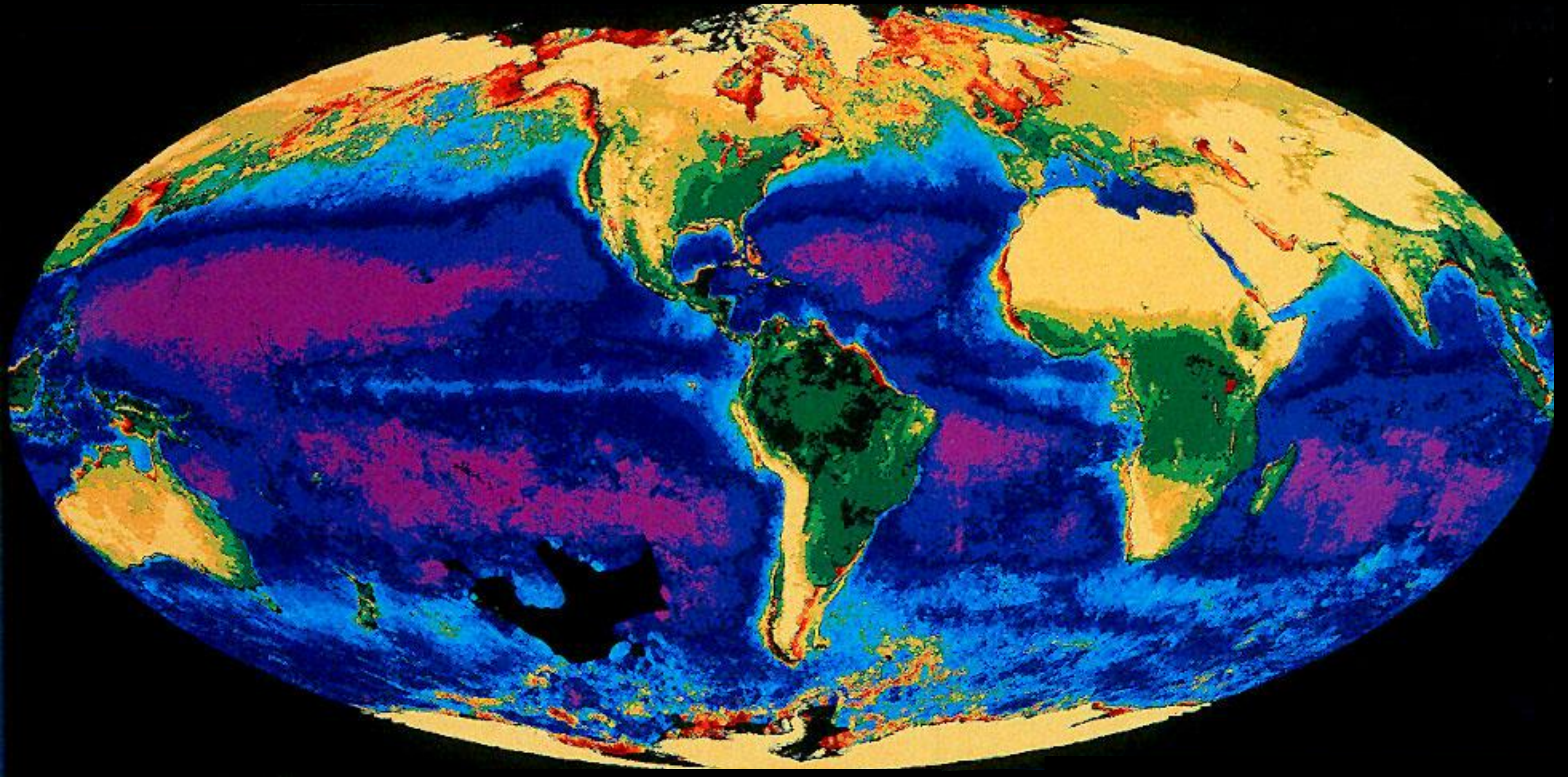
Remote Sensing of Ocean Colour: Visible Spectral Radiometry

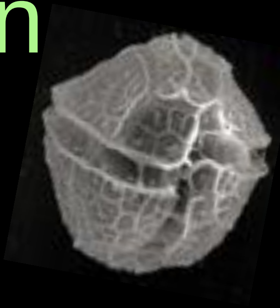


Ocean Colour: Spectral Visible Radiometry

- Colour of the ocean contains latent information on the abundance of the marine microflora (phytoplankton)
- Invisible to the naked eye at close quarters, but huge collective impact visible from space.

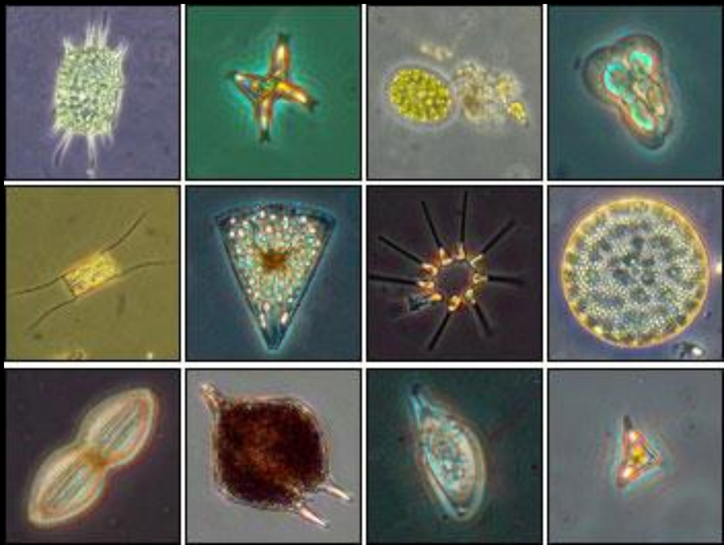
Phytoplankton bloom in the North Sea off the coast of Scotland. Image captured by ESA's MERIS sensor on 7 May 2008.

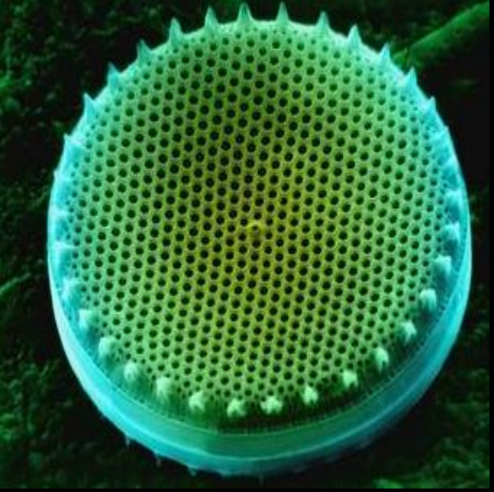
Some properties of phytoplankton



- Predominantly single-celled and microscopic (0.5 to 250μm)
- Green plants (chlorophyll pigments, photosynthesis)
- Mostly confined to the surface (illuminated) layer
- Ubiquitous and abundant (up to 10^5 cells ml^{-1})
- Control colour of water (detectable from space)
- Absorb light (modulate rate of heating)
- Consume carbon dioxide (climate)
- Collective metabolism enormous

  (50 x 10^9 tonnes per annum)
- Slightly negatively buoyant





Ocean-Colour Remote Sensing

Ocean-colour remote sensing was conceived primarily as a method for producing synoptic fields of phytoplankton biomass indexed as chlorophyll

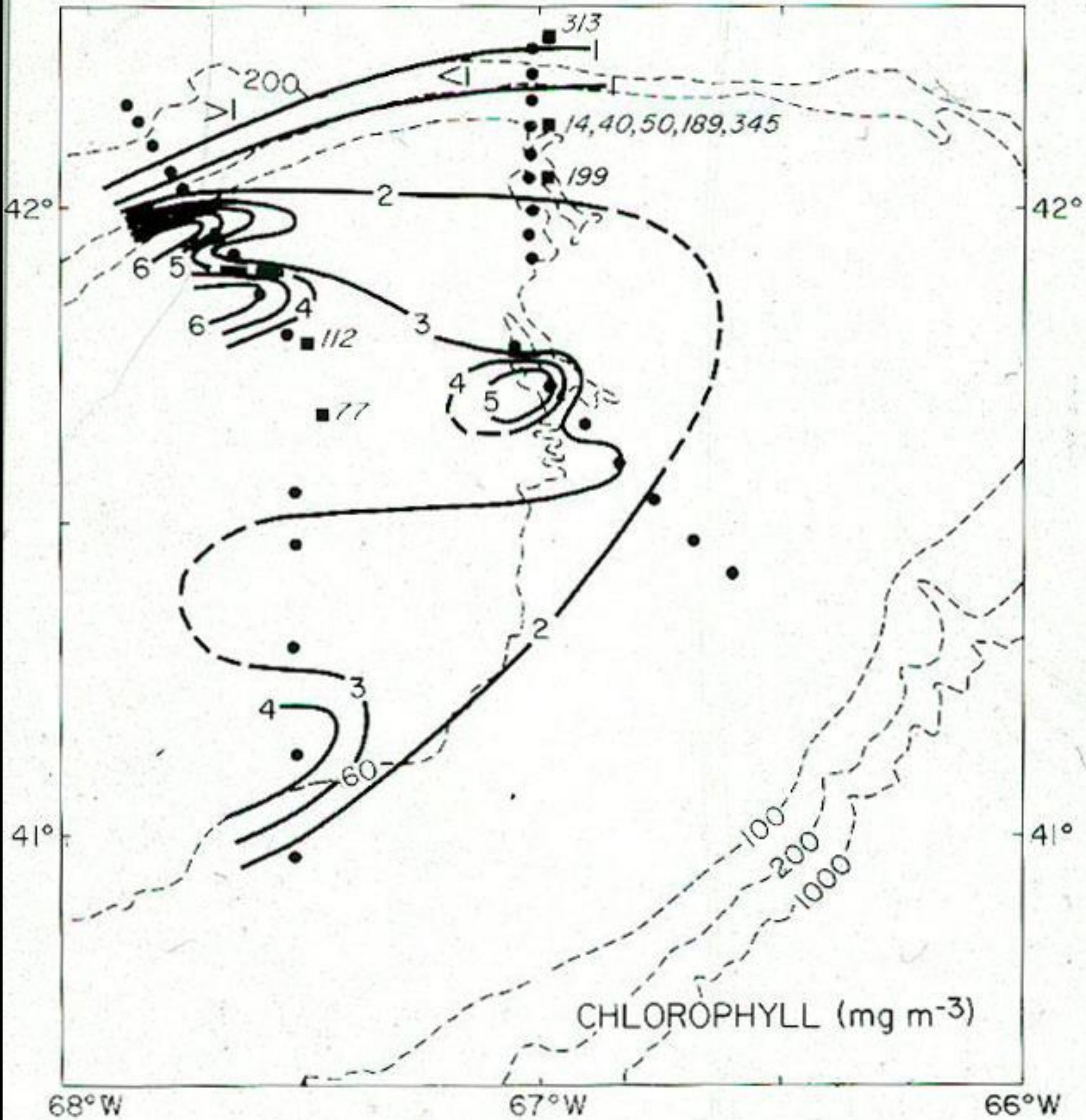
Ocean-Colour Radiometry

Primary Products — Derived directly from the ocean-colour radiometric signal

Secondary Products — Based on primary products and auxiliary information

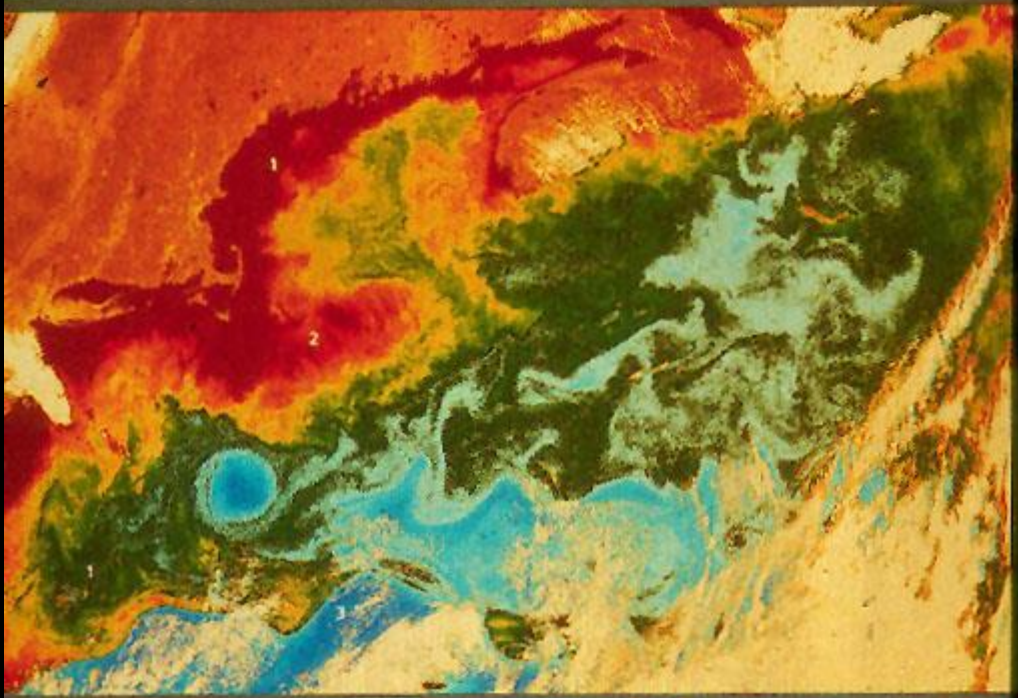
Scientific Applications — Use of primary and secondary products to address scientific issues

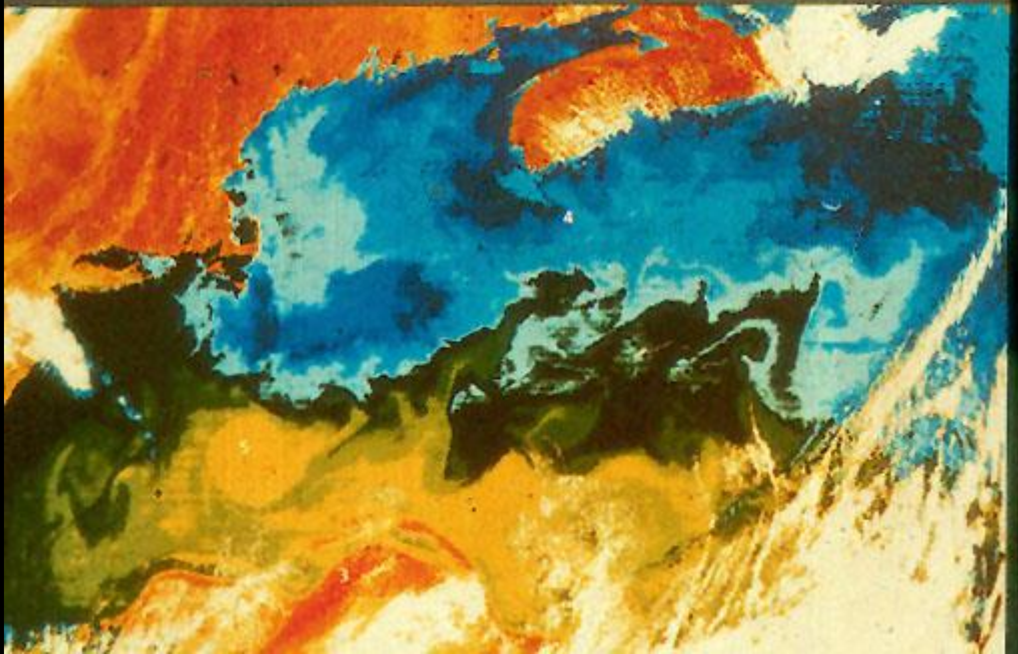
Societal Benefit Areas — Transition from research & development to operational oceanography

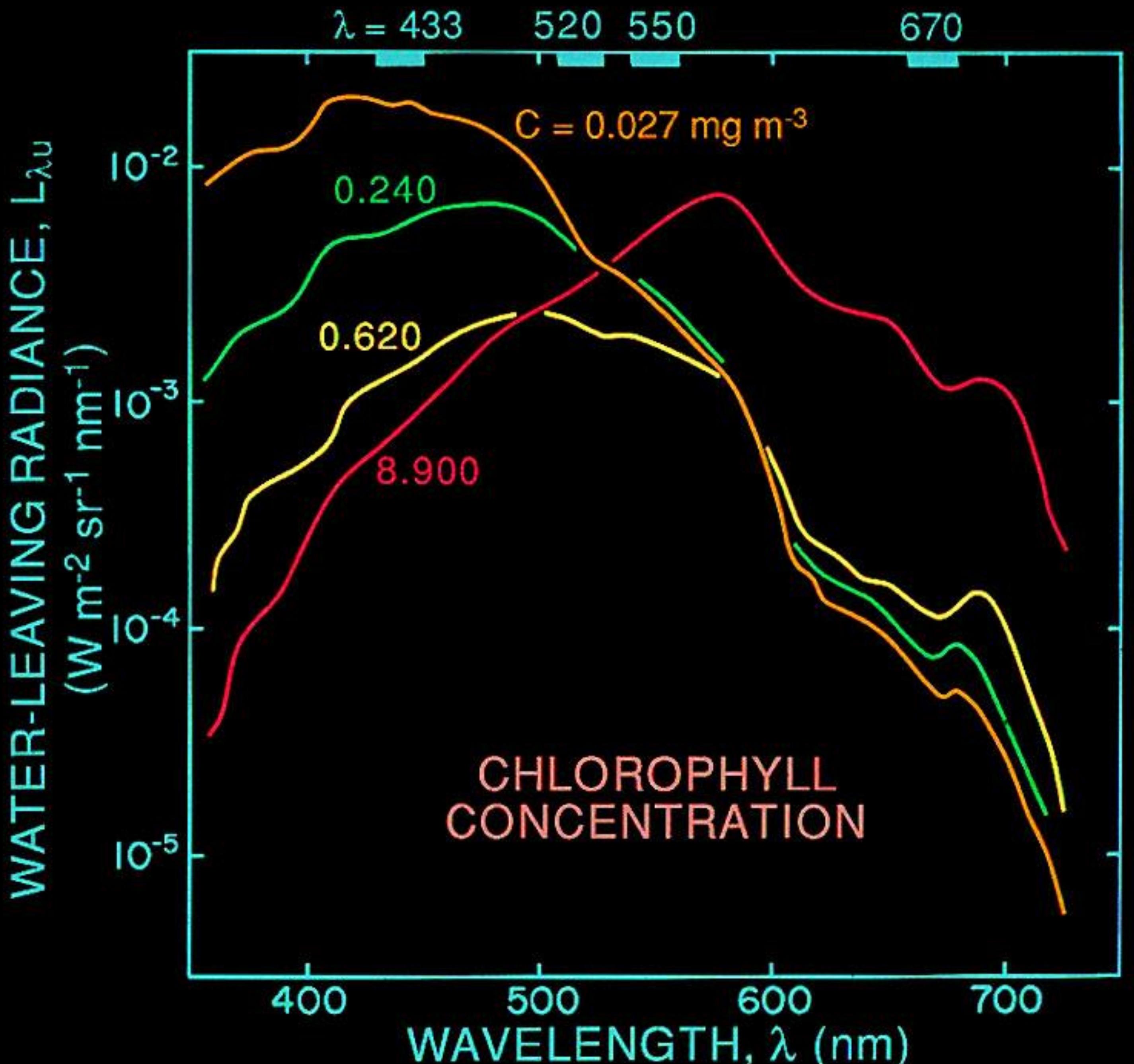


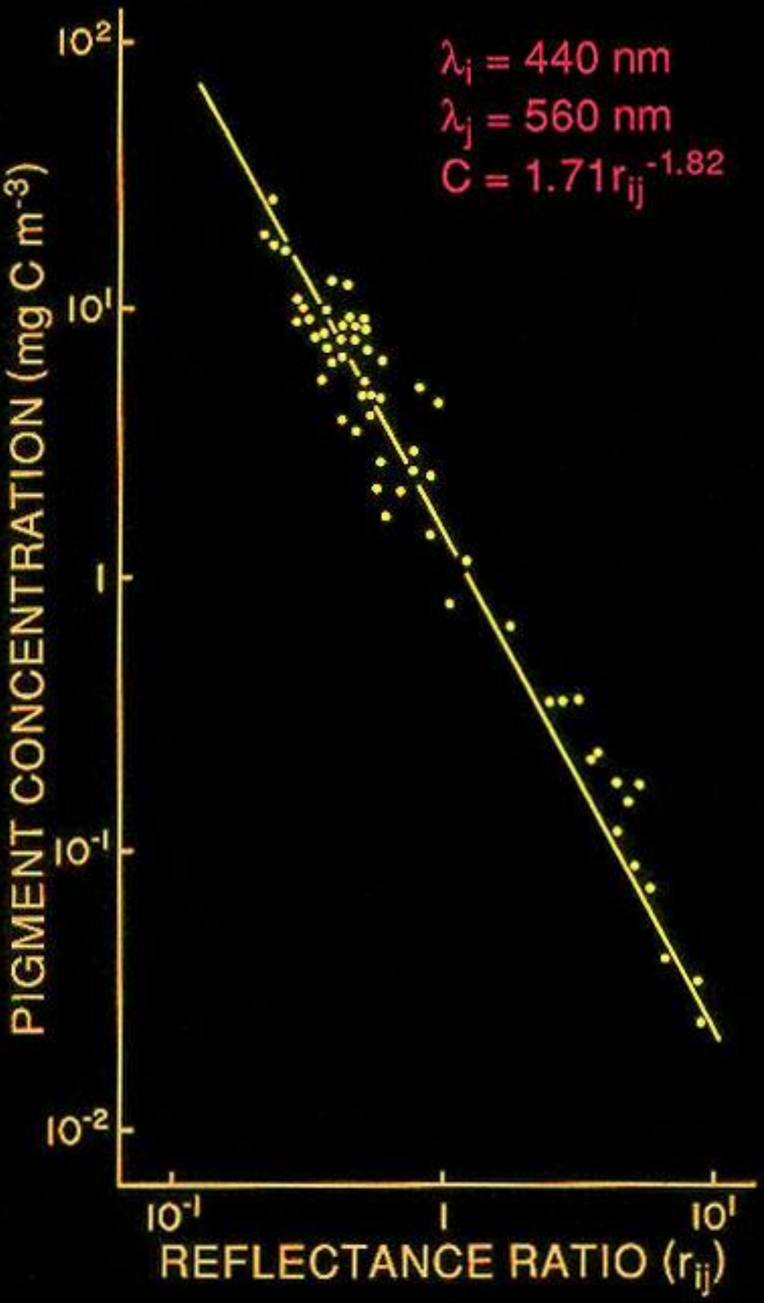
313
1
<1
200
>1
14,40,50,189,345
199
2
42°
6
5
4
6
3
112
4
5
77
2
3
4
60
41°
100
200
1000
CHLOROPHYLL (mg m-3)
68°W
67°W
66°W

Phytoplankton & Temperature Patt

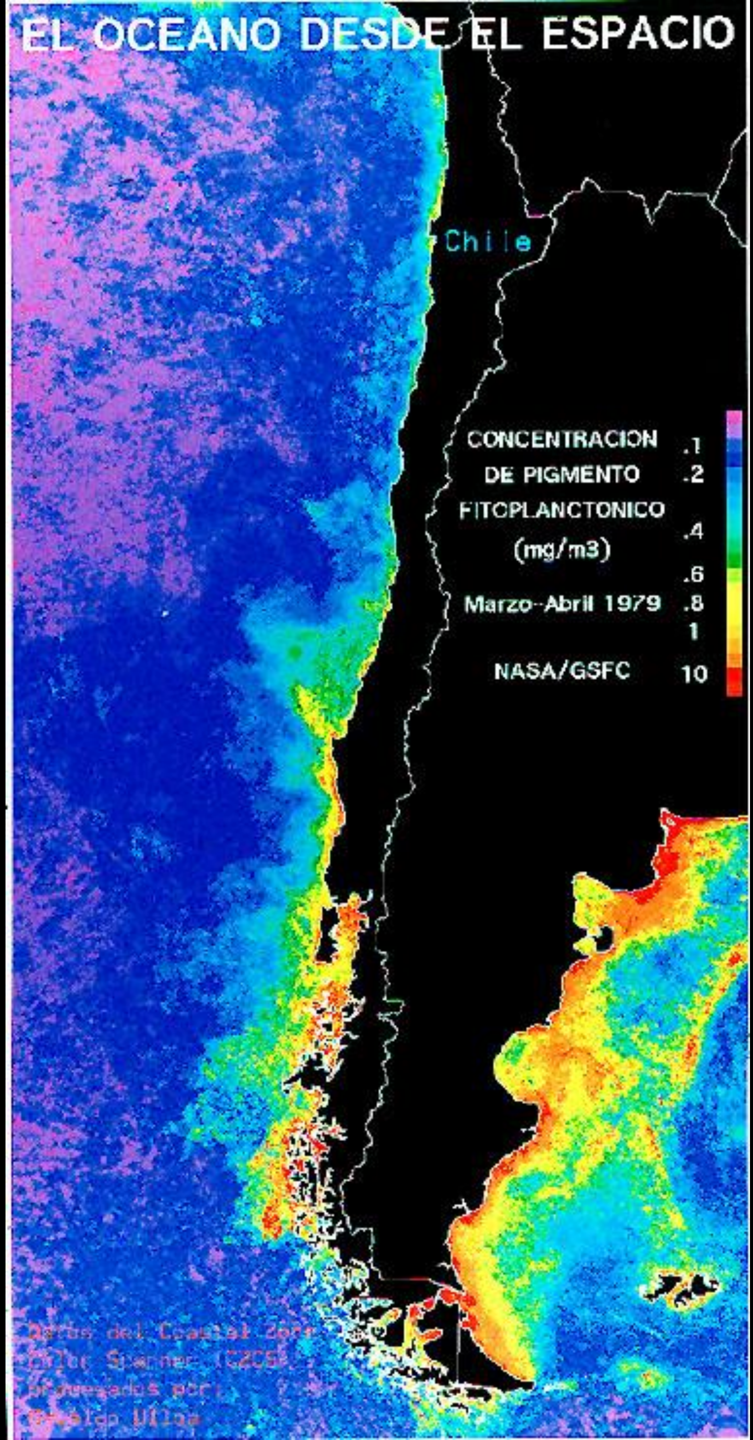


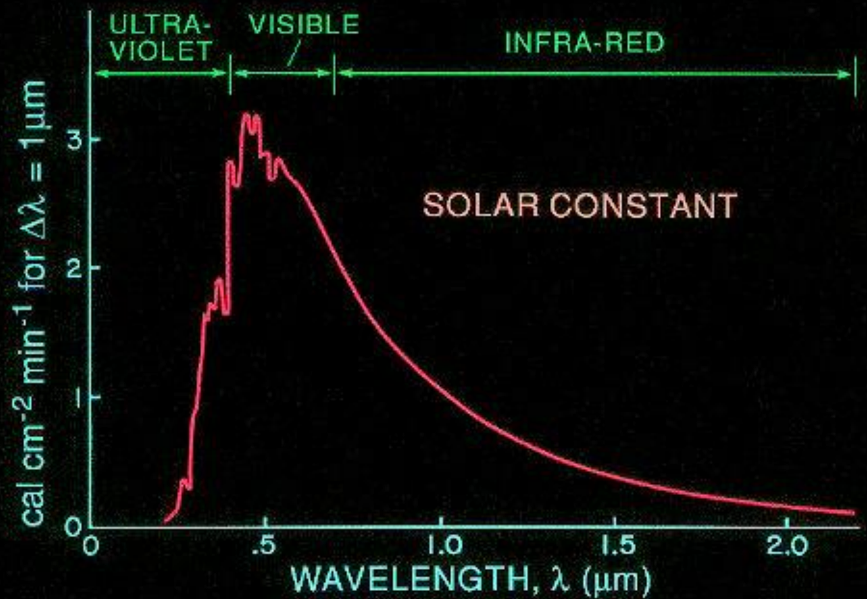


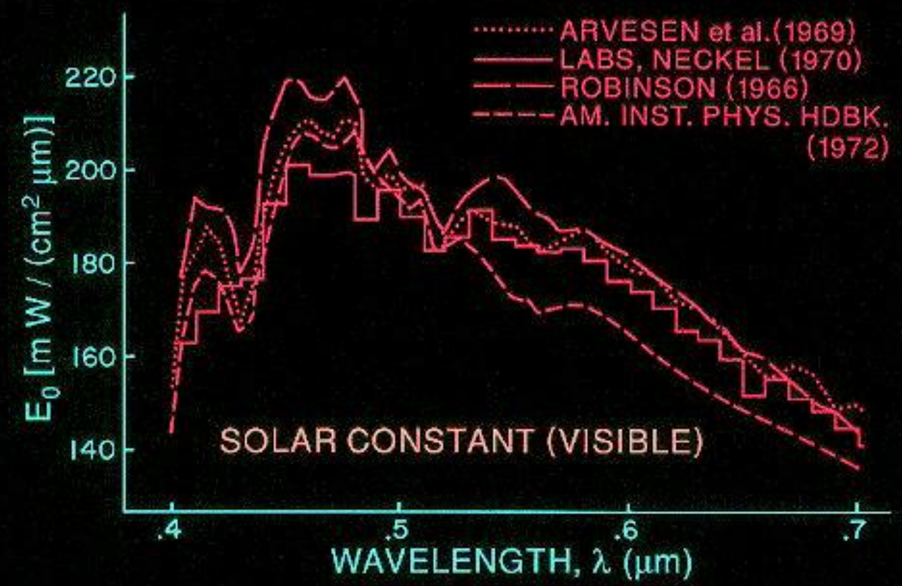

λ = 433
520
550
670
C = 0.027 mg m-3
0.240
0.620
8.900
CHLOROPHYLL
CONCENTRATION
WATER-LEAVING RADIANCE, Lλu
(W m-2 sr-1 nm-1)
10-2
10-3
10-4
10-5
400
500
600
700
WAVELENGTH, λ (nm)

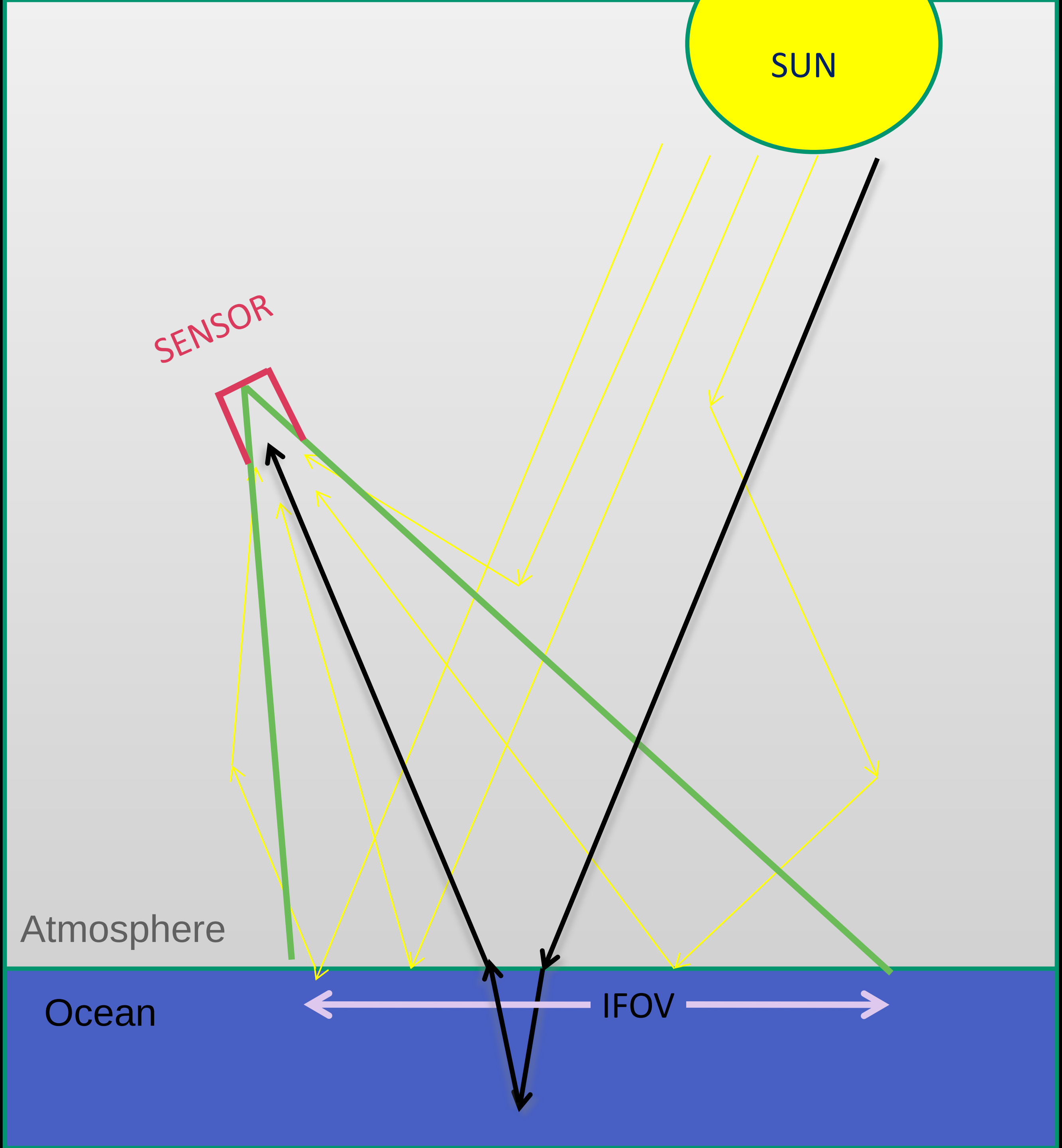


λ_i = 440 nm
λ_j = 560 nm
$C = 1.71 r_{ij}^{-1.82}$
PIGMENT CONCENTRATION (mg C m^{-3})
10^2
10^1
1
10^{-1}
10^{-2}
10^{-1}
1
10^1
REFLECTANCE RATIO (r_{ij})

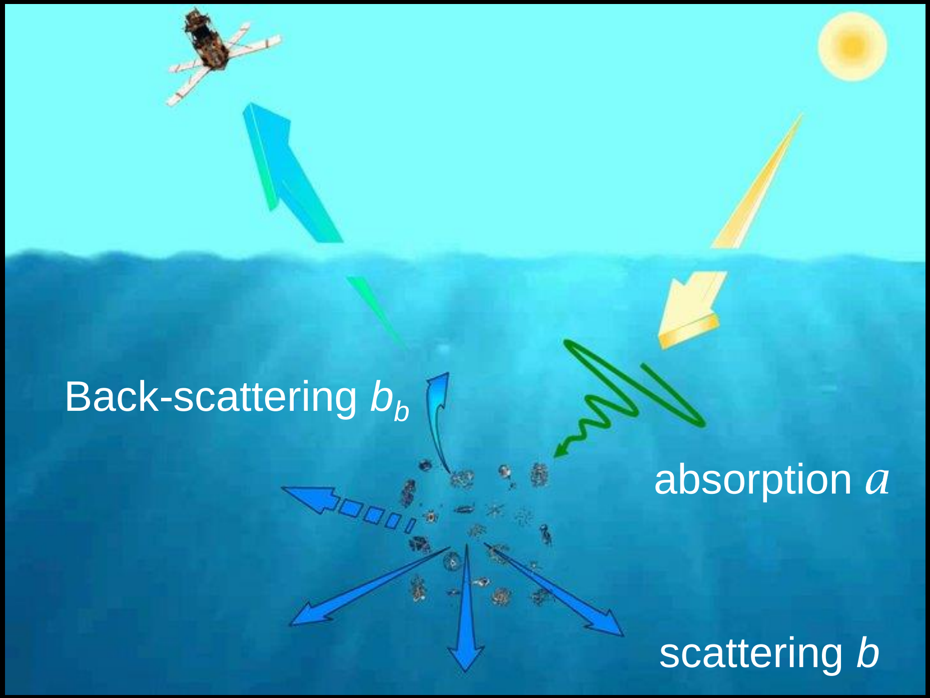

EL OCEANO DESDE EL ESPACIO
Chile
CONCENTRACION
DE PIGMENTO
FITOPLANCTONICO
(mg/m3)
Marzo-Abril 1979
NASA/GSFC
.1
.2
.4
.6
.8
1
10
Datos del Coastal Zone
Color Scanner (CZCS)
procesados por:
Osvaldo Ulloa

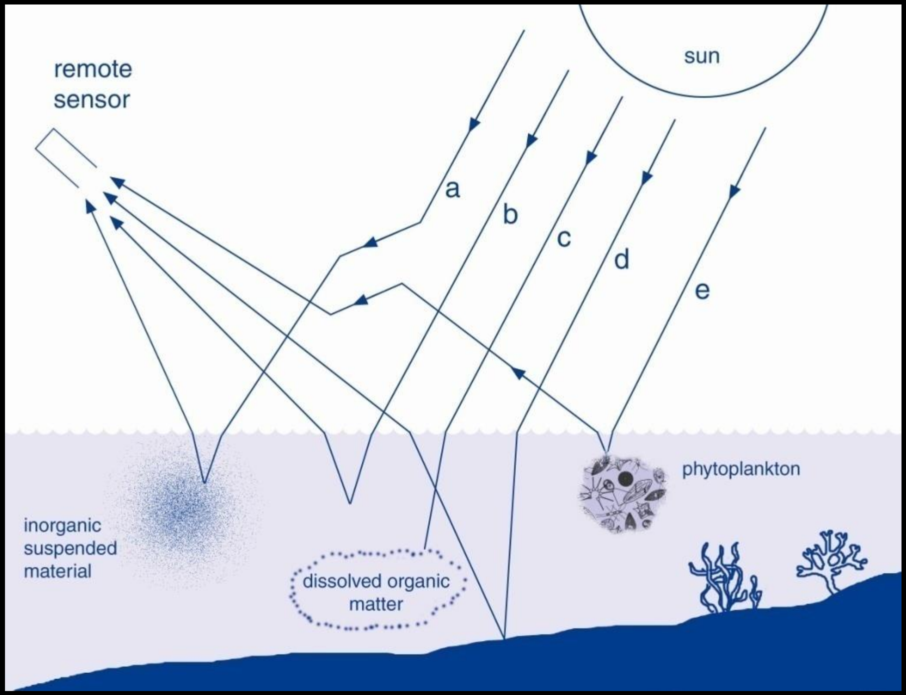

ULTRA-
VIOLET
VISIBLE
INFRA-RED
SOLAR CONSTANT
cal cm-2 min-1 for Δλ = 1μm
0
1
2
3
0
.5
1.0
1.5
2.0
WAVELENGTH, λ (μm)


ARVESEN et al.(1969)
LABS, NECKEL (1970)
ROBINSON (1966)
AM. INST. PHYS. HDBK.
(1972)
E0 [m W / (cm2 μm)]
140
160
180
200
220
SOLAR CONSTANT (VISIBLE)
.4
.5
.6
.7
WAVELENGTH, λ (μm)


SUN
SENSOR
Atmosphere
Ocean
IFOV

Factors that influence upwelling light leaving the sea surface

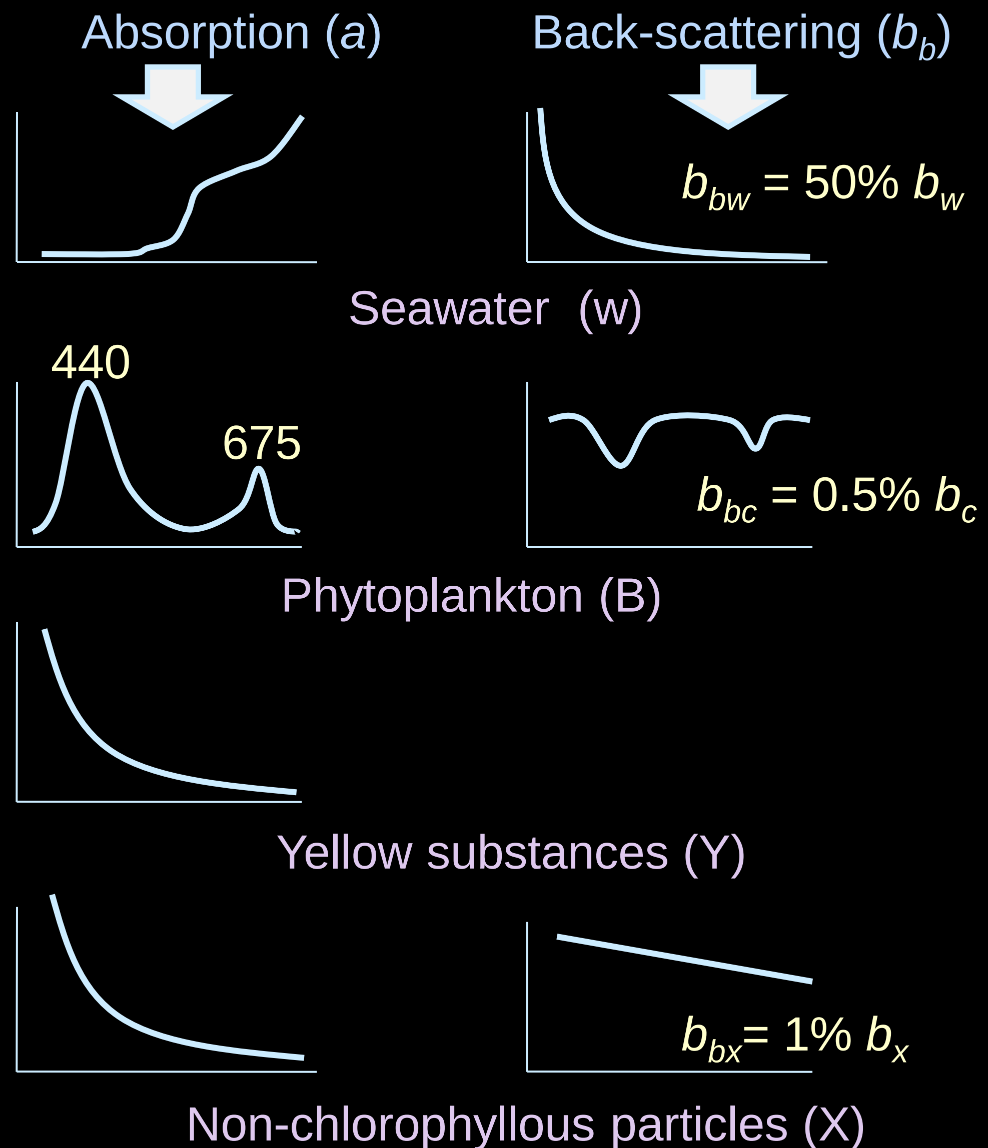




Two optical processes determine the fate of photons that penetrate into the ocean: absorption and scattering

The water-leaving radiance contains information on phytoplankton, suspended sediments, dissolved organic material and bottom type (in shallow waters)

Inherent spectral optical properties of seawater and its contents



Ocean Colour is determined by spectral variations in reflectance R at the sea surface:

$$R = f\,(a,\, b_b)$$

Both absorption and back-scattering can be expressed as sum of contributions from individual constituents.

Both absorption and back-scattering of particular components vary spectrally in characteristic manners.

Case 2 Waters

Case 1 Waters

Living algal cells
Variable concentration

Associated detritus
Autochthonous; local source (grazing, natural decay of phytoplankton)

Coloured dissolved organic matter
Autochthonous; originating from local ecosystem

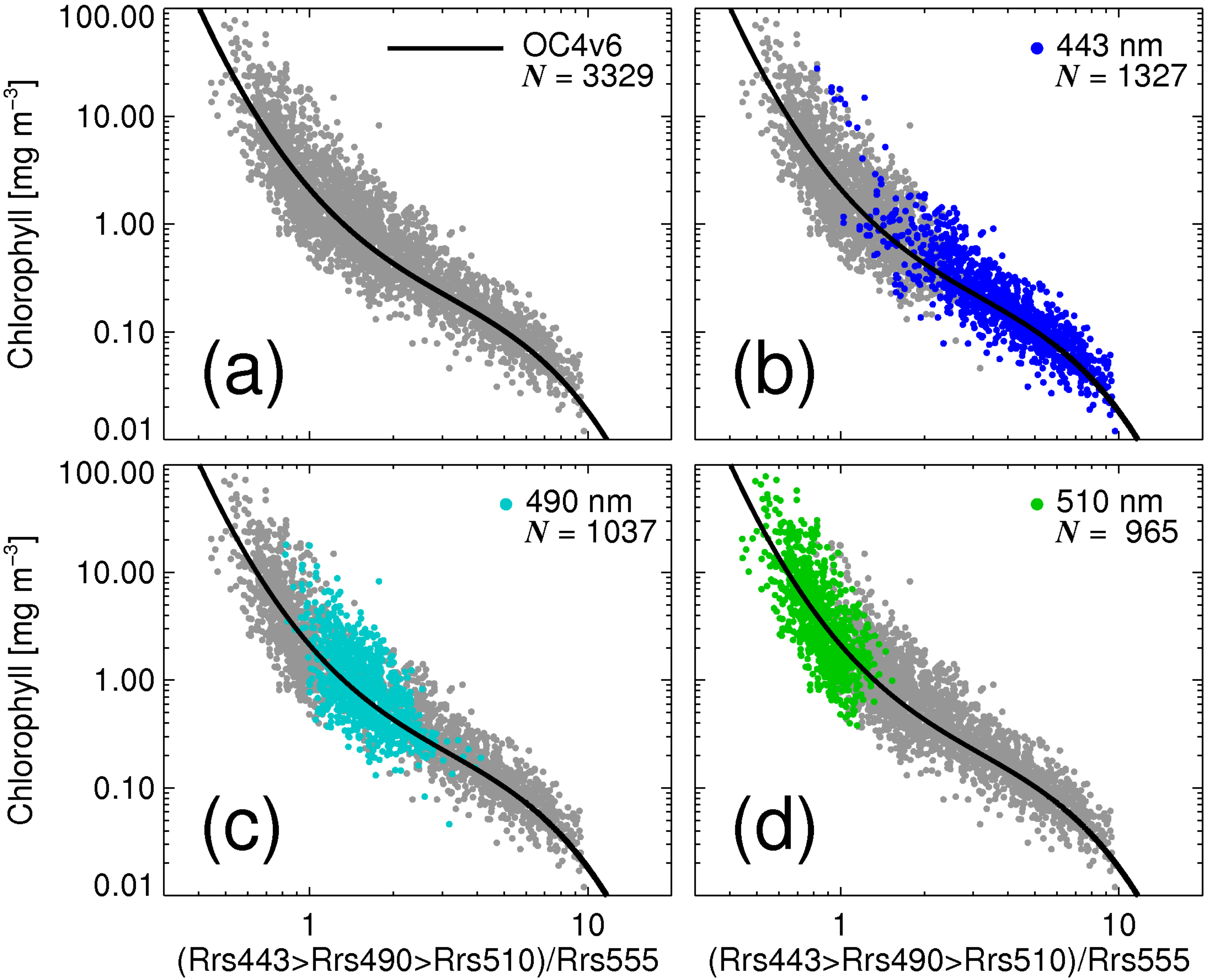
+

Resuspended sediments
Along the coastline and in shallow areas

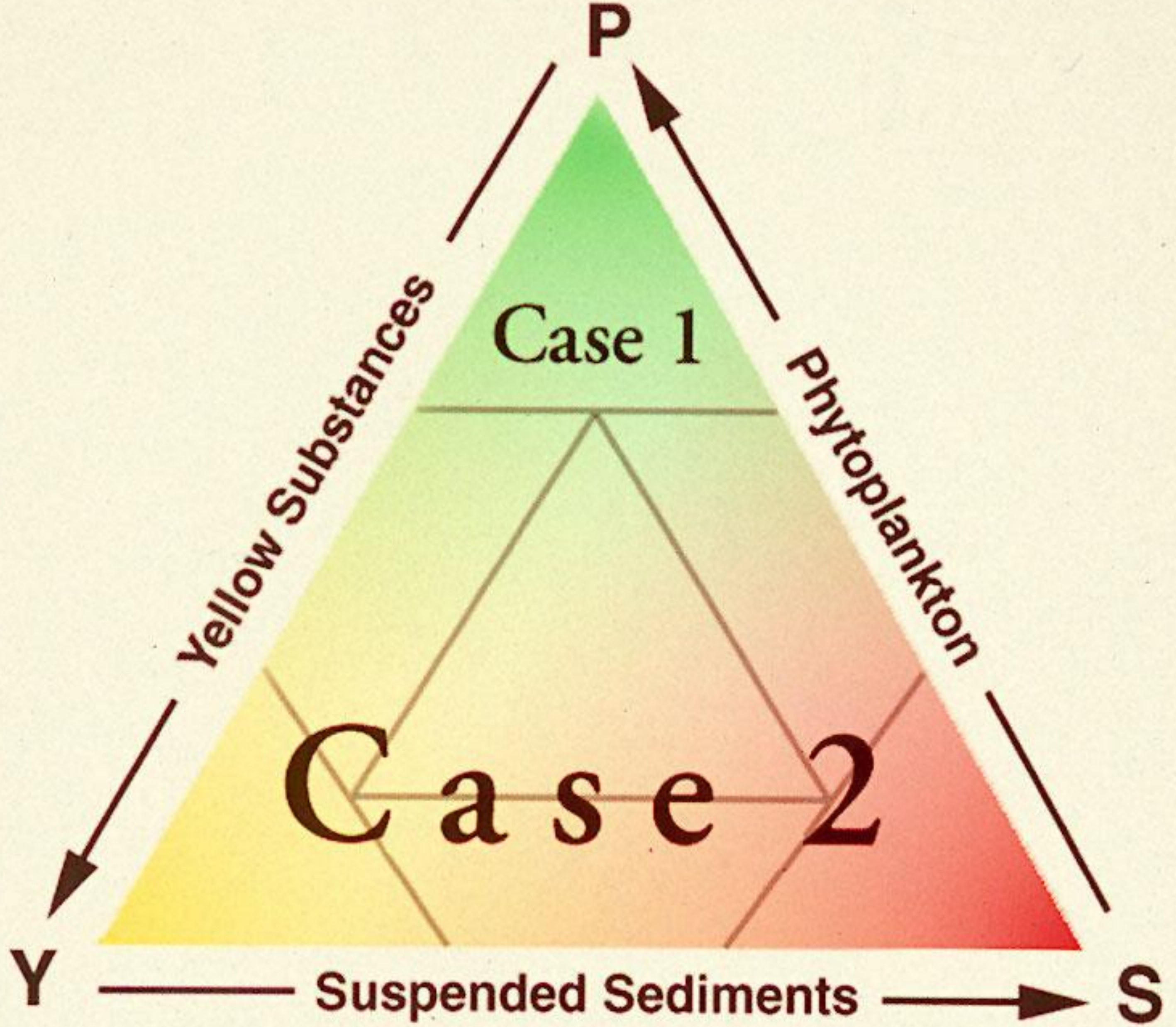
Terrigenous particles
River and glacial runoff

Coloured dissolved organic matter
Allochthonous; external to the local ecosystem (land drainage, external to the local ecosystem)

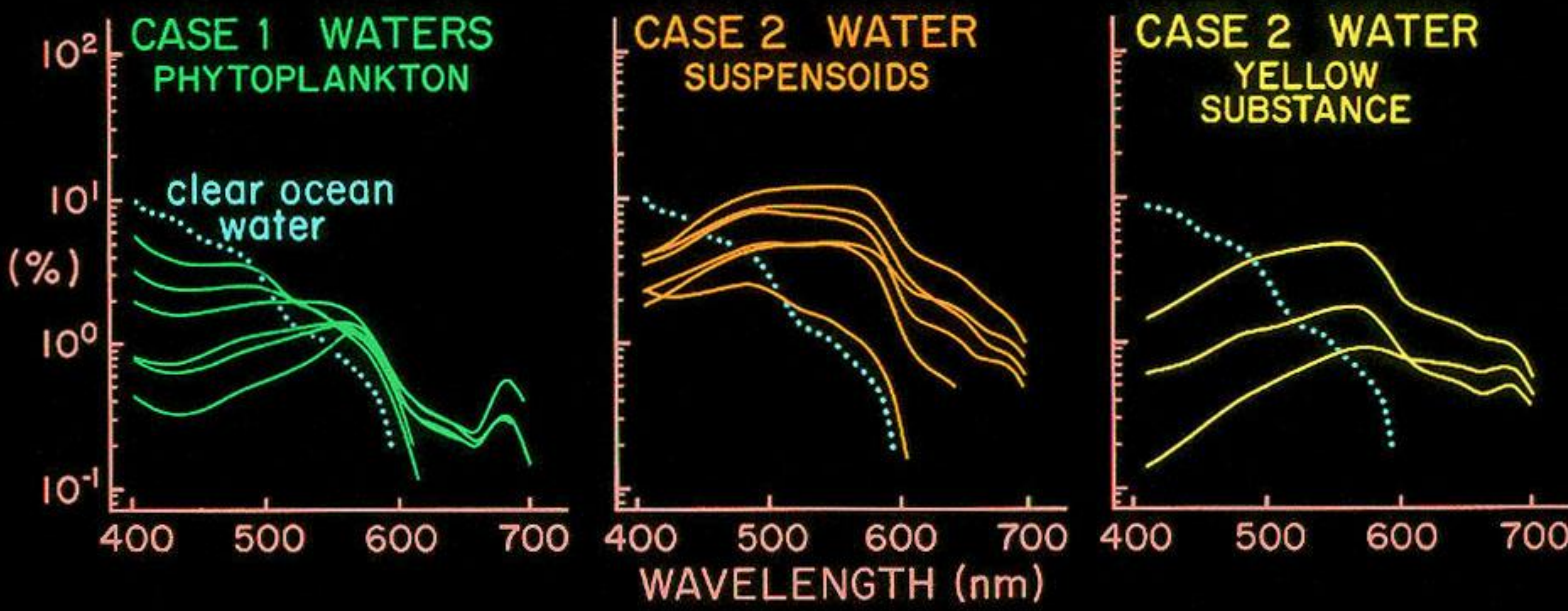
Anthropogenic influx
Particulate and dissolved materials

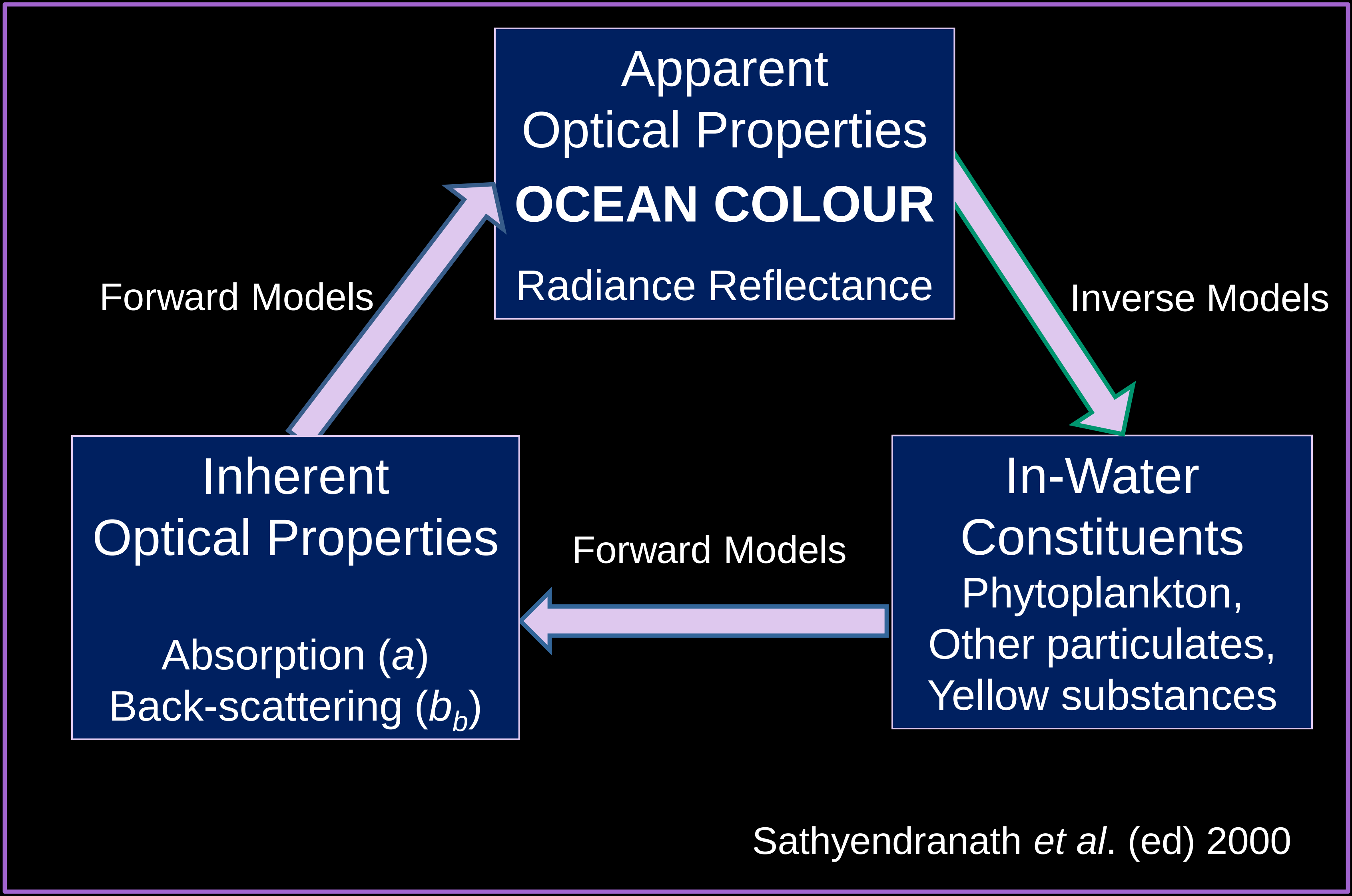


OC4v6
N = 3329
443 nm
N = 1327
490 nm
N = 1037
510 nm
N = 965
(a)
(b)
(c)
(d)
Chlorophyll [mg m^-3]
100.00
10.00
1.00
0.10
0.01
1
10
(Rrs443>Rrs490>Rrs510)/Rrs555

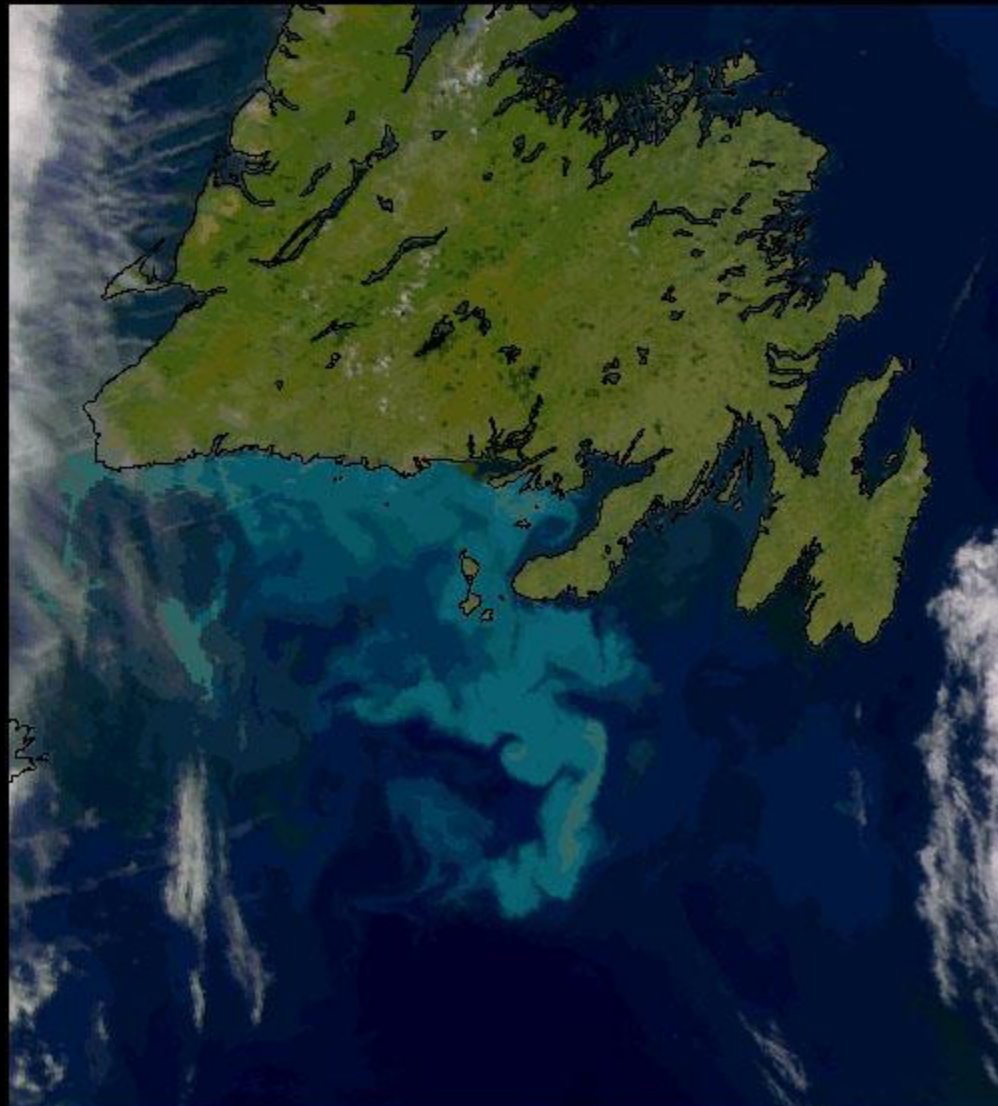

P
Yellow Substances
Phytoplankton
Case 1
Case 2
Y
Suspended Sediments
S

REFLECTANCE SPECTRA

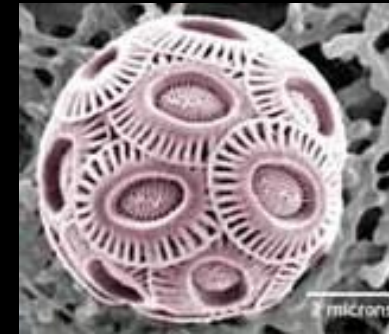


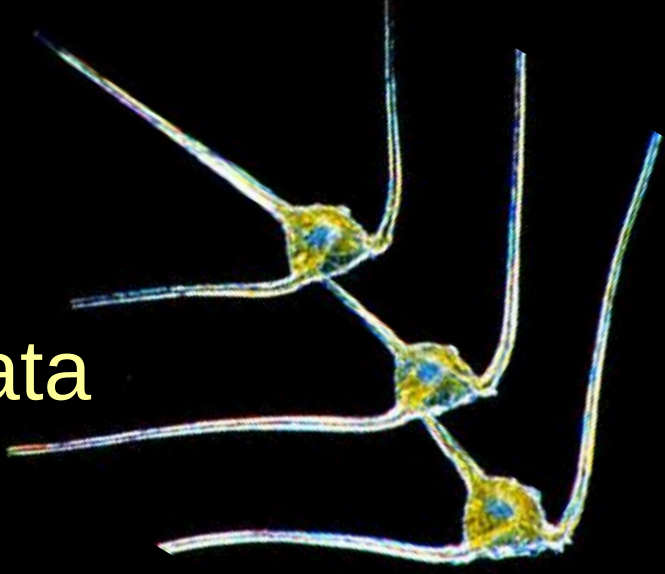


Remote sensing of ocean colour is a rigorous radiometric science, designed to infer the concentrations of the constituents, given spectral reflectance.



Coccolithophore Bloom - 29 July 2002





Limitations of Ocean-Colour Data

1. Signal-to-noise level is low
2. No data in presence of clouds
3. Retrieved pigment measure only a crude index of biomass
4. Retrieval algorithm may not be universal
5. No information on vertical structure
6. Lack of continuity in data record

Applications of the Ocean-colour Archive

To provide:

1. Synoptic fields of phytoplankton biomass for comparison with results from coupled, ocean-ecosystem models;
2. Basis for computation of regional-, and basin-, scale estimates of primary production;
3. General tool for extrapolation to large horizontal scale of sparse measurements of ecophysiological rates;
4. Typology of seasonality in the pelagic ecosystem;
5. Basis for study of feedbacks between pelagic microbiota and mixed-layer physics; and
6. Index of state of pelagic ecosystem for use in fisheries management and coastal-zone management.

The Ocean-Colour Data Base

Coastal Zone Color Scanner

1. Operated from October 1978 to May 1986.
2. Coverage once daily at best, generally much less (10% duty cycle, limitations of cloud cover
3. Composite images at monthly and annual scales
4. Resolution ~ 1 km
5. Accuracy within 35% of chlorophyll retrieval in open-ocean waters

Visible Spectral Radiometry

Following CZCS

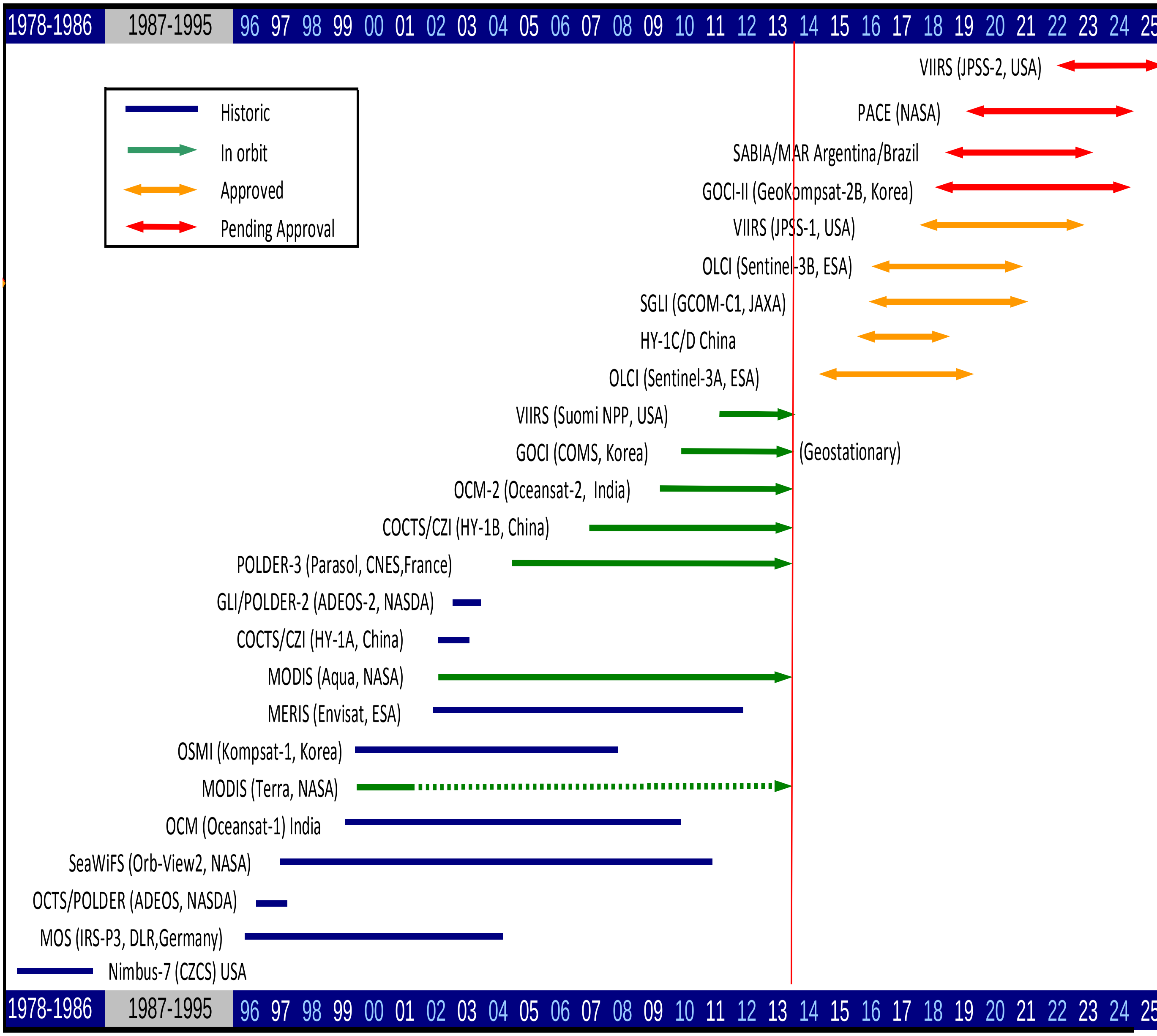
MOS, SeaWiFS, OCTS, MODIS, MERIS …

No gap in VSR data streams from space since Sept. 1997 when SeaWiFS was launched

All sensors have instrument specifications (wavebands, number of wavebands, calibration strategy) that differ from each other, many improvements have led from the CZCS experience

Inter-sensor merging of VSR data remains a challenge

IOCCG



1978-1986
1987-1995
96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Historic
In orbit
Approved
Pending Approval
VIIRS (JPSS-2, USA)
PACE (NASA)
SABIA/MAR Argentina/Brazil
GOCI-II (GeoKompsat-2B, Korea)
VIIRS (JPSS-1, USA)
OLCI (Sentinel-3B, ESA)
SGLI (GCOM-C1, JAXA)
HY-1C/D China
OLCI (Sentinel-3A, ESA)
VIIRS (Suomi NPP, USA)
GOCI (COMS, Korea)
(Geostationary)
OCM-2 (Oceansat-2, India)
COCTS/CZI (HY-1B, China)
POLDER-3 (Parasol, CNES,France)
GLI/POLDER-2 (ADEOS-2, NASDA)
COCTS/CZI (HY-1A, China)
MODIS (Aqua, NASA)
MERIS (Envisat, ESA)
OSMI (Kompsat-1, Korea)
MODIS (Terra, NASA)
OCM (Oceansat-1) India
SeaWiFS (Orb-View2, NASA)
OCTS/POLDER (ADEOS, NASDA)
MOS (IRS-P3, DLR,Germany)
Nimbus-7 (CZCS) USA

Future Challenges and Opportunities

For existing sensors, a principal challenge is to develop retrieval algorithms for coastal waters, which are optically complex.

Extracting information on phytoplankton community structure is an area of active research

For future sensors, principal challenge is in advanced applications that exploit higher resolution in wavelength.

Geo-stationary satellites (GOCI, Korea and possibly others) are emerging