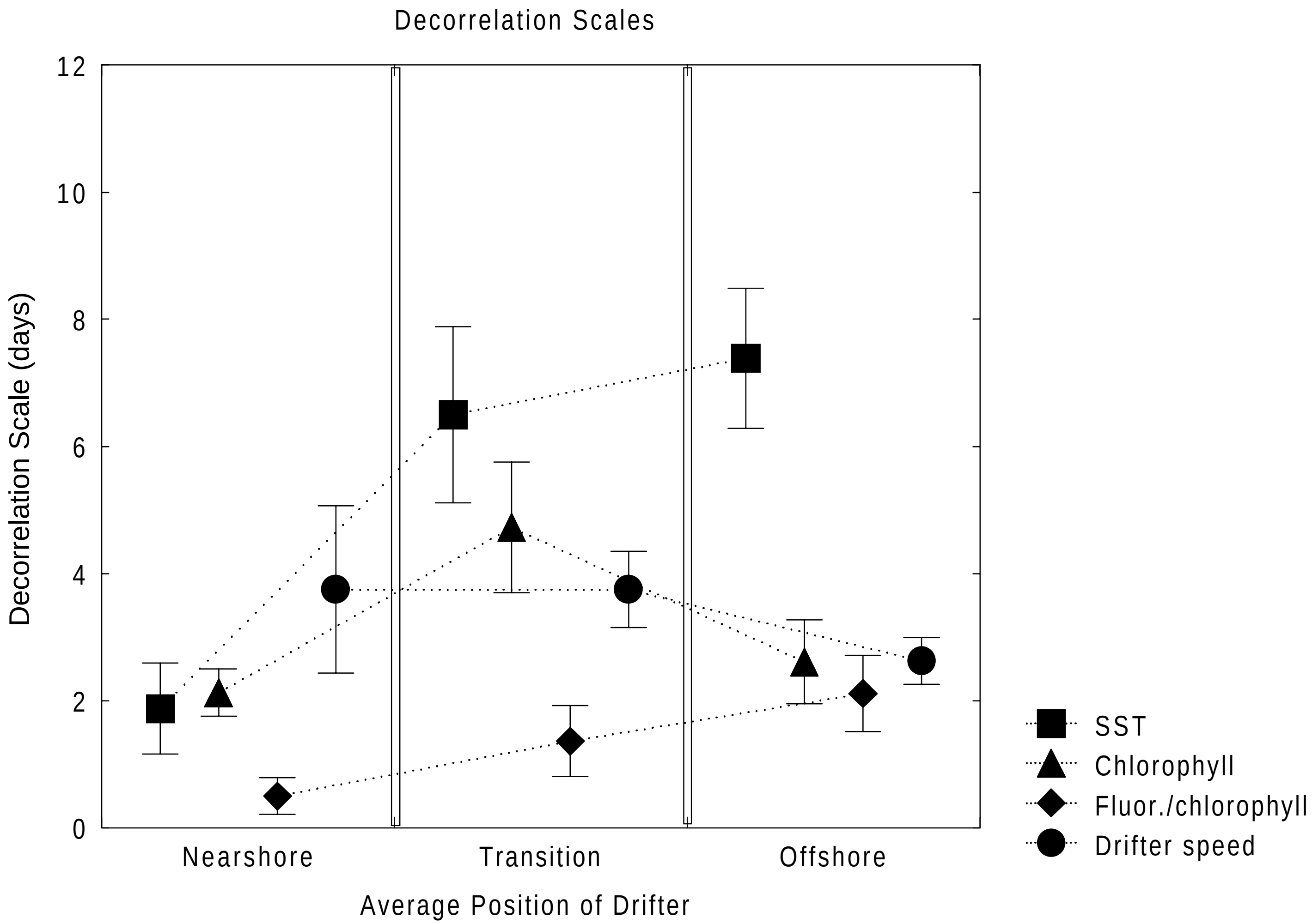
Chlorophyll Fluorescence and Primary Productivity

Mark Abbott
Ricardo Letelier
Jasmine Bartlett
College of Oceanic and Atmospheric Sciences
Oregon State University

Models of Primary Productivity

- Present chlorophyll-based productivity models focus on light absorption processes
- Variations in fluorescence quantum yield are related to light utilization
  - Related to nutrients and species composition
  - Exploit this variability to improve estimation of primary productivity
  - Require averaging over some time period

Decorrelation Scales as a Function of Cross-Shore Distance



Decorrelation Scales in the California Current

- Nearshore (within 200 km)
  - SST ≈ Chlorophyll
  - Fluor./Chl. < Chlorophyll
    - Imbalance between light harvesting and utilization
- Transition (200 - 400 km)
  - All scales increase
  - Coherent flow features (e.g., eddies)
- Offshore (> 400 km)
  - SST > Chlorophyll
  - Fluor./Chl. ≈ Chlorophyll
    - Processes in balance

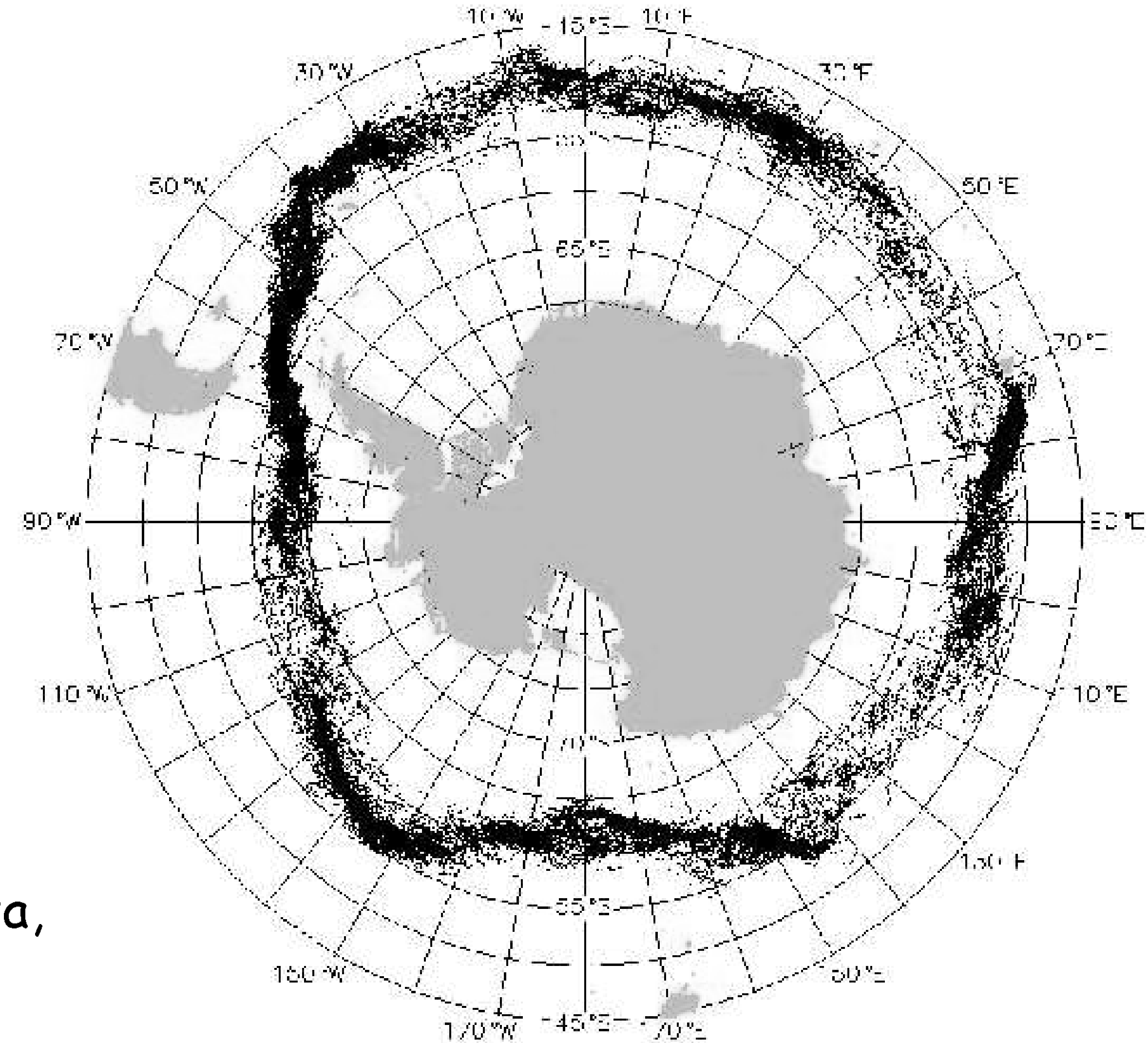
Why are SST and Chlorophyll Scales so Different Offshore?

- Different physical processes controlling SST and chlorophyll in the offshore region versus nearshore in active upwelling zone
- Change in balance of light harvesting/utilization suggests shift from non-equil. strategy nearshore to equil. strategy
  - Exploit variability in light and nutrients through storage, buoyancy, etc. → large diatom chains
  - Offshore community → small forms, flagellates

The Antarctic Polar Frontal Zone

- Mesoscale processes
  - Strong meanders associated with bottom topography
    - Large vertical velocities associated with these features
    - Typical velocities on the order of 10's of meters/day
  - Smaller scale instabilities associated with convergent fronts
- Impacts
  - Enhanced chlorophyll concentrations downstream of where Antarctic Circumpolar Current interacts with rough topography
  - Disrupts equilibrium plankton community

Weekly Position of the Polar Front



Derived from
AVHRR
Pathfinder data,
1987-1993

Moore et al, 1998

Summary of APFZ Data Sets

- Moorings
  - 11 moorings recovered; one presumably lost to interaction with iceberg
  - 2 optical sensor systems flooded; 1 short record
  - 2 current meters lost; 2 short records
  - 5 Microcat CTD records
- Drifters
  - 14 Satlantic optical drifters successfully deployed
  - 12 WOCE surface drifters deployed

Drifters in a Polar Front Meander

Drifters deployed in the Polar Front, Nov. 1997, overlain on SST field derived from SeaSoar

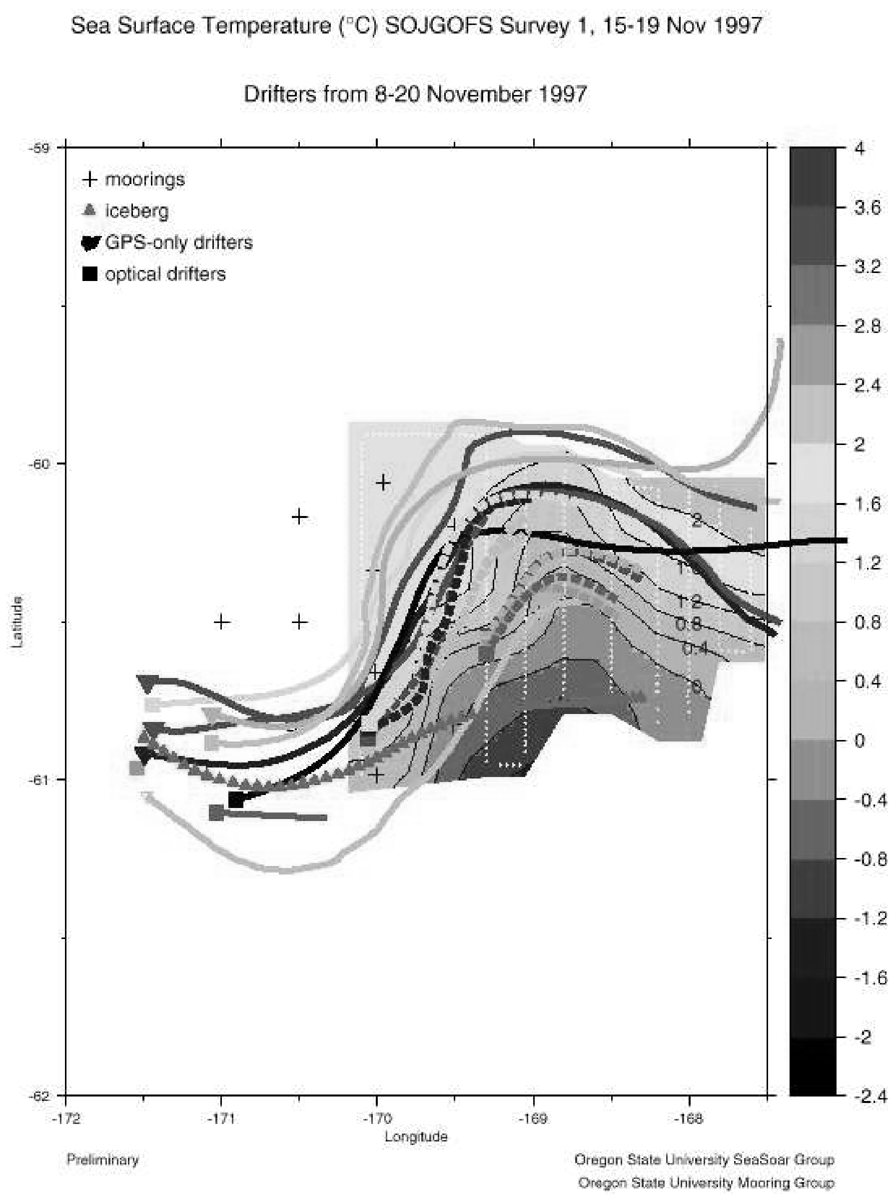
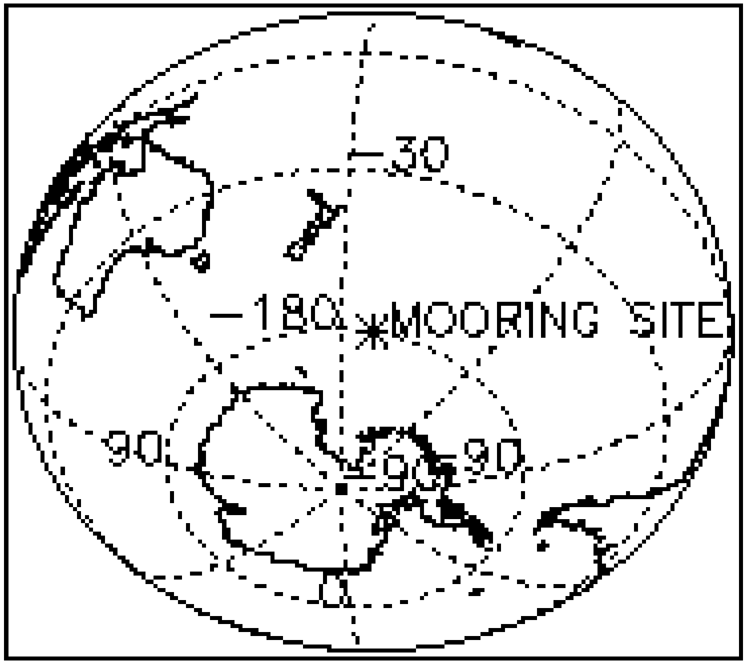
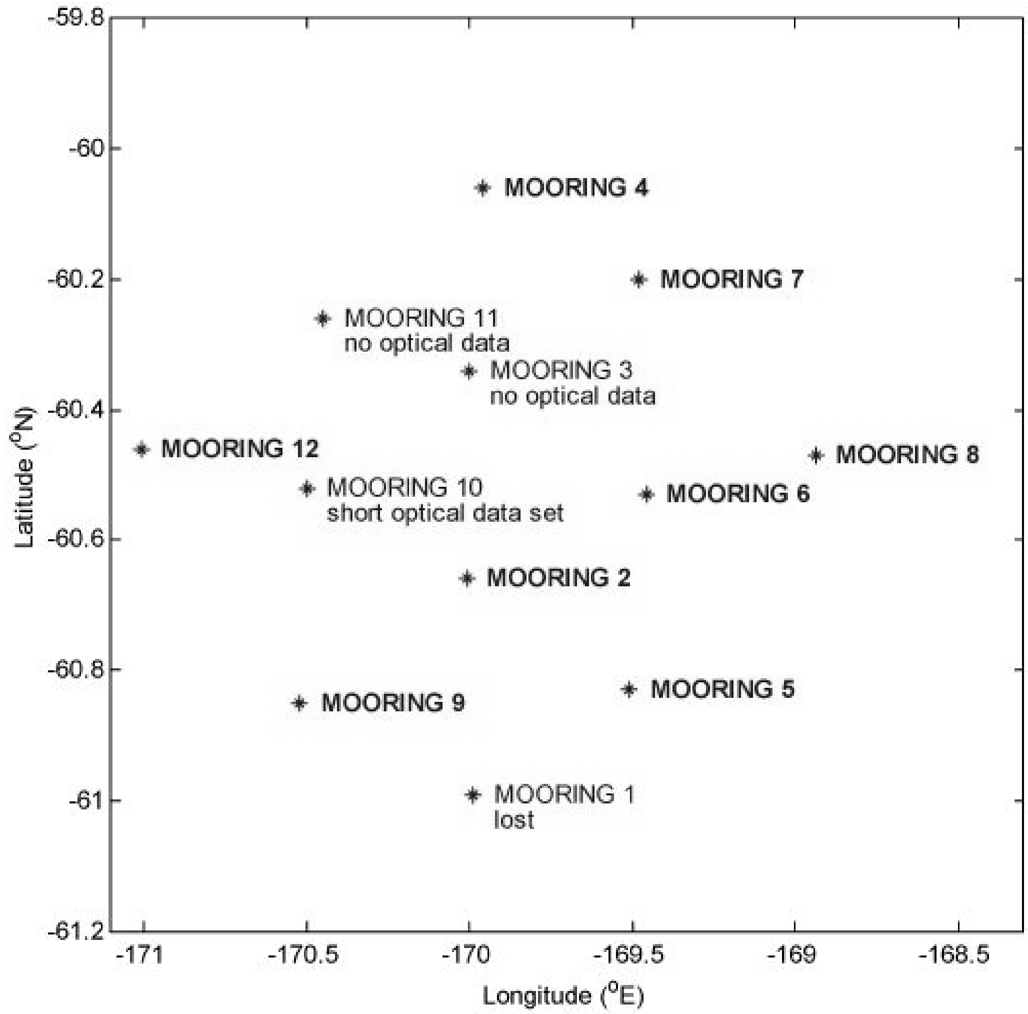


Figure courtesy of J. Barth and T. Cowles, OSU

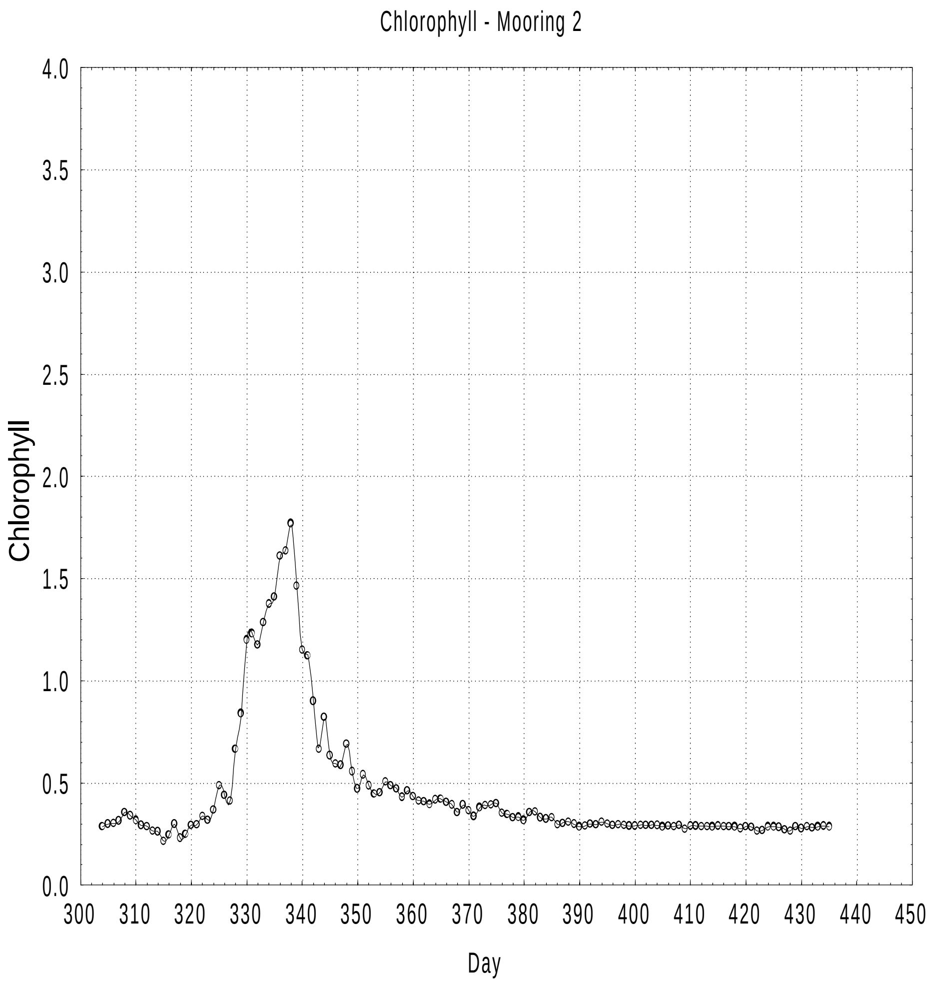
Mooring Location

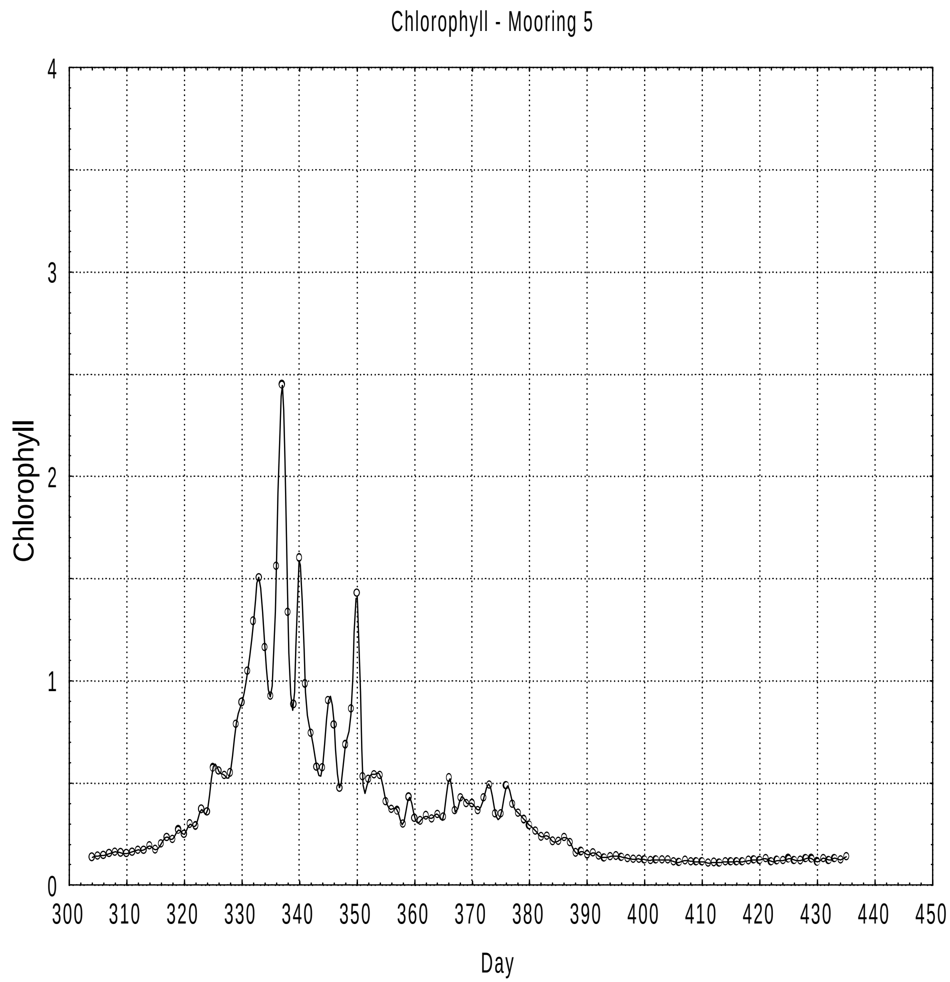


Optical/current meter moorings deployed 11/97 - 3/98

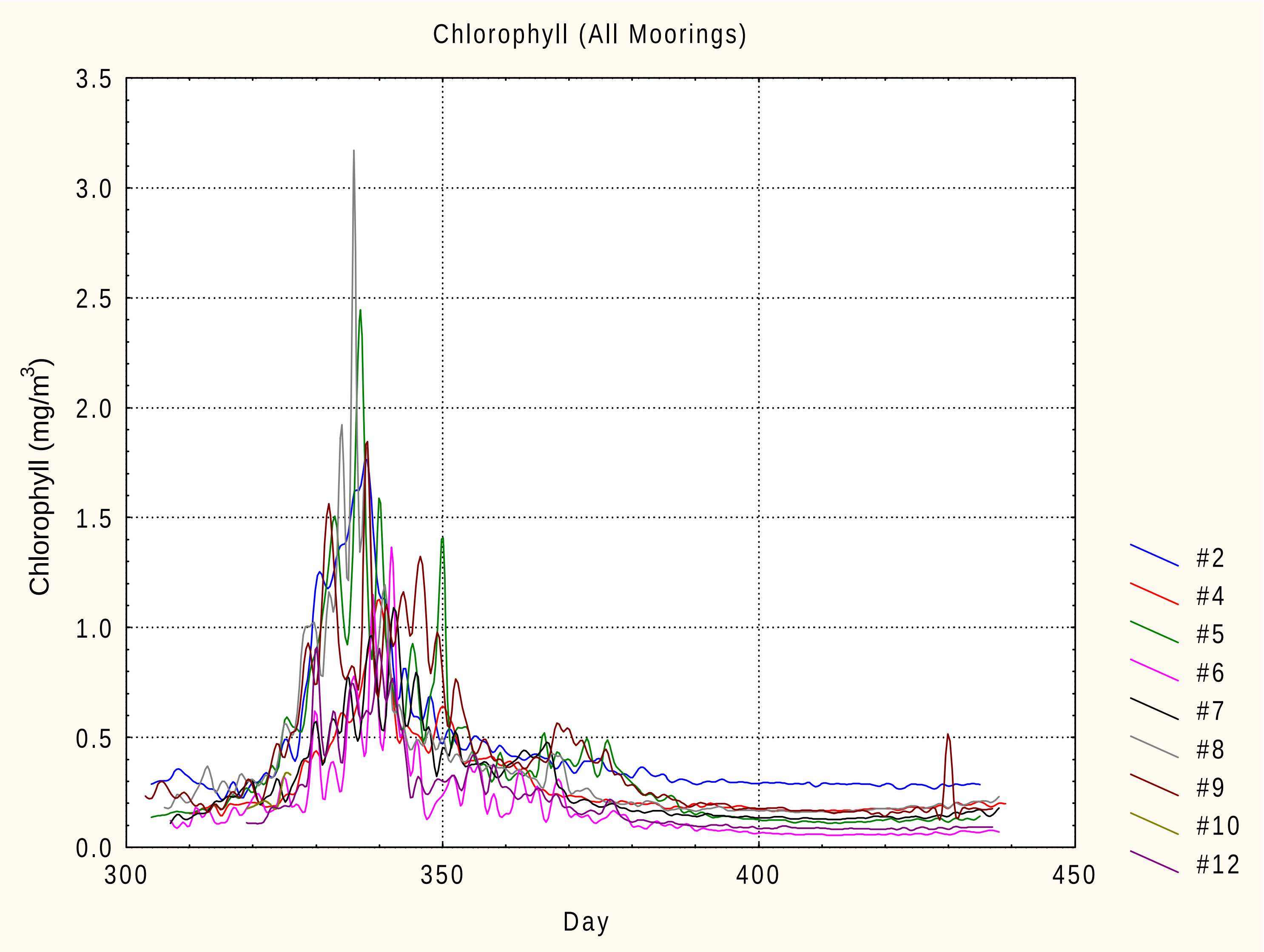


Chlorophyll Time Series from Moorings

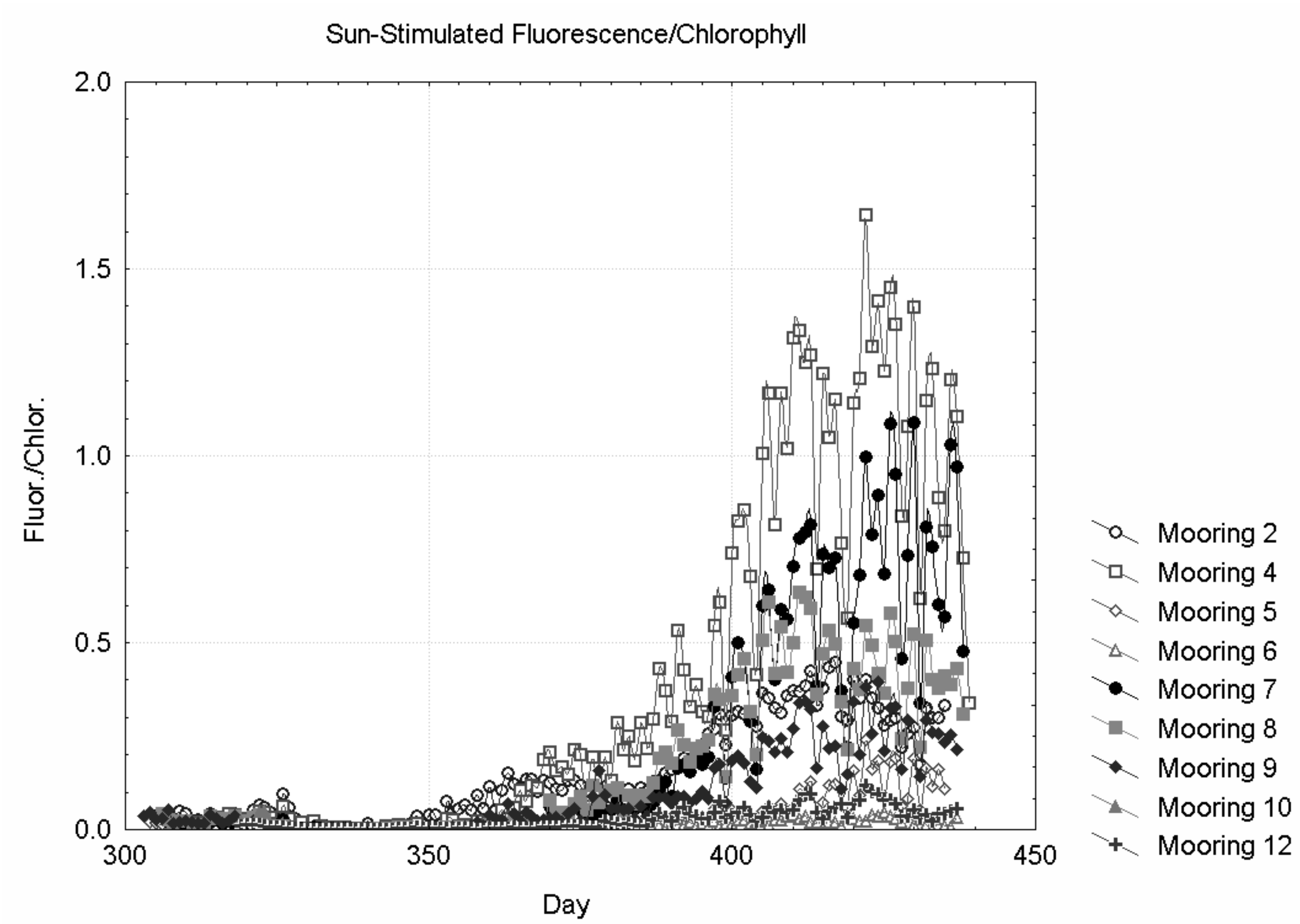




Time Series from All Moorings



Sun-Stimulated Fluorescence Time Series



Patterns of the Spring Bloom

- Initial bloom triggered by stratification
  - F/C increases briefly as phytoplankton photoadapt
- Bloom increases for about 20 days
  - F/C declines to low values and remains nearly constant
- Bloom begins to decrease
  - F/C remains constant
  - Silicate limitation?
- Chlorophyll reaches baseline values for remainder of season
  - F/C begins to increase, especially as water column stratifies further
  - Iron limitation?

SeaWiFS Time Series

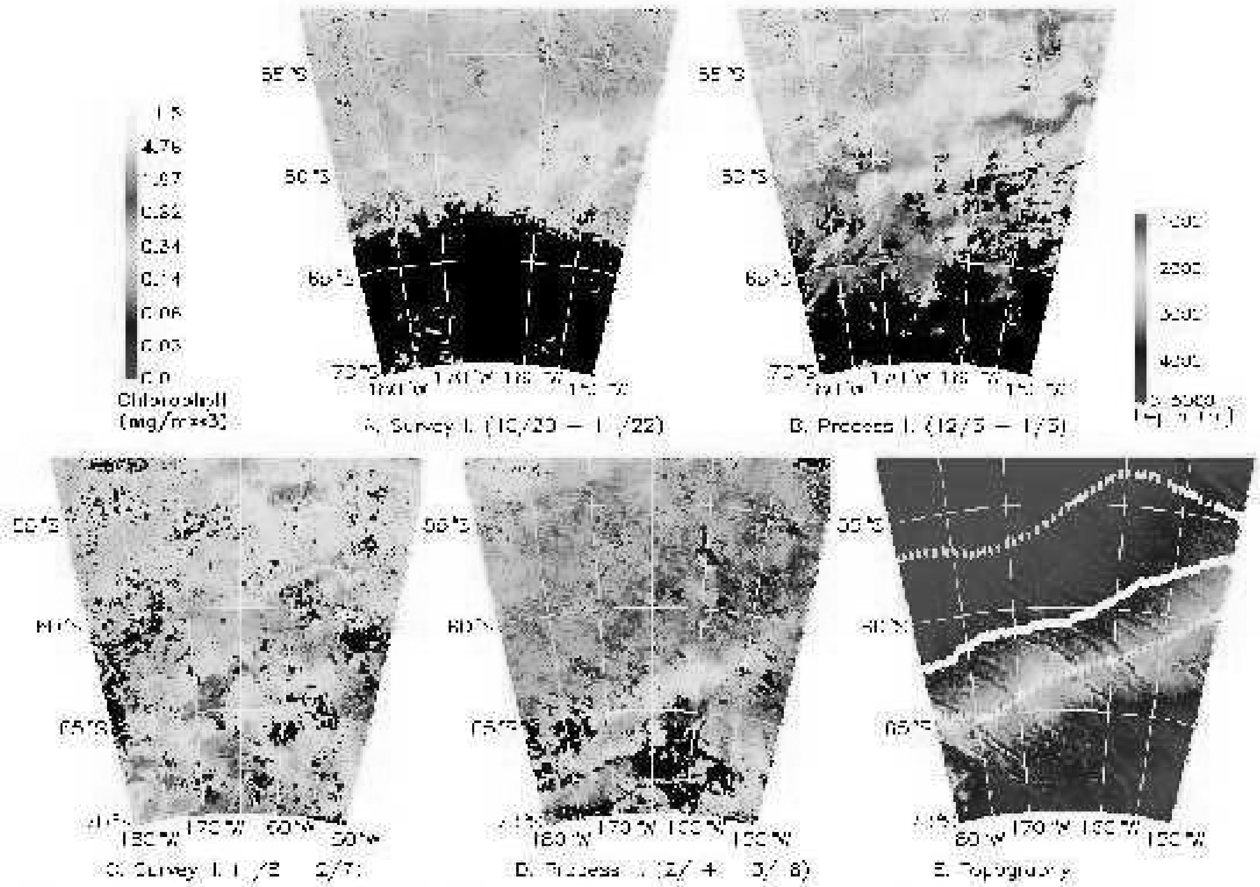


Figure 4. The mean SeaWiFS-derived surface chlorophyll concentrations during each of the four JGOFS cruises (A-D). The mean paths of Southern Ocean fronts (SAF, PF, SACCF) over the topography of the region.

Moore et al., submitted

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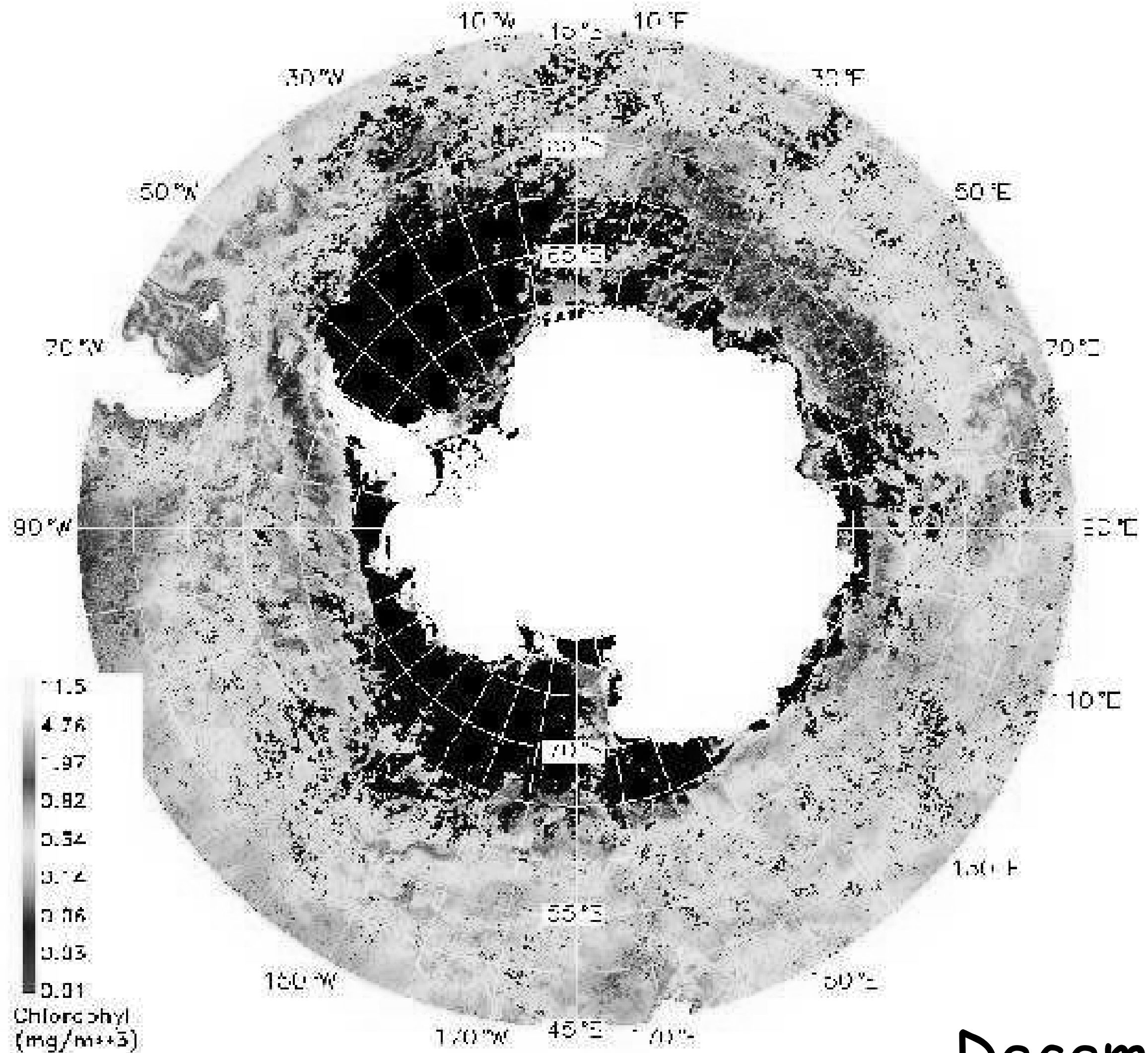
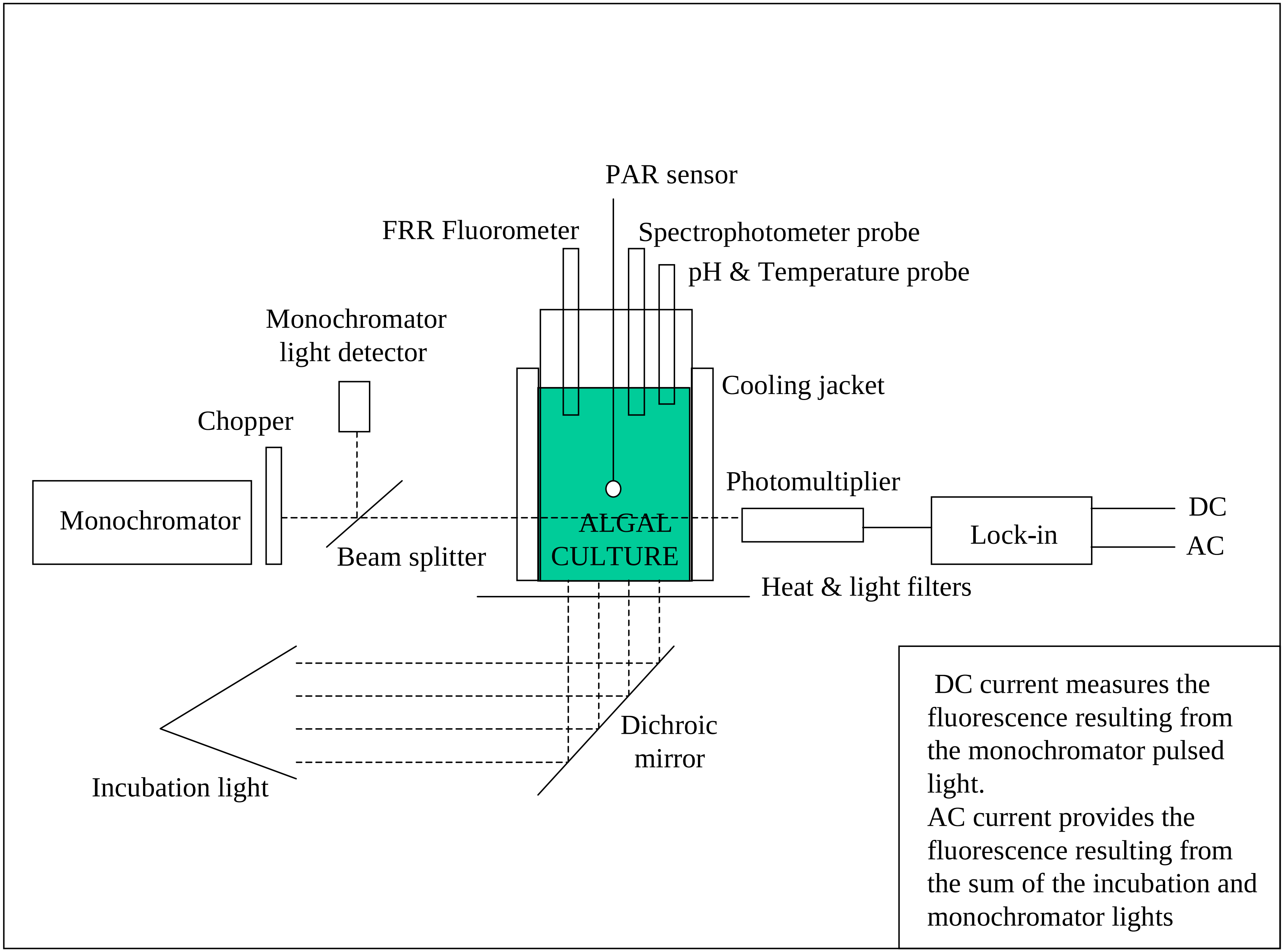
Southern Ocean SeaWiFS Composite

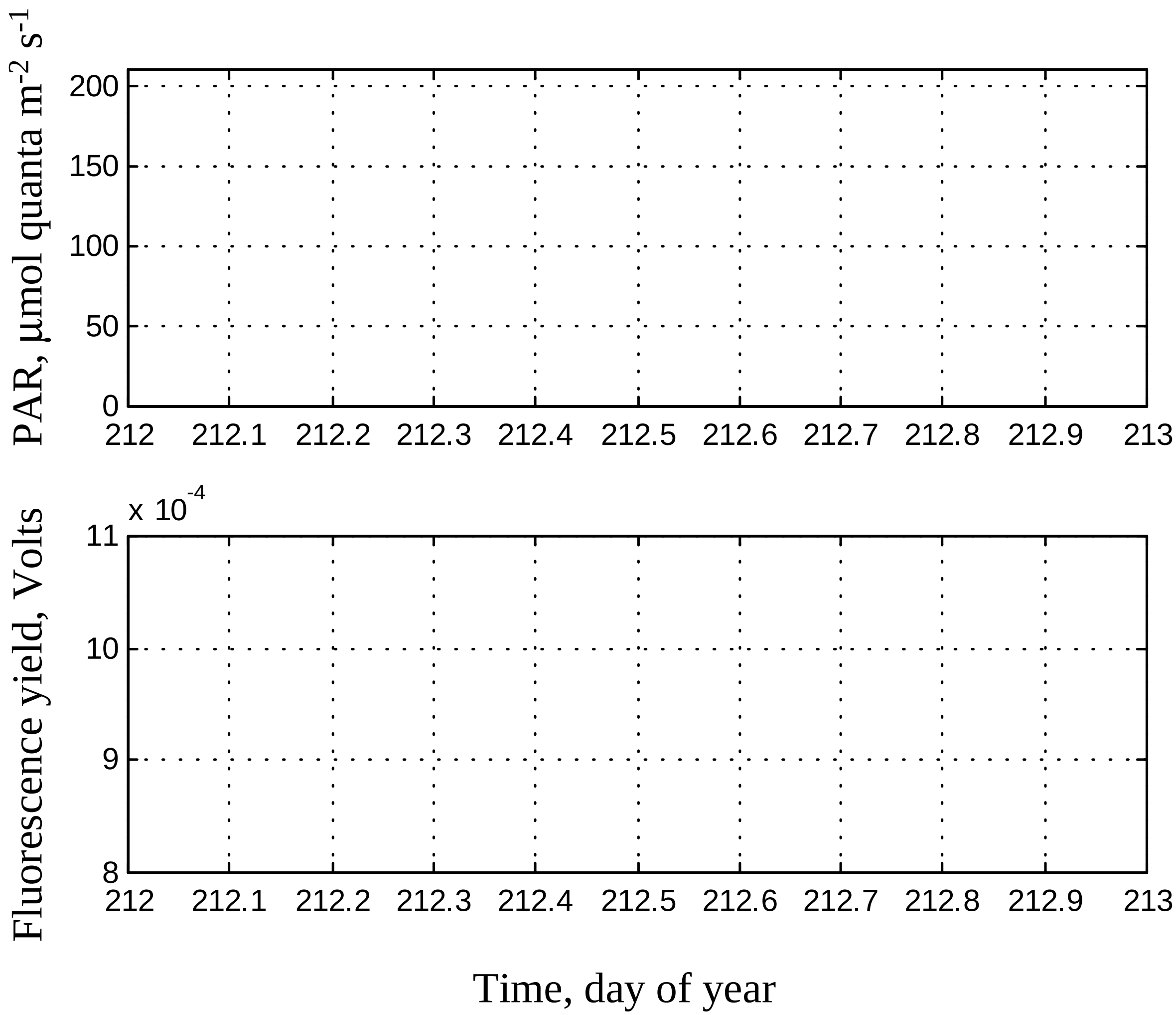


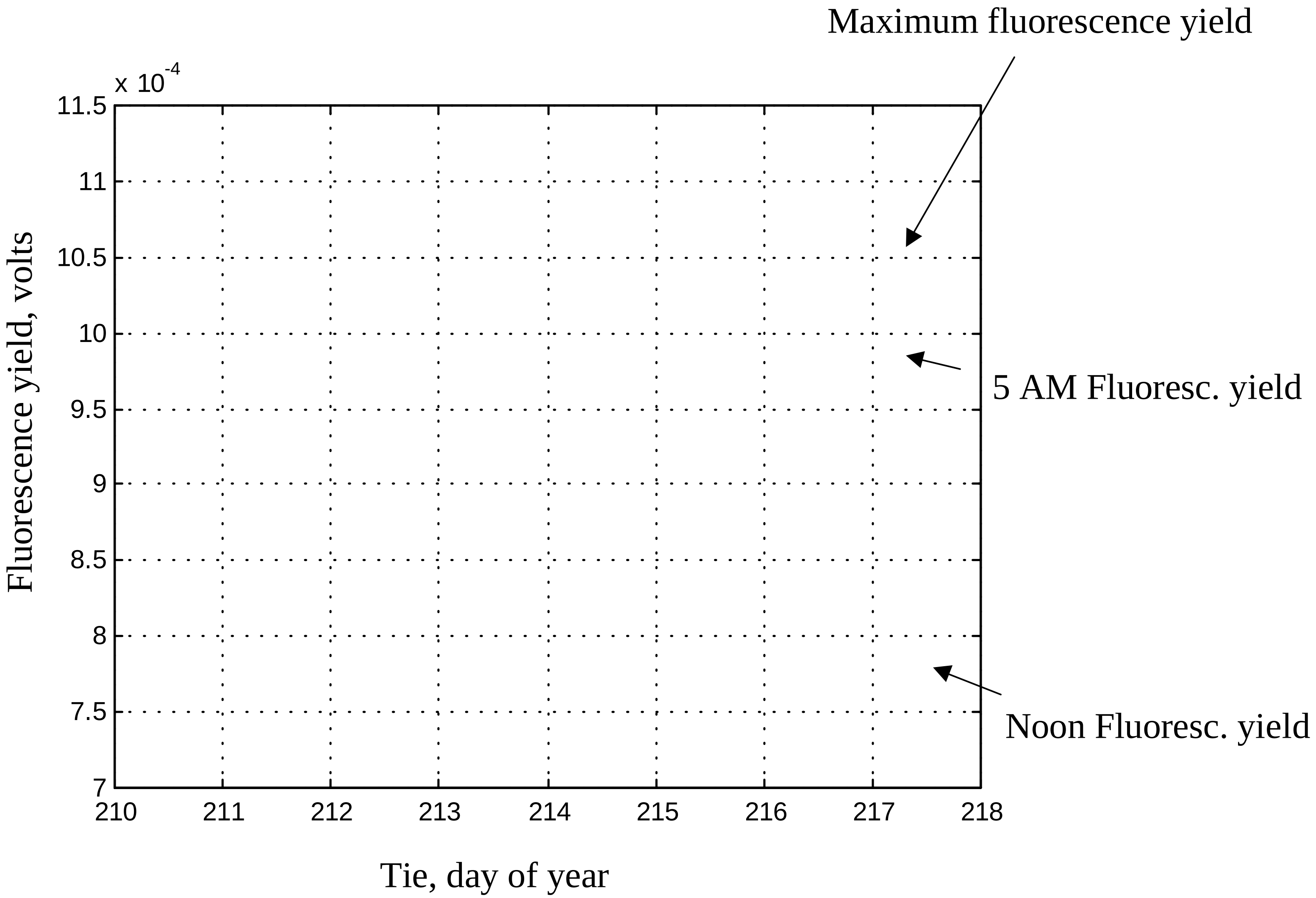
December 1997

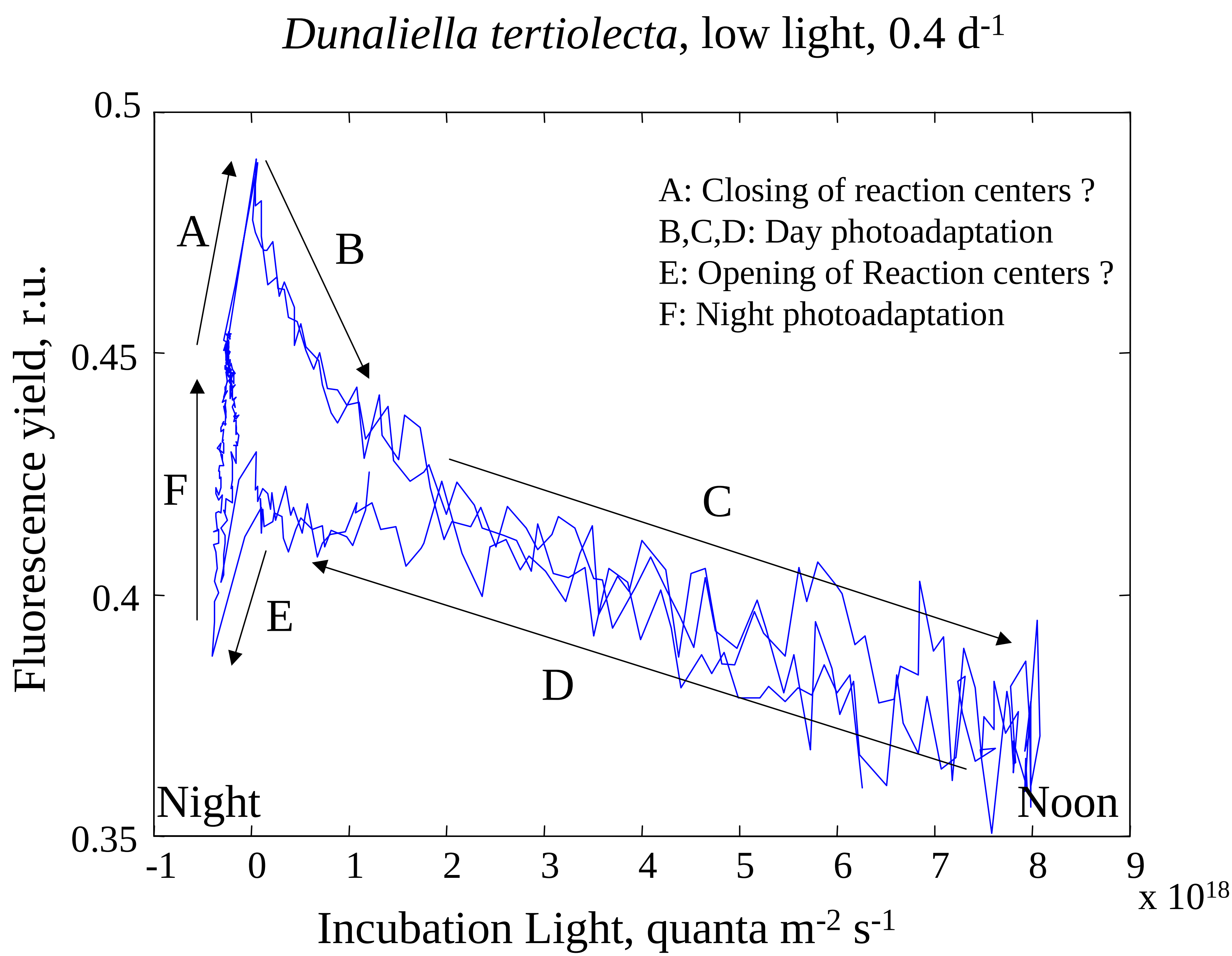
Chemostat Experiments

- Modified chemostat developed by Dale Kiefer
  - Light source for growth follows diel cycle
  - Non-saturating, pulsing source for measuring changes in fluorescence yield
  - Temperature and pH controlled
  - Measure both AC (pulsed plus incubation) and DC (pulsed) components
  - Plan to add fast repetition rate fluorometer, oxygen electrode


PAR sensor
FRR Fluorometer
Spectrophotometer probe
pH & Temperature probe
Monochromator
light detector
Cooling jacket
Chopper
Photomultiplier
Monochromator
ALGAL
CULTURE
Lock-in
DC
AC
Beam splitter
Heat & light filters
Dichroic
mirror
Incubation light
DC current measures the fluorescence resulting from the monochromator pulsed light.
AC current provides the fluorescence resulting from the sum of the incubation and monochromator lights


PAR, μmol quanta m-2 s-1
200
150
100
50
0
212
212.1
212.2
212.3
212.4
212.5
212.6
212.7
212.8
212.9
213
x 10-4
11
10
9
8
Fluorescence yield, Volts
Time, day of year

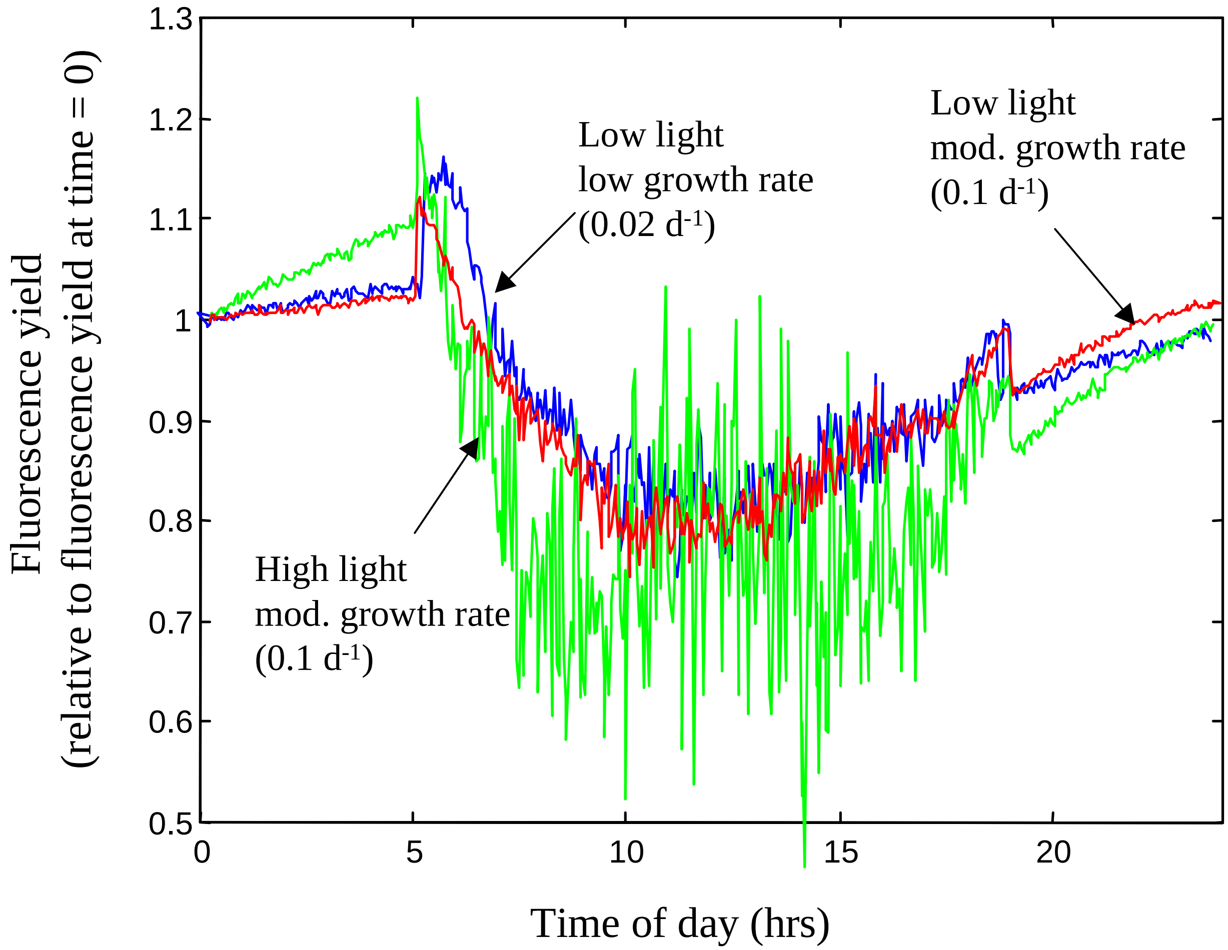

Maximum fluorescence yield
5 AM Fluoresc. yield
Noon Fluoresc. yield
x 10^-4
11.5
11
10.5
10
9.5
9
8.5
8
7.5
7
210
211
212
213
214
215
216
217
218
Fluorescence yield, volts
Tie, day of year

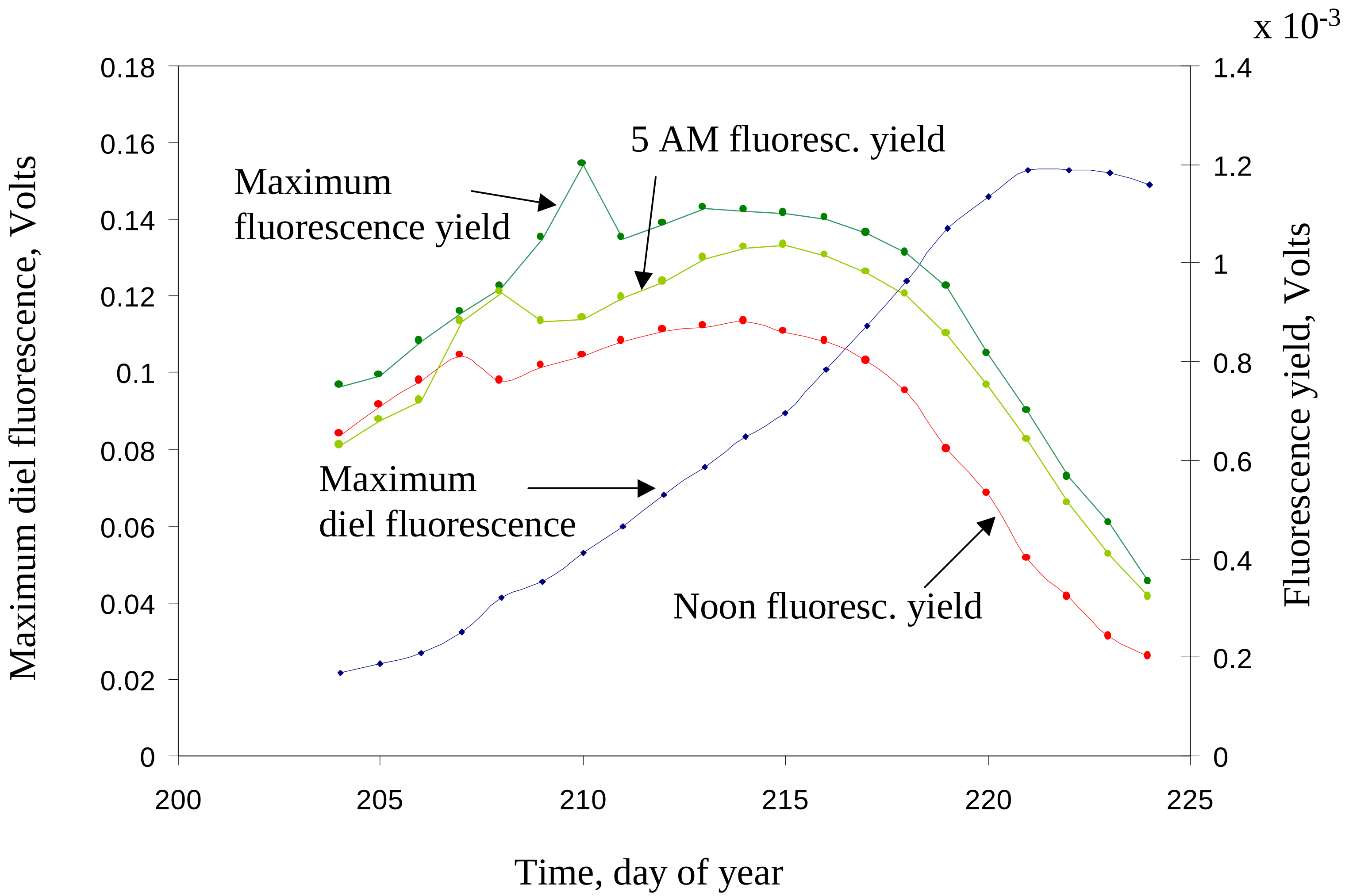


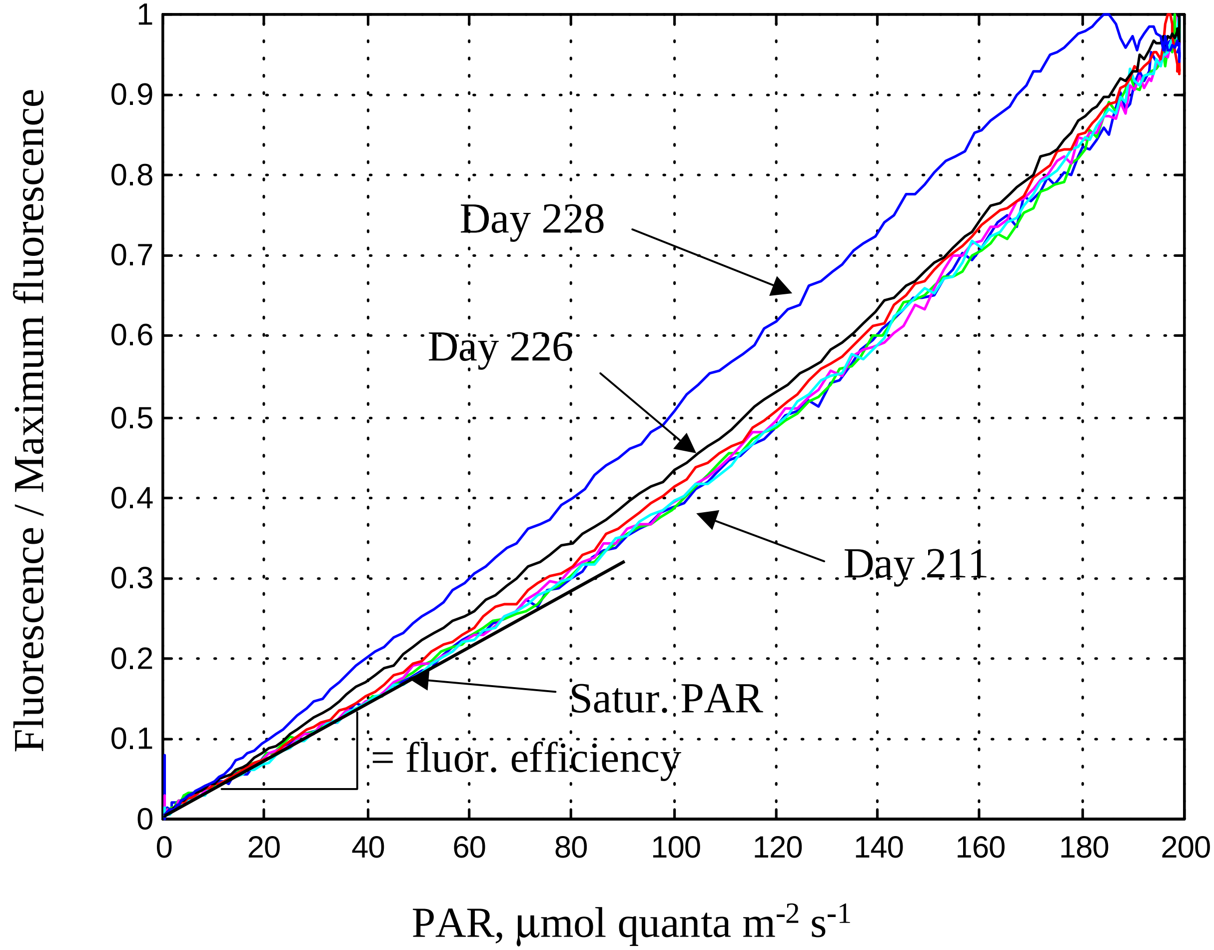
Dunaliella tertiolecta, low light, 0.4 d-1
A: Closing of reaction centers ?
B,C,D: Day photoadaptation
E: Opening of Reaction centers ?
F: Night photoadaptation
A
B
C
D
E
F
Night
Noon
Fluorescence yield, r.u.
0.5
0.45
0.4
0.35
-1
0
1
2
3
4
5
6
7
8
9
x 10^18
Incubation Light, quanta m-2 s-1

Dunaliella terciolecta

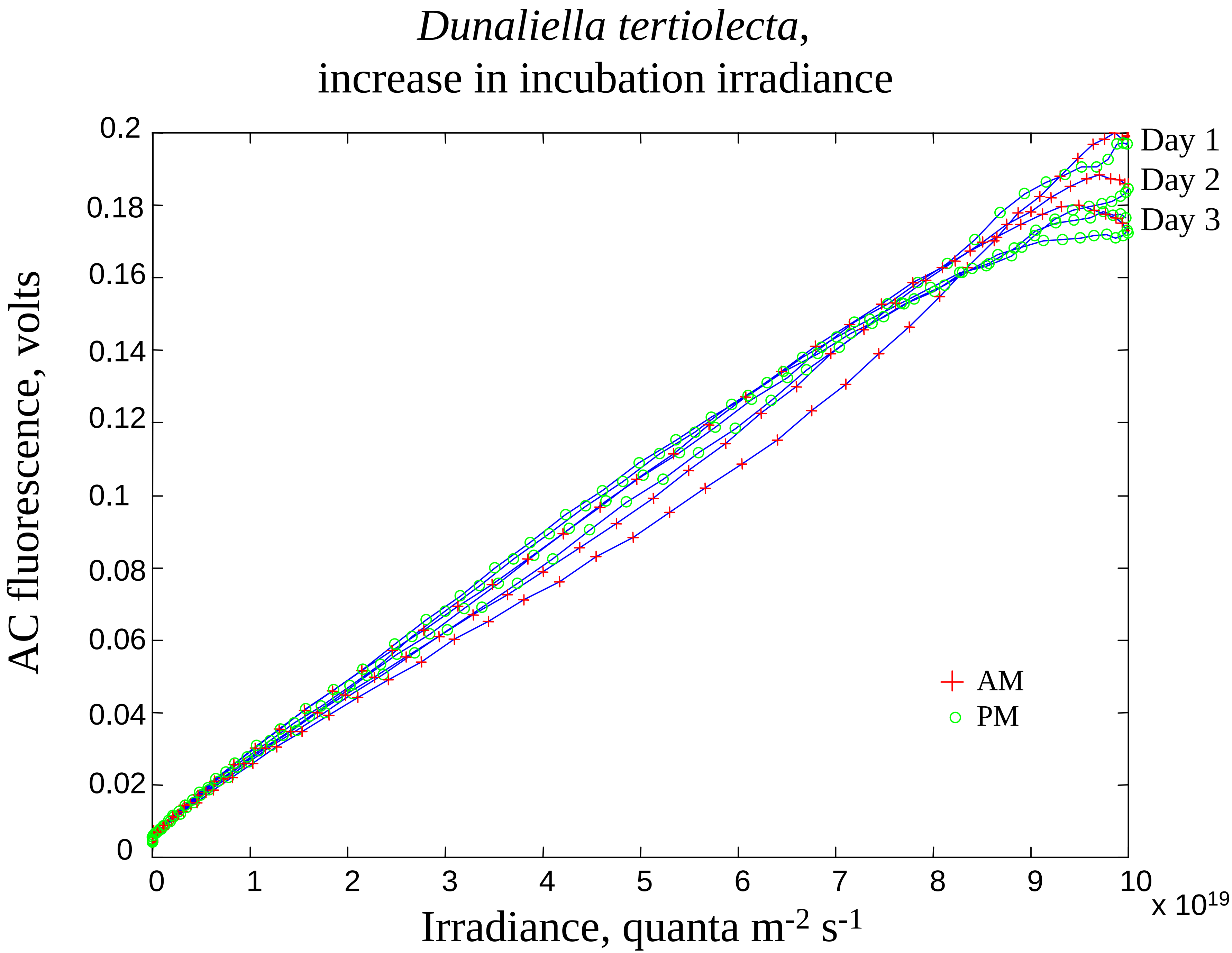
Nat. Fluor. Chem. test



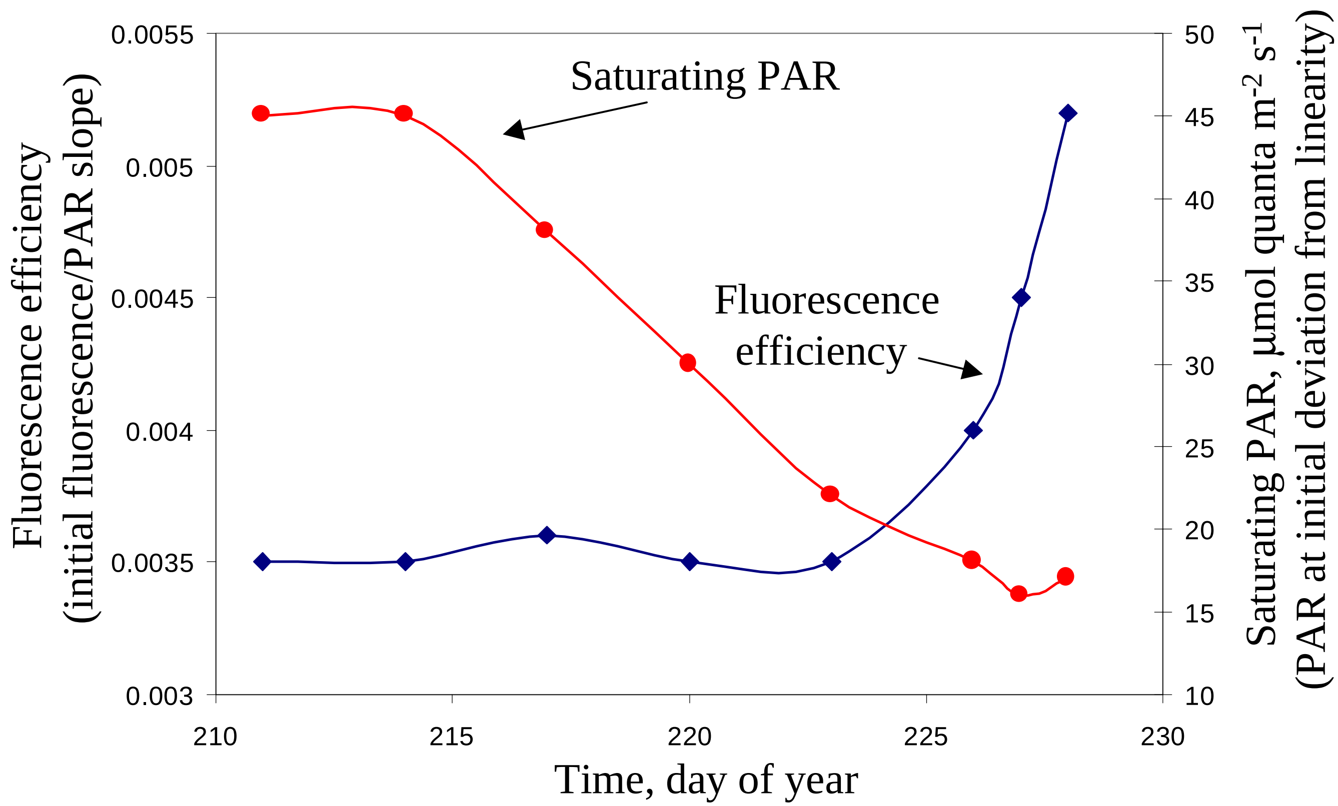

x 10-3
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1.4
1.2
1
0.8
0.6
0.4
0.2
0
200
205
210
215
220
225
Maximum diel fluorescence, Volts
Fluorescence yield, Volts
Time, day of year
5 AM fluoresc. yield
Maximum fluorescence yield
Maximum diel fluorescence
Noon fluoresc. yield



Fluorescence / Maximum fluorescence
PAR, µmol quanta m-2 s-1
Day 228
Day 226
Day 211
Satur. PAR
= fluor. efficiency
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
20
40
60
80
100
120
140
160
180
200



Dunaliella tertiolecta,
increase in incubation irradiance
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
AC fluorescence, volts
0
1
2
3
4
5
6
7
8
9
10
x 10^19
Irradiance, quanta m^-2 s^-1
Day 1
Day 2
Day 3
AM
PM

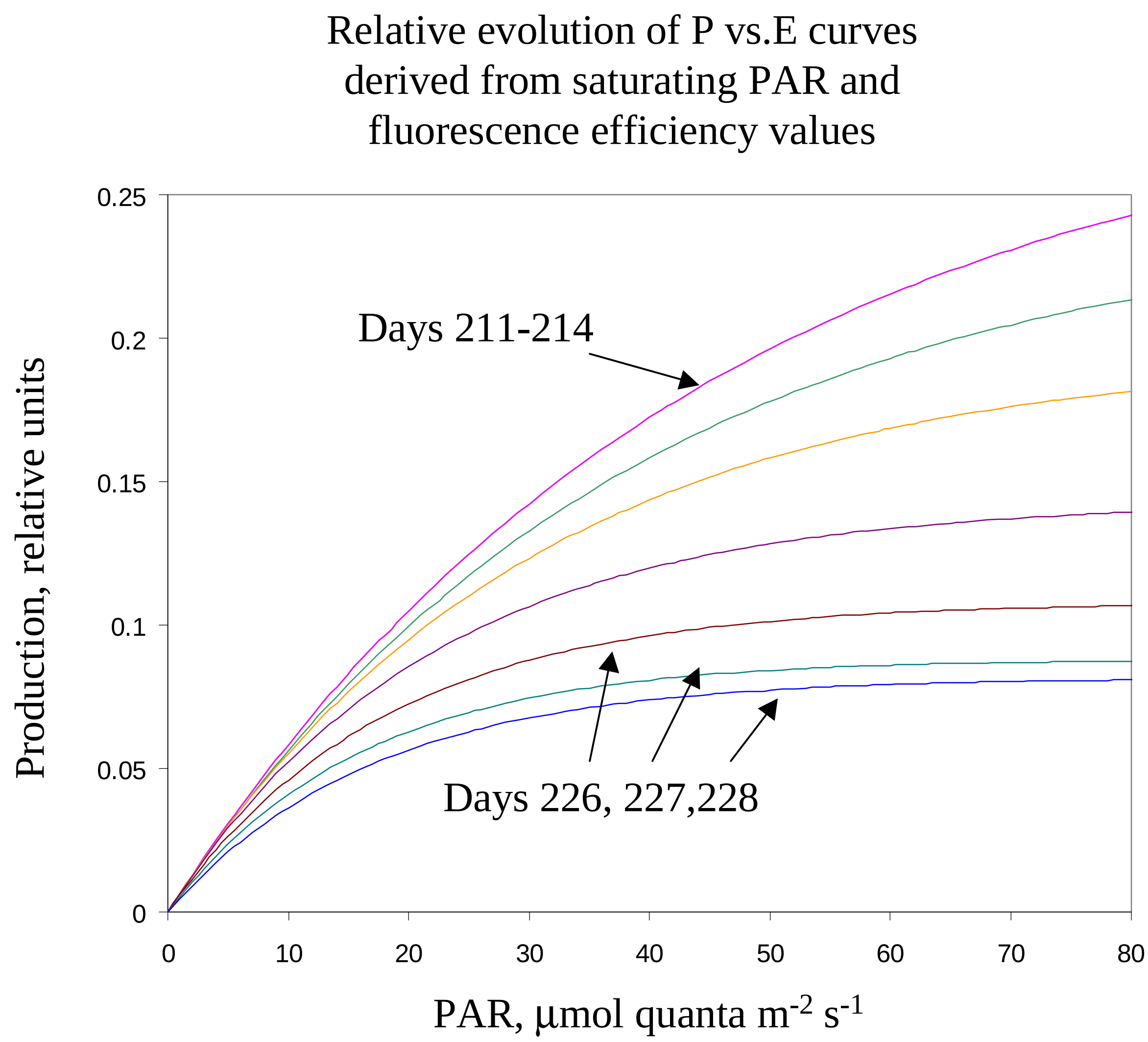

Saturating PAR
Fluorescence efficiency
Fluorescence efficiency
(initial fluorescence/PAR slope)
Saturating PAR, µmol quanta m-2 s-1
(PAR at initial deviation from linearity)
Time, day of year
0.003
0.0035
0.004
0.0045
0.005
0.0055
10
15
20
25
30
35
40
45
50
210
215
220
225
230

Preliminary Results

- Initial tests run with Dunaliella tertiolecta
  - Subsequent runs will use more “representative” cultures
- Strong increase in fluor. yield as soon as “day” begins, even though light levels are very low
  - Reaction centers may be closing
- Rapid decline in yield, followed by slower decline until solar noon
  - Day photoadaptation
- Rapid decrease in yield just before “sunset”
  - Opening of reaction centers?
- Rapid increase in yield
  - Night photoadaptation?

High vs. Low Light/Growth Conditions

- Faster decrease in yield in morning under high light conditions
- Evidence for increased photodamage under high light
- Longer period of adaptation after dawn under low growth conditions
- Evidence of photoadaptation on time scales of days
- Indication of change in fluor. yield as function of growth rate



Relative evolution of P vs.E curves
derived from saturating PAR and
fluorescence efficiency values
Days 211-214
Days 226, 227,228
Production, relative units
PAR, µmol quanta m-2 s-1
0.25
0.2
0.15
0.1
0.05
0
0
10
20
30
40
50
60
70
80

Summary

- Improved models of primary productivity essential to understand the linkages between atmospheric CO_2 and ocean uptake
- Changes in climate forcing may shift phytoplankton community composition
- Simple chlorophyll-based models of productivity will not be adequate
- MODIS represents a significant step forward in ocean remote sensing
- NPOESS/VIIRS represents a damaging step backwards from MODIS