Marine Applications

Dr Hayley Evers-King
Marine Applications Expert - EUMETSAT

EUMETSAT Satellite Application Course
Muscat, 20-24 March 2022

Agenda

Why LEO for the oceans?

What do we need to observe?

Basics of LEO for oceans

What are the characteristics of LEO satellites and instruments for ocean observation?

LEO missions for the oceans

Which satellites deliver which data?

Agenda

Marine application examples:

- Ocean Colour
- SST
- Altimetry

Where to get the data?

Which satellites deliver which data?

How to work with the data

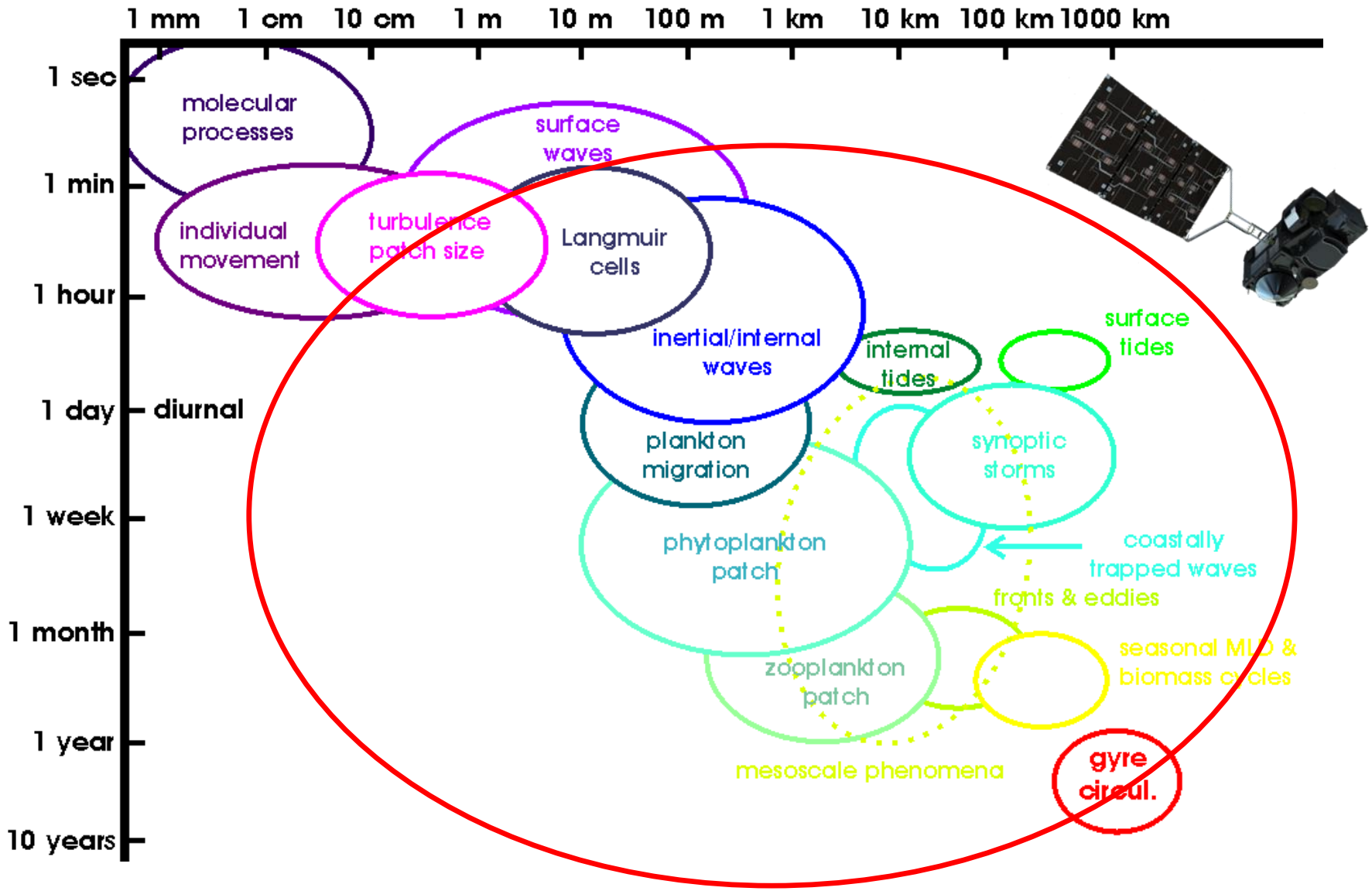
Short demonstration using SNAP

Why would we want to observe the oceans from space?

System drivers
e.g. Wind – Scatterometry, Altimetry, SAR

Physical response
e.g. Temperature - Radiometry

Biological response
e.g. Phytoplankton - Ocean colour



Why would we want to observe the oceans from space?

ALTIMETRY (& SAR)

SEA SURFACE TEMPERATURE

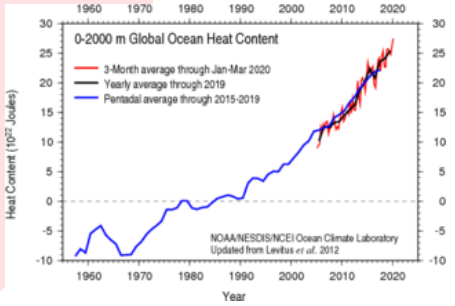
OCEAN COLOUR

Ocean currents
Weather forecasting
Storm dynamics
Maritime safety
Eddies
Thermocline

Essential Climate Variables
Climate Model Assimilation
Marine Spatial Planning
Env. Impact Assessment
Disaster response
Insurance Risk
Ocean Fronts
ENSO

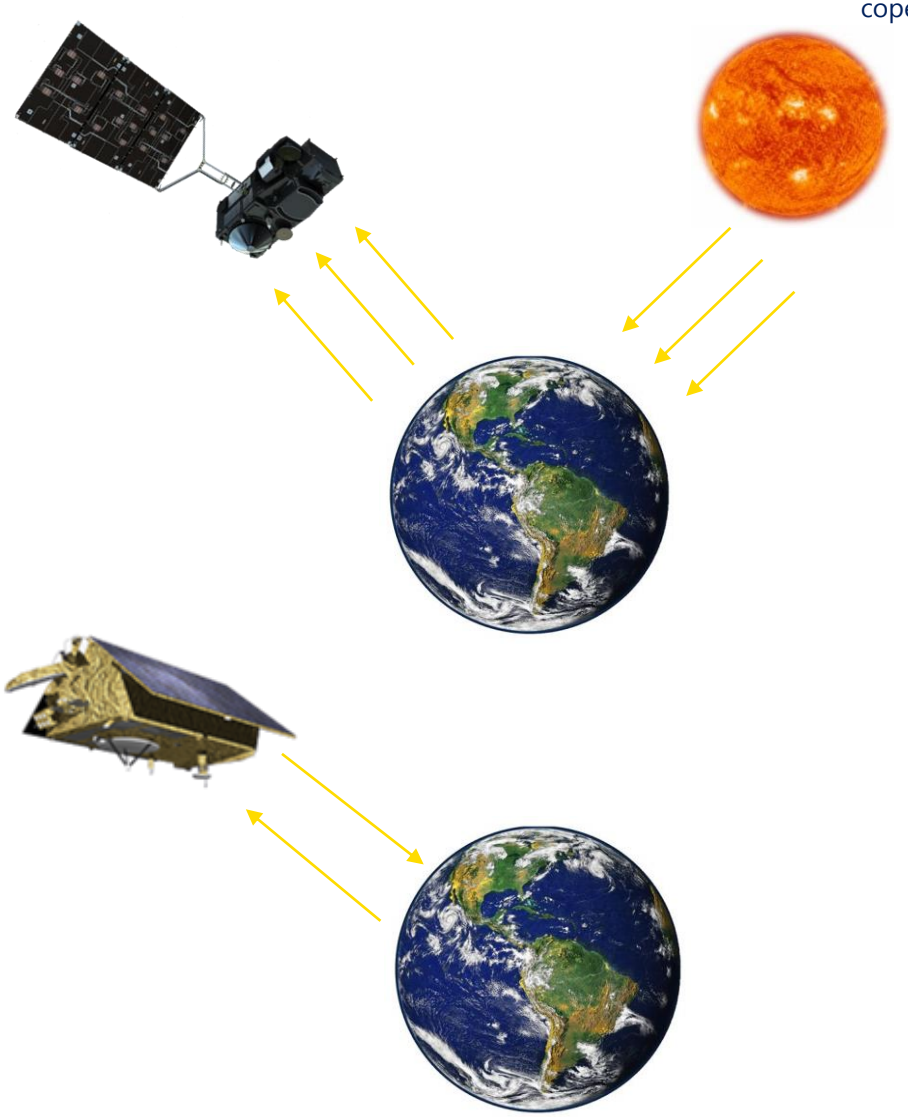
Pollutant transport
Ice detection
Oil pollution
Internal waves
Debris
Biological transport (blooms, genetics)

Fishing Zones
River plumes
Aquaculture productivity
Coral bleaching
Bio-toxins
Human health
HAB formation

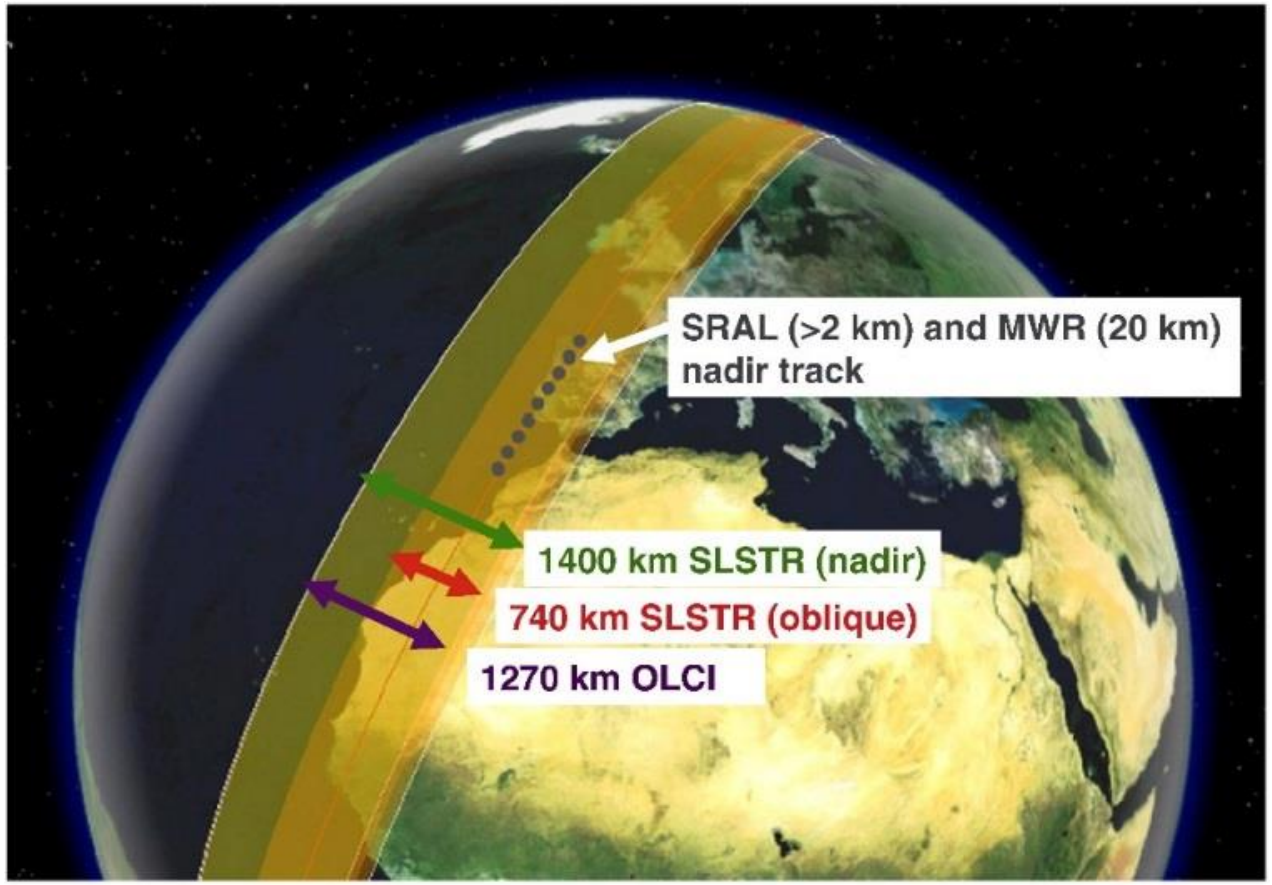


Some basic concepts about LEO for ocean applications

- Types of instrument
  - Passive
    - Detects signals emitted by the Earth
      - E.g. visible/infrared light – ocean colour, SST
  - Active
    - Sends a signal and detects a return signal
      - E.g. Radar – SAR, altimetry, scatterometry



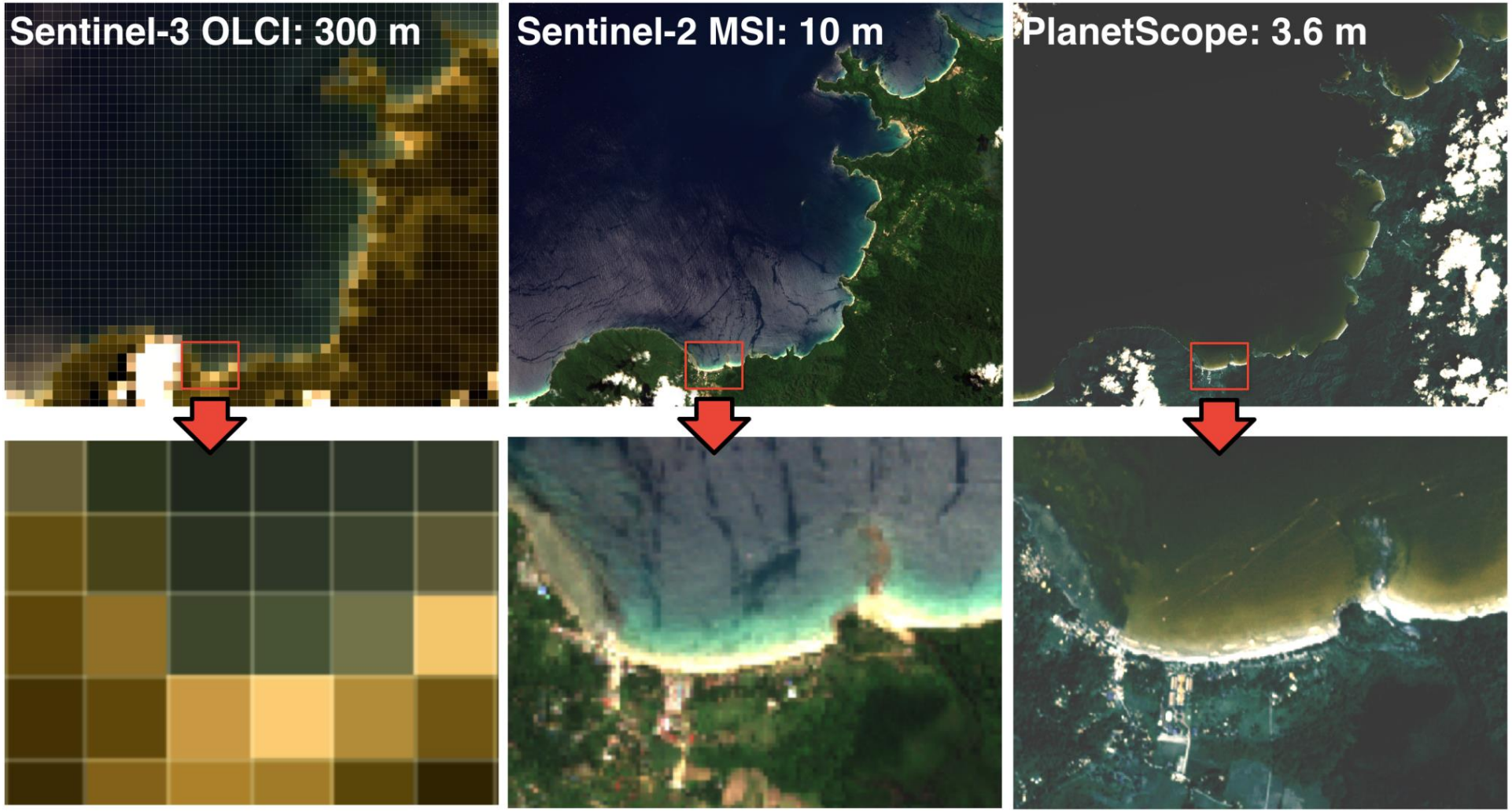
- **Resolution and revisit:** Spatial resolution



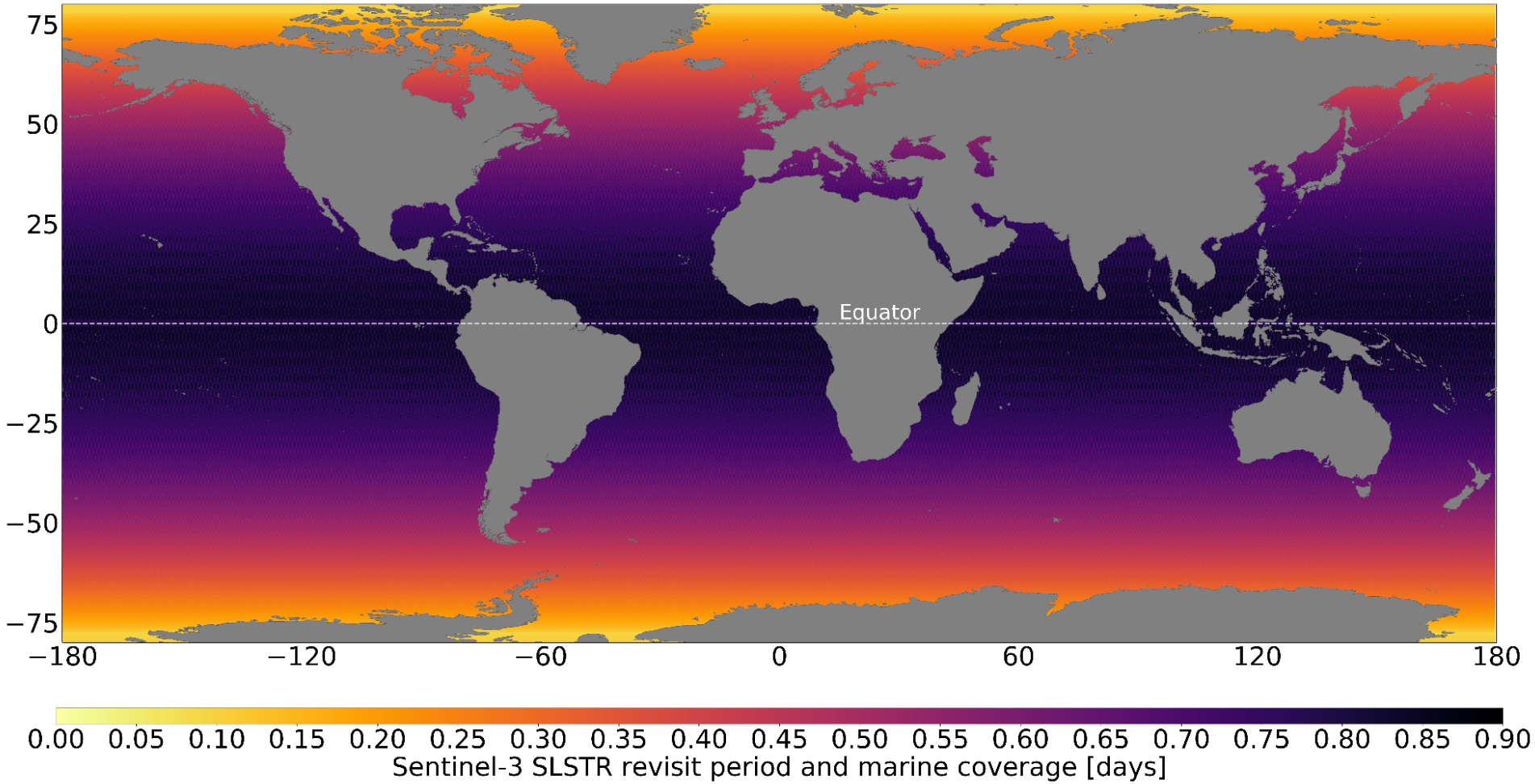
- High resolution: 10-60m (S-2, L8)
- Medium resolution: 300m – kms (S3 etc)
- Along-track: 300m
- Downstream products: 1km – degrees (see later slides)

Some basic concepts about LEO for ocean applications

- **Resolution and revisit:** Spatial resolution

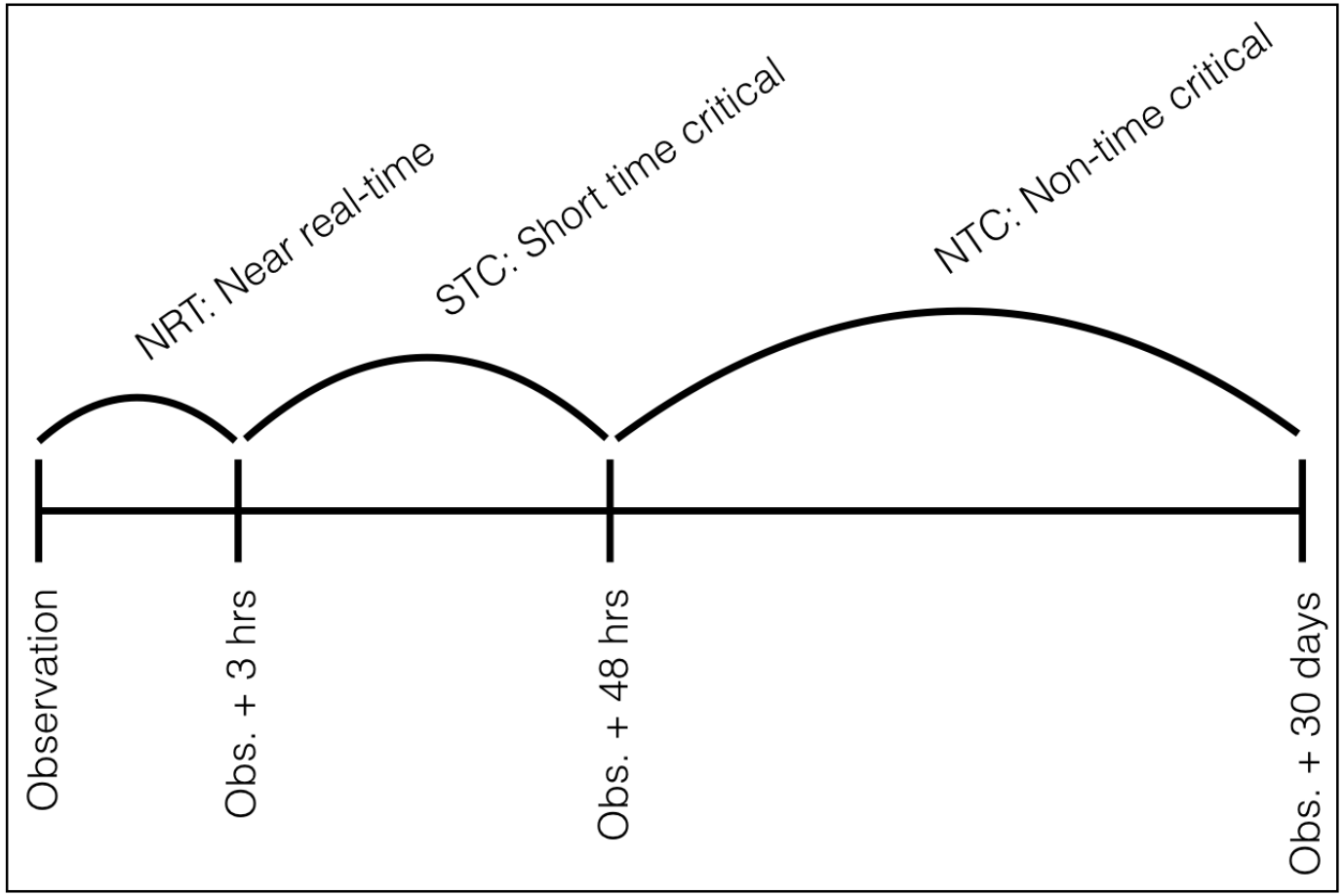


- **Resolution and revisit:** Temporal



Some basic concepts about LEO for ocean applications

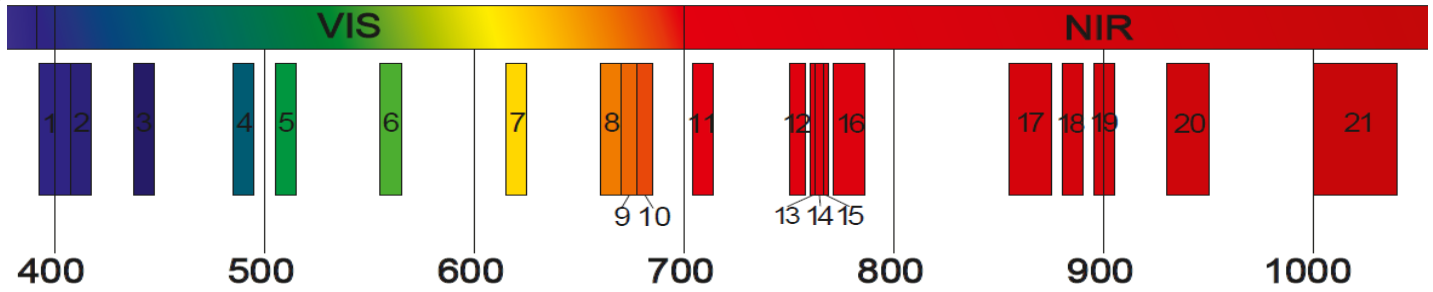
- **Resolution and revisit:** Temporal



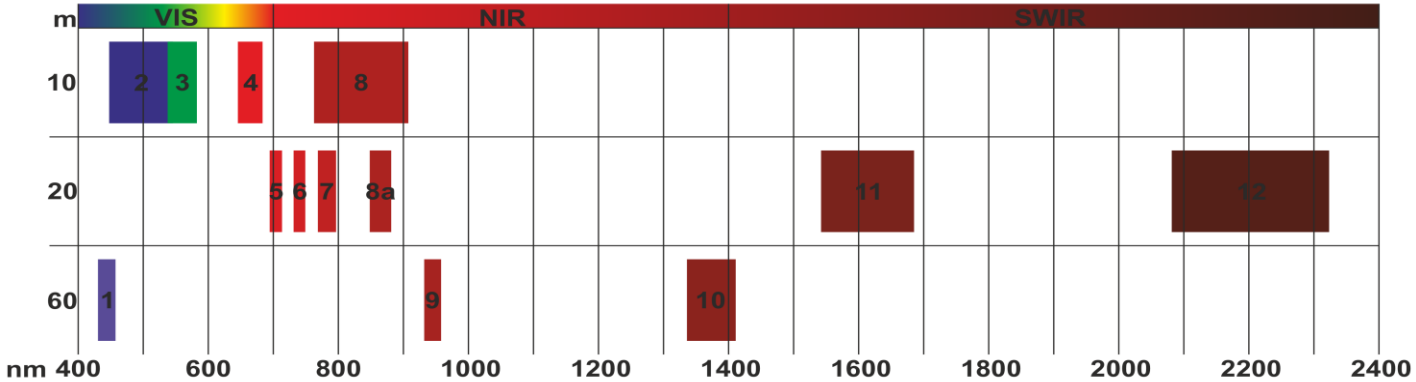
- Refers to level-1 and level-2.
- Downstream products mixed:
  - NRTish
  - Reprocessed, ICDRs and CDRs

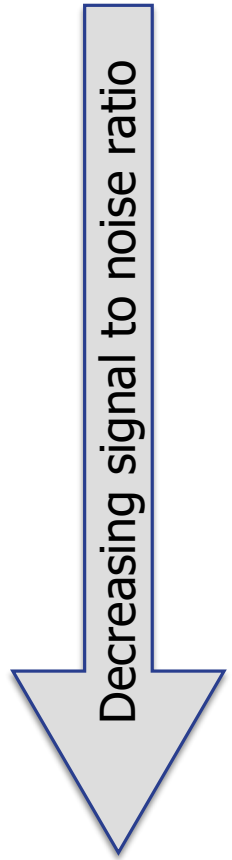
- **Resolution and revisit:** Spectral or similar

Sentinel-3 OLCI:



Sentinel-2 MSI:





PlanetScope: Red, Green, Blue, (1 x NIR)

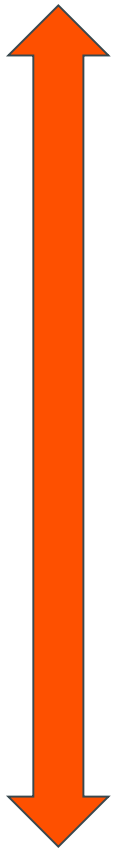
Some basic concepts about LEO for ocean applications

- Satellite data are "available" at level-0 to level-4

- **Level-0 data;** raw and largely unusable by community. Usually undistributed.
- **Level-1 data;** typically TOA, on instrument grid. Most fundamental level of useable data for applications.
- **Level-2 data;** geophysical properties (e.g. CHL, SST, SWH), corrected (including for atmosphere)

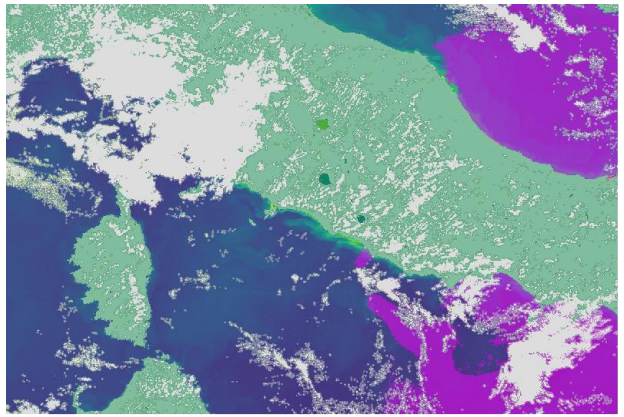
- **Level-3 data;** typically reprojected, regridded and often multi-sensor.
- **Level-4 data;** interpolated / gap-filled or temporally aggregated.

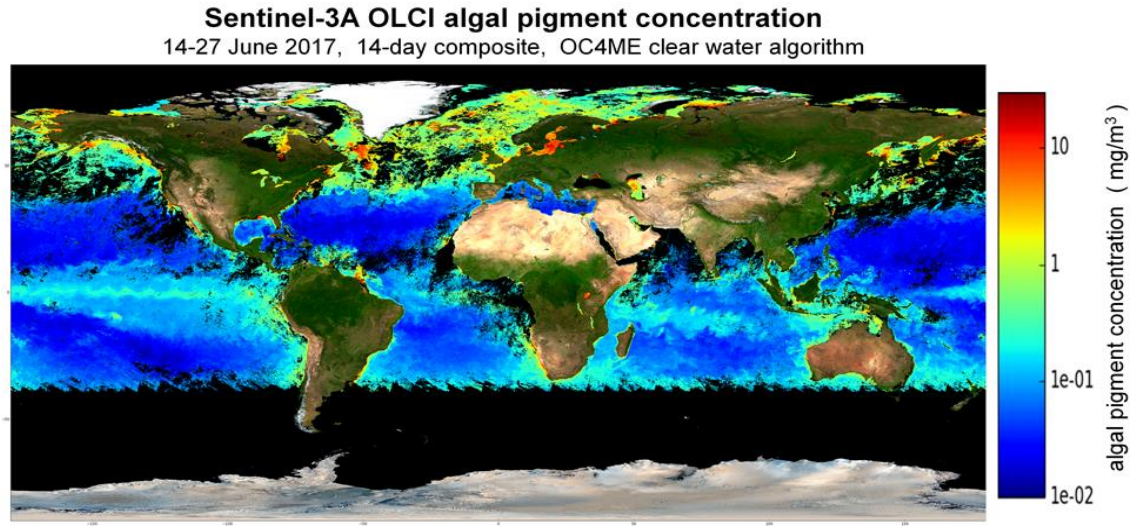
Less convenience, more control



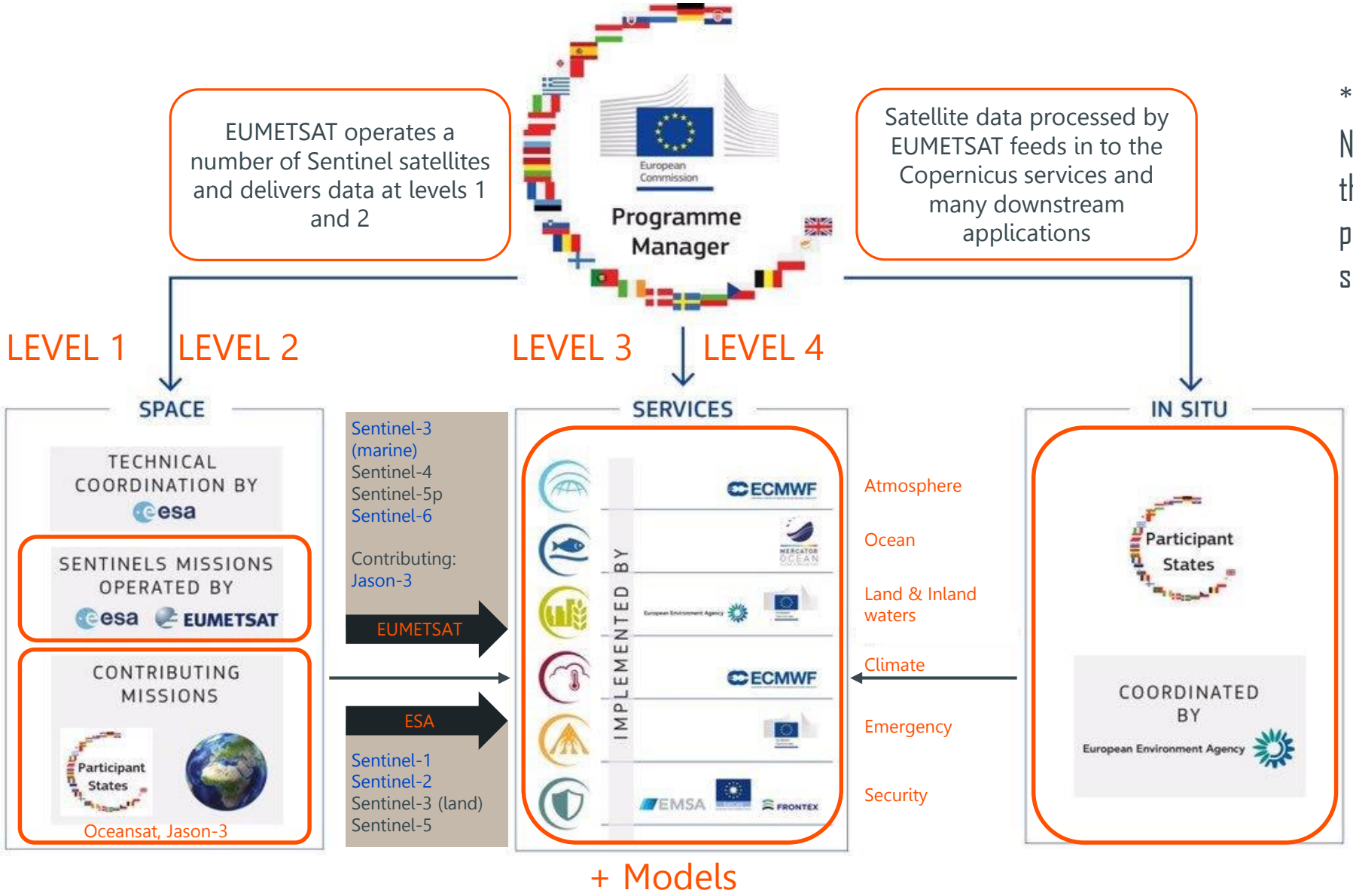
More convenience, less control

- **Common processes:**
  - Cal/Val
  - Atmospheric correction
  - Geophysical algorithms
  - Flagging
  - Regridding
  - Merging
  - Reanalysis





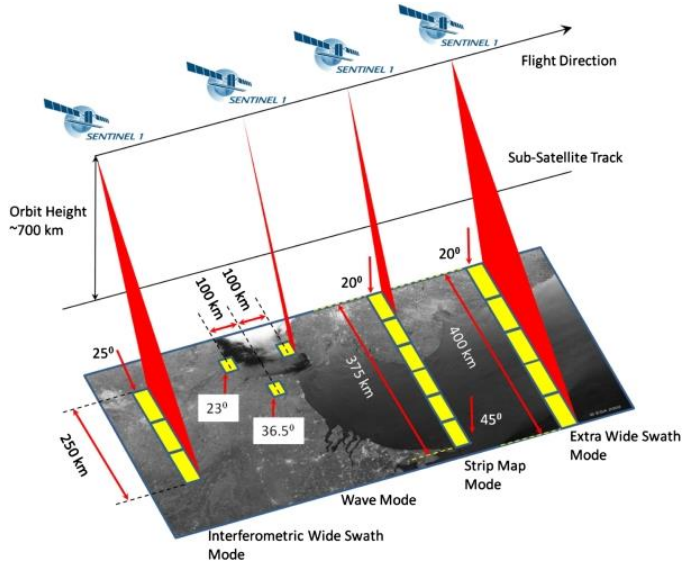
LEO satellites for the oceans – Copernicus



*Other data sources including NASA, NOAA, USGS etc. Many of these data streams are included in products from the Copernicus services)

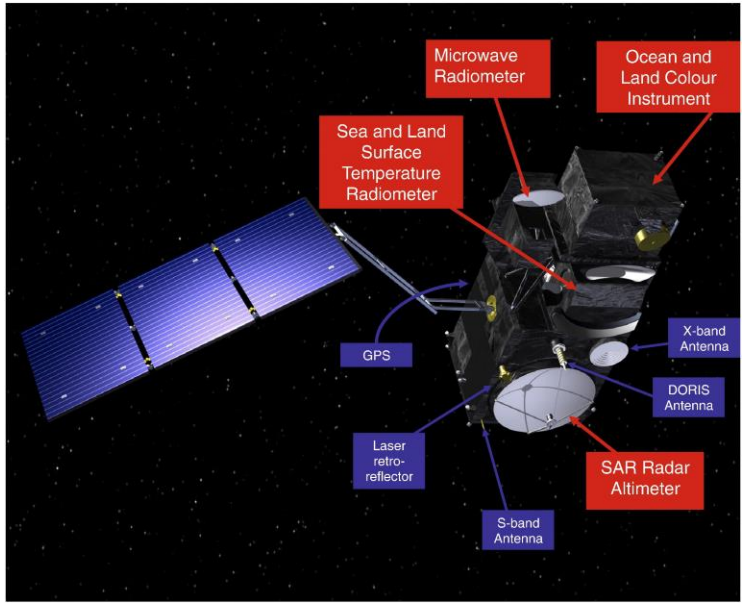
A quick summary of the Sentinels…1 and 2

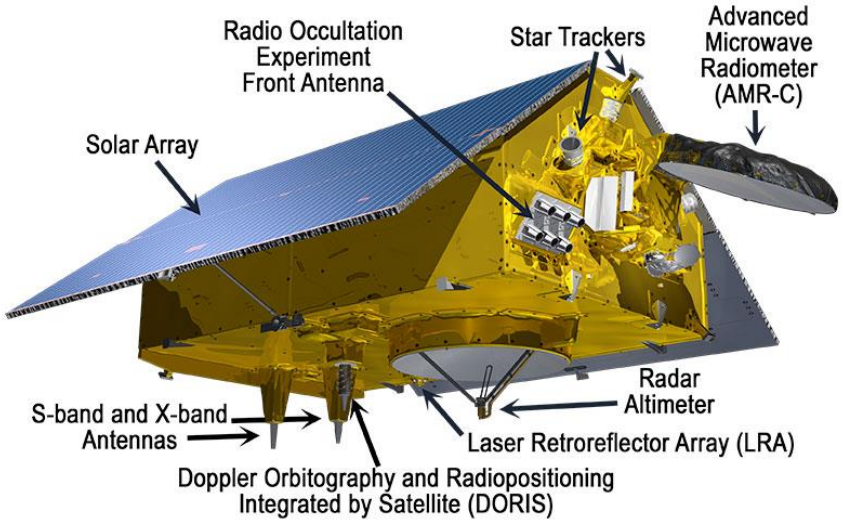
- **Sentinel-1**
  - Operated and data delivered by ESA.
  - Synthetic Aperture Radar – active method, information comes from surface roughness.
  - Ocean applications (mostly coastal and mode dependant):
    - Oil spill detection and pollution identification
    - sea-ice and iceberg monitoring
    - Wind / wave information
    - Ship and infrastructure detection
- **Sentinel-2**
  - Operated and data delivered by ESA.
  - Not technically a marine mission, but growing applications in the coastal zone.
  - Optical imager (MSI) – high spatial resolution (10 m) but low SNR and # of wavebands.
  - Ocean Applications (coastal ONLY):
    - Coastal maritime infrastructure
    - Sediment dynamics
    - Dredging
    - Marine debris
    - Water quality (reliable for TSM, but not really for CHL)



A quick summary of the Sentinels…3 and 6

- **Sentinel-3**
  - Operated and ocean (and atmosphere) data delivered by EUMETSAT. Land data handled by ESA.
  - 3 instrument suites – ocean colour (OLCI), SST (SLSTR) and altimetry (SRAL).
  - Ocean applications (global):
    - Ocean primary production and Ocean carbon pools
    - Sediment dynamics
    - Sea ice
    - Sea level and wind/wave data – maritime operations, safety at sea
    - Sea surface temperature – climate, marine heatwaves
- **Sentinel-6**
  - Operated and data delivered by EUMETSAT
  - Altimetry mission – building on the heritage of the Jason series
  - Ocean applications (global):
    - Sea surface height, significant wave height, wind speed.
    - Model assimilation
    - Climate studies
    - Maritime operations, safety at sea





Suggested break

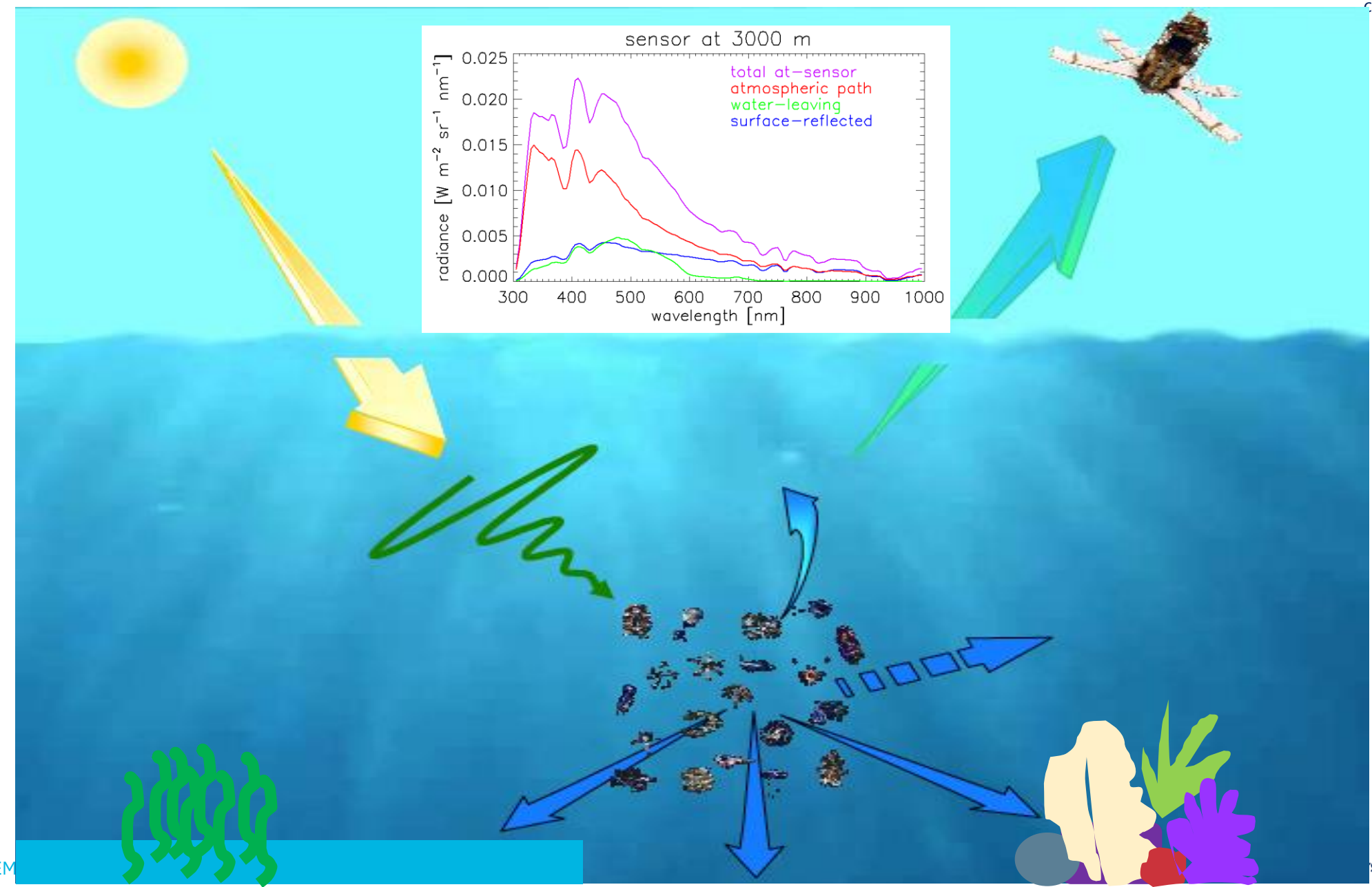
Questions so far?

Ocean Colour

Why ocean colour?

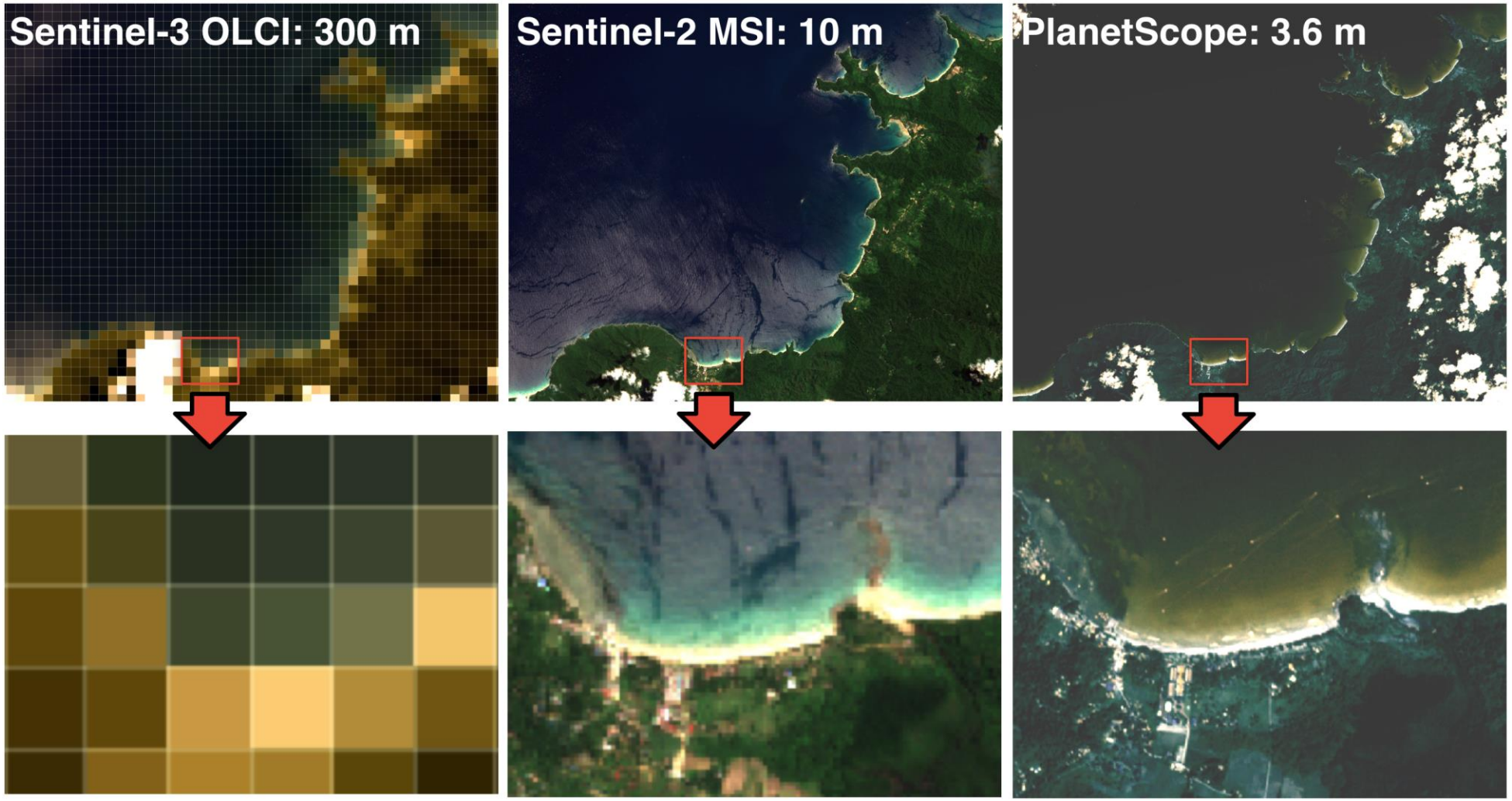
- Tells us about what's in ocean waters:
  - Phytoplankton
    - Food chain
    - Carbon
  - Sediments
  - Ice
  - Other things:
    - Pollution
    - Infrastructure
    - Debris

Measuring ocean colour - theory

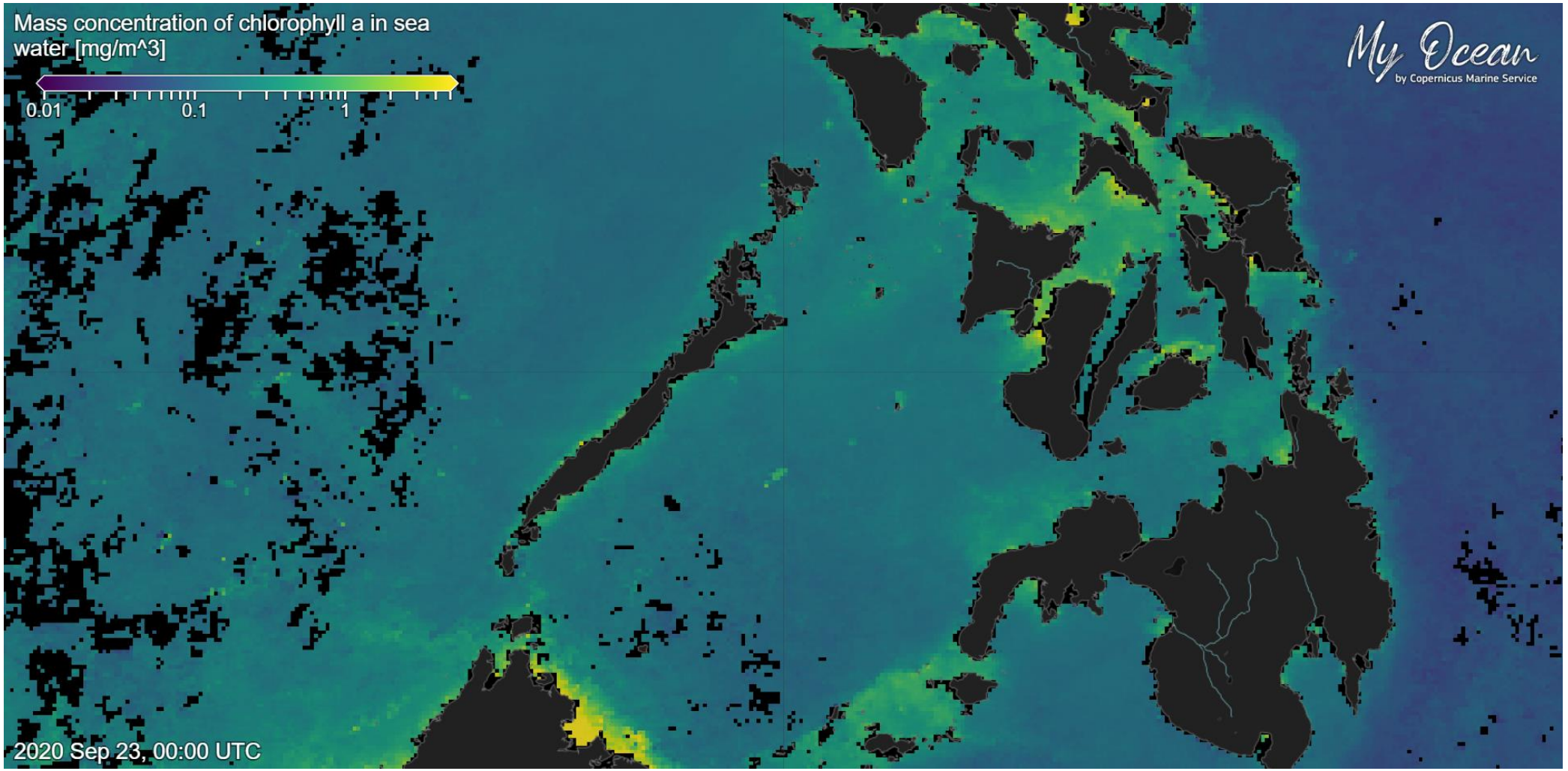



esa

Spectral and spatial resolution – level 1/2

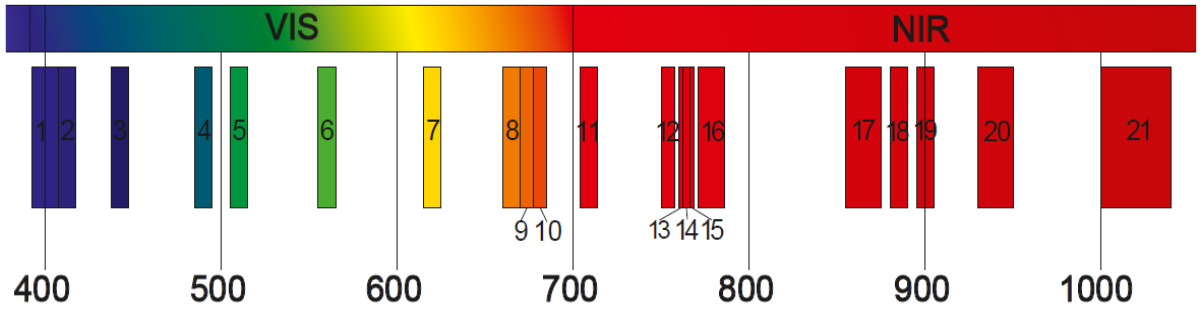


Spatial and spectral resolution – level 3/4

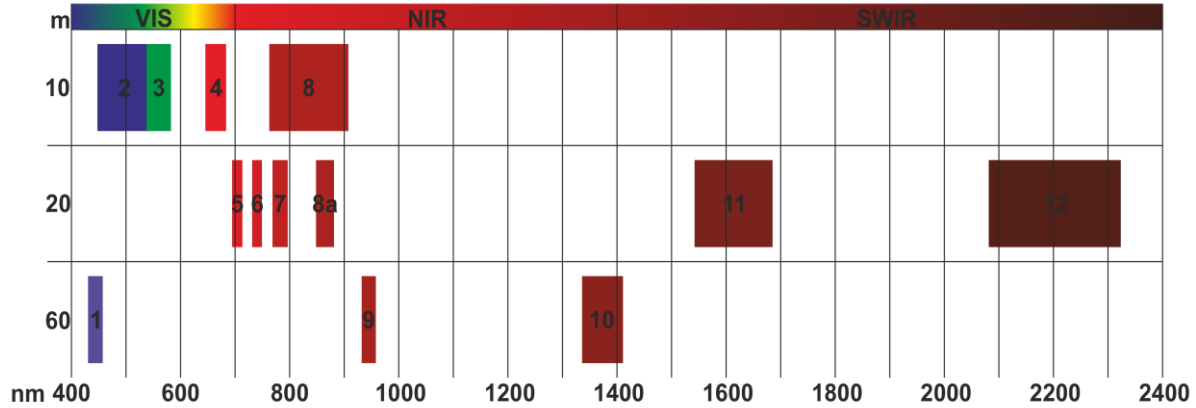


Spatial and spectral resolution

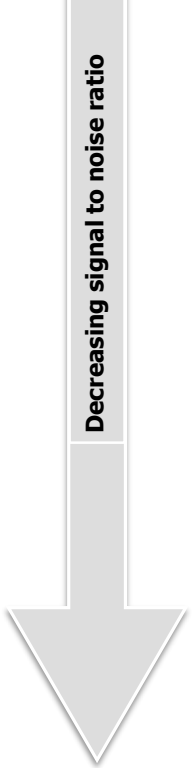
Sentinel-3 OLCI:

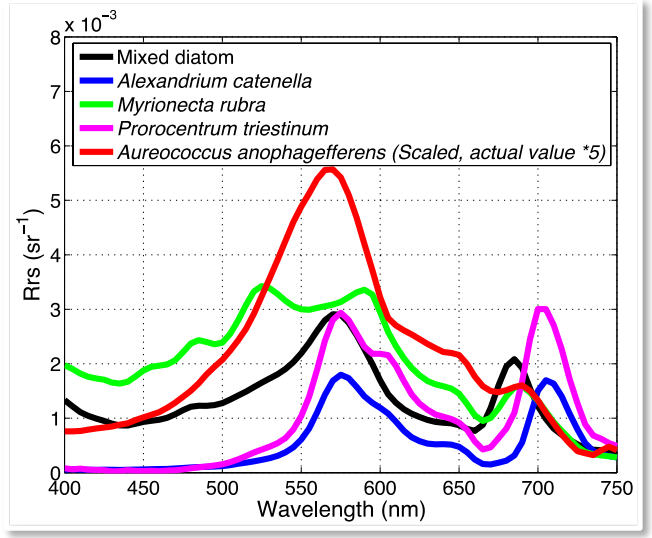


Sentinel-2 MSI:

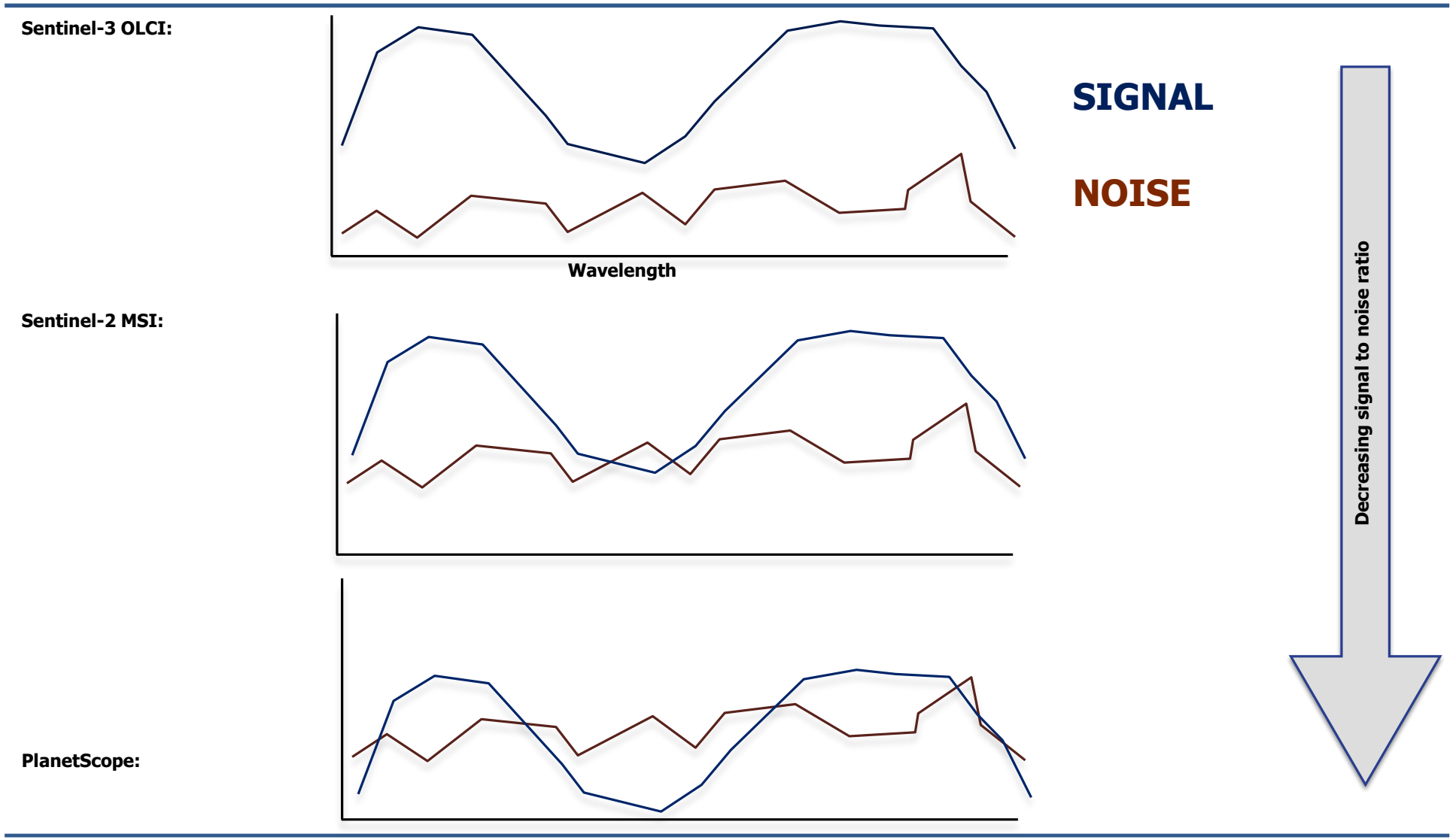


PlanetScope: Red, Green, Blue, (1 x NIR)





Spatial and spectral resolution



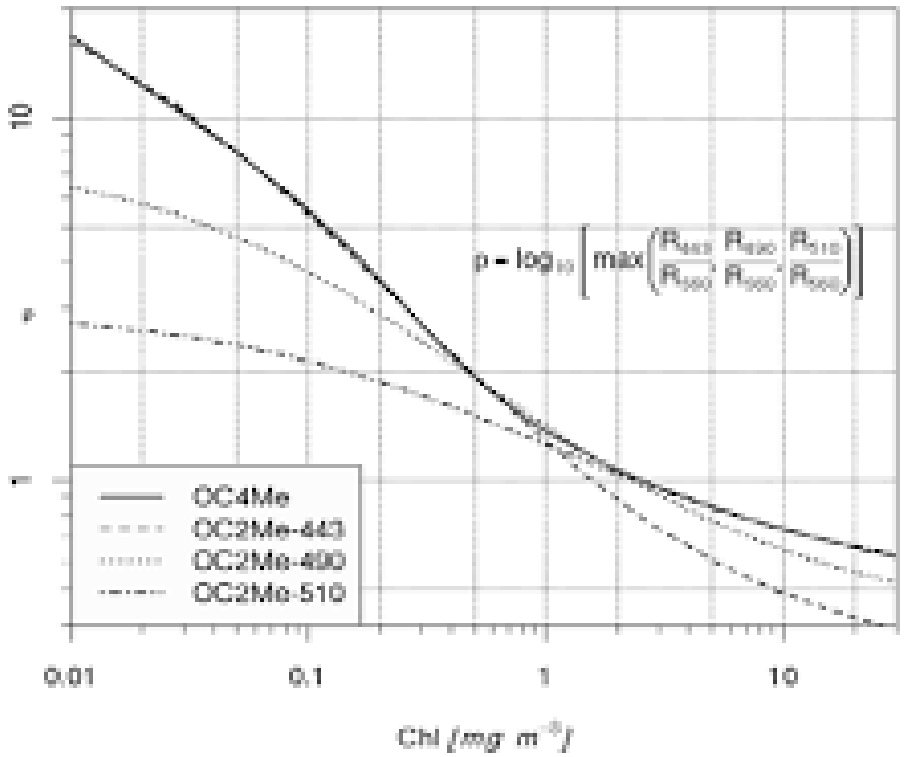
Algorithms and products

- Level 1: Top of atmosphere radiance
- Level 2: R_{rs}, IOPs, [Chl, TSM] at native res.
- Level 3: Merged, regridded – Chl (+)
- Level 4: Gap filled, single algorithm – Chl (+)

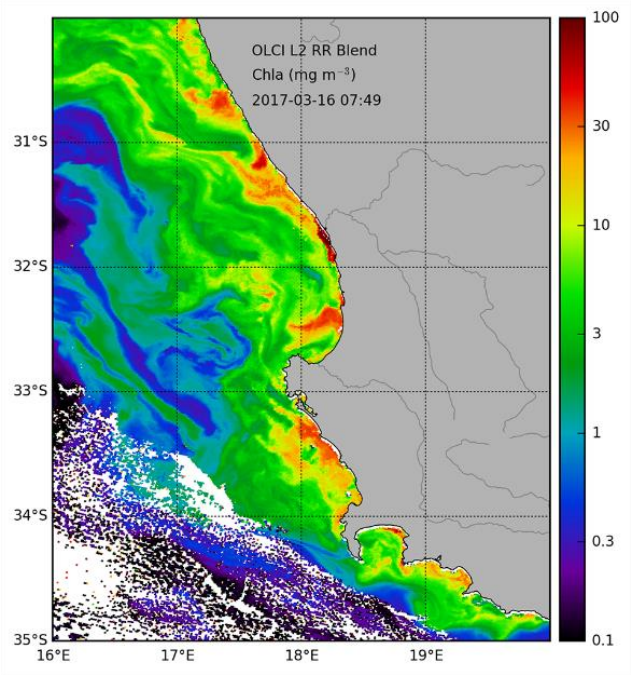
- Also many custom approaches that you can (and may need to) take to achieve optimal results:
  - Atmospheric correction, POC, sediments, HABs, bottom type habitats etc.

What is an algorithm?

- Links signal to geophysical property
- Simpler approaches – an empirical band ratio e.g. [Chl]
- More complex – inversion models, AI/ML approaches
- Validation and sensitivity is key – varies regionally/by application

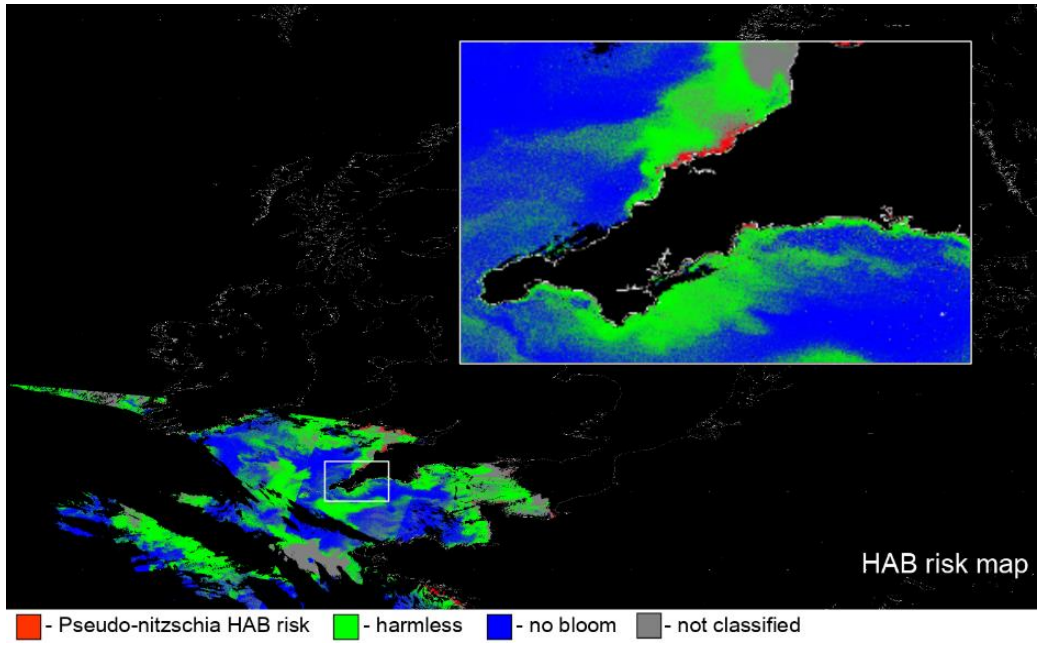


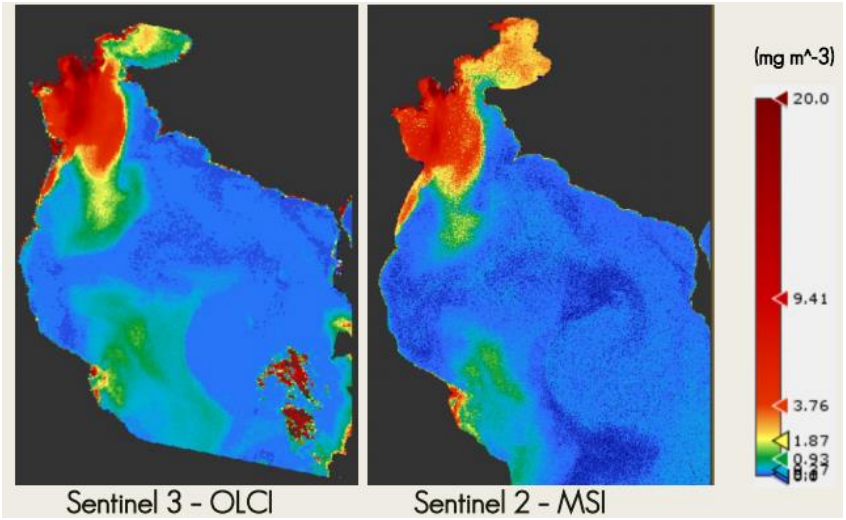
Applications of Ocean Colour - HABs



OLCI used to detect high biomass blooms in coastal environment, west coast of South Africa. Forms part of government Operation Phakisa initiatives (Marie Smith)

OLCI spectral data used to classify waters at risk of different Harmful Algal Bloom species including Pseudonitzschia (Andrey Kurekin)

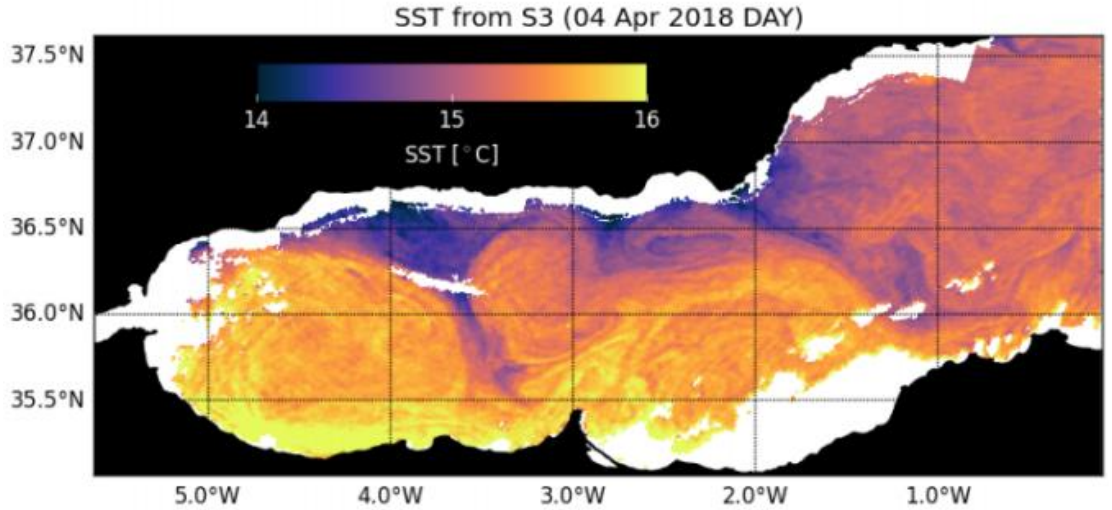




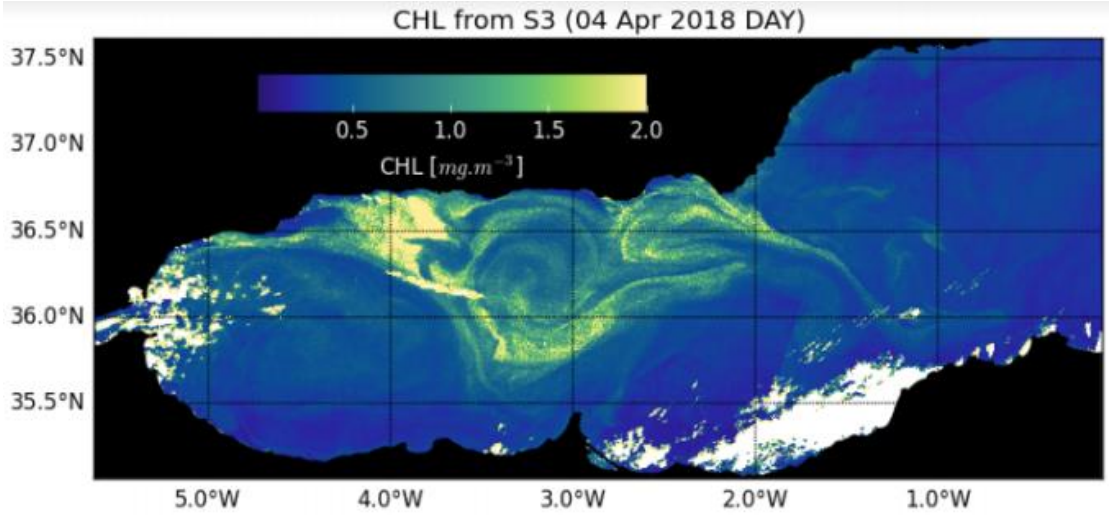
Chlorophyll concentrations for detecting blooms in Greek waters – powerful combination with Sentinel 2 (S3 higher temporal and spectral characteristics, S2 higher spatial resolution) – (Andromachi Kikaki, Riga 2018)

Applications of Ocean Colour – linking with physics

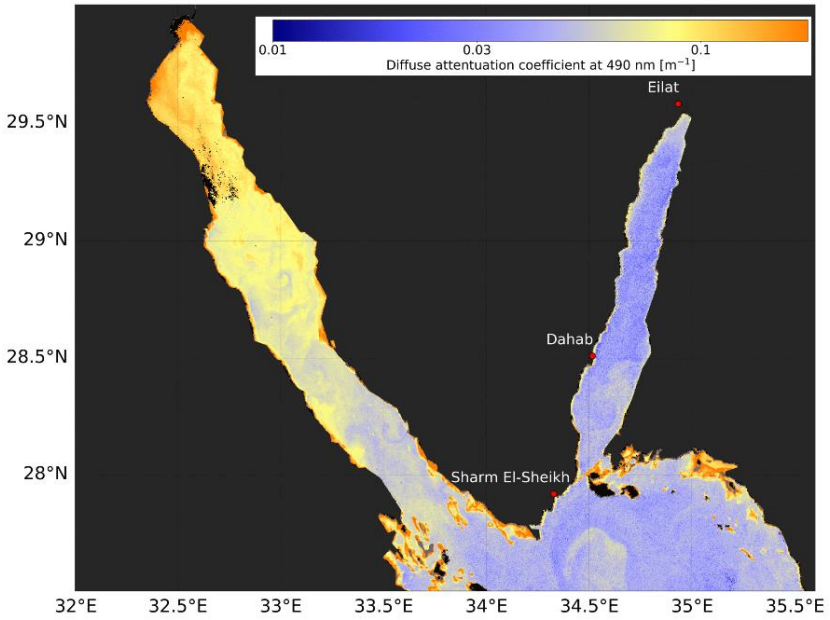
Alboran gyre identified in SST, and …



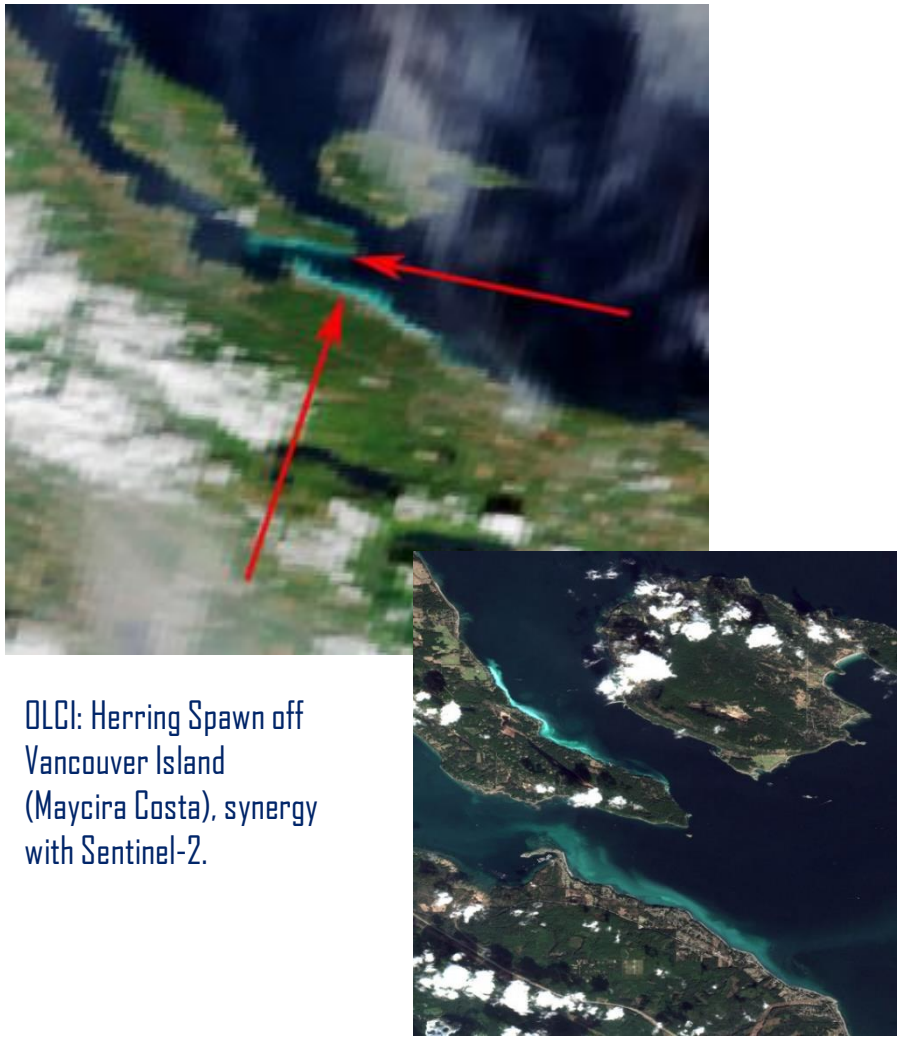
… resultant influences on chl concentration (Luisa Lamas)



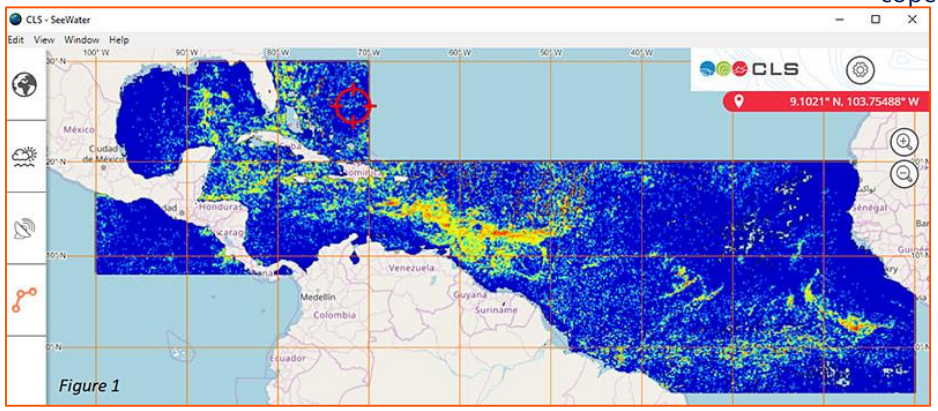
OLCI attenuation data used to correct underwater imagery. (Derya Akkaynak)

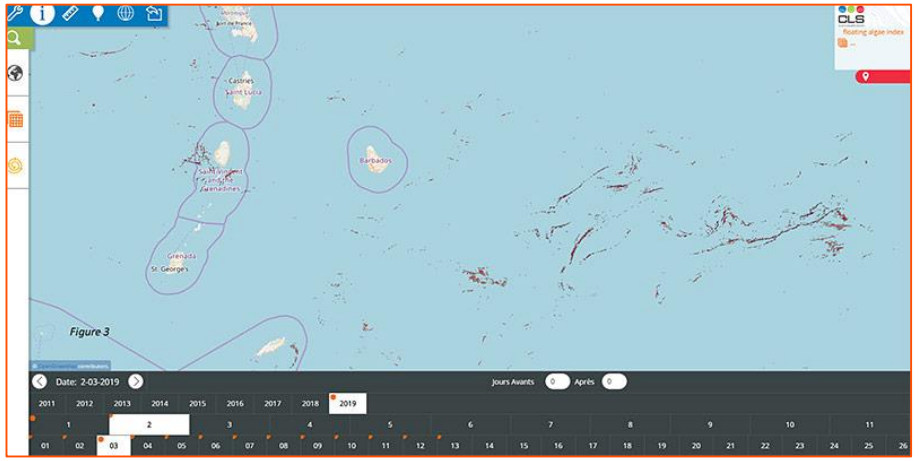


Applications of Ocean Colour - detection



OLCI: Herring Spawn off Vancouver Island (Maycira Costa), synergy with Sentinel-2.



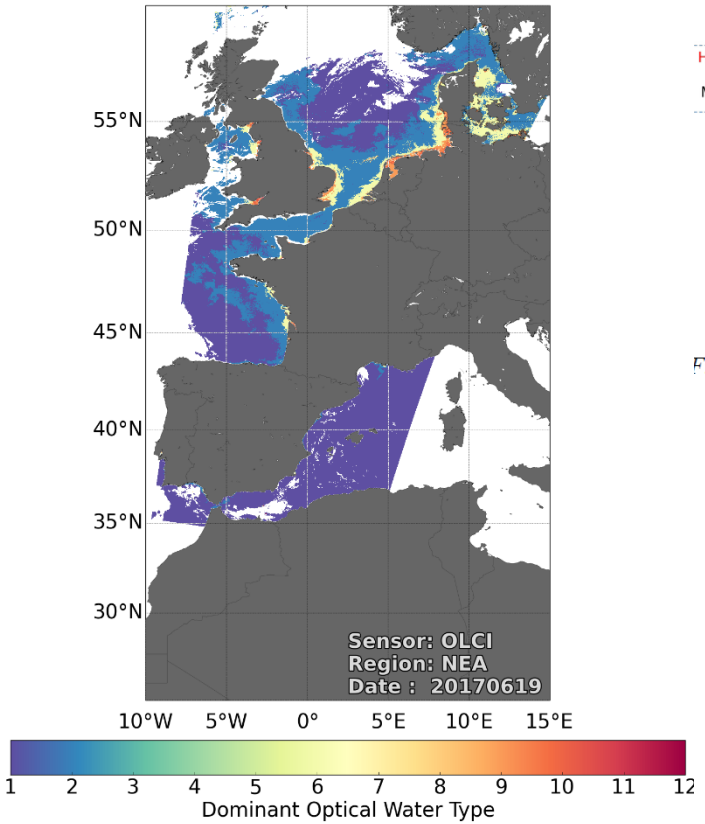


OLCI: Detection of Sargassum.
CLS operational service - https://datastore.cls.fr/cls-operational-sargassum-monitoring-service-ready-for-end-users/

Applications of Ocean Colour – water quality and policy

Various applications are exploring the use of OLCI data for meeting Marine Strategy Framework Directive (MSFD), Water Framework Directive and other relevant environmental policy.

ORSECT:UK



highroc.eu

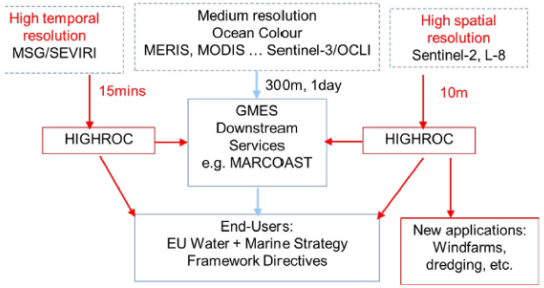
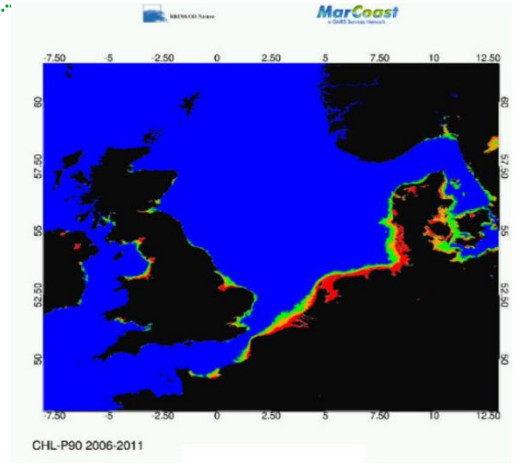


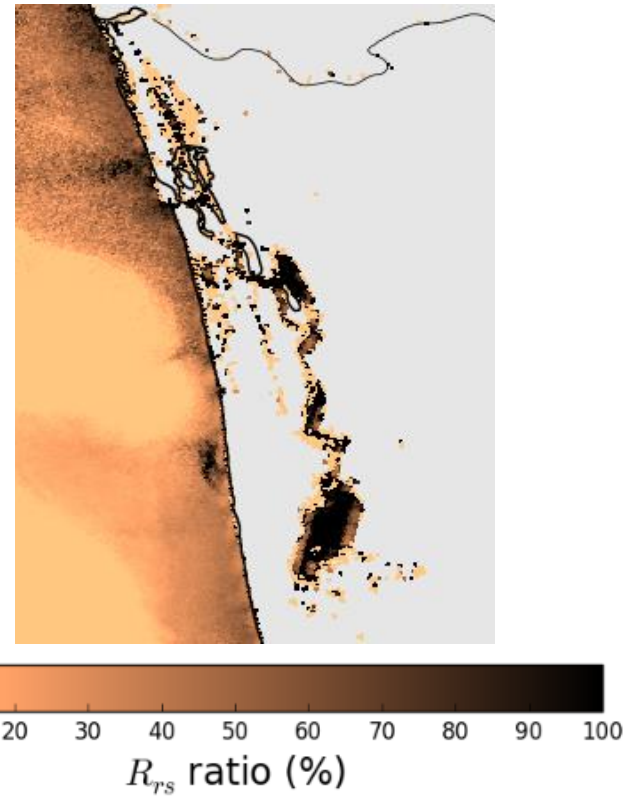
Figure 1. Positioning of the new HIGHROC products and services with respect to the existing medium resolution ocean colour data stream and services.



Ruddick et al., 2016

Application Type	User
Water Quality Monitoring and Reporting for the EU Water Framework and Marine Strategy Framework Directives (WFD/MSFD)	National governments
Dredging optimisation and monitoring	Dredging consultancies, Government
Coastal Aquaculture	Aquaculture operators, Government
Environmental Impact Assessment for coastal and offshore construction	Consultancies, Government
Initialisation/validation data for sediment transport and ecosystem models	Sediment transport and ecosystem modelling scientists

Table 1. Key applications and end-user communities for HIGHROC products and services.

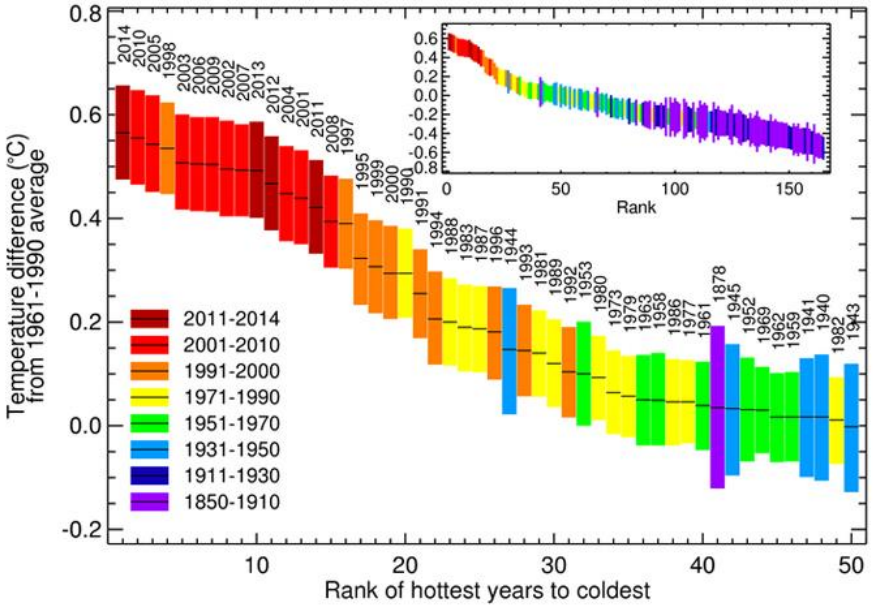


OLCI data used to develop cholera potential indicators, Kerala, India (Hayley Evers-King, Marie-Fanny Racaul, Shubha Sathyendranath)

Sea Surface Temperature

Why SST?

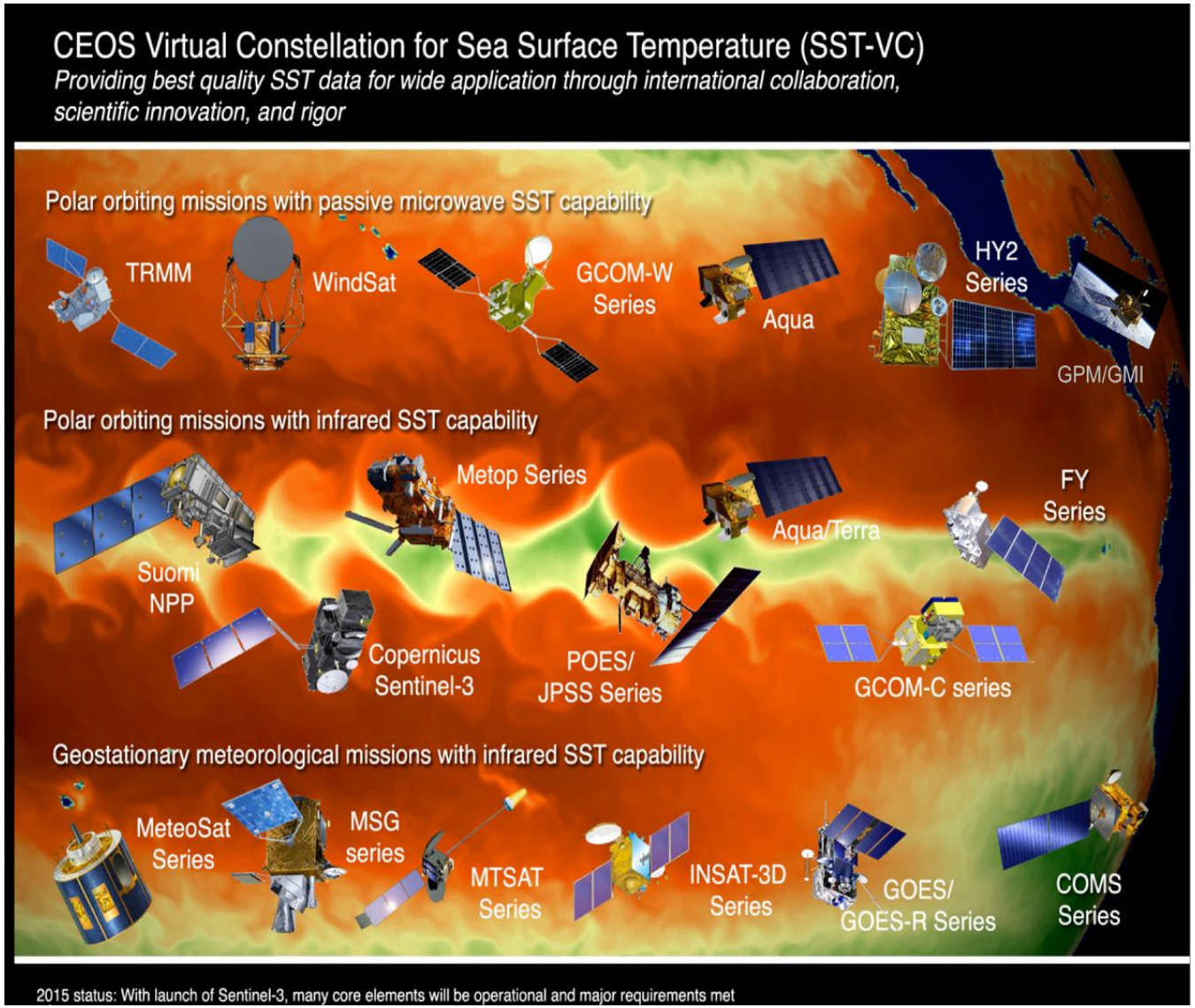
- Influences the weather
- Influences ocean circulation
- Intimately connected to ocean biology
- Climate



Measuring Sea Surface Temperature

- SST is derived from radiance; this is measured by radiometers, as with ocean colour, but also using the infrared (or microwave) part of the spectrum.

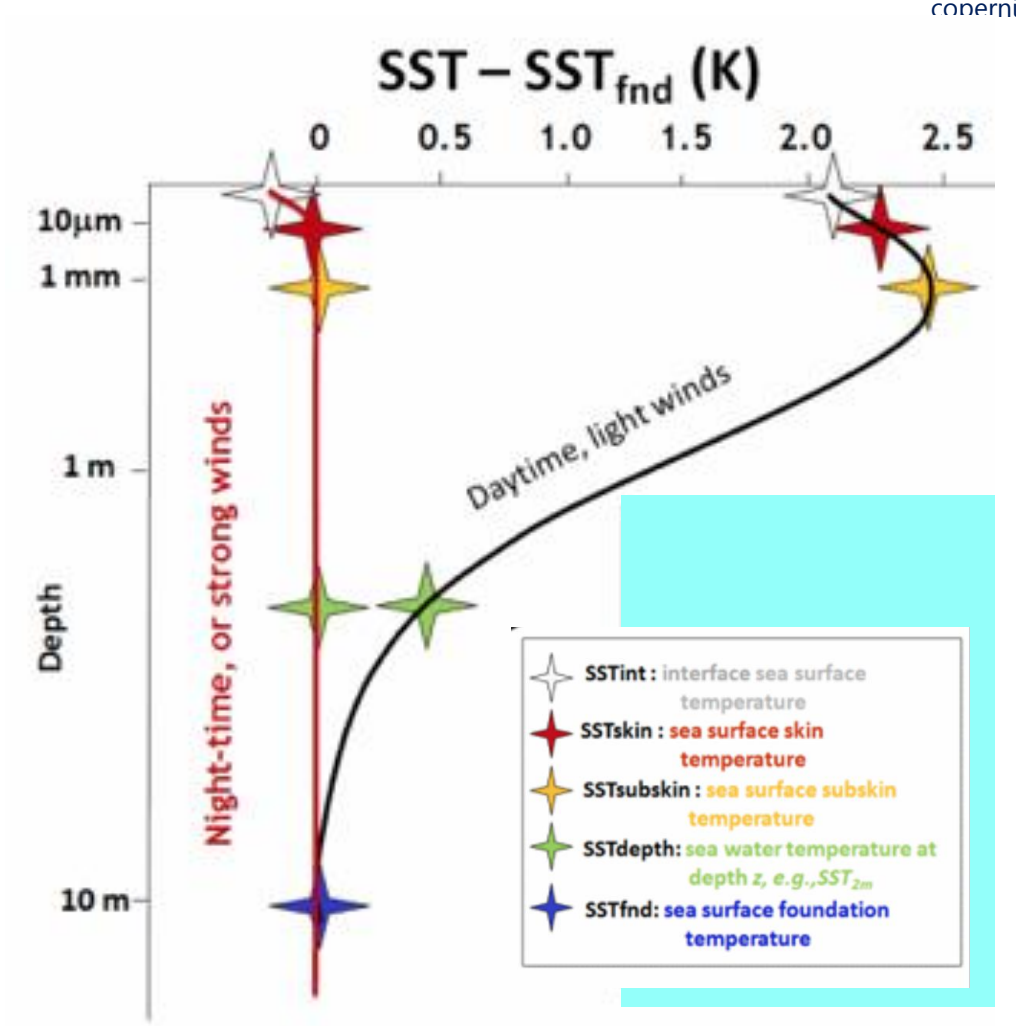
- Huge variety of missions over history, with strong drive from meteorological community.



SST missions – SLSTR example

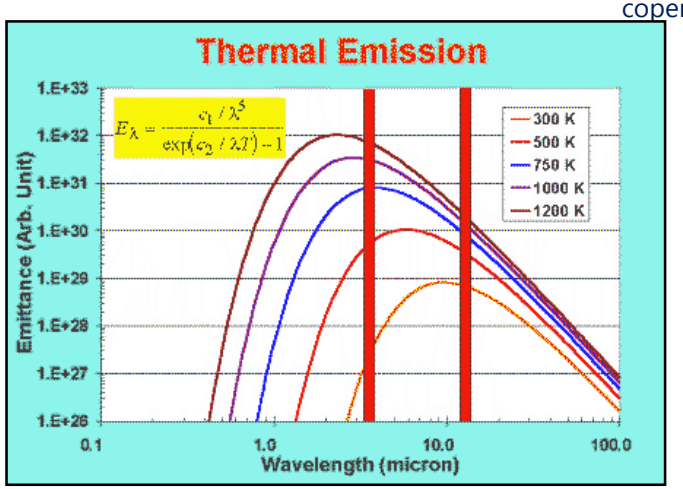
Measuring SST - Theory

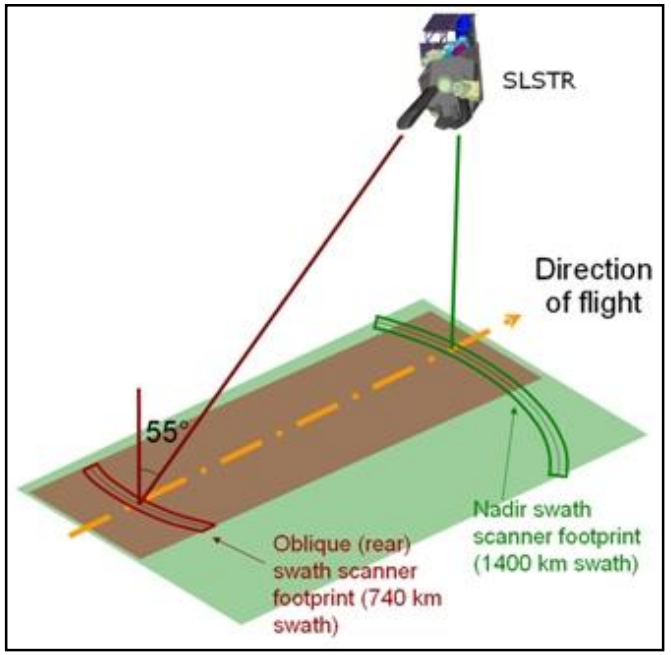
- SST can be defined in many ways (see figure), and is measured differently by different satellite and *in situ* sensors.
- These definitions are set by GHRSST (the group for high resolution sea surface temperature).
- GHRSST provide community resources on SST: www.ghrsst.org
- SLSTR (and many IR radiometers) measure **skin temperature (10 µm)**
- Passive microwave (PWM) radiometers measure sub-skin temperature.
- The IR and PMW channels used are selected as they minimise atmospheric effects.



Measuring SST – Theory (with SLSTR example)

- Microwave – is not strongly affected by cloud scattering but is measured at lower resolution (convergence of black body curves).
- IR is strongly affected by cloud scattering
- Signal at sensor (once calibrated):
  - top of atmosphere brightness temperature for IR channels (S7*-S9)
  - radiance for optical channels (S1-S6). (used primarily, in the marine case, to identify cloud).
- Dual view approach is used to correct for atmosphere (mainly water vapour), and the presence of scattering

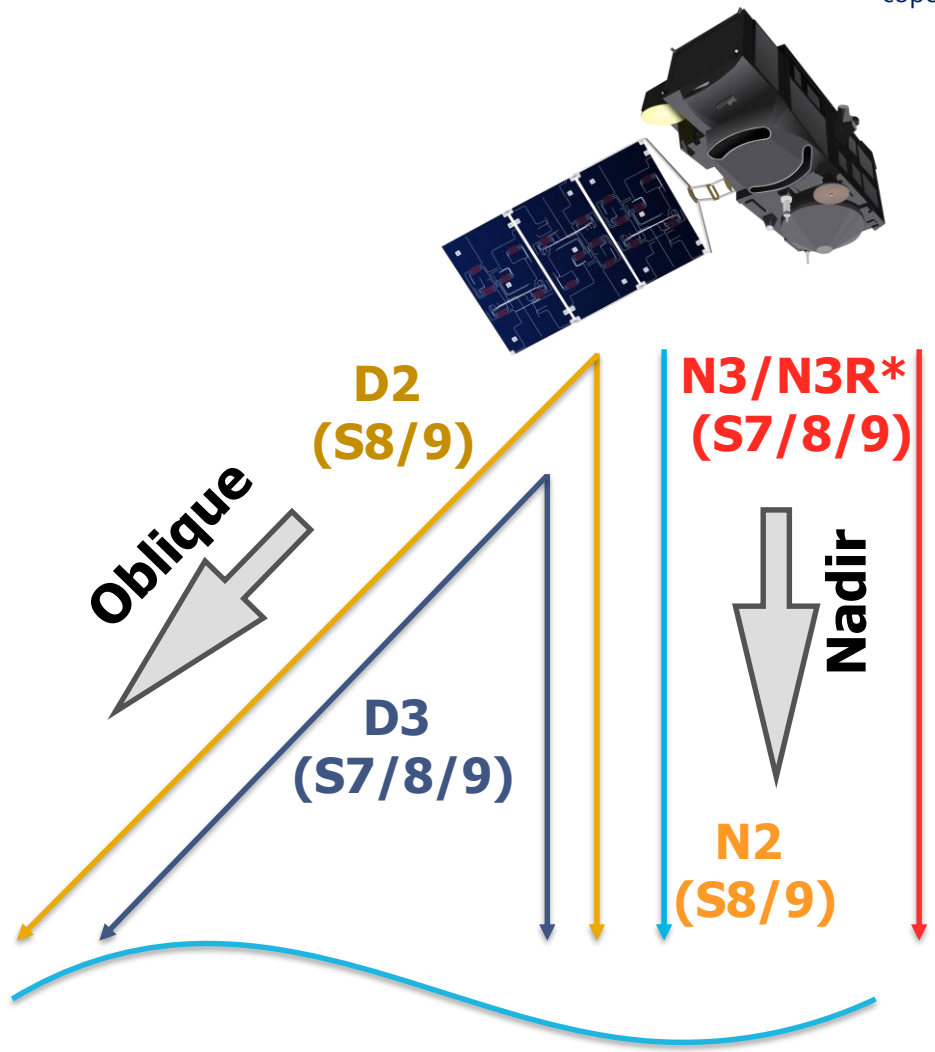




***S7 used at night only**

Measuring SST - Algorithms

- SLSTR has 5 algorithms for SST retrieval
- "N" only algorithms use only the nadir looking view.
- "D" algorithms combine both nadir and oblique view to give a "dual" view.
- D & N algorithms have variants that use 2 (day) or 3 channels (at night).
- Dual-view retrievals have the ability to provide a better atmospheric correction.



Measuring SST – other sources of data/information

Further information on GHRSST and SST can be found here:
Introduction to GHRSST

Merged SST products also exist:

- **NASA MUR**
  - Seeks to get benefit of coverage/resolution/accuracy from multi-scale combination of global TIR and microwave signals (1 km). Cannot separate MW and TIR contributions to final product.

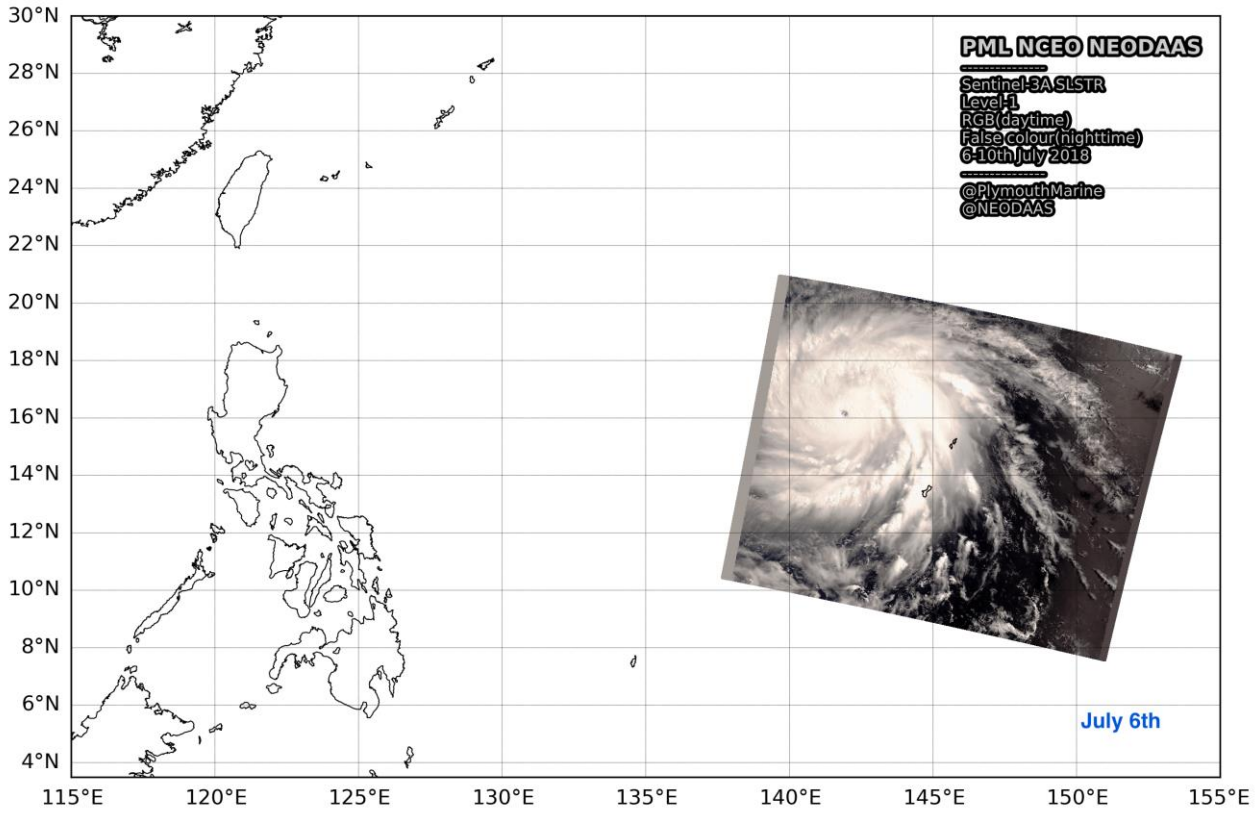
- **REMS MWIR**
  - Combines MW and TIR signals using optimal interpolation (9 km). Has a mask to allow for MW and TIR separation.

- **OSTIA**
  - L4 merged product. AVHRR, AATSR, SEVIRI, AMSRE, TMI and *in situ* data. Optimally interpolated to 0.054º grid. Highly smoothed (v1).

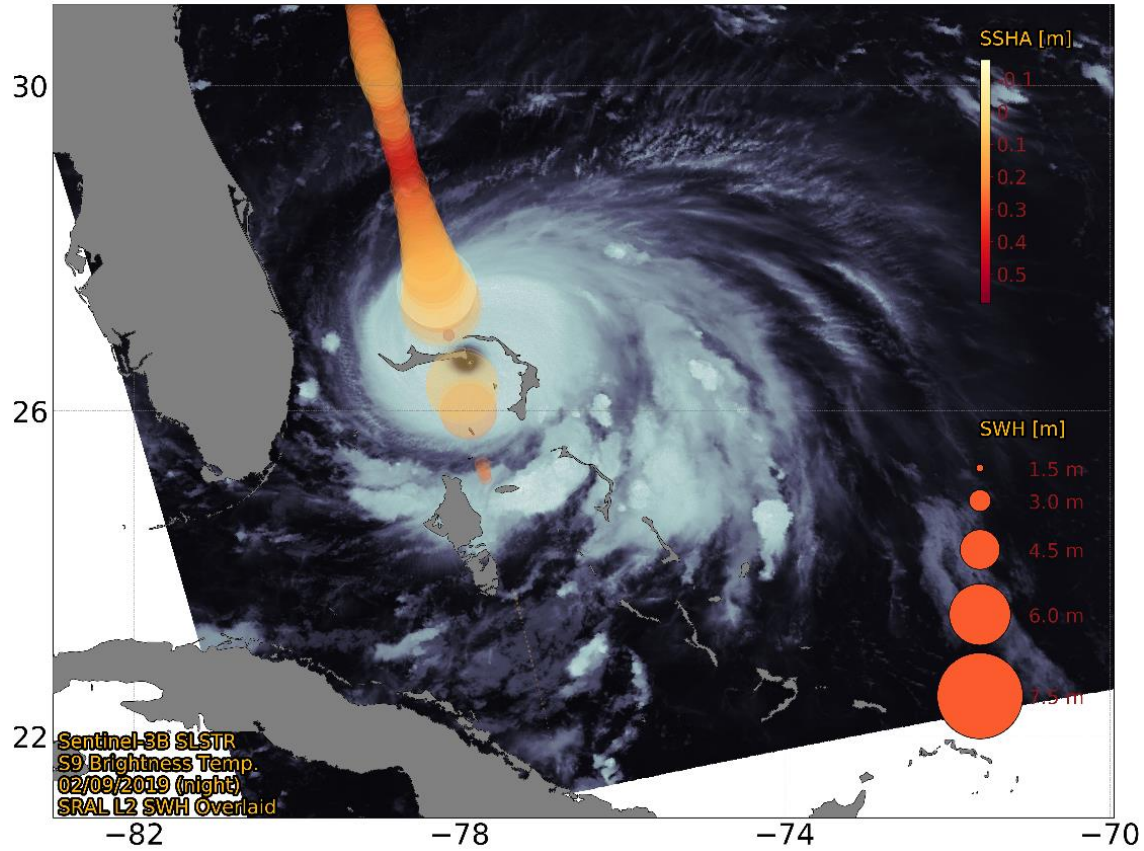
- **CMEMS**
  - Variety of products including OSTIA and ODYSSEA

- **SST-CCI**

Applications of SST

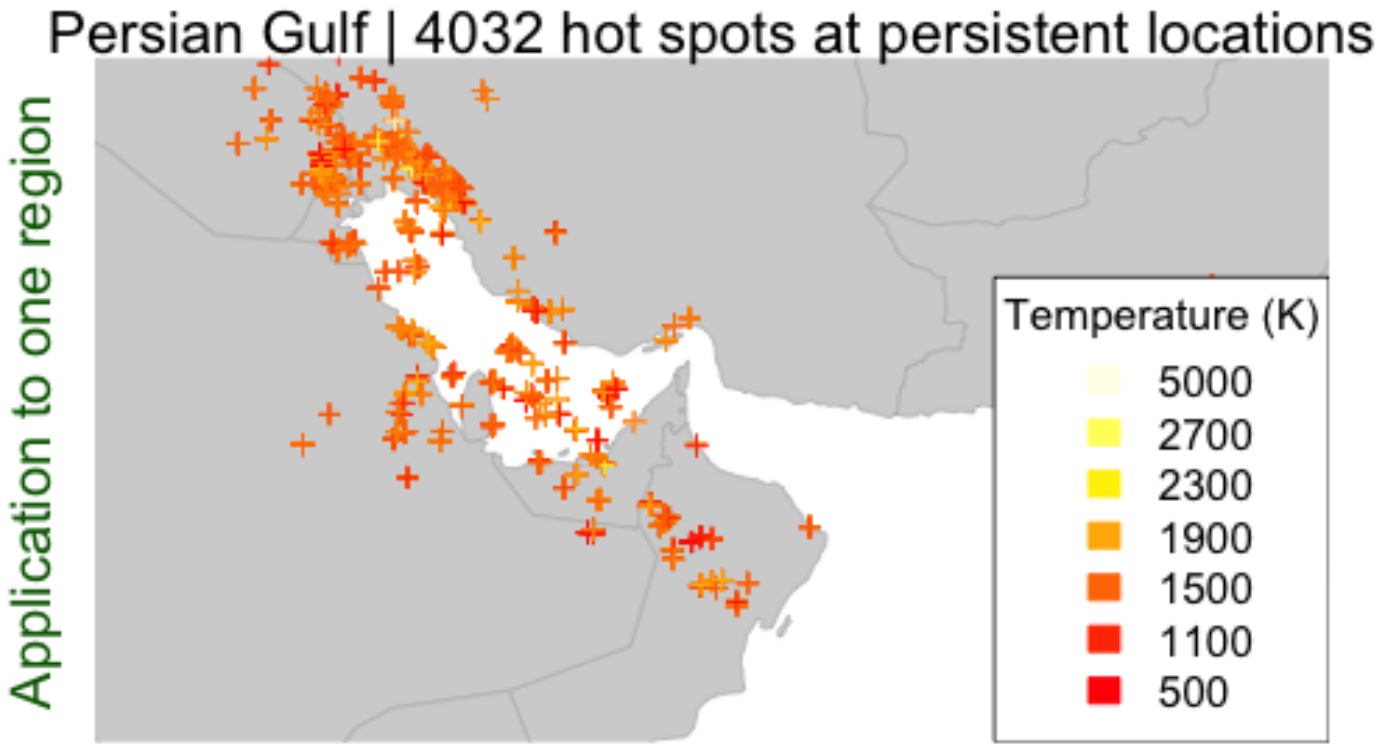


Tropical Storm Maria from SLSTR

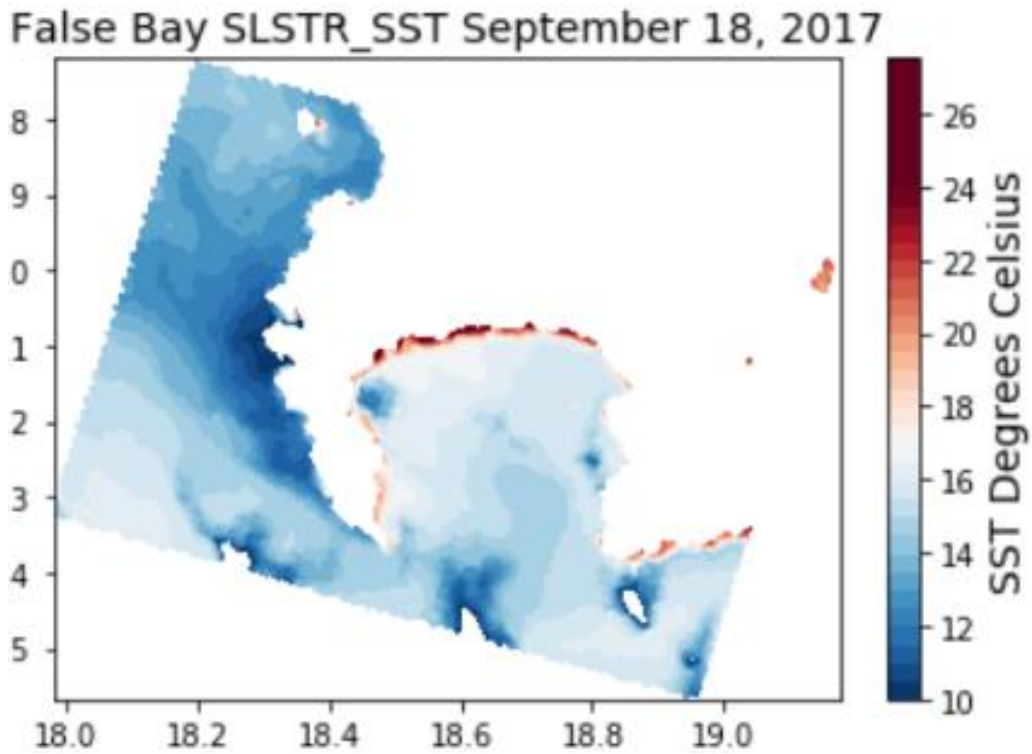


Hurricane Dorian from SLSTR and SRAL

Applications of SST



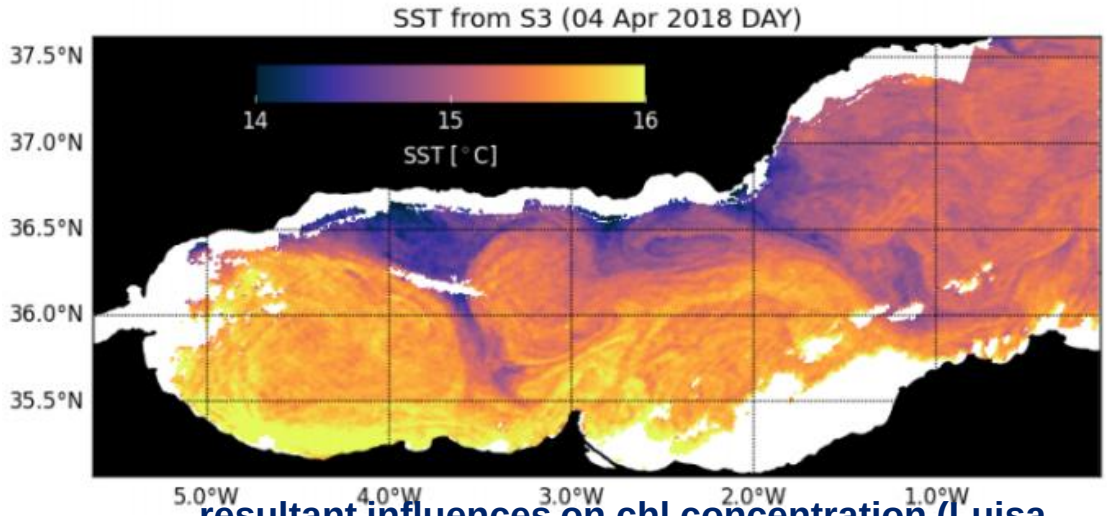
Hotspots from oil/gas works in the Persian Gulf detected in SLSTR night data (Caseiro et al., 2018)



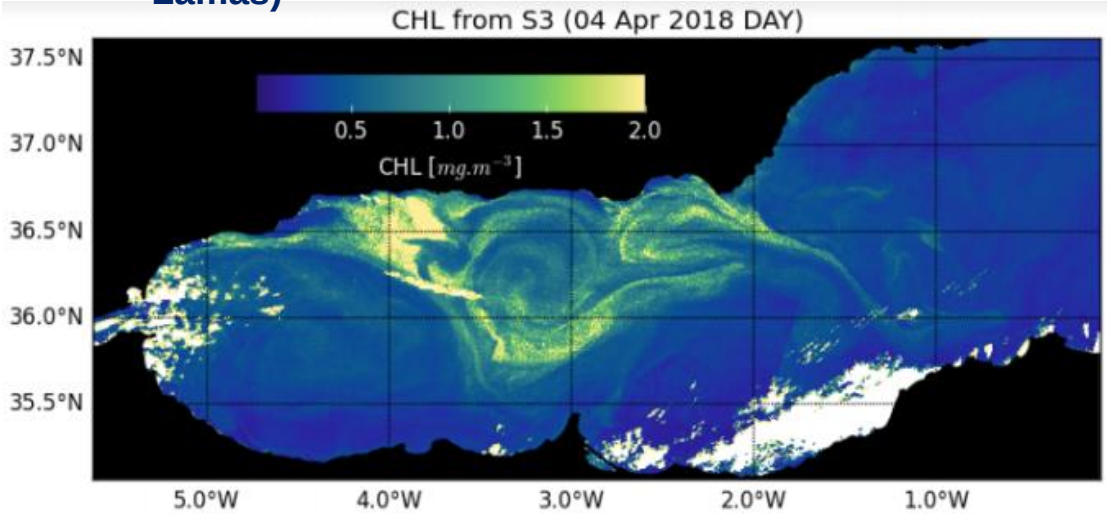
Upwelling dynamics, False Bay, South Africa (Renae Logston, 2017).

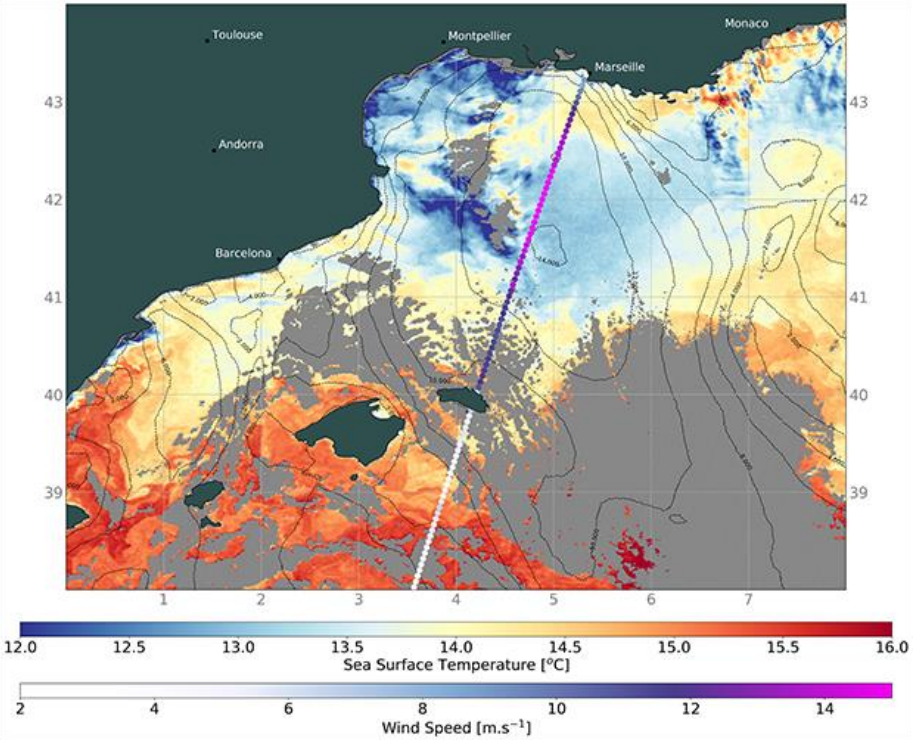
Applications of SST

Alboran gyre identified in SST, and …



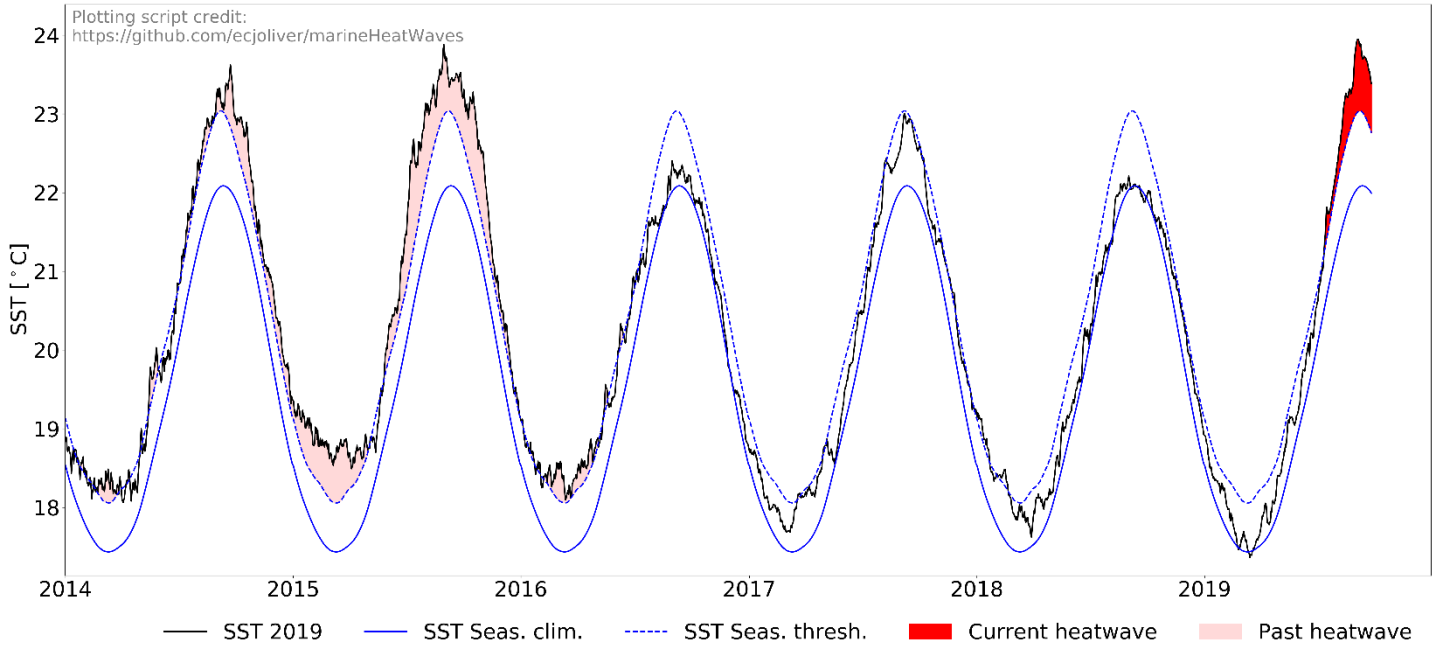
… resultant influences on chl concentration (Luisa Lamas)

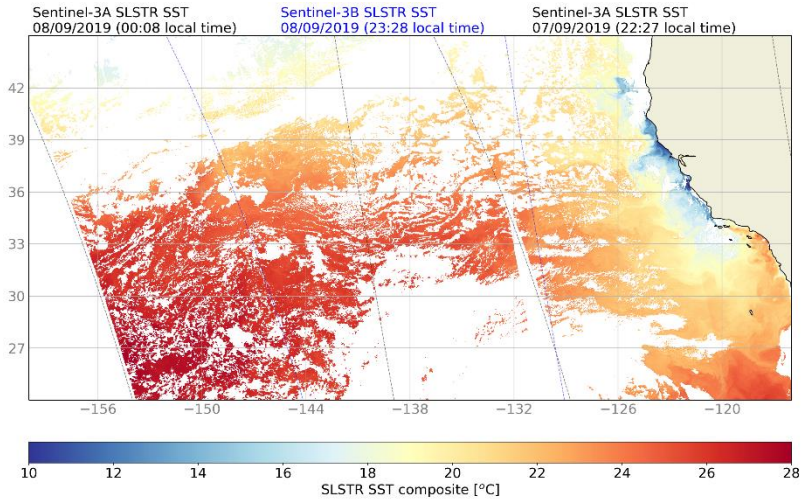


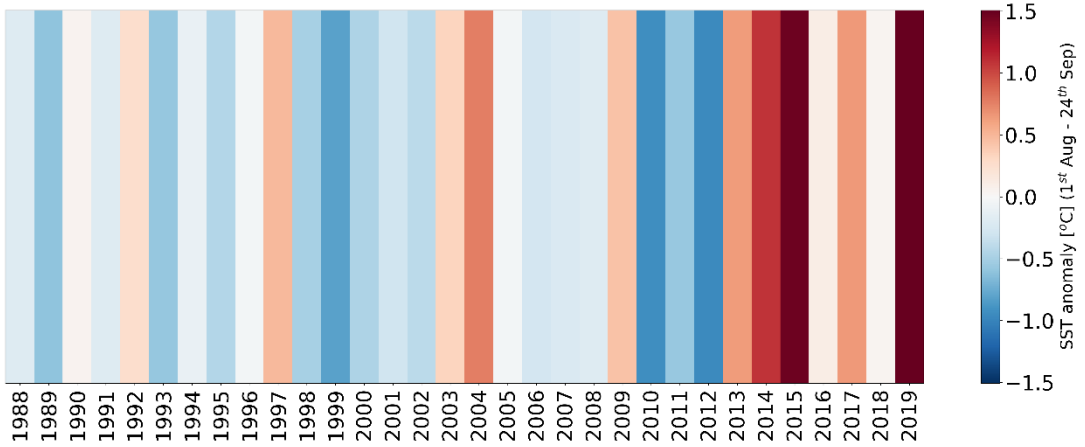


Deep water formation in the Gulf of Lion (SRAL and SLSTR)

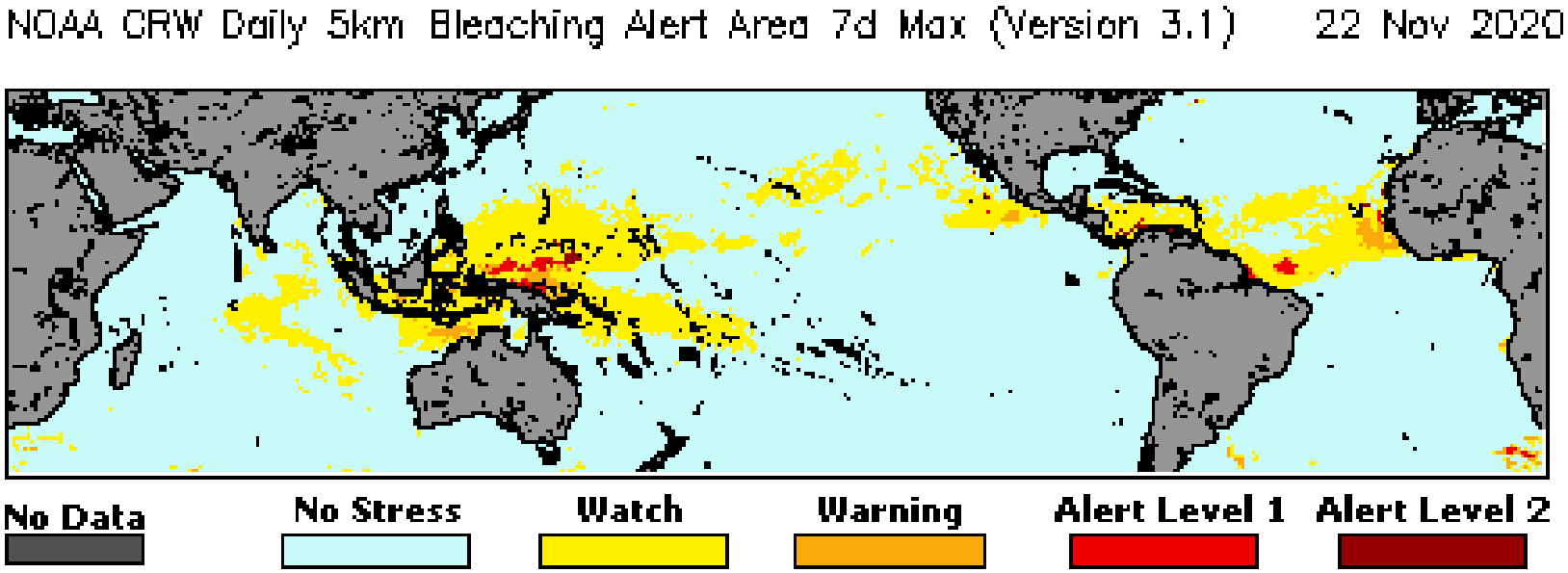
Applications of SST







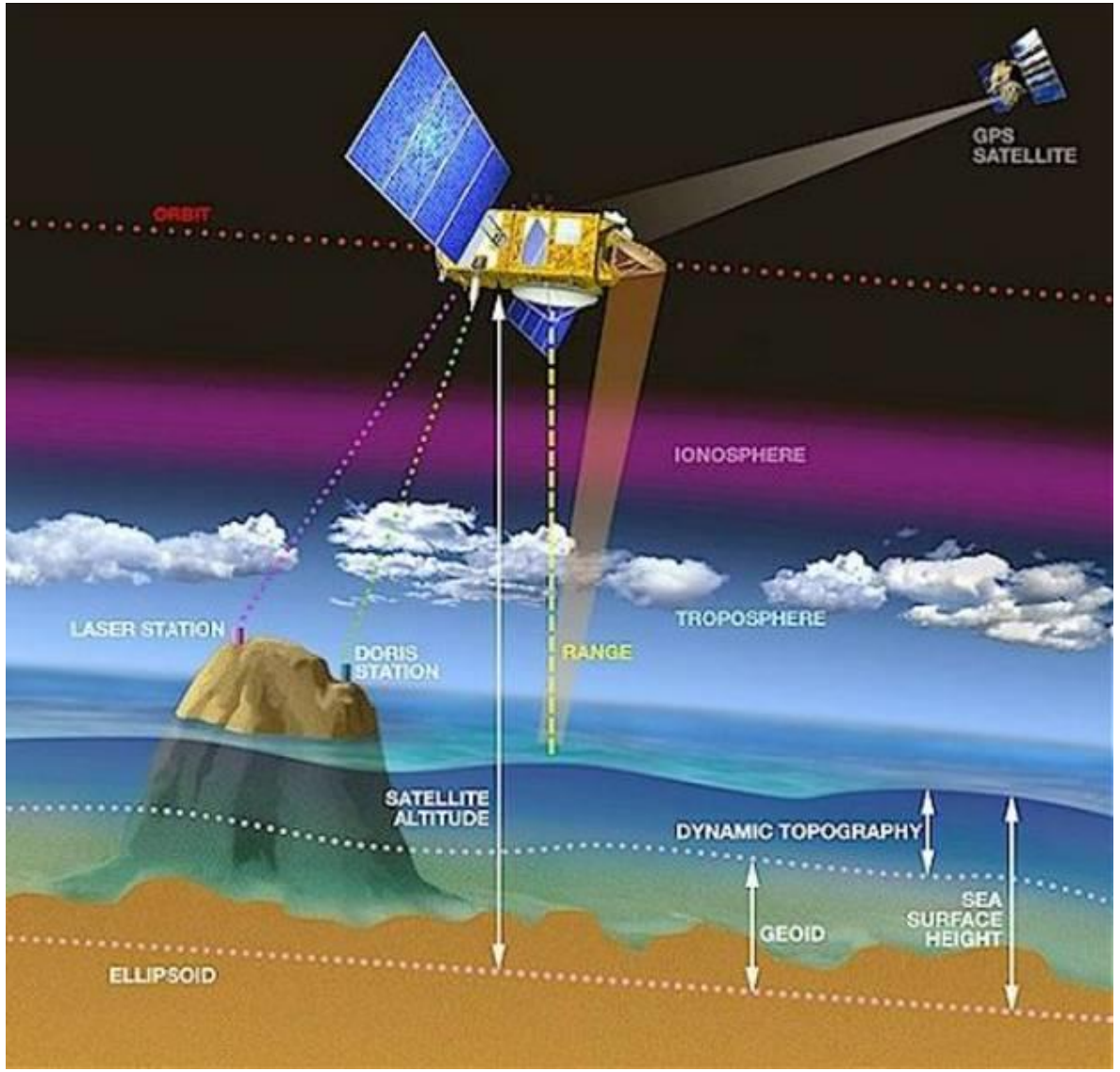
Applications of SST



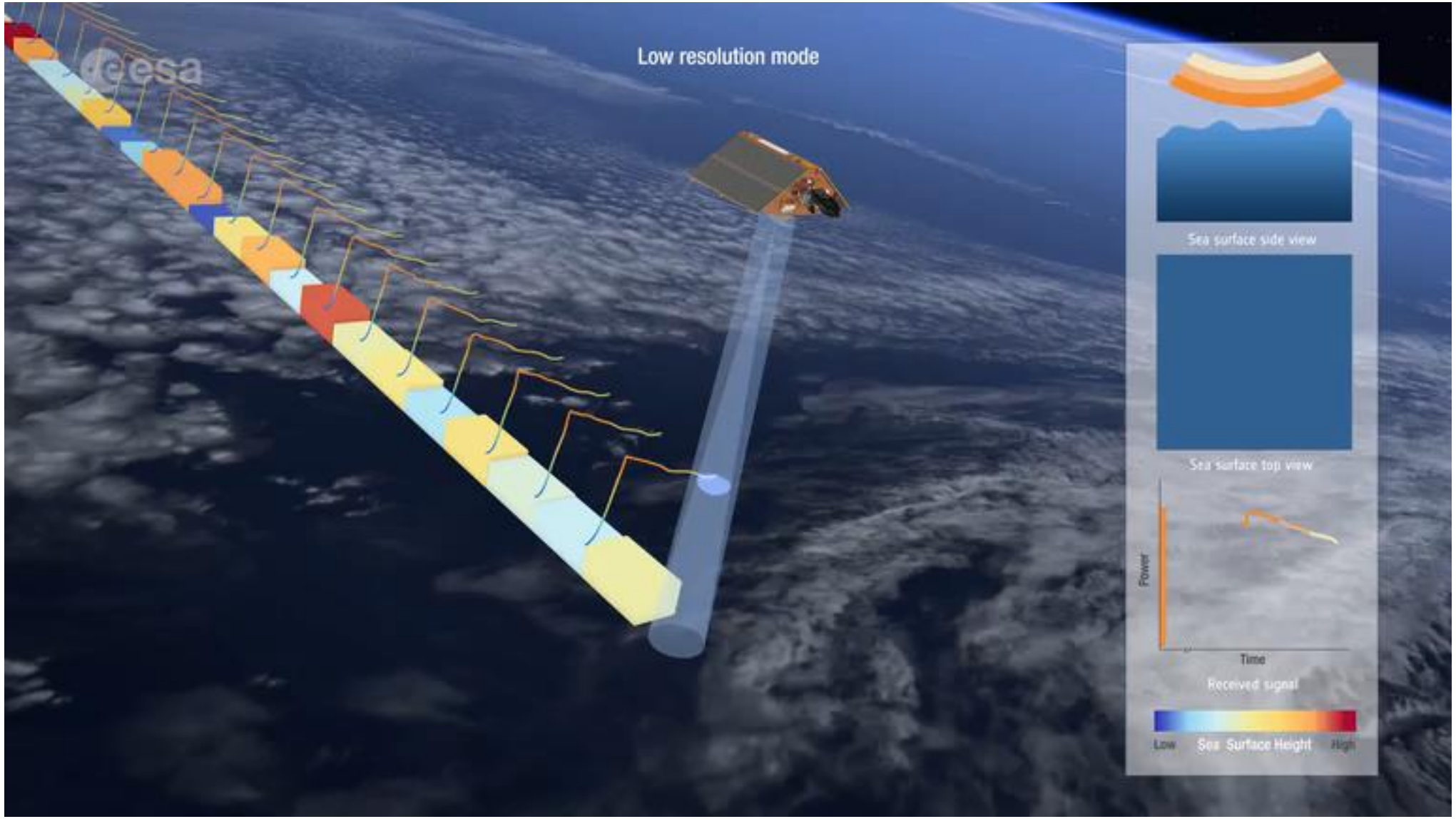
Altimetry

Altimetry measurement theory

- Altimeters measure sea surface height
- Time it takes for a radar pulse emitted from sensor to travel to surface, reflect, and be received by satellite.
- Low Resolution Mode (LRM) or **delayed doppler (SAR) mode**.
- Corrections for wet troposphere, dry troposhere, and ionosphere.
- Errors due to retracking, tides (esp on shelf) and fallible geoid characterisation.

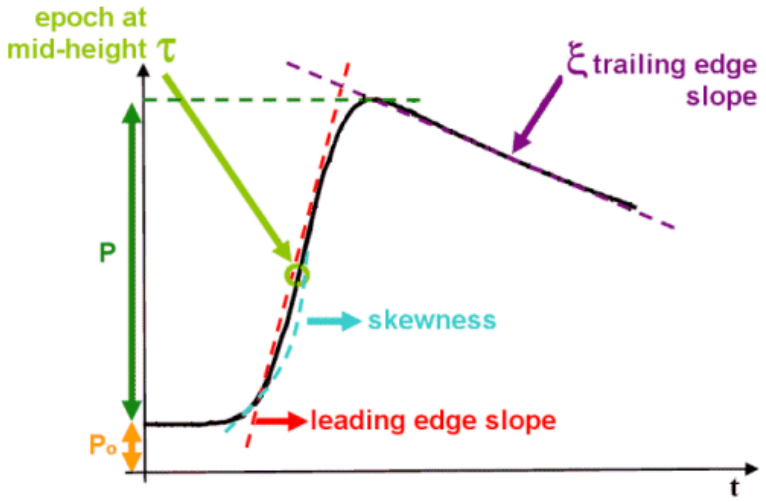


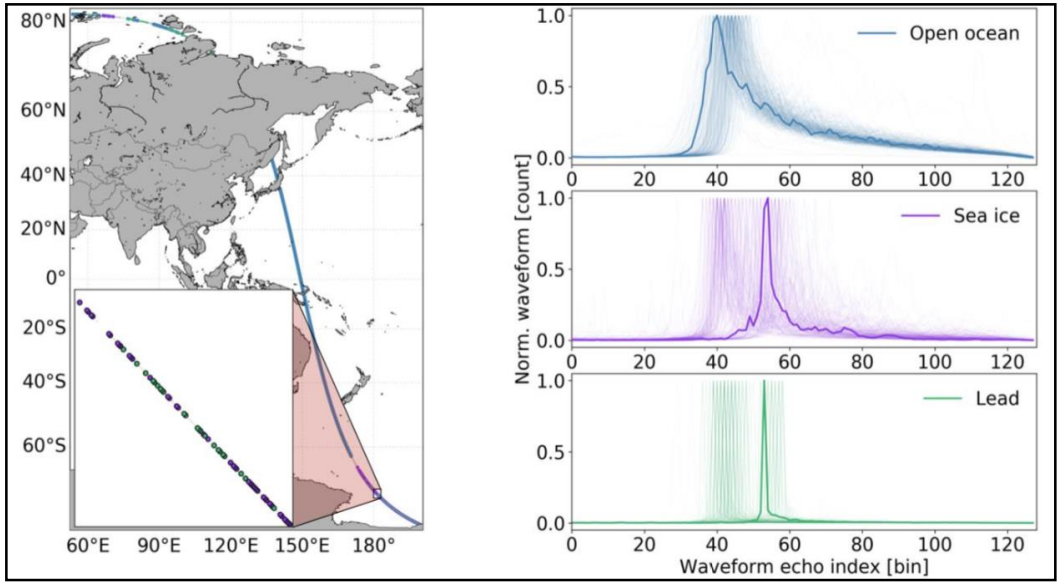
Altimetry measurement theory



Altimetry products

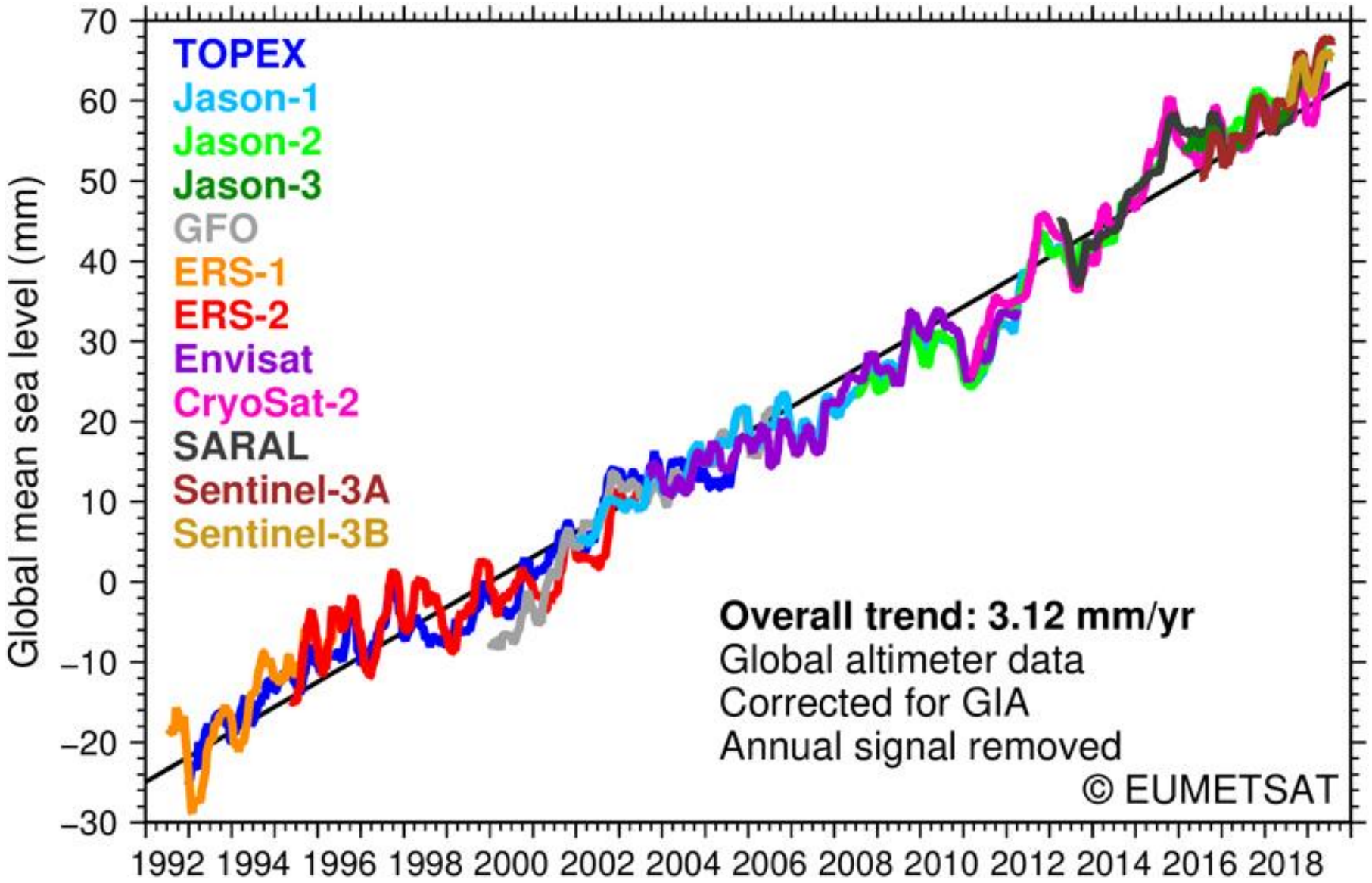
- **Products derived from the altimetry waveform:**
  - Sea-surface height (SSH). Difference in distance between the range (R) and the satellite altitude (S), relative to a terrestrial reference frame.
    - Need precision location & reference ellipsoid.
    - Accurate retracking to get R based on multiple waveforms. Varies for ocean, coast, sea ice. (related to τ)
  - Significant wave height: derived from leading edge slope of altimetry waveform
    - SWH = mean value of highest third of waves (related to LES)
  - Wind speed (not direction) – wind affects the roughness which affects the backscatter of the radar pulse and the amplitude of the waveform. (related to P)





Altimetry applications: Sea level change

Monitoring sea level change is a key task for Sentinel-3, Jason-3 and most notably Sentinel-6



Altimetry applications: Storm monitoring

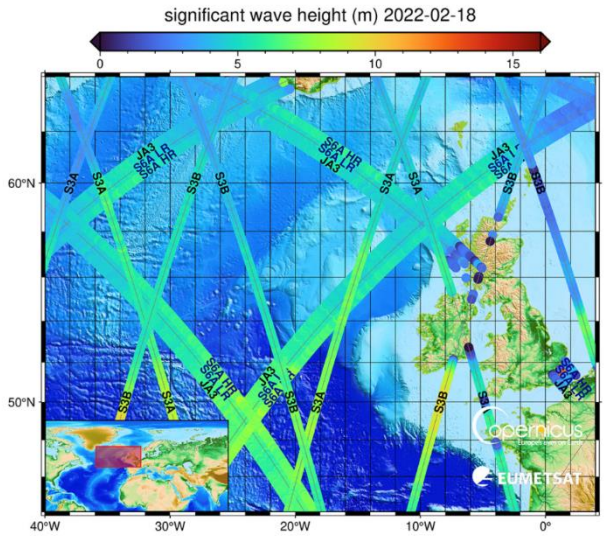


Figure 11a: Significant Wave Heights, 18 February

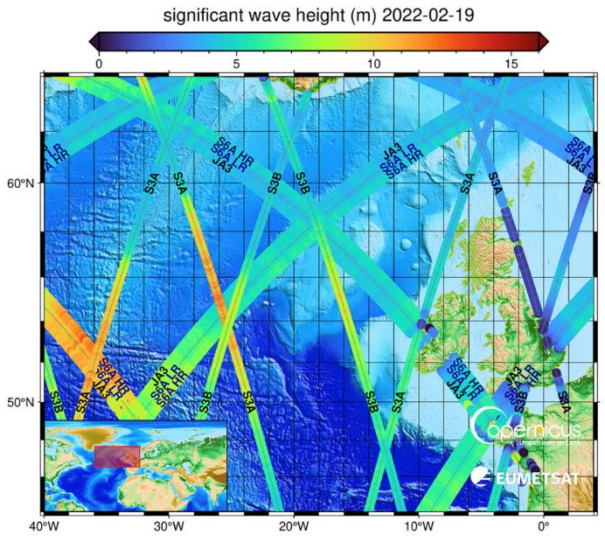


Figure 11b: Significant Wave Heights, 19 February

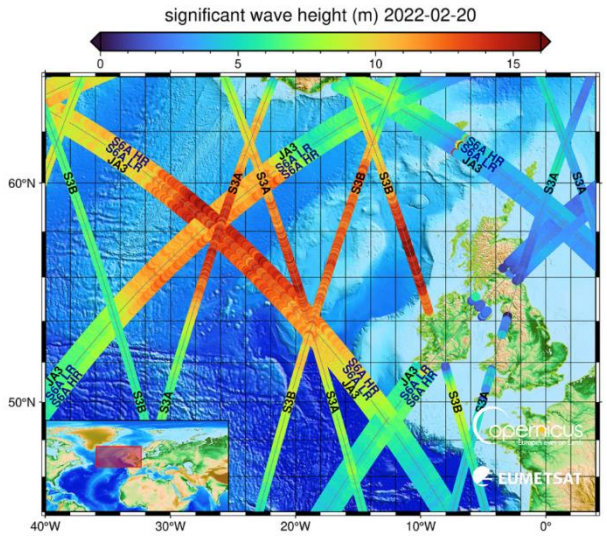


Figure 11c: Significant Wave Heights, 20 February

Significant wave height and wind speed measured from Sentinel-3, Jason-3 and Sentinel-6 over the North Atlantic; https://www.eumetsat.int/three-named-atlantic-storms-week

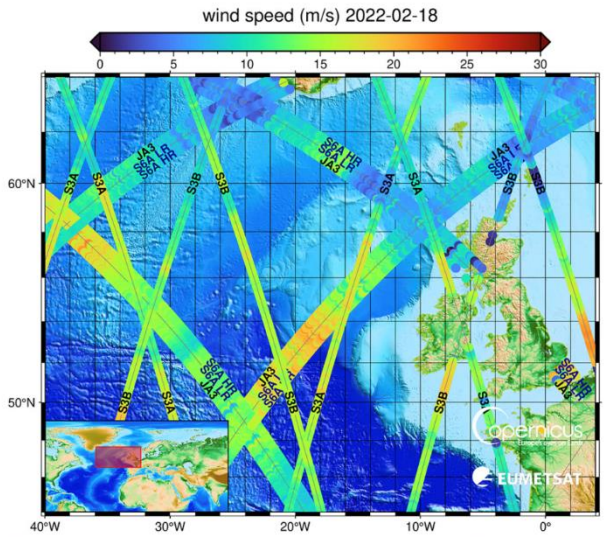


Figure 12a: Wind speeds m/s, 18 February

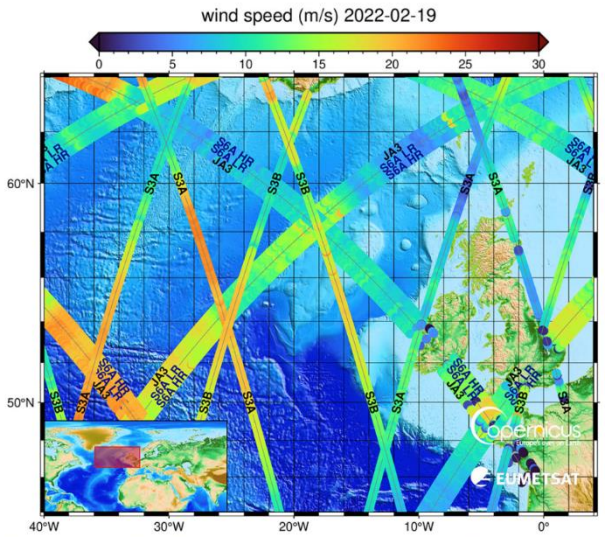


Figure 12b: Wind speeds m/s, 19 February

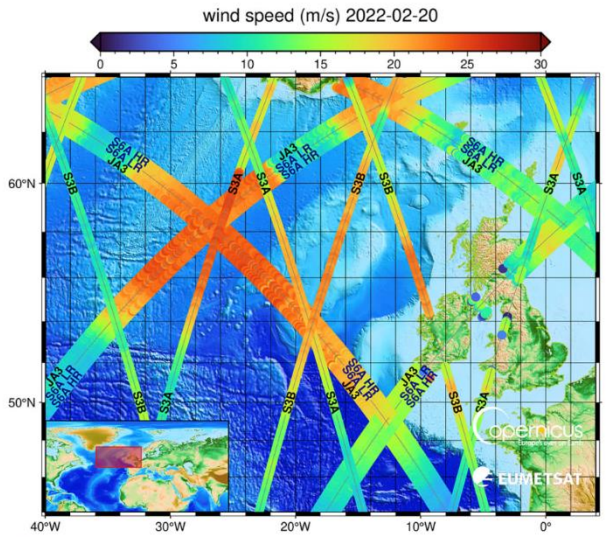


Figure 12c: Wind speeds m/s, 20 February

EUMETSAT Current Copernicus Data Access

EUMETSAT offers a range of data discovery and delivery mechanisms

Single sign on registration for online services at https://eoportal.eumetsat.int

For information on which products are available via which services, visit https://navigator.eumetsat.int

	EUMETCast	EUMETCast is a multi-service push dissemination system based on multicast technology. The multicast stream is transported to the user via satellite (EUMETCast Satellite) or terrestrial (EUMETCast Terrestrial) networks.
	Copernicus Online Data Access (CODA)*	CODA offers all Sentinel-3 products through a rolling buffer spanning the last 12 months of data. It can be accessed through its API and web-based GUI. https://coda.eumetsat.int. CODAREP also available for reprocessed data.
	Data Centre Long-Term Archive	An ordering application enables users to browse and select from the long-term archive of products including those from Sentinel-3 and https://archive.eumetsat.int/
	EUMETView	EUMETView is a visualisation service that allows users to view EUMETSAT and Copernicus data in an interactive way using an online map viewer. https://view.eumetsat.int/ (new version!)
	SFTP	Some Sentinel-6 data are provided through a rolling archive available on SFTP. Users can sign up for service access through their eoportal account

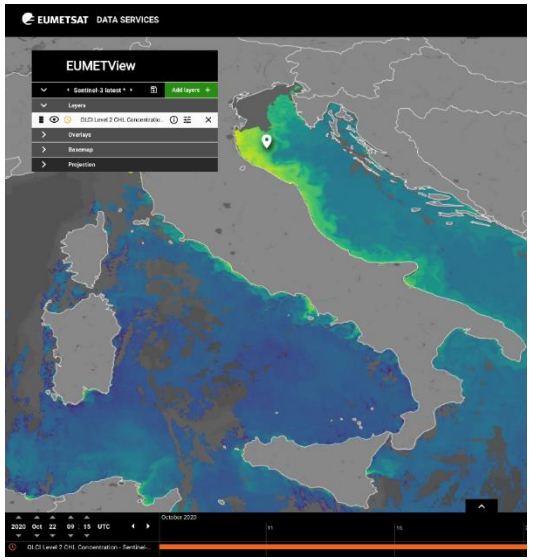
Sentinel-3 data is also available via the Copernicus DIAS services, including WEkEO

Where to get data ? And How?

- Various places – direct from operators, or downstream service providers (more detail in next slides).
- Growing array of cloud providers e.g. Copernicus DIAS – WEkEO
- Data accessible via web catalogues, visualisation portals, and more and more commonly through APIs.

New Data Access

- EUMETSAT is transitioning to suite of new data services
  - Data Store
  - Data Tailor (stand-alone and web)
  - New EUMETView
  - API access! See: https://gitlab.eumetsat.int/eumetlab/data-services



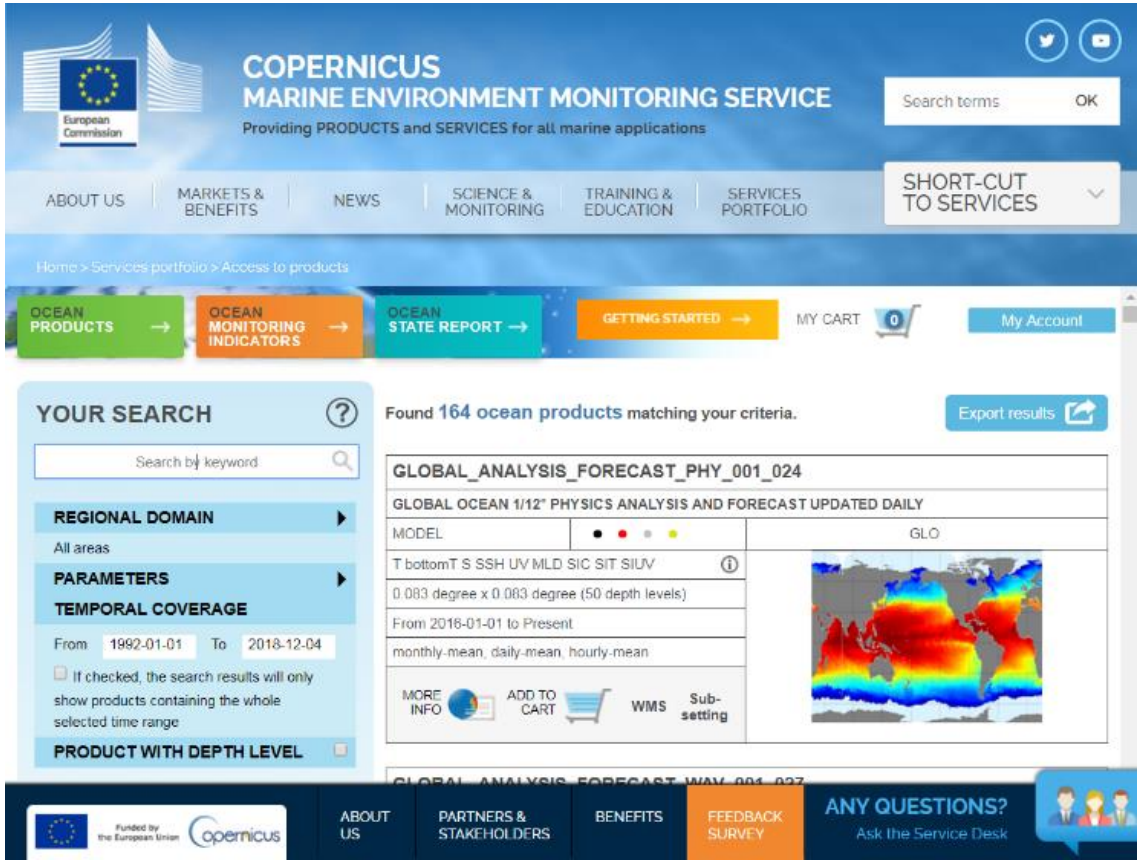
- A lot of EUMETSAT data already available
- Copernicus and SAF data will start to be integrated in to these new services more fully in early 2022.
- Copernicus data is also available through WEkEO, alongside cloud computing resources.

The Copernicus Marine Service

- http://marine.copernicus.eu
- Lead by Mercator Ocean International with many contributing organisations in Thematic Application Centres.
- Products from in situ, satellites, reanalysis and models.
- Includes: sea level, wind, waves, currents, temperature, chlorophyll, nutrients, and other biological parameters, sea ice.
- Data available through website (including data visualisation portal) and through WEkEO

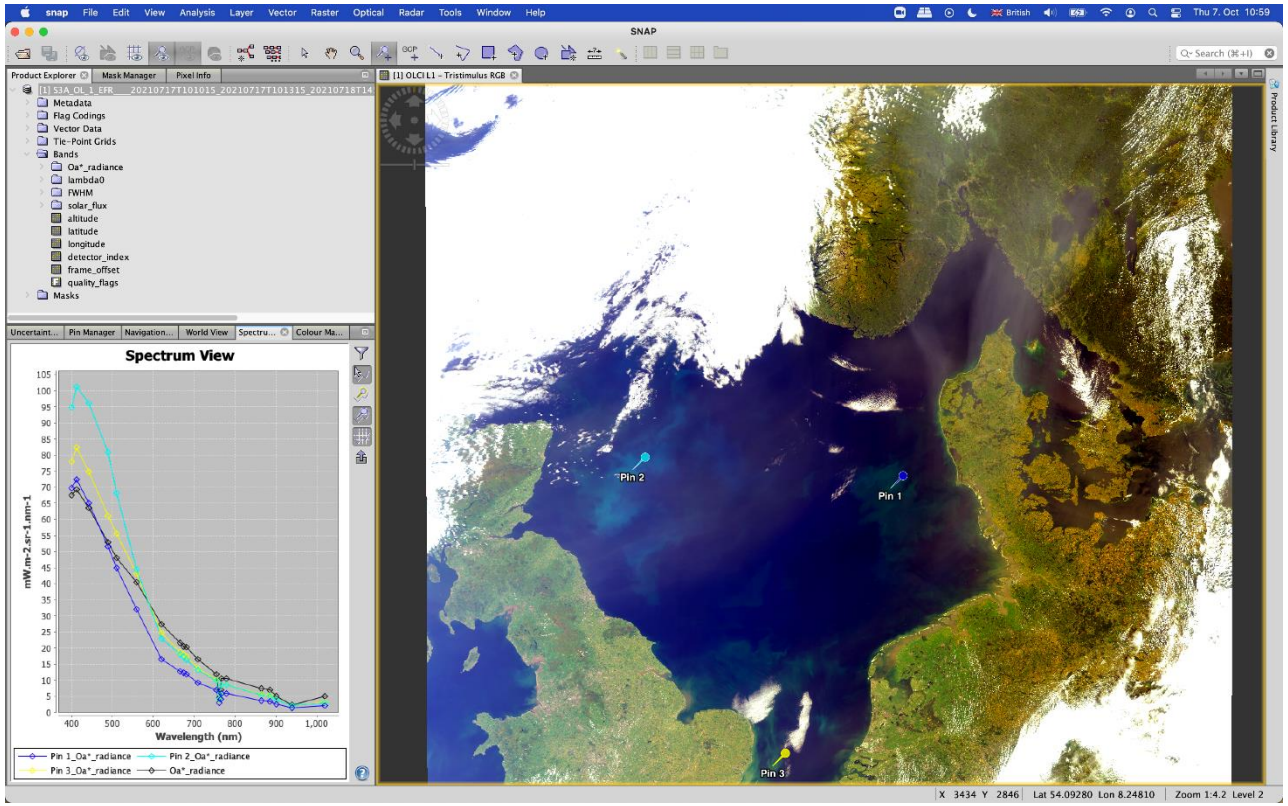
Copernicus Marine Service

MERCATOR OCEAN INTERNATIONAL



Working with the data

- Sentinel Application Platform (SNAP)
  - Open source software for working with Sentinel (and other) data
  - Open, view, interrogate data
  - Process using different algoritms
  - Conduct various common workflows – regrid, reproject, mosaic, convert etc.



Working with the data

- More advanced ways of working with ocean data through Python.
- Open source, many libraries, many examples.
- Easy to use in hosted settings (e.g. JupyterHubs/Labs)
- Check out:
  - www.gitlab.eumetsat.int/eumetlab (code)
  - www.wekeo.eu – free JupyterLab with examples

Demonstration

Further information and support on using EUMETSAT data

- EUMETSAT website – www.eumetsat.int
- Twitter: @eumetsat, @eumetsat_users
- Helpdesk – email: ops@eumetsat.int

- New knowledge base for user support (in development): https://eumetsatspace.atlassian.net/wiki/spaces/EUM/overview

- Training:
  - Visit https://training.eumetsat.int for courses
  - email: copernicus.training@eumetsat.int

- Copernicus MOOCs
  - www.atmospheremooc.org
  - www.oceansfromspace.org

- EUMETSAT YOUTUBE: www.youtube.com/user/EUMETSAT1/featured
- Science stories: https://scienceblog.eumetsat.int/
- Copernicus Podcasts: https://audioboom.com/channels/5011622

Thank you!

Questions are welcome.