Light Absorption in the Sea: Remote Sensing Retrievals Needed for Light Distribution with Depth, Affecting Heat, Water, and Carbon Budgets

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Semi-analytic Model

- Provides Inherent Optical Properties (IOPs):
  - $a_{\varpi}(\kappa)$; $a_g(\kappa)$; $a_w(\kappa)$ summing to $a(\kappa)$
  - $b_{bp}(\kappa)$; $b_{bw}(\kappa)$ or about 2% of $b_p(\kappa)$
- $a_{\varpi}(\kappa)$ infers Chl_a, particulate organic carbon, and with light, primary production
- $a_g(\kappa)$ infers dissolved organic carbon (e.g. river effluent)
- $b_{bp}(\kappa)$ infers suspended particulate matter
- These are needed to estimate the fractions of light with depth z converted to heat or carbon for the upper mixed layers for determination of carbon, heat and water budgets and heat andcarbon sequestration

Ocean Products

- Total absorption consists of absorption by water (known), phytoplankton, and colored dissolved organic matter (CDOM)
- Separating and quantifying the last two semi-analytically provides quantities for the entire visible spectrum (Carder et al. 1999)
- Chl_a3 derives from phytoplankton absorption at 675 nm
- Absorption by CDOM provides a means to estimate DOC (Walsh et al. 1992)

IPAR, ARP, γ_{FL}

- Instantaneous photosynthetically available radiation (IPAR) provides the surface photon flux for calculation the light field with depth for times of MODIS overpasses
- Total absorption for each visible band allows calculation of the light field with depth for use in heat and carbon budgets, and fluorescence
- Absorbed radiation by phytoplankton (ARP) provides the flux of photons absorbed/m^2 for use in calculating fluorescence or photosynthesis
- Fluorescence efficiency is the ratio of photons fluoresced to photons absorbed by phytoplankton; since fluorescence is a competitive pathway to photosynthesis for ARP, its increase suggests a decrease in photosynthetic efficiency

ESE Relevance

- Biology/Carbon Cycle: relevant to
  - POC, DOC, Primary Production & efficiency
  - Taxonomy from space: red tides, nitrogen-fixing trichodesmium, which requires >4X the iron of other phytoplankton groups
  - Saharan dust provides this to open ocean waters
- Global water and energy cycles
  - Ocean heat budget: absorption and reflectance, depth of heat sequestration
  - Ocean water and salt budgets
- Affect atmospheric CO2, water vapor, heat energy
- Heat sequestration affects down-stream climate

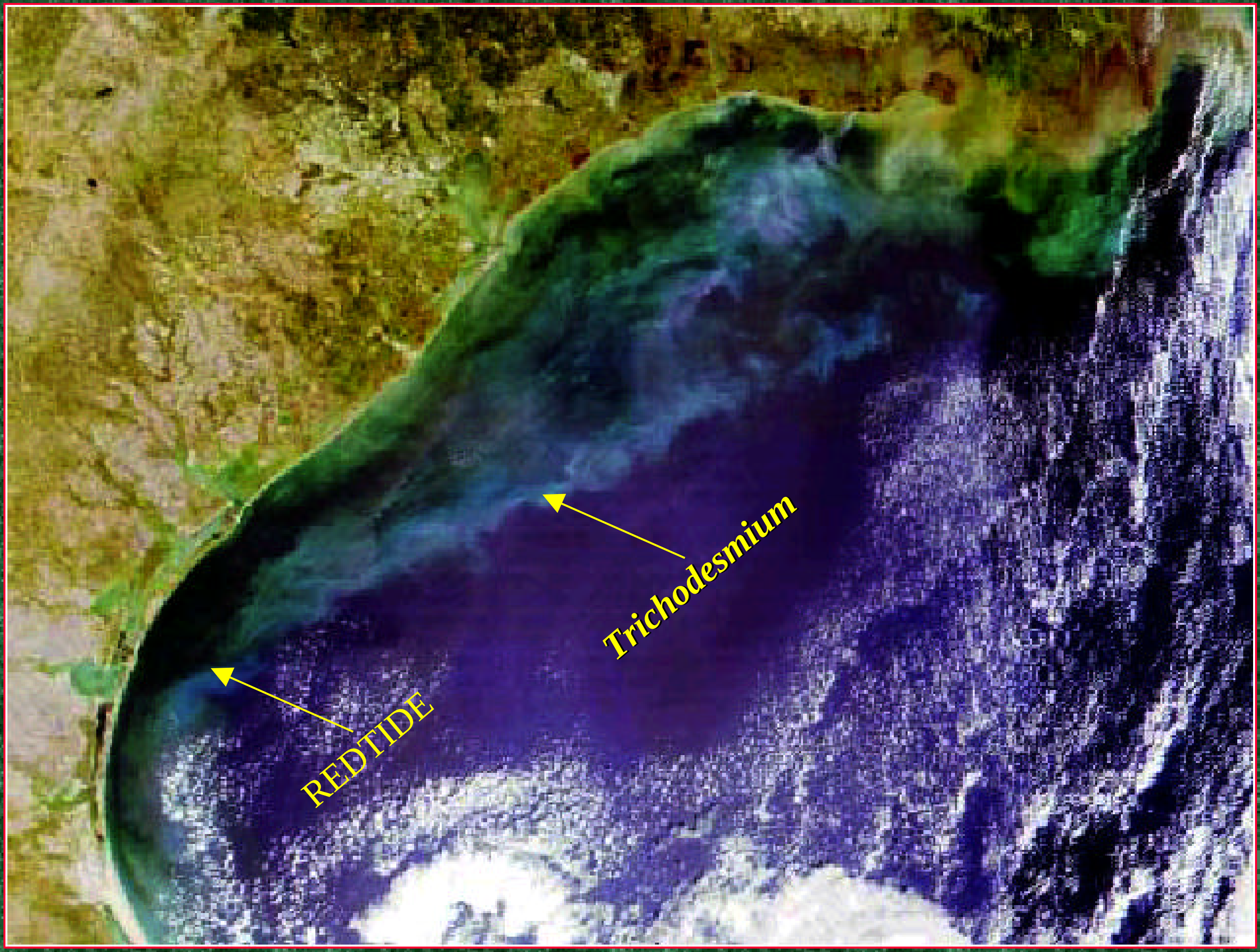


Figure 1. Red tide (black) and Trichodesmium (aqua)
29 September 2000 image using MODIS 470, 555, 645 nm, 500-m bands.

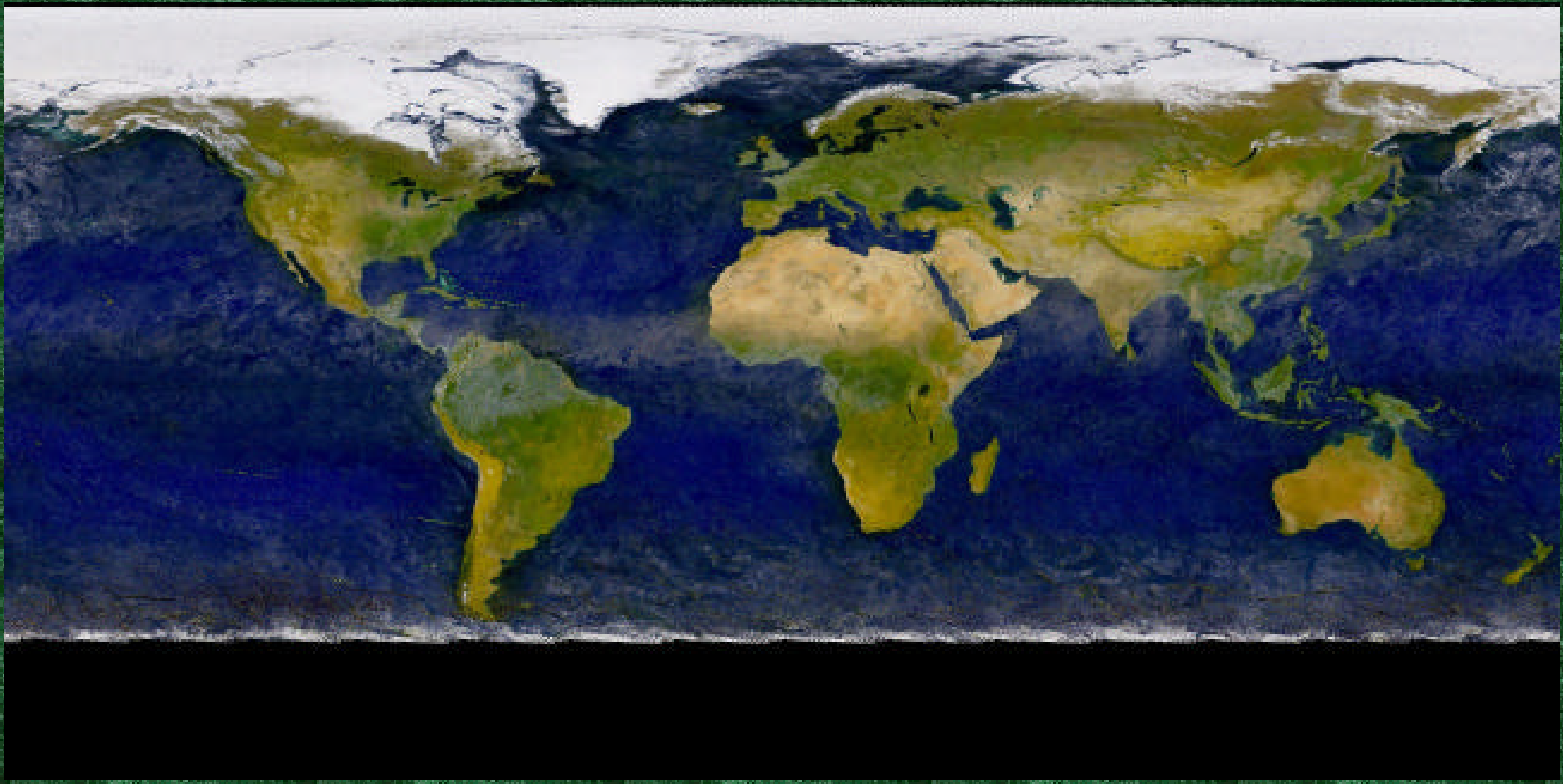


Figure 1. MAY SeaWiFS composite showing iron-rich Saharan dust reaching the Gulf of Mexico. Similar in June and July.

Product Status

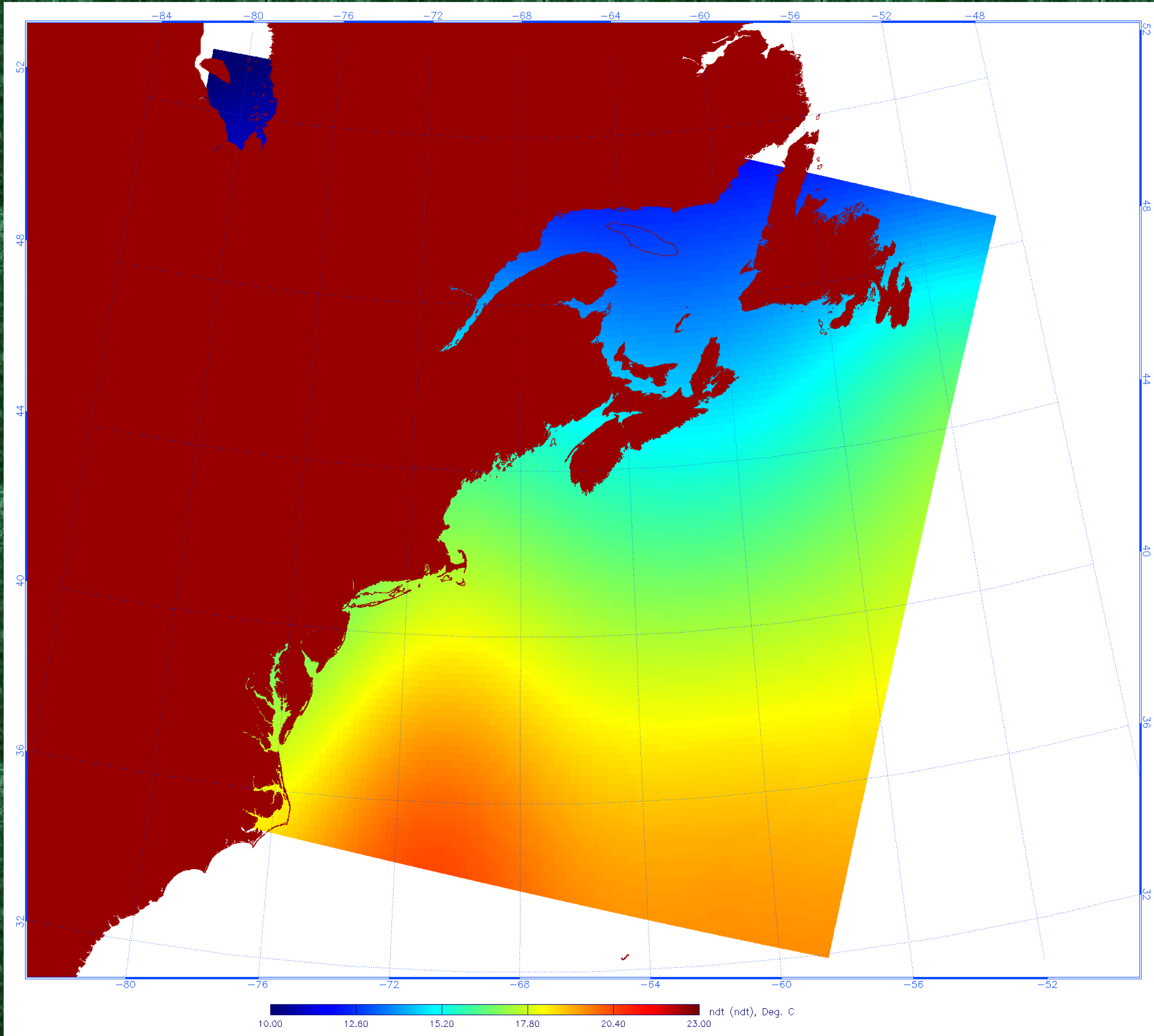
- All products are being produced globally with reasonable agreement since November 2000 with similar SeaWiFS products
- Field uniformity continues to improve as MODIS calibration and atmospheric correction improves
- Clear-water Angstrom exponents for aerosols, derived from clear-water epsilons, are consistent with AERONET values from Holben et al. (JGR, 2001) for Hawaii, Cape Verde, & Brazil fire data

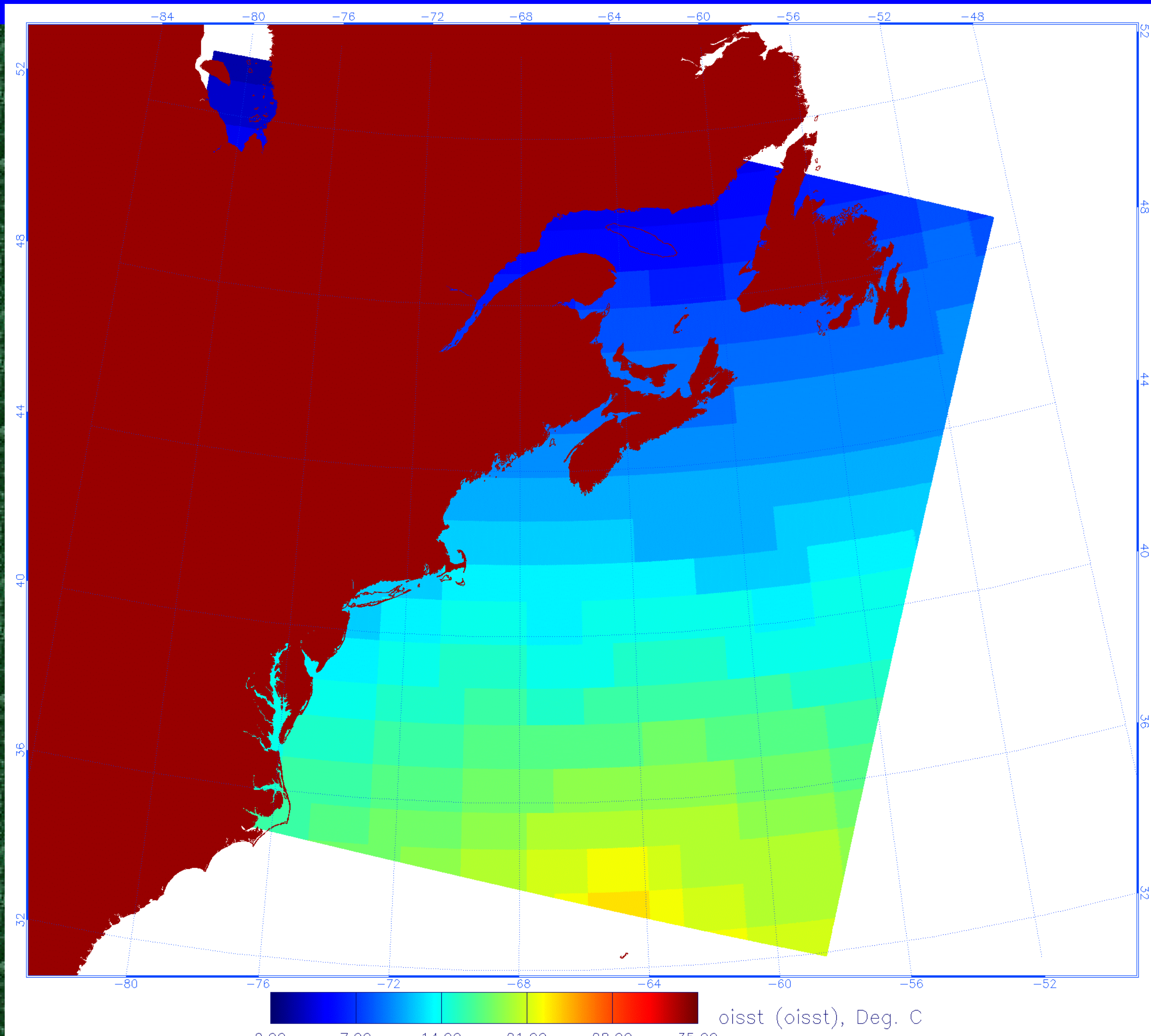
Product Status (cont'd)

- IPAR values consistent with Gregg and Carder (1990) model values for same locations and with Bahamas and MAB PAR measurements (within about 5%)
- Chl_a3 and γ_{FL} both derive from semi-analytic model absorption coefficients:
  - Chlorophylls are consistent with SeaWiFS except at high latitudes where SeaWiFS may under-estimate. Field accuracies of 25-30% (Carder et al.'99)
  - γ_{FL} values range from 0.3% to 5%, consistent with Gordon (1979) and Carder and Steward (1985) and references cited (e.g. Kiefer 1973a, 1973b)
  - γ_{FL} derives from IPAR, ARP, and total spectral absorption coefficients, supporting their relative accuracy

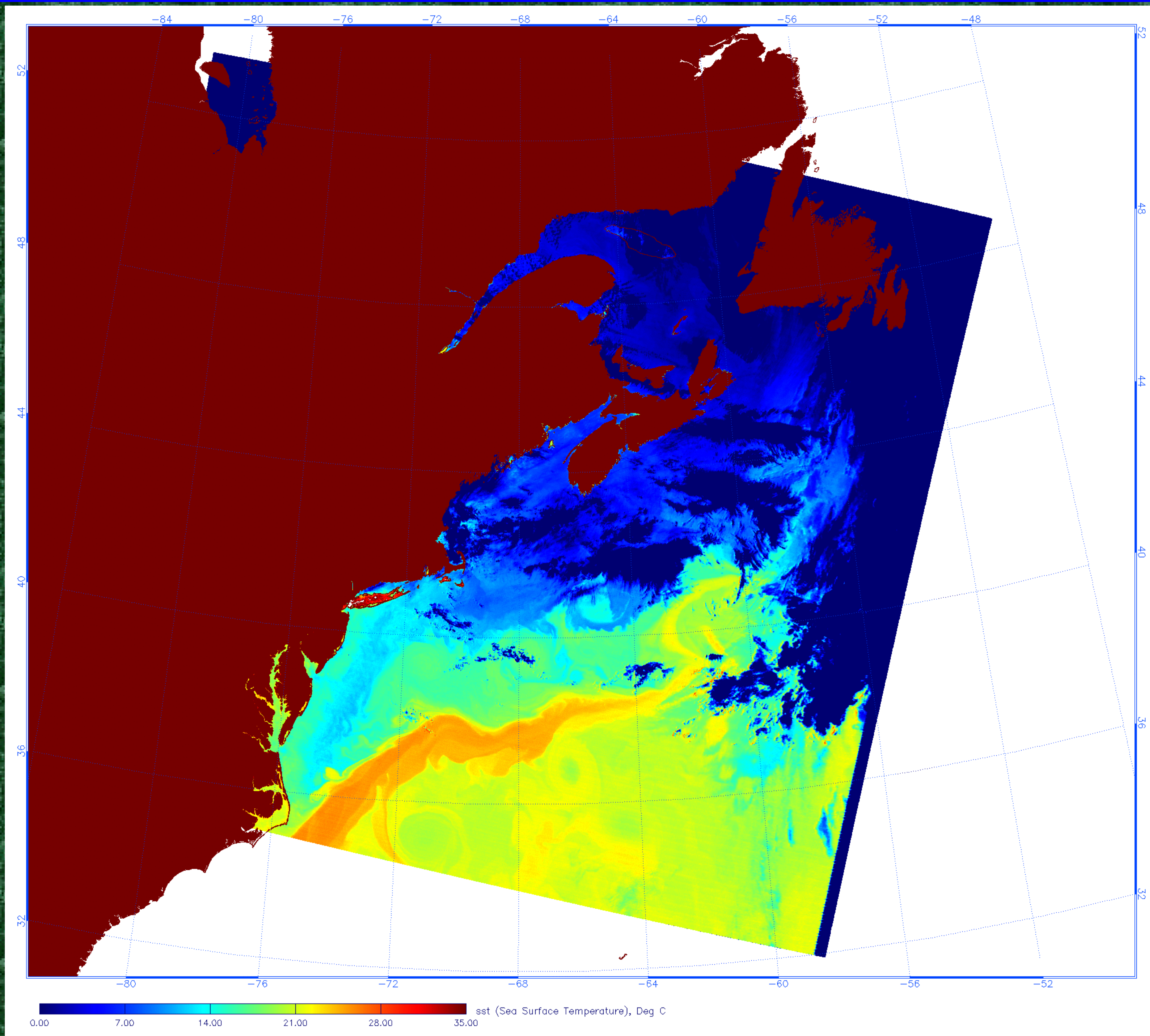
Nitrate-Depletion Temperature

- NDT: Temperatures above which nitrate is negligible
- Large, fast-growing cells (e.g. diatoms) found where T<<NDT
- Have low chlorophyll-specific absorption coefficients
- For T>NDT have small cells, photo-protective pigments and large chlorophyll-specific absorption coefficients
- The same MODIS-derived $a_{\varpi}(\kappa)$ can produce chlorophyll *a* values that range over a factor of 5 due to this package effect
- Comparing T to NDT reduces this effect to provide accuracies of about 25-30%(Carder et al. 1999)
- Need to use MODIS SST rather than Reynolds($1^o x 1^o$) SST
- Next slides show NDT and Reynolds and MODIS SST and effects on Chl_a3

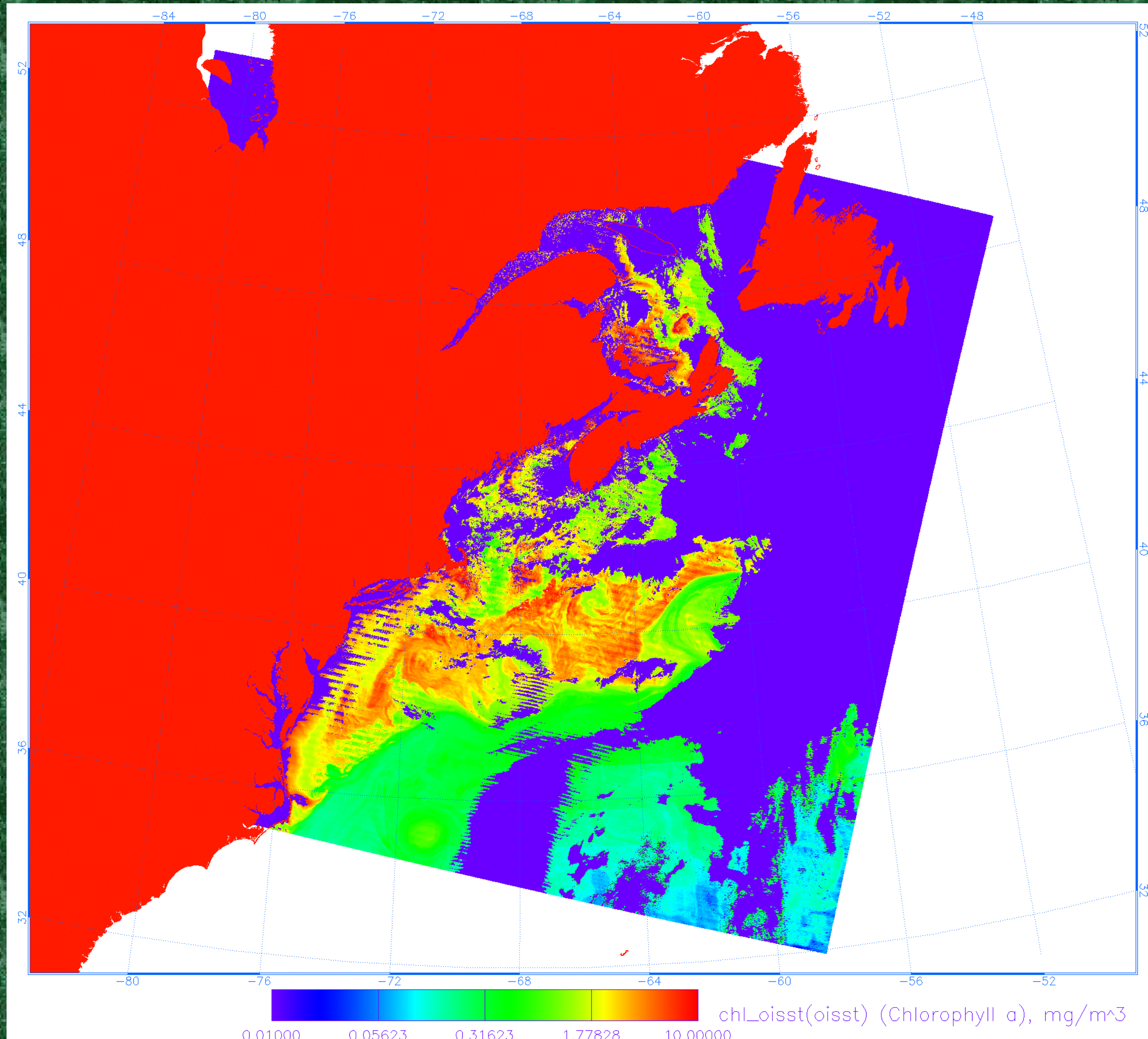

ndt (ndt), Deg. C
10.00
12.60
15.20
17.80
20.40
23.00



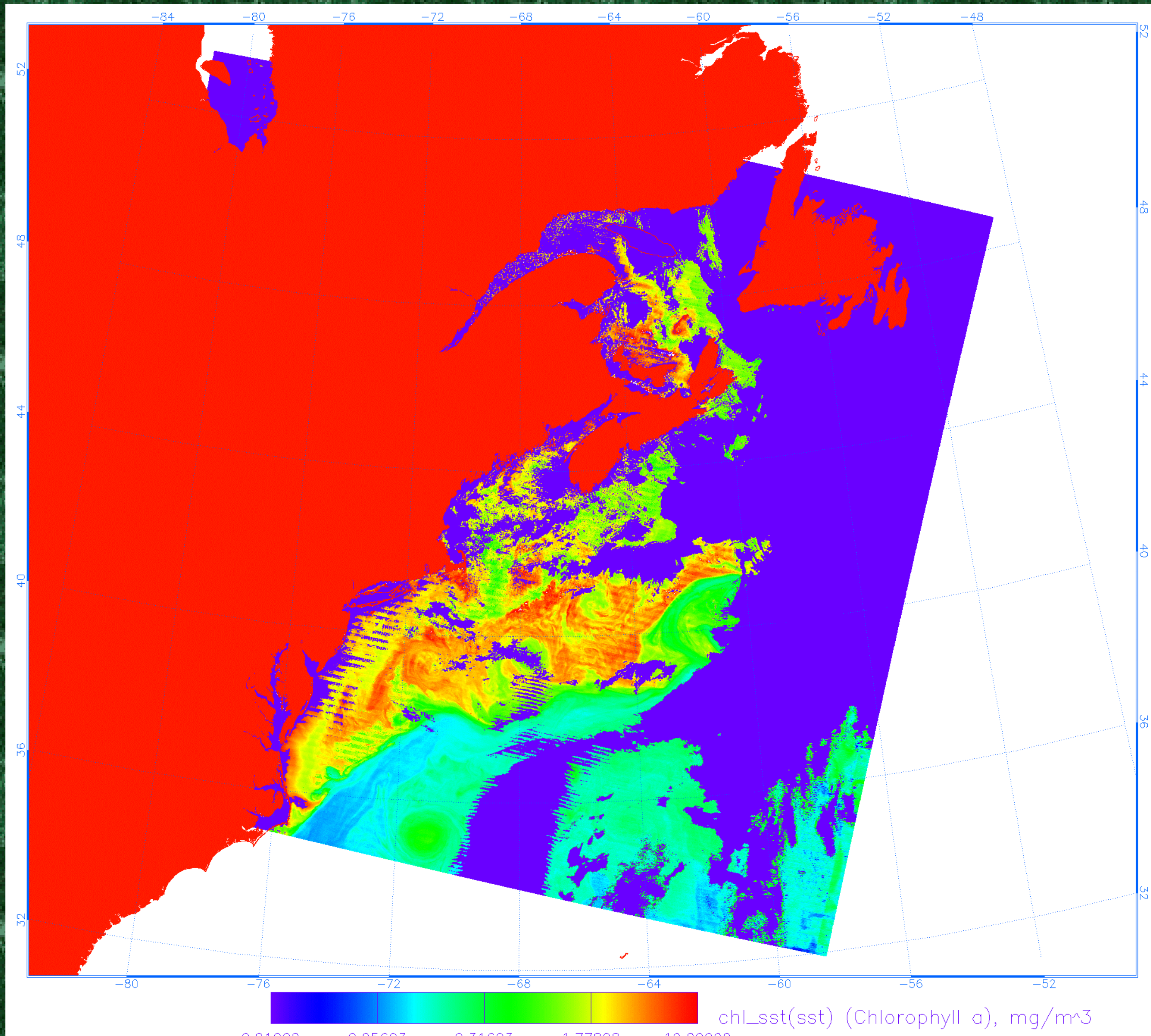
-84 -80 -76 -72 -68 -64 -60 -56 -52 -48
52 48 44 40 36 32
-80 -76 -72 -68 -64 -60 -56 -52
0.00 7.00 14.00 21.00 28.00 35.00
oisst (oisst), Deg. C



-84
-80
-76
-72
-68
-64
-60
-56
-52
-48
52
48
44
40
36
32
0.00
7.00
14.00
21.00
28.00
35.00
sst (Sea Surface Temperature), Deg C



chl_oisst(oisst) (Chlorophyll a), mg/m^3
0.01000
0.05623
0.31623
1.77828
10.00000

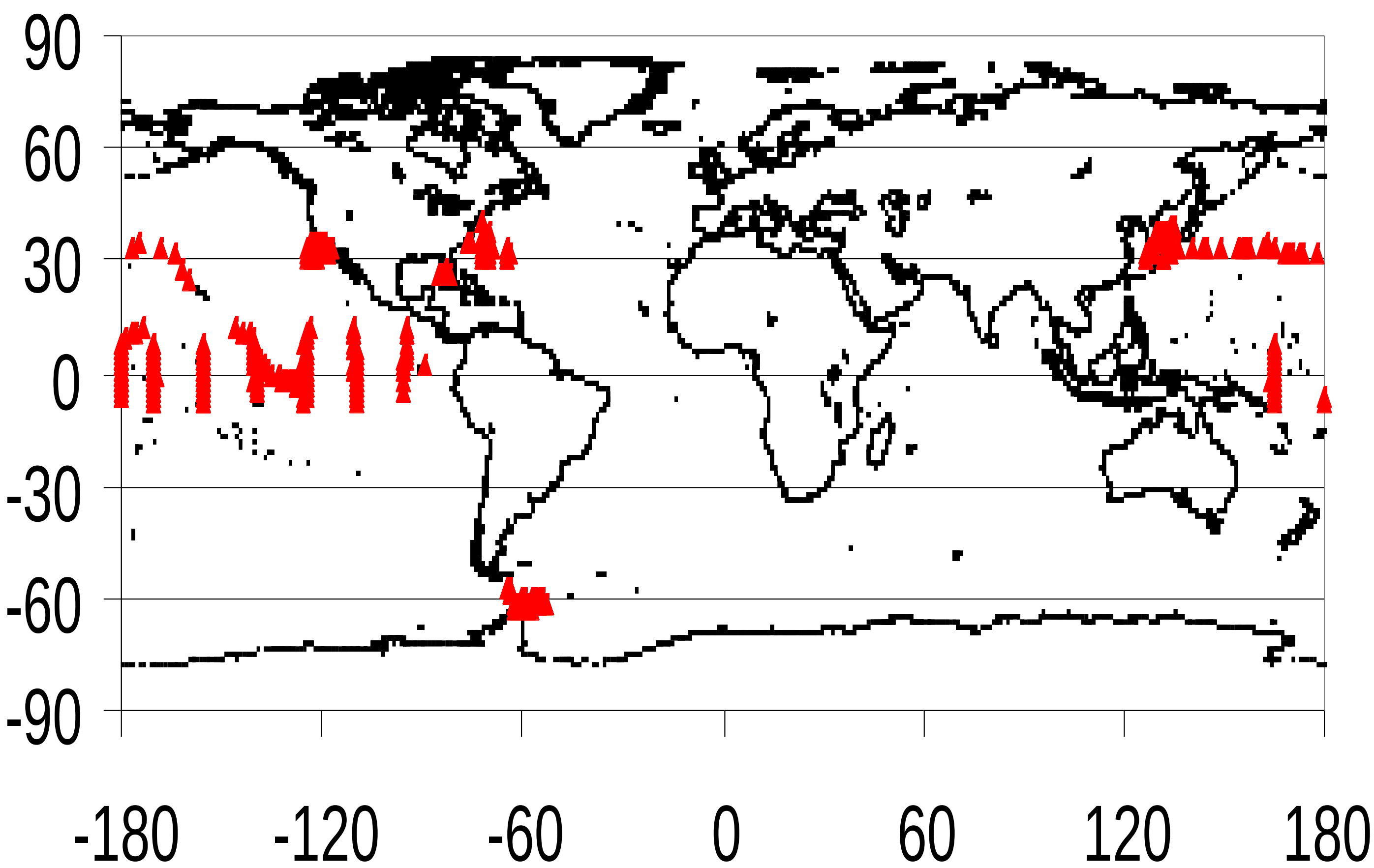


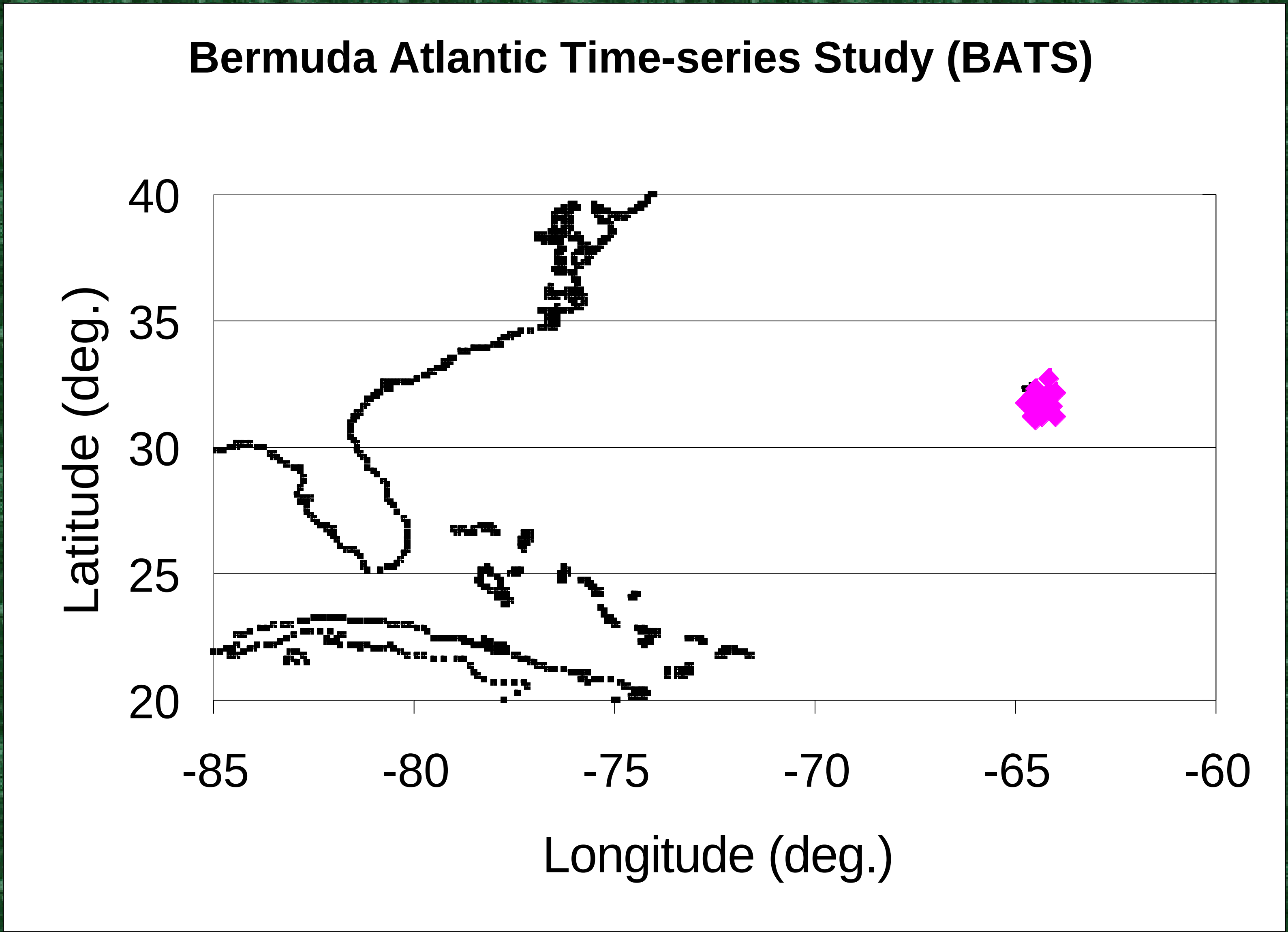
−84 −80 −76 −72 −68 −64 −60 −56 −52 −48
52
48
44
40
36
32
−80 −76 −72 −68 −64 −60 −56 −52
chl_sst(sst) (Chlorophyll a), mg/m^3
0.01000 0.05623 0.31623 1.77828 10.00000

Validation Plans

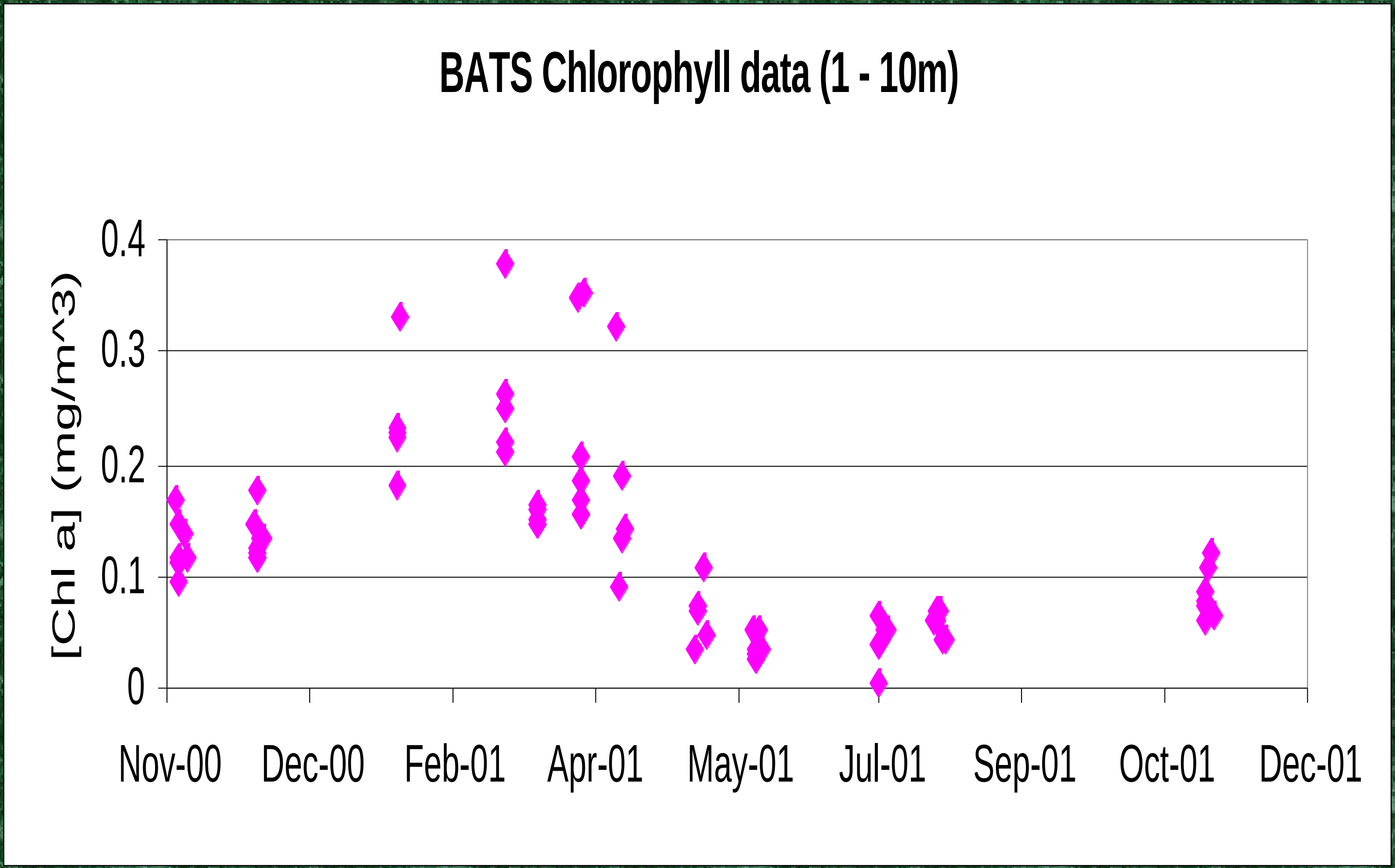
- Data Sets:
  - SeaBASS match-up values for chlorophyll and absorption coefficients
  - AERONET match-up values for clear-water epsilons and aerosol optical thickness for use with RADTRAN, a code within 5% of field IPAR data
  - Field PAR data from CoBOP and HYCODE measurements off the Bahamas, WFS, N.J.

SeaBass Chl data available Nov.'00 - Dec.'01

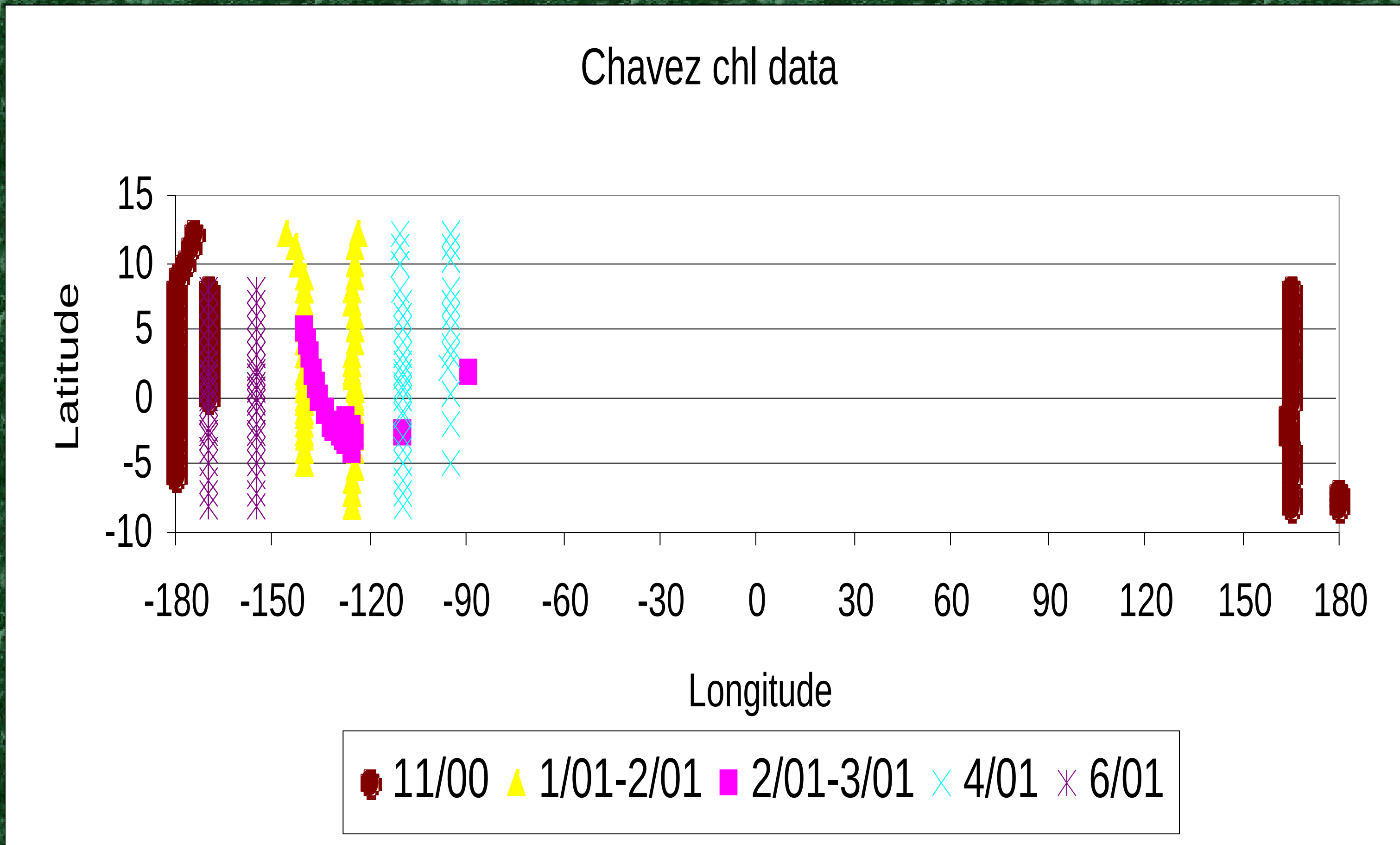


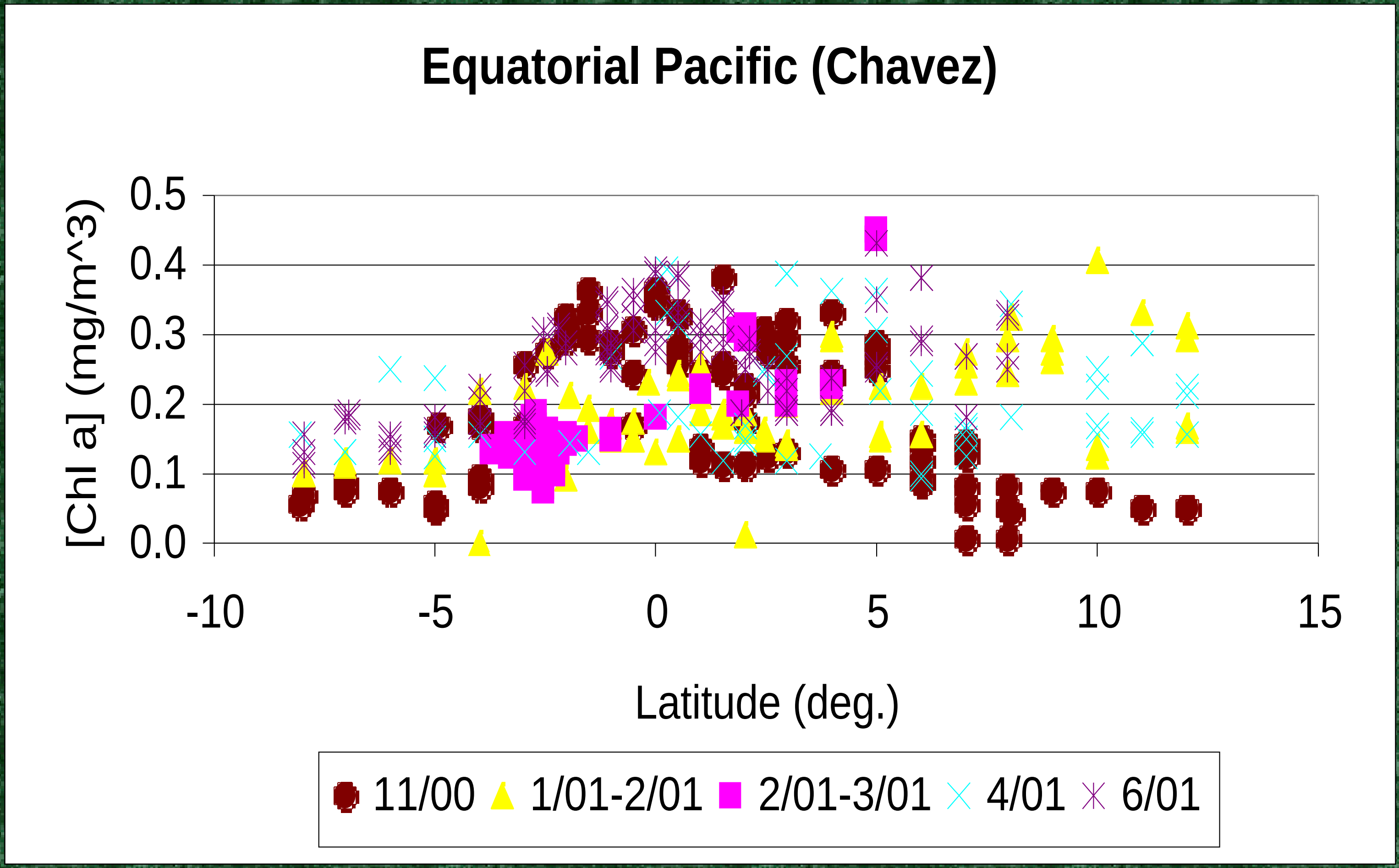


Bermuda Atlantic Time-series Study (BATS)
40
35
30
25
20
Latitude (deg.)
-85
-80
-75
-70
-65
-60
Longitude (deg.)

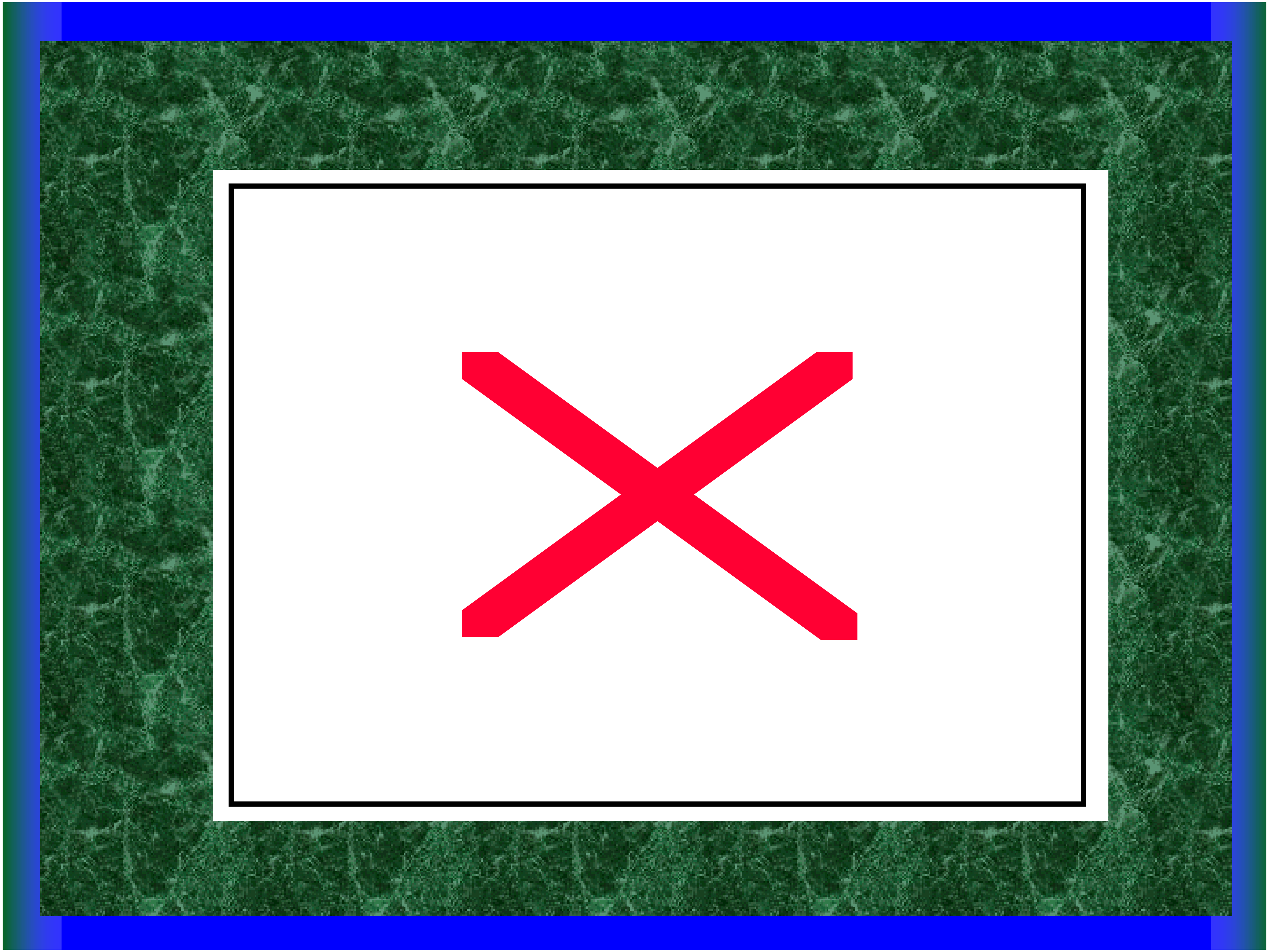


BATS Chlorophyll data (1 - 10m)
[Chl a] (mg/m^3)
0.4
0.3
0.2
0.1
0
Nov-00
Dec-00
Feb-01
Apr-01
May-01
Jul-01
Sep-01
Oct-01
Dec-01

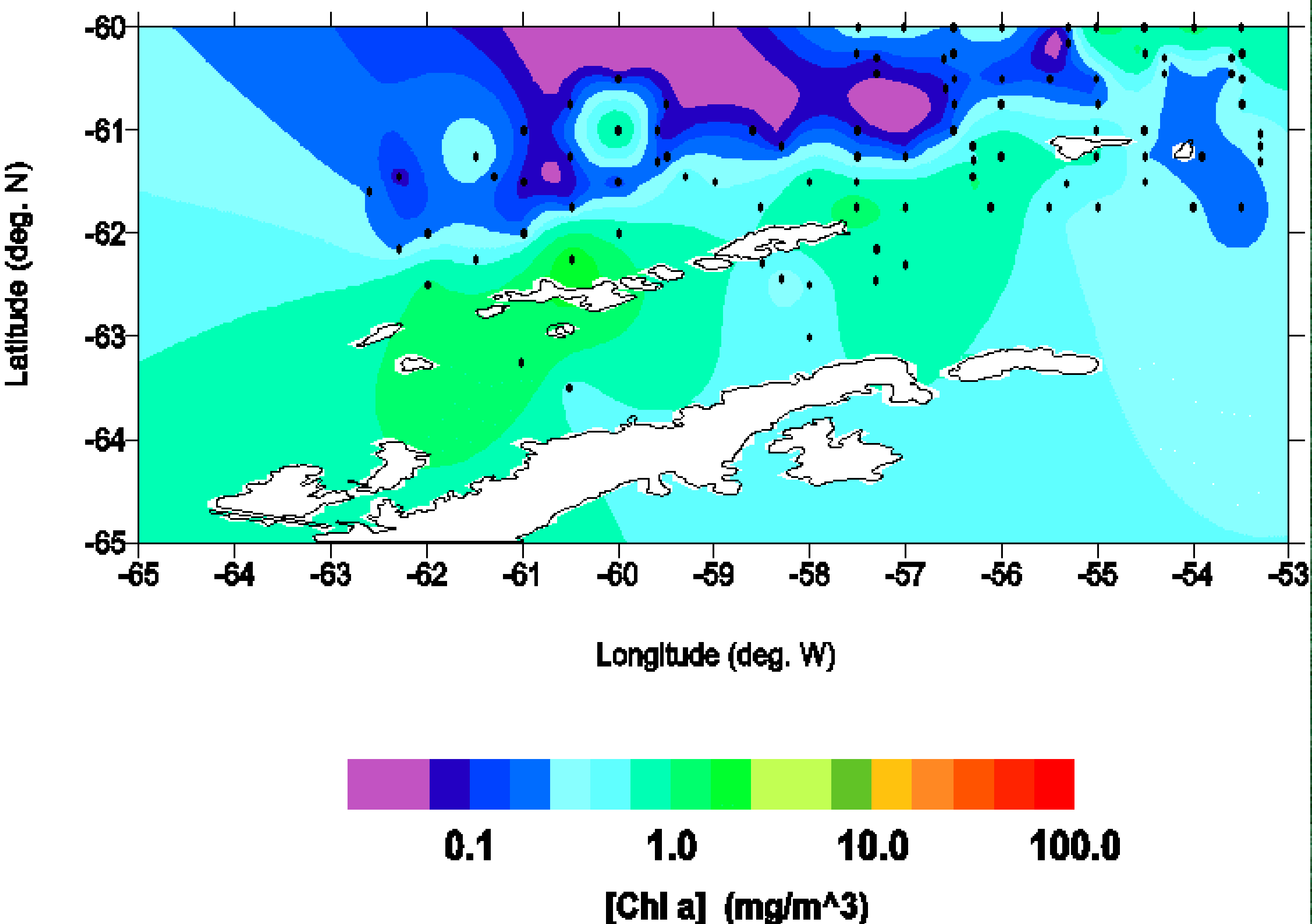

Chavez chl data
Latitude
15
10
5
0
-5
-10
-180
-150
-120
-90
-60
-30
0
30
60
90
120
150
180
Longitude
11/00
1/01-2/01
2/01-3/01
4/01
6/01



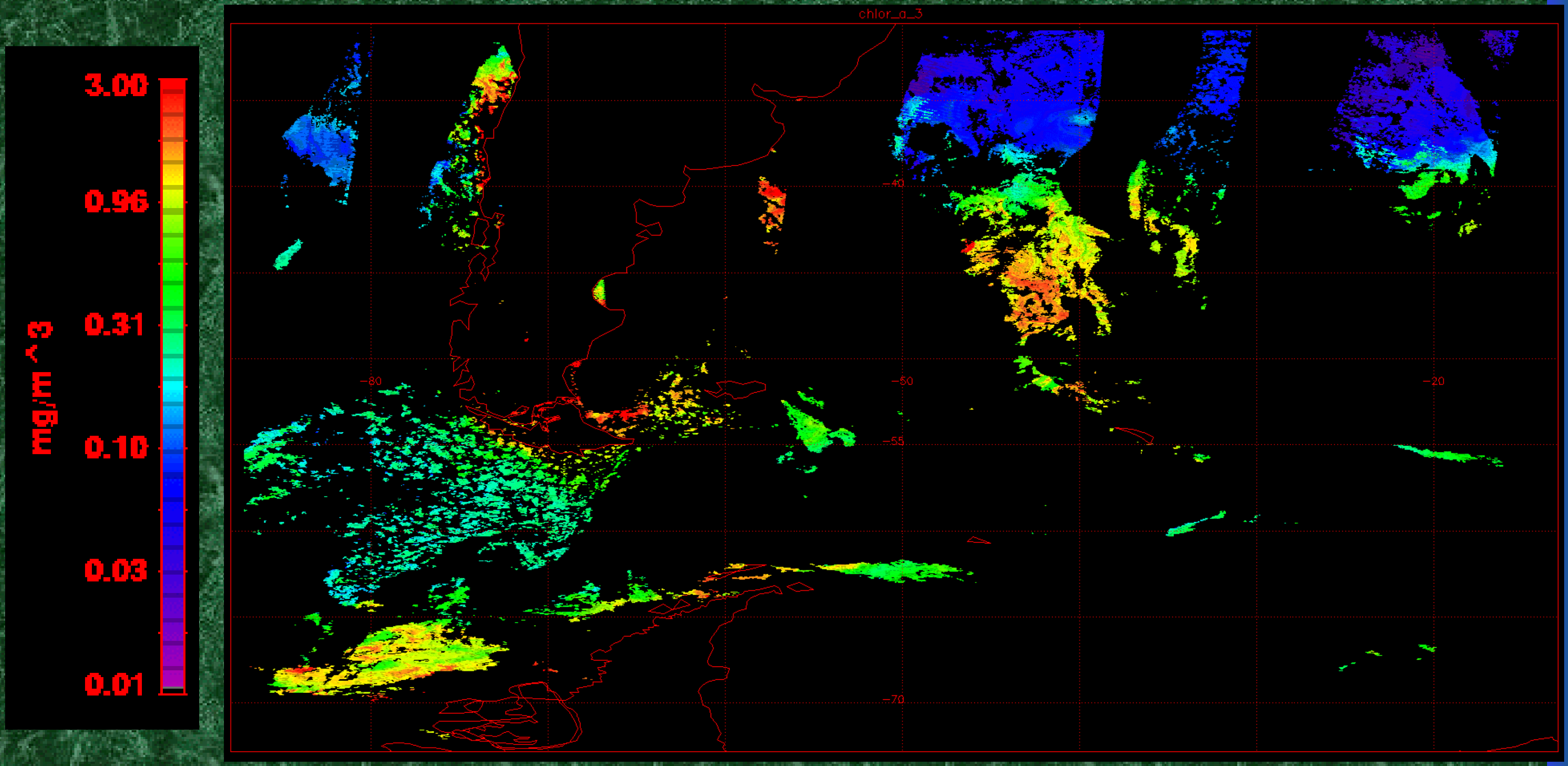
Equatorial Pacific (Chavez)
[Chl a] (mg/m^3)
0.5
0.4
0.3
0.2
0.1
0.0
-10
-5
0
5
10
15
Latitude (deg.)
11/00
1/01-2/01
2/01-3/01
4/01
6/01



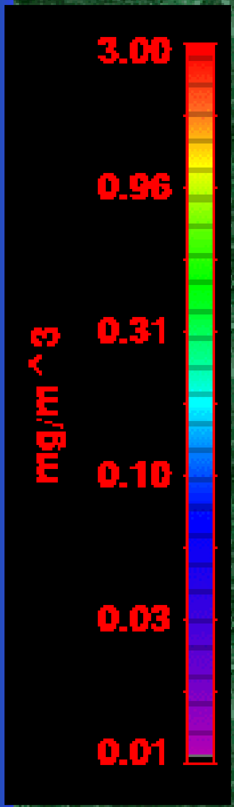
Mitchell's Southern Ocean [Chl a]: 2/12/01 - 3/2/01

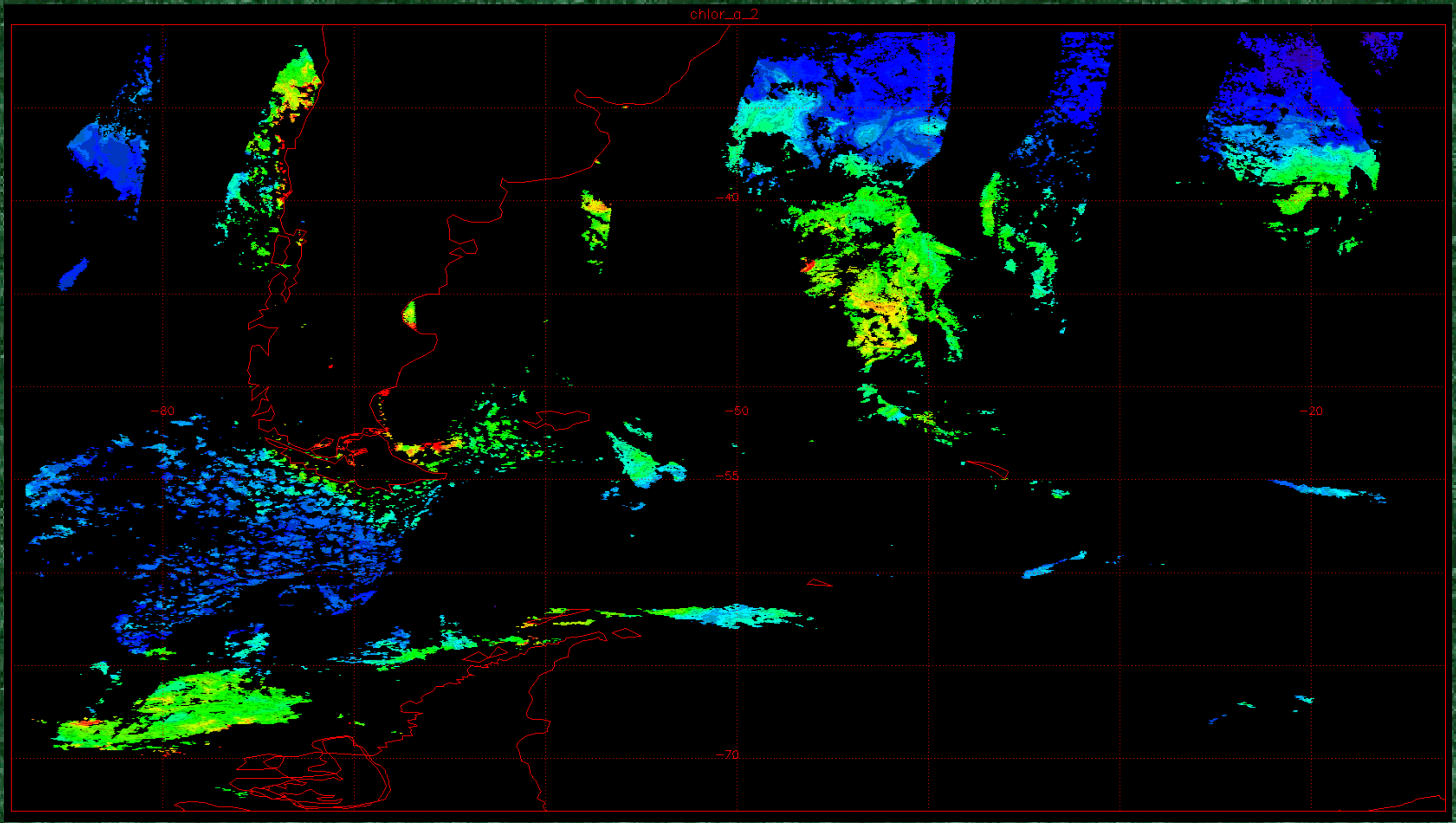


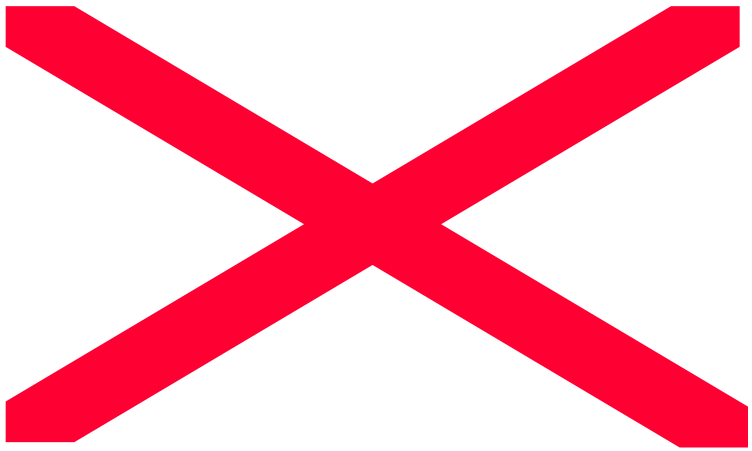
Chl_a3; Feb. 2001



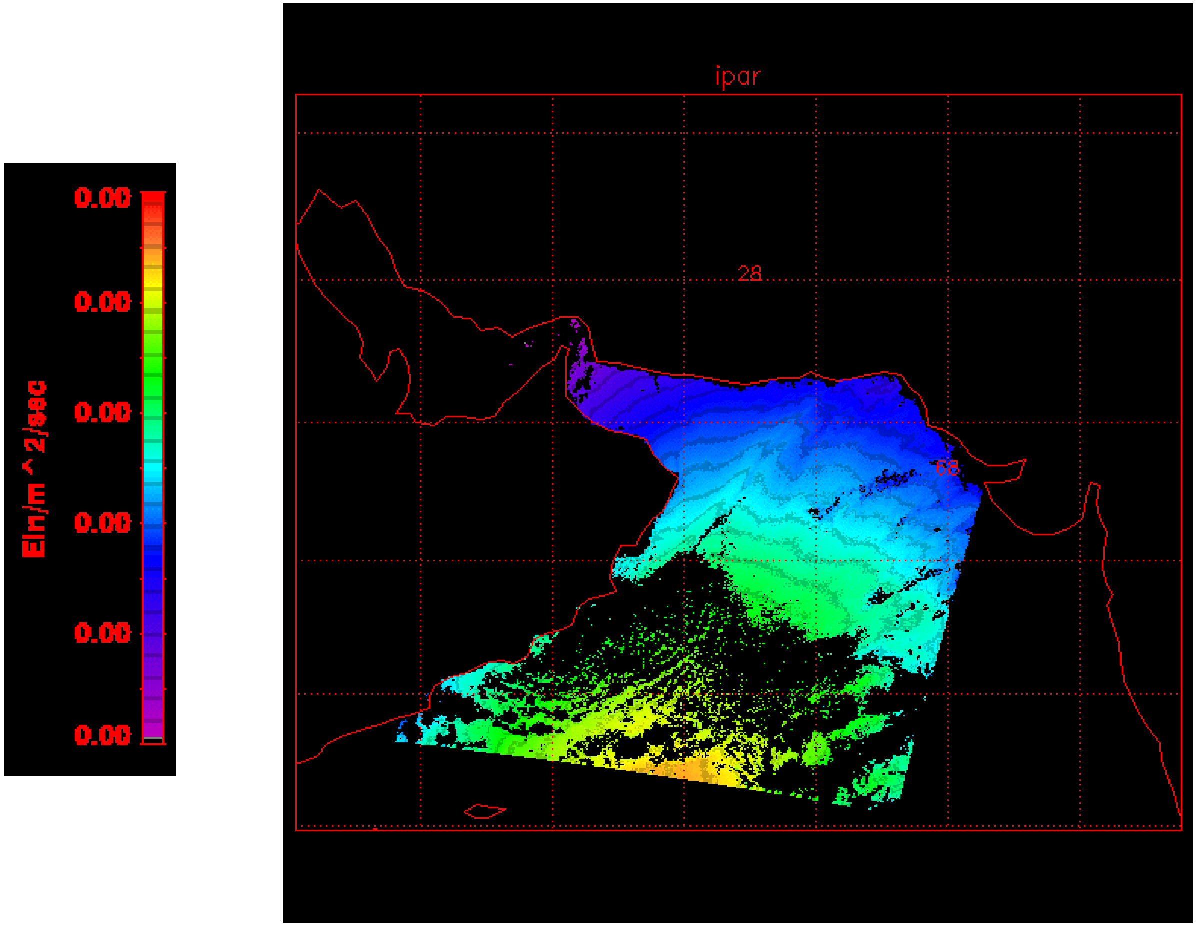
Chl_a2; Feb. 2001



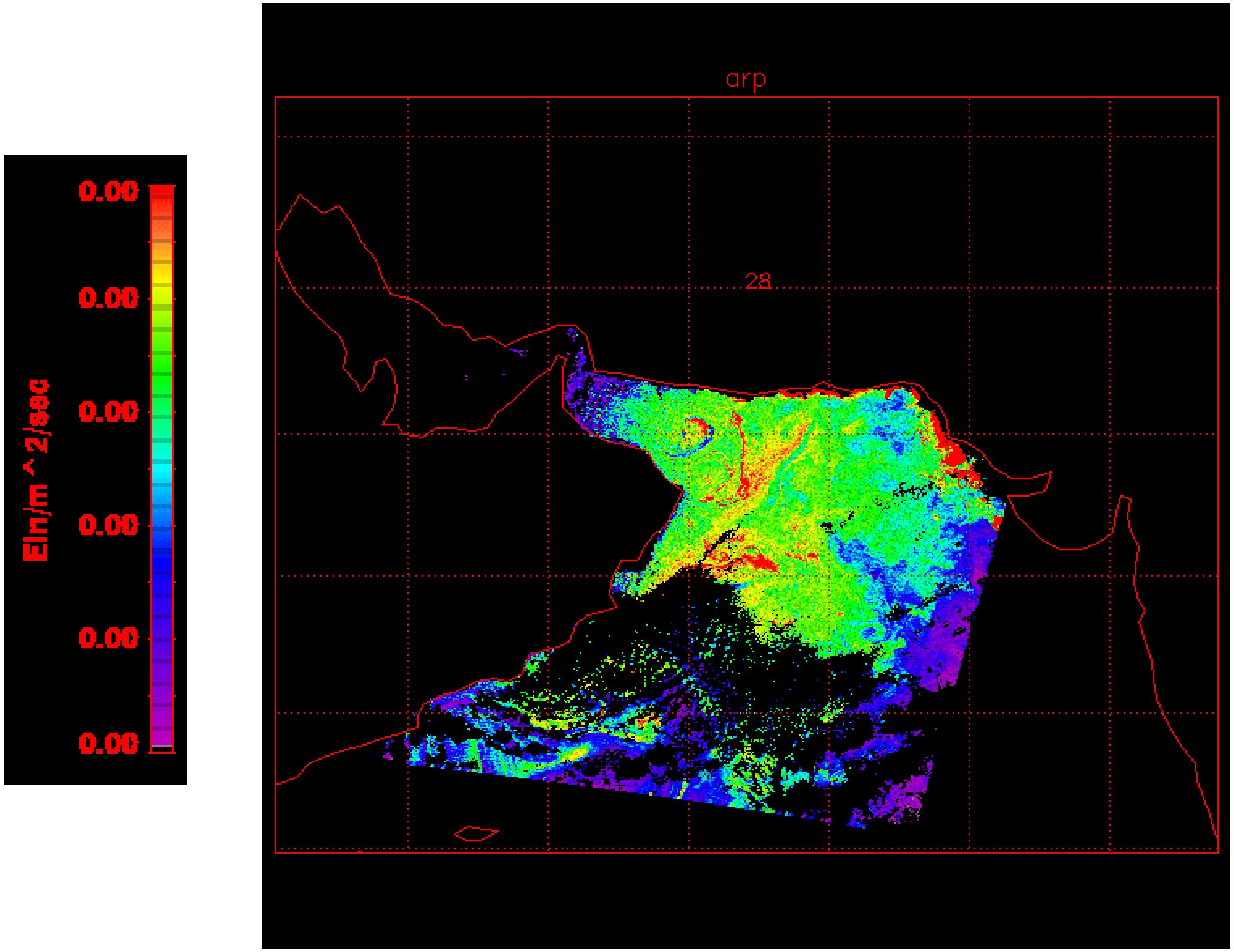




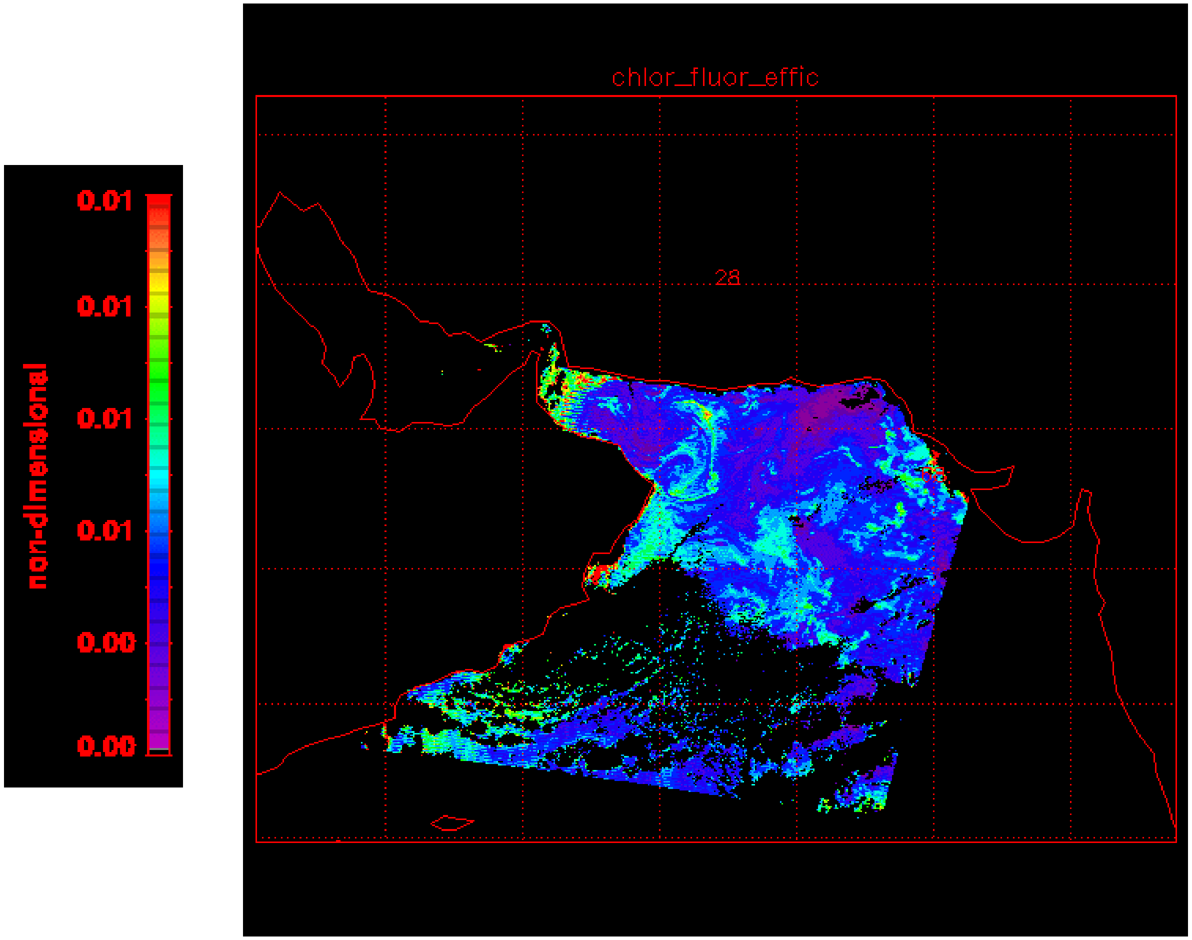
IPAR (.0013-.0018)

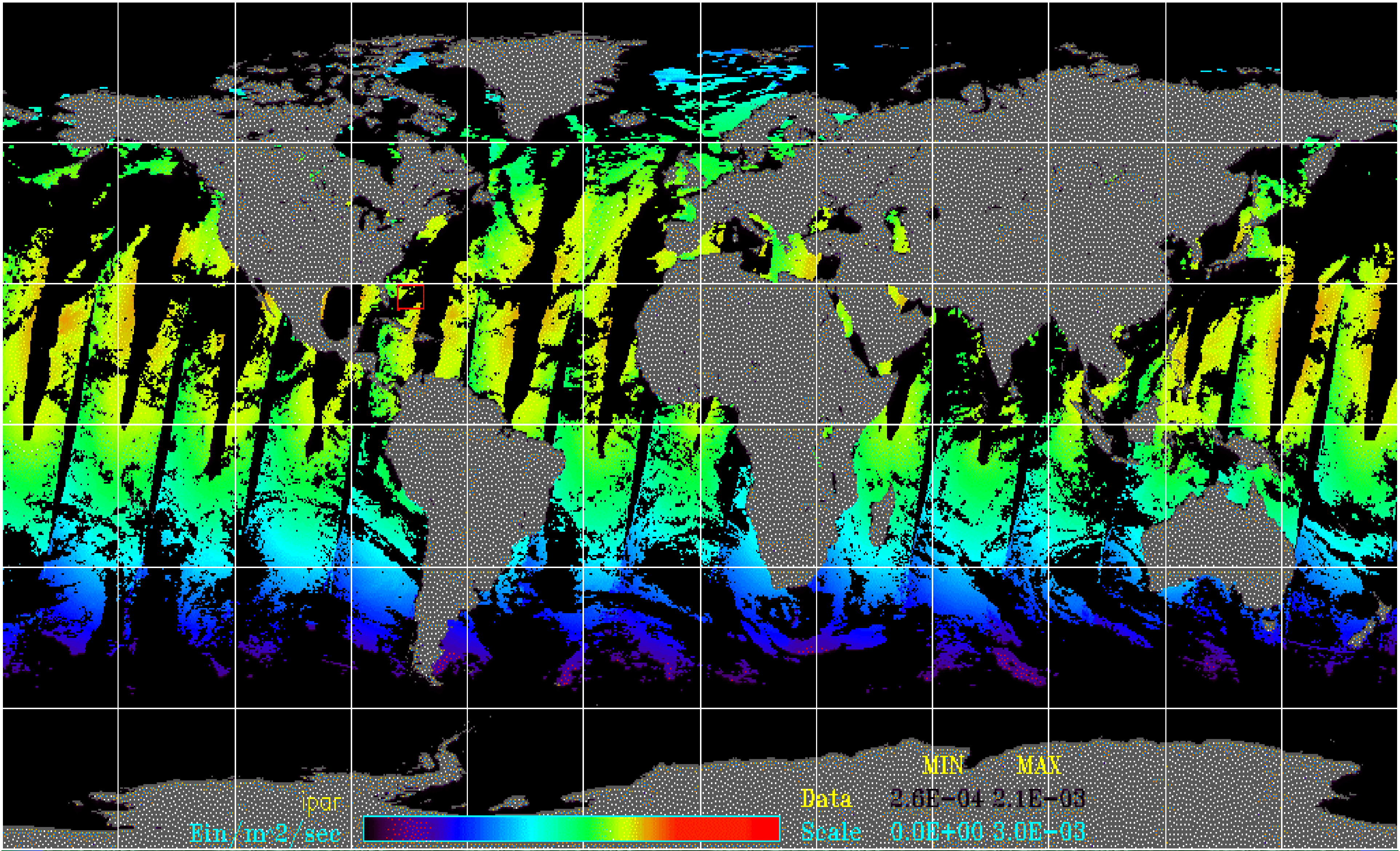


ARP (.00002-.00008)

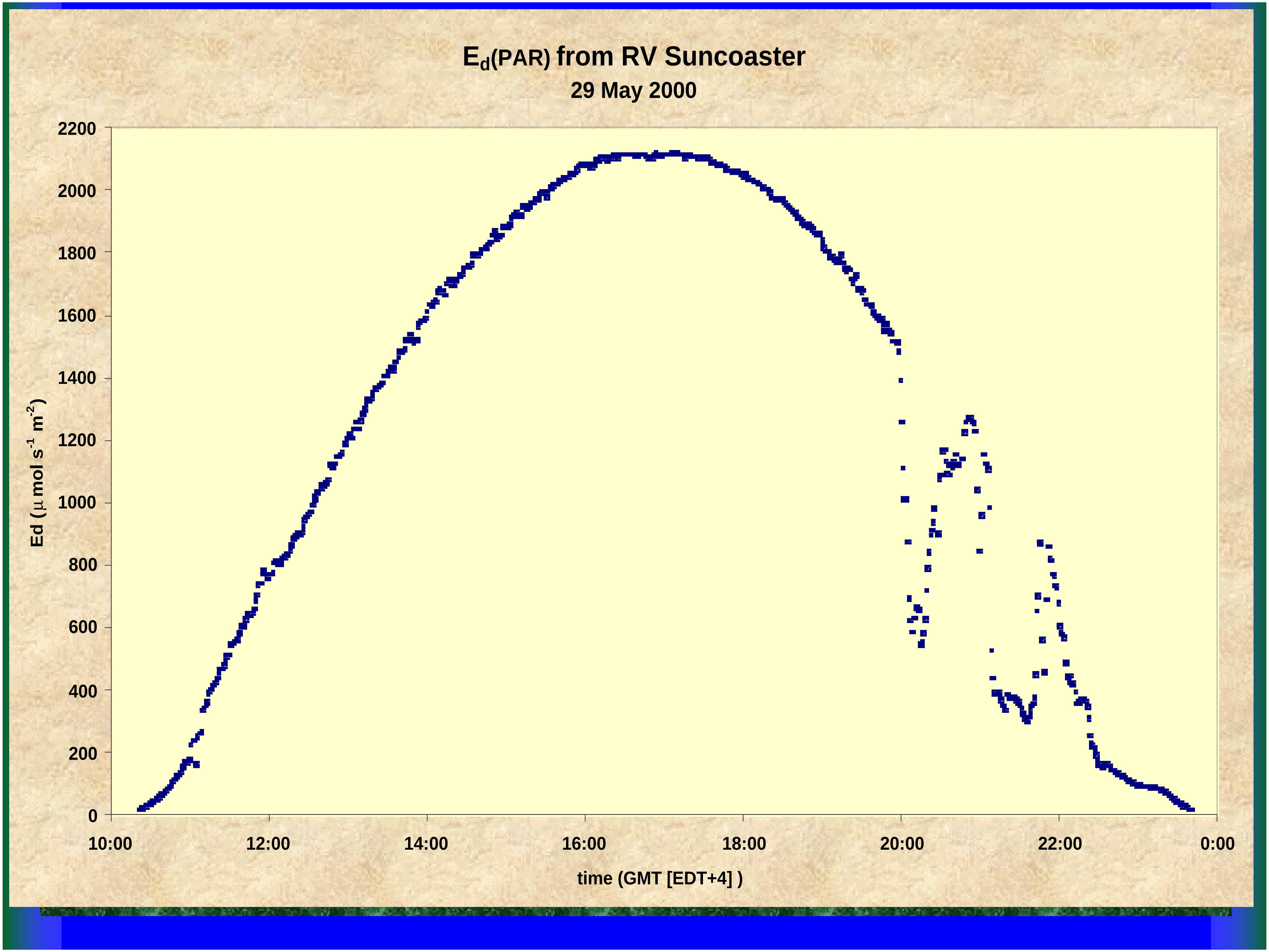


Fluorescence Efficiency (.25-1.5%)



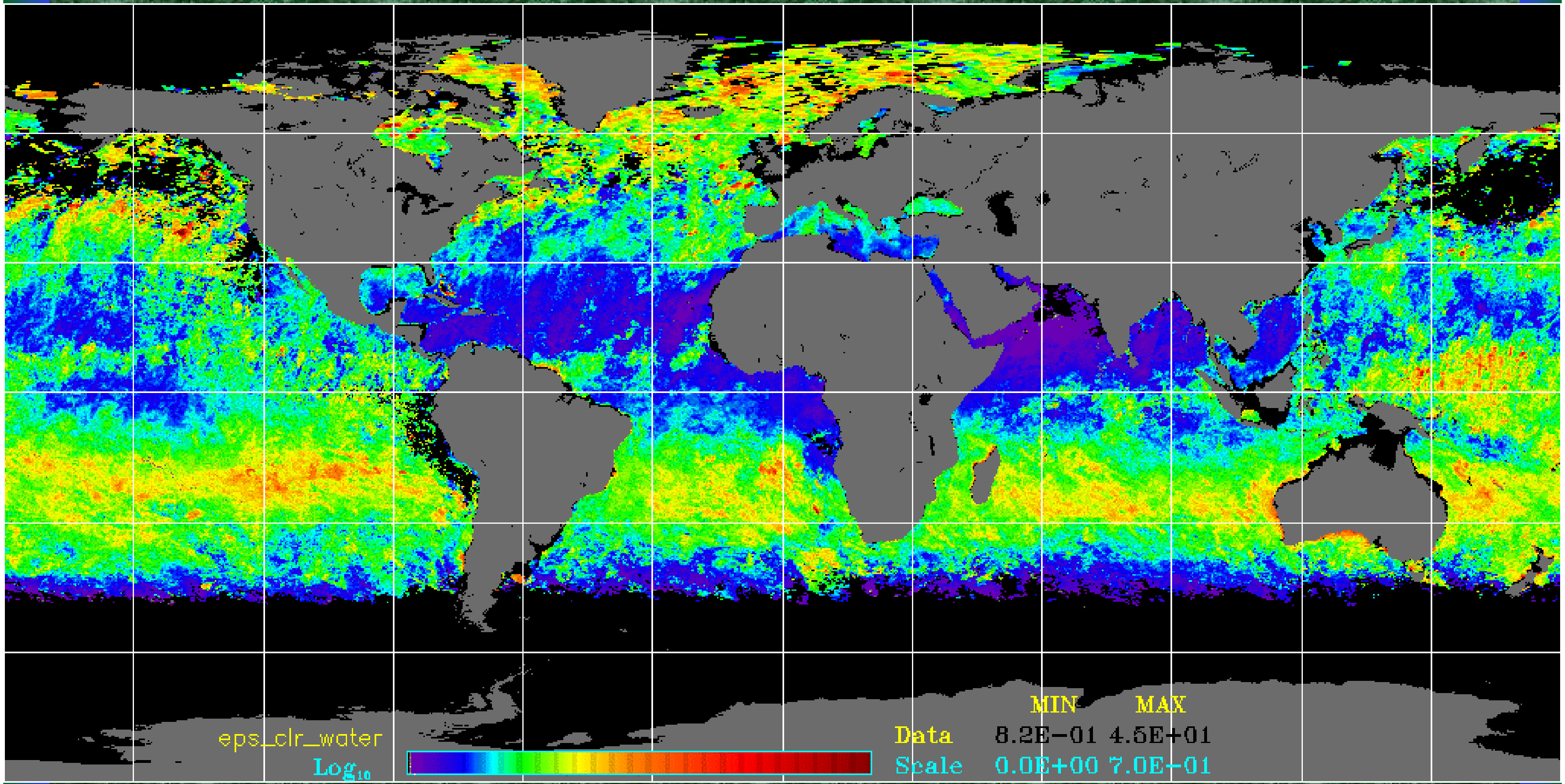


IPAR (QA0-1) 29 May’01

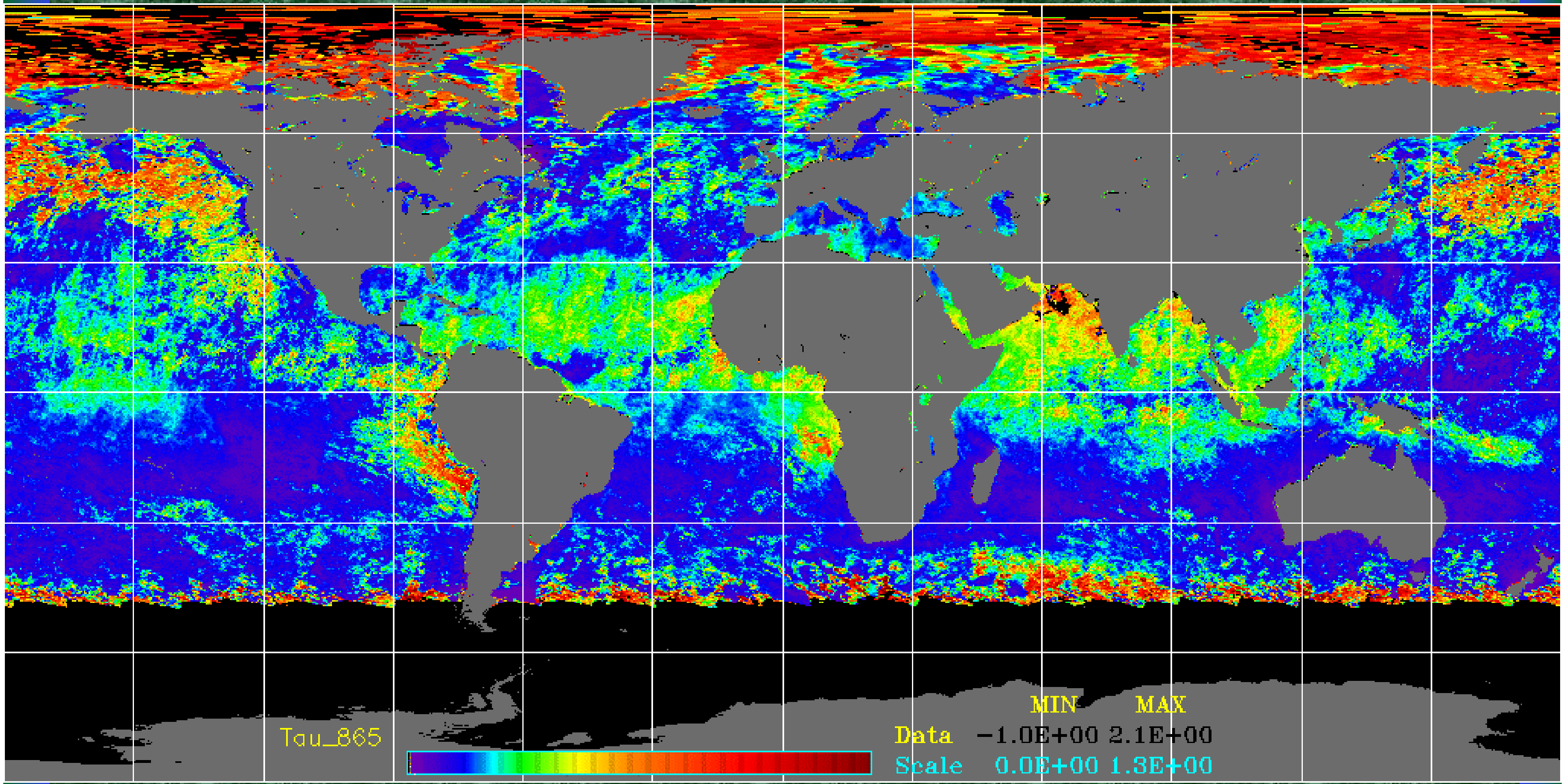


E_d(PAR) from RV Suncoaster
29 May 2000
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Ed (μ mol s-1 m-2)
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
time (GMT [EDT+4])

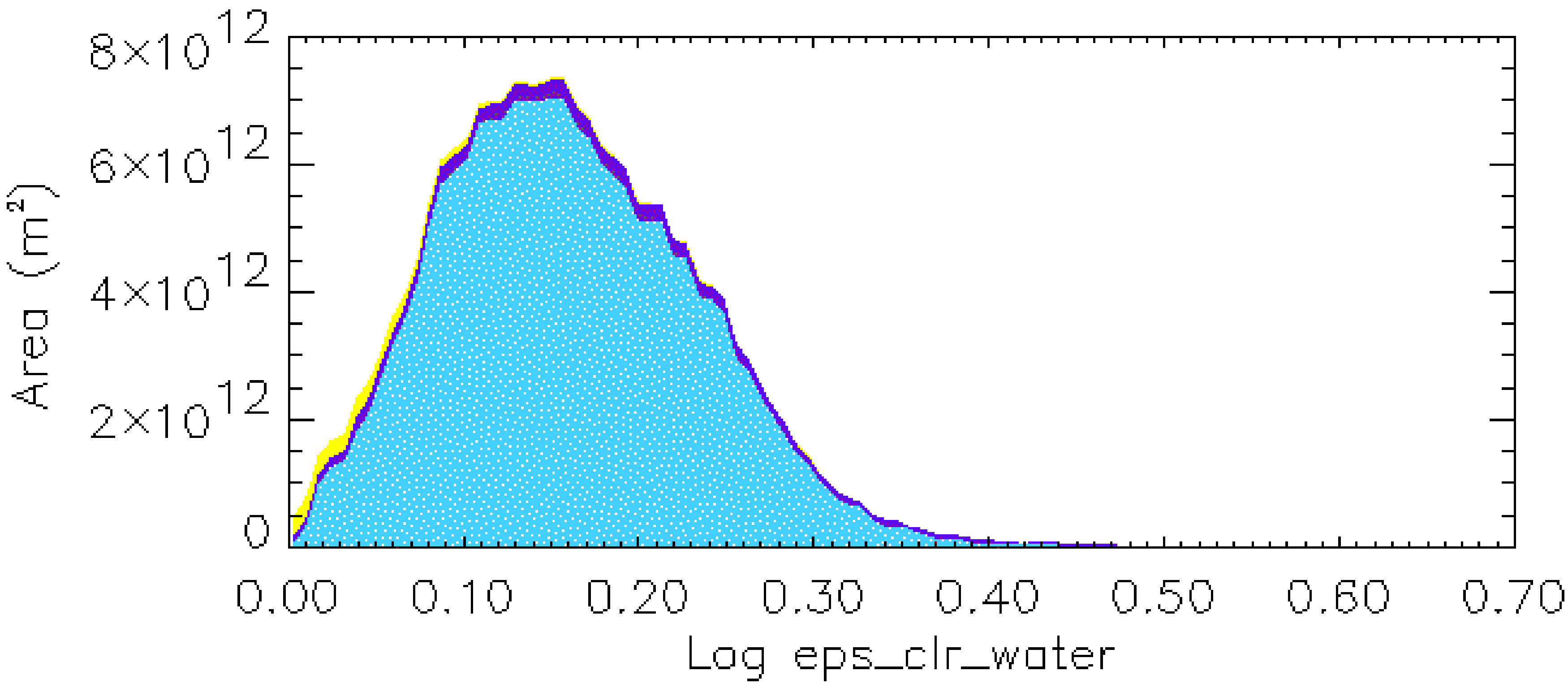
Epsilon clear water July 2001

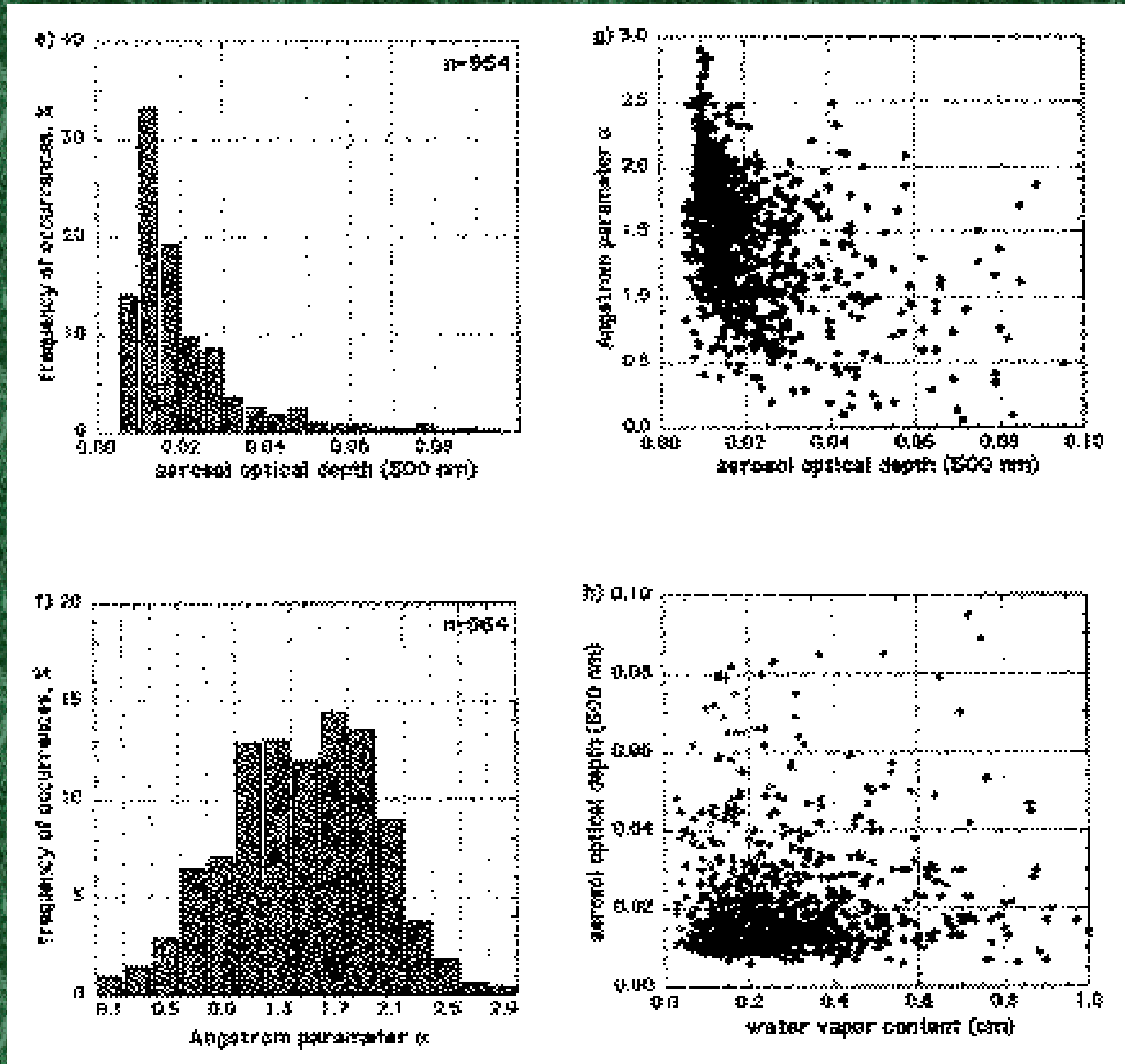


Tau 865 July 2001

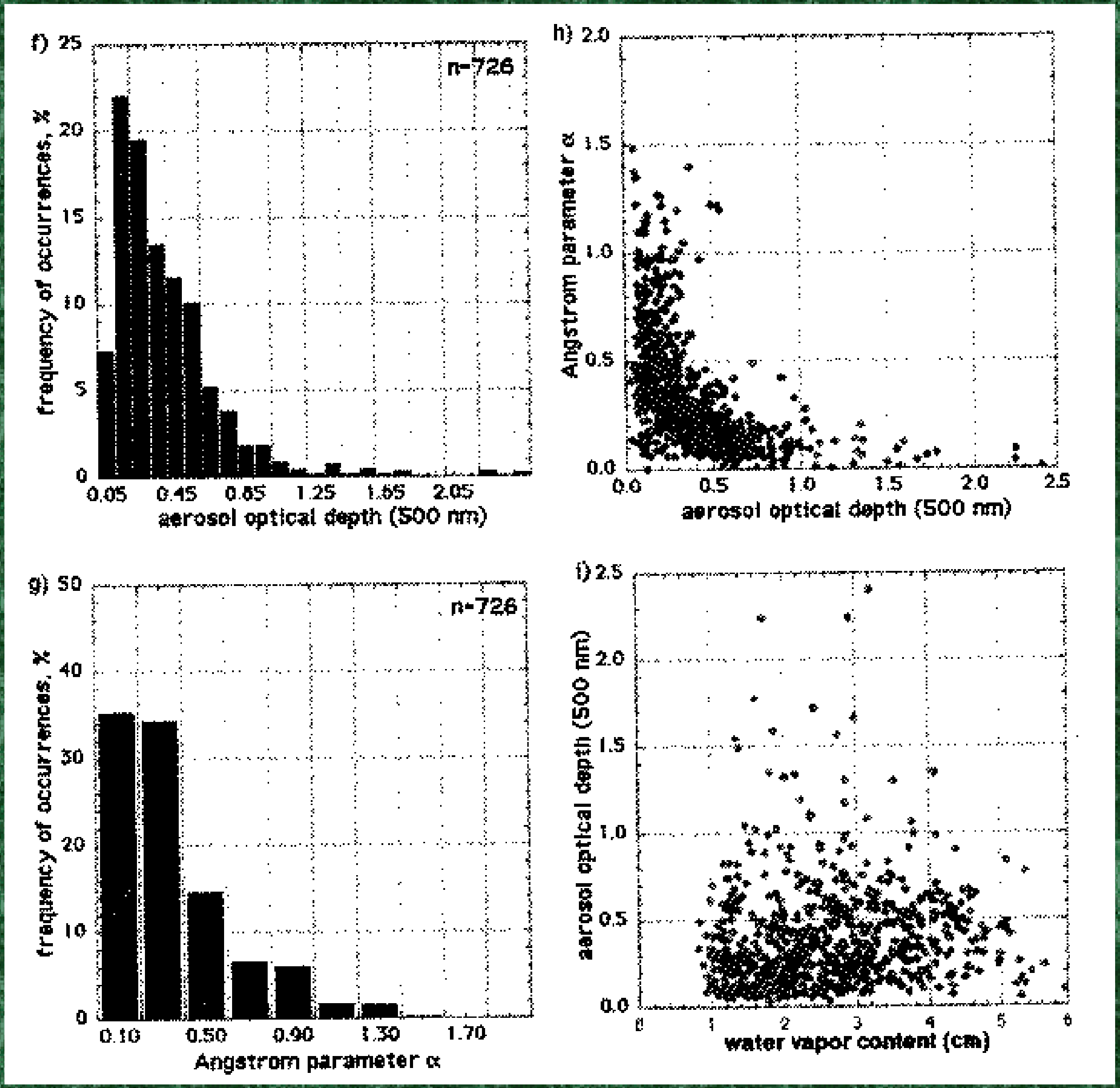


Epsilon histogram July 2001

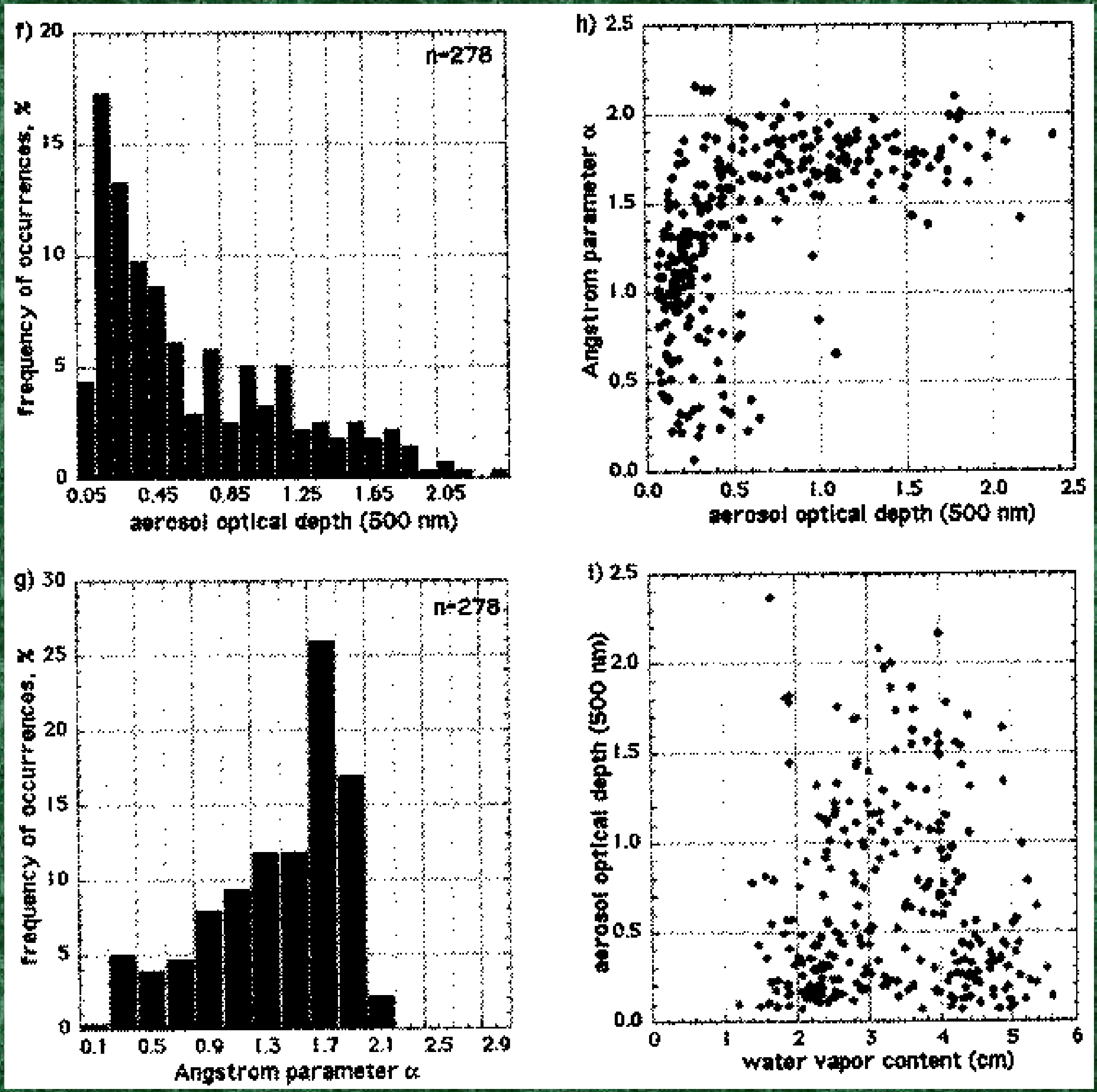




Mauna Loa, Hawaii



Cape Verde - Sal Island



Cuiaba Brazil

Validation Schedule

- Semi-analytic Chl_a3; absorptions: provisionally validated
  - Need MODIS SSTs, now using Reynolds SSTs
  - SeaBASS match-up data sets; provisionally validated
  - Validation after MODIS SST implemented & products available from Miami or before July
- Clear-water epsilons:
  - Miami calibrating red bands
  - Epsilons compared to AERONET data; provisionally validated
  - Estimate validation completed 3 months after cal.
- IPAR provisionally validated; code validated 3 months after cal.
- ARP linked to IPAR & absorption and feeds into fluorescence efficiency: provisionally validated; code validated 3 months after cal.
- Match-up data base with SeaBASS: Miami schedule???