Space-Time Scales in Oceanography and the LTER Sampling Strategy

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Palmer LTER Site Review 1994

Palmer LTER Research

Central Hypothesis:

Interannual variations in physical processes, such as the extent of pack ice and oceanic circulation, affect all levels of the food web of the Southern Ocean.

Palmer LTER General Objectives

- **Document interannual variability** in the development and extent of annual pack ice as well as in the life-history parameters of primary producers and populations of key species from different trophic levels in the Antarctic marine food web;
- **Quantify the processes that underlie natural variation** in these representative populations;
- **Construct models that link ecosystem processes** to physical environmental variables, and that simulate the spatial/temporal relationships between representative populations; and
- **Employ such models to predict and validate** the impacts of altered periodicity's in the annual extend of pack ice on ecosystem dynamics.

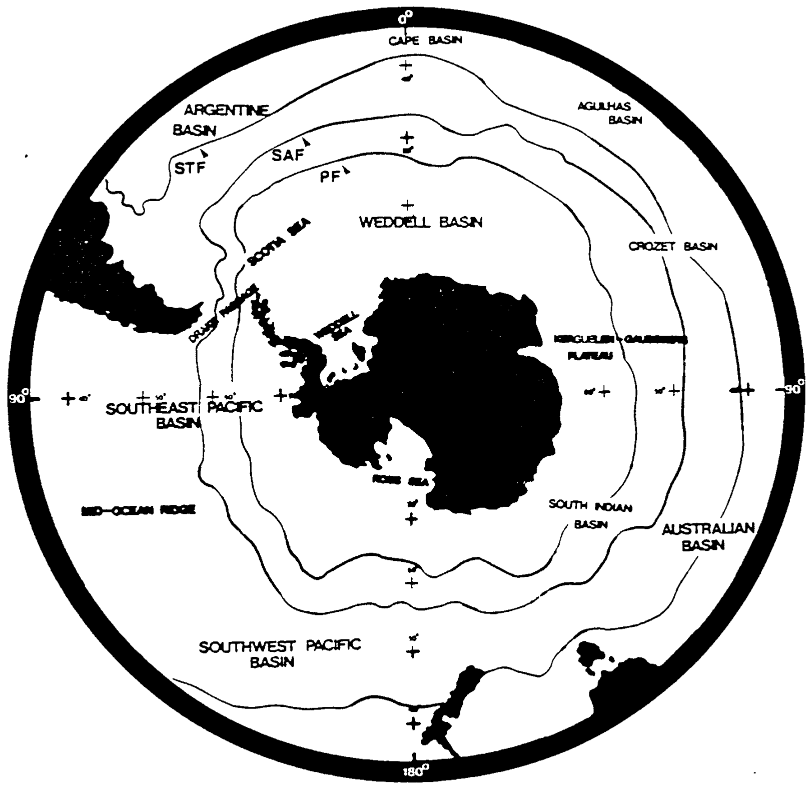
Space/Time Scales and Sampling Strategies in Oceanographic Research

- **Conceptual framework to characterize space/time scales**
  - identify important mechanisms
  - link tropic levels in context of space/time
  - significance of heterogeneity for ecosystem stability
  - increase reliability of sampling
- **Palmer Grid and Sampling Strategy**
  - match space/time scales of Palmer LTER
  - fixed geographic locations visited repeatedly over time
  - simplifies modeling computations
  - integrates space/time data from different scales
- **Example as introduction to integrated data scheme**

Antarctic LTER Space/Time Scales

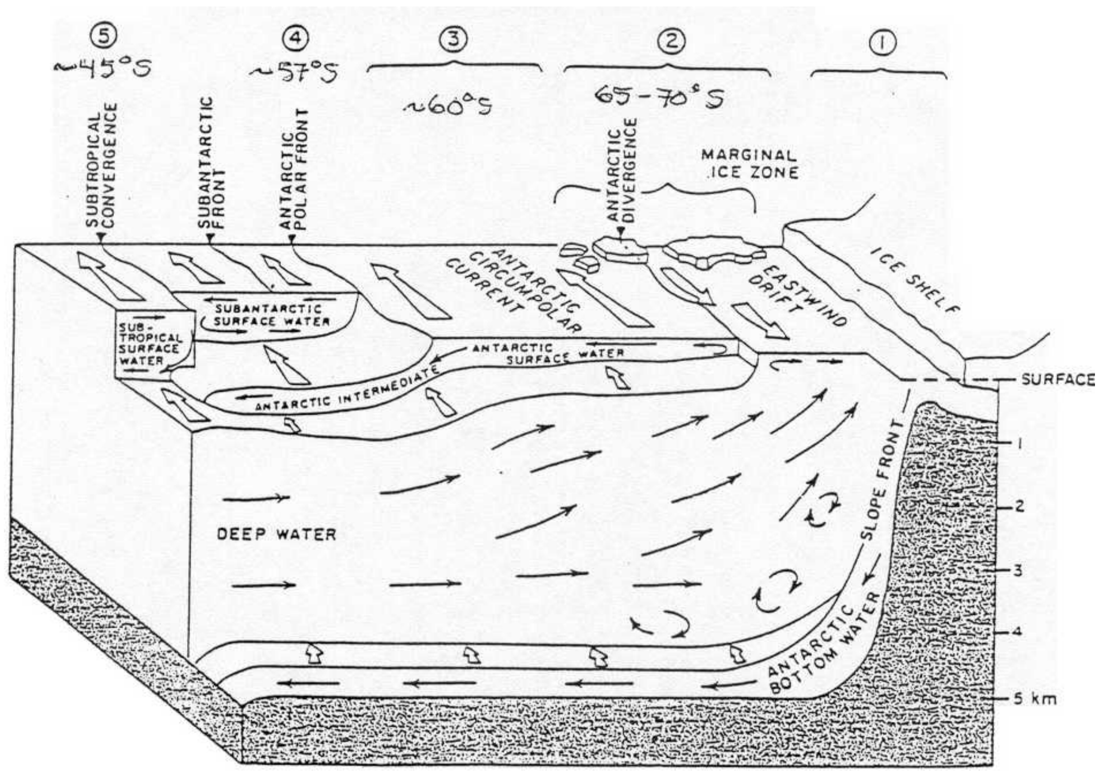
FIELD	AREA[km2]	
Phytoplankton patch	1x1	10^0
krill swarm	1x10	10^1
seabird forage	50x50	10^3
“near” field	100x100	10^4
AA Peninsula	200x900	10^5
Bellingshausen ice cover		10^6
Southern Ocean ice cover		10^7

FORCING/PROCESSES	TIME[min]	
optical variability	min-hr	10^-1
phytoplankton (diel)	hrs	10^1-10^3
seabird forage cycle	2 days	10^3
phytoplankton bloom	days	10^3
episodic weather	h-d	10^1-10^4
ice movement	h-wks	10^1-10^5
annual cycle	yr	5x10^5
life cycle krill/birds	yrs	10^6

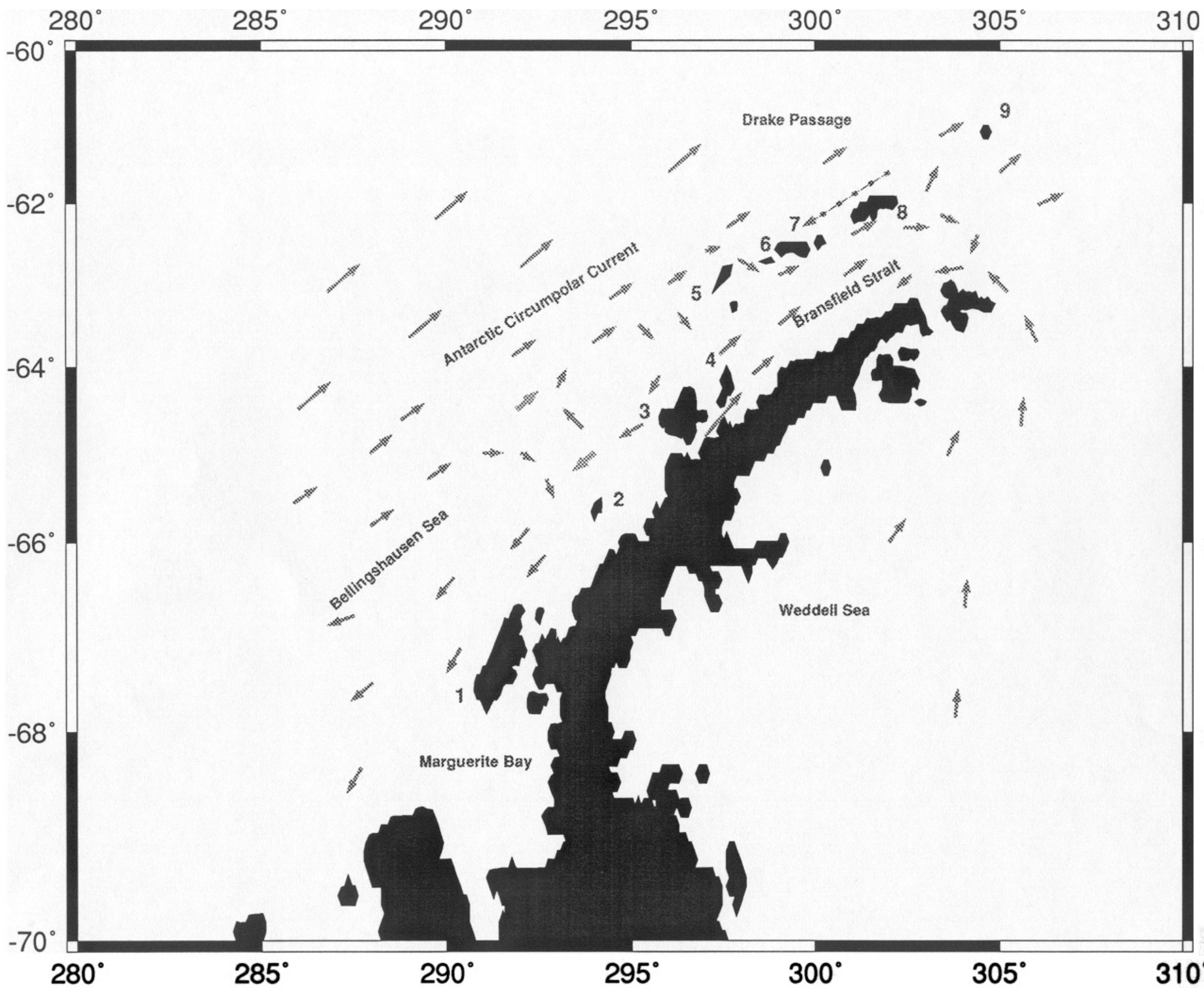


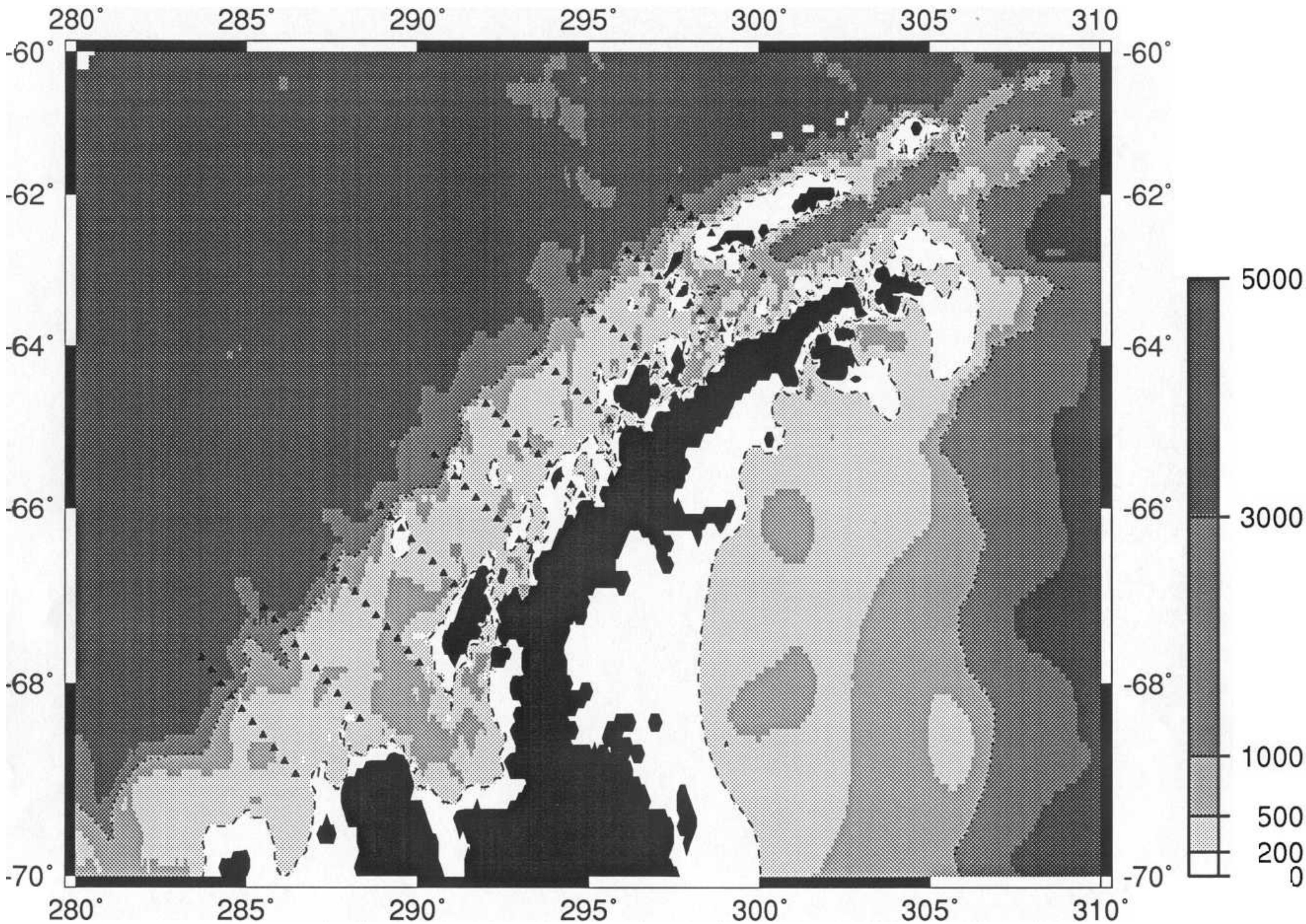
Physiography of the Arctic Basin and
the waters around the Antarctic continent.

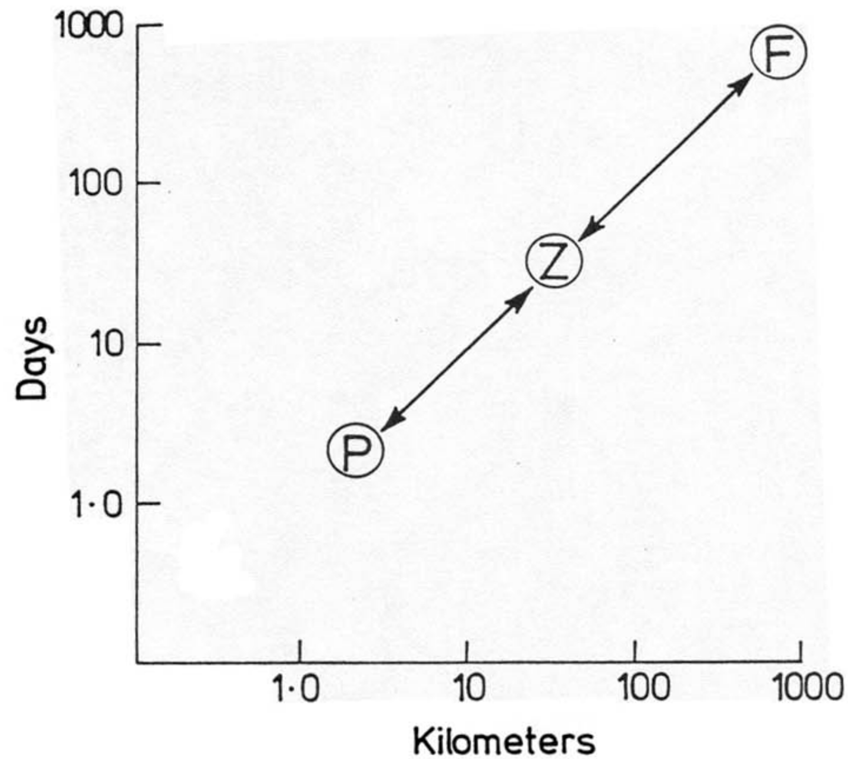
Characteristic Zones of the Southern Ocean



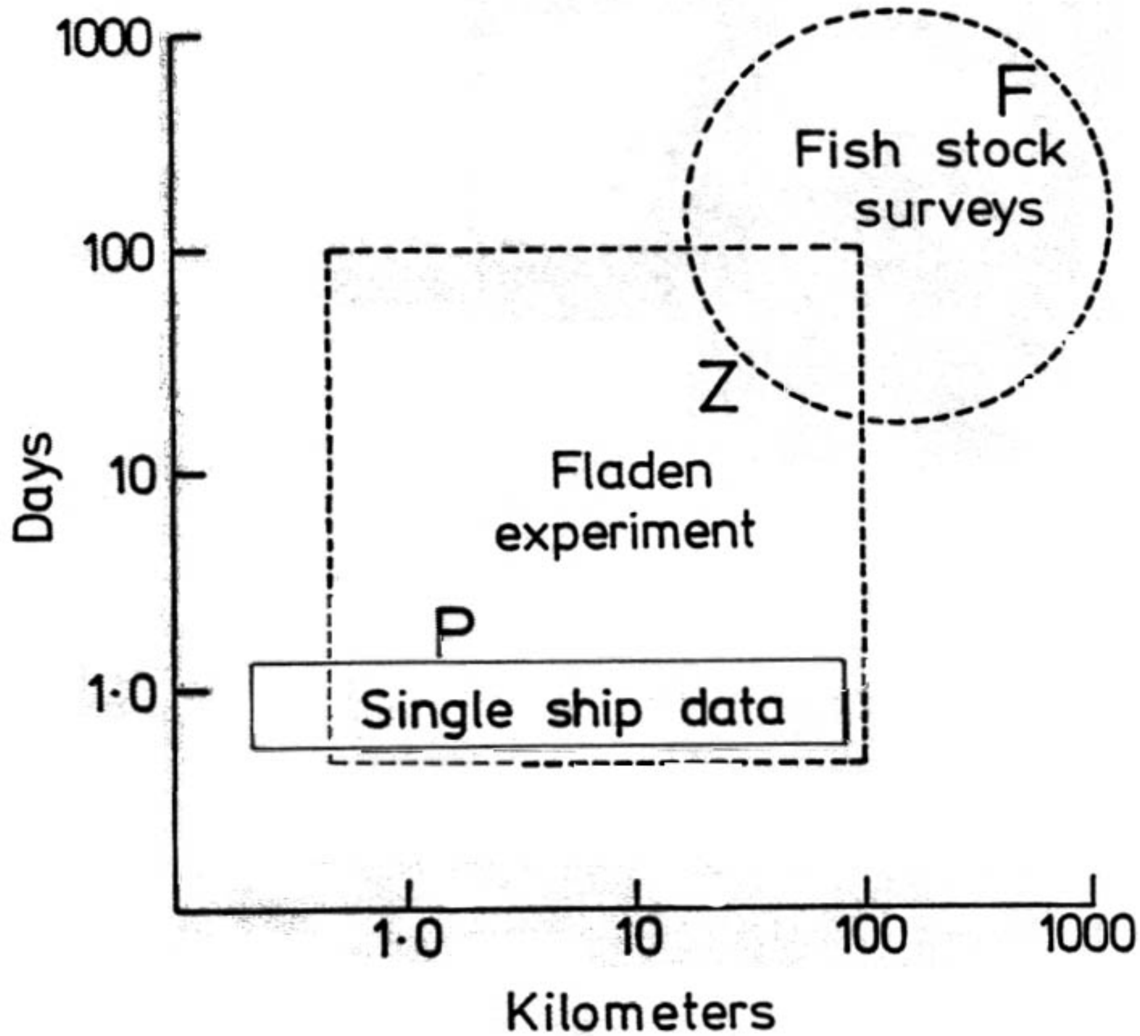
Large-scale circulation of the Southern Ocean showing five zones recommended for study within the US JGOFS Southern Ocean process study. [redrawn from Lutjeharms et al. (1985)]


280˚
285˚
290˚
295˚
300˚
305˚
310
-60˚
-62˚
-64˚
-66˚
-68˚
-70˚
Drake Passage
Antarctic Circumpolar Current
Bransfield Strait
Bellingshausen Sea
Weddell Sea
Marguerite Bay
1
2
3
4
5
6
7
8
9

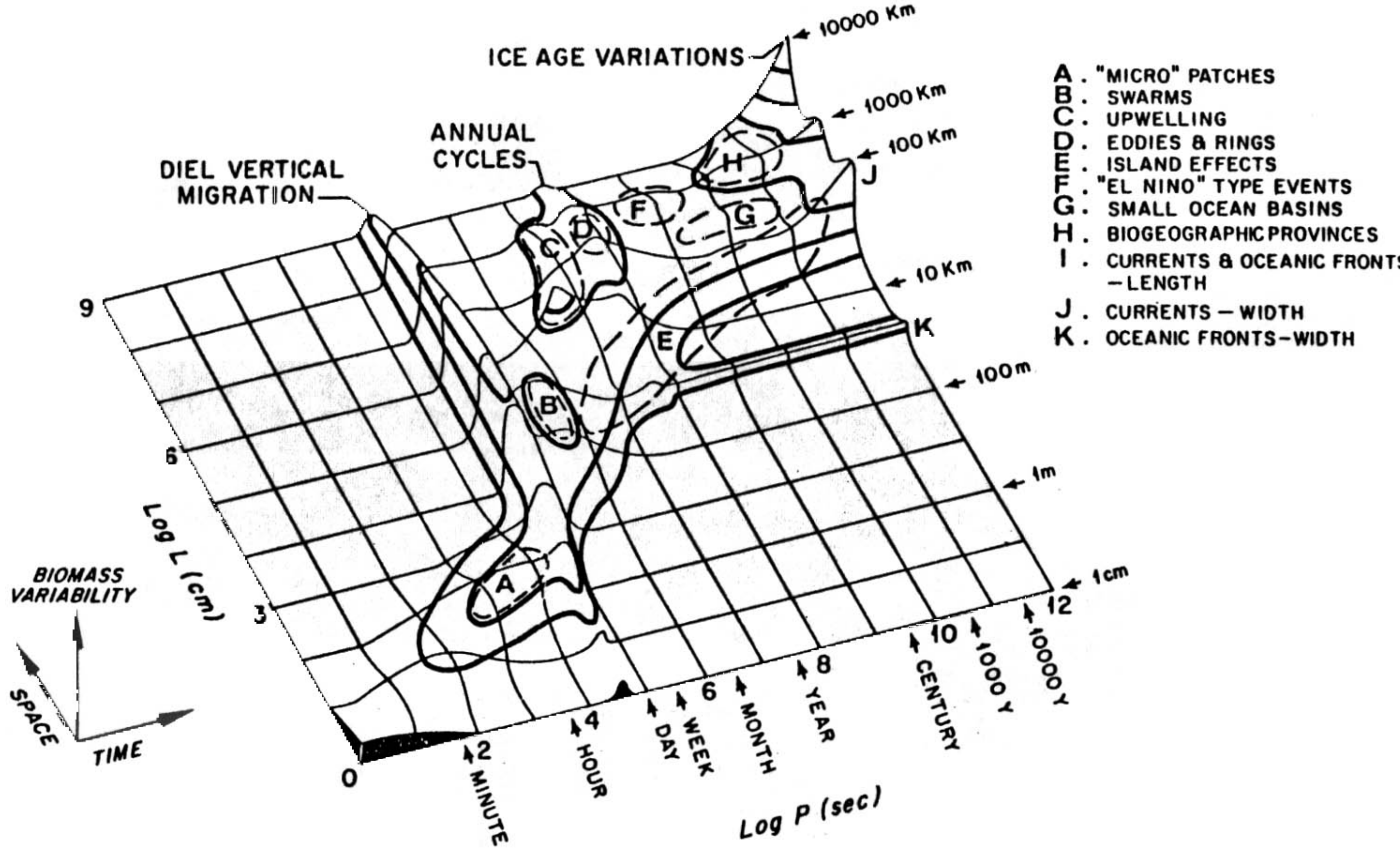

280° 285° 290° 295° 300° 305° 310°
-60° -62° -64° -66° -68° -70°
5000
3000
1000
500
200
0



A very simplified representation of typical time and space scales associated with plants (P), herbivorous zooplankton (Z) and pelagic fish (F). [Steele, 1978]

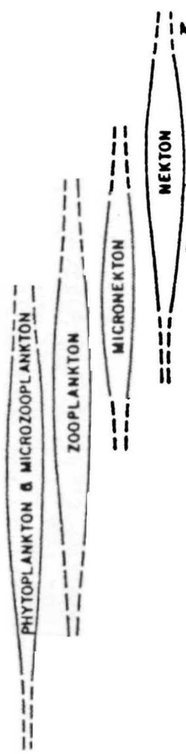


An indication of the space and time scales covered by various types of sampling programs. [Steele, 1978]



The Stommel Diagram, a conceptual model of the time-space scales of zooplankton biomass variability and the factors contributing to these scales. [Haury, McGowan and Wiebe]

Scales of Plankton Patterns

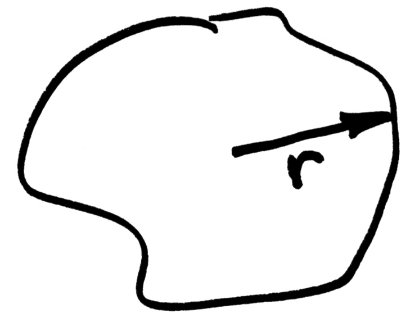


NAME	SPACE SCALE	DOMINANT PATTERN *	HOW BEST LOOKED AT	WHAT WE LEARN
MEGA	10^4 km	Vectorial	Communities Biomass Species	Biogeography Evolutionary history
MACRO	10^3 km	Vectorial Reproductive	Communities Biomass Species	Biogeography Speciation "Best" places to live Ecotones Inter-community competition "Hot spots" within ecosystems
MESO	10^2 km	Vectorial Reproductive	Biomass Species	Faunal boundaries Invasions Nekton ambit Genetic selection Relationship to environmental parameters
COARSE	10 km 1 km	Vectorial Reproductive Coactive Social	Species	Intra-community competition Upwelling responses Micronekton ambit Relationship to environmental parameters
FINE	100 m 10 m	Vectorial Reproductive Coactive Social	Species	Coexistence, niche partitioning Inter-and intra-species competition Predation Food densities required Zooplankton ambit Relationship to environmental parameters
MICRO	1 cm	Vectorial Social	Species Individual	Inter-and intra-species competition Niche partitioning Relationship to environmental parameters

* Stochastic acts on all scales

Haury, McGowan and Wiebe

Phytoplankton Patches



- a "patchy" distribution is one for which the ratio of the variance to the mean is far greater than would be expected if individual organisms were positioned randomly within the sampled region
  - loss of organisms due to diffusion through boundary = circumference=2*pi*r
  - gain through reproduction

    = area patch = pi*r*r
  - diffusion/reproduction ~ 1/r
- as size of a water mass decreases, diffusion is relatively more important and eventually a limit is reached beyond which reporduction can no longer compensate for the loss due to diffusion

D = diffusivity $[L^2 \cdot T^{-1}]$

g = growth rate phytoplankton $[T^{-1}]$

L = length

T = time

suppose critical size $L_c = F(D,g)$

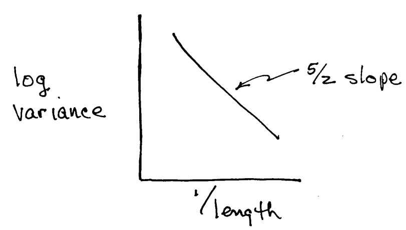
dimensional analysis leads to

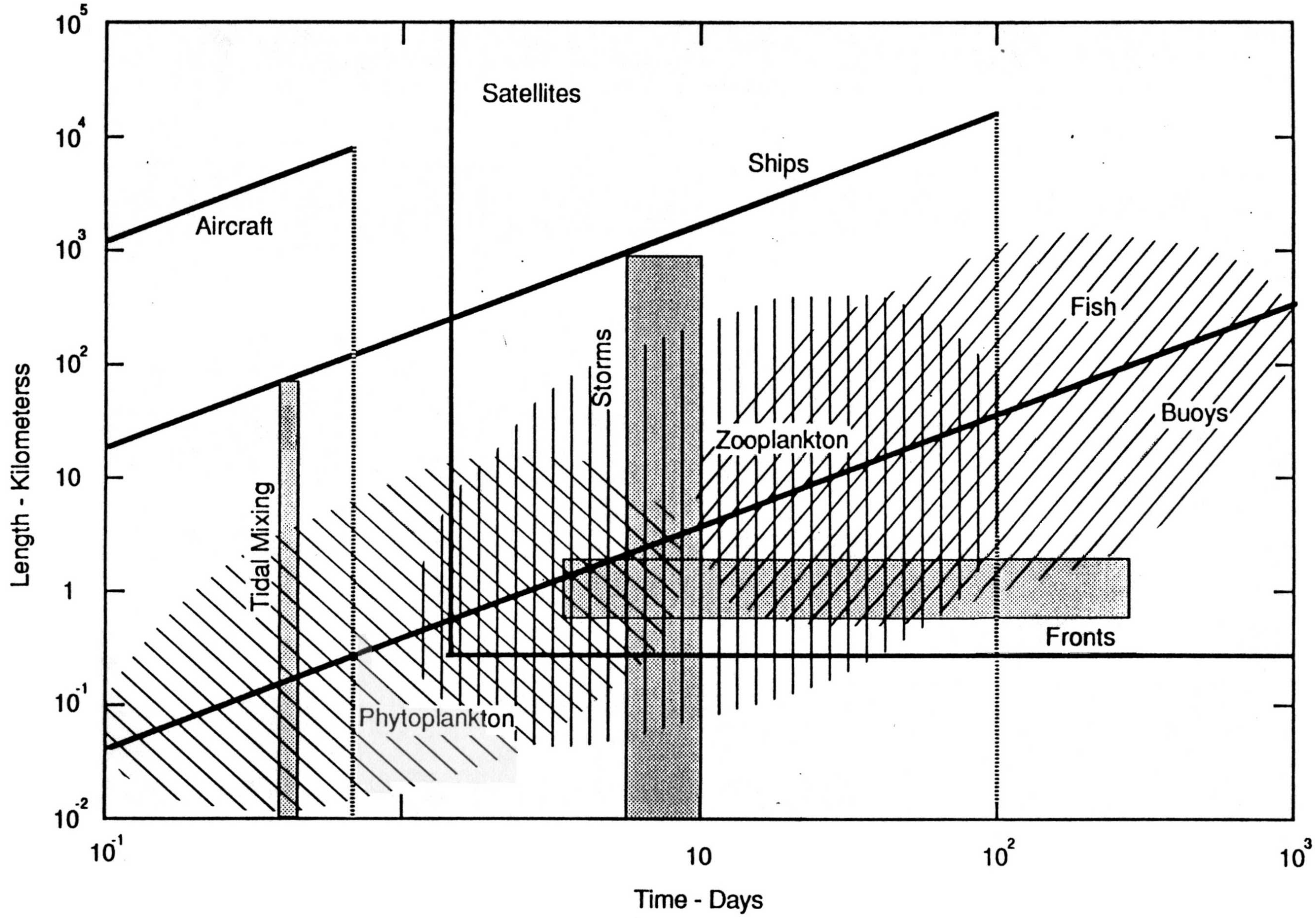
$L_c = b\,(D/g)^{1/2}$ [L]

b = non-dimensional constant of order unity

$L_c \approx$ 1 km g = 1 division/day

$L_c \approx$ 7 - 20 km g = 3 division/day





Satellites
Ships
Aircraft
Fish
Buoys
Storms
Zooplankton
Tidal Mixing
Fronts
Phytoplankton
Length - Kilometerss
Time - Days
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-1}
10
10^2
10^3

Space/Time Domains of Oceanographic Research Platforms

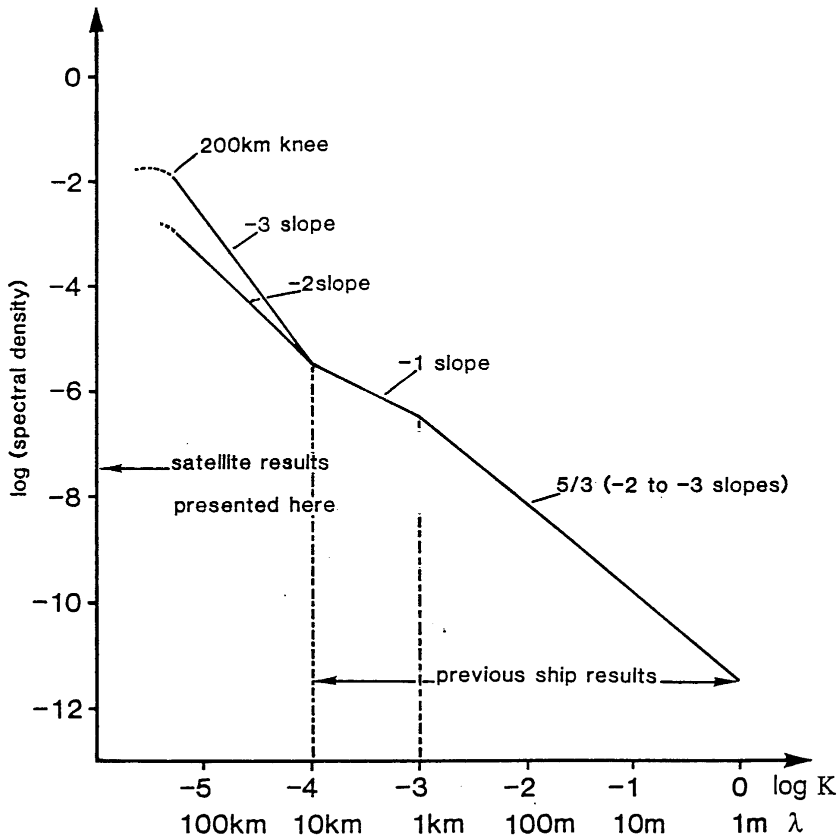
Platform Description	Sampling Domains		
	Time	Horizontal	Vertical
Moorings	1 min - years	cms	At fixed depths: 10 m - 100 m
Ship on station	<1 h - 4 weeks	On station: cms Inter-station: kms	<1 m - 100 m
Ship mapping/fixed depth	1.5 days - 4 weeks	<1 m - 100 km	± few meters upper 100 m
Ship tow-yos	1.5 days - 4 weeks	0.5 km - 100 km	<1 m - 100 m
Drifters/fixed depth	1 min - 6 months	<1 m - 1000 km	± few meters upper 10 m
Planes	1 day - 1 week	10 m - 1000 km	Upper few meters (opt. atten. depth)[a]
Satellites	1 day - years	1 km - global	Upper few meters (opt. atten. depth)

[a]optical attenuation depth

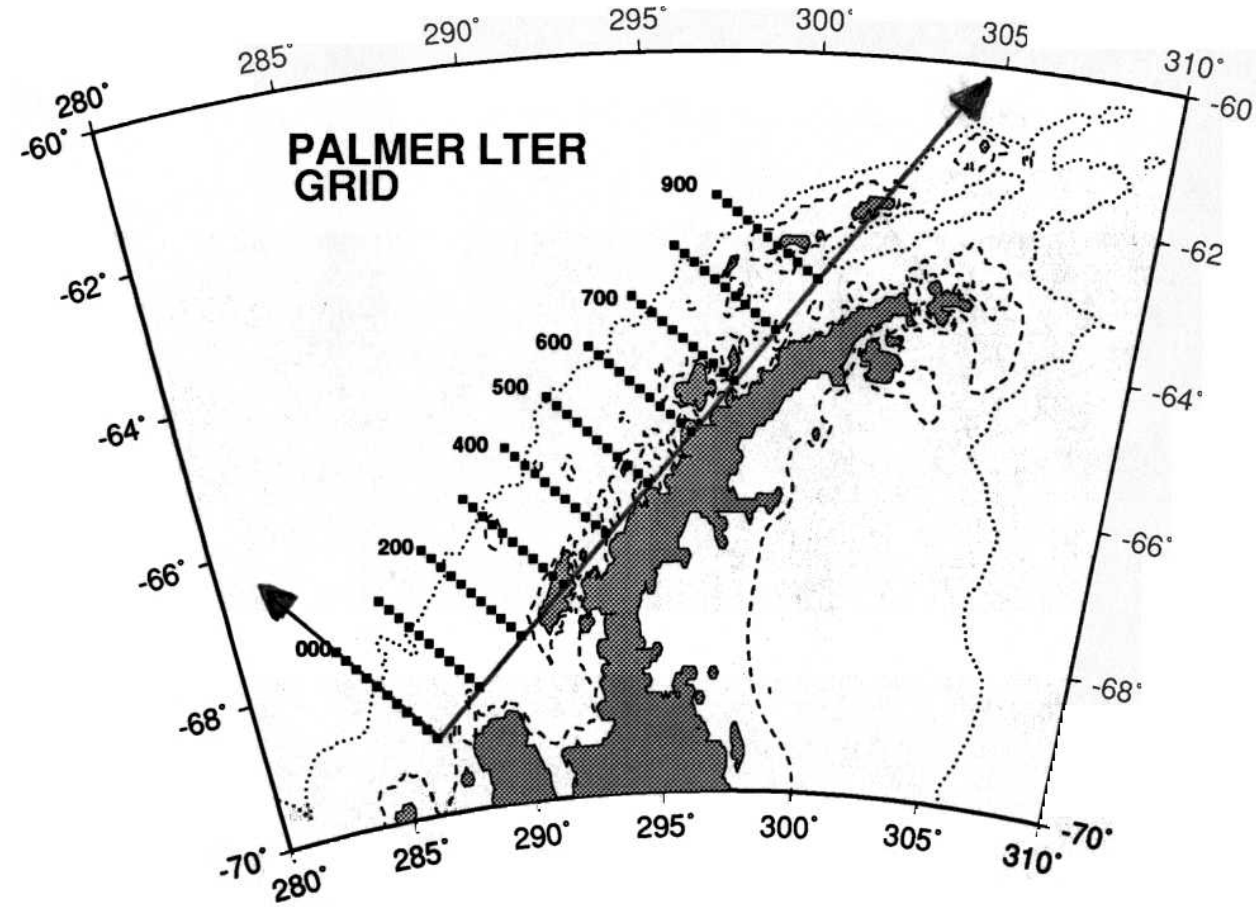
Space/Time Scales of Phytoplankton Variability

- Of interest per se
- A central component in dynamical biological oceanography to
  - characterize scales descriptively under different environmental conditions
  - identify mechanisms leading to space/time variability in phytoplankton populations
  - understand the proximal determinants of phytoplankton growth and the linkages of this growth to high tropic levels
  - understand the significance of this heterogeneity in terms of the stability of the ecosystem
  - understand the fundamental variability of the ocean environment in order to increase the reliability of sampling

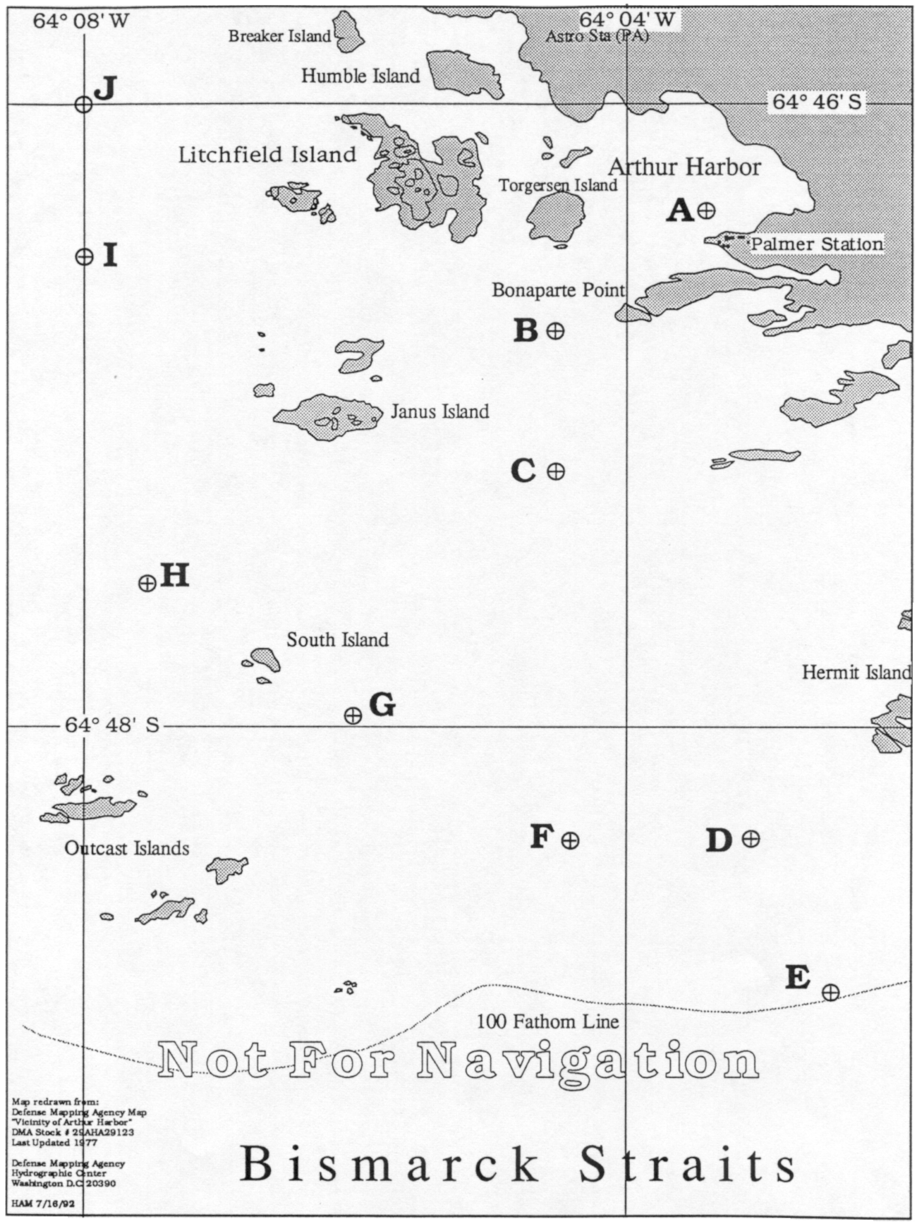
Schematic Power Spectra for the Horizontal Variability of Chlorophyll



[Smith, Zhang, Michaelsen, 1988]



GMT Aug 3 13:27 ltergridutm.ps


64° 08' W
64° 04' W
Breaker Island
Astro Sta (P.A)
Humble Island
J
64° 46' S
Litchfield Island
Arthur Harbor
Torgersen Island
A
Palmer Station
I
Bonaparte Point
B
Janus Island
C
H
South Island
Hermit Island
G
64° 48' S
F
D
Outcast Islands
E
100 Fathom Line
Not For Navigation
Map redrawn from:
Defense Mapping Agency Map
"Vicinity of Arthur Harbor"
DMA Stock # 29AHA29123
Last Updated 1977
Defense Mapping Agency
Hydrographic Center
Washington D.C 20390
HAM 7/16/92
Bismarck Straits

Palmer LTER Grid

- Facilitates integration of spatial data acquired at different scales and times, and in different formats:
  - Measure environmental parameters
  - Map abundance and distribution
  - Monitor changes in space/time
  - Model processes on range of space/time scales

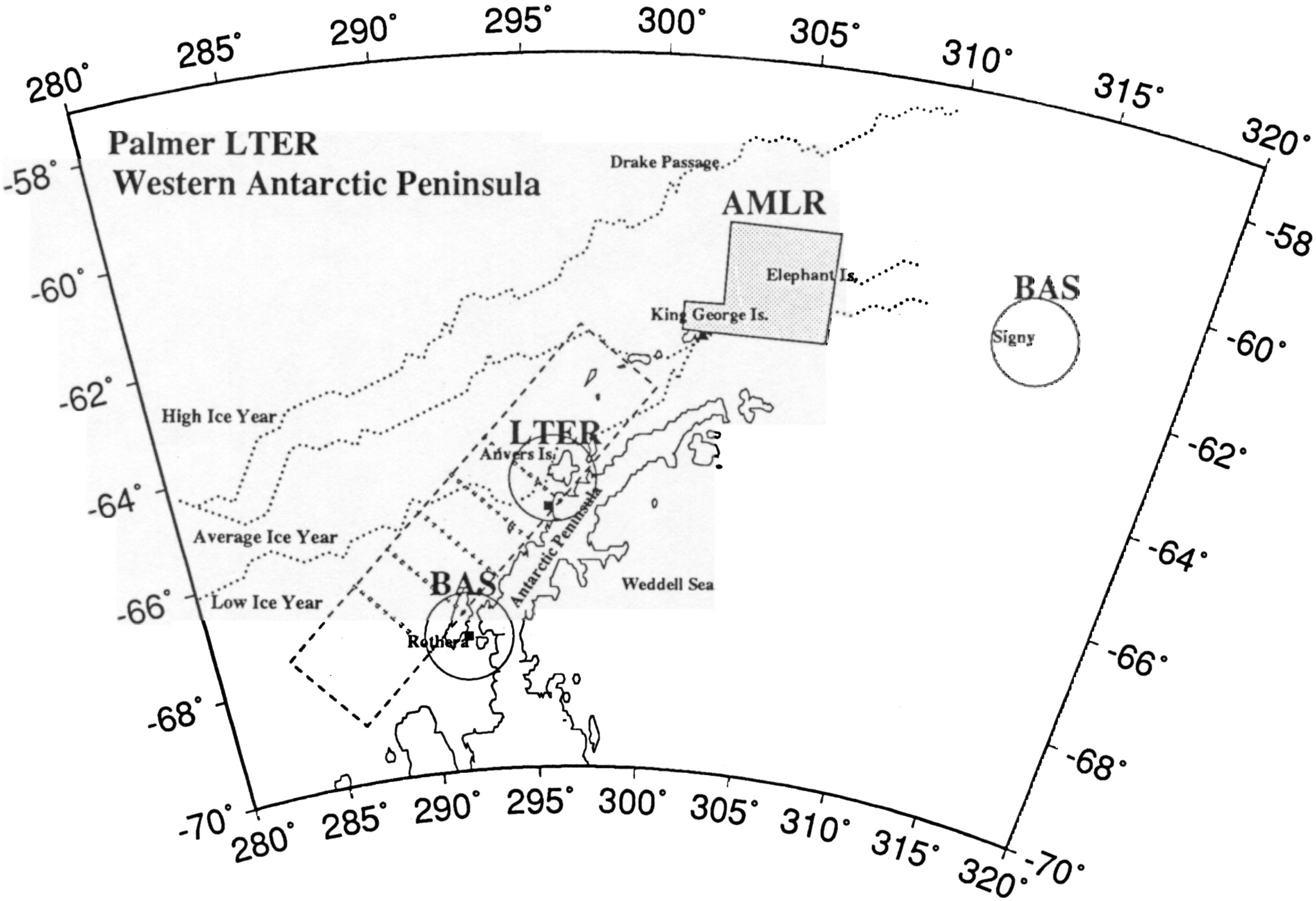
- Objectives of an integrated data scheme:
  - data acquisition (identify and gather required data)
  - preprocessing (manipulate data into useable forms)
  - data-management (creation of and access to the database)
  - manipulation and analysis (analytic operations in database)
  - product generation (final copy: graphic/digital/hard)

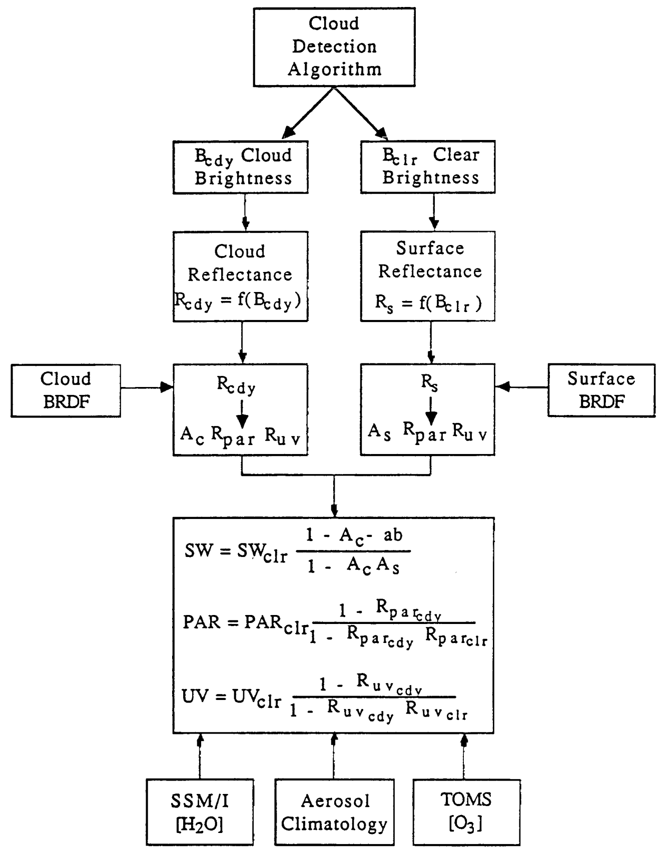
EXAMPLES

Works in Progress

related to the space/ time sampling strategy

- Sampling near the LTER area
- Bio-Optical Models of Oceanic Primary Productivity
- Net Primary Productivity


Palmer LTER
Western Antarctic Peninsula
Drake Passage
AMLR
Elephant Is.
King George Is.
BAS
Signy
High Ice Year
LTER
Anvers Is.
Average Ice Year
Antarctic Peninsula
BAS
Weddell Sea
Low Ice Year
Rothera
280° 285° 290° 295° 300° 305° 310° 315° 320°
-58° -60° -62° -64° -66° -68° -70°



Cloud Detection Algorithm
B cdy Cloud Brightness
B clr Clear Brightness
Cloud Reflectance
R cdy = f(B cdy)
Surface Reflectance
R s = f(B clr)
Cloud BRDF
R cdy
A c R par R uv
R s
A s R par R uv
Surface BRDF
SW = SW clr (1 - A c - ab) / (1 - A c A s)
PAR = PAR clr (1 - R par cdy) / (1 - R par cdy R par clr)
UV = UV clr (1 - R uv cdy) / (1 - R uv cdy R uv clr)
SSM/I [H2O]
Aerosol Climatology
TOMS [O3]

$$I_{\lambda_1-\lambda_2} = Io_{\lambda_1-\lambda_2}\ (d/d_o)^2 * \cos\theta\{\exp[-(a+b/V)/\cos\theta\}/\{1-r_{\lambda_1-\lambda_2}(a'+b'/V)\}$$

$$* \exp[-a_v(U_v/\cos\theta)^{b_v} * \exp[-a_o(U_o/\cos\theta)^{b_o}$$

where $Io_{\lambda_1-\lambda_2}$ is the monochromatic extraterrestrial irradiance from $\lambda_1-\lambda_2$

λ_1 refers to 700nm and λ_2 refers to 400nm

$(d/d_o)^2$ is the correction due to noncircular orbit of the Earth

θ is the solar zeinth angle

$r_{\lambda_1-\lambda_2}$ is the average surface reflectance over $\lambda_1-\lambda_2$

V is the surface visibility, from aerosol database

U_v is water vapor amount

U_o is ozone amount

$$NPP = (1/39)\ \rho \times PAR(0^+) \times \langle Chl \rangle_{tot} \times \Psi^*$$

where NPP is net primary production in mg C m^{-2} d^{-1},

ρ is the ratio of active pigments to all pigments,

$PAR(0^+)$ is daily integrated PAR in Joules m^{-2},

$\langle Chl \rangle_{tot}$ is surface pigment concentration in g m^{-2}, and

Ψ^* cross-section of photosynthesis m^2 (g Chl)$^{-1}$.

Global and Regional Oceanographic Net Primary Productivity from Satellite Derived Data

- **PAR is calculated using a daabase from the International Satellite Cloud Climatology Program (ISCCP)**
  - presence of land
  - precipitable water
  - cloud fraction
  - cloud reflection
  - temperature
  - satellite viewing angle

- **Chlorophyll (CZCS pigment biomass)**
  - Univ of Miami
  - Goddard Space Flight Center
  - Gene Feldman

Summary of Uncertainties

Parameter	Case I Waters	All Other Waters
rho, ρ	±20%	±20%
PAR*	±55%	±65%
$\{C\}_{tot}$	±35%	+100%, -50%
Total	±68%	+121%, -84%