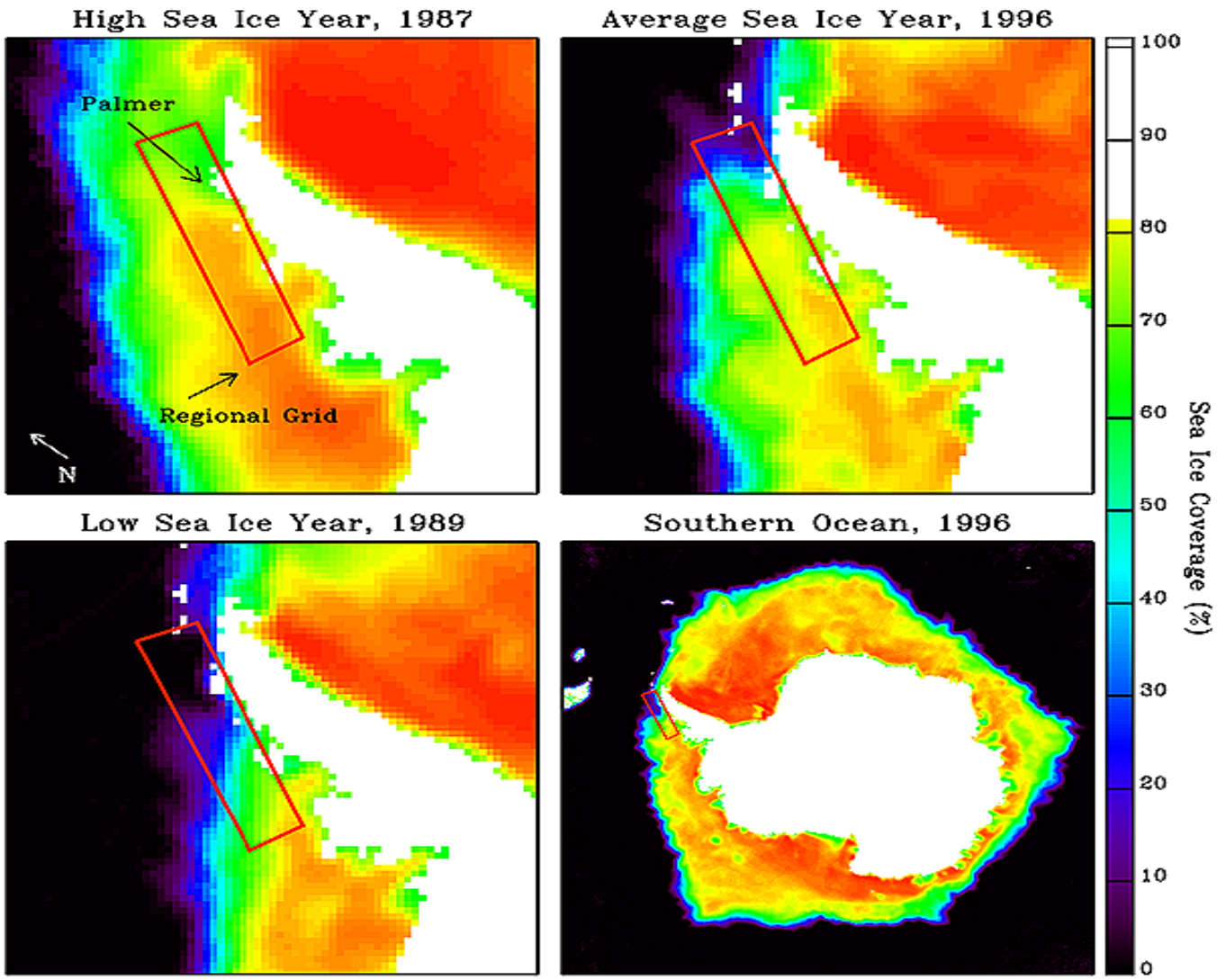

Palmer LTER Seasonal Time Line
early spring
late spring/ early summer
late summer
fall
winter
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun-Aug
Daylength (h)
11.2
14.5
18.1
20.8
19.3
15.8
12.6
9.1
5.8
3.2
7.8
Climatology
air temp (mean °C)
-4.4
-3.2
0.3
2.0
2.9
2.4
0.6
-1.3
-3.4
-5.1
-5.5
cloud cover (%)
89
90
90
89
91
88
88
85
81
83
87
Consumers
Grazing (water column)
krill
salps
copepods
Antarctic krill
init spawn
Ovary develop
Spawning season
Resting state
larval crit per
Antarctic silverfish
spawn
larval crit per
Apex Predators
Adélie penguins
peak egg lay
Fledging
Court
Incub
Brood
Creche
At sea, Molt
critical period
3 wk
~4.6 wk
0-3 wk
3-6 wk
fatten
adults
chicks
South Polar skuas
Courtship/
Incub
Brood
Chicks fly
critical period
Smith et al, Oceanography 8, ??-?? (1995)

PALMER LTER

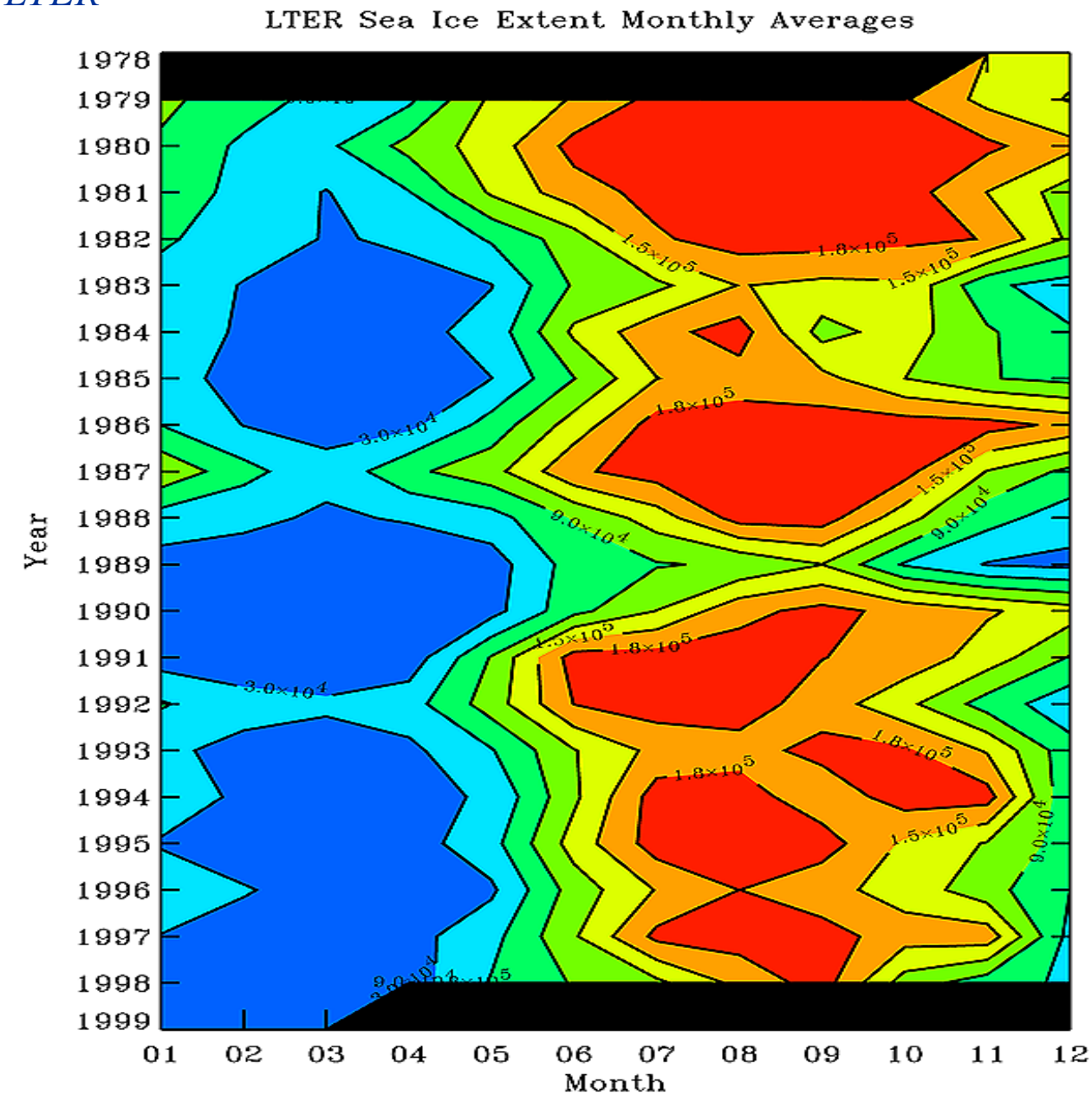

SOURCES OF DEMOGRAPHIC VARIABILITY
MARINE ENVIRONMENT
TERRESTRIAL ENVIRONMENT
SEA ICE
SNOW DEPOSITION
PREY AVAILABILITY
HUMAN ACTIVITY
REGIONAL SCALE CHANGES IN POPULATIONS
LOCAL SCALE CHANGES IN POPULATIONS

Sea Ice Coverage

NASA SSMI passive microwave



PALMER LTER



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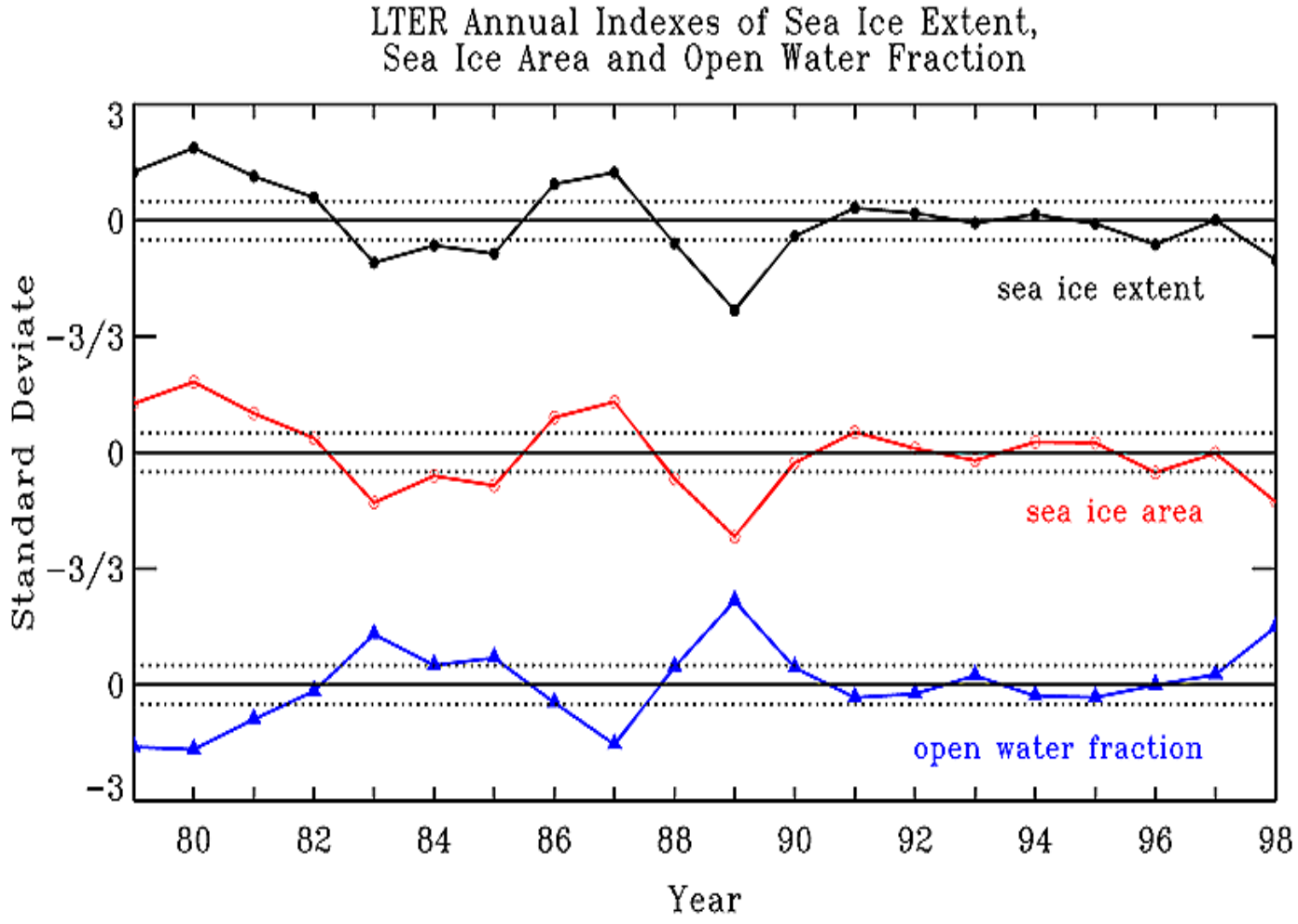
LTER Annual Indexes



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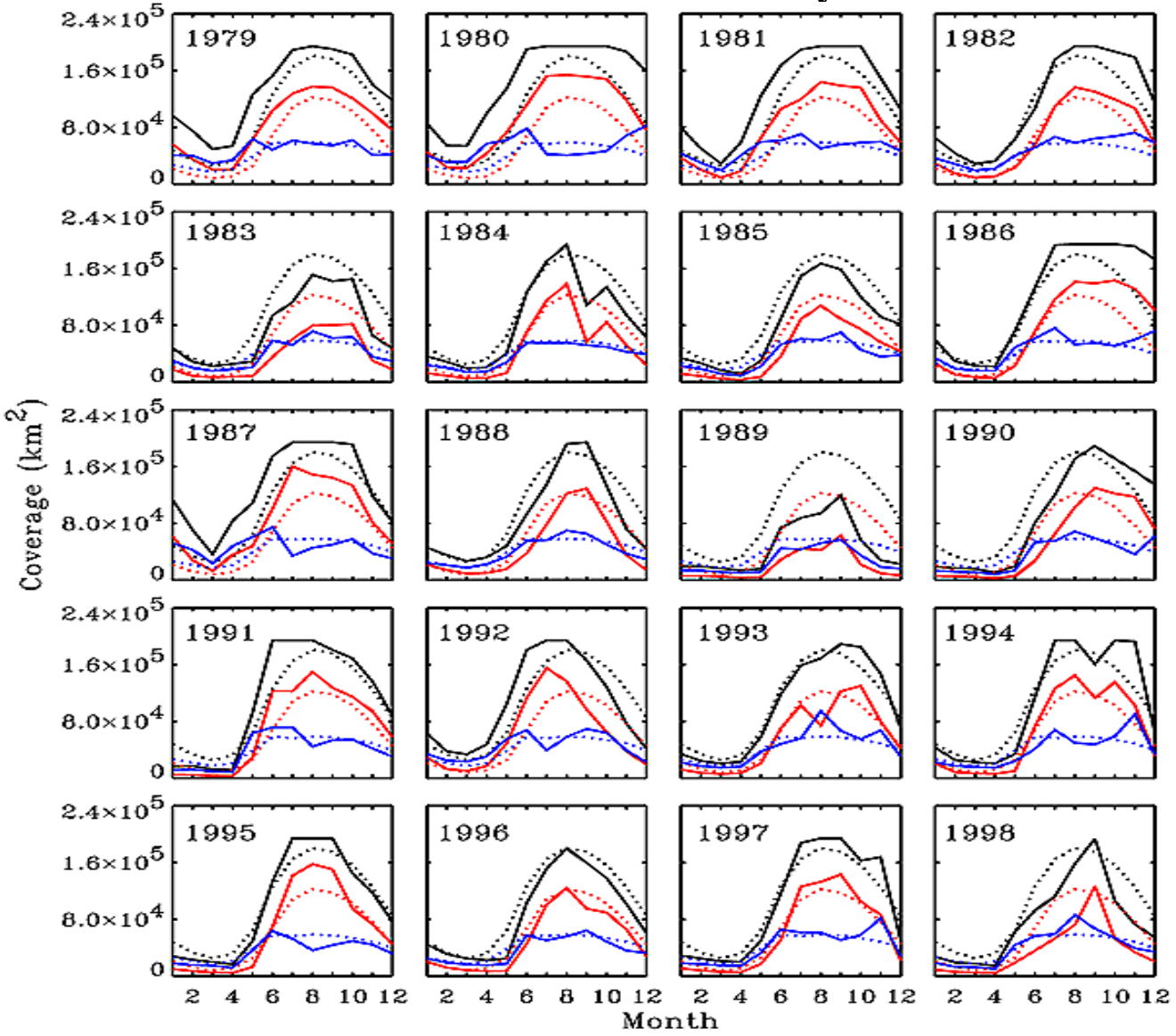
Sea Ice Index

annual curves of monthly sea ice



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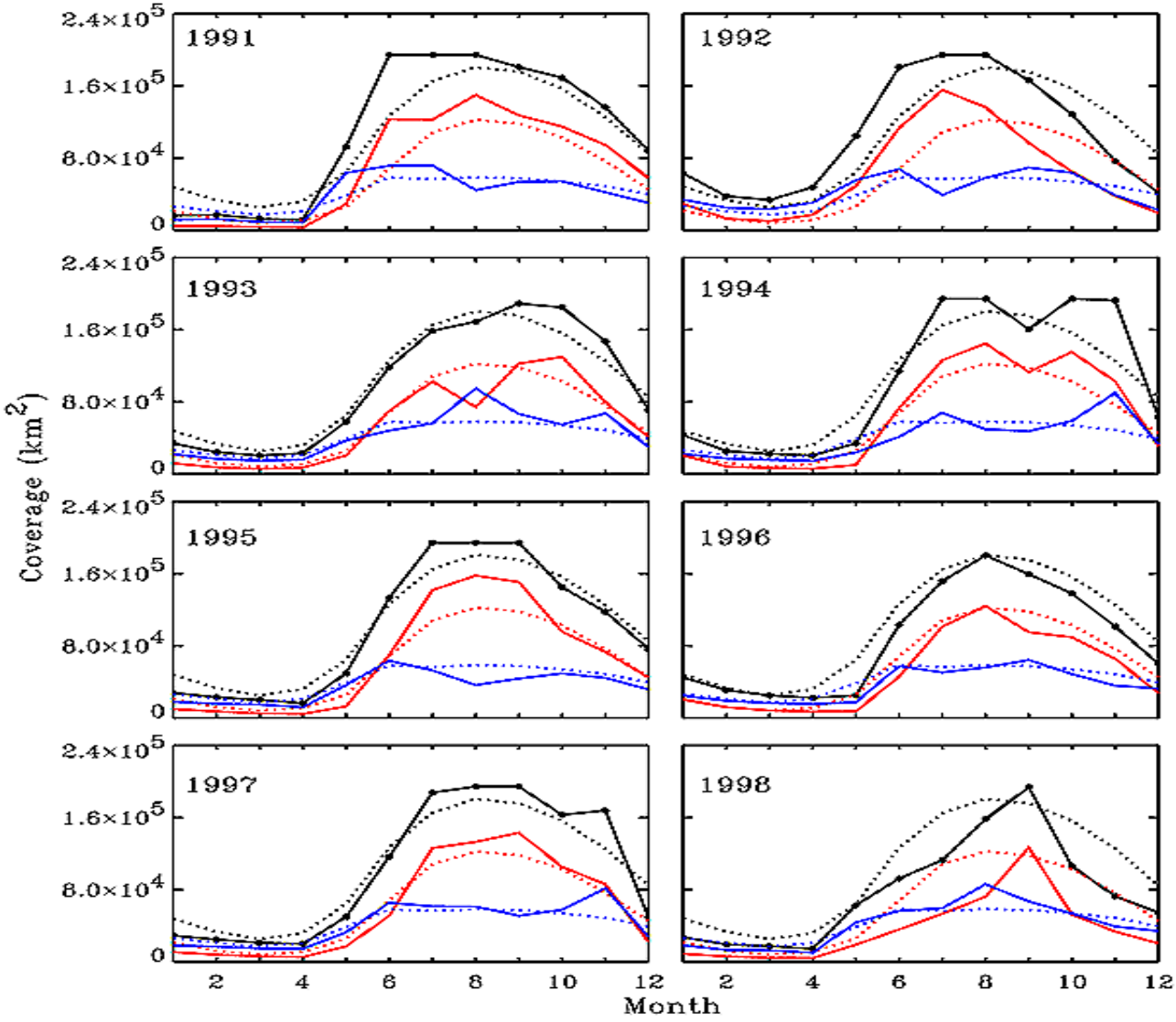

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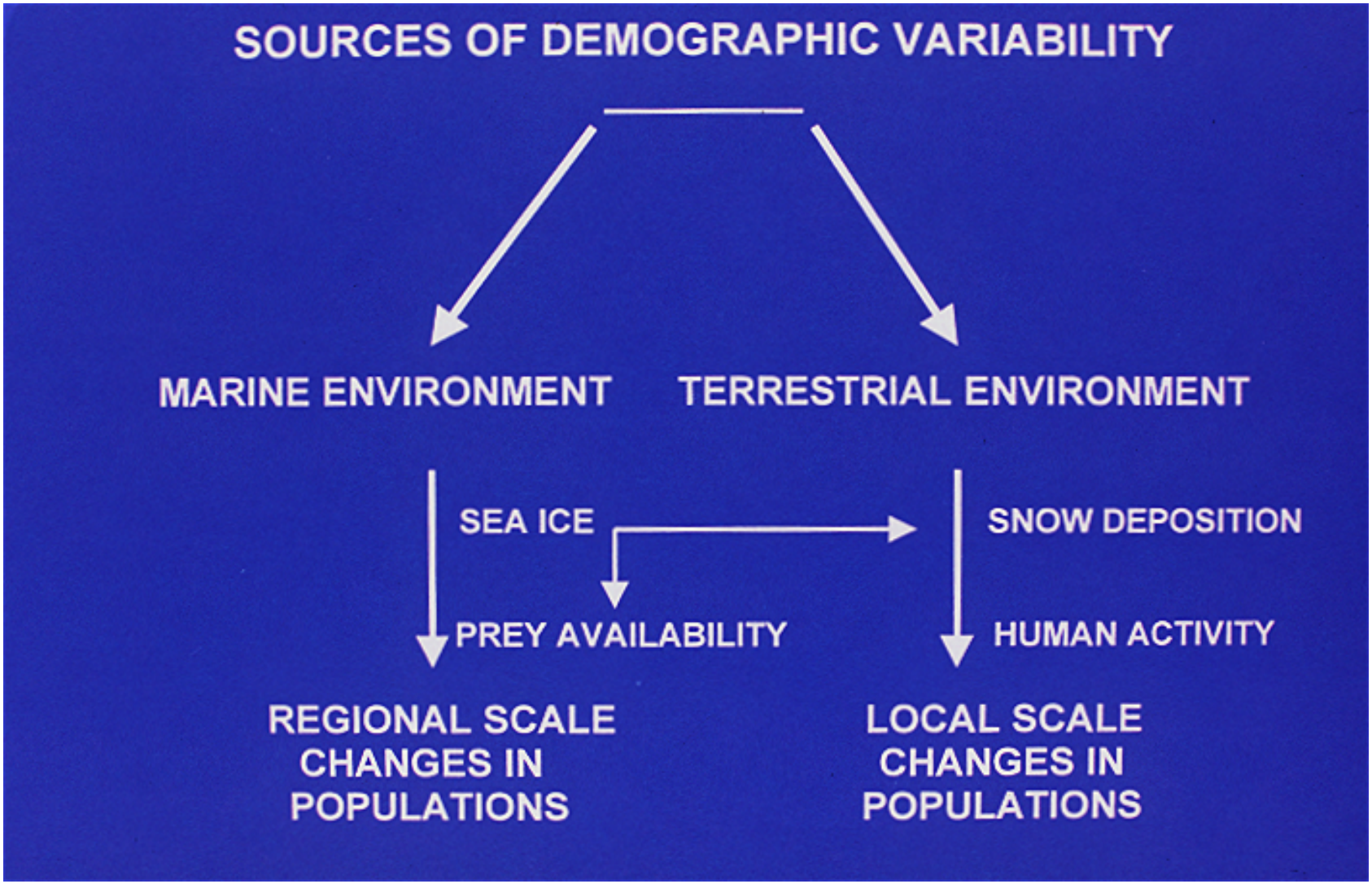
Sea Ice Index:

- **a number (or at most a few numbers) derived from a set of sea ice observations during a year which may be used as a simplified ecological indicator of the yearly behavior of sea ice**
- **provide quantitative definitions of the timing & magnitude of sea ice coverage on temporal & spatial scales relevant to testing ice-ecosystem linkages**
- **used as an indicator, or measure, of variability**
- **show large inter-annual variability in both the timing & extent of sea ice**
- **display marked regional differences in timing & extent of sea ice coverage**
- **References:**
  - Smith, Baker & Stammerjohn, "Exploring Sea Ice Indexes for Polar Ecosystem Studies", BioScience 48, 83-93 (1998)
  - Stammerjohn, Baker & Smith, "Sea Ice Indexes for Southern Ocean regional marine ecological studies", SIO Ref. 97-01 (1997)
  - Stammerjohn & Smith, "Spatial & temporal variability of western Antarctic peninsula sea ice coverage", in ARS 70, 81-104 (1996), Ross et al., eds.


SOURCES OF DEMOGRAPHIC VARIABILITY
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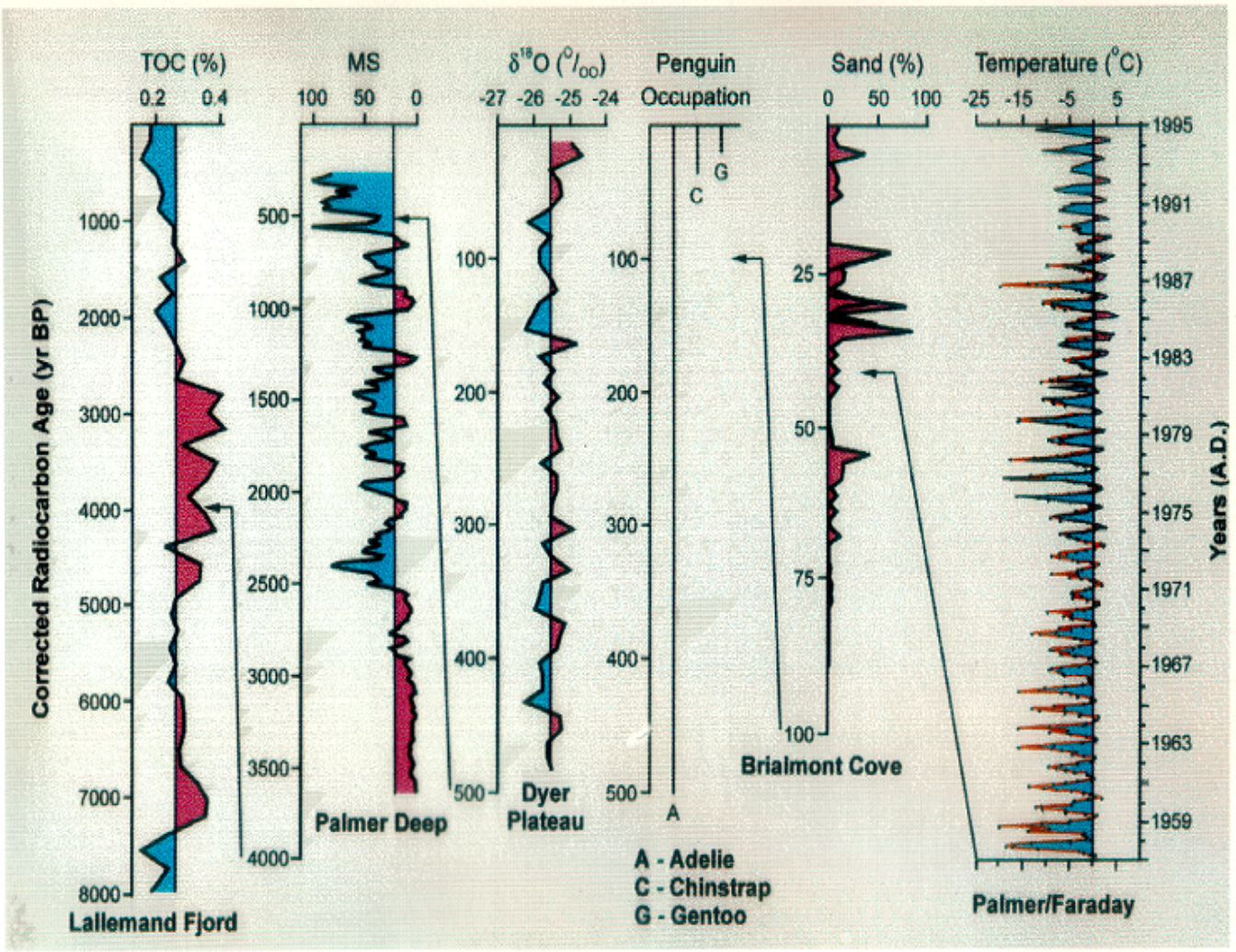
SEA ICE
SNOW DEPOSITION
PREY AVAILABILITY
HUMAN ACTIVITY
REGIONAL SCALE CHANGES IN POPULATIONS
LOCAL SCALE CHANGES IN POPULATIONS

Marine Ecosystem Sensitivity to Climate Change: Western Antarctic Peninsula (WAP)

- **Ray Smith (UCSB), Eugene Domack (Hamilton College), Steve Emslie (Western State College), Bill Fraser (Montana State U.), David Ainley (T.H. Harvey & Associates), Karen Baker (UCSD), Jim Kennett (UCSB), Amy Leventer (Colgate College), Ellen Mosley-Thompson (Ohio State U.), Sharon Stammerjohn (UCSB), Maria Vernet (UCSD)**
- **evidence of major change in the marine ecosystem of the WAP in response to climate change during the past century**
- **all records are consistent:**
  - historic & instrument records
  - distribution of sea birds
  - ice cores
  - marine sediments
- **evidence that WAP is a location where slight changes in sea ice extent may amplify the biotic response to climate variability**

Paleoenvironmental records



Smith et al Bioscience 1998

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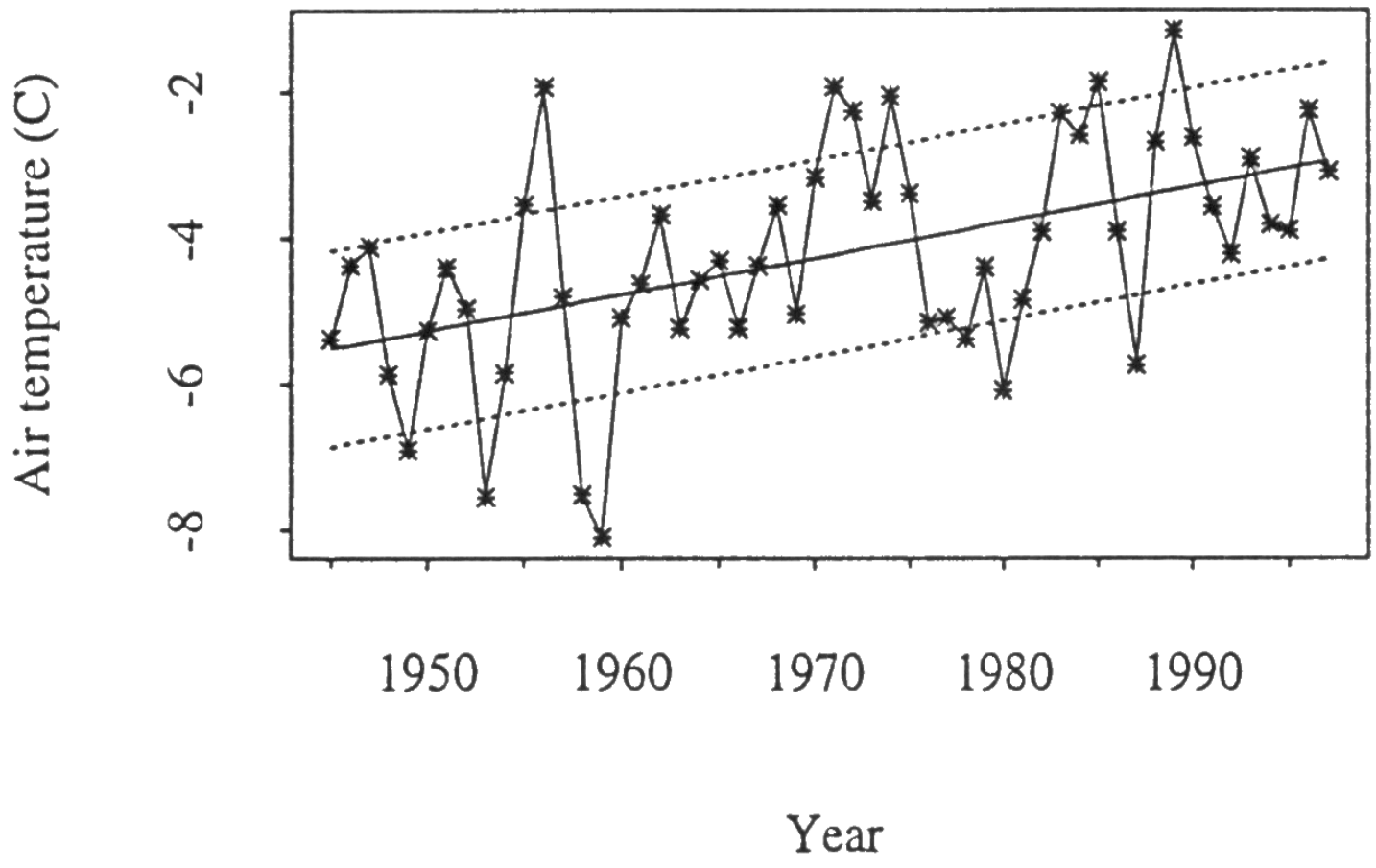
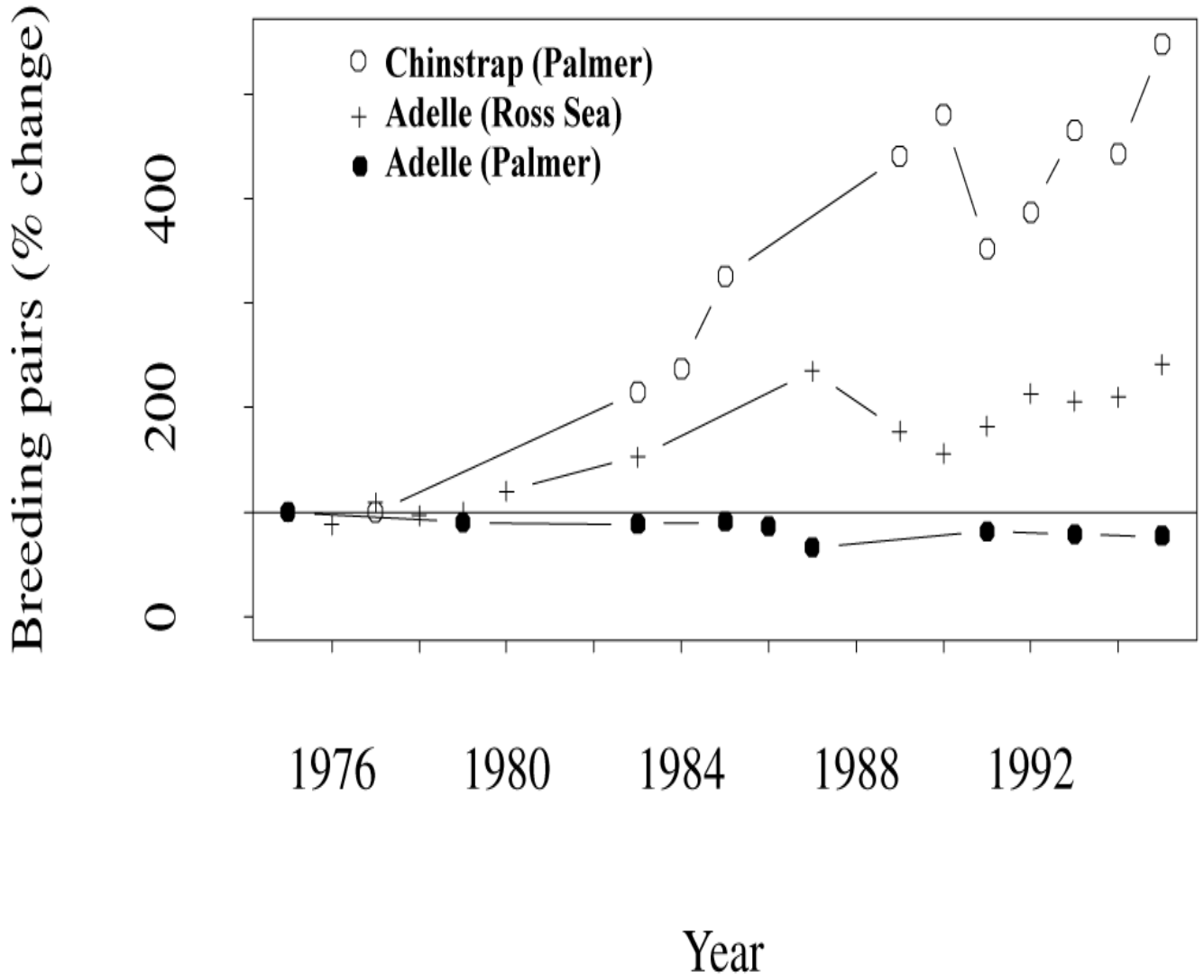
Faraday annual air temperature



Penguin trends



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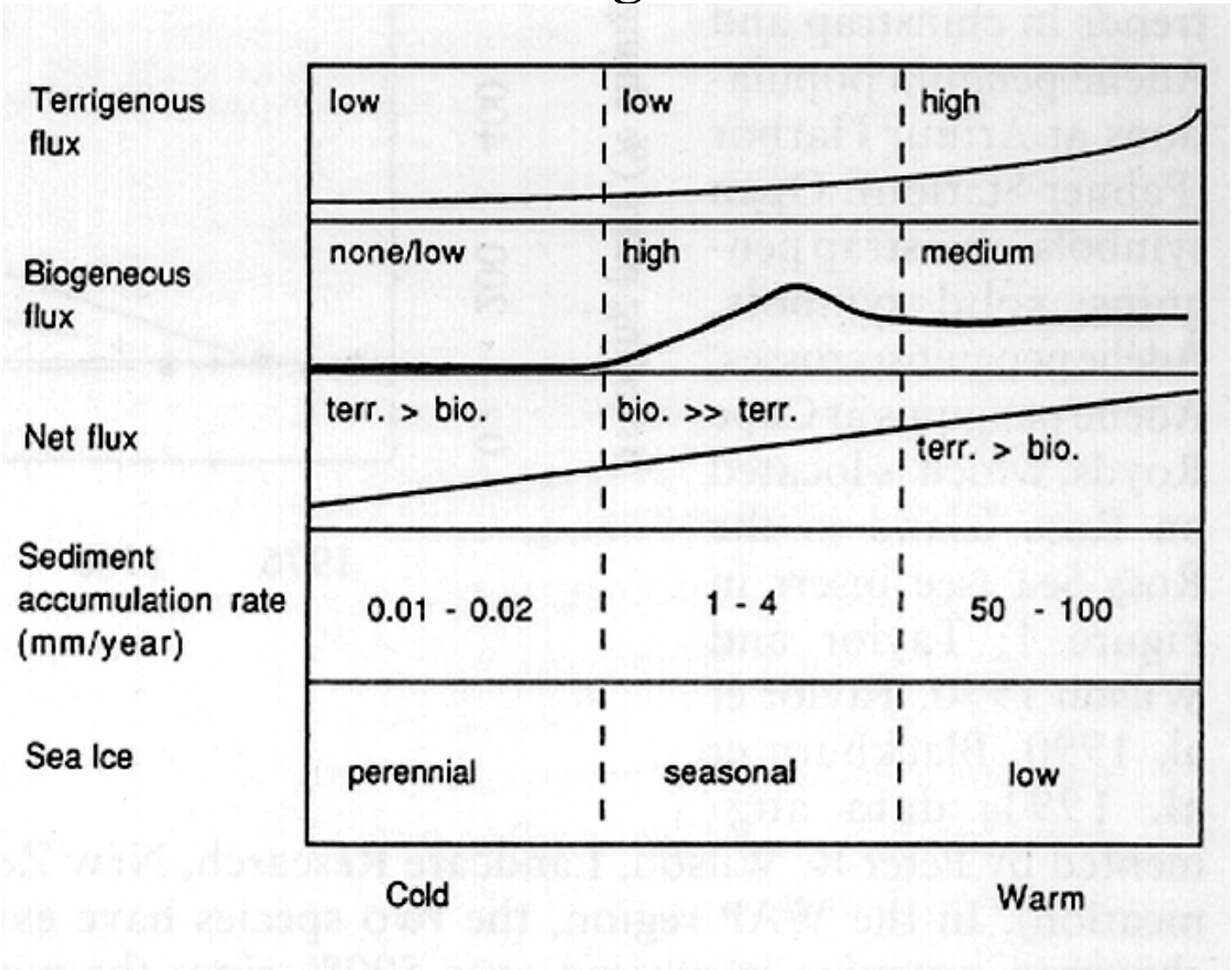
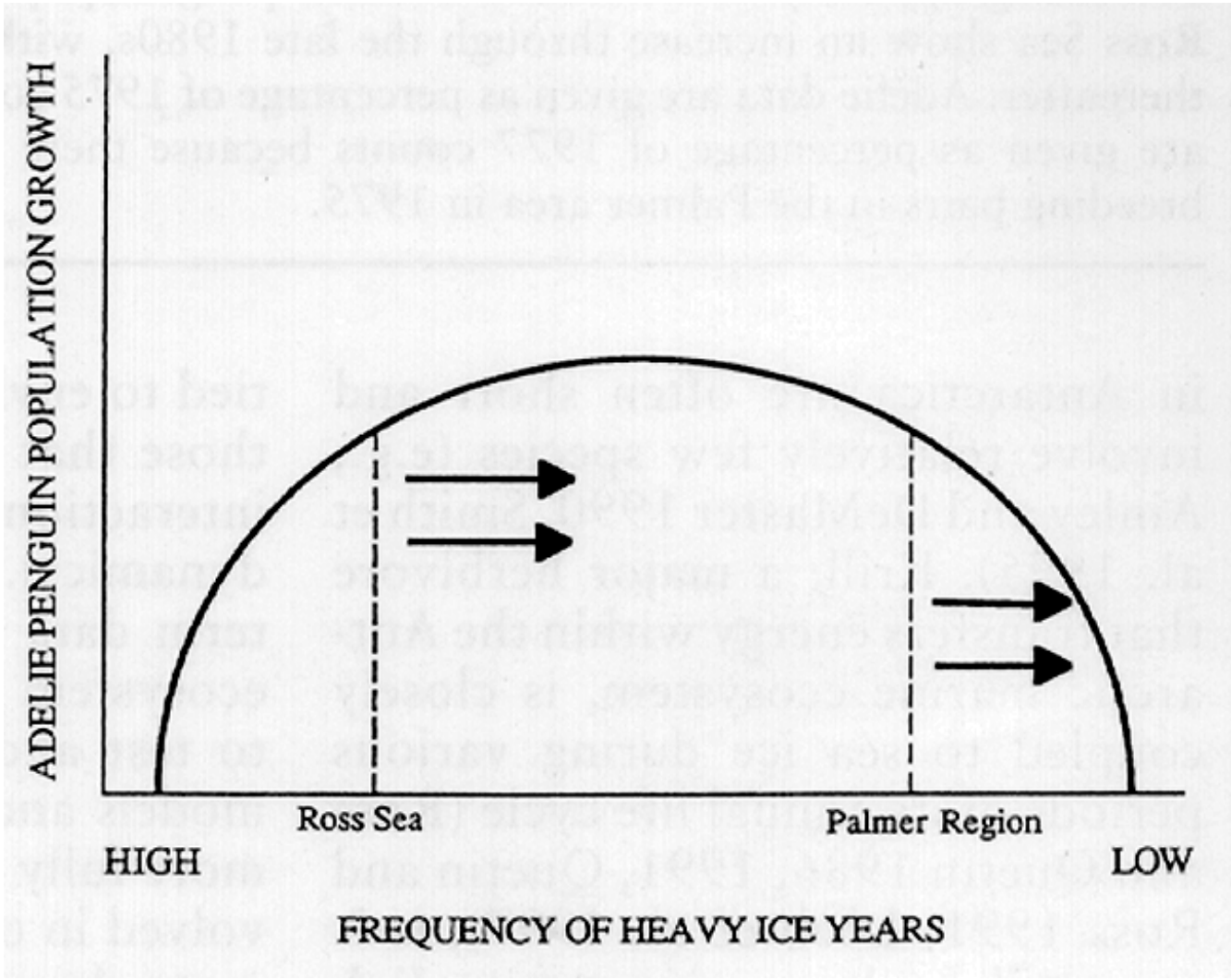
Sediment Record & Biological Production



Adelie penguin population growth & sea ice



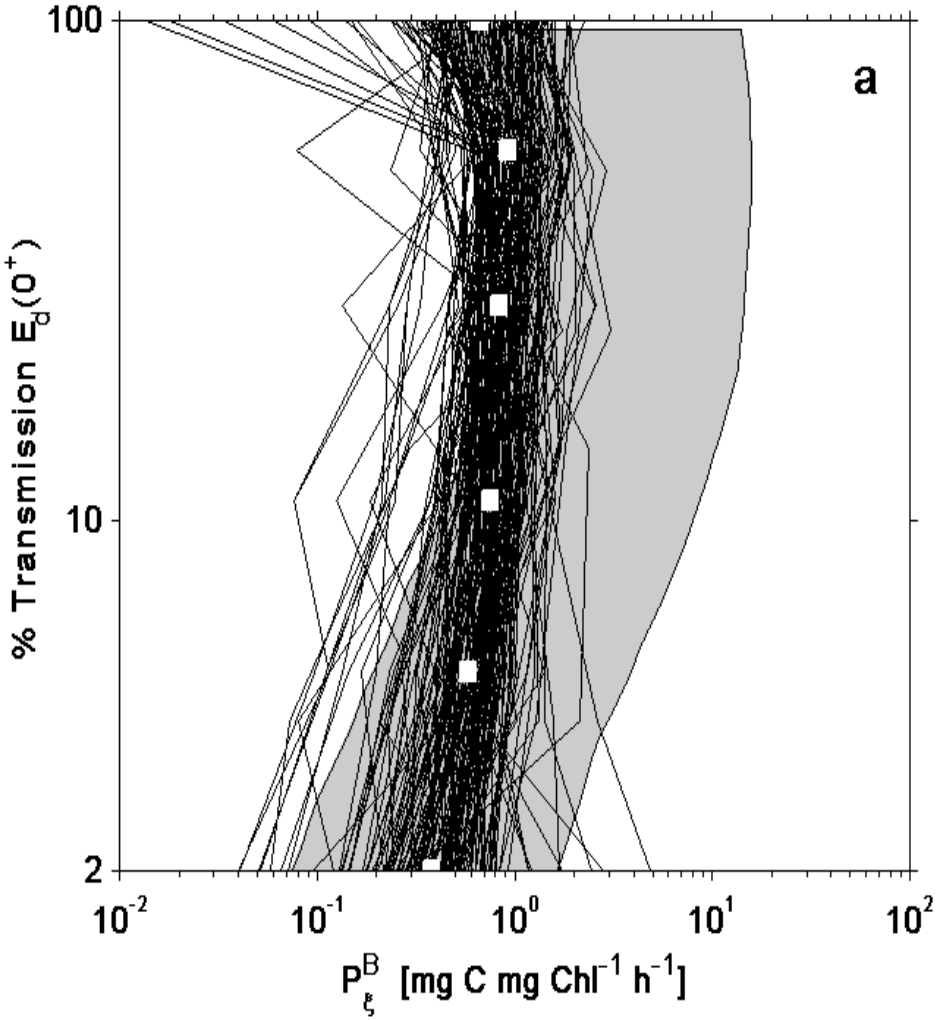
Western Antarctic Peninsula - Paleohistory Summary

- **All evidence** indicates warming during this past century
- trend evident in spite of **large inter-annual variability** & decadal scale (ENSO) variability
- **climate gradient** along WAP valuable for assessing **ecological response** to climate variability
- **marine sediment record** cooler climate (LAI) preceeded by warmer period (~ 2700 yr BP)
- WAP regions show **cyclical fluctuations** in organic matter (time scale 200-300 yrs) & associated with primary productivity
- opposite in preferred habits (ice-obligate Adelie, ice-intolerant Chinstrap penguins) provides guage for assessing ecological change
- century scale cycles challenge us to understand these fundamental processes if we are to understand, & distinguish, **natural from anthropogenic** causes

Primary Production of the Western Antarctic Peninsula and the Southern Ocean

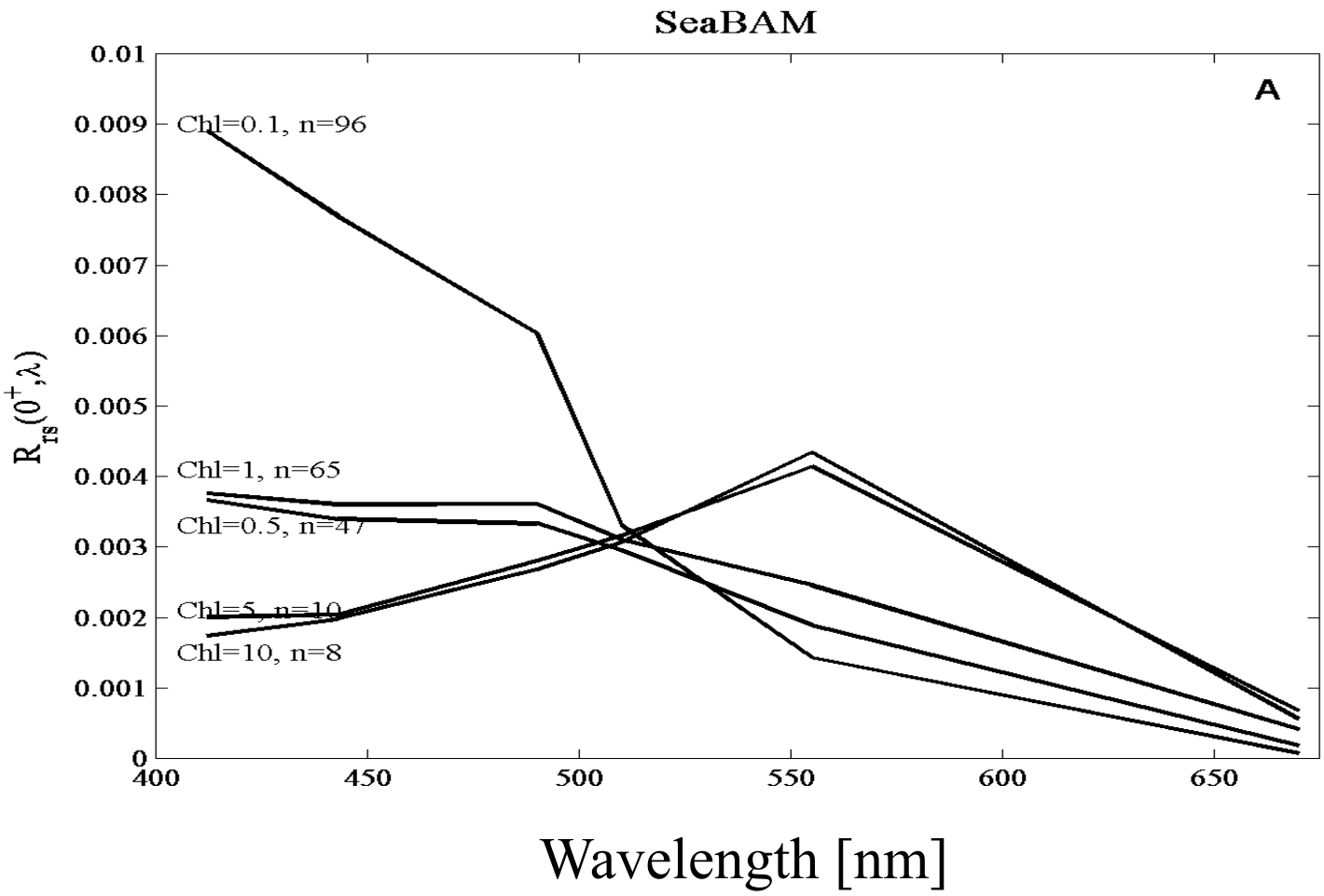
Raymond C. Smith
Heidi M. Dierssen
Maria Vernet
Karen Baker

Normalized Production

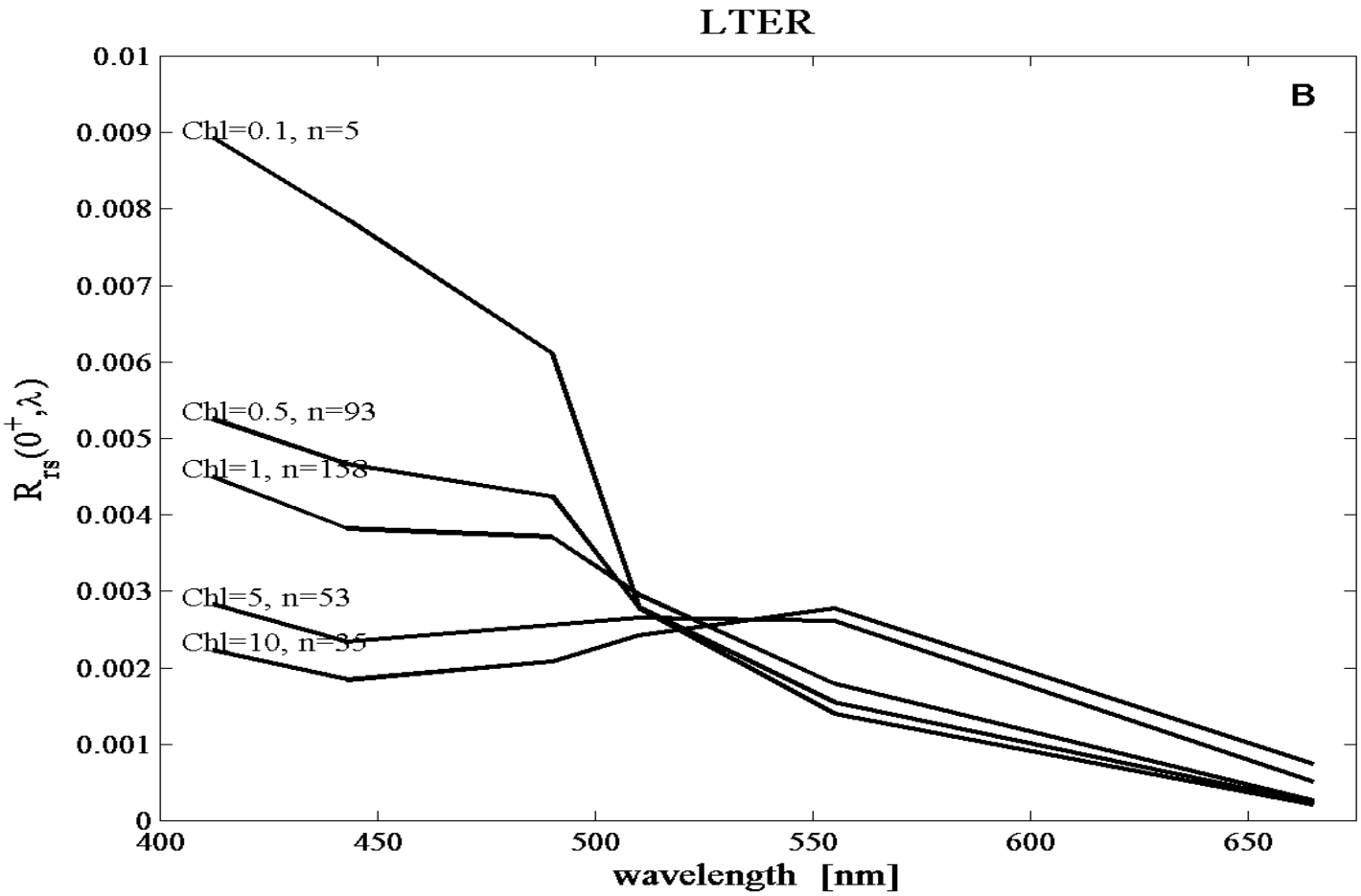


- **Grey area - 500 randomly chosen stations from MARMAP (B&F, 1997)**
- **Lines - LTER data**
- **Squares - median LTER data**

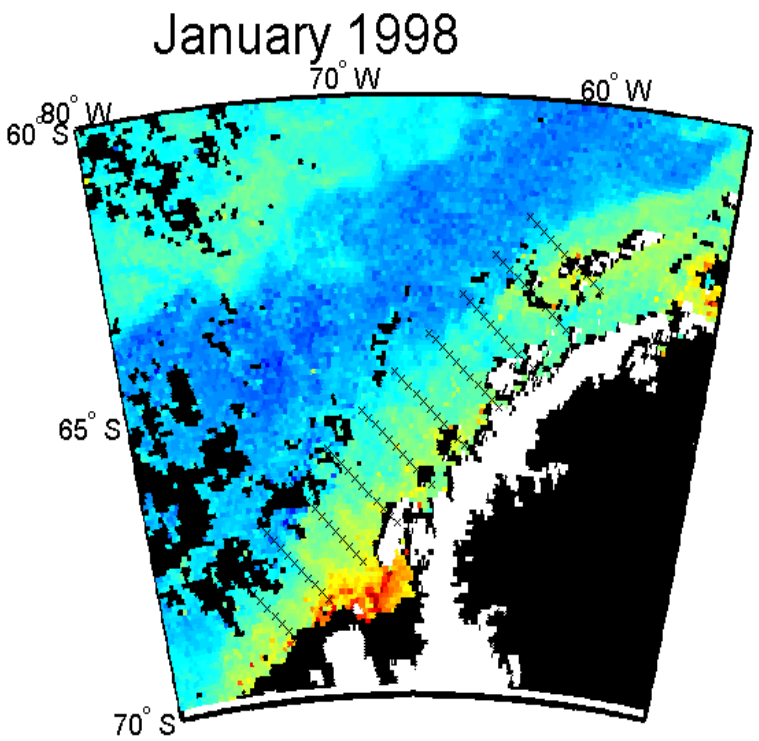
Remote Sensing Reflectance vs. wavelength

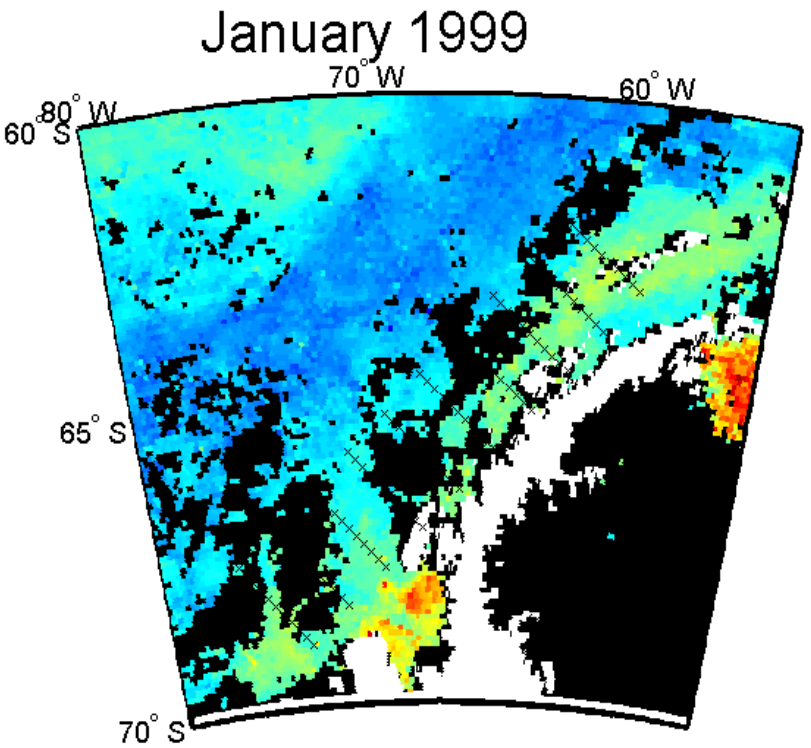


Rrs (λ) vs. λ


LTER
B
Chl=0.1, n=5
Chl=0.5, n=93
Chl=1, n=158
Chl=5, n=53
Chl=10, n=35
$R_{rs}(0^+,\lambda)$
wavelength [nm]
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
400
450
500
550
600
650

LTER Primary Production (SeaWiFS)





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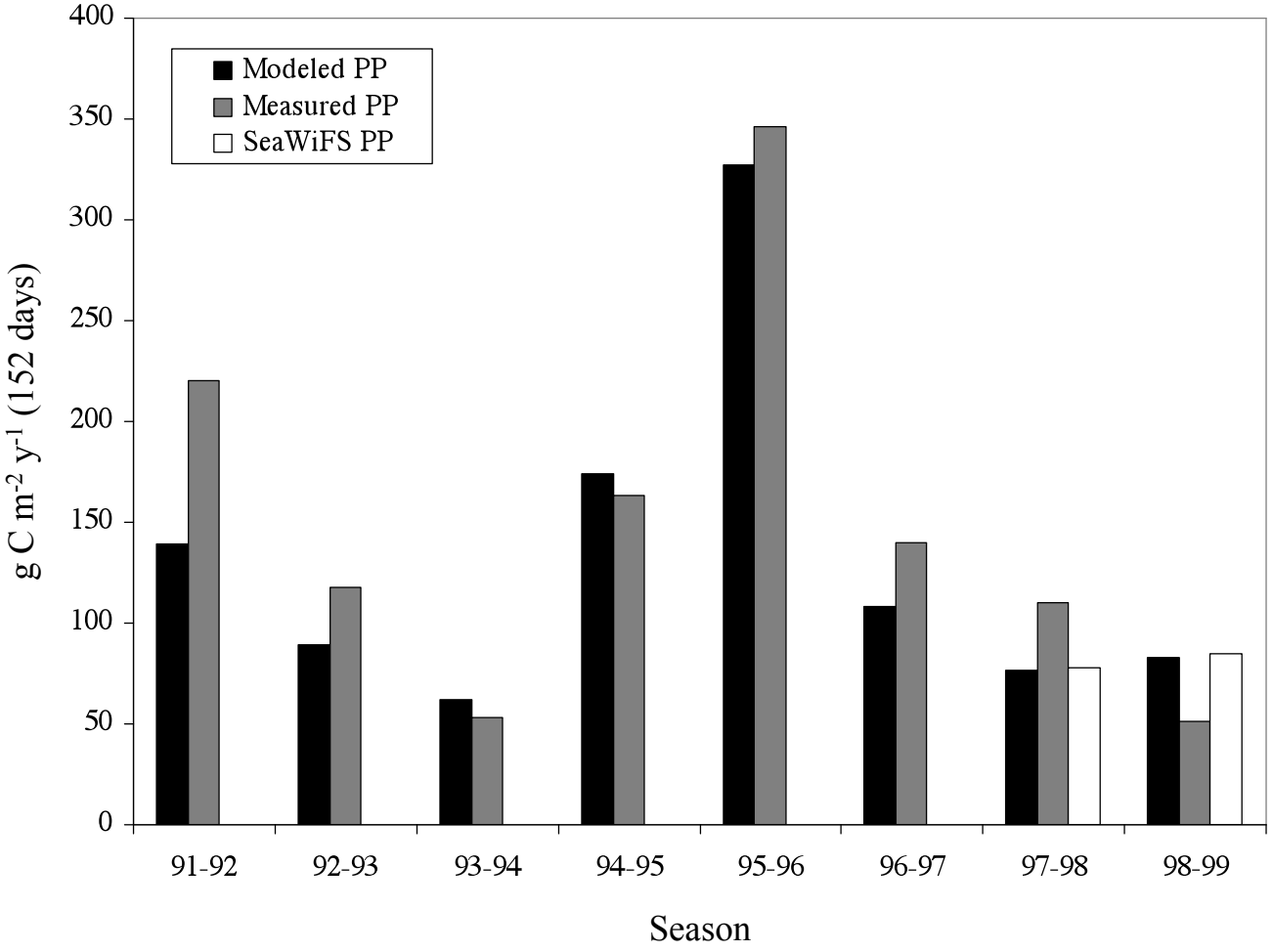
Long Term Ecological Research

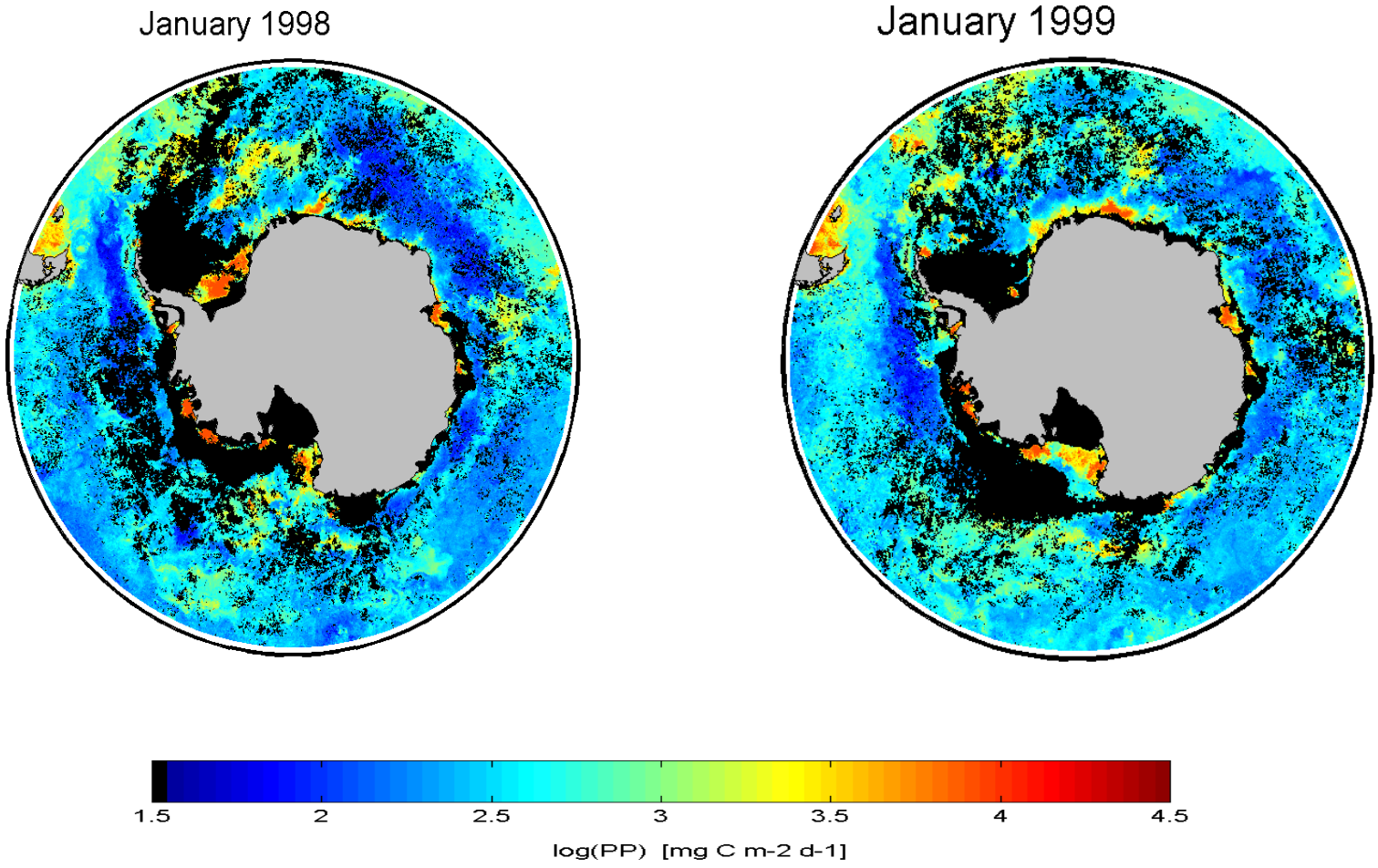
LTER Annual Primary Productivity



PALMER Long Term Ecological Research

LTER Long Term Ecological Research

Southern Ocean Primary Productivity



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Comparison

	PP ($x10^{15}$g yr^{-1})
• ***In situ***	
○ El-Sayed (1968)	3.3
○ Holm-Hansen (1977)	0.5
○ Berger (1987)	5.2
• ***CZCS - annual averages***	
○ Longhurst et al. (1995)	6.5
○ Smith et al. (1995)	2.1(1)
○ Antoine et al. (1996)	5.9(2)
○ Behrenfeld & Falkowski (1997)	4.8(2)
○ Arrigo et al. (1998)	3.2-4.4
• ***SeaWiFS***	
○ this study (with cloud)	2.4
○ this study (max. area)	3.2(3)

- **(1)=to 55°S; (2)=corrected CZCS images; (3)using monthly area estimates from Arrigo (1997)**

Summary

- **unique LTER bio optical data set for SO**
- **bio optical properties in waters of the SO are distinct compared to other regions**
  - chl normalized production
  - Rrs
- **modified SeaWiFS derived chl for SO**
- **optimized primary production model for SO**
- **estimated primary production for the SO**
- **Good agreement between LTER and SeaWiFS (corrected) Chl**
- **Annual PP estimates**
  - **Palmer Station**
    - **93-95 gC m^{-2} y^{-1}**
    - within range of previous years
    - but with high interannual variability
  - **Southern Ocean**
    - **2.4-3.2 x10^{15} g yr^{-1}**
    - consistent with earlier estimates