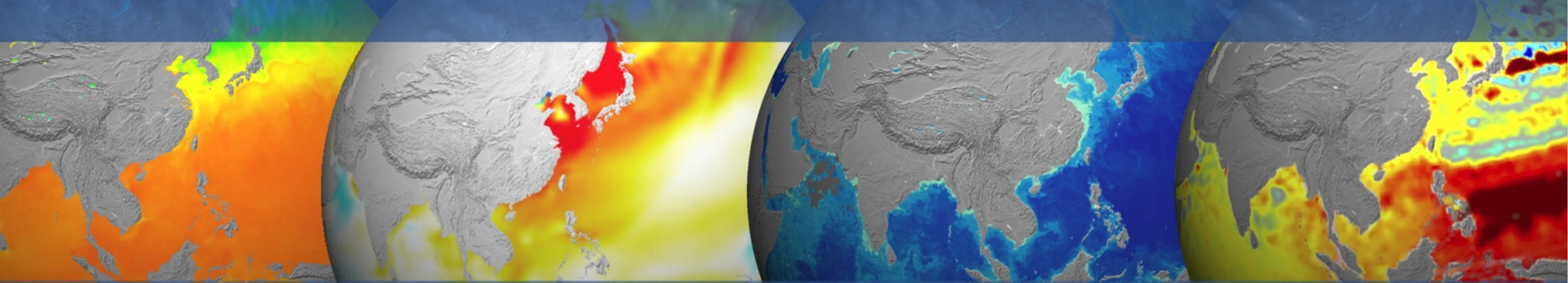
ESA–MOST China Dragon 4 Cooperation

→ ADVANCED TRAINING COURSE IN OCEAN AND COASTAL REMOTE SENSING



12 to 17 November 2018 | Shenzhen University | P.R. China

Sea Surface Temperature and Intro to S3 SLSTR

Francesco Nencioli (Plymouth Marine Laboratory)

Hosted by

Welcome

Francesco Nencioli
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Remote Sensing Group
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Twitter: @f_nencio

PML | Plymouth Marine Laboratory

Research expertises

Physical dynamics and physical-biogeochemical interactions at the (sub)mesoscale using in-situ, remote sensing and numerical model data

Research experience

2004 — ***Laurea* thesis** (*Equivalent to a MS*)
University of Bologna (Italy)

2005 – 2010 — **PhD**
University of California Santa Barbara

2010 – 2014 — **Postdoc + Marie Curie IEF Fellowship**
Mediterranean Institute of Oceanography, Marseille

2014 — **CNES Postdoc (Oct - Dec)**
Laboratoire de Physique des Oceans, Brest

2015-now — **Researcher**
Plymouth Marine Laboratory

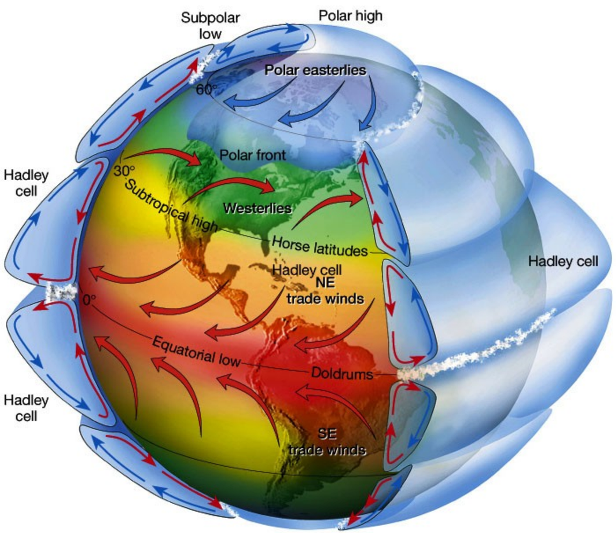
Outline

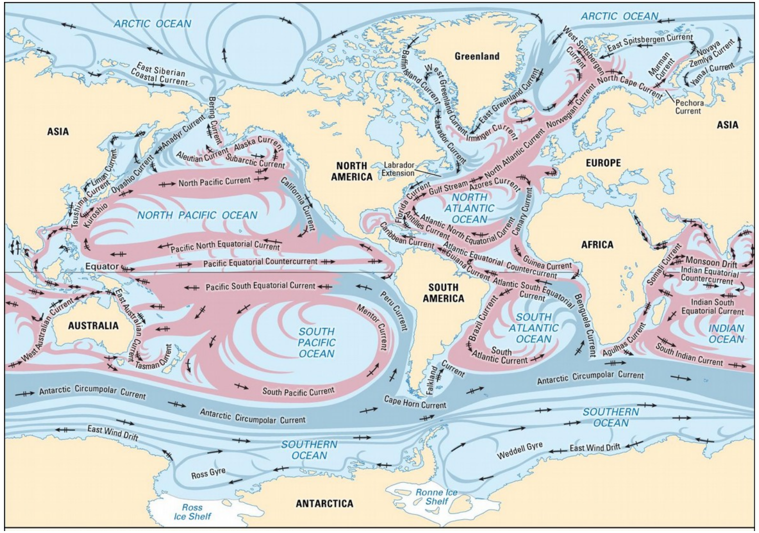
- Importance of sea surface temperature
- Brief historical overview of remote sensing SST
- Definition of “Surface” in SST
- How to measure SST from space
- Sentinel-3 SLSTR
- Characteristics of the Yellow and East China sea

Why sea surface temperature

Heat is the main fuel of atmosphere and ocean dynamics

Solar radiation ⇨ Atmosperic circulation ⇨ Wind-driven ocean circulation



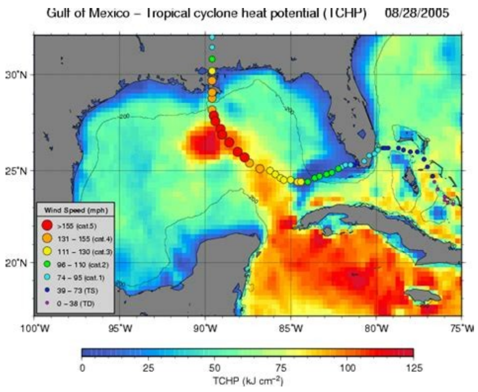


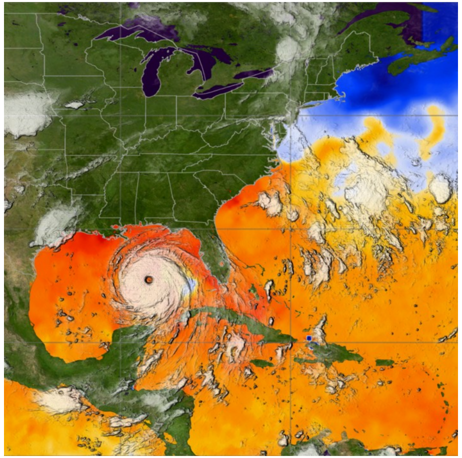
SST can identify **warm** and **cold** surface currents

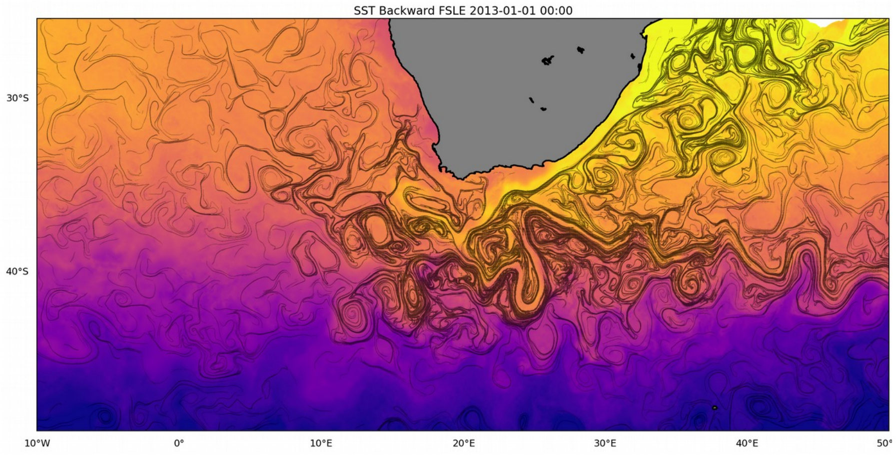
Why sea surface temperature

SST field influences many physical and ecological processes

1. **Hurricane intensification** over warm surface waters (e.g. Hurricane Katrina in Gulf of Mexico)





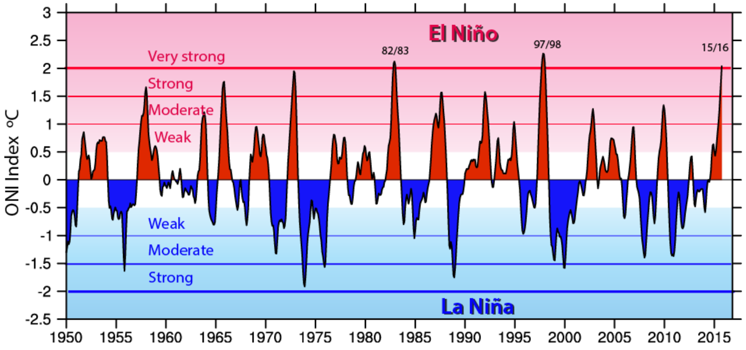


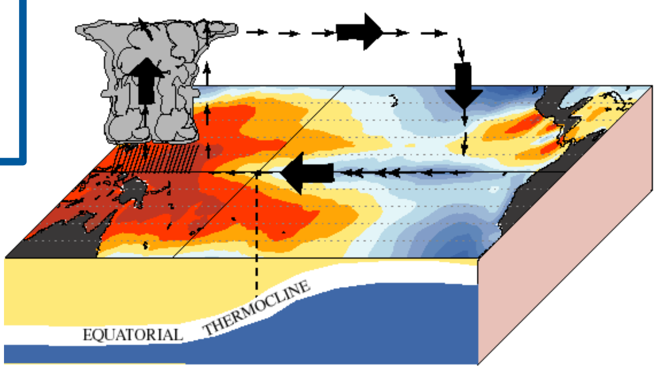
2. Ocean fronts can affect **spatial distribution of marine ecosystem** (e.g. more phytoplankton → fish → fishing activity)

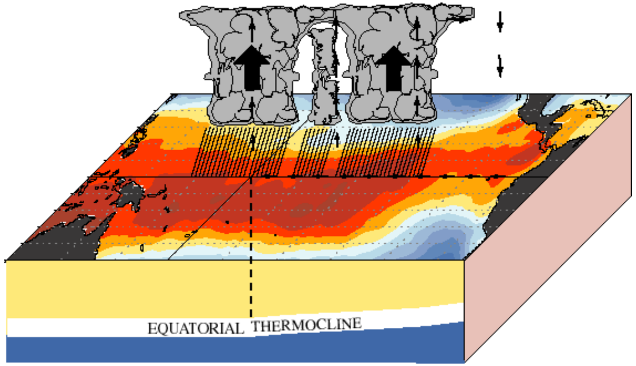
SST is an **essential climate variable**: used to monitor **cycles and trends**

1. El-Nino southern oscillation (ENSO)

ENSO indices include SST differences between western and eastern equatorial pacific



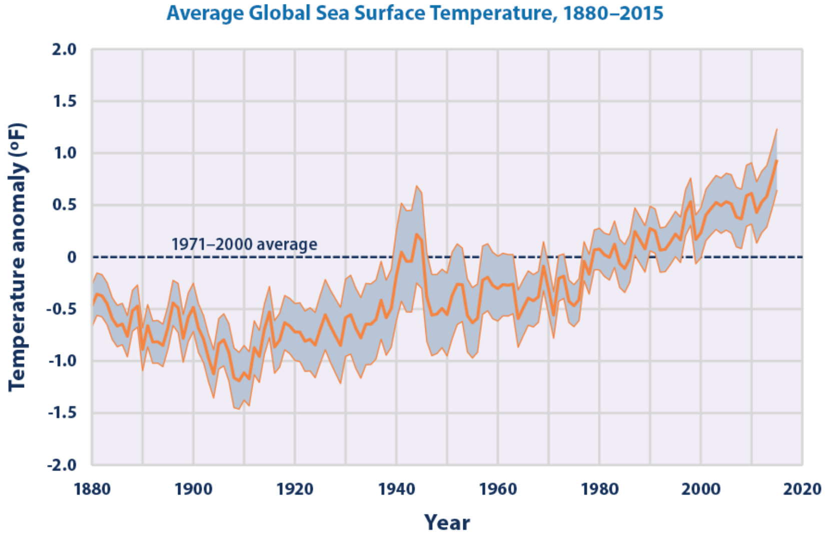


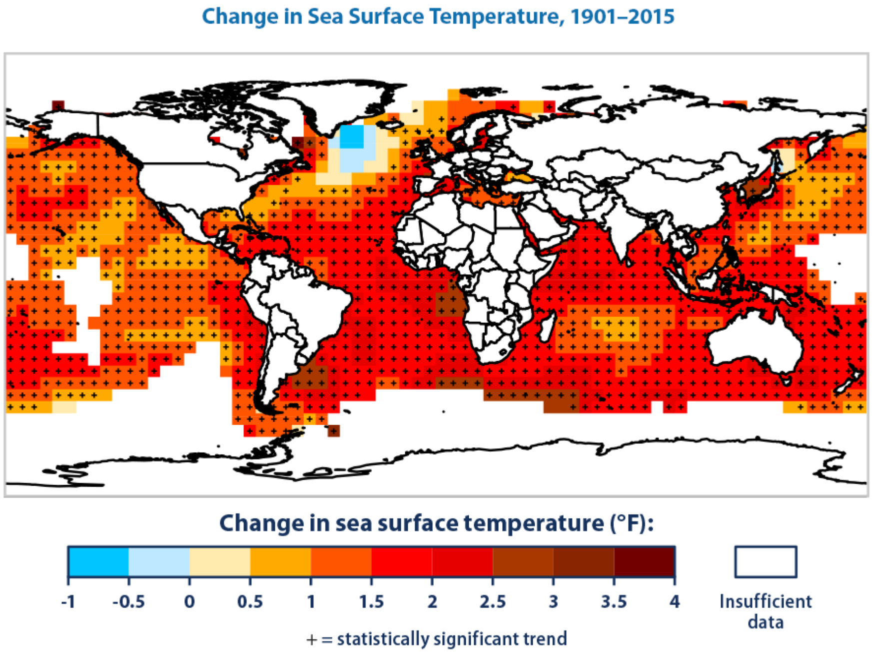


Source: Intergovernmental Panel on Climate Change (IPCC: https://ipcc.ch/)

SST is an **essential climate variable**: used to monitor **cycles and trends**

2. Global warming

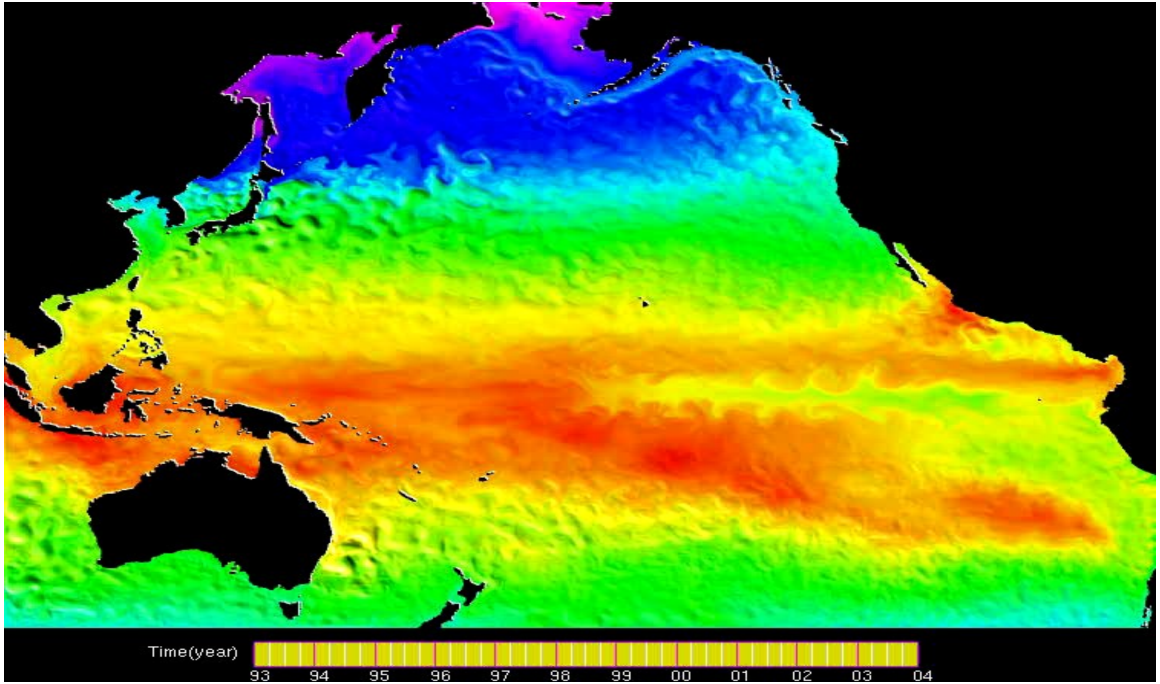




Why sea surface temperature

Example: Pacific ocean SST from numerical simulation

- ROMS Model
- 12.5 km resolution
- Real-time forcing: 1-day (NCEP reanalysis 1950-2004)
- Jet Propulsion Laboratory



→ (Courtesy of Yi Chao)

SST signature associated with certain currents already well know in the past

Example:

- Chart of North Atlantic currents published by **Benjamin Franklin** and Timothy Folger in **1770**

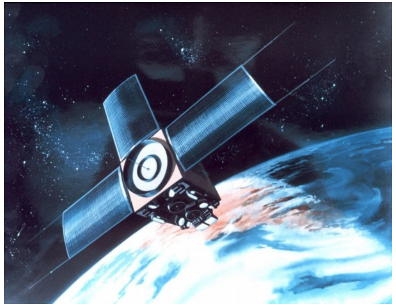
- Gulf Stream indicated by surface flow as well as by the associated **temperature gradients**

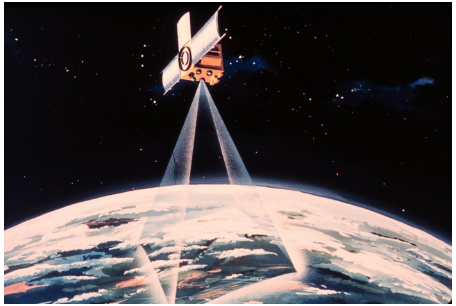
Brief historical overview

First satellite images of SST from Very High Resolution Radiometer (VHRR) on the NOAA-3 Satellite (ITOS/Tiros-M)

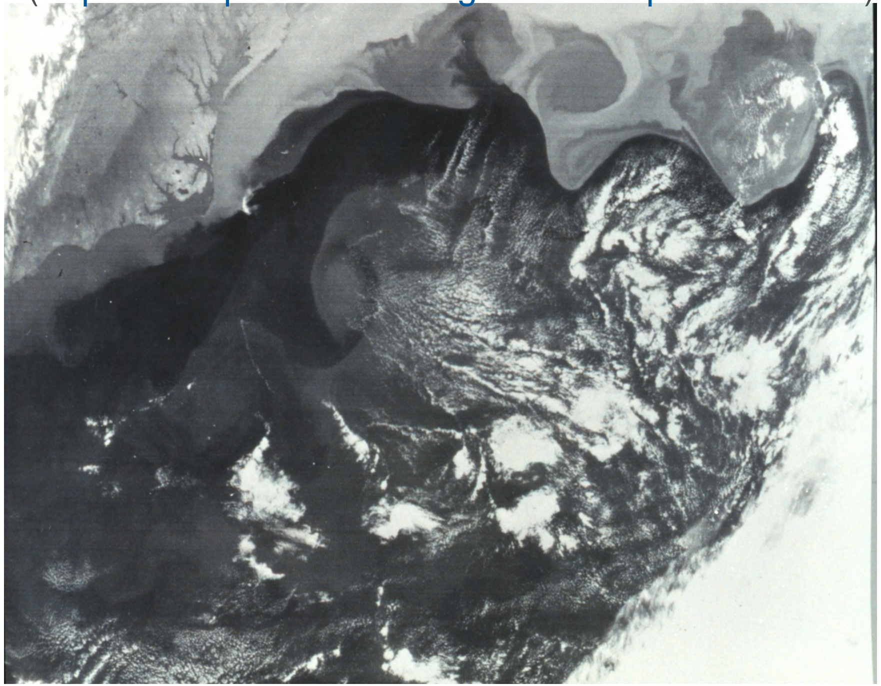
Example
Gulf Stream (seen as dark water)
April 28,1974

→ Synoptic view provides much more details than in-situ observation





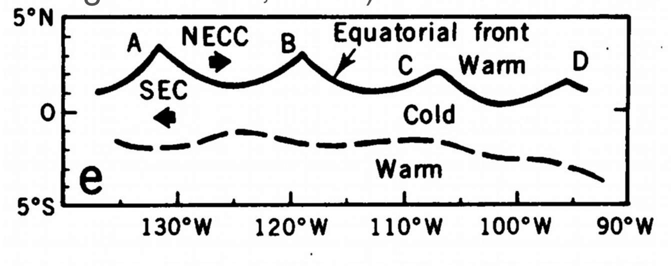
(http://www.photolib.noaa.gov/htmls/spac0301.htm)

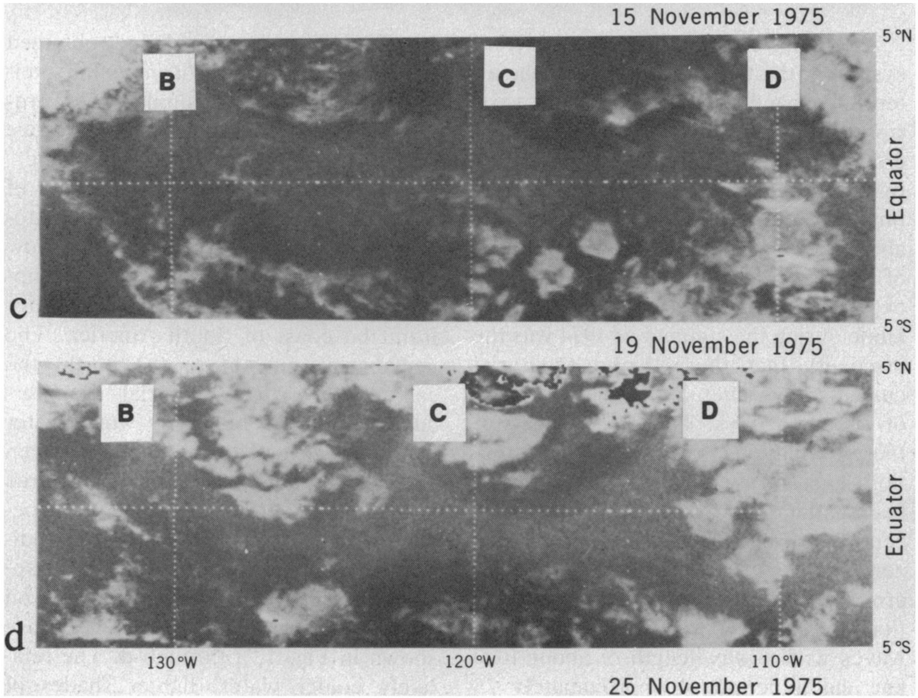


Not only large scale currents
Satellite SST revealed also smaller scales processes (e.g. mesoscale)

Example
Tropical instability waves (TIWs)
Eastern Equatorial Pacific Ocean

(from Legekis et al., 1977)

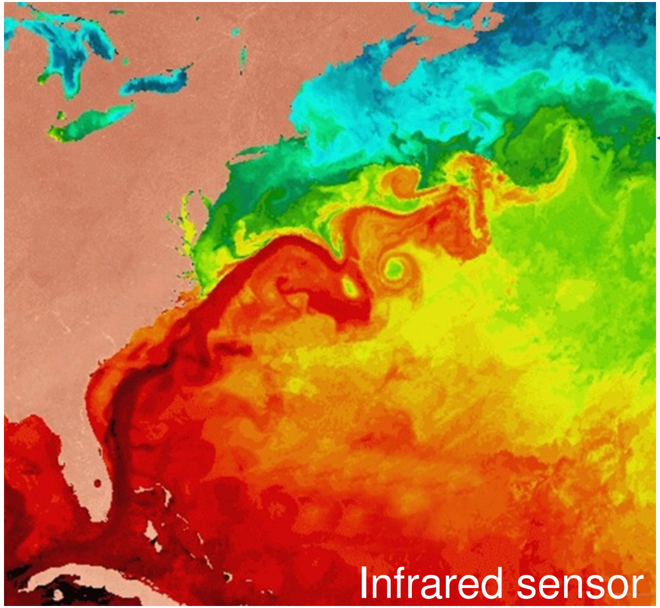


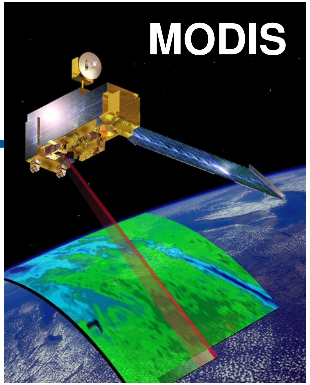


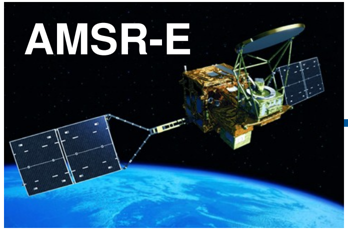
Brief historical overview

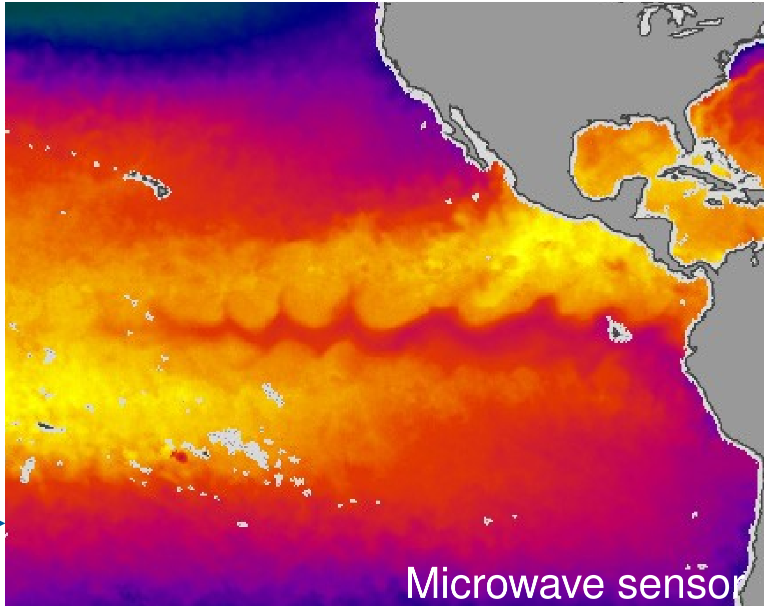
Same regions nowadays

New satellite missions and sensors: improved resolution and data quality

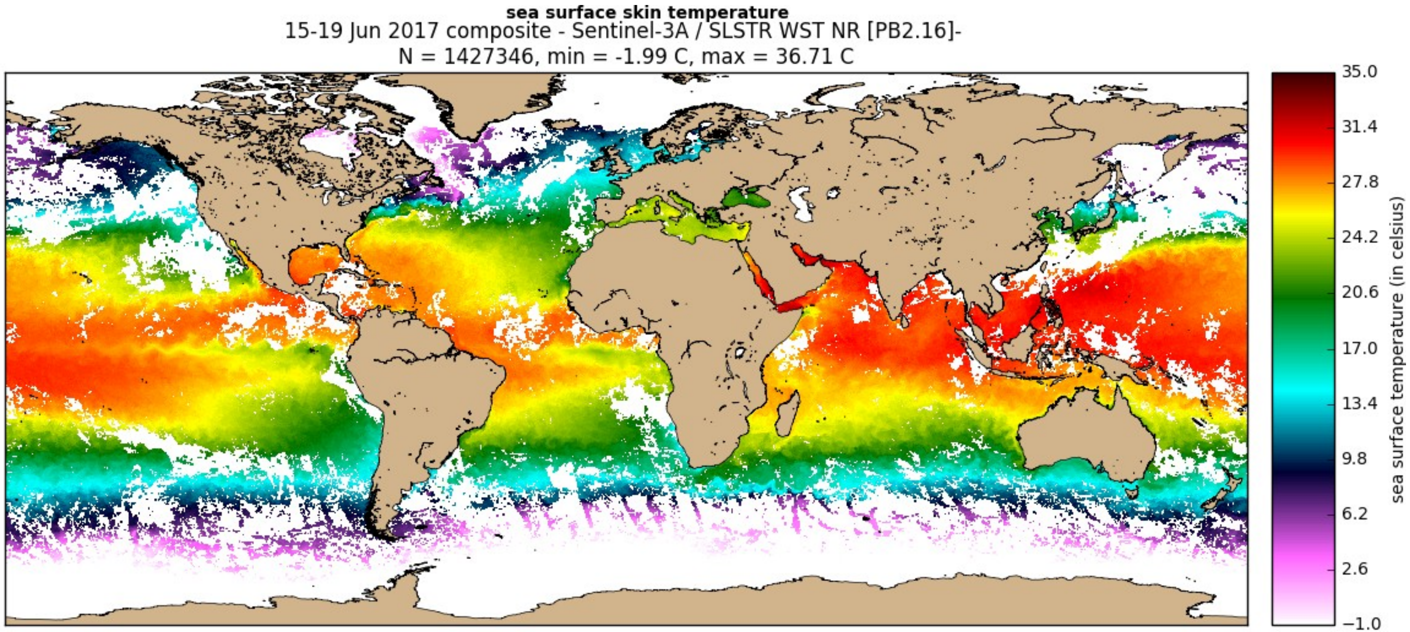








Satellite passes combined to retrieve global maps
Example: 4-day composite map from Sentinel-3 SLSTR



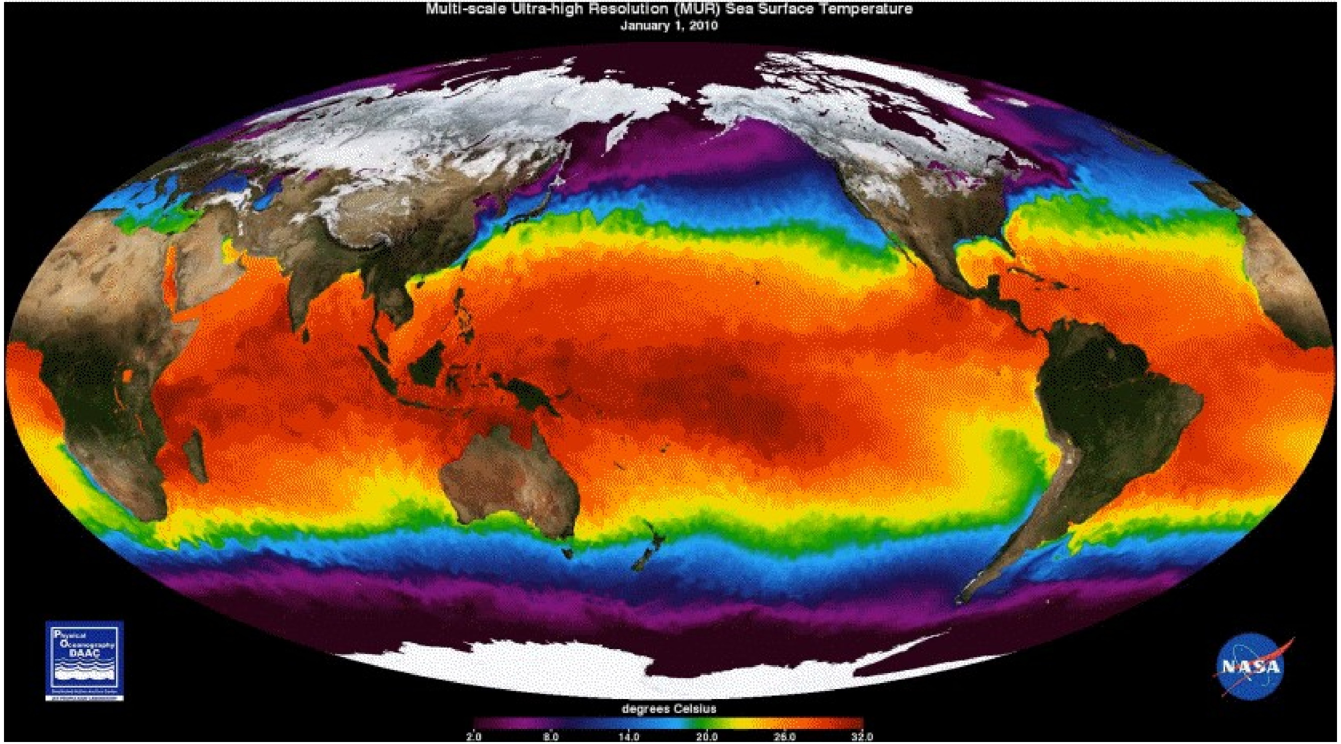
Brief historical overview

Improved coverage with merged products (L4):

- Combine all available satellites (polar and geostationary)
- Merge different sensors and resolutions

Examples:

1. Multi-sensor Ultra-high Resolution (**MUR**) SST (mur.jpl.nasa.gov)
2. Operational SST and Sea Ice Analysis (**OSTIA**) (ghrsst-pp.metoffice.com)

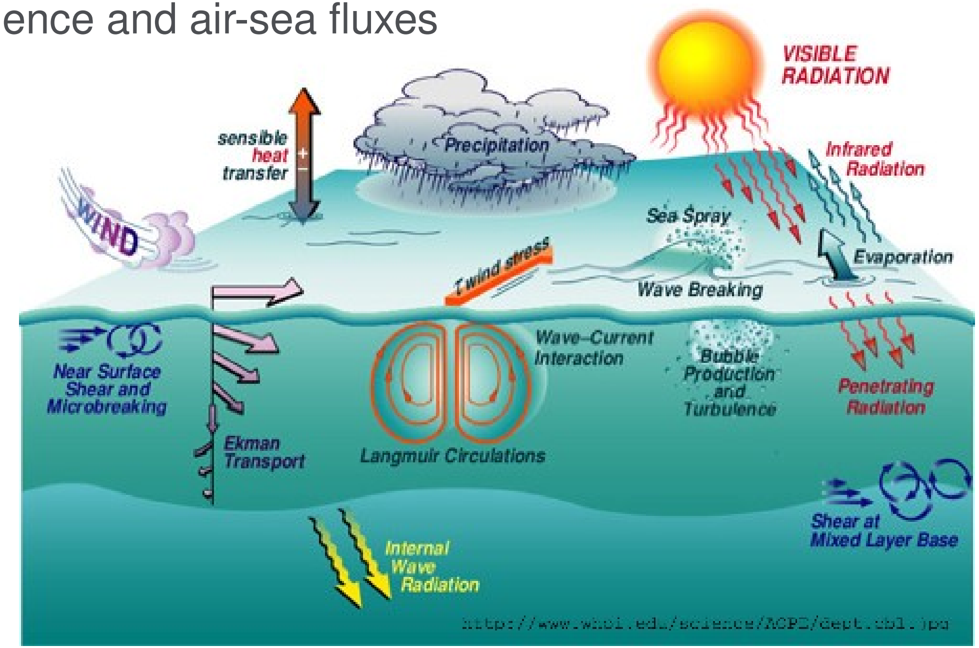


What is “Surface” in SST?

Not a trivial definition:

→ Upper 10m of the ocean have complex and variable structure

→ Impact of ocean turbulence and air-sea fluxes

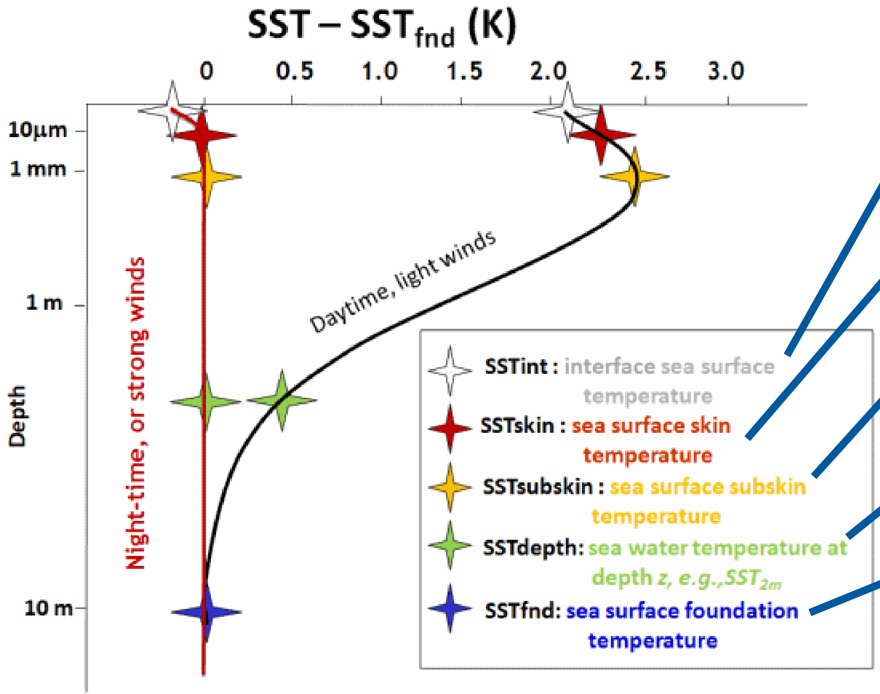


What is “Surface” in SST?

“Surface” definition varies depending on the **platform of observation**

More than just satellites!!!

What is "Surface" in SST?

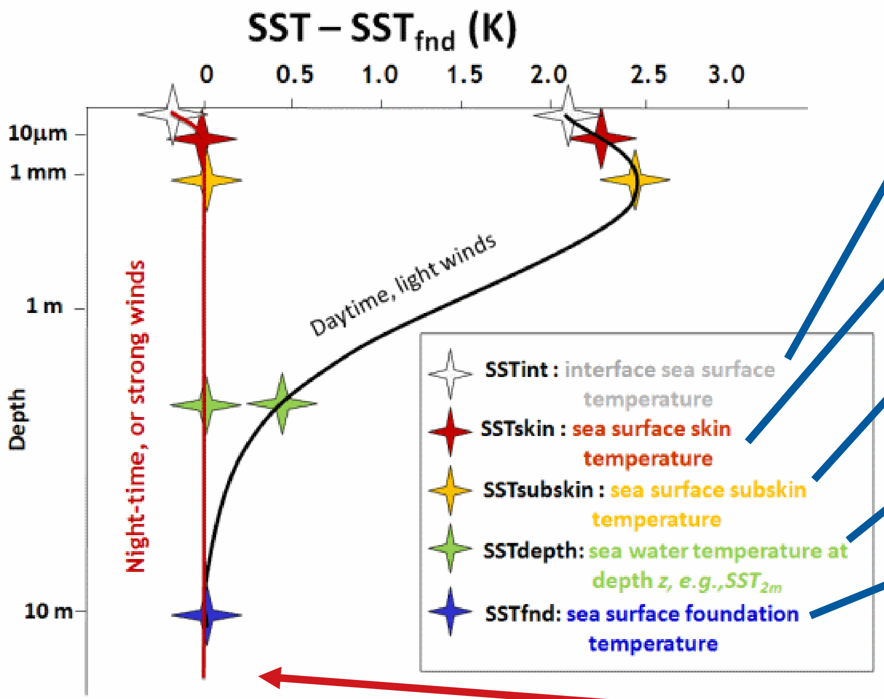


From https://www.ghrsst.org

5 definitions of SST adopted by the GHRSST
(Group for high resolution sea surface temperature)

1. **Air-sea interface**: cannot be masured (no practical use)
2. **10-20 µm**: conductive diffusion-dominated sub-layer (measured by **infrared radiometers**)
3. **1-2 mm**: base of conductive laminar sub-layer (measured by **microwave radiometers**)
4. **cm to m**: turbulent sub-layer (measured by **in-situ platforms**)
5. **O(10)m**: free of diurnal variability (depth varies depending on local conditions)

What is “Surface” in SST?



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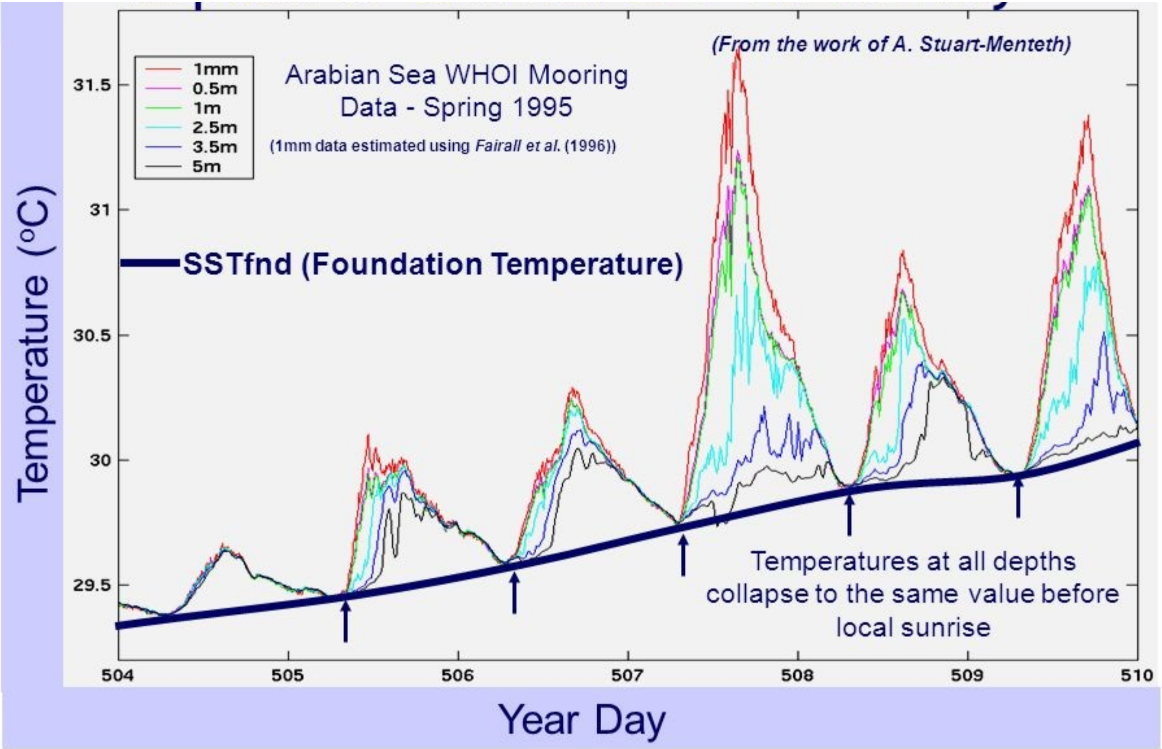
For high-winds and at pre-dawn 2 to 5 are all the same!!!

What is “Surface” in SST?



Example: Daily cycle of surface temperature at different depths

- SSTfnd can only be estimated from in-situ observations
- Anaysis procedures to convert remote sensing observations to SSTfnd

(Image courtesy of Craig Donlon)

How to measure SST from space

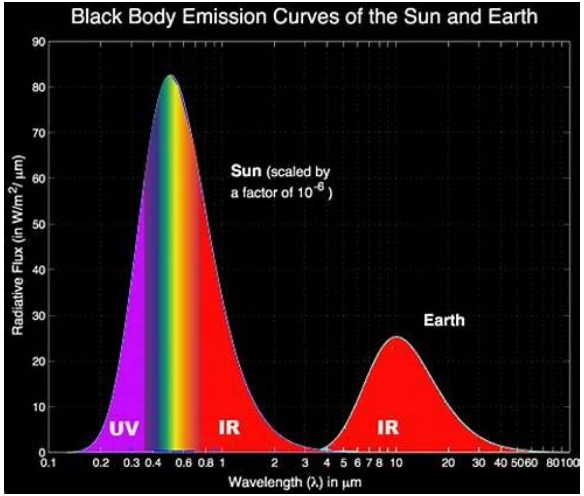
- Passive measurement: derived from **top of atmosphere (TOA) radiation**
- Radiation **emitted** by earth surface (not reflected like OC!!!)

Earth emits energy because it has a temperature

Energy emitted according to **Planck's law** (black body radiation):

$$B_\lambda(\lambda, T_b) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_B T_b}} - 1}$$

K_B = Boltzmann const.
λ = Planck's constant
c = speed of light



Emitted energy and peak of emission function of body temperature:

1. Energy decreases (rapidly) with decreasing body temperature
2. Peak shifts to longer wavelengths for decreasing body temperatures

$$T_b = \epsilon T$$

T_b = brightness temperature
T = surface temperature
ε = emissivity (from 0 to 1)

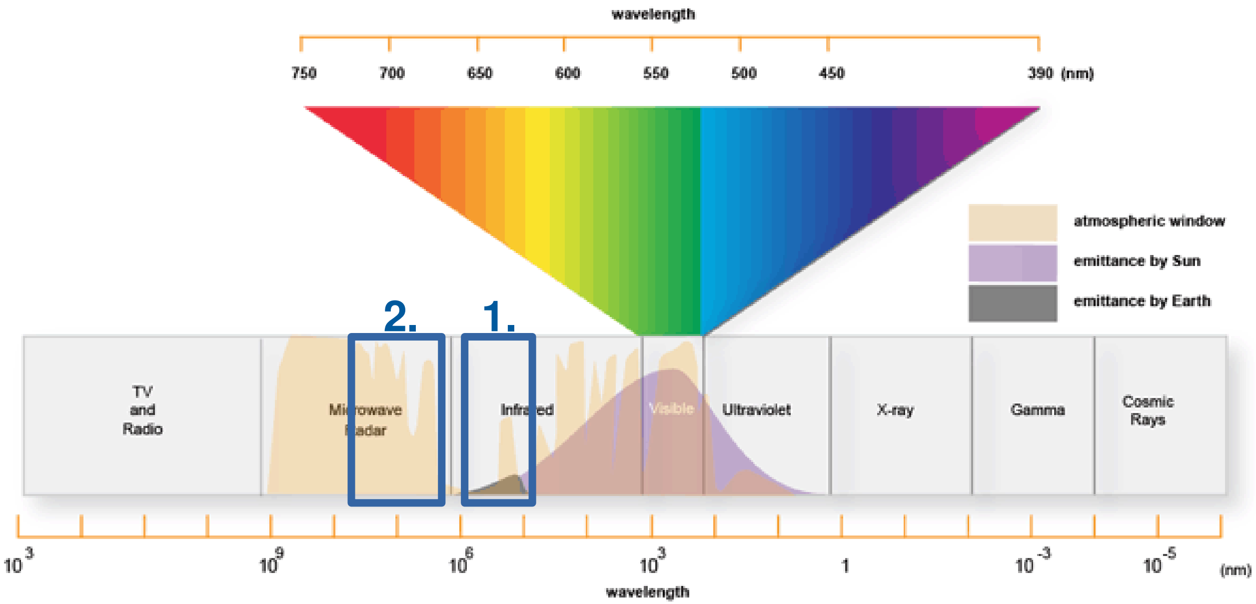
How to measure SST from space

TOA radiation measured in bands with high atmospheric transmittance

Two main type of sensors:

1. Infrared radiometers

2. Microwave radiometers



How to measure SST from space

TOA radiation measured in bands with high atmospheric transmittance

Two main type of sensors:

1. Infrared radiometers

Wavelenghts: 1 to 10 µm

High energy (near earth emission peak)

- ➔ High resolution
- ➔ Sensitive to clouds

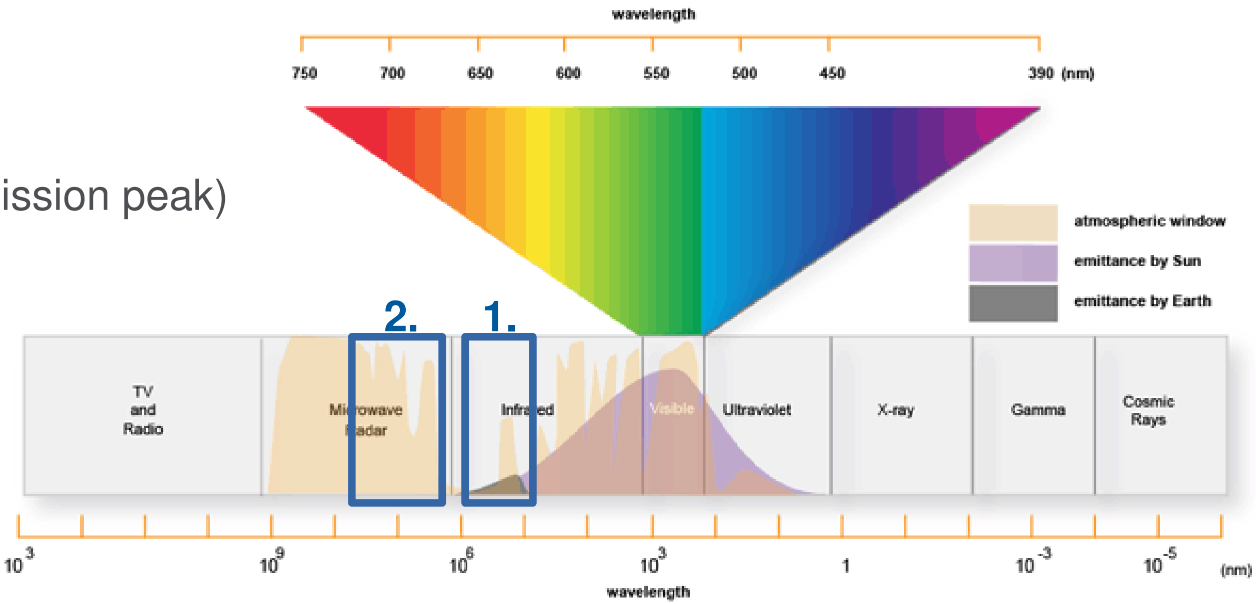
2. Microwave radiometers

Wavelengths: 0.1 to 1cm

Frequencies: 4-11GHz)

Low energy

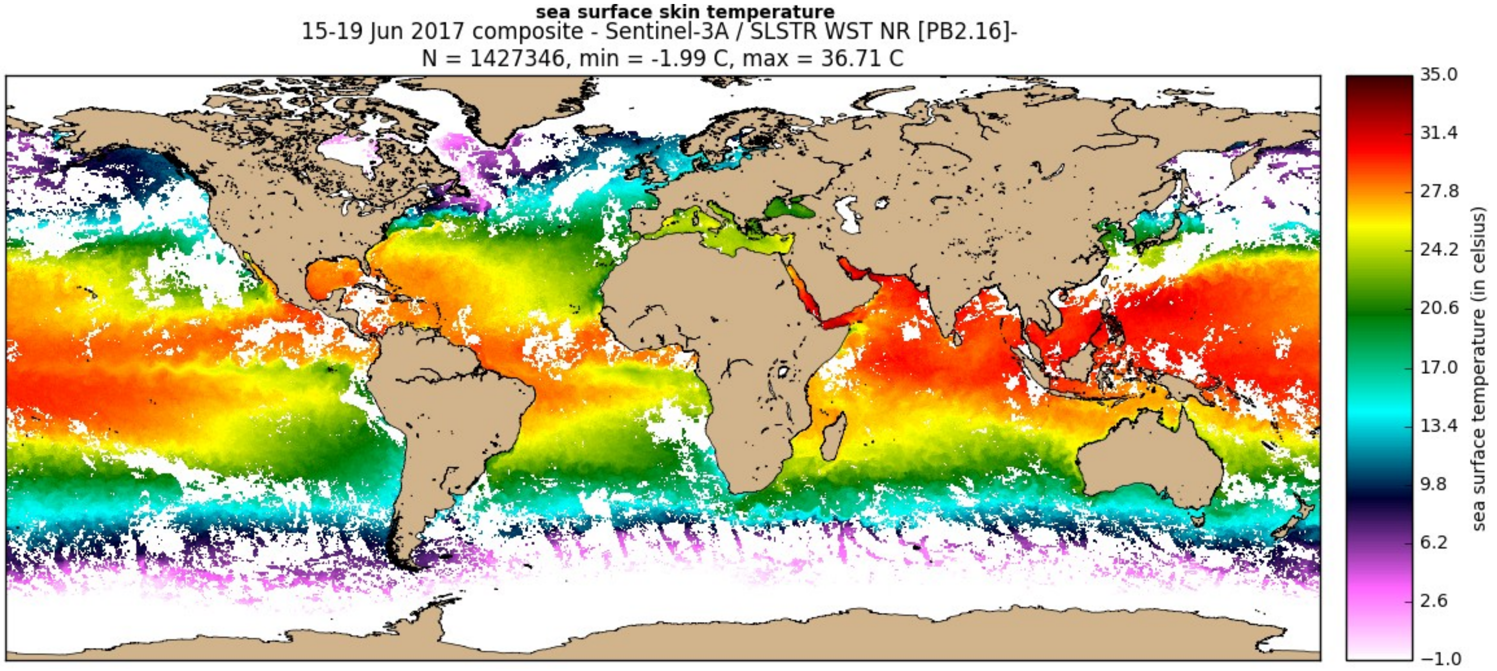
- ➔ Low resolution
- ➔ Sensitive to wind and rain (**but no clouds**)



How to measure SST from space

Global IR SST 4-day composite map (from Sentinel-3 SLSTR)

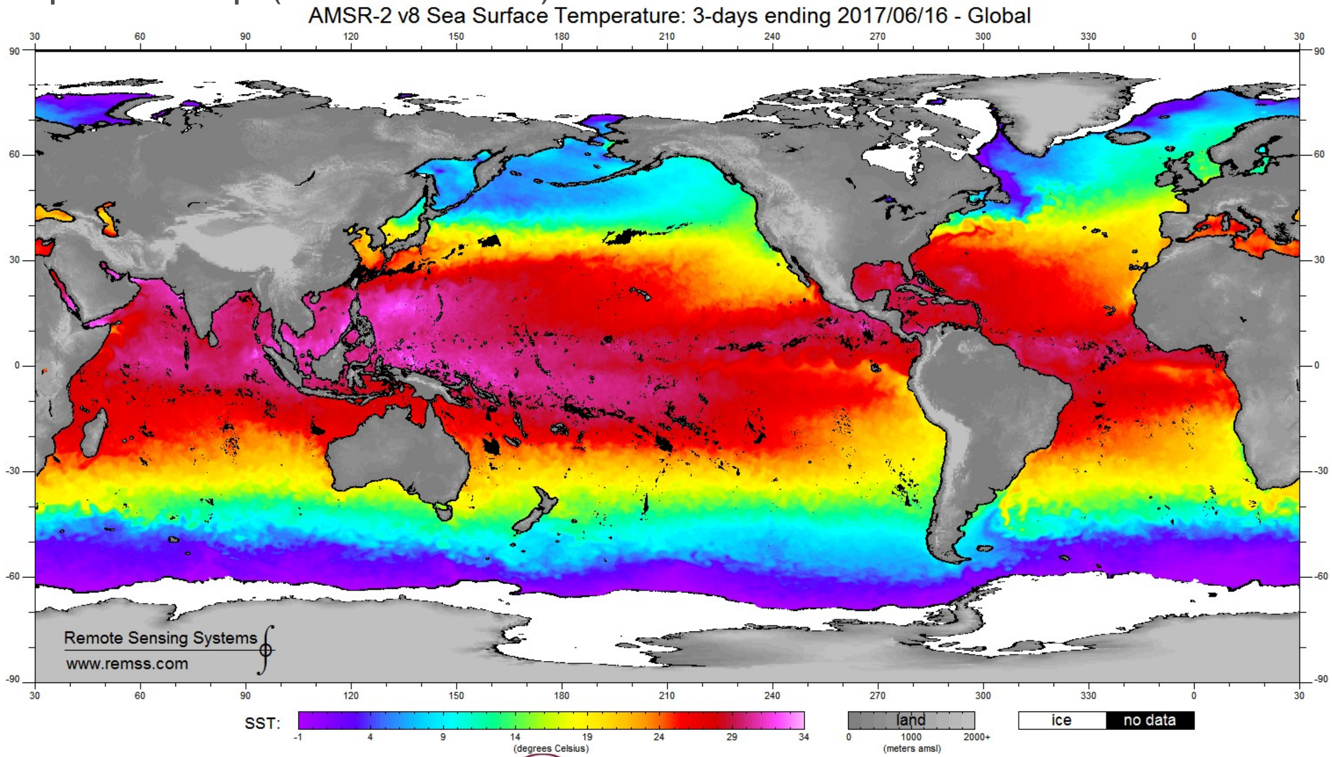
- Main circulation features represented with high level of details
- Gaps due to cloud cover



How to measure SST from space

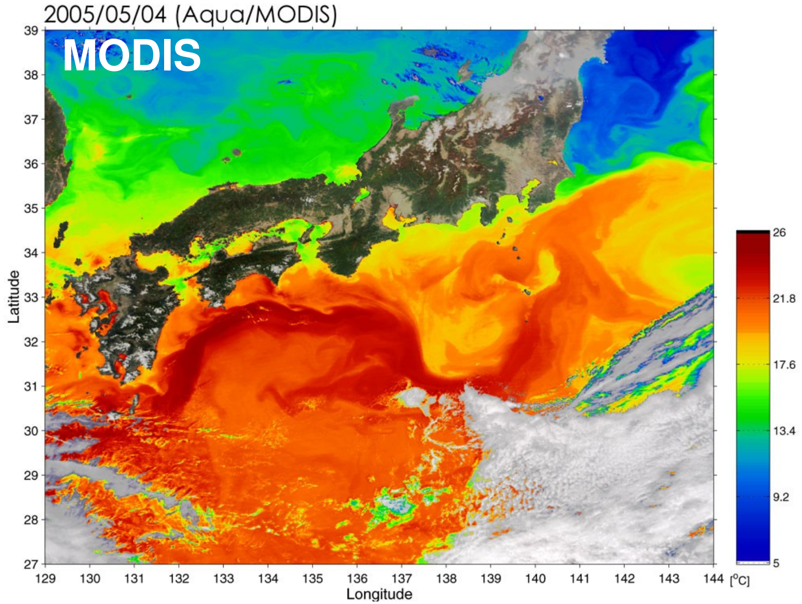
Global MW SST 4-day composite map (from AMSR-2)

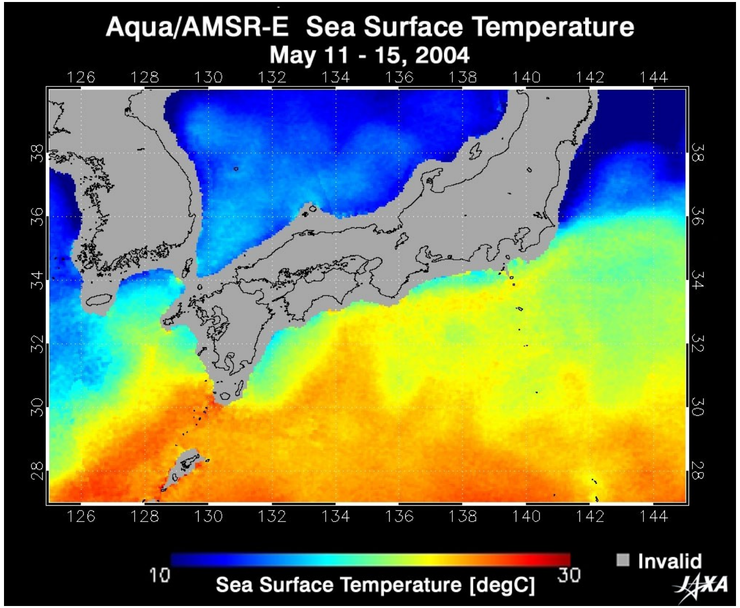
- Reduced gaps due to clouds
- Main ocean circulation features are resolved
- Much improved coverage in polar regions



How to measure SST from space

Comparison of MW to IR at **smaller scales** (example Kuroshio extension; different dates!!!)





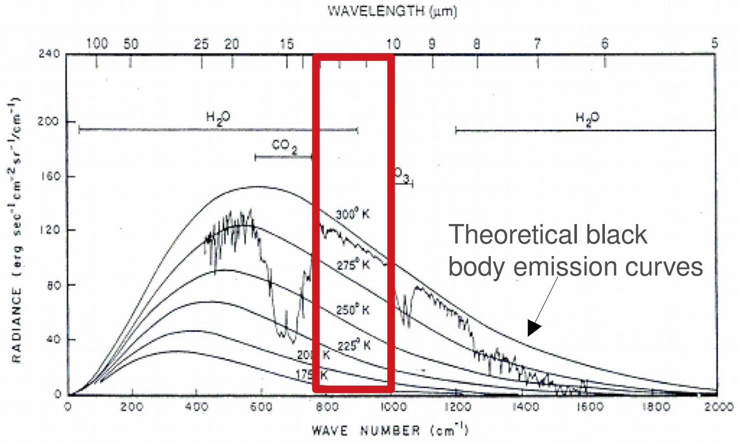
➔IR is affected by clouds but much richer in details
(can resolve much smaller process; e.g. eseddies and filaments)

How to measure SST from space

More on infrared measurements (used by SLSTR):

- SST derived from 3 Bands
  (S7 to S9: 3.74, 10.85 and 12 µm)
- Region with little influence by other source/sinks...
- ...but gradients in emitted radiance

TOA IR Radiance



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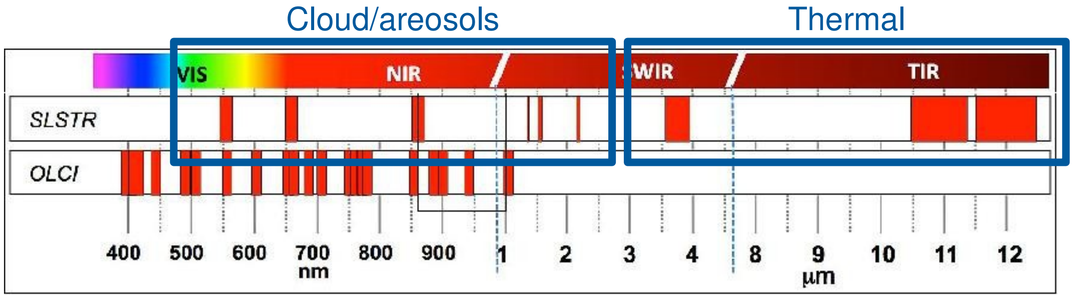
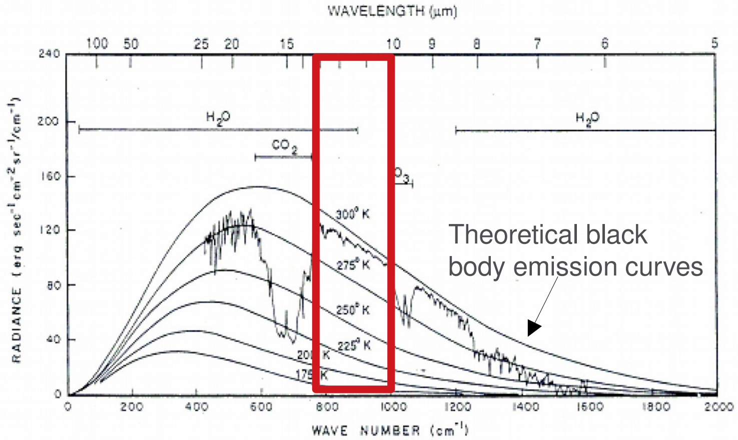


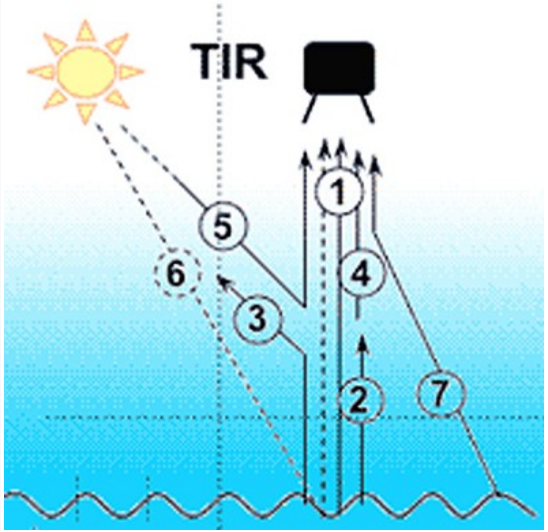
TOA IR Radiance



Other 6 bands in the VIS and NIR field (S1 to S6):

Used to evaluate contributions other than from the ocean surface (**cloud/areoslos**)

TOA Radiance contributions



1) Useful signal (radiation from ocean surface only!!!)
2) Absorbed by atmosphere
3) Scattered out of field of view

1+2+3 = Signal received if no other sources

4) Emitted by atmosphere
5) Atmospheric scattering into field of view
6) Reflected into field of view
7) Surface ocean scattering into field of view

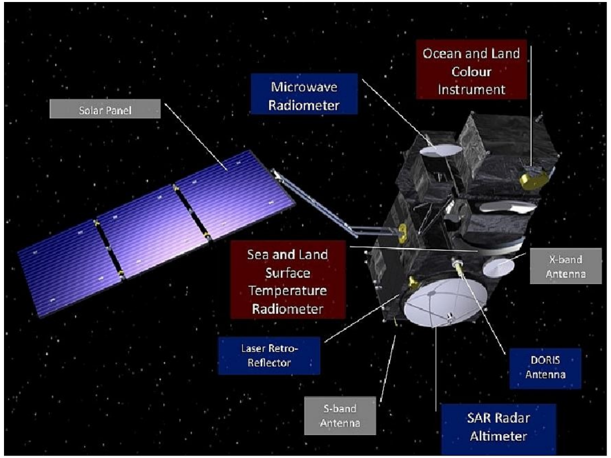
4+5+6+7 = Noise

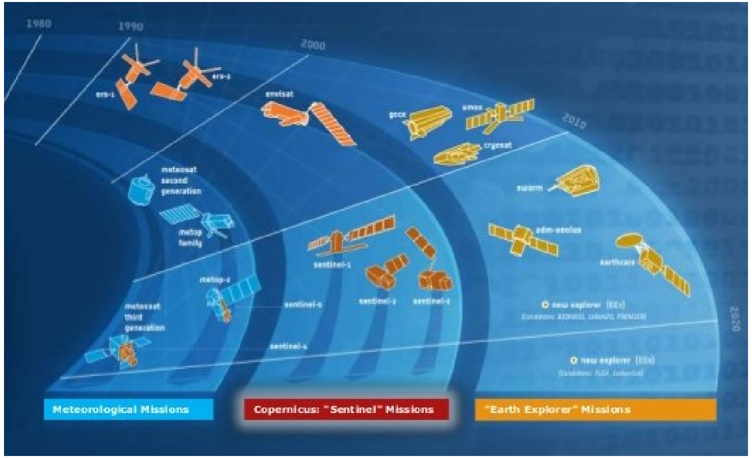
→ S7 to S9 to measure signal

→ S1 to S6 to evaluate noise (IMPORTANT: noise can also be reduced by instrument design!!!)

Sentinel-3 SLSTR

Sea and Land Surface Thermal Radiometer





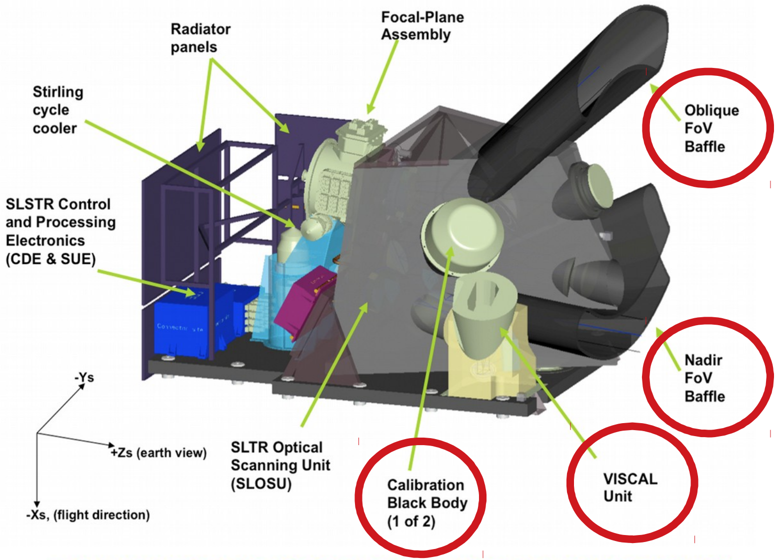
- Dual scan temperature radiometer
- Continuity from previous infrared radiometers:
  ASTR (ERS-1) – ASTR-2 (ERS-2) – AASTR (ENVISAT)
- Equivalent baseline performance as AASTR

Full documentation at https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-slstr

Sentinel-3 SLSTR

SLSTR design

- Two onboard black bodies for calibration of each scan (level1 processing)
- 9 spectral bands (two more than AASTR; also for fire detection)
- Dual view (Nadir and Oblique) for improved atmpspheric correction
- (Wider swath compared to AASTR)



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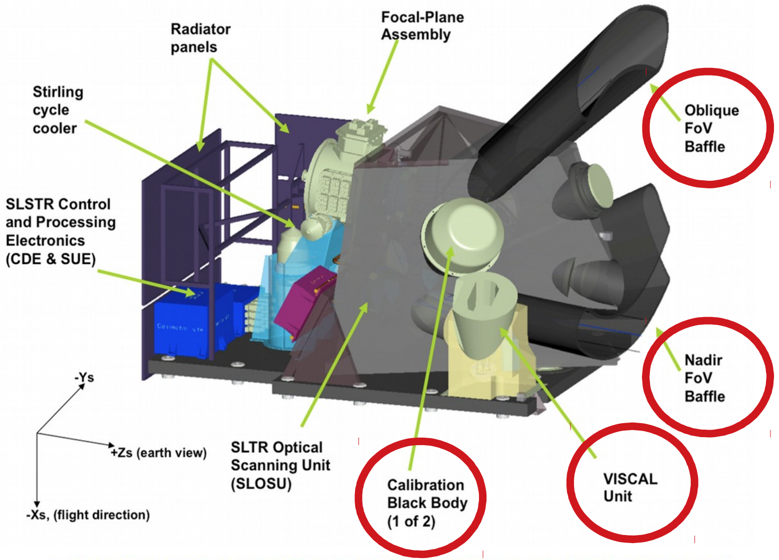
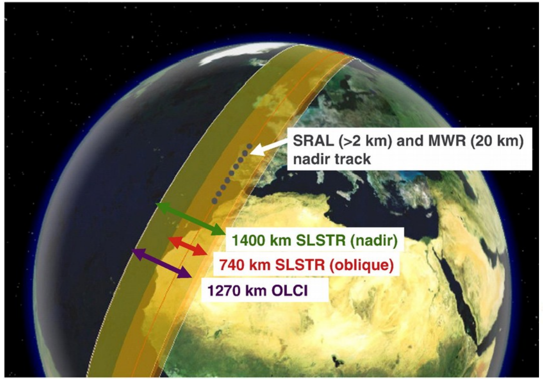
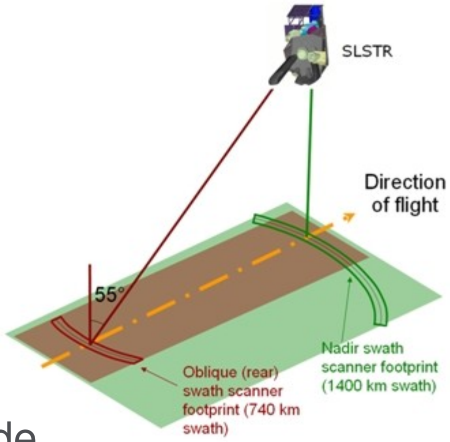
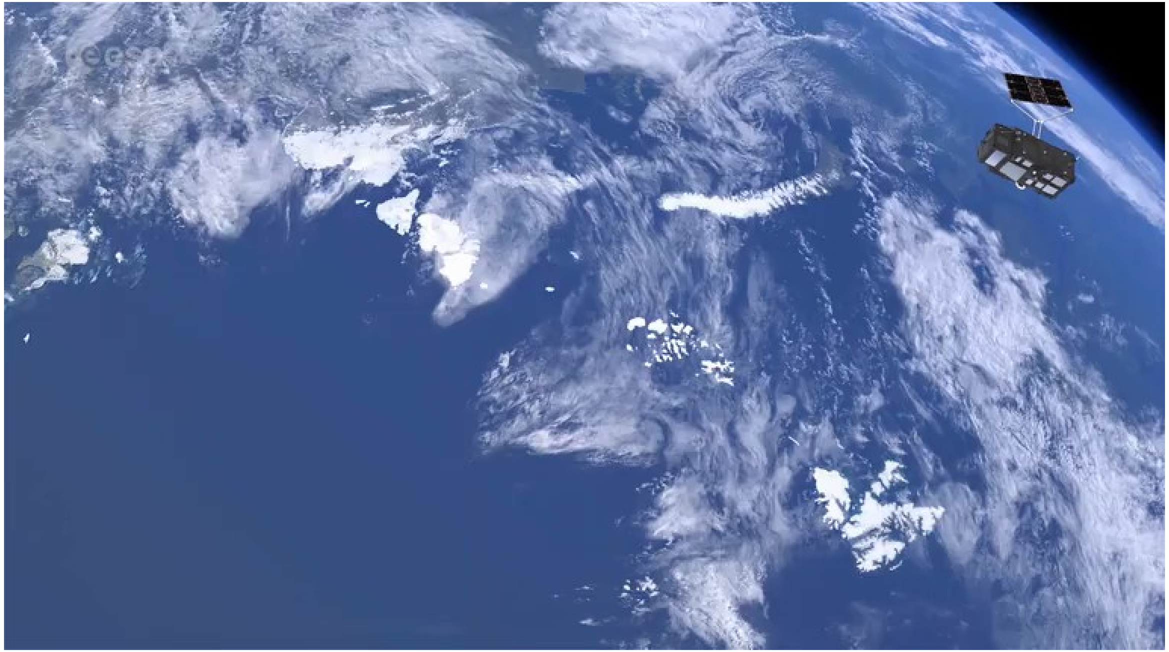






- Oblique swath 740 km wide
- Nadir swath 1400 km wide
- Nadir swath offset to match OLCI

SLSTR dual view



Advantages

Multi-view atmospheric correction technique (**along-track scanning**):

Same pixel viewed from two different angles with **different atmospheric pathlengths**

Differences between the two views are due to atmospheric effects (**directly measured!!!**)

Video courtesy of M-H Rio

Sentinel-3 SLSTR

Processing chain

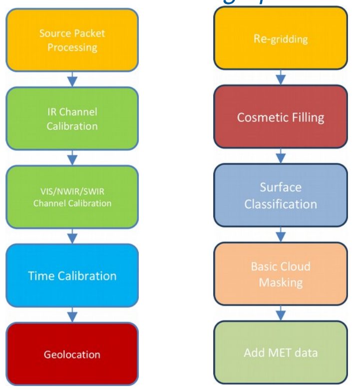
Level 0

- Process raw data (instrument counts) into instrument source packets (IPS) (Not for users)

Level1

- Compute calibration coefficients (slope and intercept):
  1. for IR (S7 to S9) from the two black bodies (hot and cold)
  2. for VIS/NIR/SWIR (S1 to S6) from diffuse calibration (VISCAL)
- Convert instrument counts to radiance/brightness temperature
- Time and geolocation
- Cloud masking

Level1 instrument & image processing



Level2

- Convert TOA radiance to SST:
  5 algorithms available: **N2, N3, N3R, D2, D3**
  (Dual or nadir view + # of bands used; e.g. S7 not used during day due to solar contamination)
- All based weighted combination of observed brightness temperatures
  (coefficients from radiative transfer models)

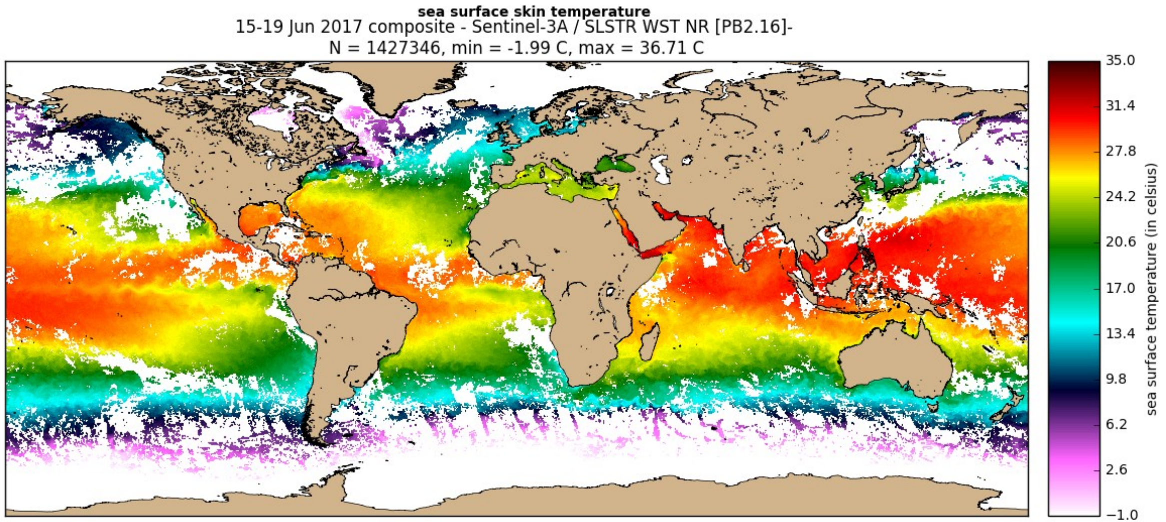
Final products

1. Level1 RTB (radiance and brightness temperature for each channel and view)
2. Level2 WST (best SST from the 5 algorithms; **used in the practical**)

Resolution
- 1 km for IR bands (S7 to S9)
- 500 m for VIS/NIR/SWIR bands (S1 to S6)

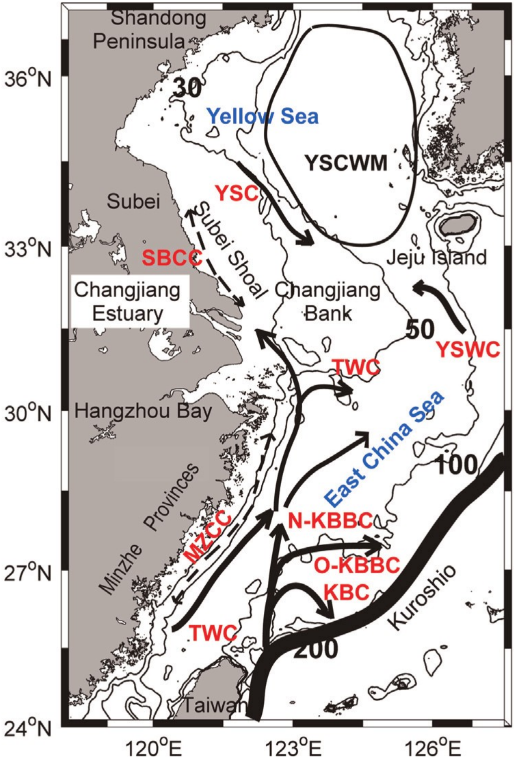
SST accuracy: 0.3 degK

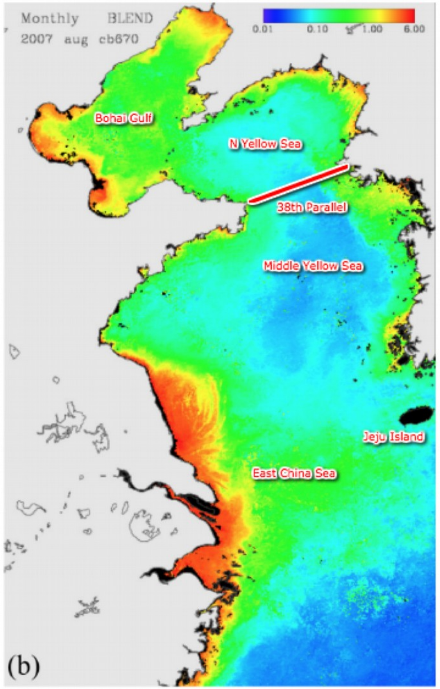
Sentinel-3 revisit time 27 days with subcycle of 4 days



Data available at **https://coda.eumetsat.int/**

Characteristics of East China Sea and Yellow Sea





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Thank You