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The role of satellite observations and perspectives for the next decade

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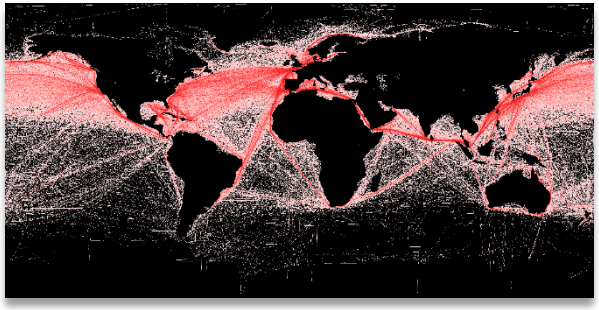
Satellites

- Satellite is a recognized element of the ocean observing system.

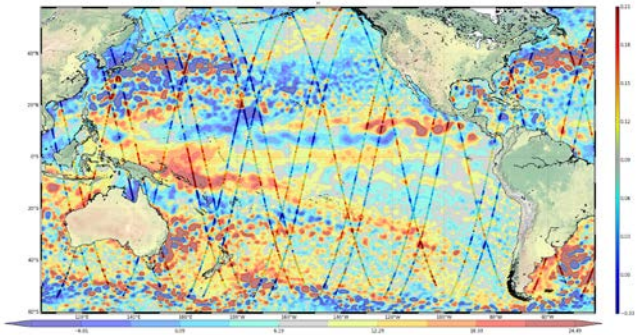
- Deep ocea warming, steric effect repartition (GRACE)
- Decadal ion of PDO & ENSO
- Global ma dies
- Iceberg tracki
- *Complex interactio cesses er masses (SST, OC vs ARGO)*
- *Ship routing*
- *Ocean bottom geodesy*
- *Hurricane forecast impr ontent through altimetry)*
- *Wind- eddies coupli ometr try)*
- *Subduction an otropical and m*
- *Tide mod ent (altimetry), importan ion on continental shelves e la marée su eaux*
- Internal w es
- Etc…

Satellite observation is

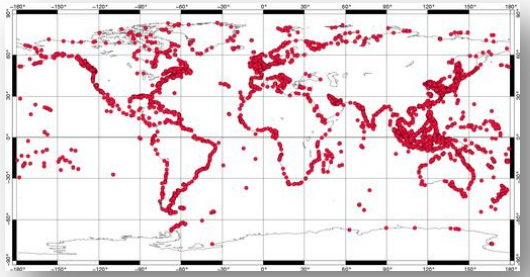
- Global



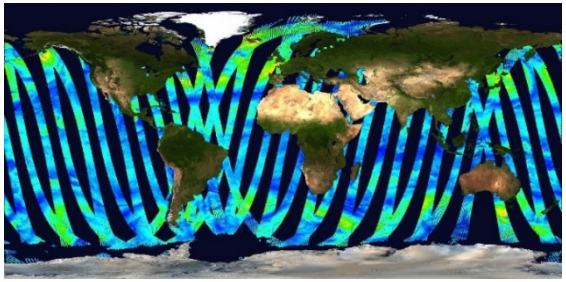
vs



- Homogeneous

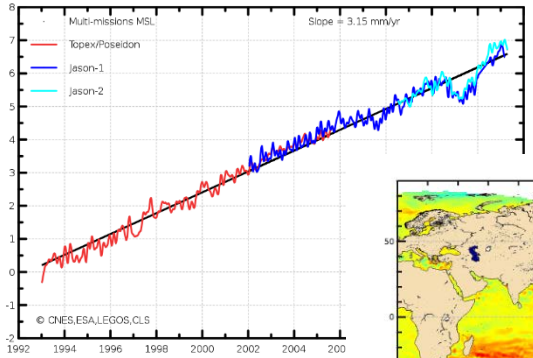


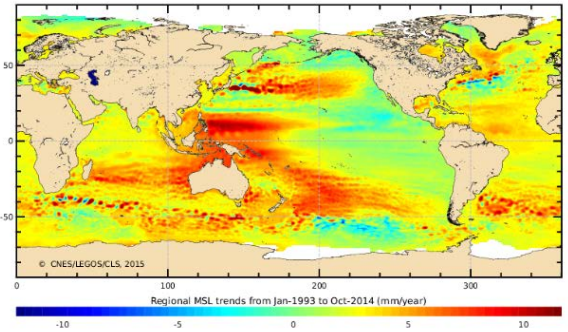
vs



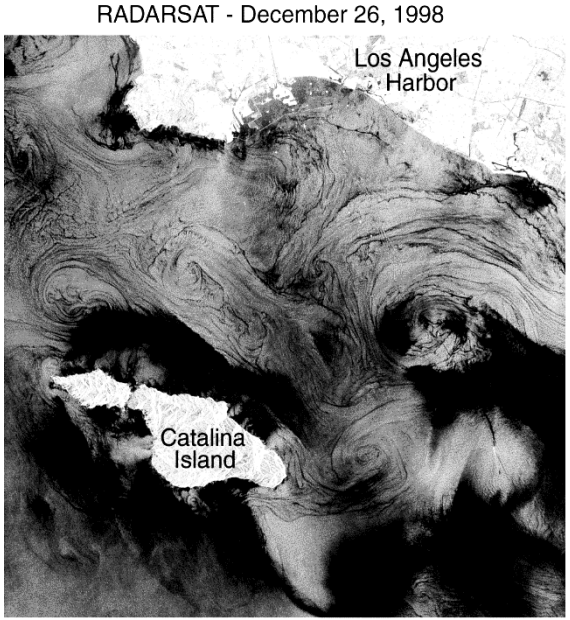
…but also

- Repetitive / long term

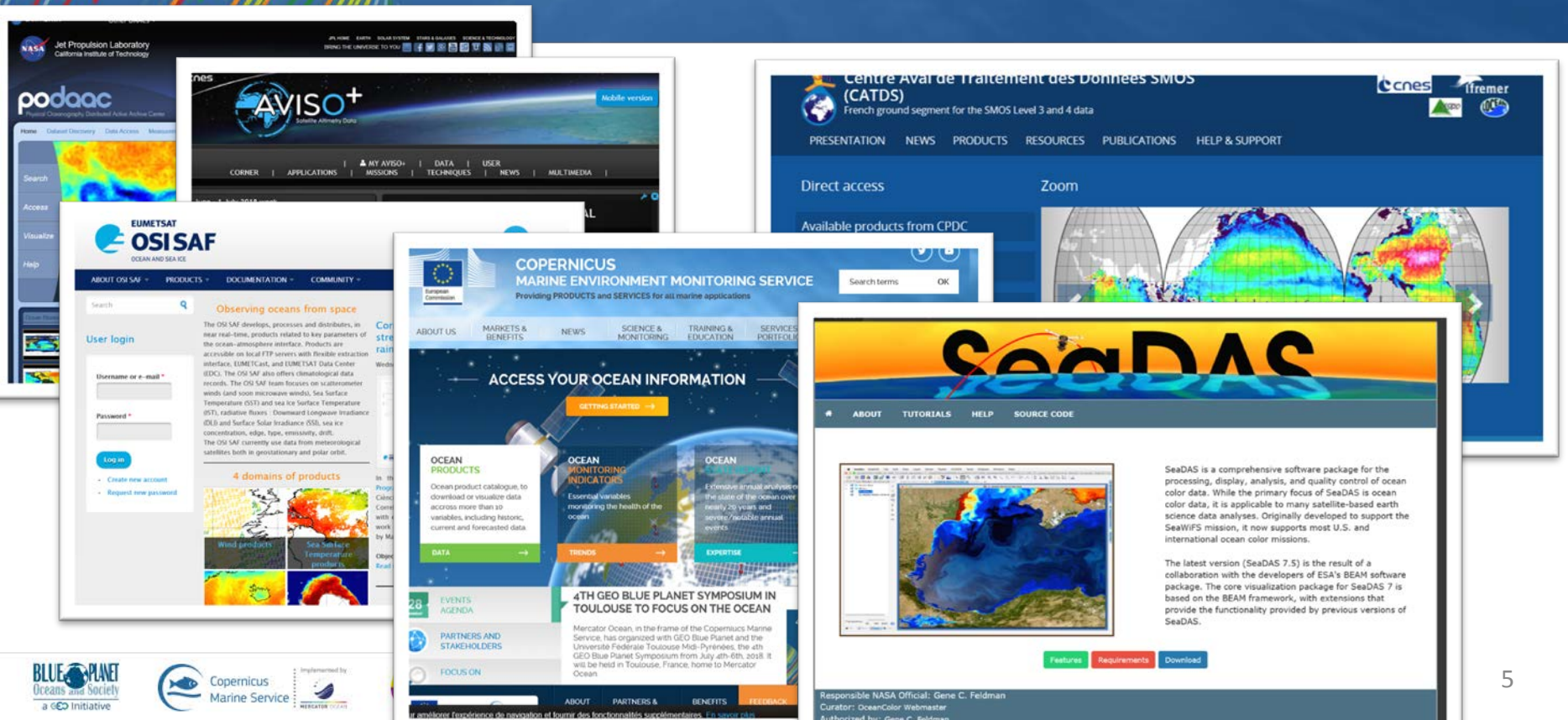




- Wide field / high resolution



And in most cases quite accessible



BLUE PLANET Oceans and Society a GEO Initiative

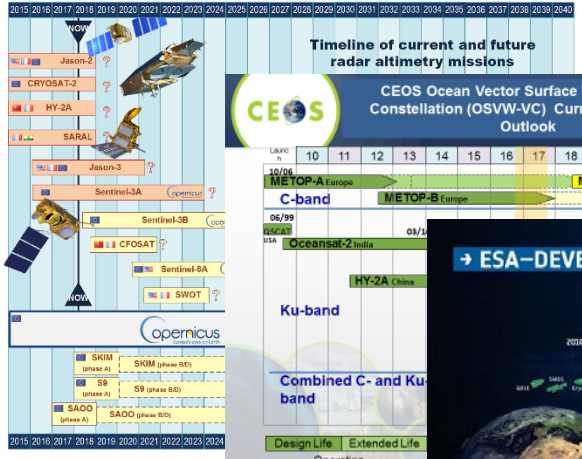
Copernicus Marine Service

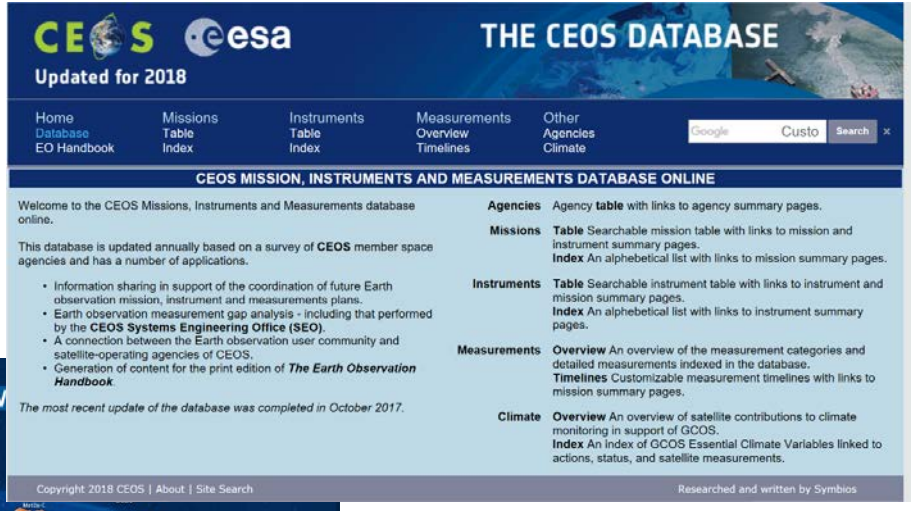
Key satellite-based ocean parameters

- Surface parameters
  - Sea surface temperature
  - Sea Surface salinity
  - Ocean color
- Sea surface topography
  - Tides
  - Ocean circulation
  - Sea level rise
  - Bathymetry
- « Sea state » parameters
  - Ocean Surface Wind
  - Waves
  - Surface Currents
- Gravity
- Sea ice

Current status: rich context

- past/current/approved: 97 records



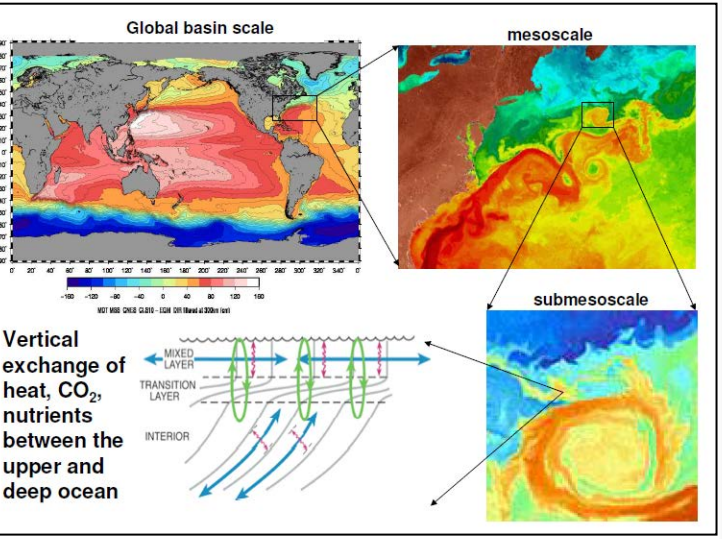


- Operational ocean monitoring from space is a reality!

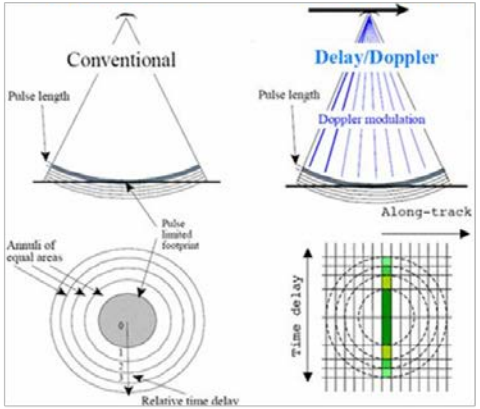
Challenges

- Evolution of operational missions
  - Altimetry: from nadir to swath
  - Enhancing space/time coverage & resolution: geo ocean color
- New measurements
  - Ocean surface currents
  - Sounding ocean color
- Continuity (or enhanced continuity)
  - Salinity
  - Gravimetry

Altimetry evolution



Conventional : Jason - Saral

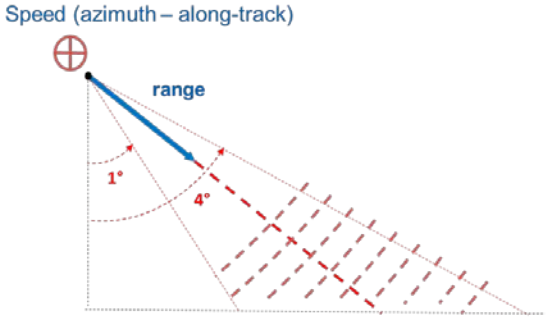


Res: ~10 km diam.
Posting: ~300 m

SAR alongtrack – CR2, Sentinel-3

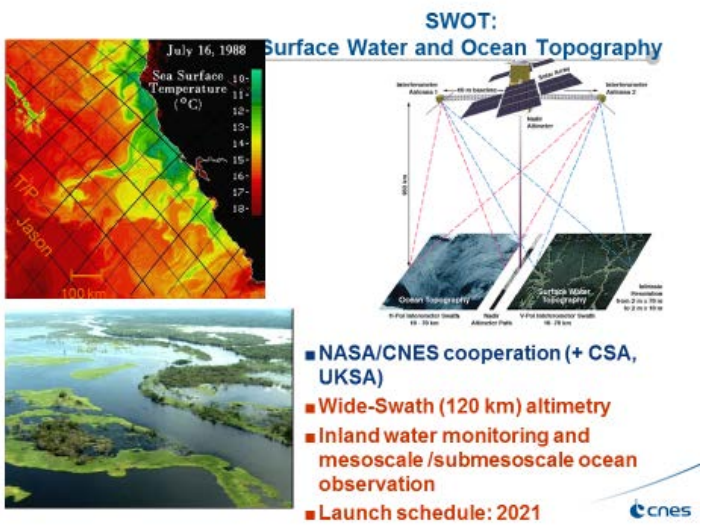
Res:
300 m along-track
~10 km cross-track
Posting: 300 m

SAR interferometry – SWOT



LR ocean data :
Res: 500 m along-track x 500 m cross-track
Posting: 250 m along-track x 250 m cross-track
2D SSH measurements

SWOT mission: wide-swath altimetry



2D data provided in swath
Latitude, Longitude
Surface type
SSH, σ0, SWH
Associated uncertainties, quality indicators
Ice and rain flags
Corrections (geophysical and calibration)
Geophysical parameters (MSS, tides, …)

2D data provided in swath
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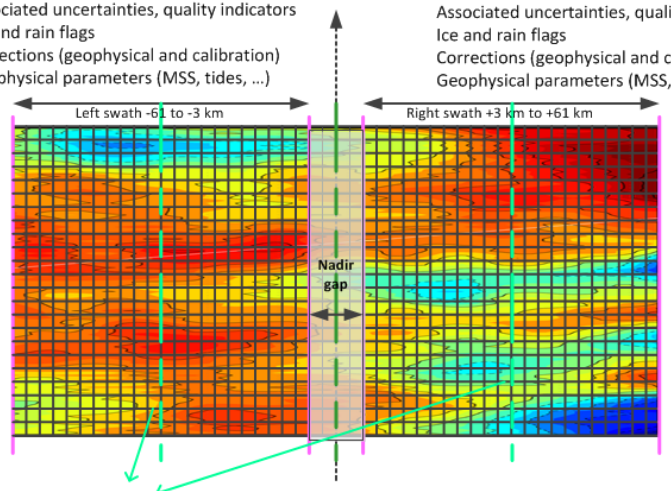
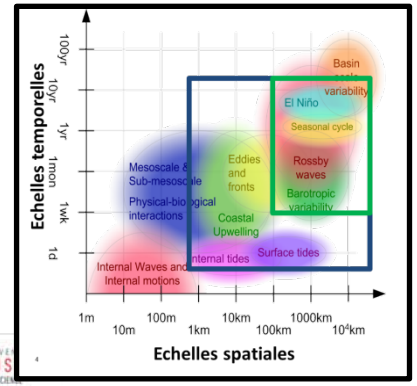


1 value per swath
Radiometer BT measurement in their geometry (at +2.27° / -2.43 TBC in the swath)
Other radiometer parameters

1 value at nadir along track
Time tag
Orbit data
Nadir altimeter measurement (Jason like product in a separate file)

Altimetry - current Constellation URD

- « Next 15 years of altimetry », 2009: Constellation User Requirement Documents + Assmanhausen OST-VC meeting
  - Reference mission + complementing
    - Nadir altimetry only (swath altimetry mentionned)
    - Structured the current constellation (reference mission Jason + SARAL/S3/Hy-2/Cryosat)
    - Standards for products



REQ-6.2.1.a The constellation shall allow sampling the earth surface with the following time and space characteristics delivering measurement of the following accuracy:

Application	Parameter	Spatial Resolution	Time Resolution	Latency	Accuracy
Mesoscale variability	Sea surface topography	25-50 km	5 days	3 days	2-4 cm

Table 3 – Sampling requirements

TARG-6.2.1.b For high resolution altimetry applications the constellation will allow to sample the earth with the following time and space characteristics:

Application	Parameter	Spatial Resolution	Time Resolution	Latency	Accuracy
Sub- mesoscale variability and Coastal features	Sea surface topography	10 km	1-2 days	1 day	1-2 cm
Tides near coasts and Topography	Tidal constants—sea surface height	10 km	> 100 visits	N/A	1-2 cm
Barotropic tides	Tidal constants—sea surface height	5 km	> 100 visits	N/A	2 cm
Non-linear tides	Tidal constants—sea surface height	5 km	> 100 visits	N/A	1 cm

Table 4 – Sampling requirements for high-accuracy applications

Update of constellation URD (CEOS – Ocean Surface Topography Virtual Constellation)

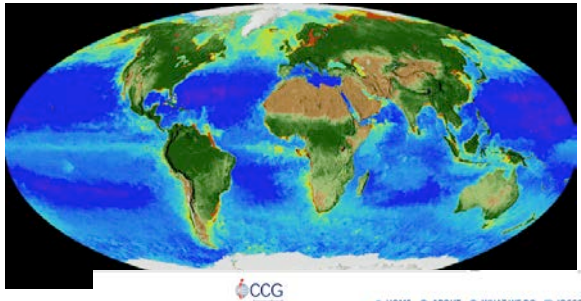
- Objective 2018-2019: prepare a new URD
  - Discussed in OST-VC meeting 2016 and 2017
  - Early works through CNES phase 0 study (mix nadir/swath, global UR analysis)
  - Coordination CNES-ESA (swath altimeter for operational oceanography => URD SAOO)
- What should be in it?
  - Analysis of user needs: systematic + exploratory
  - Swath altimetry + nadir altimetry : combined
  - Recommandation for an « operational constellation » (targets: copernicus NG, China altimetry programme)
  - Recommandation for additional science missions in complement
  - Links with other obervables

Example SAOO URD

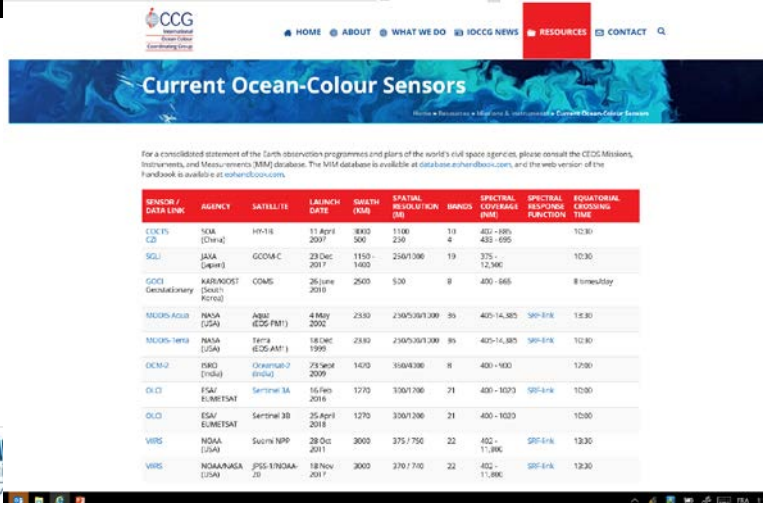
- 50 km/5 days as effective resolution
- Precision/accuracy set so that this effective resolution is met everywhere-everytime with an 80% probablility
- Identify auxilliary information needed (tides, gravity field…)
- Identify what is not considered in requirement (internal wave, submesoscale)

Ocean phenomenon	Characteristics	Priority for wide-swath altimeter	Specific requirement
Open ocean circulation	100 to 1000 km, amplitudes ~10cm or higher; time scales 30-100 days	High	The SAOO must provide a continuity to this observation (in combination with concurrent nadir altimeters). Has a major impact on the orbit choice (requires a well chosen repeat cycle or near-repeat sub-cycles).
Mesoscale eddies	Scale 50 to 500 km, amplitudes ~5 cm or more; typical time scales 5-50 days	High	Challenging in terms of coverage / revisit and error budget. Main driver for the swath interferometer technology.
Rossby waves	100 to 1000 km, amplitudes 2-10 cm typical time scales 5-100 days	High	The SAOO must provide a continuity to this observation (in combination with concurrent nadir altimeters).
Mean sea level	3 mm/yr at global scale; up to cm/yr locally.	High for the altimeter constellation as a whole. Medium for wide-swath altimeters.	Here we assume that this important objective is met by a climate-oriented mission such as Jason-CS / Sentinel-6 follow-ups. Climate-level stability may be challenging for a wide-swath interferometer.
Sub-mesoscale turbulence	~10 km; amplitudes ~ or >1cm; typical time scales ~5 days	Medium for the next generation of Copernicus missions (read: no monitoring, limited to periodic observations)	Systematic monitoring requires 3 or more SWOT-like systems with extremely low error levels. Model prediction capability not able to assimilate and forecast evolution.

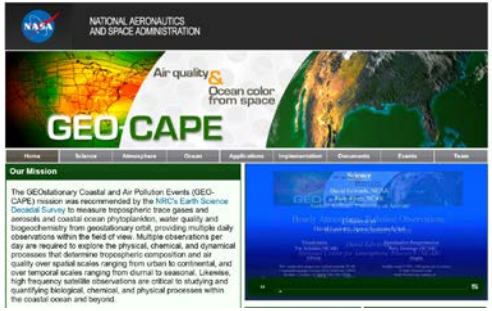
Ocean color

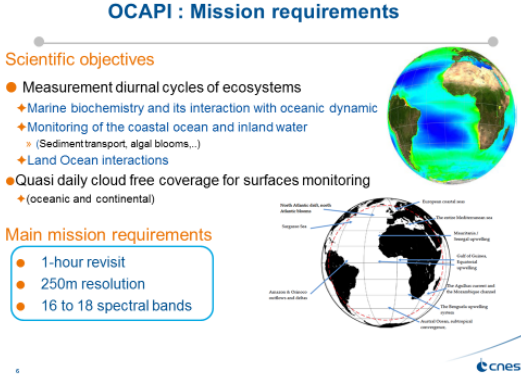


Need for more geostationary ocean color (beyond GOCI, GOCI-2)



SENSOR / DATA LINK	AGENCY	SATELLITE	LAUNCH DATE	SWATH (KM)	SPATIAL RESOLUTION (M)	BANDS	SPECTRAL COVERAGE (NM)	SPECTRAL RESPONSE FUNCTION	EQUATORIAL CROSSING TIME
COCTS CZI	SOA (China)	HY-1C	11 April 2007	8000 500	1100 250	10 4	402 - 885 433 - 695		10:30
SGLI	JAXA (Japan)	GCOM-C	23 Dec 2017	1150 - 1400	250/1000	19	375 - 12,500		10:30
GOCI GeoKompsat	KARI/KOST (South Korea)	COMS	26 June 2010	2500	500	8	400 - 865		8 times/day
MODIS-Aqua	NASA (USA)	Aqua (EOS-PM1)	4 May 2002	2330	250/500/1000	36	405-14,385	SRF-link	13:30
MODIS-Terra	NASA (USA)	Terra (EOS-AM1)	18 Dec 1999	2330	250/500/1000	36	405-14,385	SRF-link	10:30
OCM-2	ISRO (India)	Oceansat-2 (India)	23 Sept 2009	1420	360/4000	8	400 - 900		12:00
OLCI	ESA/ EUMETSAT	Sentinel 3A	16 Feb 2016	1270	300/1200	21	400 - 1020	SRF-link	10:00
OLCI	ESA/ EUMETSAT	Sentinel 3B	25 April 2018	1270	300/1200	21	400 - 1020		10:00
VIIRS	NOAA (USA)	Suomi NPP	28 Oct 2011	3000	375 / 750	22	402 - 11,800	SRF-link	13:30
VIIRS	NOAA/NASA (USA)	JPSS-1/NOAA-20	18 Nov 2017	3000	370 / 740	22	402 - 11,800	SRF-link	13:30





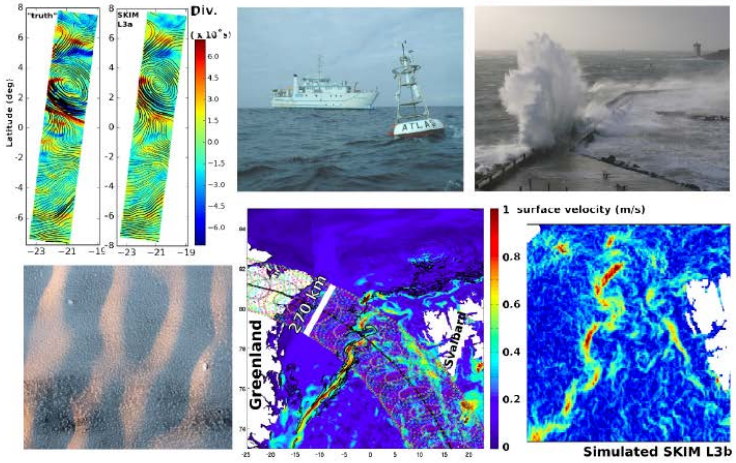
Wind, waves, currents

- Winds => Meteorological satellites
- Waves: SAR, CFOSAT 30 oct 2018 (2D spectrum)
- Currents: SKIM proposal EE9

Ocean surface currents

- Ocean surface currents can be monitored « directly »
  - SAR imagery
  - Along-track interferometry
  - Doppler scatterometry
  - Surface kinematics
- Challenging measurement
  - Many 1st order corrections (sea state)

The Surface KInematics Multiscale (SKIM) : proposal for ESA EE9



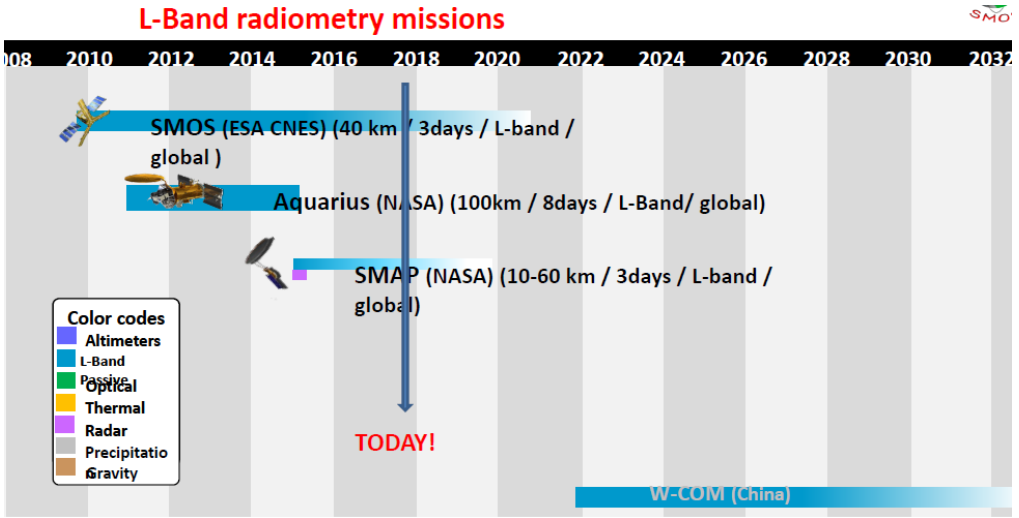
Fabrice Ardhuin (LOPS / IUEM & Ifremer)
and the SKIM team

https://www.facebook.com/SKIM4EE9 http://tinyurl.com/SKIMonRG

http://www.umr-lops.fr/Projets/Projets-actifs/SKIM

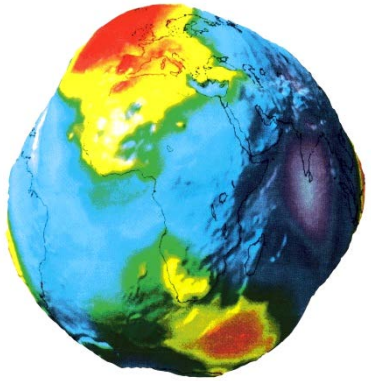
Ocean surface salinity

- L-band radiometry offer measurement of sea surface salinity
- Extremely rich measurement
- Continuity/enhancement issue



Gravity / geodesy

- GRACE – GRACE-FO
  - Earth mass balance,
  - Ice sheet, hydrology
  - Precise orbit determination
- Geodetic networks/ geodetic mission
  - Earth reference frame



Take-home message

- Ocean monitoring from space is a key element of the ocean observing system
- Global, homogeneous, revisit, wide field, space resolution, accessibility
- Very mature measurements => operational mission
- Challenges in
  - Achieving the required space/time sampling and accuracy
  - Coastal ocean
  - New observables require new technologies
- Synergy research/operational and science/engineering

Thank you !

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