

Life of a Pixel

*Satellite Remote Sensing of Ocean Color:
from the satellite to the community*

NASA GSFC Ocean Biology Processing Group

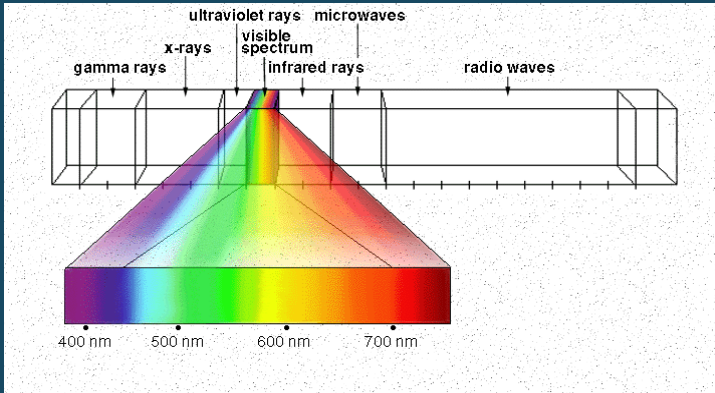
Given by

Paula Bontempi

Darling Marine Center – SMS 598

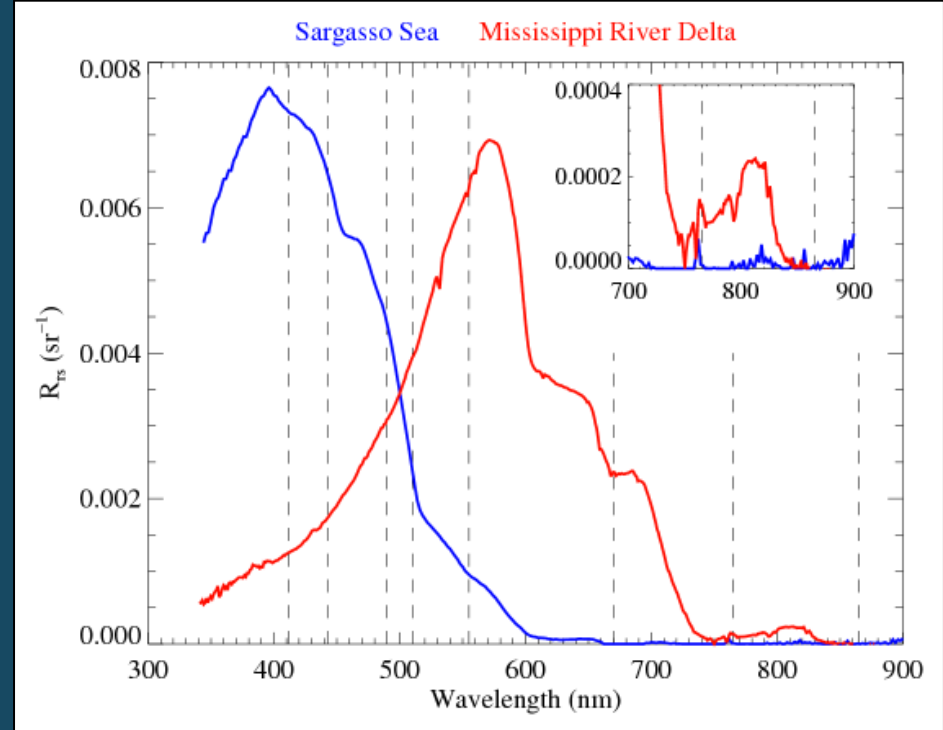
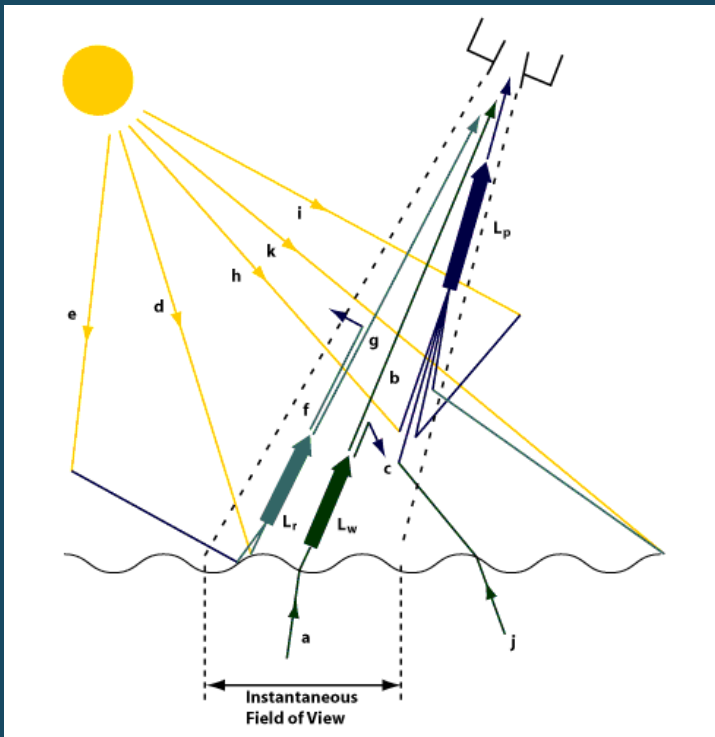
10 July 2007

What is ocean color?



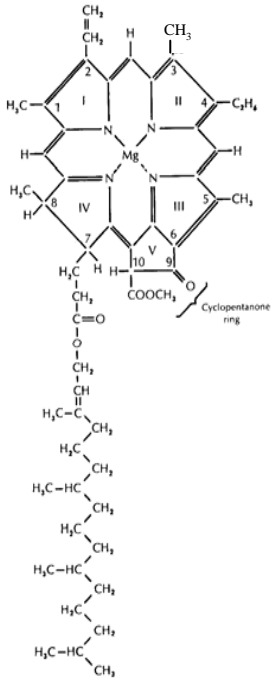
Ocean color is the measurement of spectral distribution of radiance (or reflectance) upwelling from the ocean in the visible regime.

Marine Spectral Reflectance

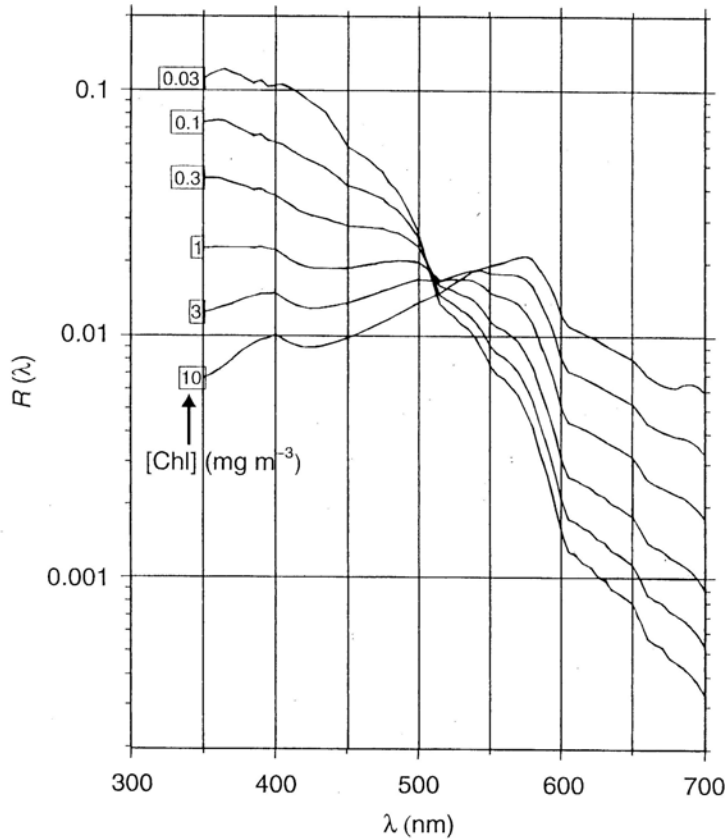


Spectral Wavelength (λ)

Chlorophyll-a

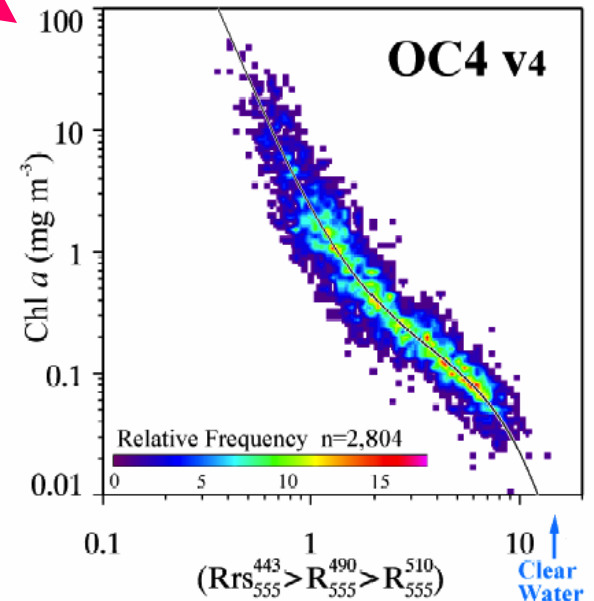


Quantifying Phytoplankton Processes Remotely



Marine Spectral Reflectance

Chlorophyll Algorithm



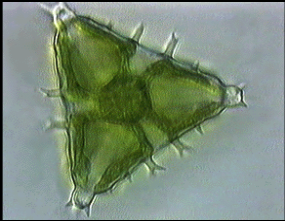
Phytoplankton

the chlorophyll concentration that we observe is associated with the distribution of phytoplankton

phytoplankton are microscopic plants that represent the first link in the marine food chain

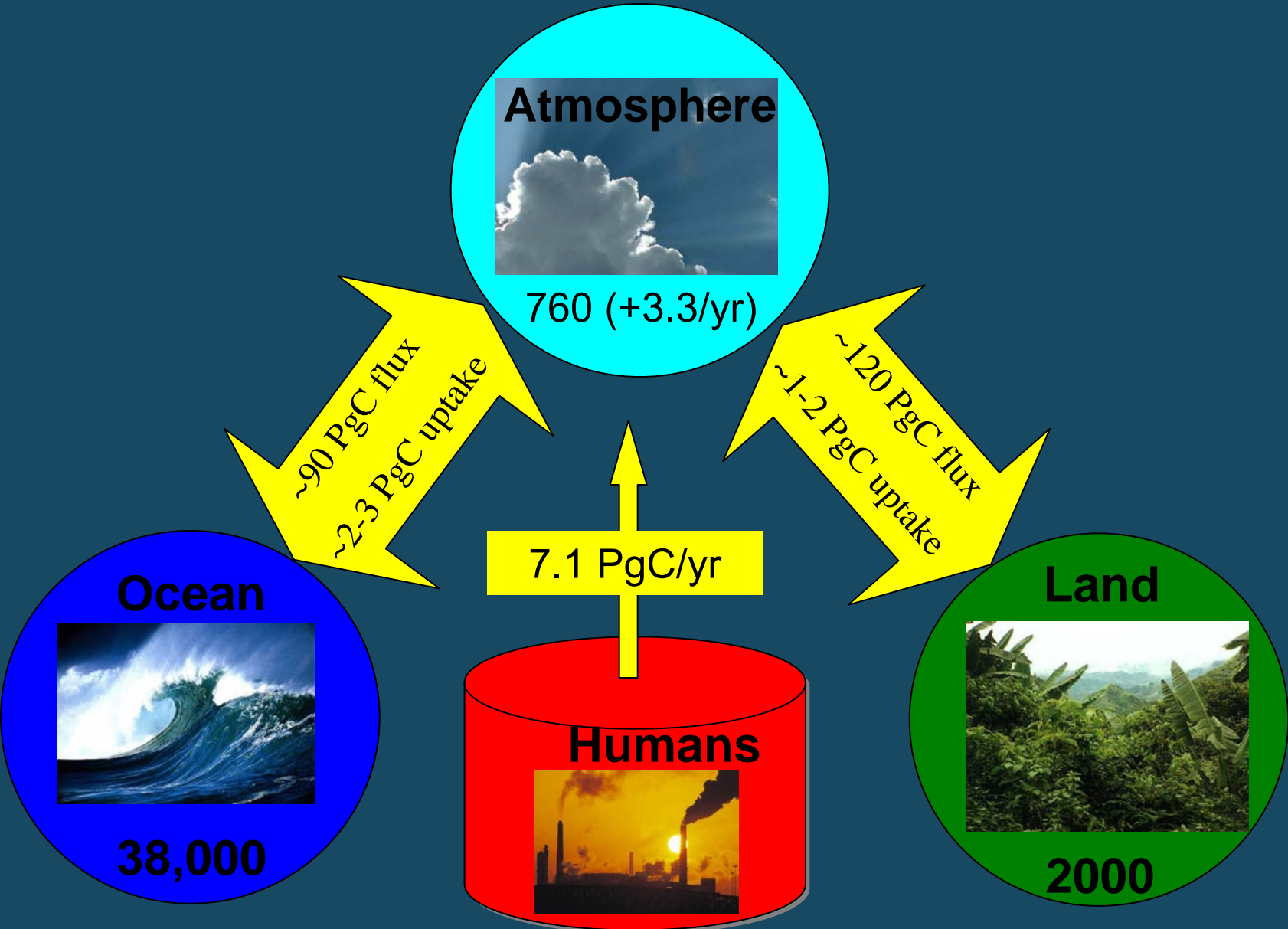
the patterns of distribution are related to both physical and biological processes

phytoplankton require light, water, nutrients, and carbon dioxide to grow



Why measure phytoplankton from space?

Global Carbon Budgets



Petagrams (Pg) of Carbon

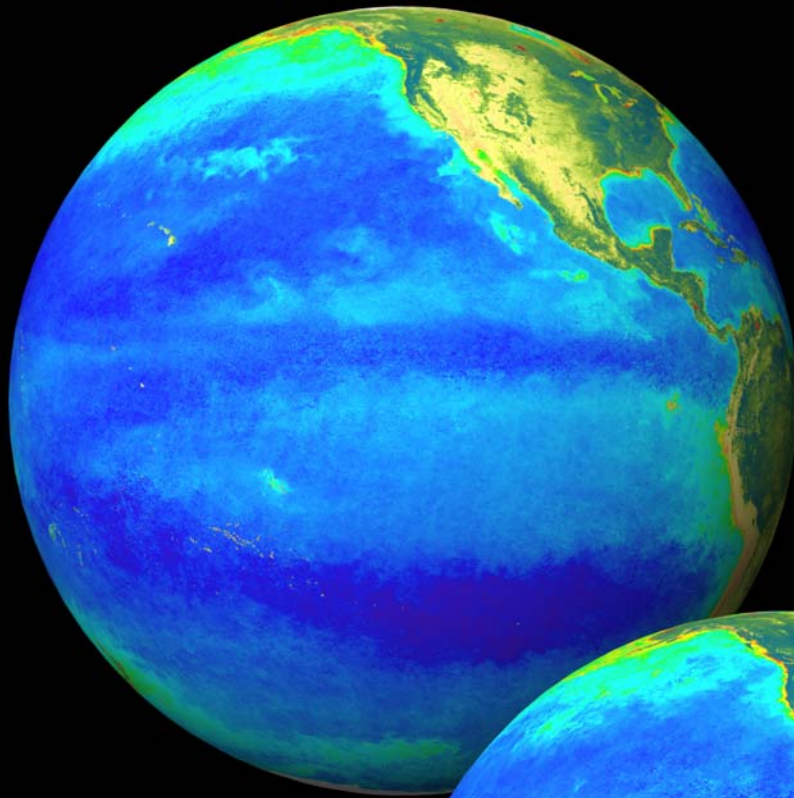
Impact of Natural Disasters

Hurricane Floyd

- massive flooding
- rivers carried
 - sediment
 - sewage
- discharged into coastal areas
- resulted in anoxic conditions in bay

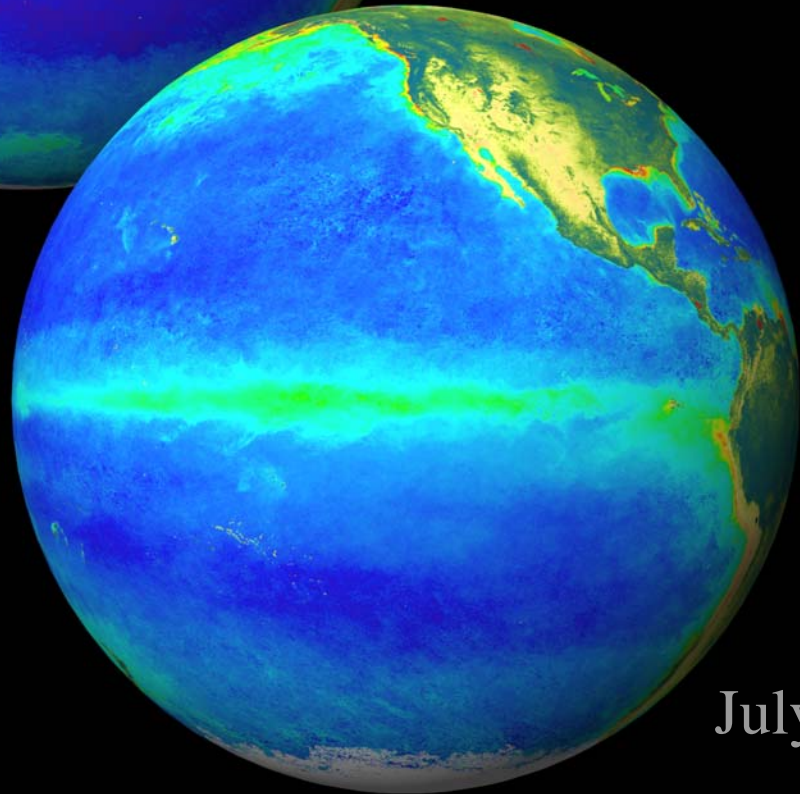


Sept. 23, 1999

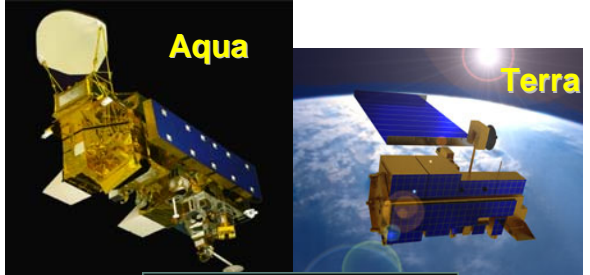


January 1998

SeaWiFS captures
El Niño / La Niña
transition



July 1998

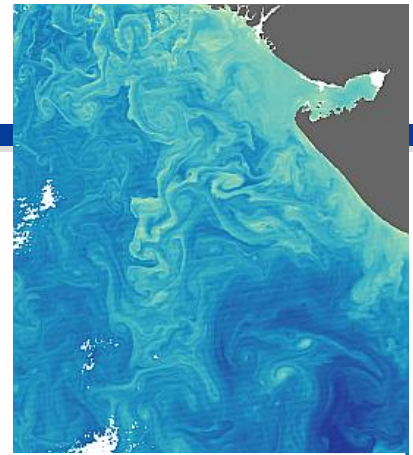
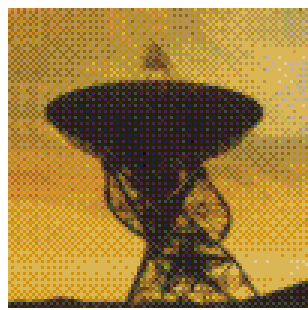


Aqua

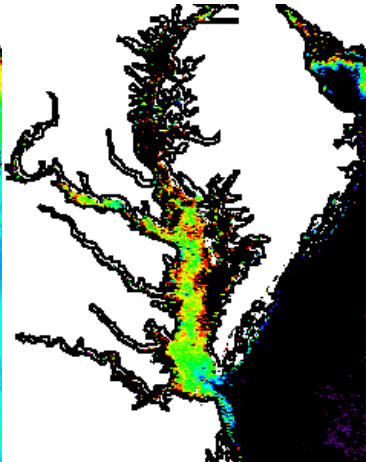
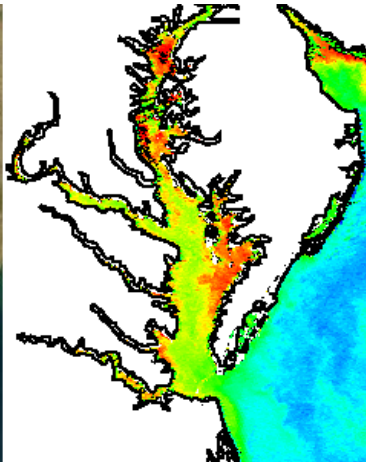
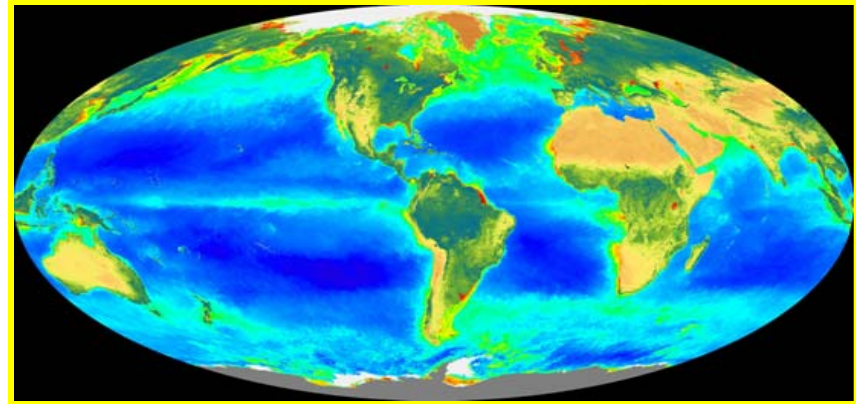
Terra



SeaWiFS



Chlorophyll Concentration (mg / m³)



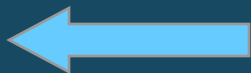
Data Levels & Flow

Binary data are relayed from the satellite data recorder to the ground station

Bits and bytes



Formatted data



Attitude, Ephemerous, Geolocation

Calibrated Reflectances



Ancillary Data

Geolocated, Geophysical Products



Geophysical Binned Products

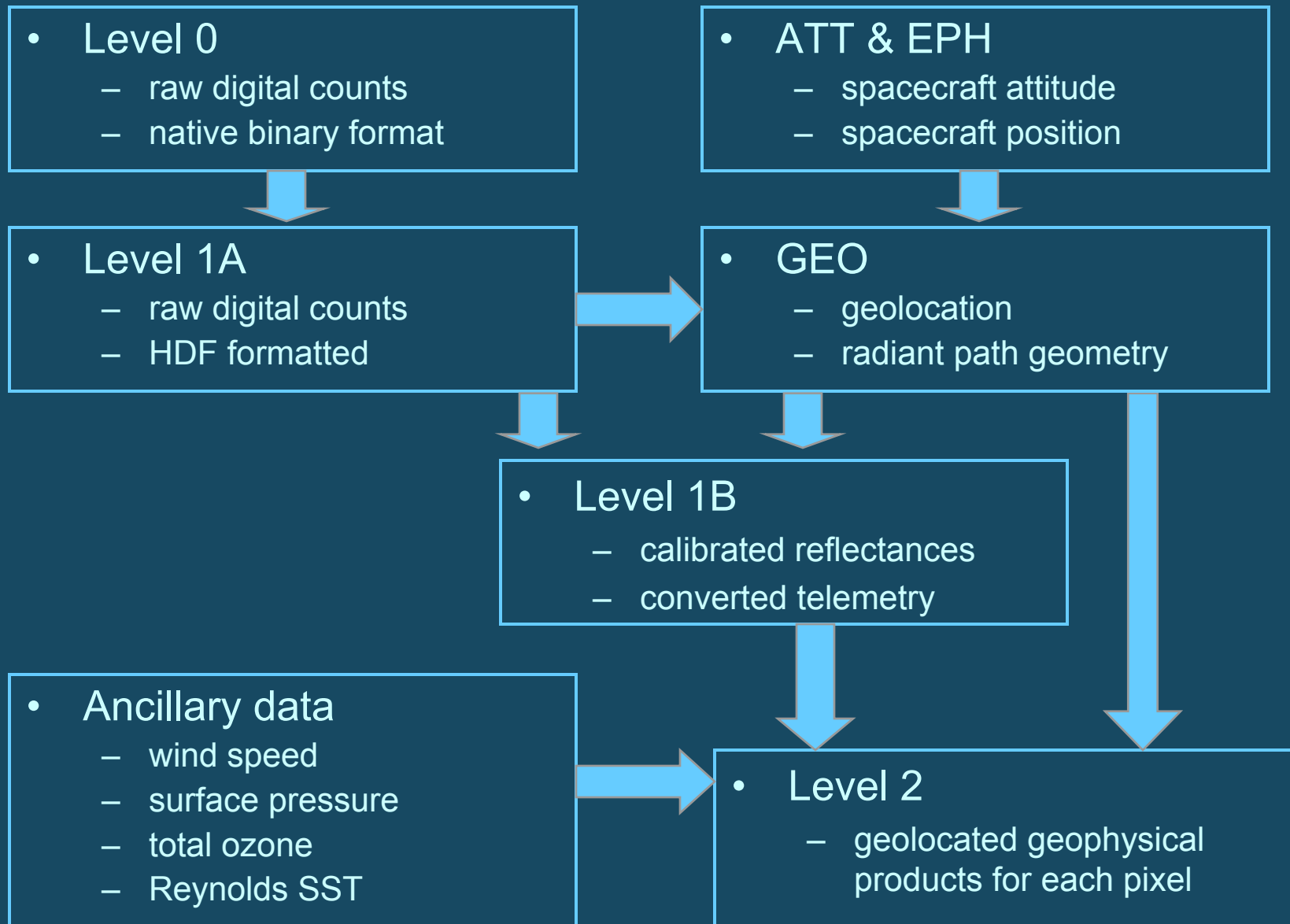


Geophysical Mapped Products

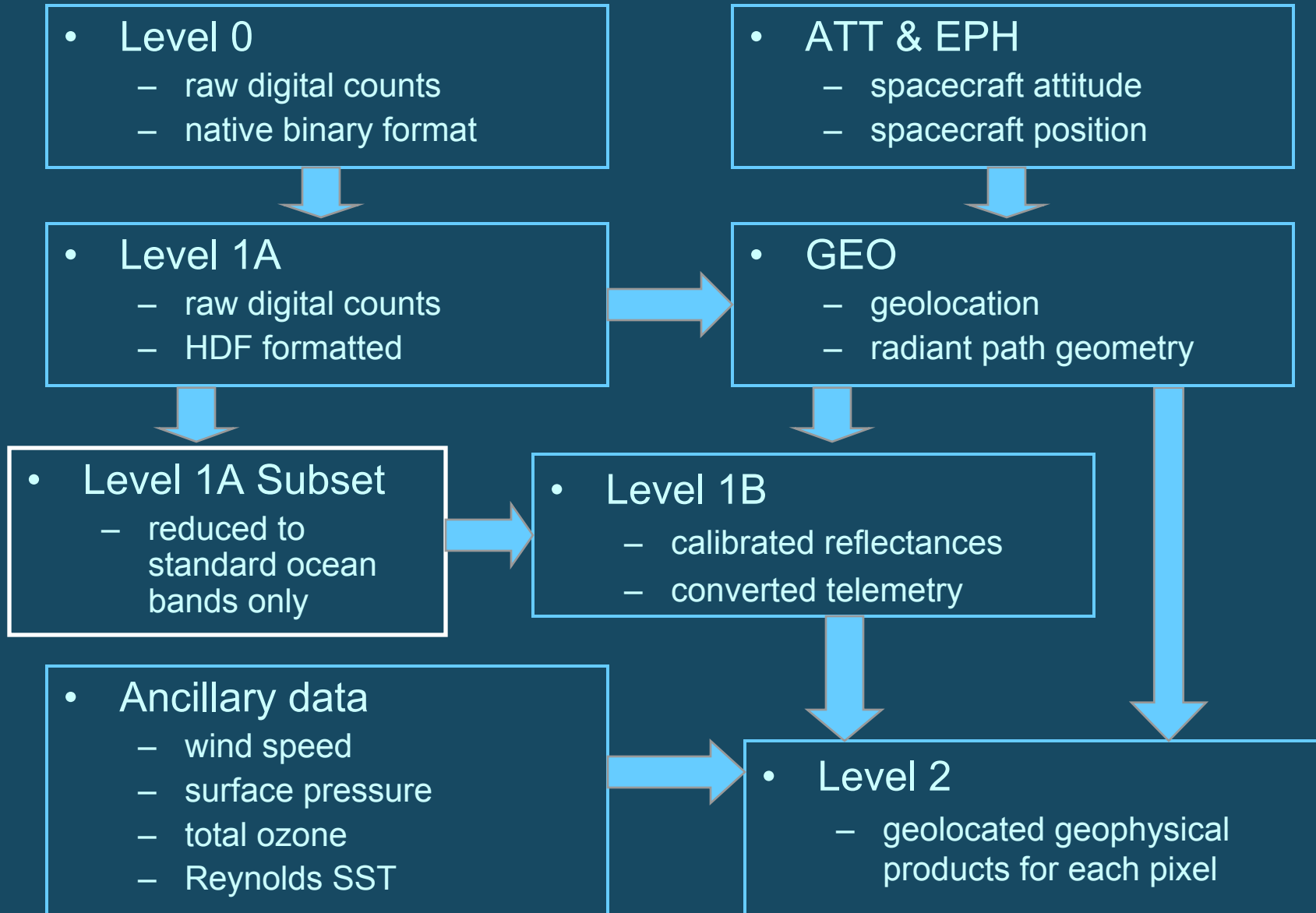
Getting from there to here

- From bits to research quality data....

MODIS Data Levels & Flow



MODIS Data Levels & Flow

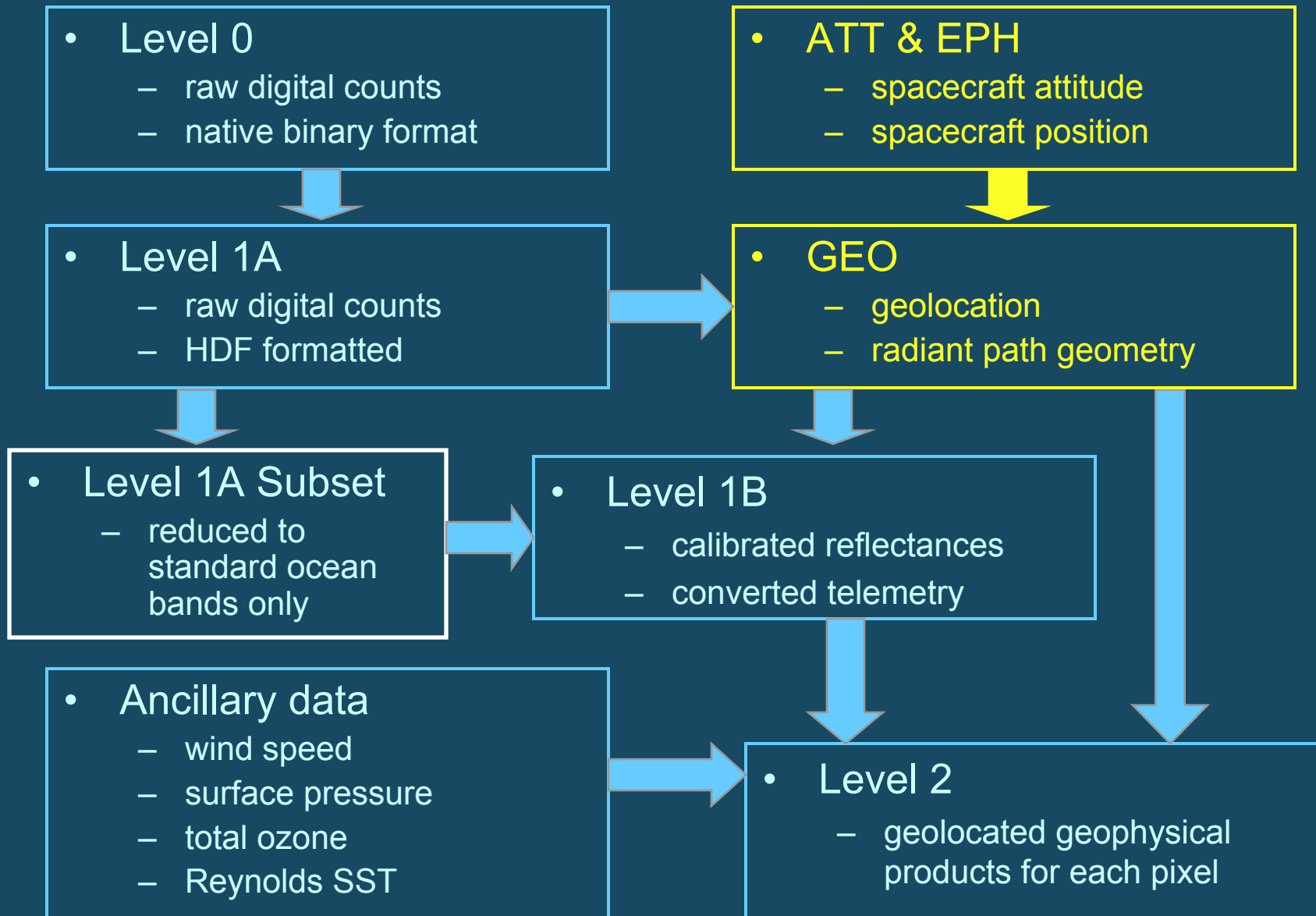


From Level 0 to Level 1A

- Appending to the file, not applying:
 - Calibration data – on board and vicarious– another lecture
 - Navigation data – where instrument is vs. where scene taken
 - Instrument telemetry information
 - Selected Spacecraft telemetry information

Result: Raw radiance values for each of the bands; file is formatted as HDF “hierarchical data format”

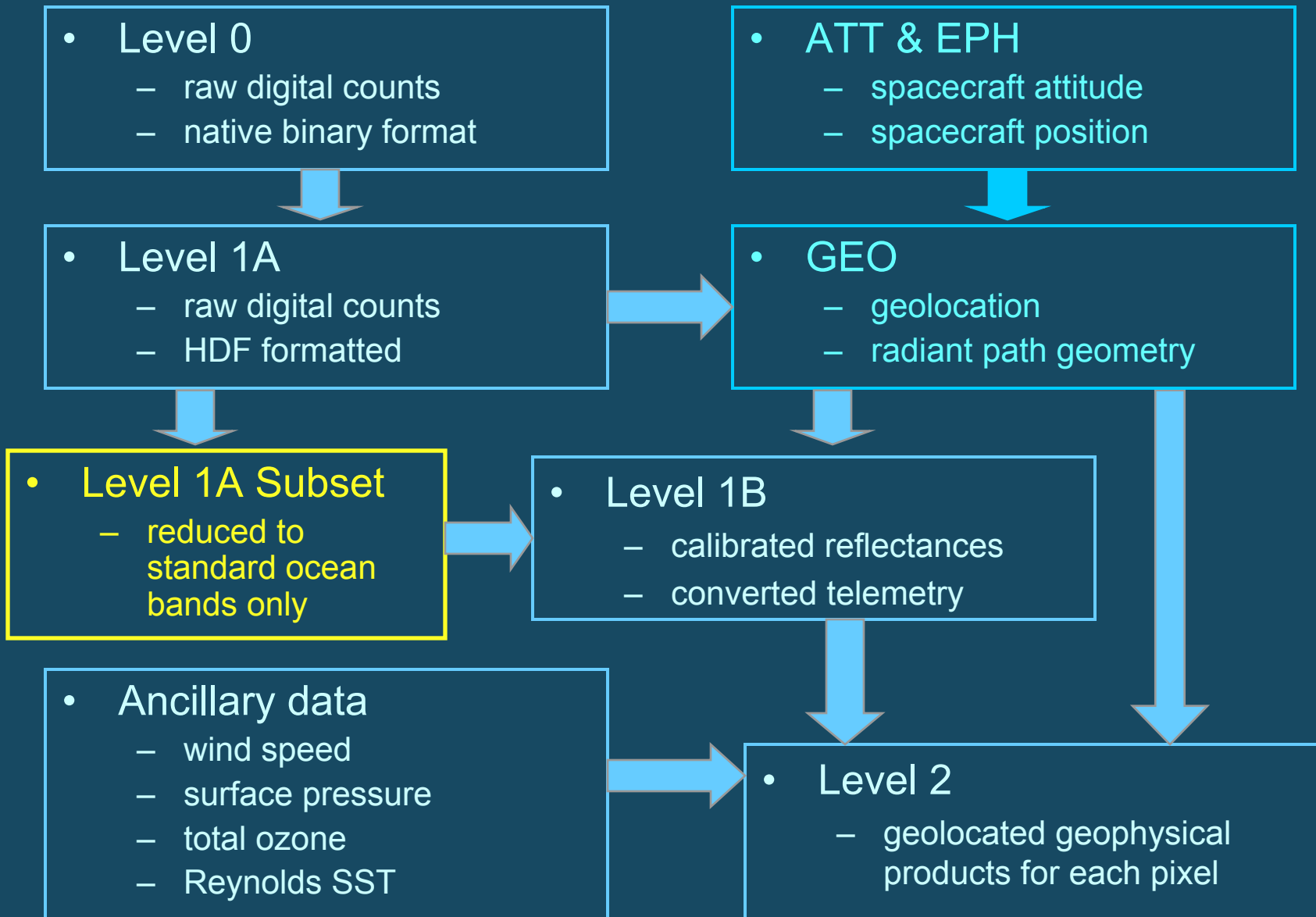
MODIS Data Levels & Flow



In parallel, and before moving on to Level 1B

- ATT & EPH (attitude and ephemerous) – used to get geolocation
 - Spacecraft attitude – orientation in space relative to the orbital plane or velocity vector (spacecraft stability and control) – where the instrument is pointing, roll, pitch, yaw
 - Spacecraft position – GPS
 - Ephemeris – orbit position in the x,y,z frame as a function of time
- GEO
 - Geolocation
 - Radiant path geometry – where pointing on the Earth relative to sun and normal vector on the Earth
- Result: Level 1B files are calibrated reflectances and converted telemetry (converted from coded to derive info such as temperature)

MODIS Data Levels & Flow



L1A Subset

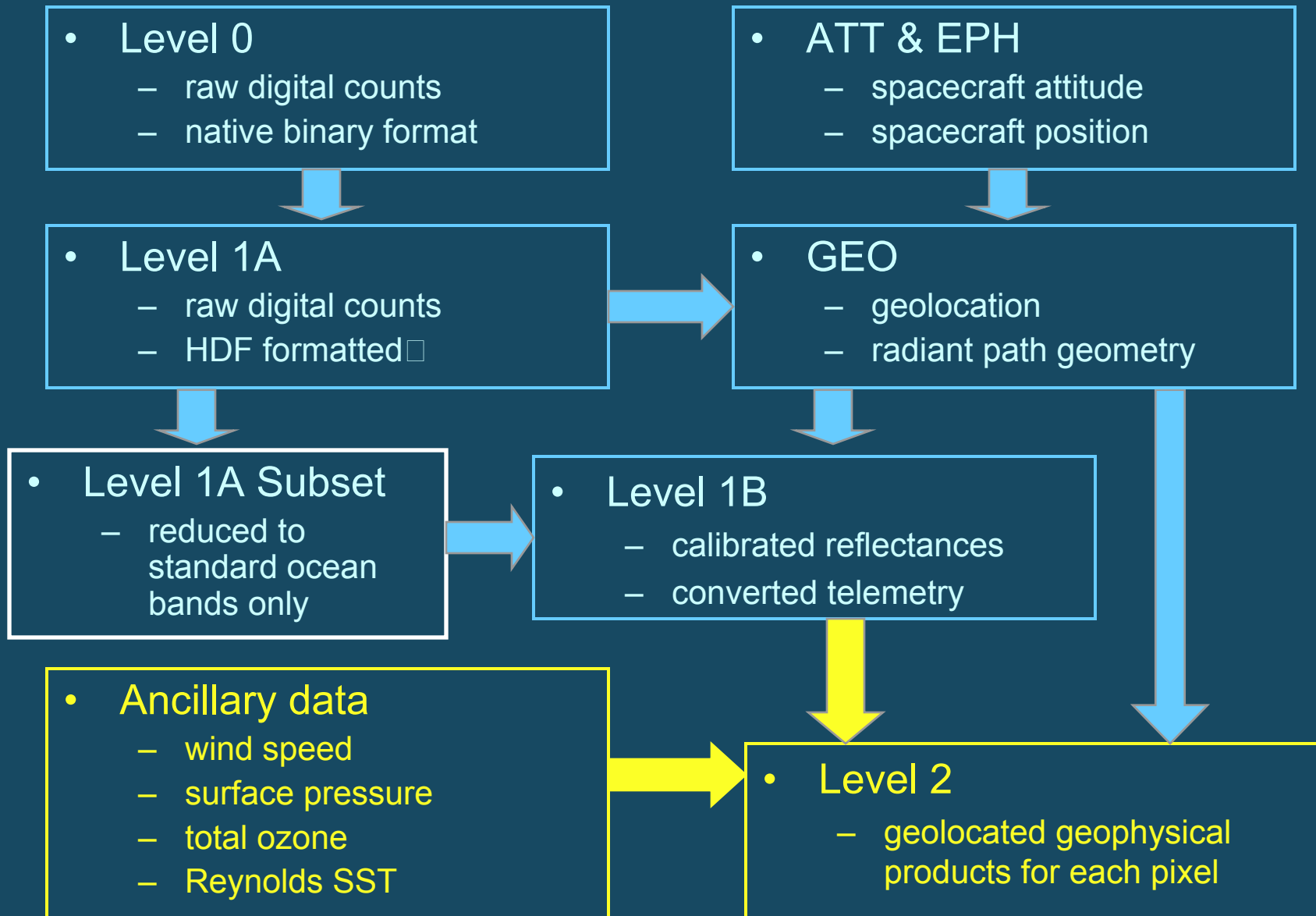
- SeaWiFS vs. MODIS
 - Excess bands and data not utilized by the ocean are removed

VIS/NIR

Ocean
Color

Band Number	Wavelength (nm)	Band Width (nm)	Spatial Resolution (m)	SNR at L_{typ}	L_{typ} $mW\ cm^{-2}\ \mu m^{-1}\ sr^{-1}$	L_{max} $mW\ cm^{-2}\ \mu m^{-1}\ sr^{-1}$
8	412	15	1000	1773	7.84	26.9
9	443	10	1000	2253	6.99	19.0
10	488	10	1000	2270	5.38	14.0
11	531	10	1000	2183	3.87	11.1
12	551	10	1000	2200	3.50	8.8
13	667	10	1000	1962	1.47	4.2
14	678	10	1000	2175	1.38	4.2
15	748	10	1000	1371	0.889	3.5
16	869	15	1000	1112	0.460	2.5

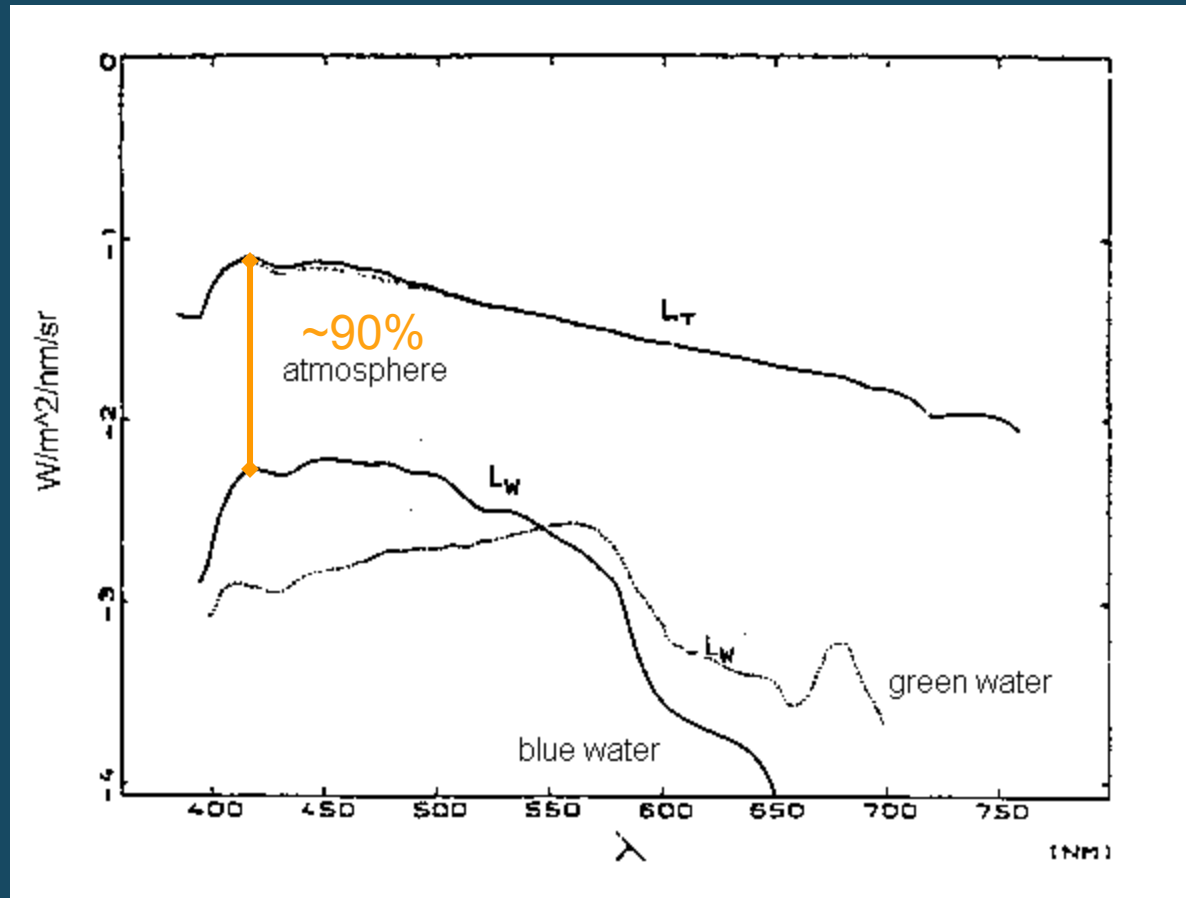
Data Levels & Flow



L1B to Level 2

- **Bring on the Ancillary Data**
 - wind speed
 - surface pressure
 - total ozone
 - Reynolds SST

Ocean Color from Space



1% error in instrument calibration or atmospheric model
~10% error in water-leaving radiance

Effects of the Atmosphere

- Gaseous absorption (ozone, water vapor, oxygen)
- Scattering by air molecules (Rayleigh)
- Scattering and absorption by aerosols (haze, dust, pollution)
- Polarization (MODIS response varies with polarization of signal)

Rayleigh (80-85% of total signal)

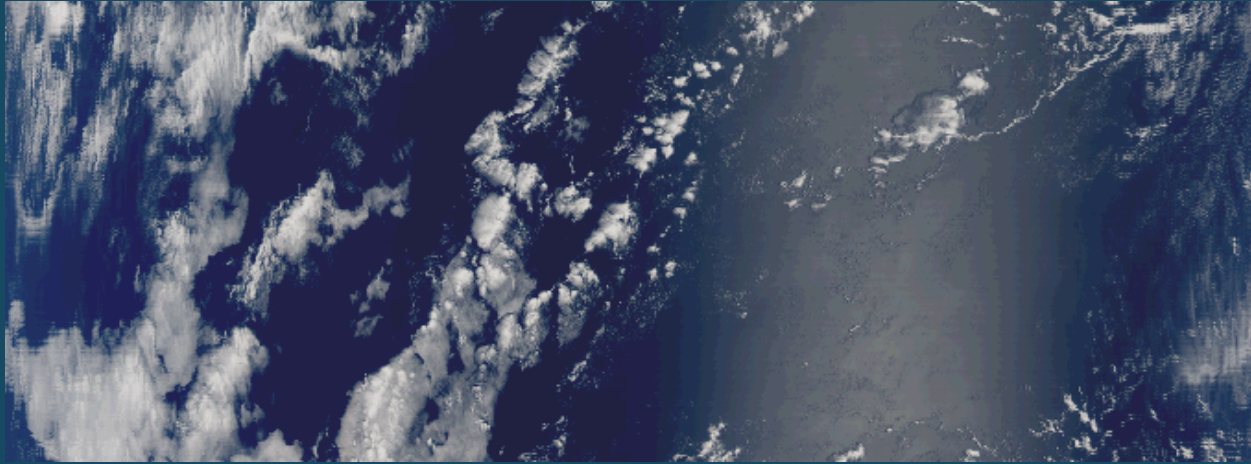
- small molecules compared to nm wavelength, scattering efficiency decreases with wavelength as λ^{-4}
- reason for blue skies and red sunsets
- can be accurately approximated for a given atmospheric pressure and geometry (using a radiative transfer code)

Aerosols (0-10% of total signal)

- particles comparable in size to the wavelength of light, scattering is a complex function of particle size
- whitens or yellows the sky
- significantly varies and cannot be easily approximated

Surface Effects

Sun Glint



White Caps



Corrections based
on statistical models
(wind & geometry)

Level-2 Ocean Color Processing

1. Determine atmospheric and surface contributions to total radiance at TOA and subtract.
2. Normalize to the condition of Sun directly overhead at 1 AU and a non-attenuating atmosphere (nLw or $Rrs = nLw/F_0$).
3. Apply empirical or semi-analytical algorithms to relate the spectral distribution of nLw or Rrs to geophysical quantities.
4. Assess quality (set flags)

Level-2 Flags and Masking

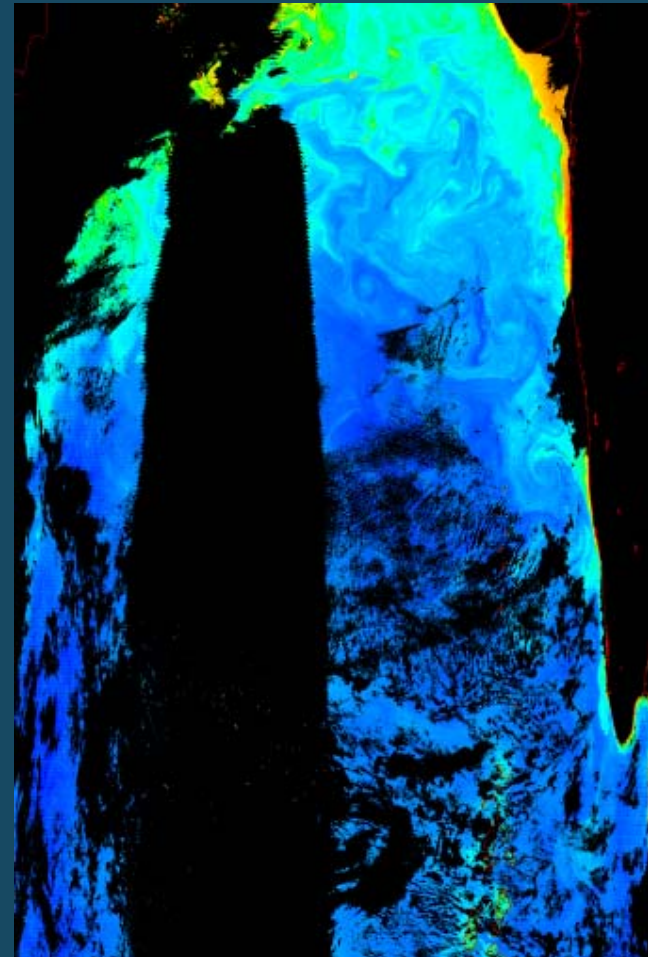
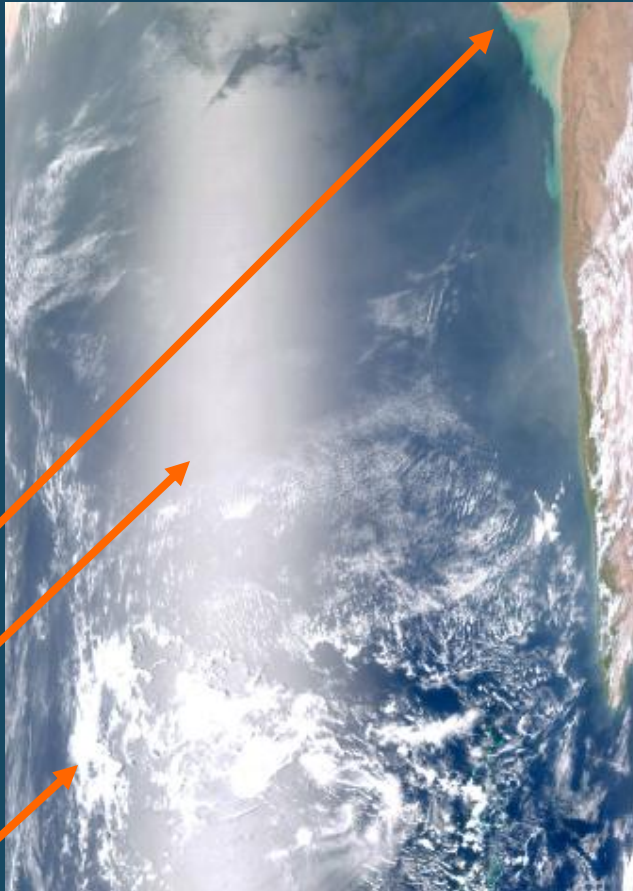
RGB Image

Chlorophyll

Sediments

Glint

Cloud



Calibration

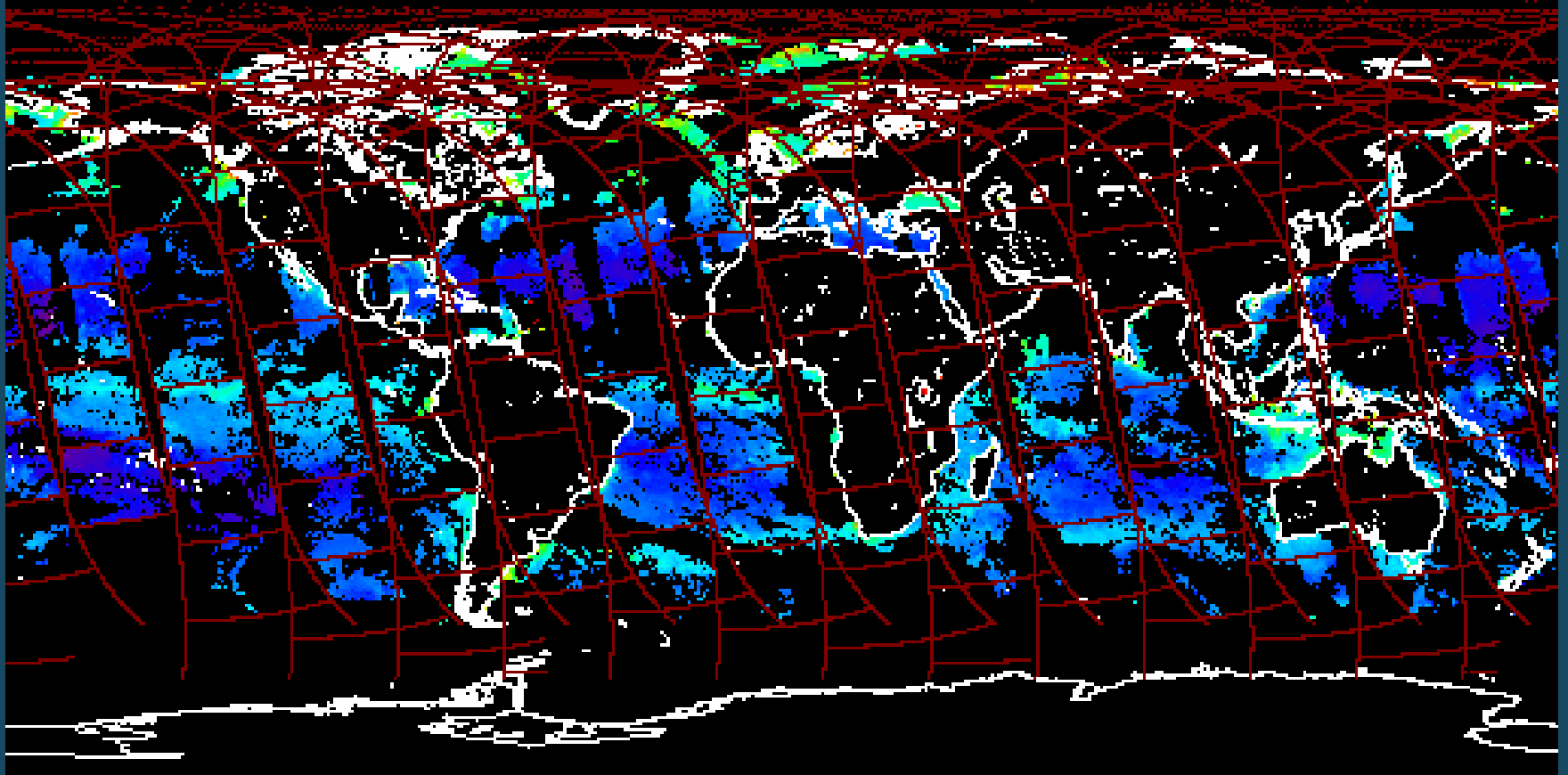
Not here, another lecture.

But: on-board, lunar, and vicarious...

and by the way

Calibration \neq Validation!

Level 2 8-day



Aqua-MODIS Chl a – 7.9.2007

Level-3 Processing

- Level 2
 - geolocated geophysical products for each pixel
- Level 3 binned
 - geophysical products averaged spatially and/or temporally
 - sinusoidally distributed, equal area bins
- Level 3 mapped
 - images created by mapping and scaling binned products
 - user-friendly, cylindrical equiangular projection

Standard Products

- Bin resolution 4.6 x 4.6 km²
- Mapped resolution
 - 0.042-deg (4.6 km at equator)
 - 0.084-deg (9.2 km at equator)
- Composite Periods
 - Daily
 - 8-day
 - Monthly
 - Seasonal
 - Yearly
 - Mission

Level-3 Processing

Let's talk about binning vs. mapping...

- Bin resolution 4.6 x 4.6 km²
- Mapped resolution
 - 0.042-deg (4.6 km at equator)
 - 0.084-deg (9.2 km at equator)
- Composite Periods
 - Daily
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 - Monthly
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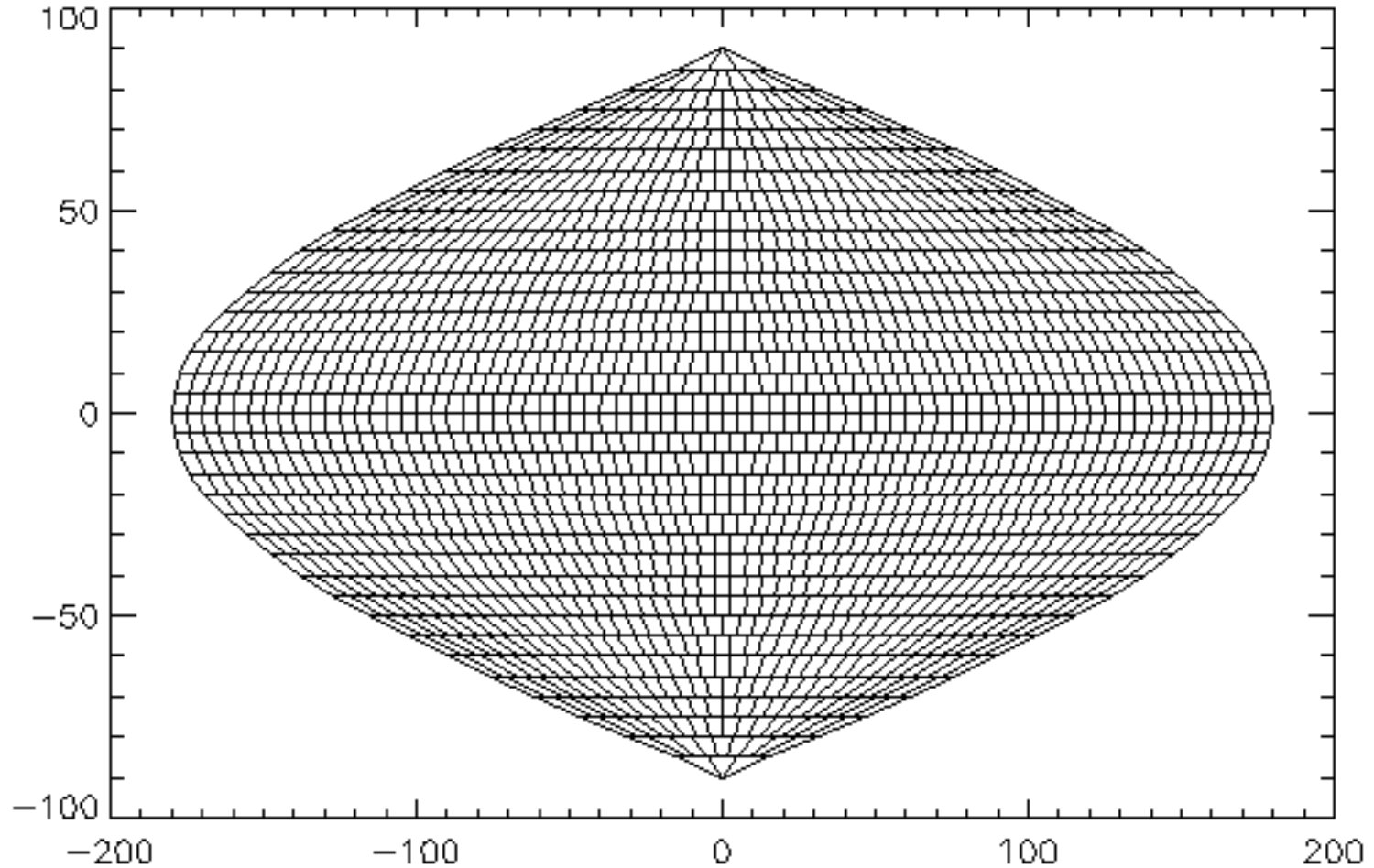
Definitions

- Projection - any process which transforms a spatially organized data set from one coordinate system to another. For MODIS Ocean data products this will refer to two-dimensional data sets.
- Mapping - a process of transforming a data set from an arbitrary spatial organization to a uniform (rectangular, row-by-column) organization, by processes of projection and resampling.
- Binning - a process of projecting and aggregating data from an arbitrary spatial and temporal organization, to a uniform spatial scale over a defined time range. Ideally the binning process will preserve both the central tendency (e.g., average) and the variation in the data points that contribute to a bin.

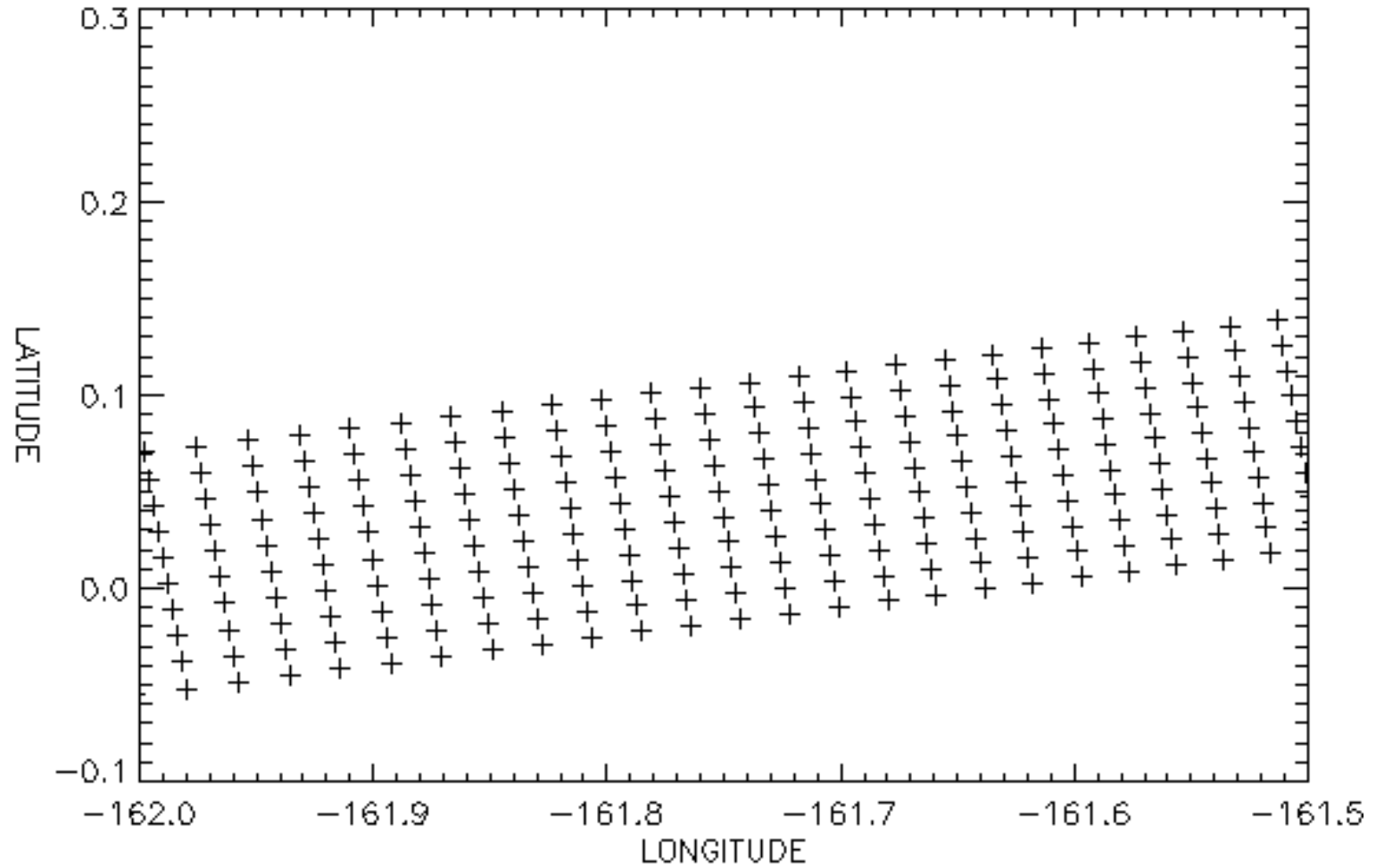
MODIS Ocean Product Projections

- Equal-area: sinusoidal, with equally spaced rows and number of bins per row proportional to sine of latitude; resolutions of 4.6 and 9.2 km
- Equal-angle: rectangular (Plate Carrée) with rows and columns equally spaced in latitude and longitude; resolutions of 24 and 12 points per degree.
- Ocean equal-area and equal-angle projections are equivalent at the equator.

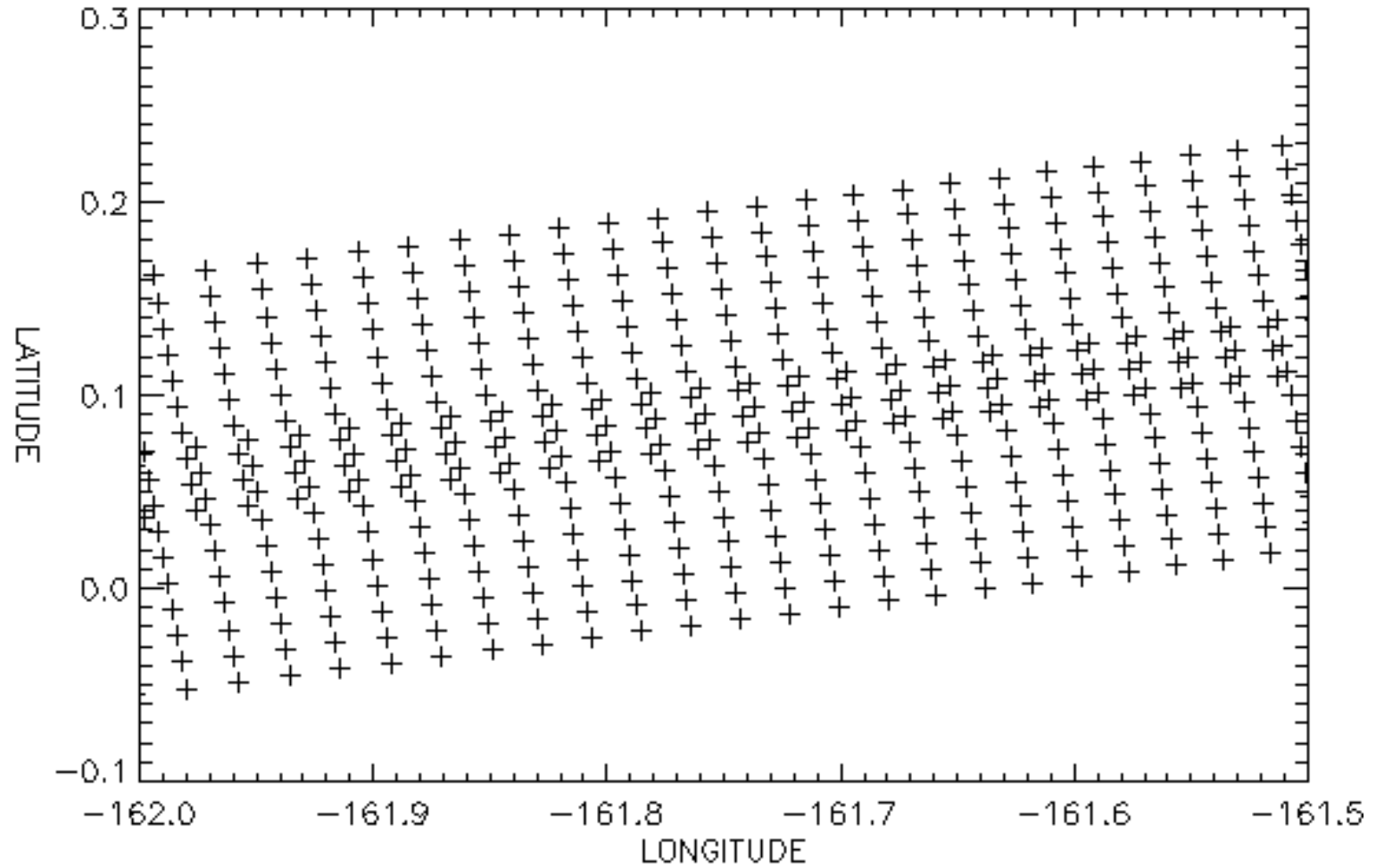
Sinusoidal Equal-Area Projection



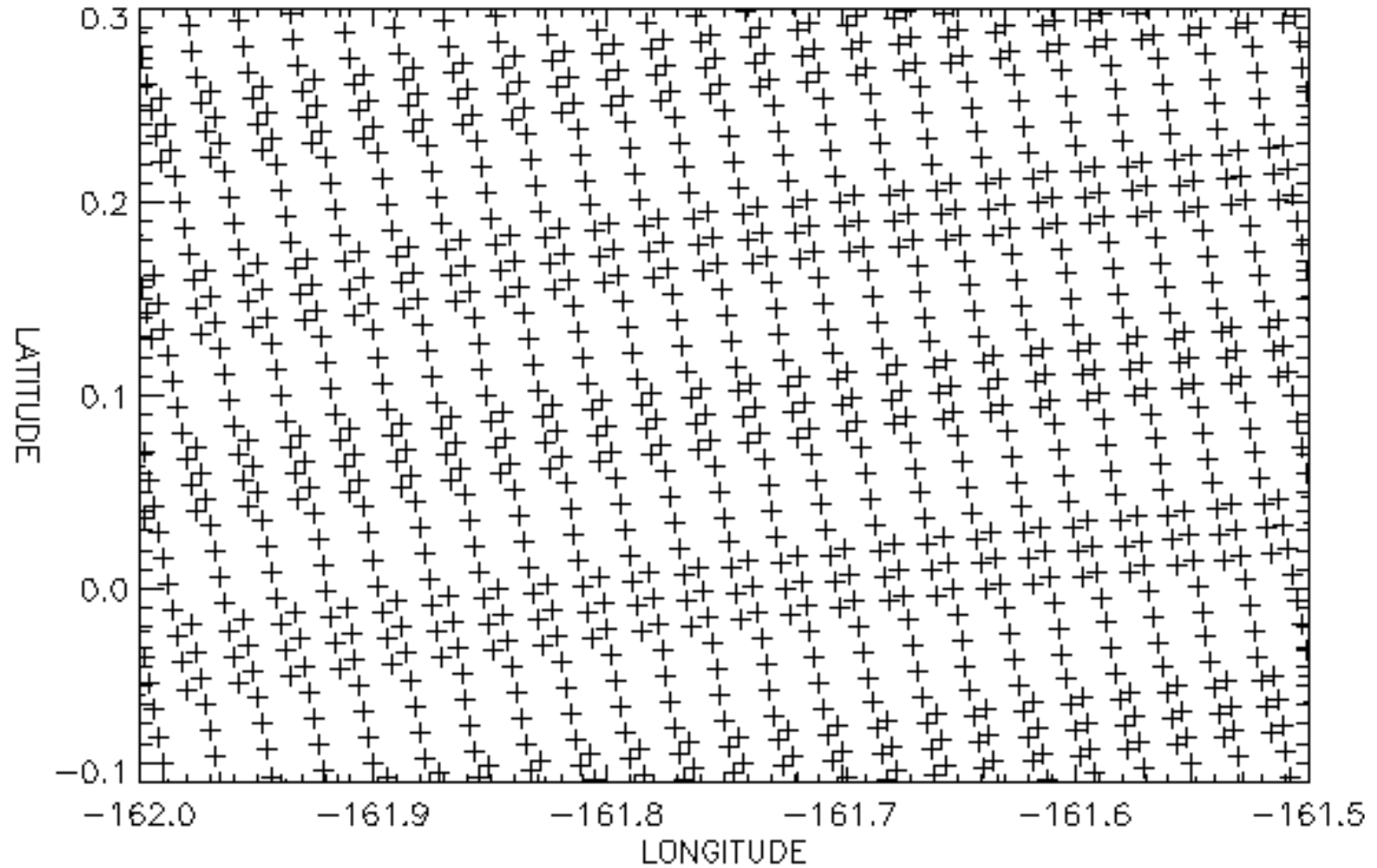
One MODIS scan at ~45 degrees scan angle



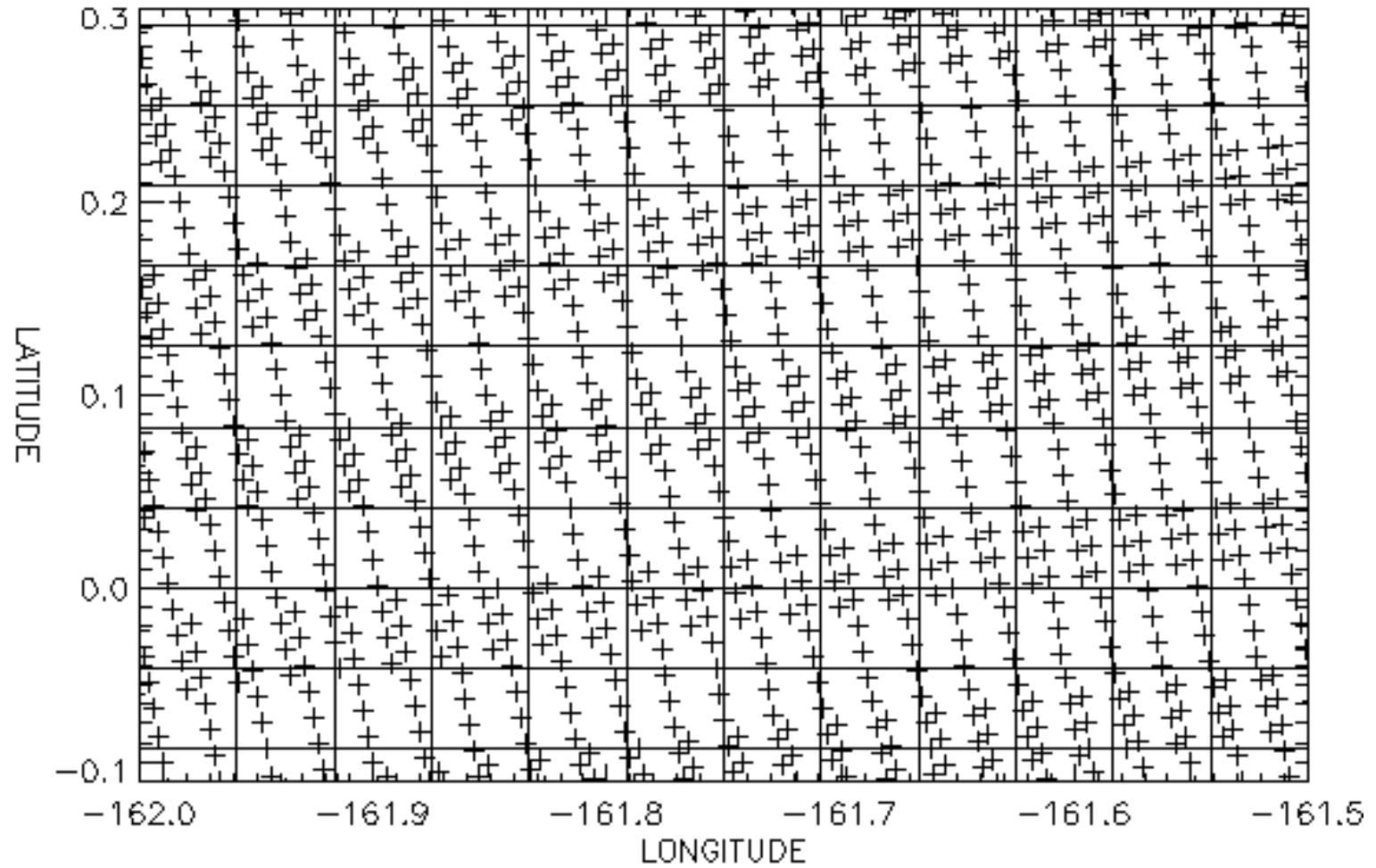
Two MODIS scans showing overlap of pixels



Multiple MODIS scans showing pixel overlap



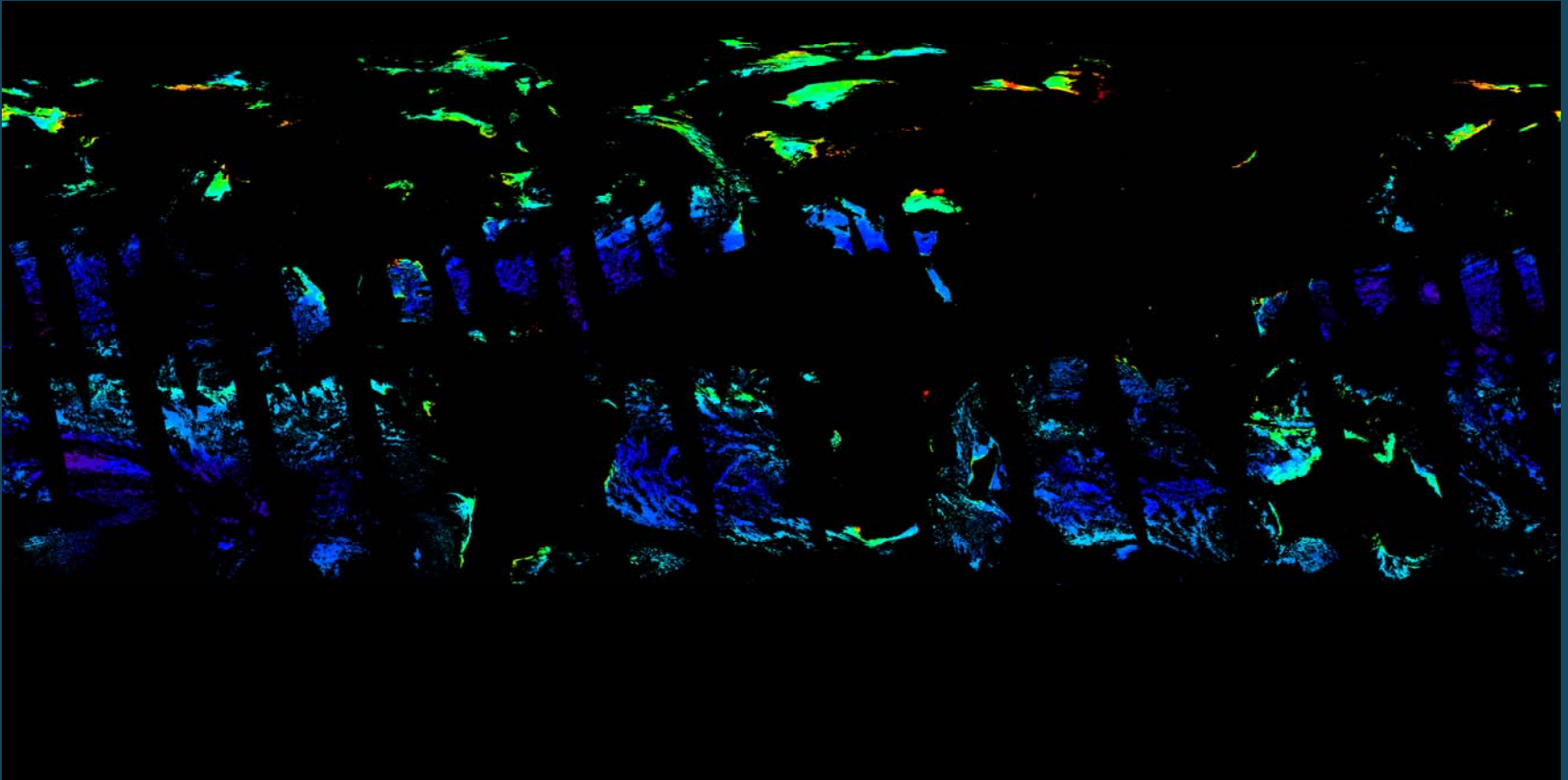
Bin boundaries overlaid on pixel locations



Binned and Mapped Products

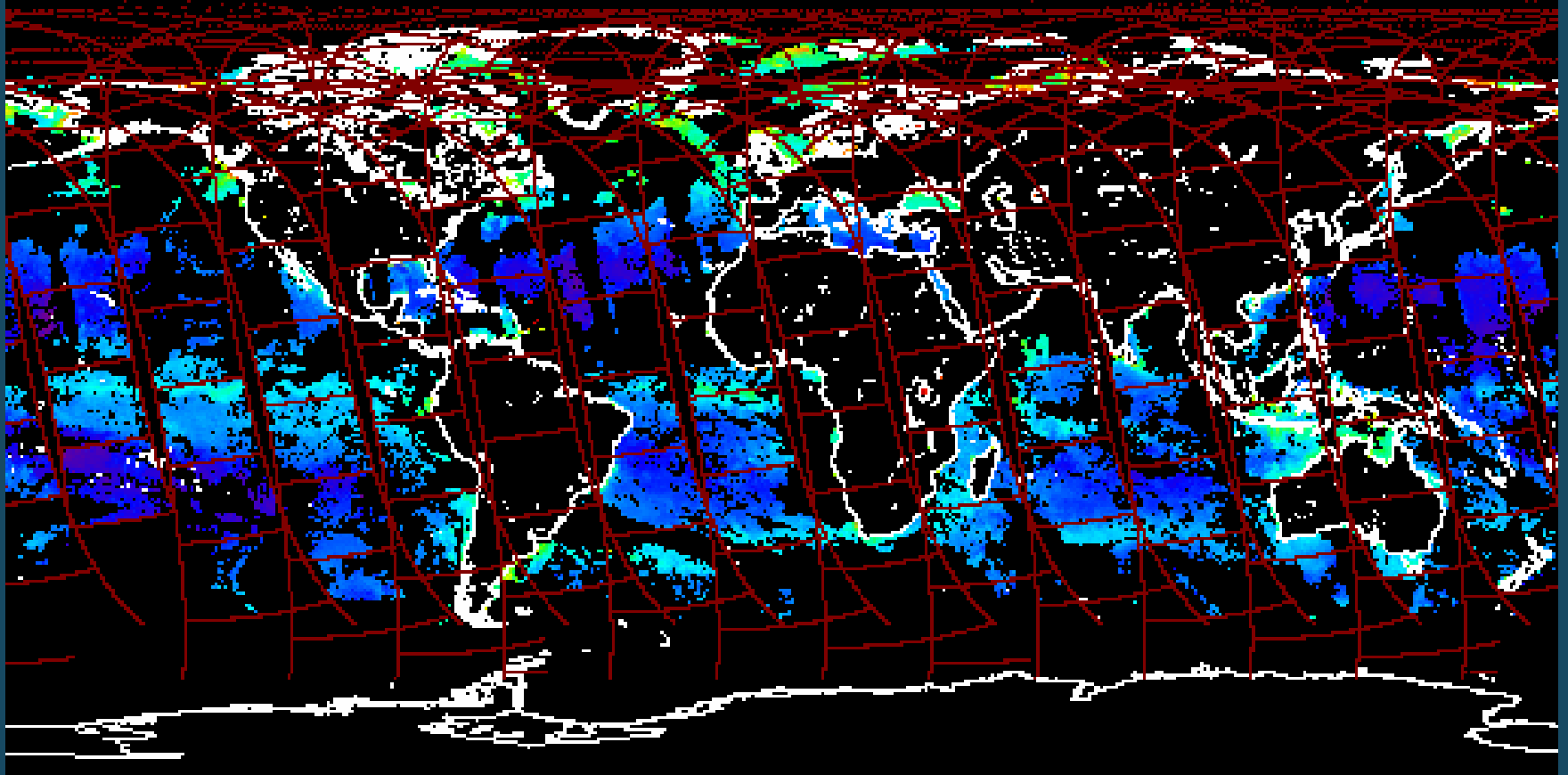
- Binned products are generated daily from Level-2, and then aggregated to 8 days, monthly, seasonal, annual and mission.
- Standard mapped image (SMI) products are generated at each temporal resolution by projecting binned files to the equal-angle grid.

Level 3 SMI



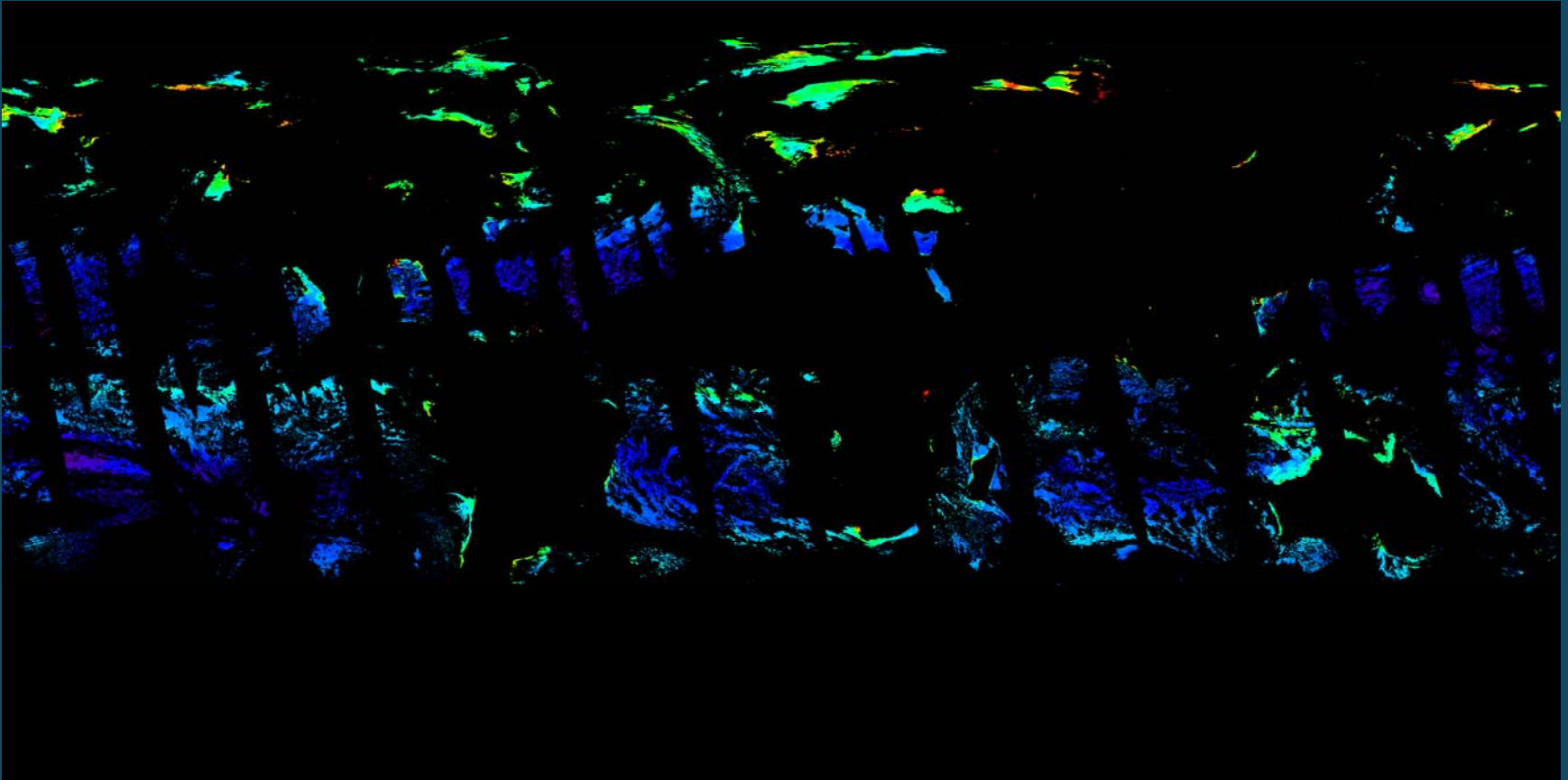
Aqua-MODIS Chl a – 7.9.2007 - Daily

Level 2 8-day



Aqua-MODIS Chl a – 7.9.2007

Level 3 SMI



Aqua-MODIS 4km Chl *a* – 7.9.2007 - Daily

Are the results valid?

Another lecture, but this is when it all happens.

Data Products and Distribution

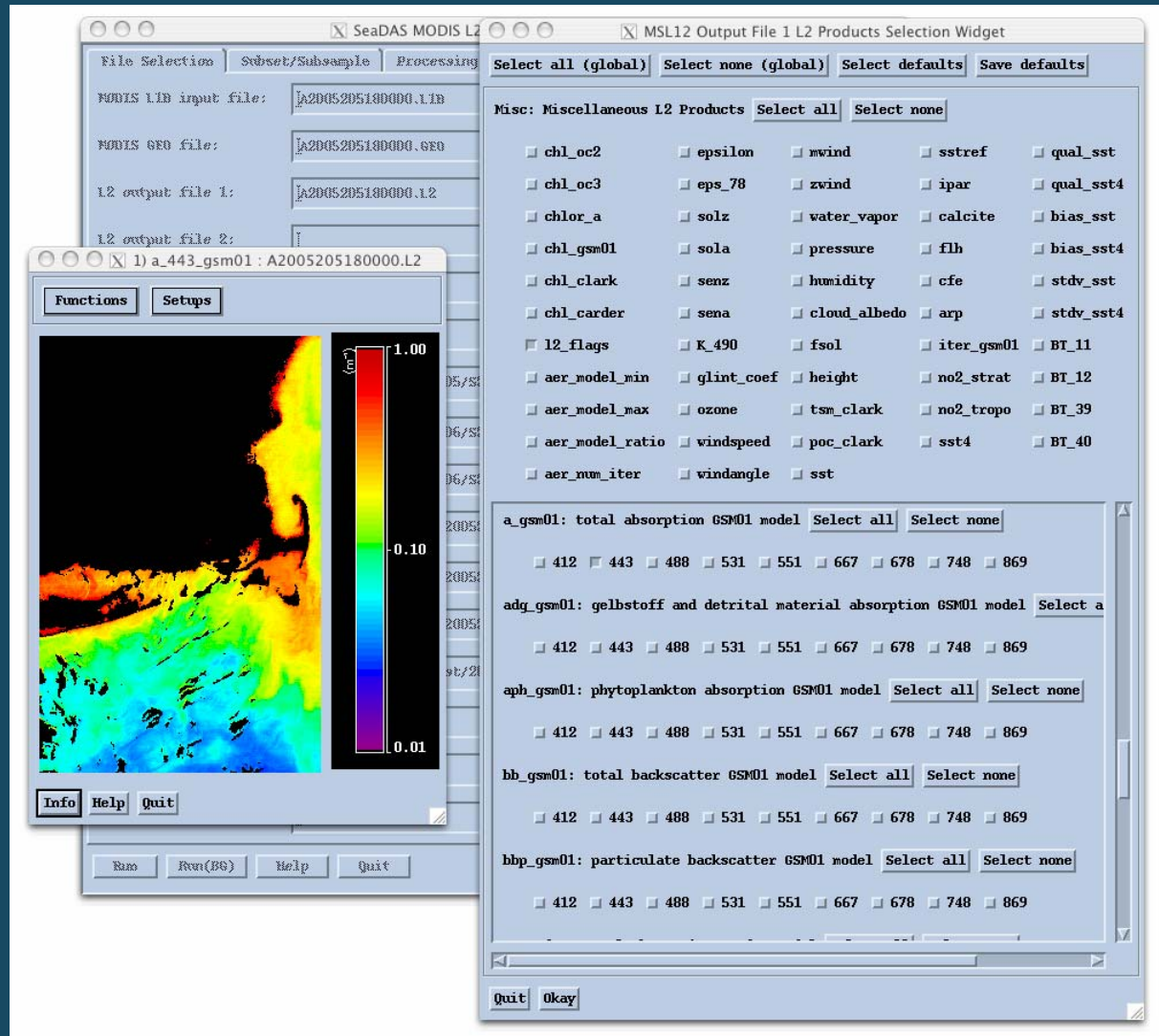
Standard Ocean Products

- Ocean Temperature (MODIS only)
 - Long-wave SST (11-12 μm), day and night
 - Short-wave SST (3.9 - 4.0 μm), night only
 - SST quality level
- Ocean Color
 - Normalized water-leaving radiances, $nLw(\lambda)$
 - Chlorophyll, C_a
 - Diffuse attenuation, $K_d(490)$
 - Aerosol type and concentration
 - Processing flags
- Data Types
 - Level-1: observed radiances (swath-based)
 - Level-2: retrieved geophysical parameters (swath-based)
 - Level-3: global gridded composites (daily, 8-day, monthly, merged)

SeaDAS

Data Processing, Analysis, and Display Software

- free
- multi-mission
- display tools
- analysis tools
- processing
- open source



Examples of Non-standard Ocean Products

- Alternate C_a and K_d algorithms
- Chlorophyll fluorescence, FLH
- Particulate inorganic carbon, Calcite
- Inherent optical properties (various bio-optical models)
 - absorption (total, phaeophytin, dissolved matter)
 - backscatter (total, particulate)
- Euphotic depth (Z_{eu} , Z_{sd})
- Spectrally integrated diffuse attenuation, $K_d(\text{PAR})$

Data Distribution

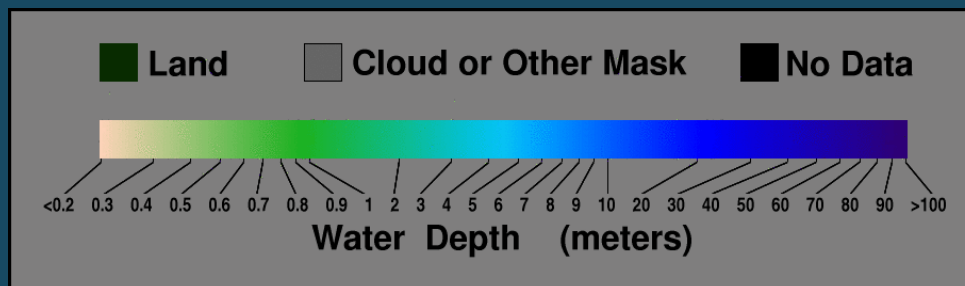
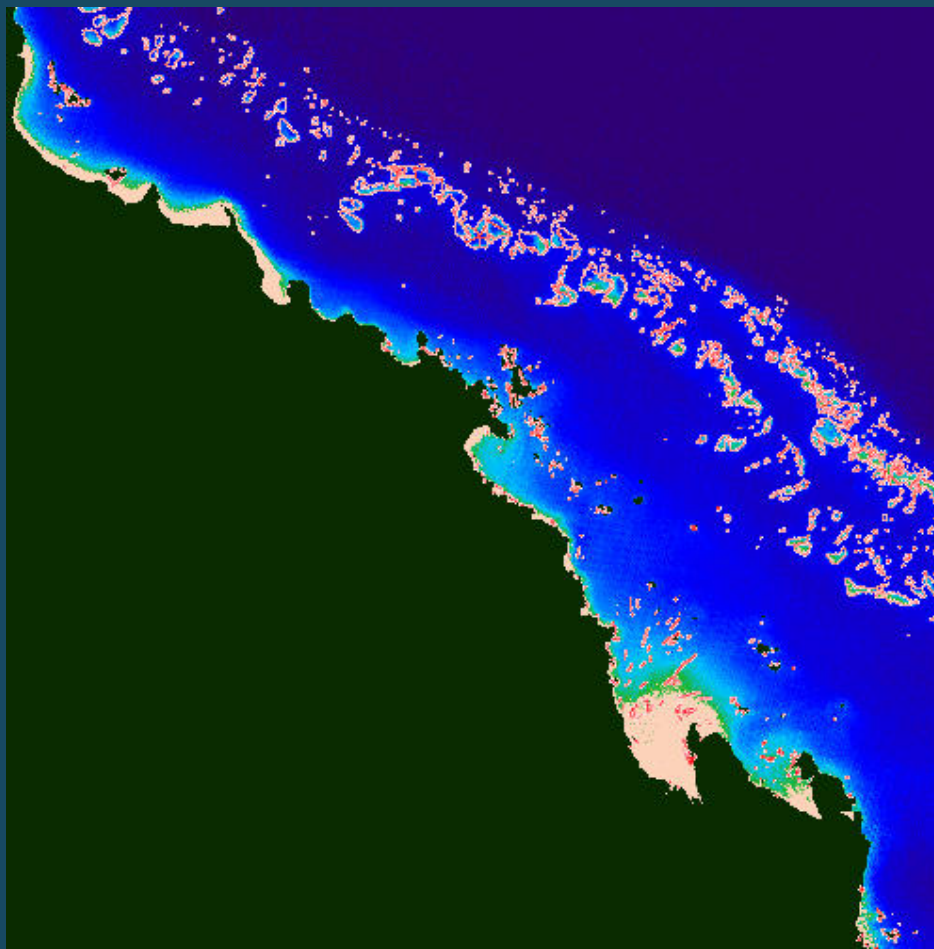
- Free and open data distribution policy (MODIS)
 - Level-1, Level-2, and Level-3
 - ocean color and SST
 - CZCS, OCTS, SeaWiFS, MODIS
- Web-based browsing and direct ftp access
- Automated ordering system
- Subscription services
- Geographic and parameter sub-setting

Remote Sensing of Coral Reefs

<http://oceancolor.gsfc.nasa.gov/cgi/reefs.pl>



Water Depth Classification from SeaWiFS





Data Access

Data Production and Distribution Status



All systems nominal

NOTE: FTP connections must be made in PASSIVE mode

Level 1 and 2 Browser

Visually search the ocean color data archive and directly download and/or order data from single files to the entire mission. Extensive online [HELP](#) and tutorials available.

Level 3 Browser

Browse the entire Level 3 global ocean color data set for many parameters and time periods and download either JPEG images or digital data in HDF format. View [time series plots](#) of selected SeaWiFS parameters for selected regions of the globe.

Data Subscriptions

Request a subscription for Aqua data to be staged on an FTP site. You can [check the status](#) of an existing subscription. Requires a Support Services [username and password](#).

Data by FTP

The Project maintains several FTP sites containing the most popular data products including the complete Level 3 data archive.

Giovanni

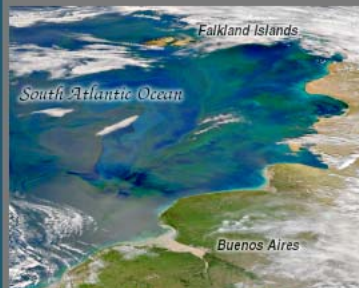
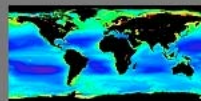
A GES DISC DAAC tool to provide users with an easy-to-use, Web-based interface for the visualization and analysis of the Earth Science data.

Ocean Color Web Feature

Recent topics and imagery of interest to the OceanColor community.

AQUA/SeaWiFS Merged Chlorophyll Data

The OBPG now produces a merged Level-3 chlorophyll product derived from SeaWiFS and MODIS/Aqua. The products are being created routinely for daily, 8-day, monthly, seasonal and annual time periods. Details about this new product can be found [HERE](#)



Some of the authors of a [recent paper](#) describing the timing of [coccolithophore](#) blooms in the South Atlantic Ocean off the coast of Argentina are once again at sea in this area endeavoring to improve our understanding of the phytoplankton communities that add so much color to these waters.

Click on the above 26 October 2006 MODIS image for a [larger version](#) or click [here](#) for the full-sized (98.6 megabyte) image.

[Image Gallery](#) [Ocean Color Distribution Statistics](#)

Support Services

SeaDAS

A comprehensive image analysis package for the processing, display, analysis, and quality control of ocean color data.

SeaBASS

An archive of in situ data, both oceanographic and atmospheric, used for algorithm development and satellite validation.

[Register for Support Services](#)

Register for support services, including:

- SeaWiFS data access authorization
- Access to Near Real Time image support
- Request a new password or change email address
- Ocean Color Forum
- Ocean Color Mailing List

[Support Services](#)

- Overflight predictions
- Near real-time imagery and data for cruise support

[Data Processing](#)

The ODPS site contains information related to the ocean color data production system.

[Employment Opportunities](#) (IOCCG listings)

TC OIL SST SeaWiFS User Login

SeaWiFS
 GAC LAC MLAC
 OCTS (ADEOS) MODIS (Aqua) CZCS (Nimbus-7)

Radius (km) about map click or typed-in location:
 36 400 800 1200 1500

Select swaths containing (at least):
 any part 25 % 50 % 75 % all of the area of interest.

Display results at a time.

Monday, 30 October 1978 through Wednesday, 5 October 2005

Chlorophyll

Select one or more regions:
 AdriaticSea
 AegeanSea
 Antarctica
 ArabianSea
 AralSea
 Australia
 Azores

or specify boundary coordinates or a single location:
 N:
 W: :E
 S:

or check this box to select all of this time period's scenes.

M
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1978	J	F	M	A	M	J	J	A	S	O	N	D
1979	J	F	M	A	M	J	J	A	S	O	N	D
1980	J	F	M	A	M	J	J	A	S	O	N	D
1981	J	F	M	A	M	J	J	A	S	O	N	D
1982	J	F	M	A	M	J	J	A	S	O	N	D
1983	J	F	M	A	M	J	J	A	S	O	N	D
1984	J	F	M	A	M	J	J	A	S	O	N	D
1985	J	F	M	A	M	J	J	A	S	O	N	D
1986	J	F	M	A	M	J	J	A	S	O	N	D
1996	J	F	M	A	M	J	J	A	S	O	N	D
1997	J	F	M	A	M	J	J	A	S	O	N	D
1998	J	F	M	A	M	J	J	A	S	O	N	D
1999	J	F	M	A	M	J	J	A	S	O	N	D
2000	J	F	M	A	M	J	J	A	S	O	N	D
2001	J	F	M	A	M	J	J	A	S	O	N	D
2002	J	F	M	A	M	J	J	A	S	O	N	D
2003	J	F	M	A	M	J	J	A	S	O	N	D
2004	J	F	M	A	M	J	J	A	S	O	N	D
2005	J	F	M	A	M	J	J	A	S	O	N	D

August 2005							September 2005							October 2005							
S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	
	1	2	3	4	5	6						1	2	3							1
	xxx	xxx	xxx	xxx	aaa	aaa						xxx	xxx	xxx							xxx
7	8	9	10	11	12	13	4	5	6	7	8	9	10	2	3	4	5	6	7	8	
aaa	aaa	aaa	aaa	aaa	aaa	ooo	xxx	xxx	aaa	aaa	aaa	aaa	aaa	xxx	xxx	xxx	xxx	xxx	xxx	aaa	
14	15	16	17	18	19	20	11	12	13	14	15	16	17	9	10	11	12	13	14	15	
ooo	ooo	ooo	ooo	ooo	ooo	ooo	aaa	aaa	aaa	ooo	ooo	ooo	ooo	aaa	aaa	aaa	aaa	aaa	aaa	aaa	
21	22	23	24	25	26	27	18	19	20	21	22	23	24	16	17	18	19	20	21	22	
***	***	***	***	***	***	***	ooo	ooo	ooo	ooo	***	***	***	ooo	ooo	ooo	ooo	ooo	ooo	ooo	
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													30	31							
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Multi-Mission Approach

- Common software for Level-1 through Level-3
 - reduces potential for algorithm and implementation differences
 - sensor-specific issues consolidated in i/o function and external tables
- Mission-independent, distributed processing system
 - controls staging/sequencing of processing jobs for max through-put
 - 150x global reprocessing for MODIS, 1600x for SeaWiFS
- Standard procedures for calibration and validation
 - temporal calibration via On-Board Calibration system (OBC)
 - vicarious calibration to MOBY (instrument + algorithm calibration)
 - validation against SeaBASS *in situ* archive
 - temporal trending analysis of Level-3 products