Ocean & Coastal observations from a geostationary orbit: science focus and preliminary design of the OCAPI mission

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OCAPI means:

Ocean Color Advanced Permanent Imager

"Running head":
A breakthrough in ocean sciences thanks to hourly observations of ocean colour in coastal zones and the open ocean from a geosynchronous orbit

Science focus of the OCAPI mission

- Coastal environments are spatially complex, and the processes are extremely dynamic and ephemeral

- The open ocean also needs to be “scrutinized” at higher temporal and spatial scales

- A LEO system can hardly reach the required temporal revisit; we need the observations from the GEO orbit

- LEO constellations + GEO sensors will provide nested global, regional and local coverage

- A comprehensive understanding of the ocean ecosystems requires an integration of observations over a wide range of scales

Science focus of the OCAPI mission

Scientific and applied domains include:

- ✓ The diurnal cycles of ocean properties
- ✓ The ocean carbon cycle and its coupling to physics
- ✓ Particle (primary) production from the diel changes in particulate attenuation
- ✓ Biological-physical coupling at meso and sub-meso scales
- ✓ Data assimilation in coupled biological-physical ocean models, and operational oceanography
- ✓ Improved marine biogeochemistry and ecosystem models
- ✓ Dynamics of coastal ecosystems and environments
- ✓ Sediment transport in river plumes and carbon sequestration in ocean margins
- ✓ Operational services for the coastal zones
- ✓ Aerosol transport
- ✓ Land-ocean interactions
- ✓ The unknowns (new observations always lead to non-anticipated findings)

OCAPI specifications

as of September 2010

subject to change

General & essential requirements for satellite ocean colour observations

- "Discriminating 10 classes of chlorophyll concentration within the 3 decades from 0.03 to 30 mg(Chl) m^{-3}."

- When expressed in terms of reflectance, this means uncertainties of 1-2 10^{-3} in the blue (*ca* 443 nm) and about 2 10^{-4} in the green (*ca* 550 nm) (Antoine and Morel, 1999, Int. J. Remote Sensing 20, 9: 1875-1916)

- Another way to express this is: "an uncertainty of about 5% on the normalized water-leaving radiance in the blue for an oligotrophic ocean" (Gordon, 1997, J. Geophys. Res., 102, 17081–17106)

- This translates into very high SNR (> 1000) for the instrument

- Dynamic range adapted to oceanic targets

- Onboard calibration (sun and moon) is also mandatory to set the radiometric accuracy at the highest standard and to track any temporal change in the instrument response

- Other requirements (spatial & spectral resolution, hyper-spectral versus multi-spectral, swath width, etc…) depend on the mission

Products & associated requirements (1/2)

Variable name	Short description	Spectral range (nm)	Units	Required accuracy (goal)	Type
Basic quantity derived from the TOA signal					
$R_{rs} = \frac{L_w}{E_s}$	Spectral remote-sensing reflectance	400-900	sr^{-1}	1 10^{-3} @ 440nm to 2 10^{-4} @ 550 nm. 5% @ 440nm for clear waters	S
Inherent optical properties (IOPs)					
a	Total absorption coefficient	412, 443	m^{-1}	30%	I
a_ϕ	Phytoplankton absorption coefficient	443	m^{-1}	30%	I
a_{CDOM}	CDOM absorption coefficient	412	m^{-1}	30%	I
a_{CDM}	CDM absorption coefficient	412	m^{-1}	30%	I
b_{bp}	Particulate backscattering coefficient	443, 560, 590	m^{-1}	30%, 0.0005 m^{-1}	I
S	b_{bp} spectral slope	N/A	unitless	30%	R
c_p	Particulate beam attenuation coefficient	660	m^{-1}	0.05 m^{-1}	R
Apparent optical properties (AOPs)					
K_d	Diffuse attenuation coefficient for downward irradiance	490	m^{-1}	30%	S
K_{PAR}	Diffuse attenuation coefficient for PAR	400-700 integrated	m^{-1}	30%	S
Z_{sd}	Secchi depth	N/A	m	30%	S

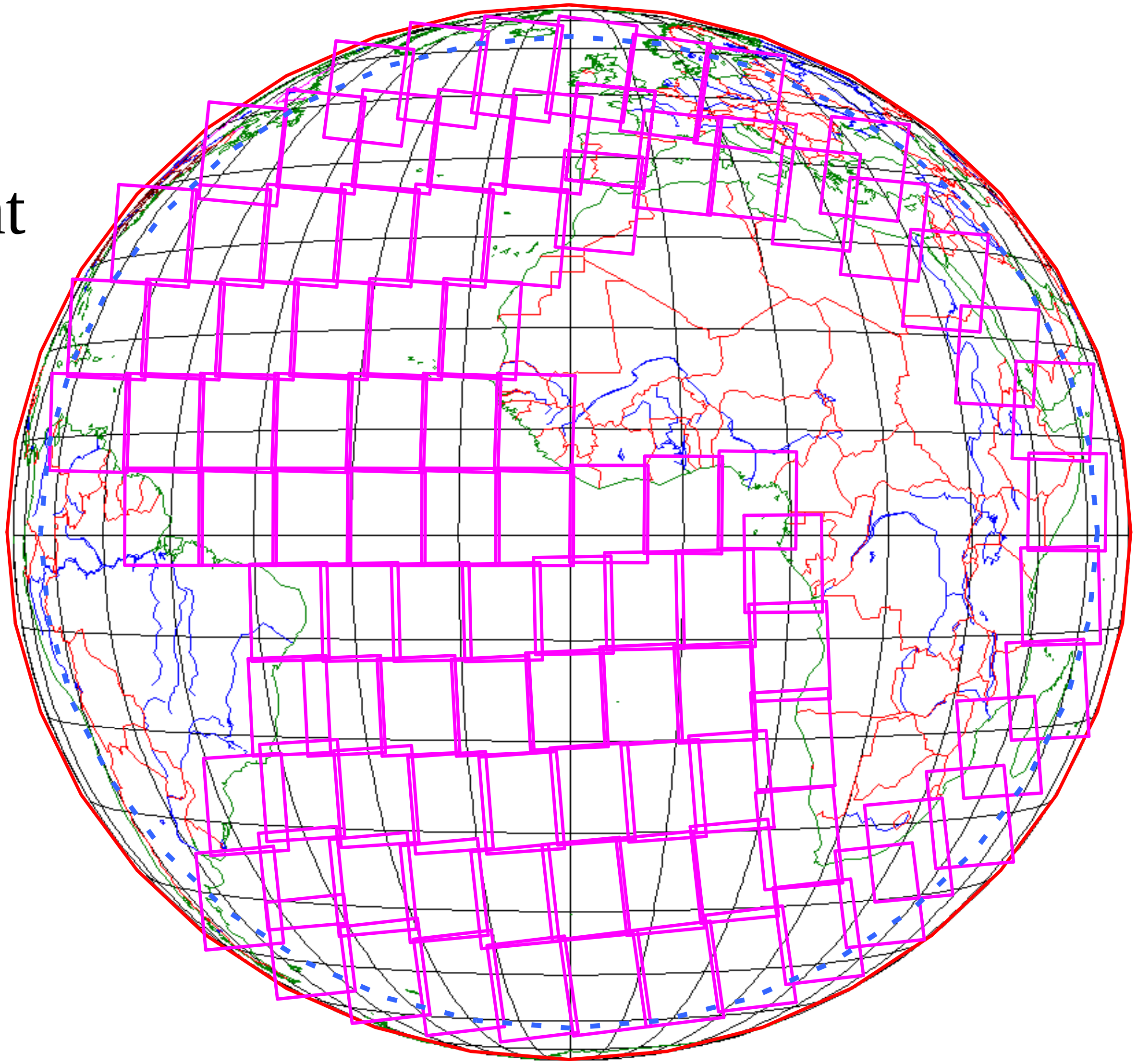
Product types S: “standard” I: “intermediate” R:”research”

Products & associated requirements (2/2)

Variable name	Short description	Spectral range (nm)	Units	Required accuracy (goal)	Type
Basic quantity derived from the TOA signal					
Bio-geophysical / ecological parameters					
Chl	Chlorophyll concentration	N/A	mg m^{-3}	30%	S
TSM	Total suspended matter	N/A	mg m^{-3}	30%	S
POC	Particulate organic carbon	N/A	mg m^{-3}	30%	I
DOC	Dissolved Organic Carbon	N/A	mg m^{-3}	30%	R
PIC	Particulate inorganic carbon	N/A	mg m^{-3}	30%	R
FLH	Fluorescence line height	N/A	unitless	N/A	I/R
IPAR	Instantaneous above-water PAR	400-700 integrated	Einstein m^{-2} s^{-1}	10%	S/I
PAR	Daily PAR	400-700 integrated	Einstein m^{-2}	10%	S/I
NPP	Daily net particulate production	N/A	gC m^{-2}	30%	R
PSD	Particle size distribution	N/A	N/A	N/A	R
PFTs	Phytoplankton functional types	N/A	N/A	N/A	I/R
RTI	Red tide index	N/A	N/A	N/A	R
TUi	Turbidity index	N/A	FNU	N/A	I
Atmospheric parameters					
AOT	Aerosol optical thickness	865	unitless	0.05 @ 550 nm	S
Aerosol type	Aerosol type	N/A	unitless	N/A	S
ε	Spectral dependency of aerosol scattering	778-865	unitless	0.1	S
AAI	Absorbing aerosol index	N/A	unitless	N/A	I/R
Others					
QF	Quality flags	N/A	unitless	N/A	S/I

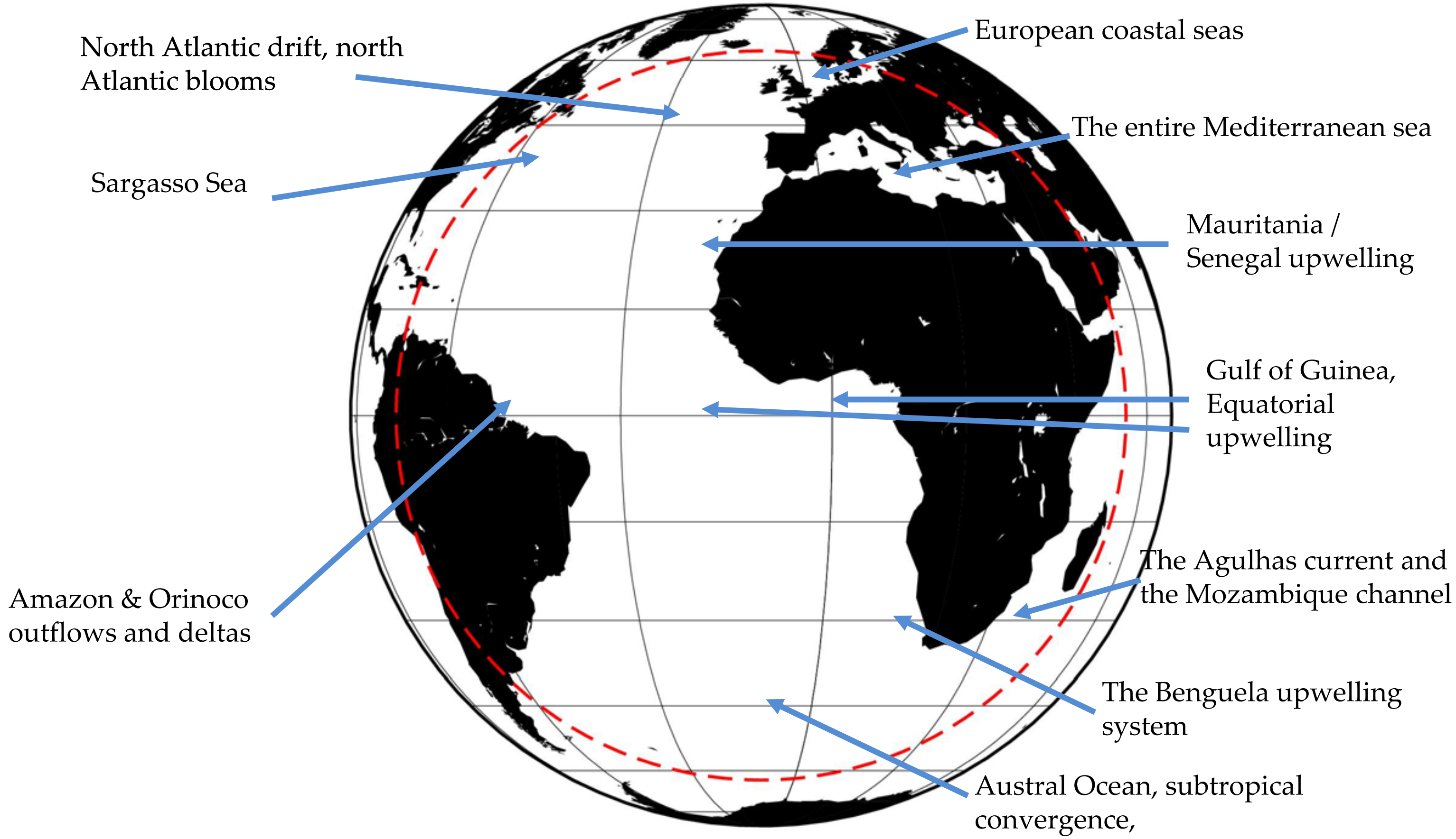
General concept: step & stare approach

Entire Earth disk about every hour at ~300 m resolution (at ssp)



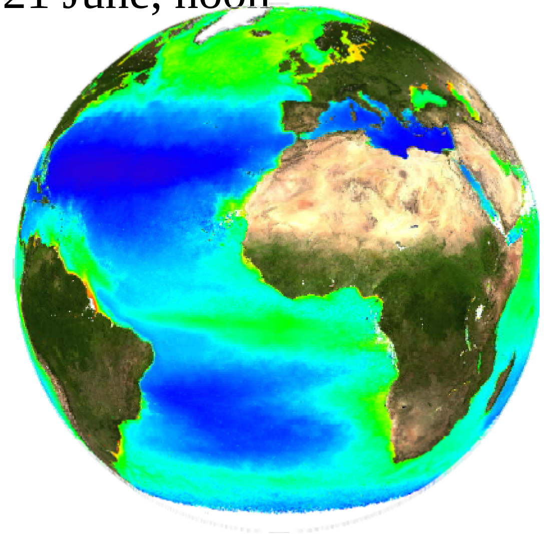
Combination of a number (TBD) of individual scenes (size TBD as well) in order to cover the area of interest . Position 10°W, Equator

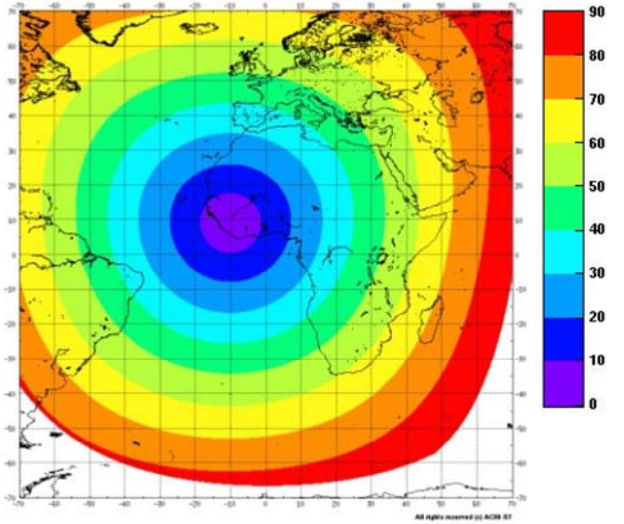
Areas of interest (non exhaustive)

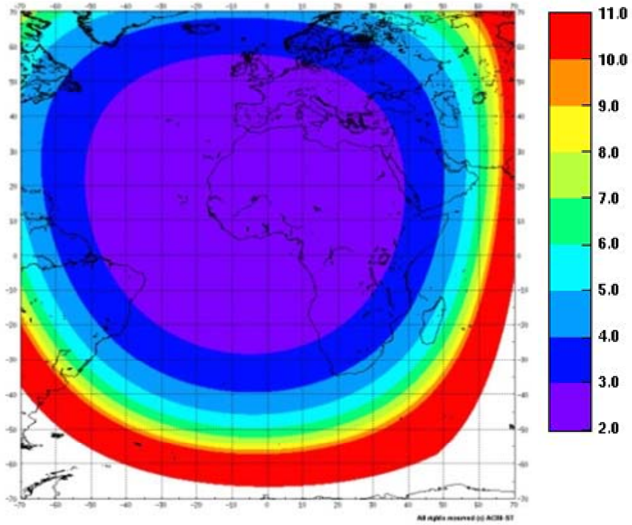


Orbit: geosynchronous, about 10°inclination

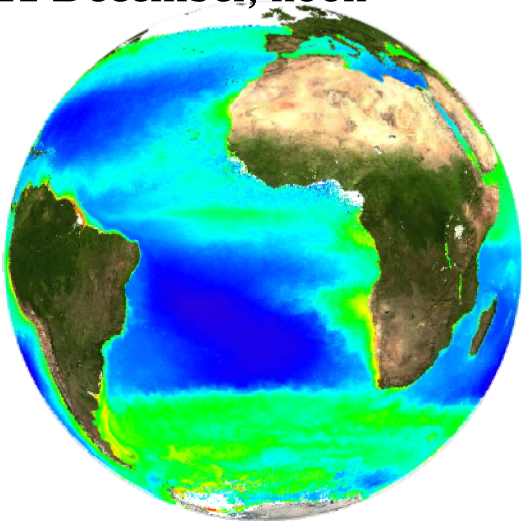
21 June, noon

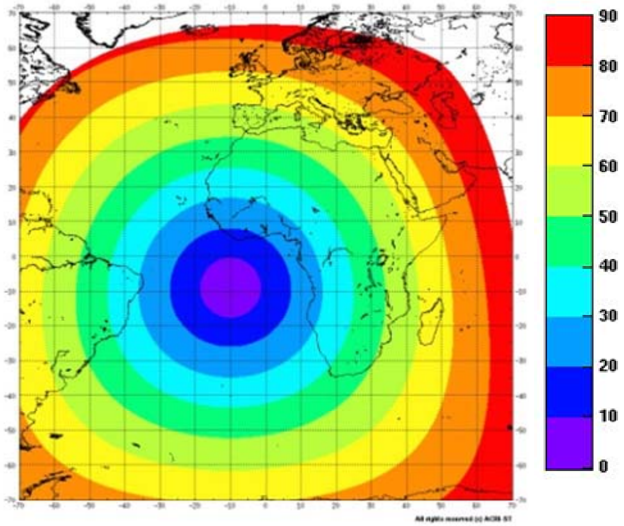


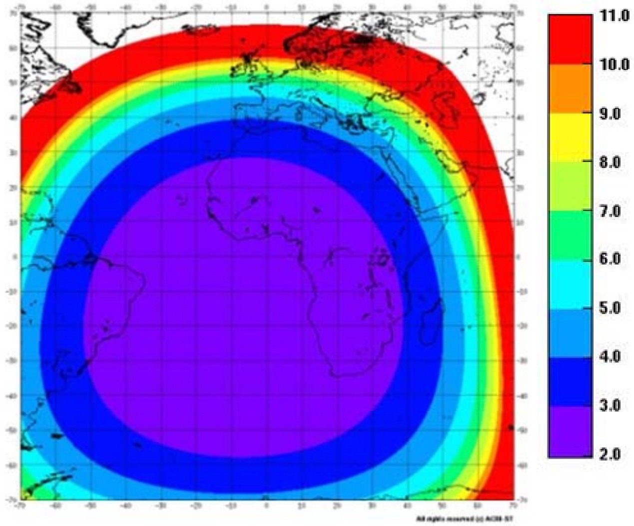




21 December, noon







View angle

Air mass

Band set

SNRs are for a 250m resolution

Grey cells indicate continuity / compatibility with MERIS and OLCI

Last column is priority / feasibility for the mission

Band	λ (nm)	Δλ (nm)	L_{min}	L_{ref}	L_{max}	$L_{max, ocean}$	SNR@ 250m[1] and L_{ref}	M/O[2]	Use	P[3]
			W m^{-2} sr^{-1} μm^{-1}							
1	395	10	12	65	580	180	400		Chl – CDOM separation	+
2	412	20	12	70	550	190	400		CDOM, possibly atmospheric correction above "black waters"	+++
3	442	20	12	65	650	185	400		Chlorophyll, TSM, CDOM	+++
4	470	20	11	60	650	175	400		Specific anomalies of the reflectance spectrum	+++
5	490	20	10	50	665	165	400		Chlorophyll, TSM, CDOM, Diffuse attenuation coefficient, Secchi transparency	+++
6	510	20	8	45	620	155	400		Chlorophyll, TSM, CDOM, detection of blue-absorbing dust-like aerosols	+++
7	560	20	6	30	580	132	300		Chlorophyll, TSM, turbidity index, Secchi transparency	+++
8	590	20	5	25	550	120	300		Spectral slope b_{bp}, max R in Case 2 waters	+++
9	620	20	4	20	550	95	300		Chlorophyll , TSM	+++
10	660	20	3	15	500	86	300		Chlorophyll , TSM, Chl fluorescence (baseline)	+++
11	681	7.5	3	15	500	82	200		Chl fluorescence (peak)	+++
12	709	10	3	13	450	75	200		Chlorophyll , TSM, Secchi transparency, Chl fluorescence (baseline)	+++
13	750	15	3	11	450	65	150		Atmospheric corrections	+++
14	754	7.5	2	10	400	65	150		Reference for O2 A-band	+
15	761	2.5	2	6	400	63	30		O2 A-Band (aerosol scale height, clouds)	+
16	779	15	2	9	380	60	150		Atmospheric corrections	+++
17	865	35	1	6	300	45	150		Atmospheric corrections	+++
18	1020	40	1	4	220	45	150		Atmospheric corrections (turbid waters), cirrus clouds	+

Other requirements (1/2)

Parameter	Goal	Breakthrough	Threshold	Comments
Orbit	Geosynchronous (10° inclination; TBC)	N/A	Geostationary	
Satellite location	10°W – 10°E	N/A	N/A	Final position to be determined in phase A
Type of Coverage	Complete Earth disk (oceans & lands)	Complete Earth disk (oceans & coastal zones)	Selected areas of interest	
Revisit	30 min	1 hour	1h in average	
Accessibility to specific revisit areas	15 min	N/A	none	
Resolution (Nadir GSD)	100 m	250 m	500 m	Aggregation might be acceptable for some bands
Imager bands	18 (See Table 3.2)	16	10	
Temporal co-registration for 1 scene	< 1 minute			Duration for acquisition of a given point in all bands
Out of band integrated signal	< 1%			
SNR	See Table 3.2			

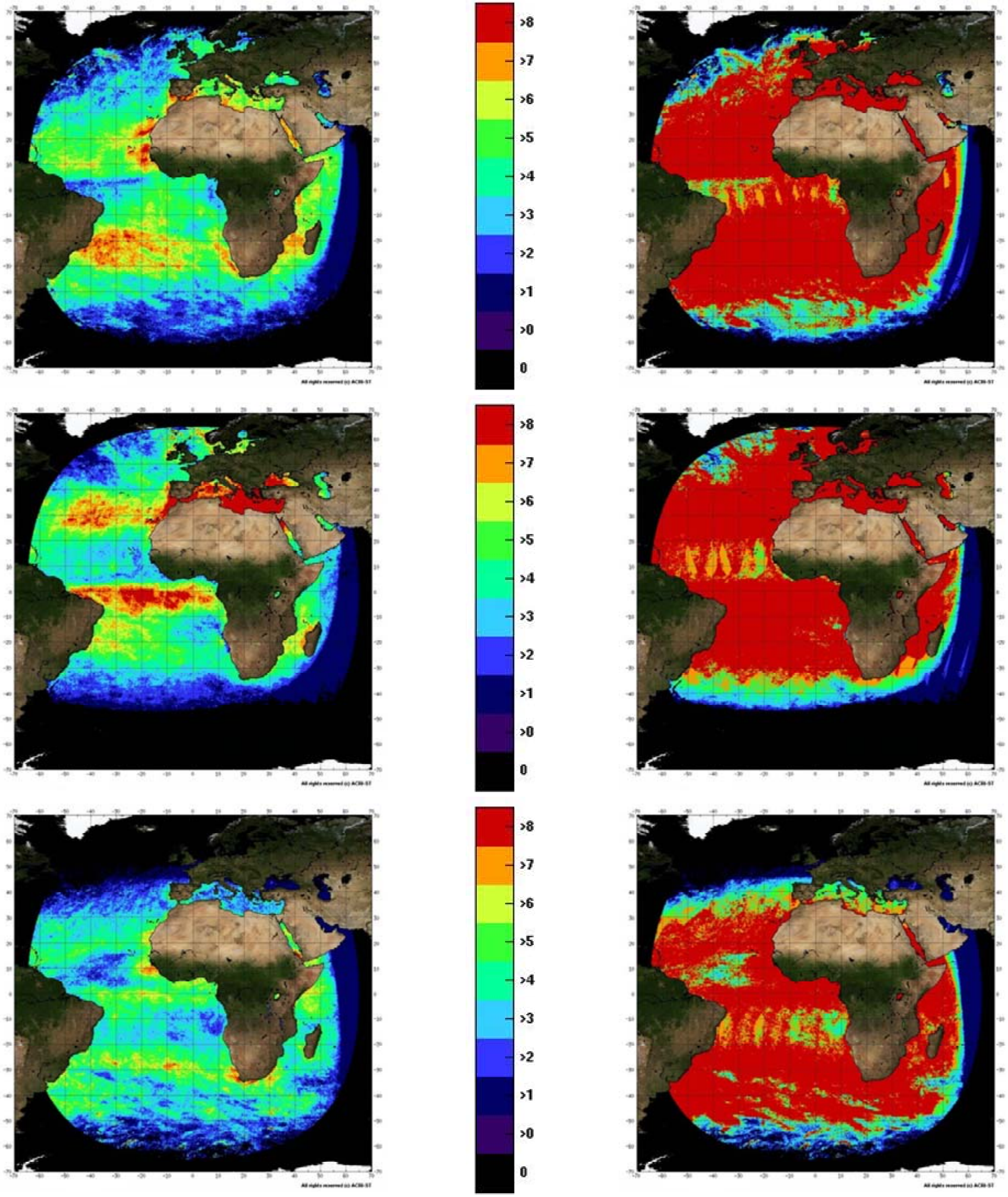
Other requirements (2/2)

Solar calibration	On-board devices			
Temporal stability	0.1% over the mission (moon observations)			
Vicarious calibration	Based on fixed-sites			This is a mandatory element for the success of any ocean colour mission
Pre-launch absolute Radiometric accuracy	2 % in radiance, w.r.t. a laboratory standard	N/A	4 %	
Relative accuracy between bands	1%			
Polarisation sensitivity	1%			
MTF	0.3	0.2	0.15	
Clouds	Clouds to be observed	Degraded SNR for clouds	No data required	
Geolocation	¼ pixel	½ pixel	1 pixel	
Latency	NRT	1 hour	1 day	Time between data acquisition and Level 1b availability
Lifetime	10 years	7 years	5 years	

COVERAGE

Mean(left) and max (right) number of daily available observations, for two LEOs (S3 A&B) complemented by OCAPI in March, June and December (top to bottom).

The observation area is here constrained by the MSG observation area (from which realistic cloud coverage was taken)



ACRI ST

Overall schedule

• A proposal was submitted to CNES in 2008 → Selected as a high priority at the issue of the CNES "5-year scientific prospective seminar" in February 2009

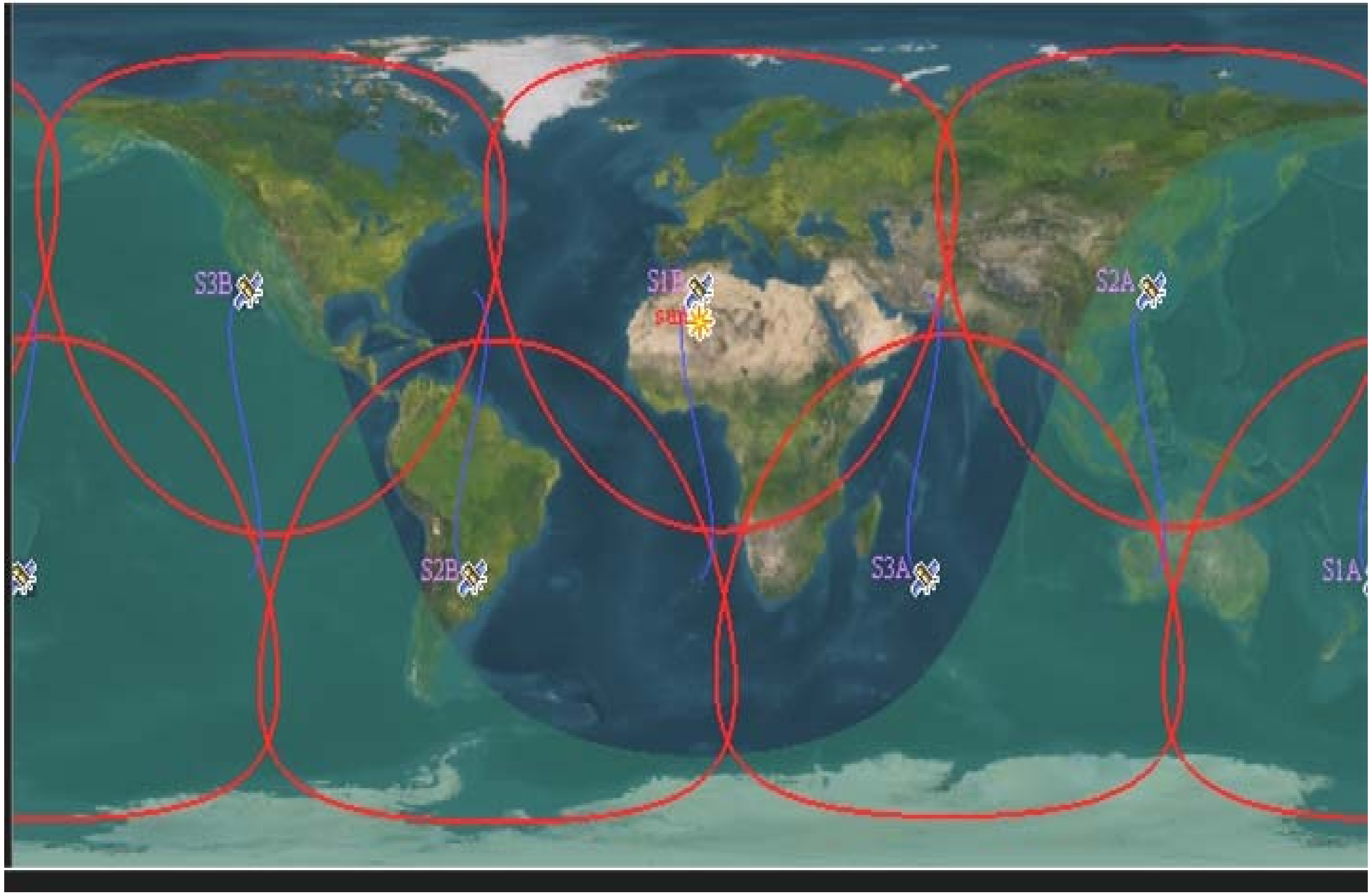
• A proposal was submitted to ESA in June 2010 (8th "Earth Explorer" opportunity mission); GeoCAPE PIs were invited to be part of the science team

• Results were announced in November 2010: not selected. Excellent scientific review, however. A specific recommendation was issued by the ESA' Earth Science Advisory Committee: "*…who recognizes that this concept has very high scientific value, and encourages ESA to investigate opportunities to deploy such an observing system on future geostationary satellites*".

• Phase 0 studies have been ordered to industry by CNES, to further define the concept. One study by Astrium-France was closed by April 2011; another one by Thales Alenia Space (TAS) will be closed by the end of 2011. Several concepts are therefore ready for being further evaluated during a phase A, which might start in 2012 (led by CNES).

• In parallel, a "Hosted version", similar to GOCI (i.e., limited target area and number of bands), is being evaluated by ESA as a possible intermediate solution, to be hosted on the EDRS-C telecomm satellite (decision to implement by fall-winter 2011; if decided, launch should be in 2014). Would pave the way for the more ambitious OCAPI at the 2018-2020 horizon

Global monitoring with 6 satellites in geosynchronous orbits

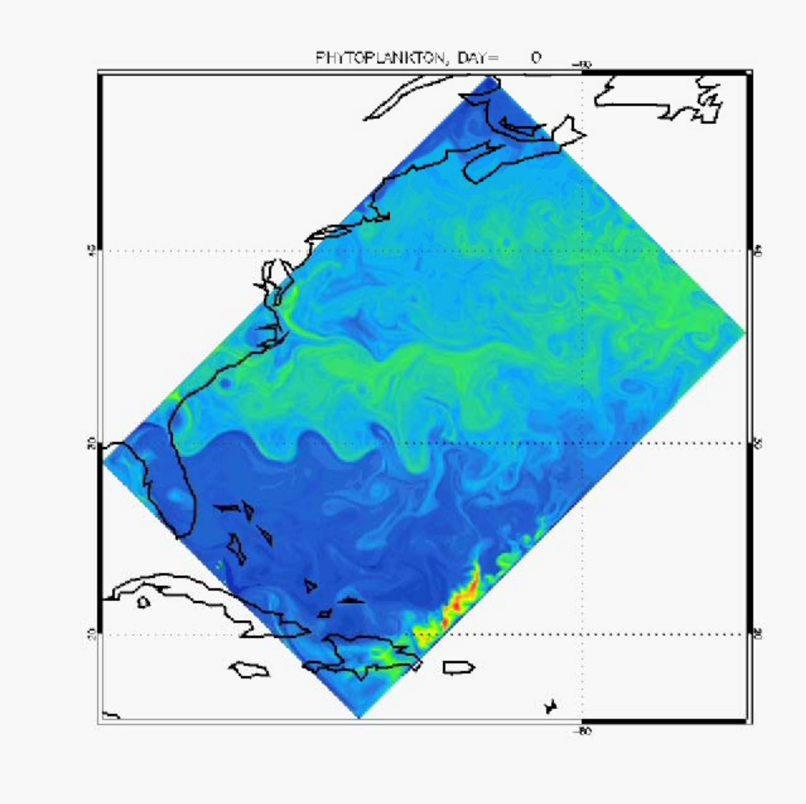


Ever feasible ... ??

Thank you

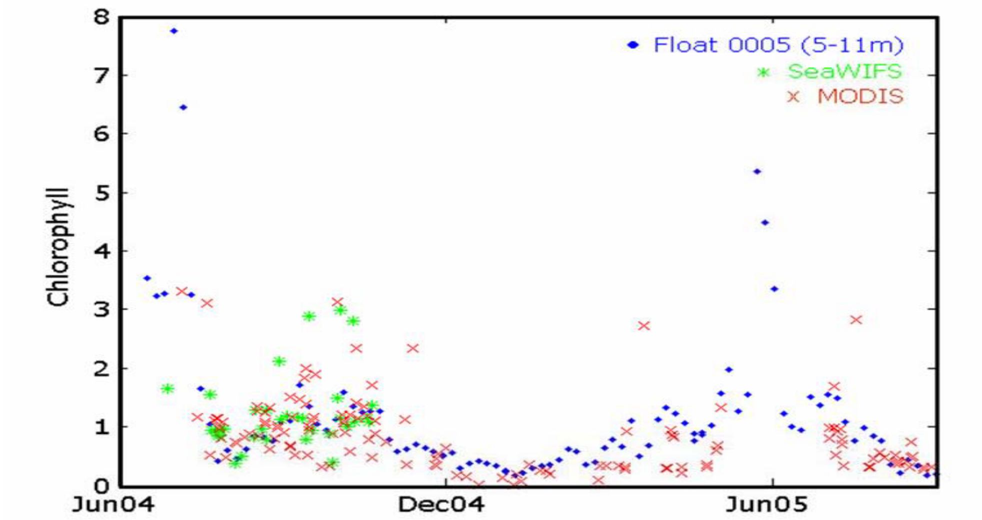
Biological-physical coupling at meso and sub-meso scales

Sub-meso scale coupling



High-resolution simulation (1/54 of a degree)
(Fom: M. Lévy, LOCEAN-IPSL, and K. Takahashi, ESC)

Timing, duration of phytoplankton blooms

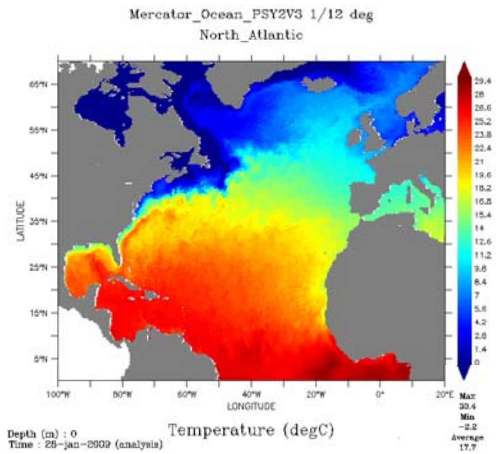


From: Taylor et al., poster at the Ocean Optics conference 2006, Montreal. Surface chlorophyll concentration in the North Atlantic, as derived by a biogeochemical profiling float (blue points), onto which remote sensing data (Red MODIS, Green SeaWiFS) extracted along the track of the profiling float are superimposed. In spring 2005 (late May, early June), satellite data from the current LEO missions were unable to detect the blooming event in this area

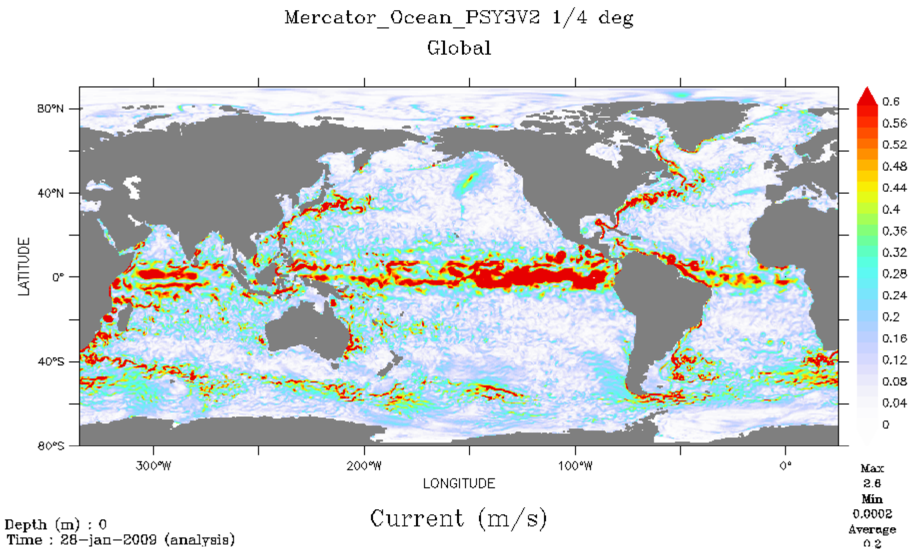
The need is to get at least one good clear-sky observation per day

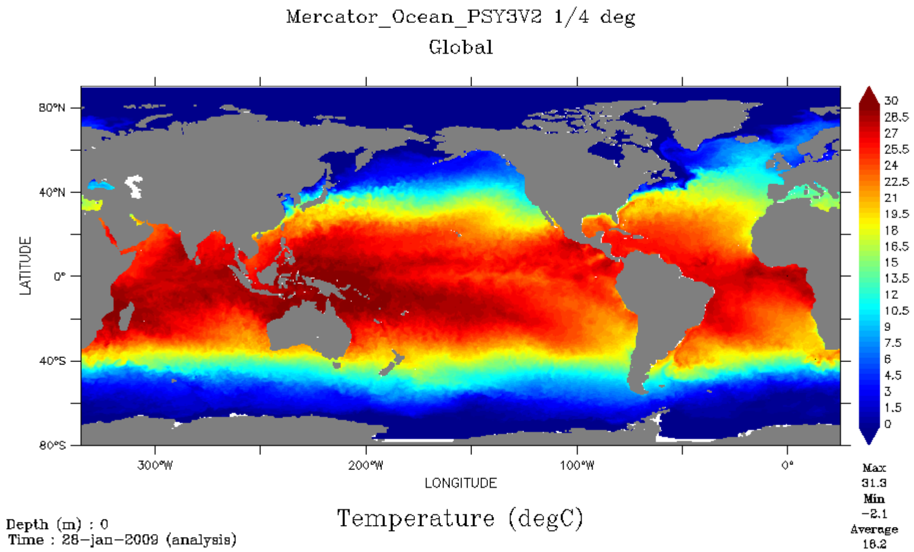
Data assimilation in
Coupled physical-biological models

Providing forecasts of ocean state (SST, currents, waves, ..) at higher and higher spatial resolution. Improve reliability and domain of these forecasts (physics → biology, open ocean → coastal domain)



- ○ Mercator-OCEAN: global forecasts at ¼ degree, data assimilation: SST, SSH
- ○ Operational services
- ○ Transition towards « MyOcean « (GMES Marine Core Services)



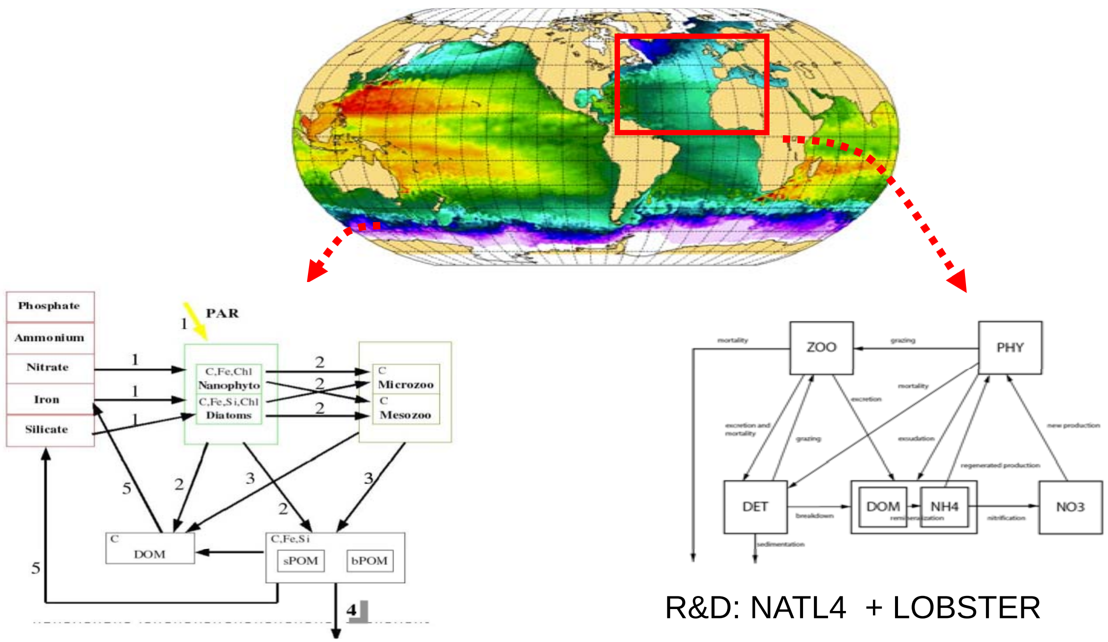


From: P. Brasseur CNRS-LEGI, Grenoble, E. Dombrowski, Mercator, Toulouse

Data assimilation in
Coupled physical-biological models

Current limitations:
Spatial resolution, data frequency for assimilation, inadaptation of assimilation schemes for incorporation of biogeochemistry

Needed evolutions:
- ○ Improving ocean-atmosphere coupling (air-sea interface)
- ○ Extension to the coastal domain
- ○ Adaptation of assimilation schemes to incorporate biogeochemistrv



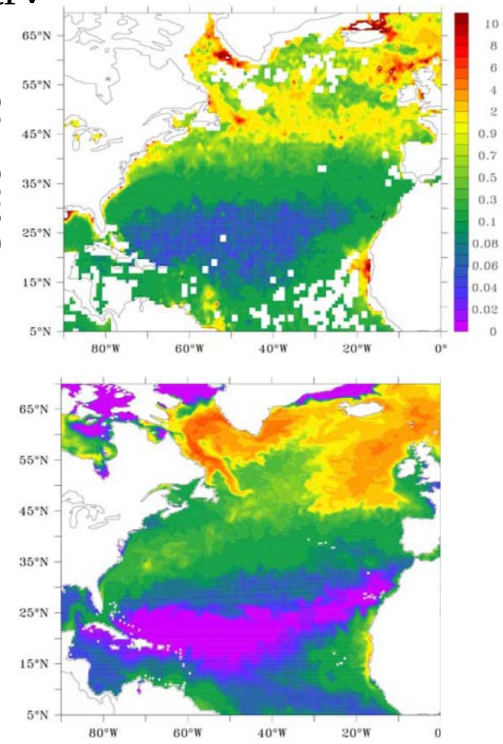
Demo: ORCA025 + PISCES

R&D: NATL4 + LOBSTER

Source: P. Brasseur CNRS-LEGI, Grenoble

Satellite

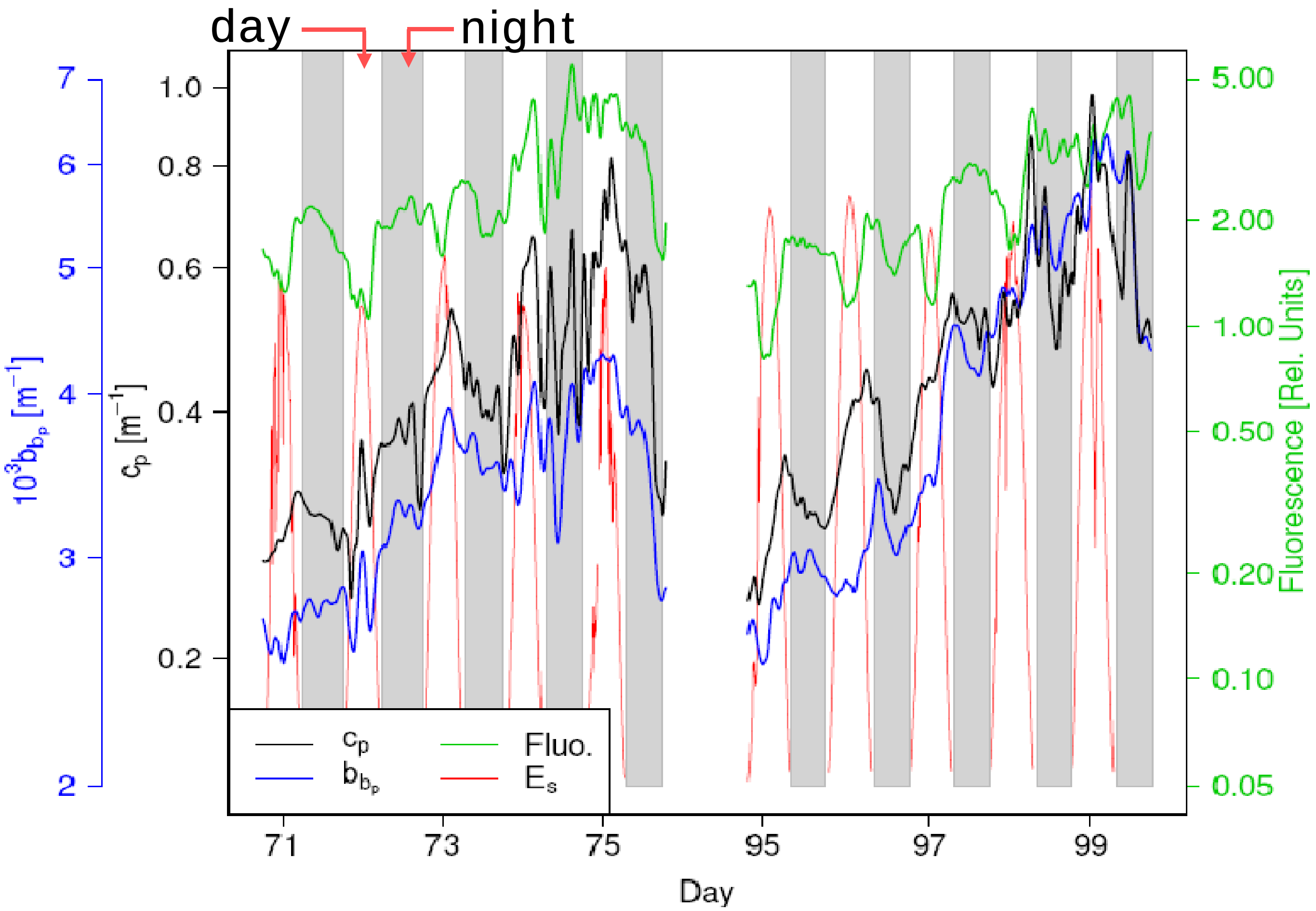
Nemo-Lobster



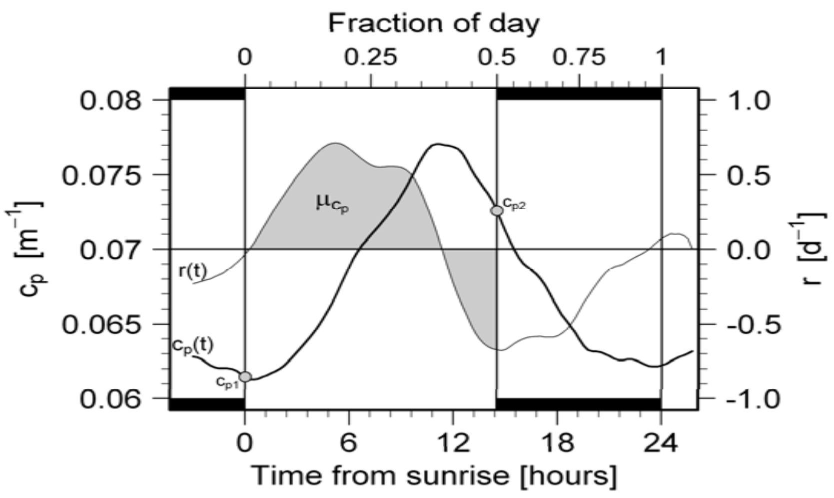
Diurnal cycles of ocean properties

The daily cycle of some properties becomes accessible

Example: the beam attenuation coefficient of particles ($c_p(660)$), as measured at the BOUSSOLE site in the Mediterranean (a few days during the 2007 spring phytoplankton bloom). $c_p(660)$ is a proxy of the particle load

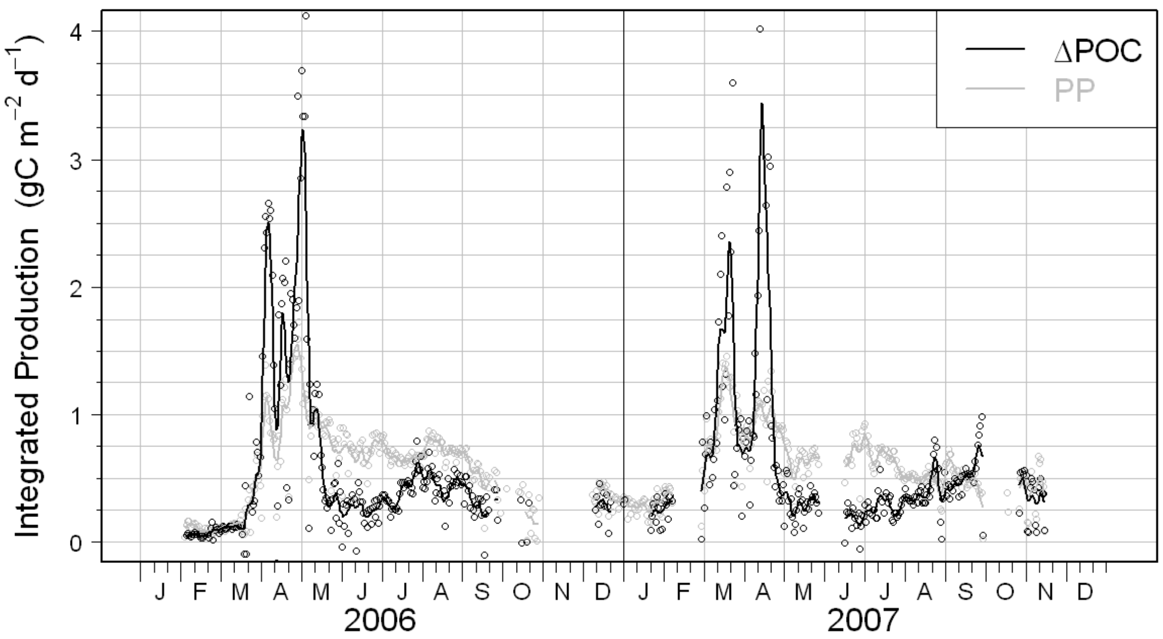


Diurnal cycles of ocean properties



Possible to go from Δc_p to ΔPOC.
After integration over the productive layer, one gets an estimate of "primary production"

From Gernez, Antoine and Huot, L&O, accepted



Can be potentially used to derive ocean primary production

Sediment transport in coastal areas

Fluxes of sediments to the ocean

$$Q \times MES \times POC_{ter}/MES(\%)$$

Flow

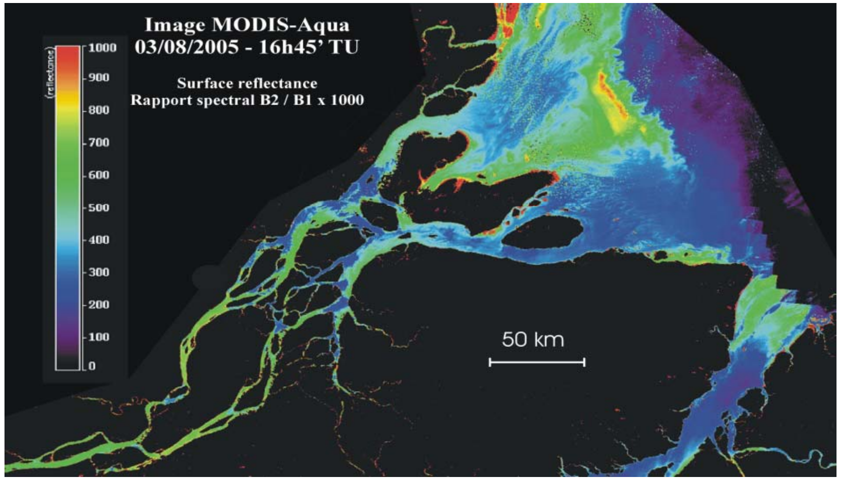
- In situ measurements
- Hydrodynamic models

Suspended matter concentration

- Ponctual measurements
- Remote sensing

POC_{ter} into susp. matter

- in situ measurements
- Remote sensing ?

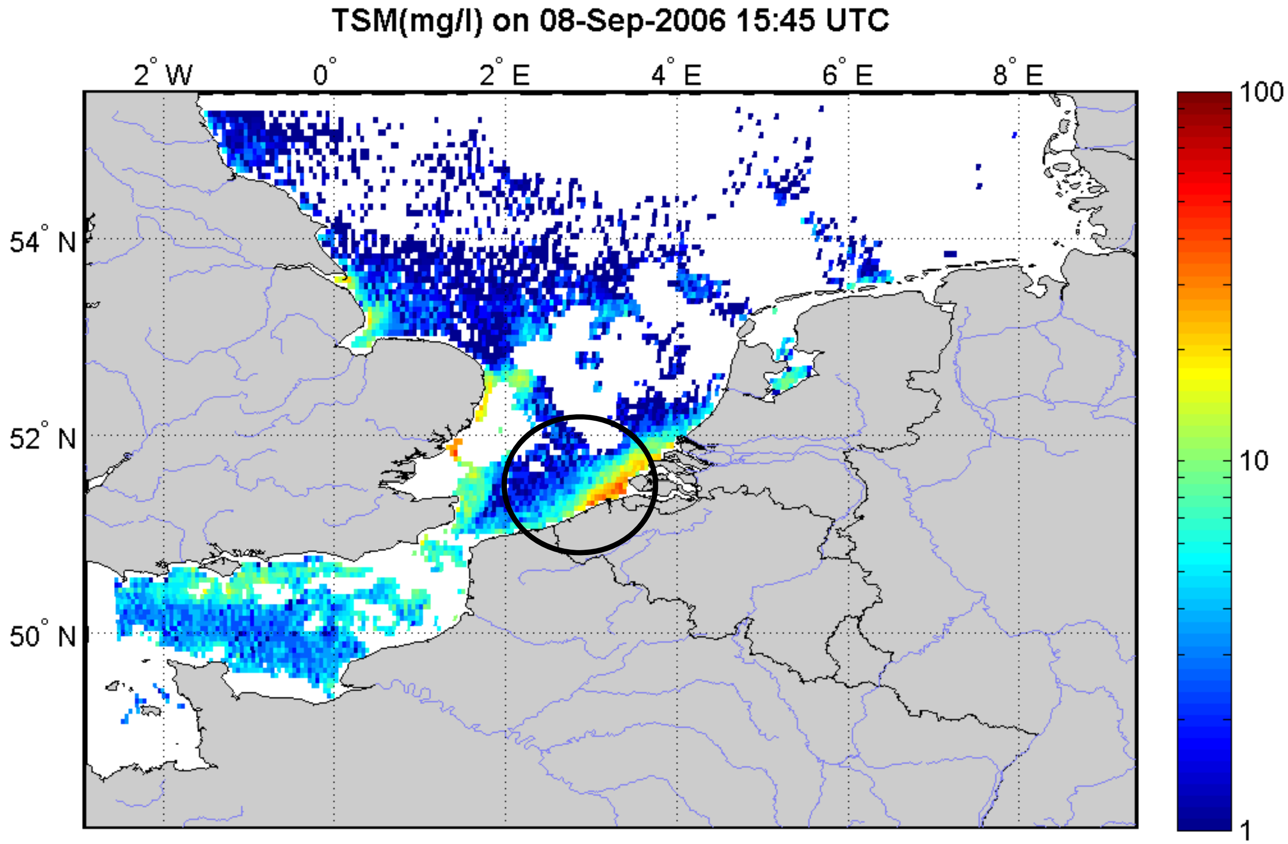


← Suspended matter concentration over the mouth of the Amazon river

Source: D. Doxaran

Sediment transport in coastal areas:

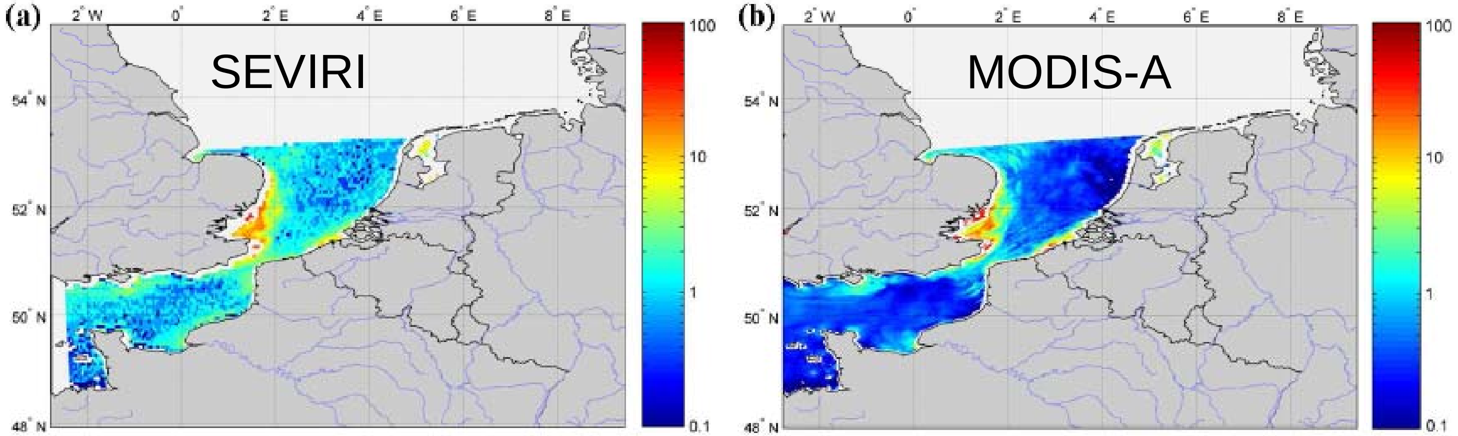
A test study using SEVIRI on MSG



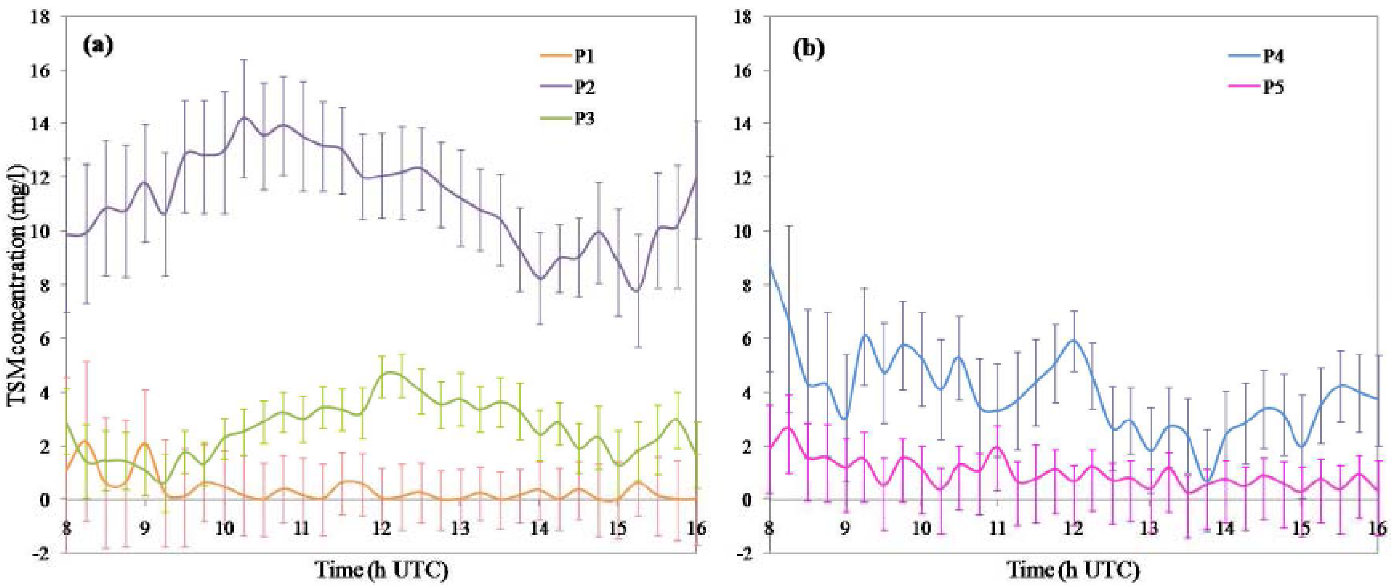
Source: K. Ruddick & G. Neukermans, MUUM

Sediment transport in coastal areas

An example using SEVIRI on MSG (Neukermans et al., 2009, Optics Express, 17(16))

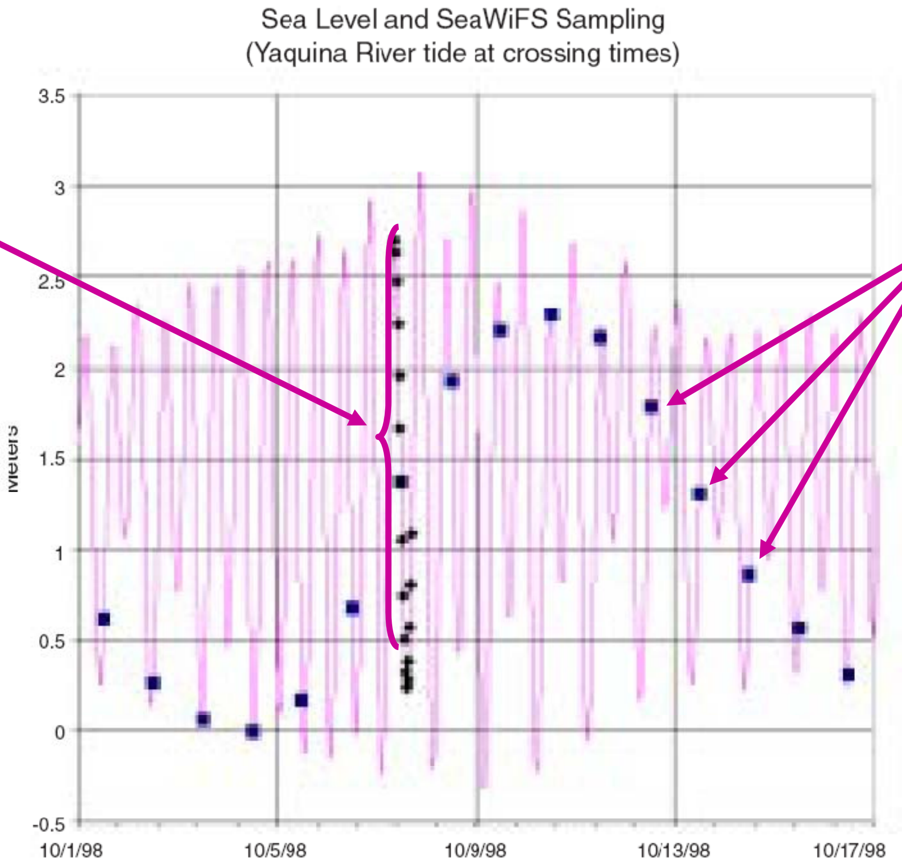


Time series of TSM concentration over a clear day, at two coastal stations



Tidal effects in the coastal environment

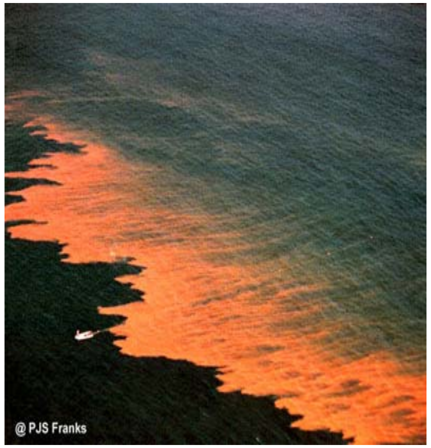
« GEO sampling »



« LEO sampling » needs 2 weeks to sample a full tidal cycle

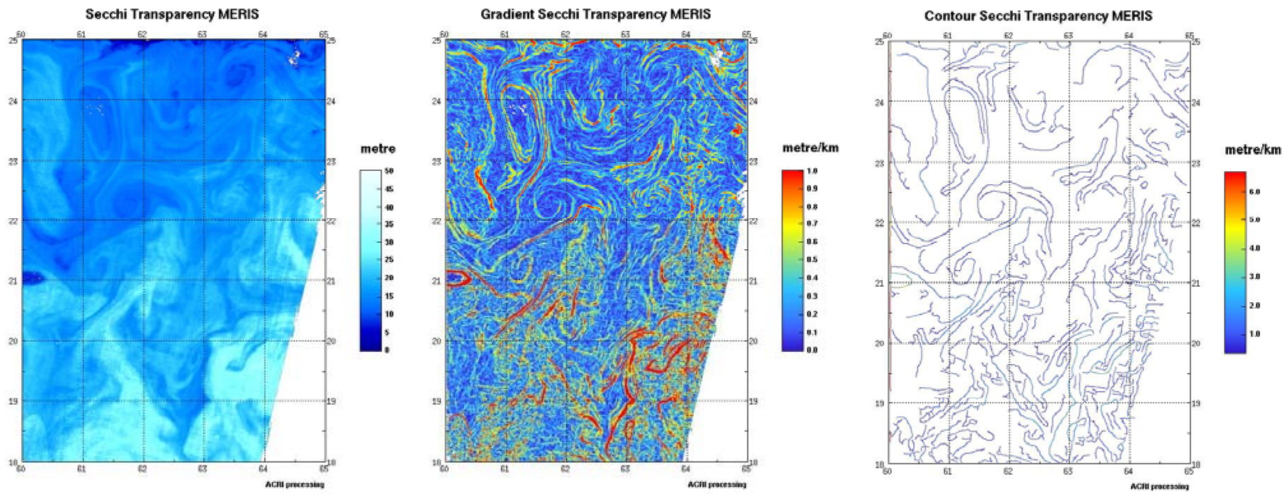
From *Esaias W.E. and C.W. Brown*, SEI fact sheet, NASA/NOAA, Dec. 1998. Example of the Yaquina river, Oregon, US

Operational services in the coastal zones



HABs

Such services exist as demonstration studies.
Truly operational services are rare, however, because the availability of LEO observations is insufficient
→ Very high potential of the GEO observations

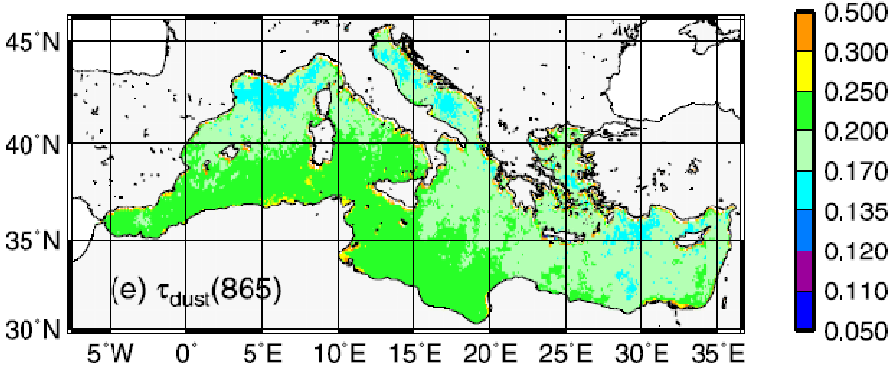


Front detection

Images courtesy, ACRI-st

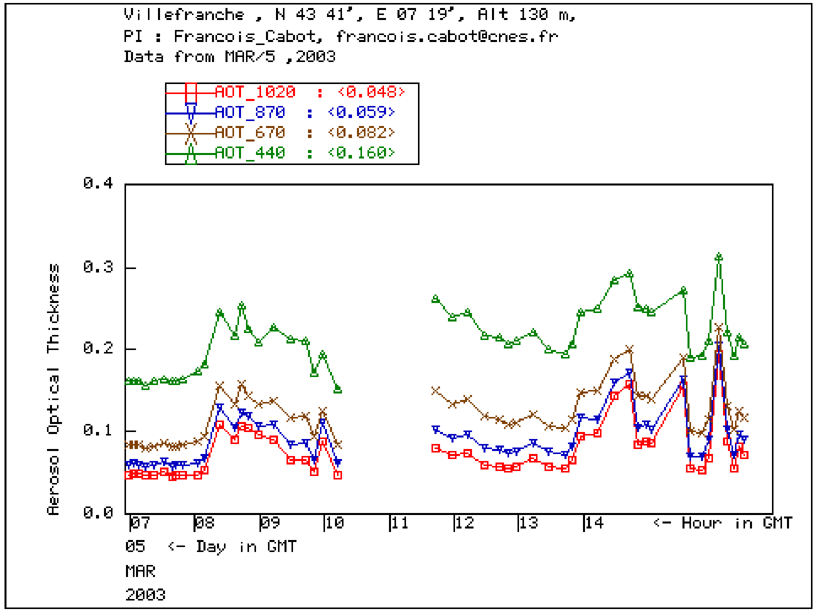
The quality / reliability of these services is, again, much dependent on the significant improvements we'll be able to bring to ocean color interpretation in optically-complex waters

Study / monitoring of aerosols



Typical average description from LEO satellites

Smoke plume, as an example of a dynamic feature badly sampled by LEO observations



Daily variability at an AERONET site

- Significant step to study dynamic aerosols (dusts, smokes, volcanic)
- Better climatological representation of this rapidly evolving component of the atmosphere system

Diurnal cycles of ocean properties

Foreseeable difficulties:

- b_{bp} is retrievable from space, but not c_p (at least for the moment)

- Different inherent optical properties (IOPs) may have different cycles (b_{bp}, c_p, etc…)

- Do the cycles in IOPs translate as cycles in AOPs (*e.g.*, nL_w's) $R \sim f\, b_b/a$

- In case a cycle exists in AOPs, is it still exploitable when atmospheric corrections errors are considered?

- Over what portion of a day can we reasonably envisage to exploit the signal?

- Are *in situ* measurements of cycles exempt of artificial diurnal variability? (*e.g.*, effect of the acceptance angle of transmissometers)

Blooms and HABs in coastal zones

• The potential is high to follow episodic blooms, by qualitatively mapping “bright areas” or identifying spectral features or looking at anomalies w.r.t. climatologies…

• Difficulties are still enormous, however.

• Mostly because atmospheric correction in coastal zones is still poorly performed.

• This is where the major effort should be placed (and this is valid for both LEO & GEO satellites)

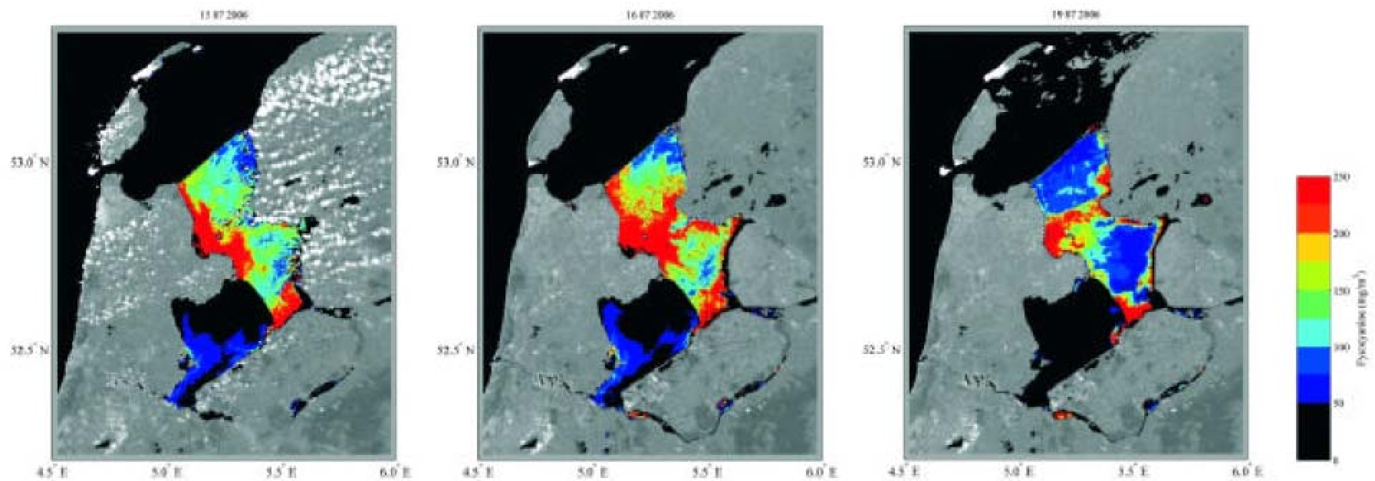


Fig. 1. Spatial distribution of the phycocyanin pigment in the Netherlands eutrophic Lake IJsselmeer (courtesy of Stefan Simis). Phycocyanin is associated with the presence of cyanobacteria such as Aphanizomenon flos-aqua *and* Microcystis *sp. Those results were obained using the algorithm from Simis et al. (2007) applied to imagery from the European sensor MERIS (Full resolution), collected over three days during the July 2006 heatwave. This short time series illustrates the potential of ocean colour remote sensing for monitoring with great spatial detail the temporal evolution of highly dynamic phytoplankton blooms.* Reference: S.G.H. Simis, et al., Remote Sensing of Environment 2007, 106: 414-427.

Areas where we need more work

• Atmospheric corrections (open ocean and coastal zones)
  Generic difficulties of atmospheric correction of ocean color observation, plus some specific aspects (e.g., backscattering geometry)

• Diurnal cycles of IOPs and AOPs

• Radiative transfer for low solar elevations and grazing observation angles

• Calibration / validation (including vicarious calibration)

• Cloud “masks”

• Exploitation of the temporal / spatial coherency of the oceanic structures under observation by a GEO ocean color sensor

…

OCAPI science team (June 2010)

Name	Laboratory / institution / Country	Title	Main interest / role in the OCAPI science team
David ANTOINE	Laboratoire d'Océanographie de Villefranche, **LOV**, Villefranche sur mer, FRANCE (marine optics and remote sensing team). http://www.obs-vlfr.fr/LOV/OMT	Dr.	Project PI, diurnal cycles, primary production modelling, atmospheric corrections, biogeochemical modelling
Hervé CLAUSTRE		Dr.	Diurnal cycles of ocean properties
André MOREL		Emeritus Pr.	Expertise
David DOXARAN		Dr.	Sediment transport in river plumes
Fabrizio D'ORTENZIO		Dr.	Diurnal cycles, physical-biological coupling
Malik CHAMI		Dr.	Atmospheric corrections, Sediment transport in river plumes
Annick BRICAUD		Dr.	Diurnal cycles of ocean properties
Marcel BABIN		Dr.	Remote sensing of highly dynamic phytoplankton blooms in coastal waters.
Marina LEVY, Francesco D'OVIDIO	Laboratoire d'Océanographie et du Climat: Expérimentations et approches numériques (**LOCEAN**), Paris, FRANCE http://www.locean-ipsl.upmc.fr/	Dr.	Physical-biological coupling at sub-meso scale
Cyril MOULIN	Laboratoire des Sciences du Climat et de l'Environnement (**LSCE**), Gif-sur-Yvette, FRANCE http://www.lsce.ipsl.fr/	Dr.	Phytoplankton functional type (PFT) determination , data assimilation into coupled biological-physical models
Hubert LOISEL,	Laboratoire d'Océanologie et de Géosciences (**LOG**), Wimereux, FRANCE http://log.univ-littoral.fr/	Pr.	Marine optics & bio-optics, bio-optical algorithms, coastal applications & monitoring
Séverine ALVAIN		Dr.	PFT determination
Pierre BRASSEUR	Laboratoire des Ecoulements Géophysiques et Industriels (**LEGI**), Grenoble, FRANCE / **MERCATOR** group http://www.legi.inpg.fr/	Dr.	Data assimilation into coupled biological-physical models for research and operational applications
Eric DOMBROWSKY	**MERCATOR** Ocean, FRANCE http://www.mercator-ocean.fr/	Dr.	Data assimilation into coupled biological-physical models
Frédéric JOURDIN	**SHOM**, Brest , FRANCE http:// www.shom.fr	Dr.	Coastal environment monitoring applications
Francis GOHIN	**IFREMER**, Brest, FRANCE http://www.ifremer.fr		Coastal environment monitoring applications, validation is coastal waters, coupled models in the coastal environment
Odile FANTON D'ANDON	**ACRI-st**, Sophia Antipolis, FRANCE http://www.acri-st.fr/	Dr., Dir.	Coastal environment monitoring applications Ground segment development, cal/val activities
Constant MAZERAN		Dr.	
Antoine MANGIN		Dr., Sci. Dir.	

OCAPI science team (June 2010), continued

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<tr><td>Yu-Hwan AHN</td><td>Korean Ocean Research & Development Institute (KORDI), http://www.kordi.re.kr/english/bin/main.asp</td><td>Dr.</td><td>Cal/val activities, HABs, bio-optical algorithms, coastal environment monitoring applications</td></tr>
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<tr><td>Stéphane MARITORENA</td><td rowspan="2">Univ. California at Santa Barbara (UCSB), ICESS, USA http://www.icess.ucsb.edu/</td><td>Dr.</td><td rowspan="2">IOP algorithms, primary production and coupling with physics, diel variability</td></tr>
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<tr><td>Antonio MANNINO</td><td>NASA / GSFC, USA</td><td>Dr.</td><td rowspan="2">Liaison with the GeoCAPE science team</td></tr>
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