→ ESA ADVANCED OCEAN SYNERGY TRAINING COURSE 2019

4–8 November 2019 | Center of Mediterranean Architecture | Chania, Greece

Investigating sea surface salinity from space

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07/11/2019

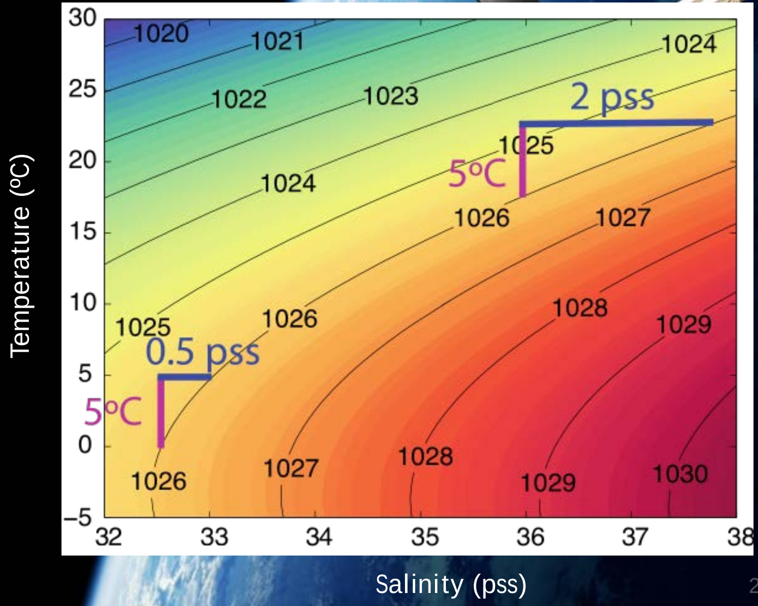
Why measuring sea surface salinity?

1- A tracer of freshwater fluxes and ocean circulation

- Insights into freshwater fluxes (precipitation, evaporation, runoff, freezing and melting of ice)
  - Global oceans are the engine room of the **water cycle**
- Ocean circulation: advection and mixing

2- A strong influence on sea water density & Air-sea exchanges

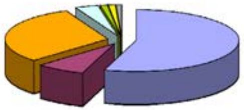
- Salinity affects sea water density, which in turn governs ocean circulation & air-sea exchanges
- =>Large freshwater fluxes (river, rain) => strong haline stratification at the ocean surface => high SST => cyclones



Salinity of the Ocean: What do we know about it ?

Total amount of dissolved material in grams in one kilogram of sea water" (Sverdrup et al, 1942)

At the sea surface it is referred to as “SSS” (Sea Surface Salinity)



Chloride (Cl-):	19 g
Sodium (Na+):	11 g
Sulphate (SO4--):	3 g
Magnesium (Mg++):	1.5 g
Calcium (Ca++):	0,35 g
Potassium (K+):	0,35 g
Others :	0,00.. g

Total ≈ 35 g/kg

(Mean chemical composition)

99% of oceanic waters have salinity between 33.1 and 37.2:
=>a global variation in salt concentration between 3.31% and 3.72% !

Absolute vs Practical Salinities

Because of the (quasi) unvarying composition of salt ions in seawater, salinity can theoretically be deduced by measuring Chloride and using a simple scaling.

Using **Copenhagen “Normal water” standards**, Salinity is defined by Knudsen (1903) based on chlorinity (*Cl*) as: $S_1=0.03+1.805*Cl$

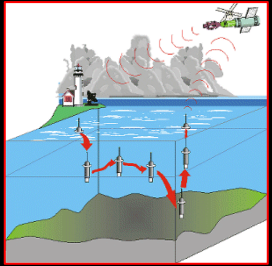
Since the 60s, Cl is measured by conductivity and a new (more complicated) definition of salinity is established as the official « **Practical Salinity Scale 1978** » (Unesco, 1981), still in use today.

A new standard called TEOS-10 (Thermodynamic Equation of Seawater, 2010) was adopted by the International Oceanographic Commission (IOC). The Normal Water (from North Atlantic - no nutrient) has a

“**Absolute Salinity**” (S_A) of 35.1650 $g.kg^{-1}$,

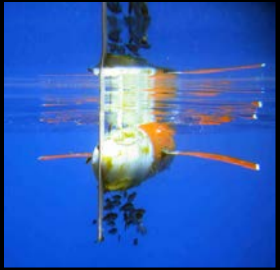
“**Practical Salinity**”(S_P) of 35 pss.

In Situ Salinity Measurements



Profilers from the Argo

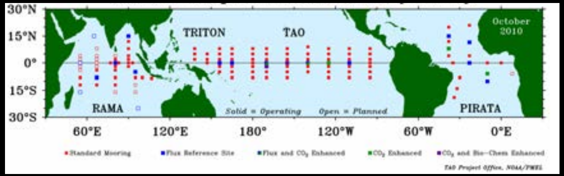
Equipped Mammals



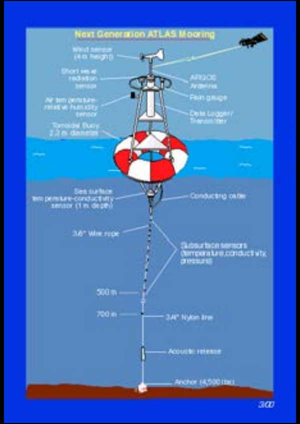
Gliders

Surface ‘Drifters’

Thermo-salinographs installed onboard reasearch Vessels and ships of opportunity



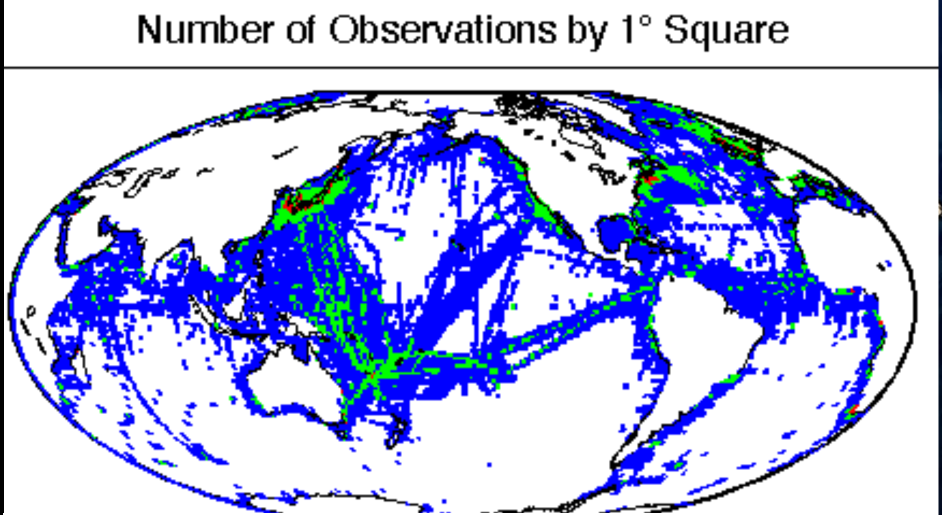
Permanent Moorings



Historical Observations of surface salinity (1874-2002)

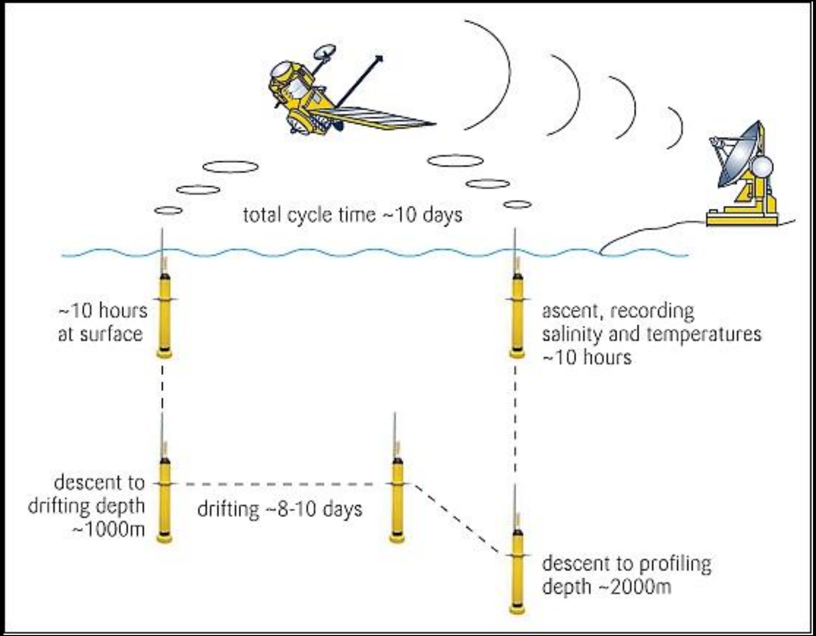
1.3 million SSS observations distributed over the global ocean since 125 years:

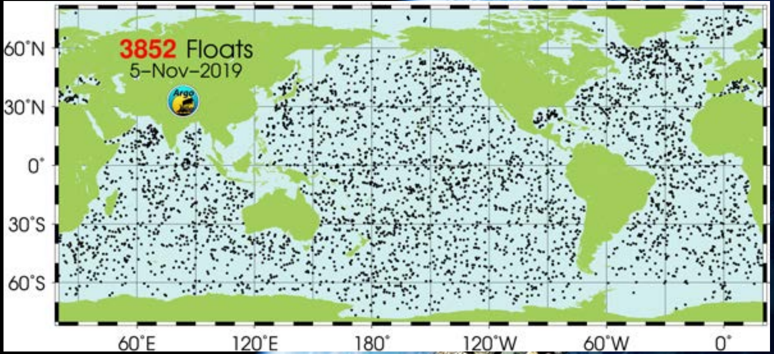
- No data in 27% elementary oceanic 1° x1° area, not accounting for arctic zones.
- 70% of these surfaces present at most 10 historical observations
- 28% of all observations were sampled in the coastal domain
- Until 1960, there was no more than 10,000 observations/year ⇔ 1 observation per 4°X4° cell
- Since 2002, very net increase in the density of measurements (Argo network)

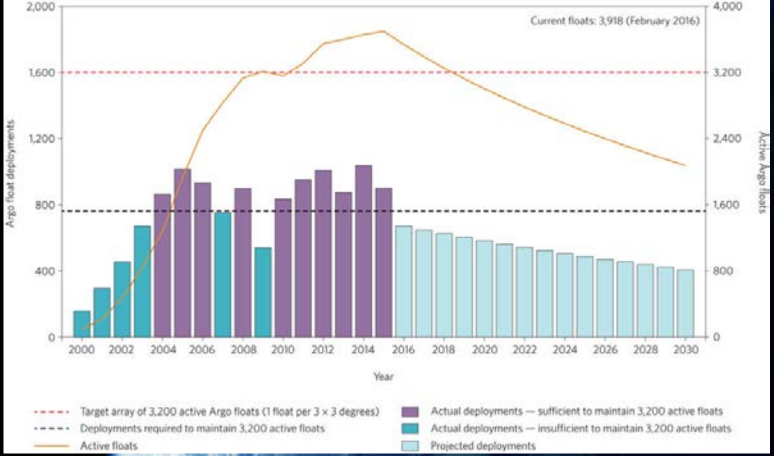


White - N < 10
Blue - 10 < N < 100
Green- 100 < N < 1000
Red - 1000 < N

The Argo Floats Array (2000-present)





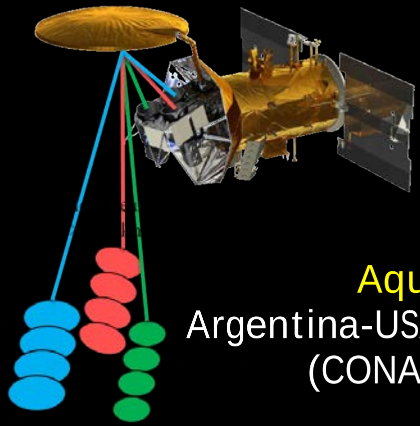


Argo is a global array of 3,800 free-drifting profiling **floats** that measures the temperature and salinity of the upper 2000 m of the ocean

Surface Salinity from space (*1973*-2010-present)

SMOS
Soil Moisture Ocean Salinity
ESA Earth Observer (France and Spain)

Interferometer in the L-Band



Aquarius
Argentina-USA collaboration
(CONAE/NASA)

3 radiometers in the L-Band
+ 1 scatterometer

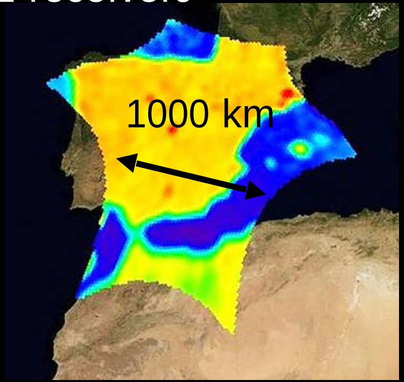
SMAP
Soil Moisture ~~Active~~ Passive
Built at JPL

L- Band radiometer
Failure of SAR in July 2015

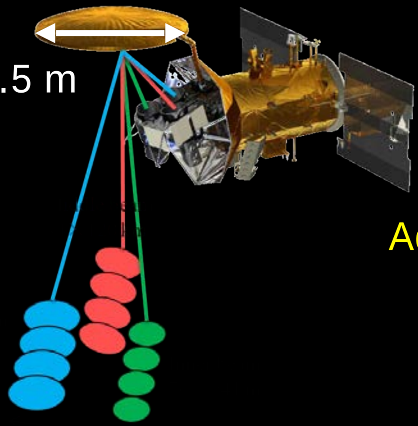
Surface Salinity from space (*1973*-2010-present)

8 m
72 receivers

SMOS
758 km



23 days repeat cycle
(with sub repeat cycle of 3 days)
40 km resolution, 1000 km swath

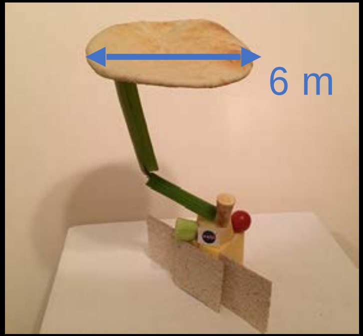


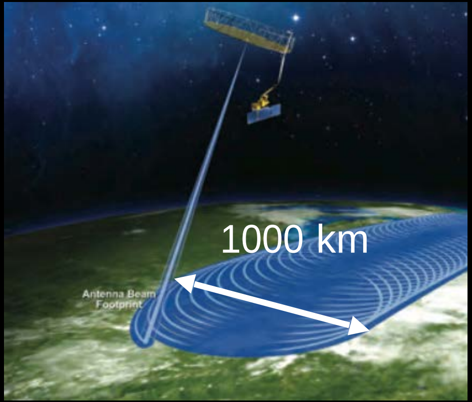
Aquarius
657 km

7 days repeat cycle
100 km resolution, 390 km swath

ISS : 380 km
Geostats : 36 000 km

SMAP
685 km

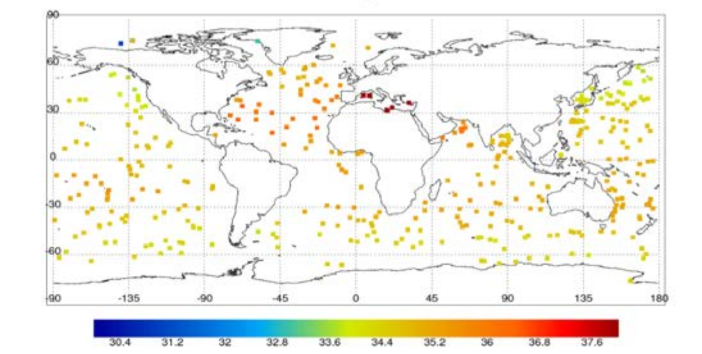




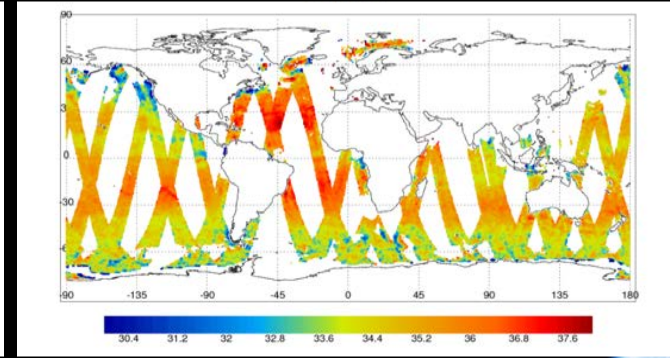
8 days repeat cycle
40 km resolution, 1000km swath

Surface Salinity Observations

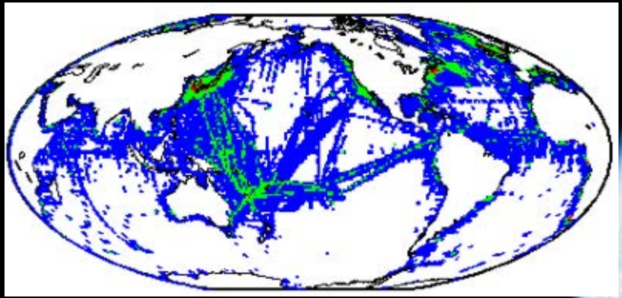
One Day Argo



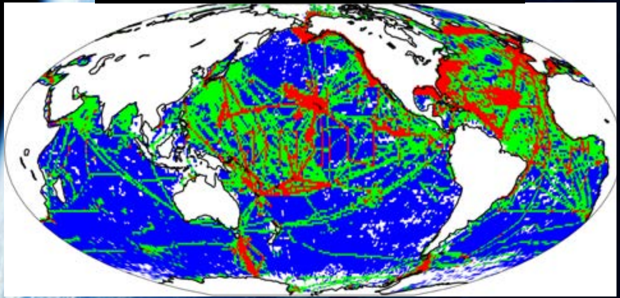
One Day SMOS



SSS Obs 1874-2002



SSS Obs 2010-2018



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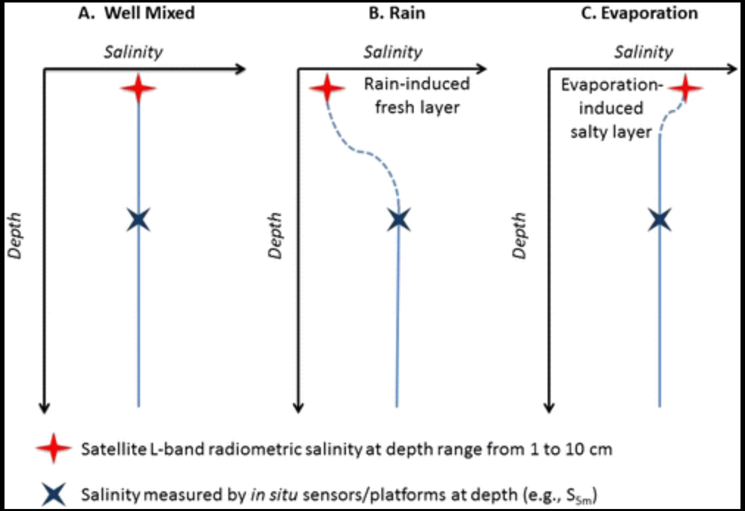
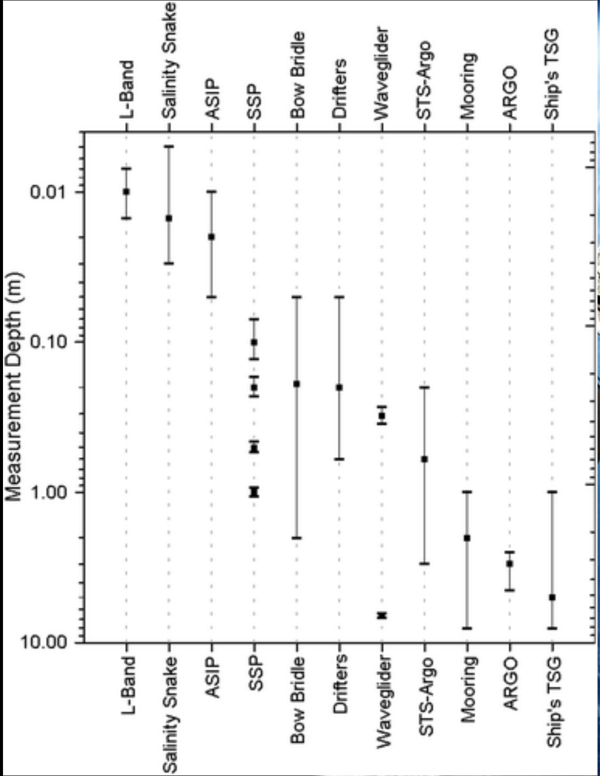
Green- 100 < N < 1000

Red - 1000 < N

"Surface" Salinity measurement depth





Typical depth at which near-surface salinity is measured by various sensors/platforms

How do we get Surface Salinity from L-Band Radiometers ?

How do we get Surface Salinity from L-Band Radiometers ?

Satellites measure brightness temperatures …

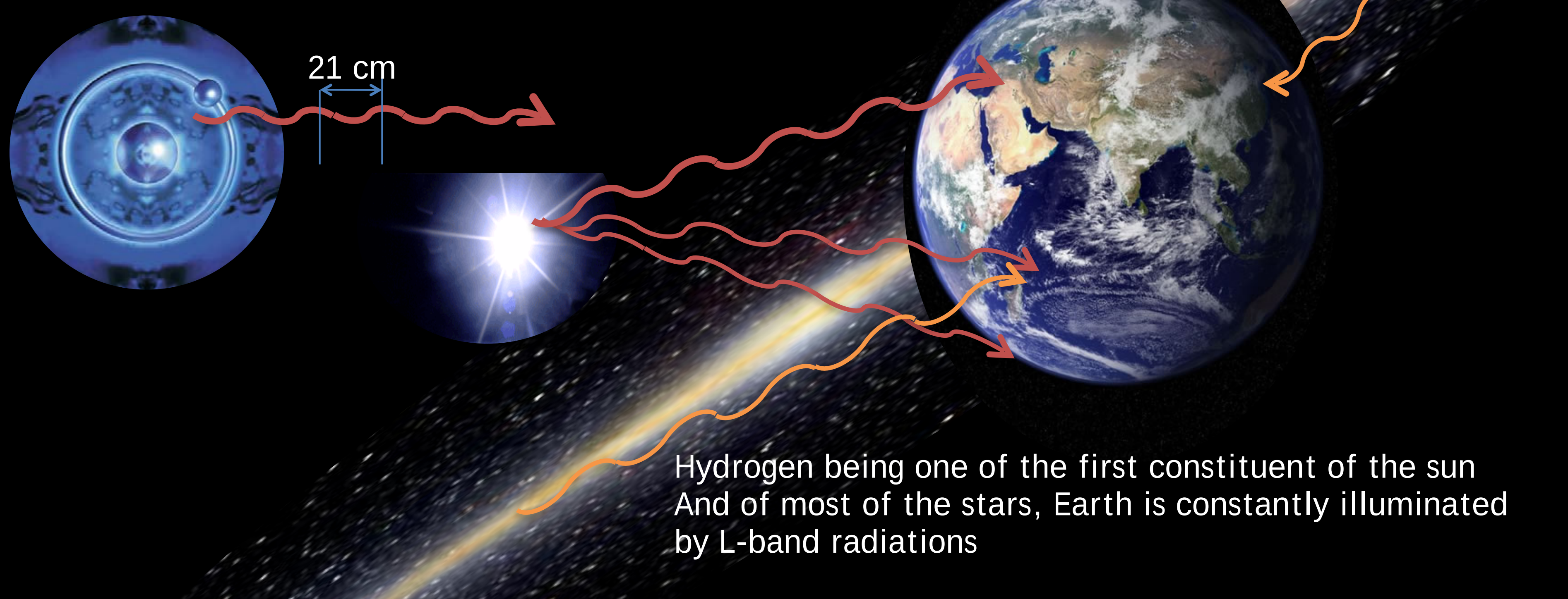
Physical Contributions to the brightness temperature

at satellite antenna level (~700 km altitude)

- The Hydrogen emission

The Hydrogen line

A change of state in the Hydrogen atom energy generates micro-wave electromagnetic radiations at a frequency of 1420 MHz (L band) ≡ length 21 cm known as the « Hydrogen line »



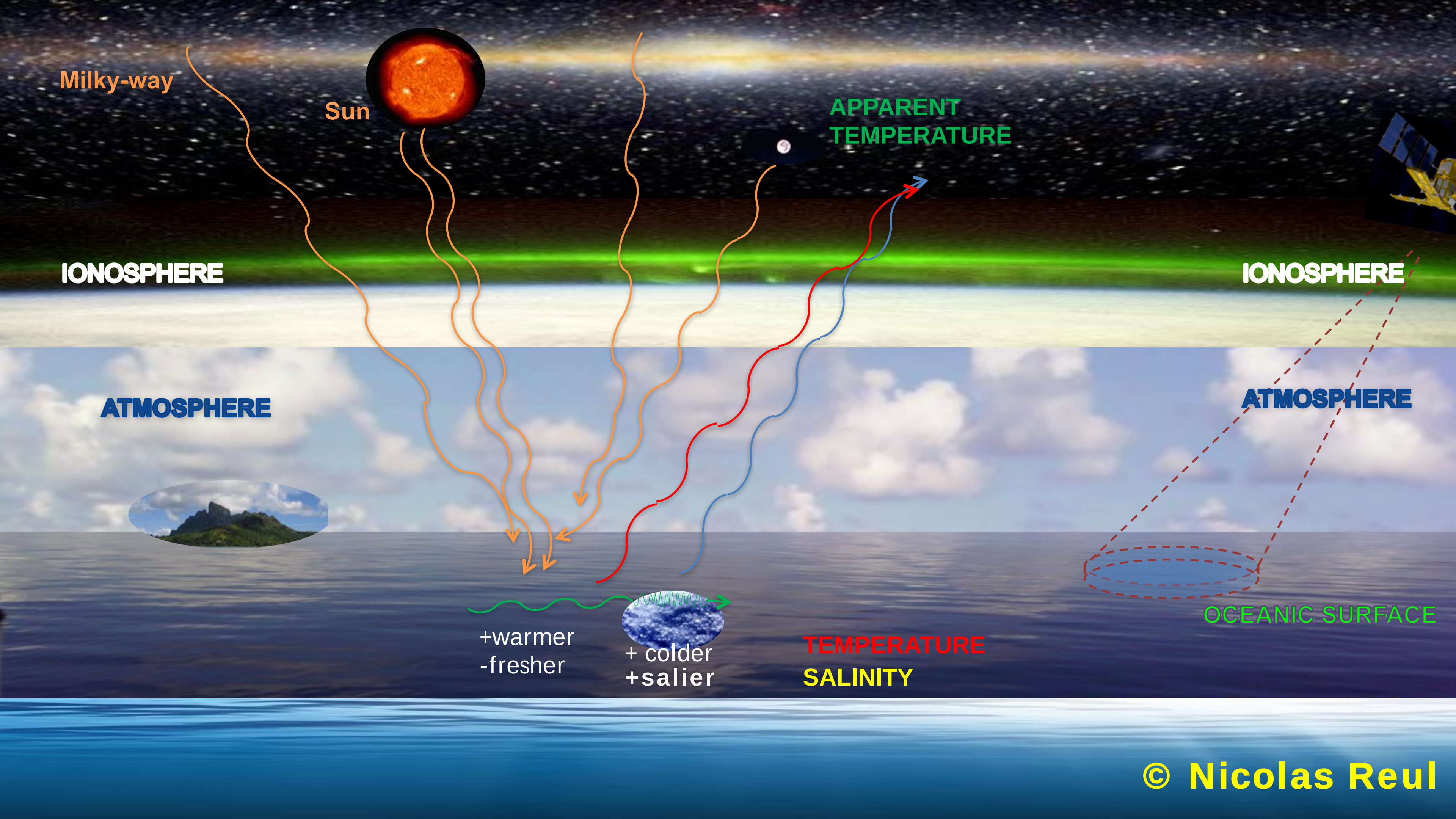
Hydrogen being one of the first constituent of the sun And of most of the stars, Earth is constantly illuminated by L-band radiations

Physical Contributions to the brightness temperature

at satellite antenna level (~700 km altitude)

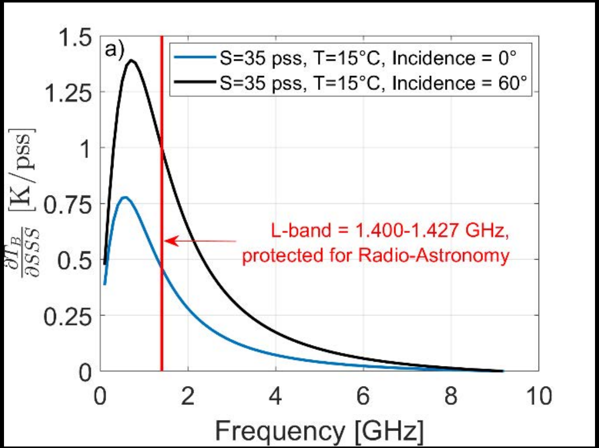
- The Hydrogen emission

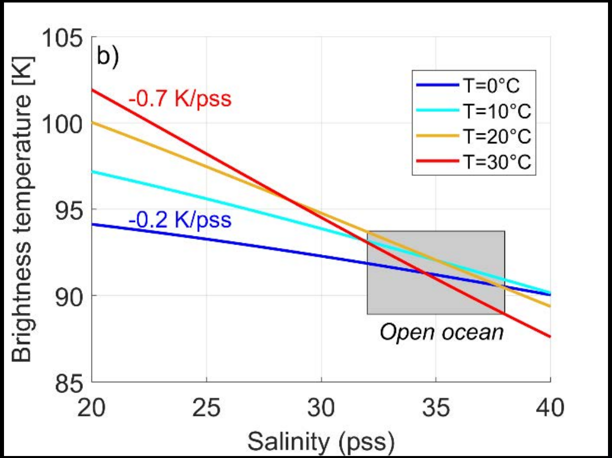
- Sea Surface Temperature



Milky-way
Sun
APPARENT TEMPERATURE
IONOSPHERE
IONOSPHERE
ATMOSPHERE
ATMOSPHERE
OCEANIC SURFACE
+warmer
-fresher
+ colder
+salier
TEMPERATURE
SALINITY
© Nicolas Reul

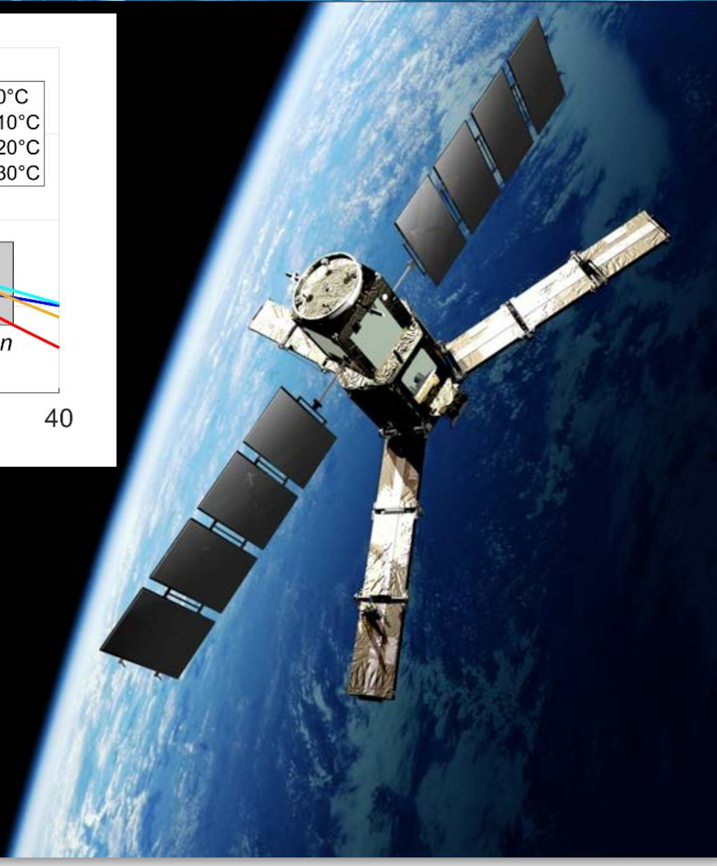
Sensitivity to surface temperature





(a) sensitivity of the ocean surface microwave brightness temperature to Salinity (First Stokes parameter) as a function of electromagnetic frequency and incidence angle (blue curve=0°, black curve=60°) and for a water body with salinity of 35 pss and temperature of 15°C.

(b) brightness temperature changes at 1.4 GHz as a function of salinity (x-axis) and temperature (colors). The gray domain indicates the range of SSS values mostly encountered in the open ocean.



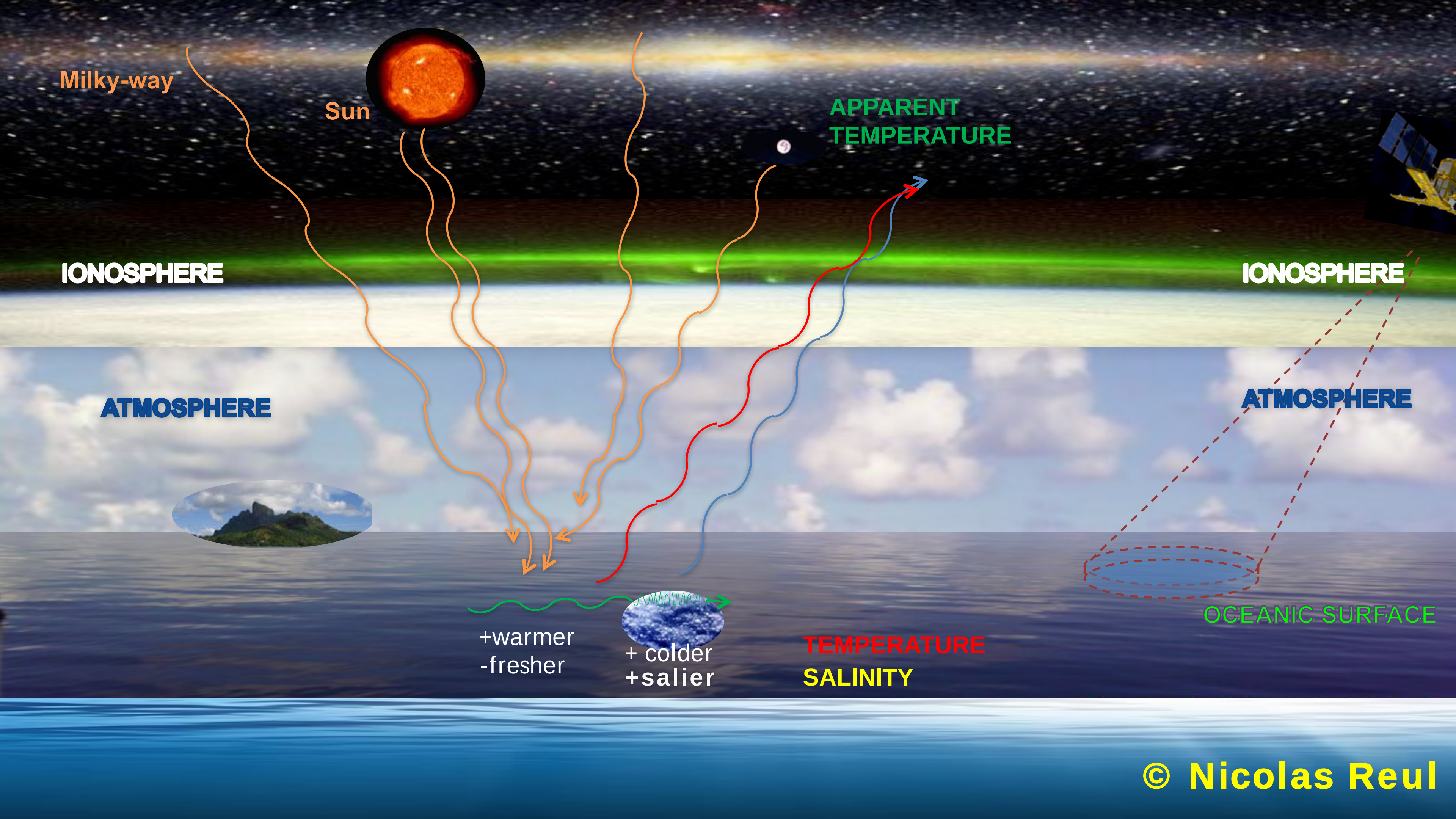
Physical Contributions to the brightness temperature

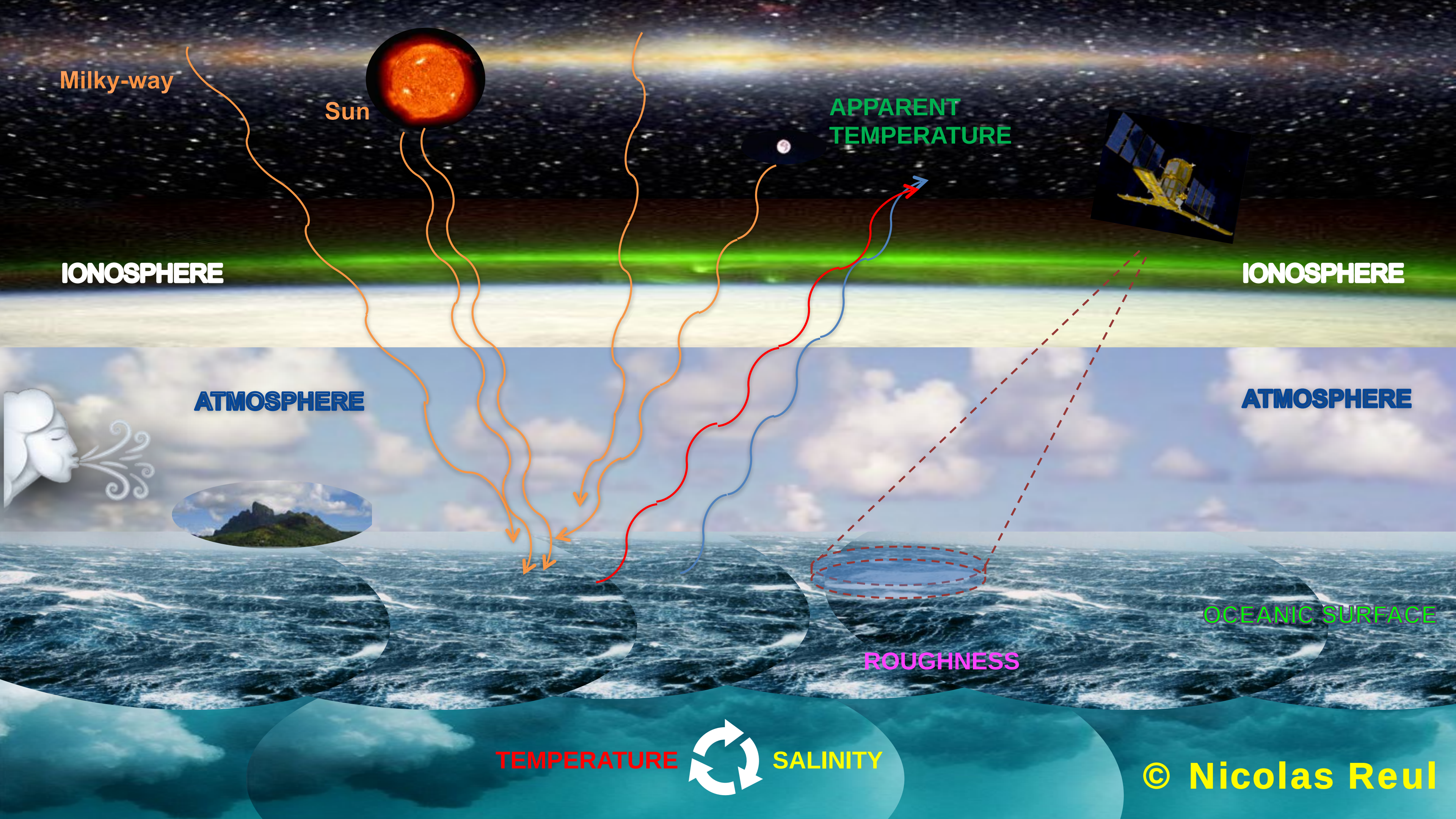
at satellite antenna level (~700 km altitude)

- The Hydrogen emission

- Sea Surface Temperature

- Sea Surface Roughness


Milky-way
Sun
APPARENT TEMPERATURE
IONOSPHERE
IONOSPHERE
ATMOSPHERE
ATMOSPHERE
OCEANIC SURFACE
+warmer
-fresher
+ colder
+salier
TEMPERATURE
SALINITY
© Nicolas Reul

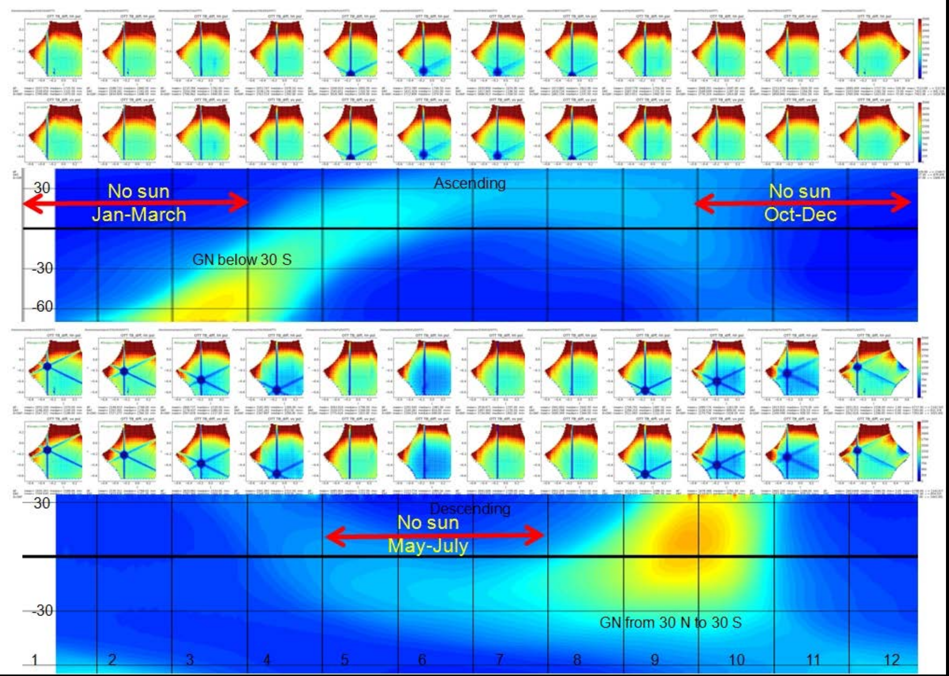

Milky-way
Sun
APPARENT
TEMPERATURE
IONOSPHERE
IONOSPHERE
ATMOSPHERE
ATMOSPHERE
OCEANIC SURFACE
ROUGHNESS
TEMPERATURE
SALINITY
© Nicolas Reul

Physical Contributions to the brightness temperature

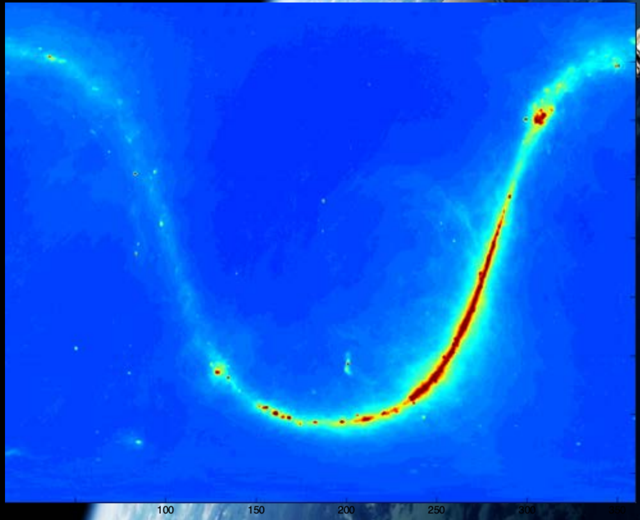
at satellite antenna level (~700 km altitude)

- The Hydrogen emission
- Sea Surface Temperature
- Sea Surface Roughness
- Specular Reflexion

Sun/Moon Glint and Galaxy Specular Reflection

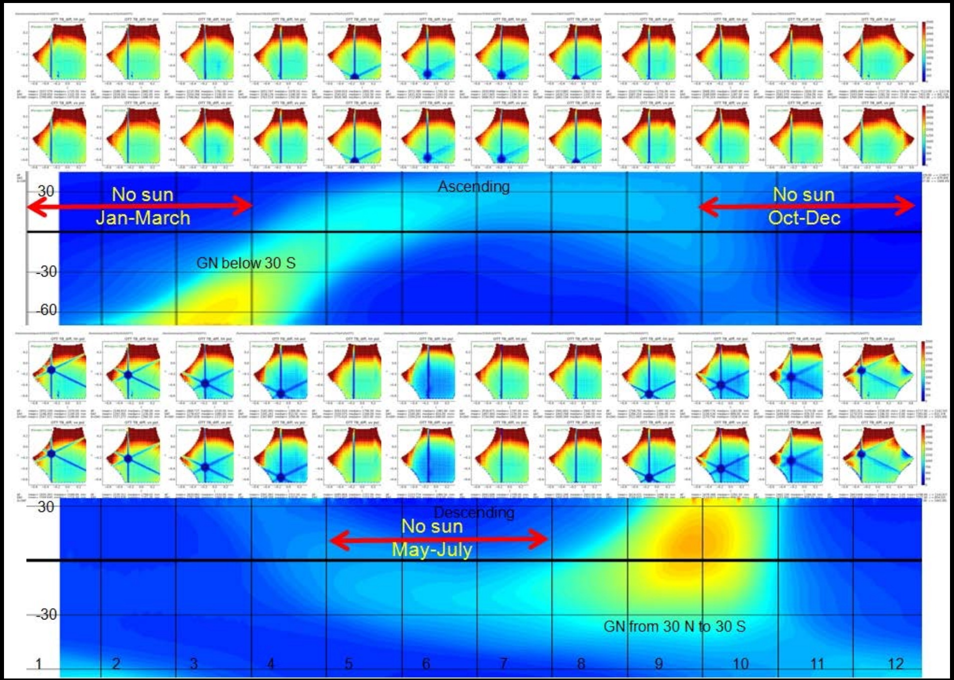


Galaxy Emission at 1.4 GHz
(up to 15 K)



Seasonal corrections applied to SMOS Asc/Desc passes

Sun/Moon Glint and Galaxy Specular Reflection



Seasonal corrections applied to SMOS Asc/Desc passes

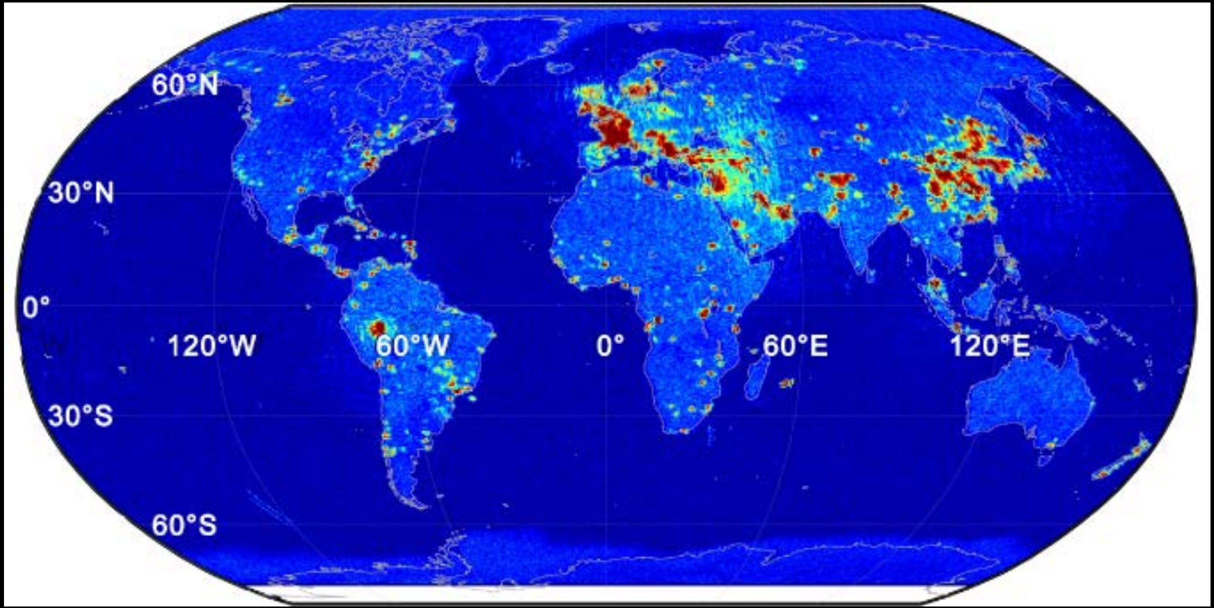
Sun Glint in the visible spectrum

Physical Contributions to the brightness temperature

at satellite antenna level (~700 km altitude)

- The Hydrogen emission
- Sea Surface Temperature
- Sea Surface Roughness
- Specular Reflexion
- Human Emissions

Radio Frequency Interferences aka RFIs



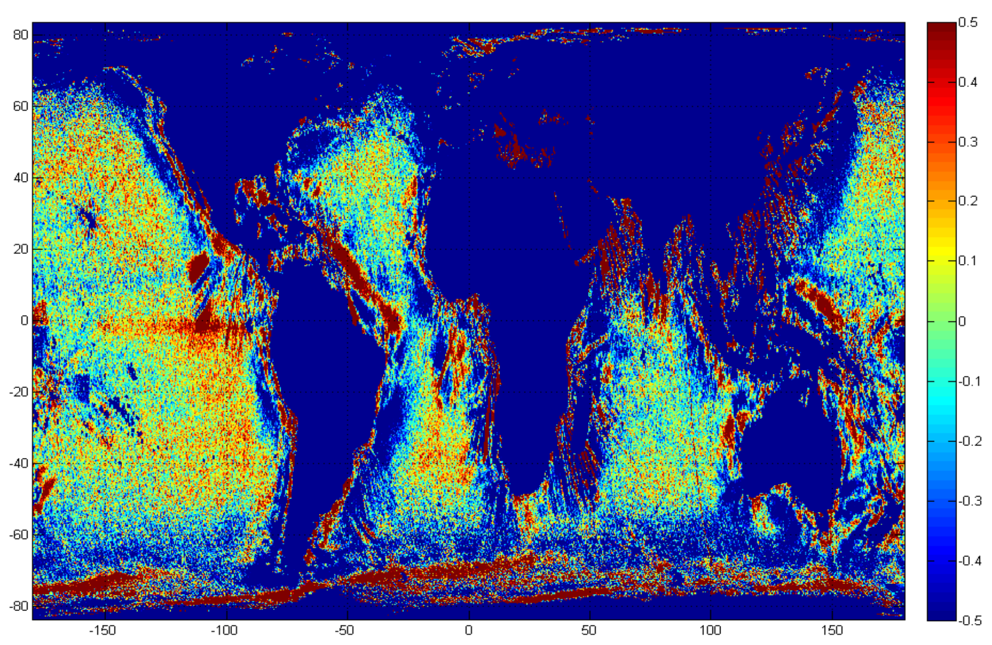
RFI @ 1.413 GHz (Aquarius)

Physical Contributions to the brightness temperature

at satellite antenna level (~700 km altitude)

- The Hydrogen emission
- Sea Surface Temperature
- Sea Surface Roughness
- Specular Reflexion
- Human Emissions
- Land/Sea Ice Contamination

Land/Sea Ice Contamination Correction



Constant correction applied to the latest SMOS CEC-LOCEAN Product

Physical Contributions to the brightness temperature

at satellite antenna level (~700 km altitude)

- The Hydrogen emission
- Sea Surface Temperature
- Sea Surface Roughness
- Specular Reflexion
- Human Emissions
- Land/Sea Ice Contamination

Salinity Retrieval Algorithm

Radiometer Counts L0
Earth + Calibration View

↓

Radiometer Calibration & reconstruction Algorithm
RFI flagging

↓

Total Antenna Temperature L1B

↓

Remove Space Contributions: Galaxy, Sun, Moon, CS

↓

Earth Antenna Temperature

↓

Remove the Antenna Pattern Effect

↓

Earth Brightness Temperature (TOI)

↓

Correct for Faraday Rotation

↓

Top of the Atmosphere Brightness Temperature (TOA)

↓

Remove Atmospheric Contribution

↓

Sea-Surface Brightness Temperature

↓

Remove Surface Roughness Effects

↓

Specular Brightness Temperature

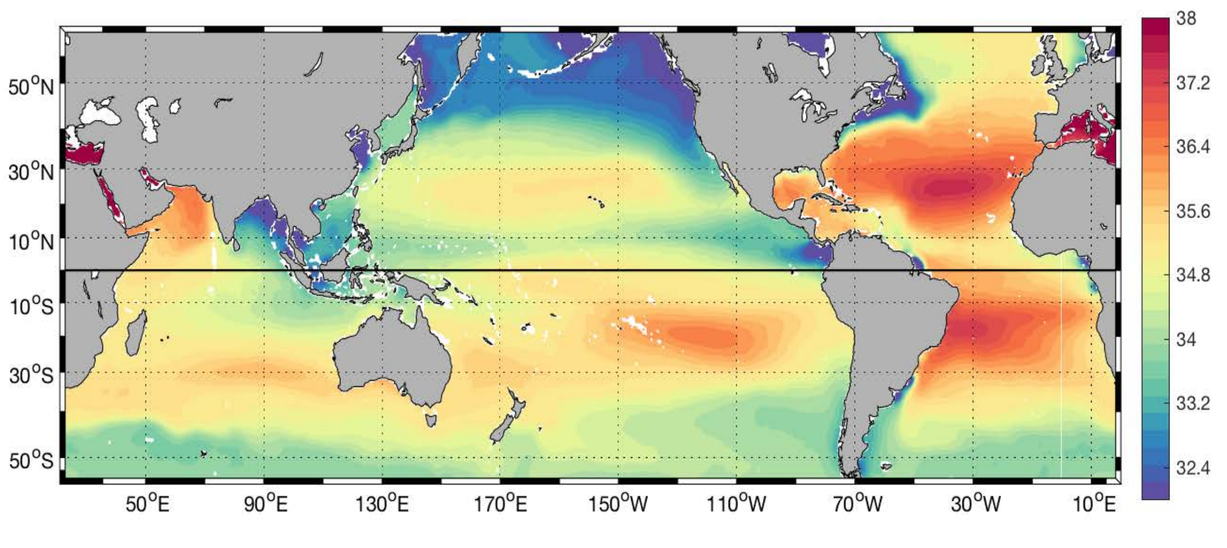
↓

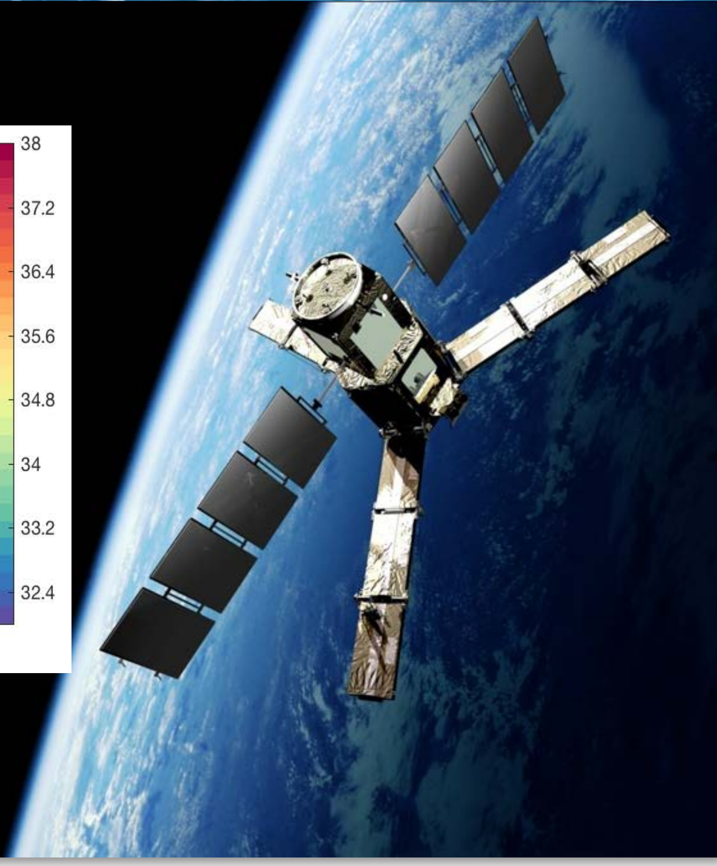
Find Salinity for which emissivity of model matches TB measurements

↓

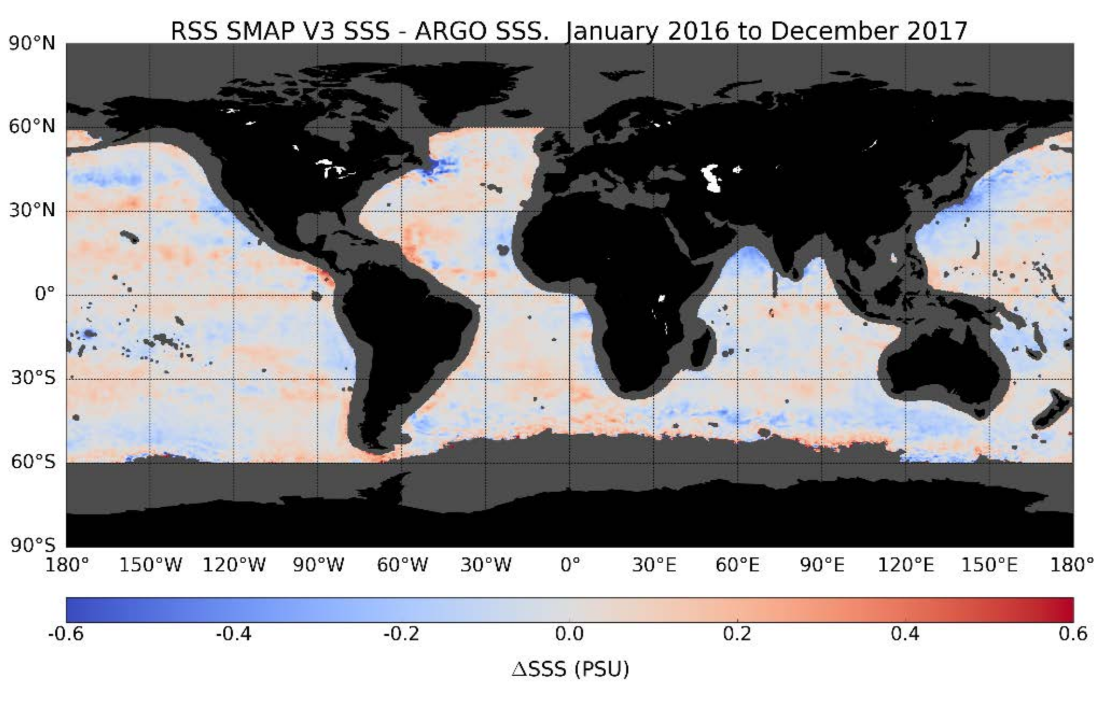
Salinity L2 → Salinity L3

SMOS mean SSS 2010-2018



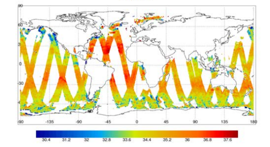


Biaises between Argo OI and Satellite : Error ?

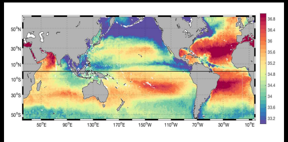


So should I use L1, L2, L3 or L4 ???

L1-2 : picture of the satellite



Along the satellite path (swath)



Maps nicely gridded

L3-4 : different passes/times mixed together

From Smap user guidelines

Data Product Level	Description
Level 0	Reconstructed, unprocessed instrument data at original resolution, time ordered, all communications artifacts removed.
Level 1A	Level 0 data time referenced and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (i.e., platform ephemeris) computed and appended, but not applied to Level 0 data.
Level 1B	Radiometrically corrected and geolocated Level 1A data that have been processed to sensor units.
Level 1C	Level 1B data that have been spatially resampled.
Level 2	Derived geophysical parameters at the same resolution and location as the Level 1 data from which they are derived.
Level 3	Geophysical parameters derived from Level 1 or 2 data that have been spatially and/or temporally re-sampled to a global grid.
Level 4	Geophysical parameters derived by assimilating Level 1, 2, or 3 data into a land surface model.

Brightness Temperature

Practical Salinity

The limit between L3 and L4 gets blurry. All L4 assessment must be done with extra care

So, it's all about what you want to do with the data …
It all depends on the scales you're interested in and the satellite characteristics

L2-L3 Datasets Bonzana

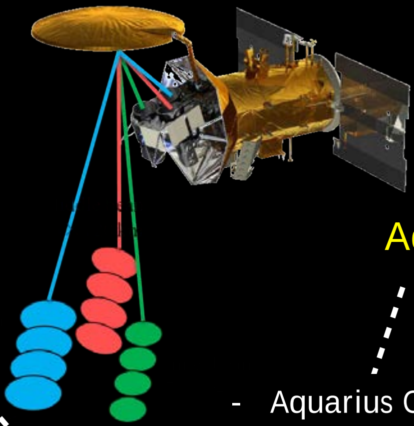
SMOS

L2 Operational Products Developed and distributed at ESA

L3 Science Products Developed by 3 ”Expert Centers”
- Ifremer (France)
- LOCEAN (France)
- BEC (Barcelona)

Official products
- 8d. means
- monthly means

products distributed by PIs and the CATDS (Ifremer and LOCEAN)



Aquarius

- Aquarius Official Product by REMSS
- JPL Based product - CAP

Distributed by PODAAC

SMAP

- JPL Based product - CAP
- SMAP by REMSS

Distributed by REMSS

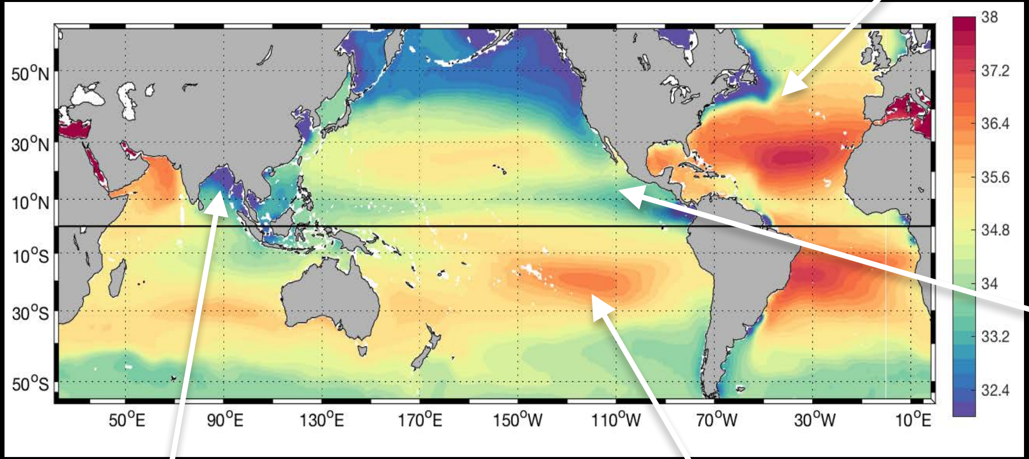
ESA SSS Climate Change Initiative: weekly and monthly synergic products

Once strengths and limitations of the different products are known :

We can do science !

All of this, so we can do science !

SMOS mean SSS 2010-2018



Strong front associated with Gulf Stream

Salinity minimia in atmospheric convergence zones

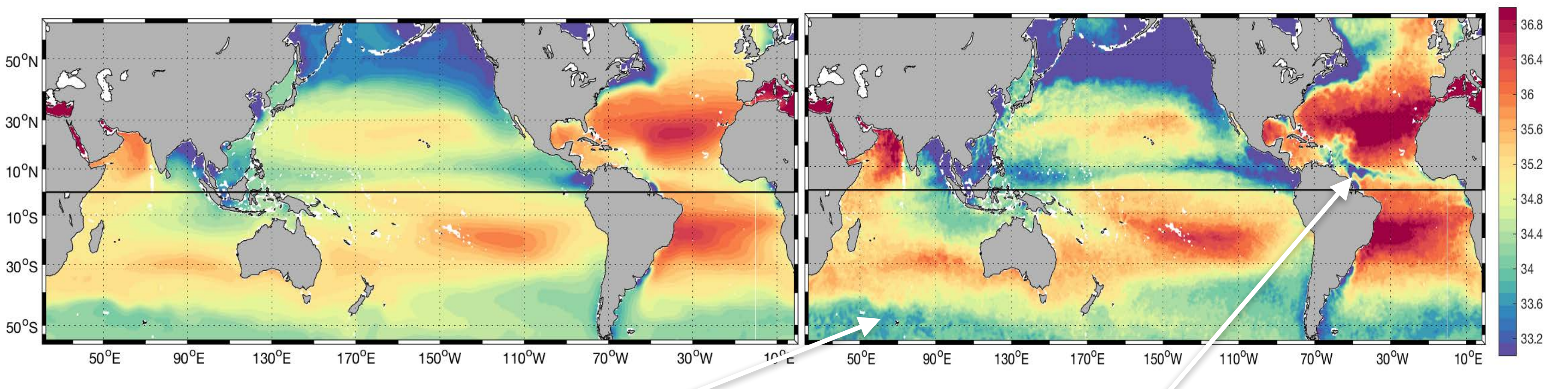
Gange/Brahmaputra outflow

Salinity maxima at the center of each gyre

All of this, so we can do science !

SMOS mean SSS 2010-2018

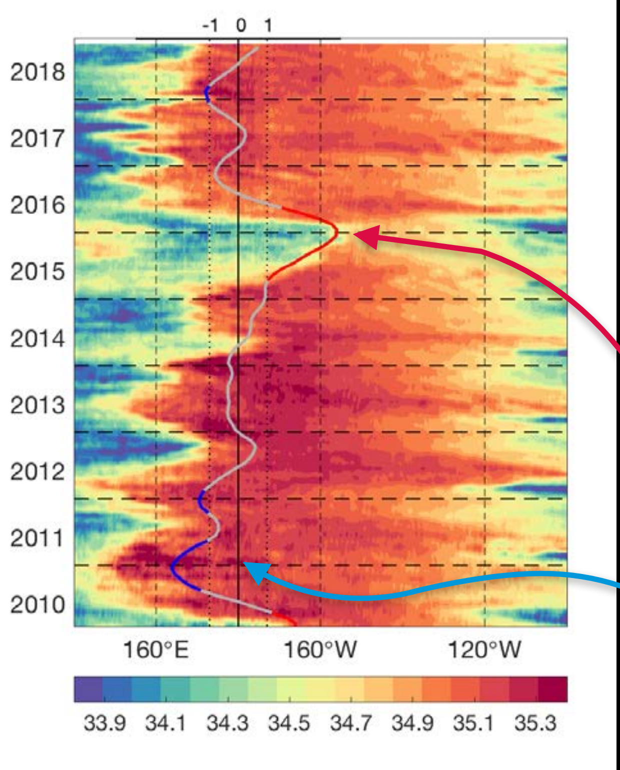
SMOS SSS Sept. 2011

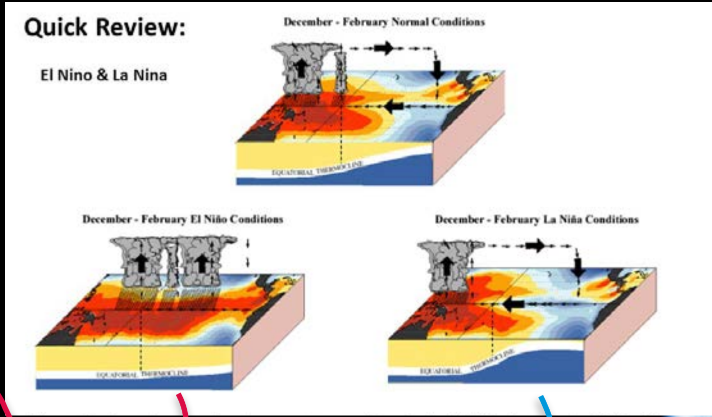


Instabilties in the Sub-antarctica Front

Eddies in the Amazon plume

Surface Salinity and El Niño Southern Oscillation





El Niño

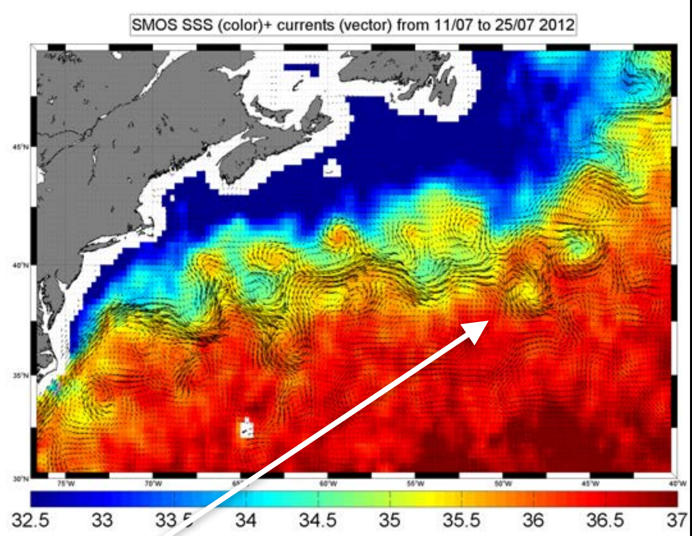
La Niña

2°S-2°N average SSS

We can track SSS anomalies generated by ENSO for 18 months, reaching Hawaii. Salinity does not erodes as fast a surface temperature.

More in practical lecture 13

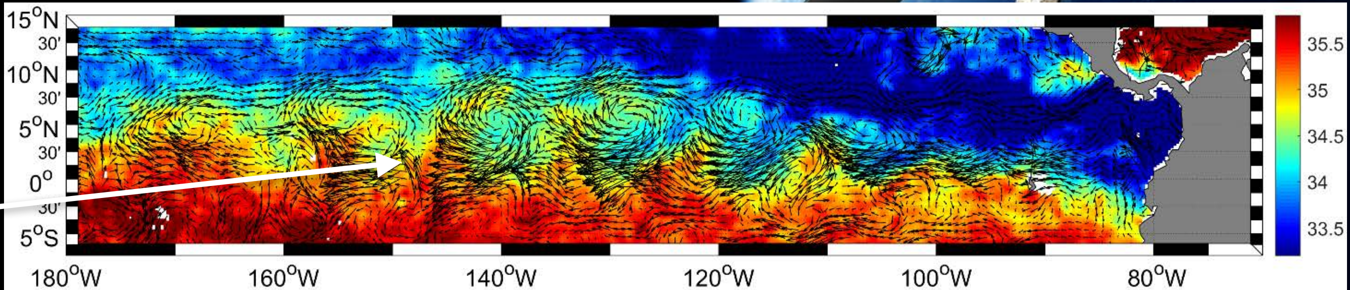
Surface Salinity and Currents Instabilities



In regions of intense gradients, surface salinity interacts with ocean currents : large scale and smaller scale (meso and lower)

Gulf Stream meanders

Tropical
Instability Waves

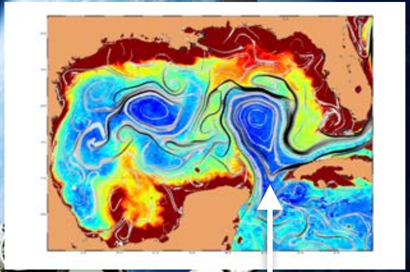


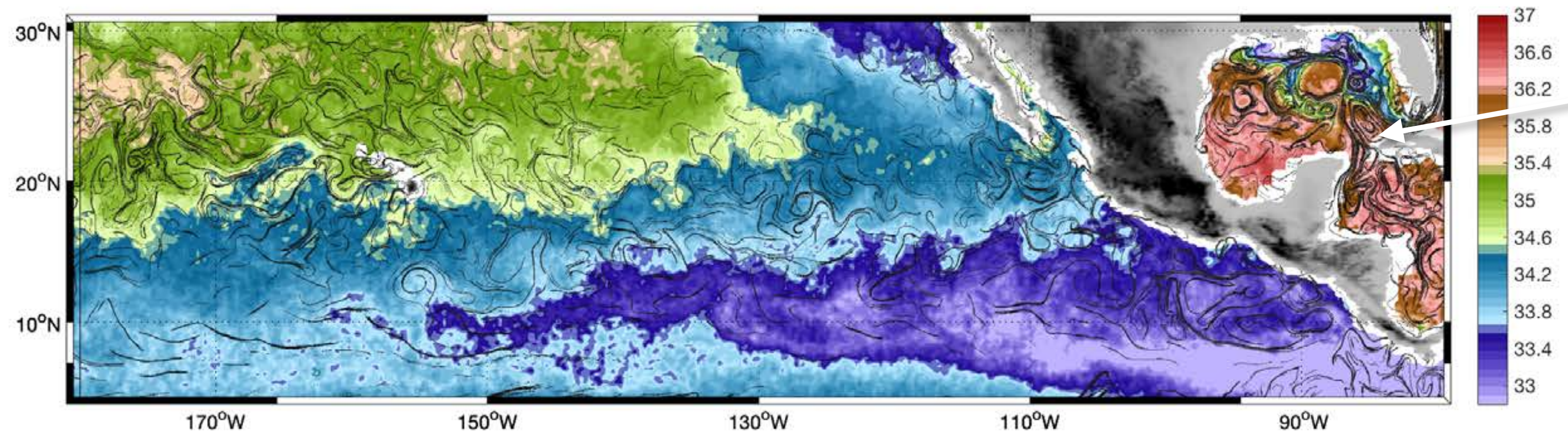
Surface Salinity, currents and plumes

Depending on the season, river plumes have a very strong surface salinity signal.

Plumes create barrier layers and can interact with Tropical Cyclones as described by Bertrand yesterday.

Chl-a, CLS



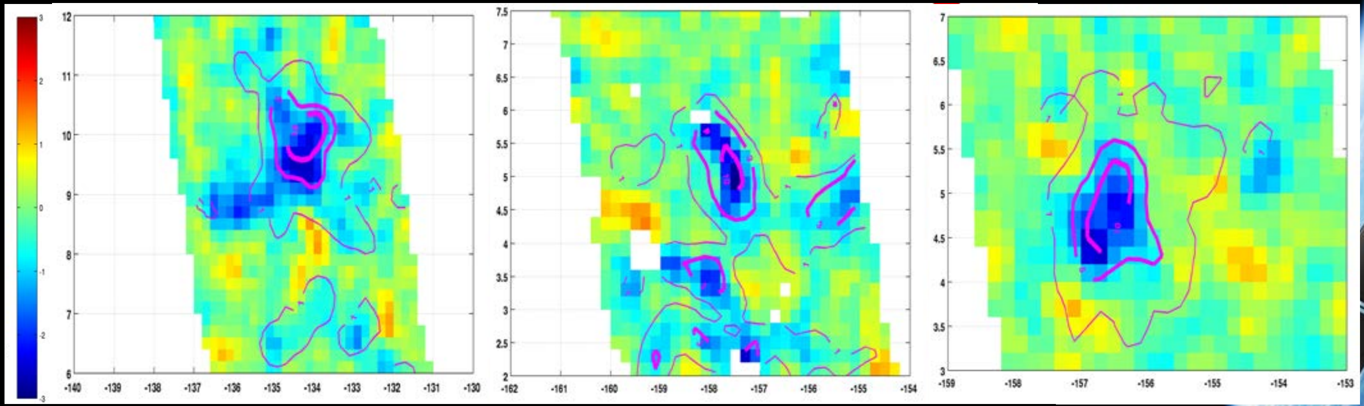


Coherent signal between SSS and Chl-a in the Mississippi plume

More in practical lecture 12

Surface Salinity and Rain events

- Satellite rainfall (SSMIs) and SMOS freshenings (ΔSSS = SSS-SSSref) are closely correlated at local scale and short temporal scale (<30mn)



1 mm/h
5 mm/h
10 mm/h

Supply et a., 2017

All you need in 2 papers…

Vinogradova et al., 2019 Front. Mar. Sci. https://doi.org/10.3389/fmars.2019.00243

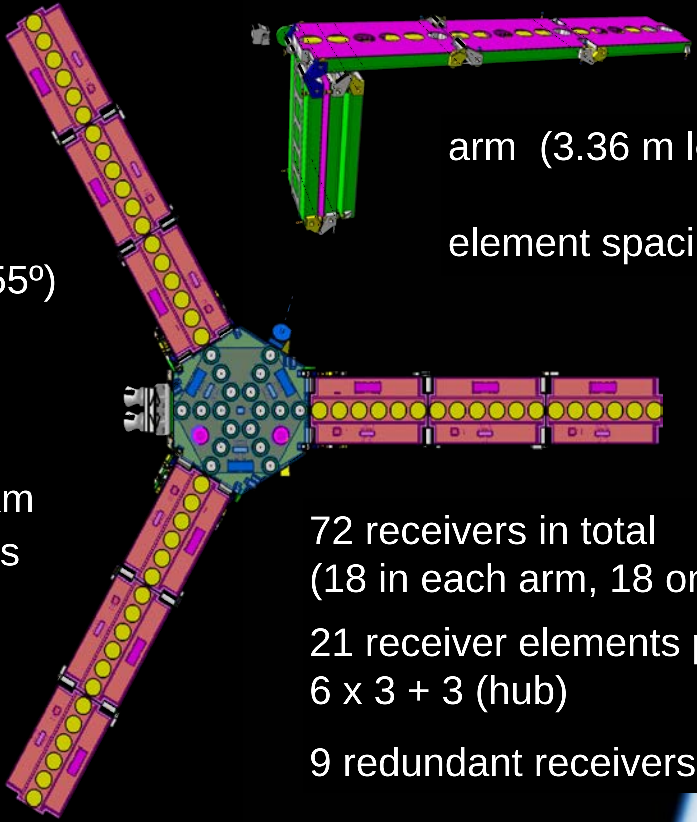
&

Reul et al., re-submitted to Remote Sensing of the Environment 🤞

Movie !

SMOS Instrument

- Passive microwave radiometer
(L-band - 1.4GHz)
- 2D interferometry
- multi-incident angles (0°-55º)
- ~ 1000 km swath
- Fully polarimetric observations
- spatial resolution: ~43 km
- revisit time: 3 days
- Launch: 2009
- Nominal 3 year mission,
- Extended to 2017



arm (3.36 m length)

element spacing: 0.88 λ

72 receivers in total
(18 in each arm, 18 on the hub)

21 receiver elements per arm:
6 x 3 + 3 (hub)

9 redundant receivers (in hub)

- SMOS (Soil Moisture & Ocean Salinity)
  Launch date: November 2nd, 2009

  L band radiometer required: No existing device

  How to by-pass the antenna size technical difficulty ?:
  Antenna deployed in space and Interferometry

ESTAR instrument (NASA) selected by: esa, cnes, CDTI

- AQUARIUS/SAC-D (NASA/CONAE): launch date: July 2010
- SMAP (NASA/CONAE): launch date: April 2015

<u>Goal of both missions:</u>

- SSS measurments with an accuracy of 0.1-0.2 psu and a spatial resolution of 100x100 km every 10 days (GODAE requirements).