Satellite Oceanography: an integrated perspective

How to contribute/accelerate new skills/discoveries to help reveal and model unknow unknowns from all available multi-modal satellite ocean remote sensing measurements ?

Some Earth Observation Challenges:

Upper vertical motions i.e. 3D dynamics (e.g. including time evolution) of the upper ocean, Mesoscale and submesoscale circulation as key to control the vertical ocean pump and its impact on energy transport and biogeochemical cycles

Climate modelling due to these vast and diverse scales of fluid motions: in the upper ocean, horizontal scales as big as basins and as small as cm-mm (capillary-gravity surface waves) contribute non-negligibly to air-sea exchanges and climate, and dynamics of scales of less than 30 km, is characterized by departures from the Earth's rotation constraint, i.e ageostrophic motions and strong impact of wind/wave transient forcings.

Problem: introduction of new regimes for heat, salinity and chemistry distribution which threaten the sustainability of life in the sea and increase the frequency of extreme events !

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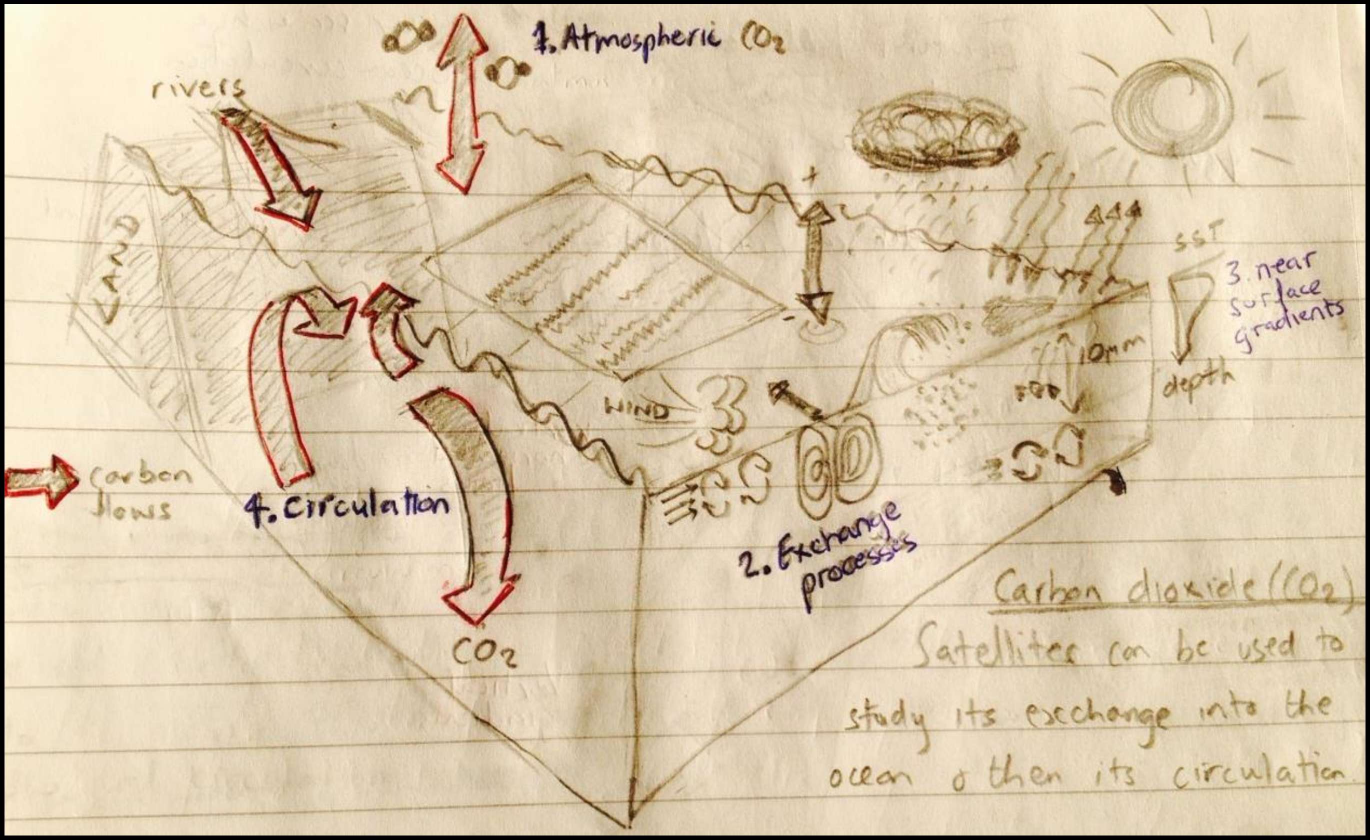


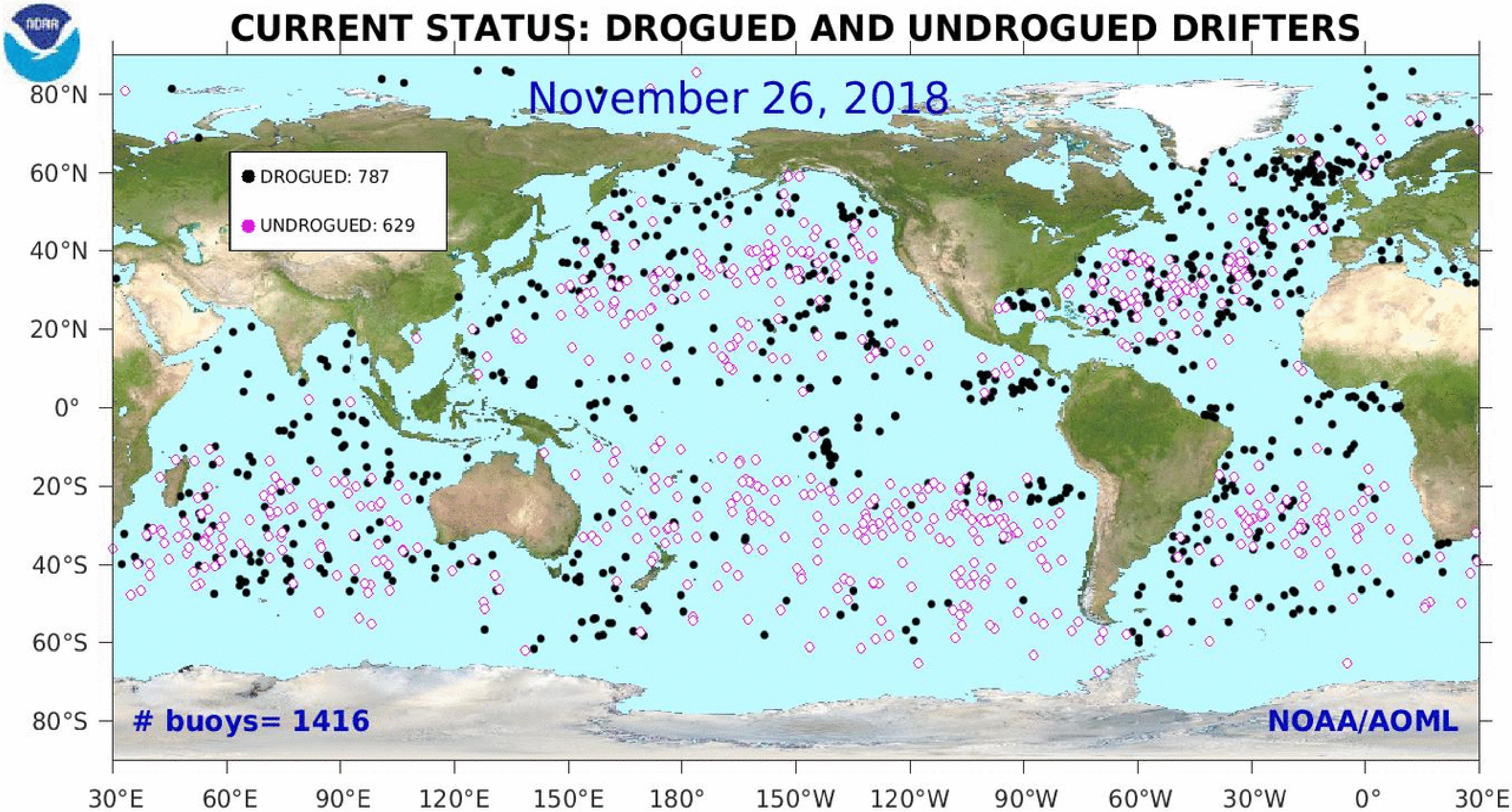
Future goals are to contribute/accelerate to new skills/discoveries to help reveal and model unknow unknowns from all available multi-modal satellite ocean remote sensing measurements ?

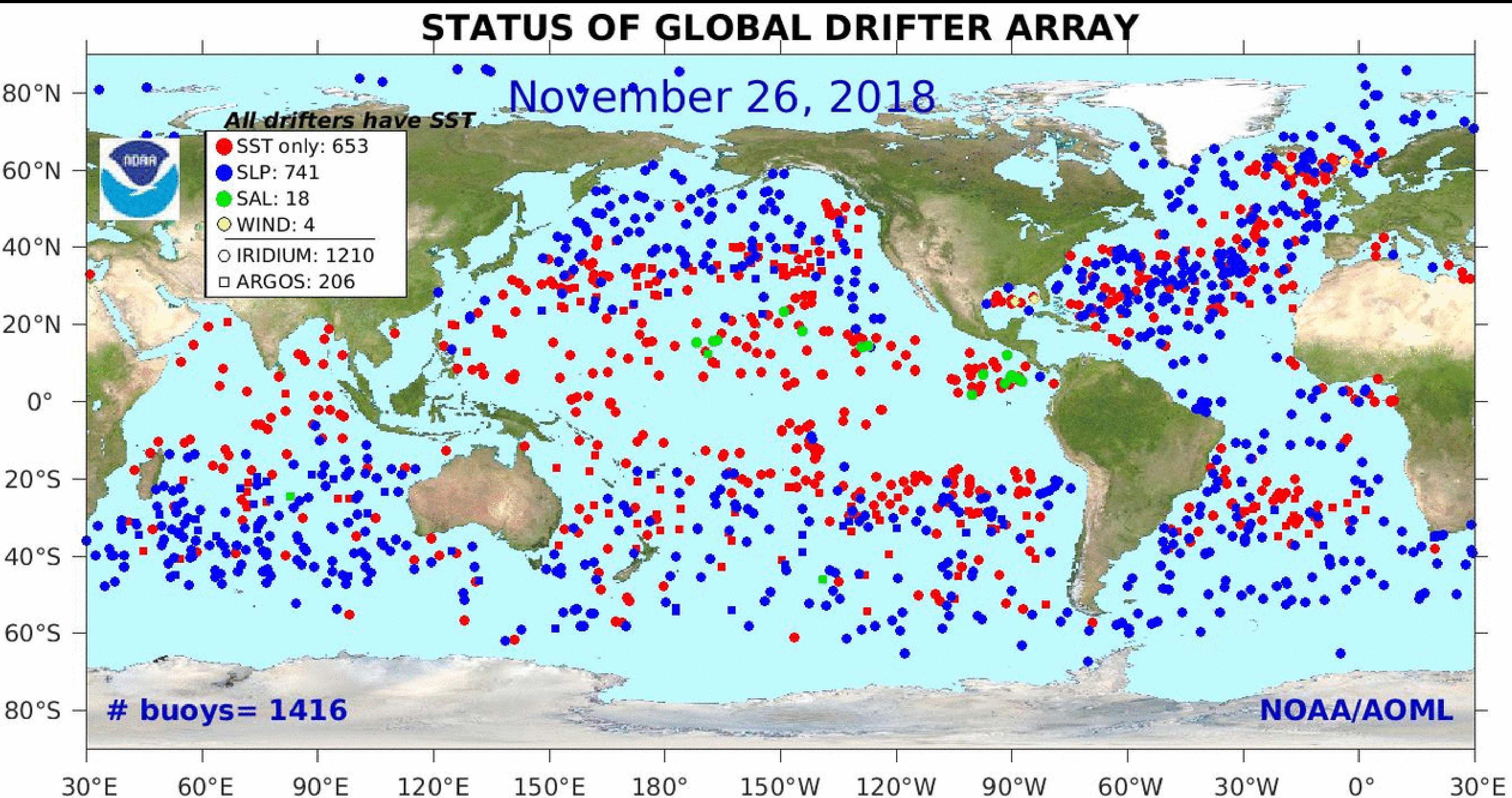
Computational simulations have a limiting "irreducible imprecision" compared to measured quantities in the turbulent regimes of the upper ocean. This limiting feature explains the observed irreproducibility among different model schemes which are supposed to be solving the same problem. The imprecision of simulations is due to the variety of independent selections of different numerical algorithms, model parameterizations, and representations of couplings among the different processes.

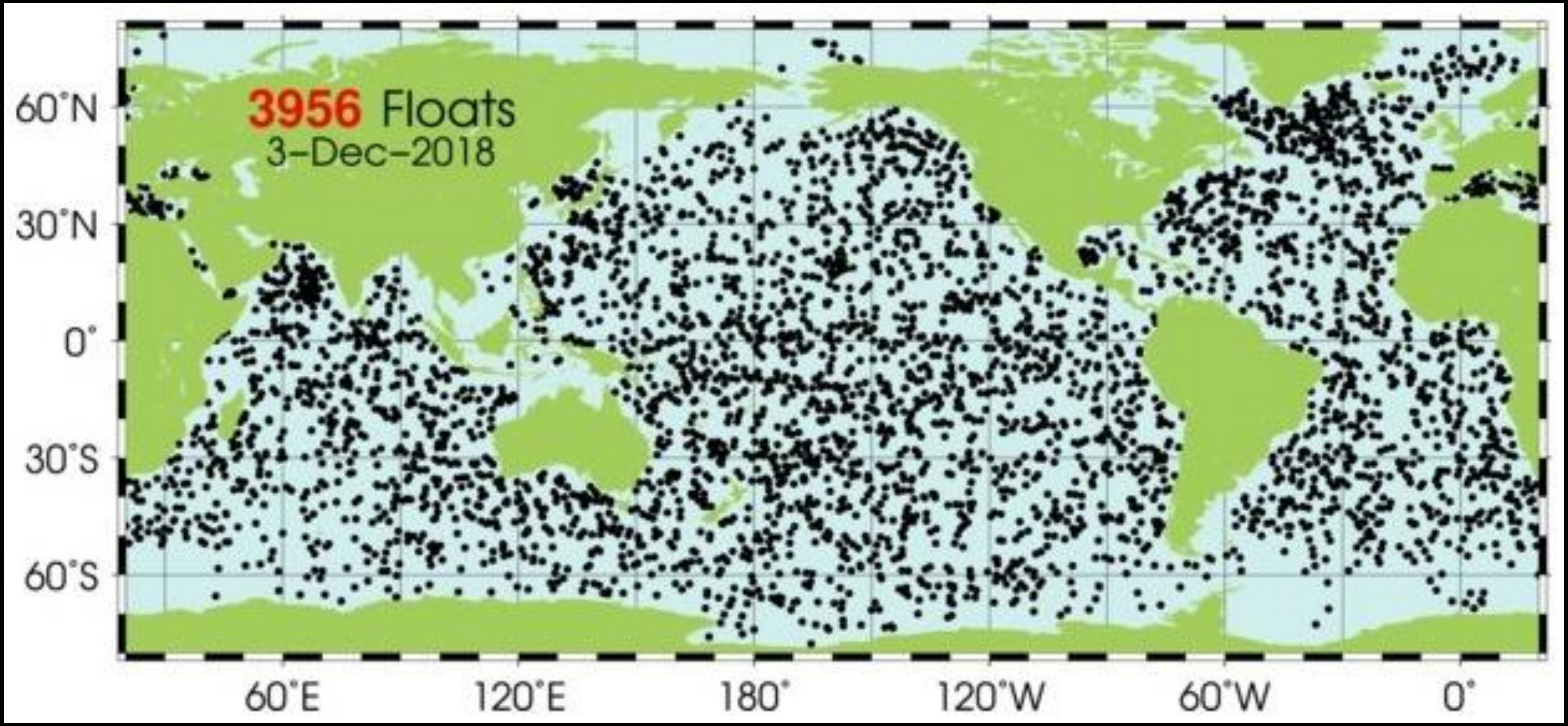
70% Earth’s surface covered by water

“If I were to choose a single phrase to characterize the first century of modern oceanography, it would be a century of under-sampling.”

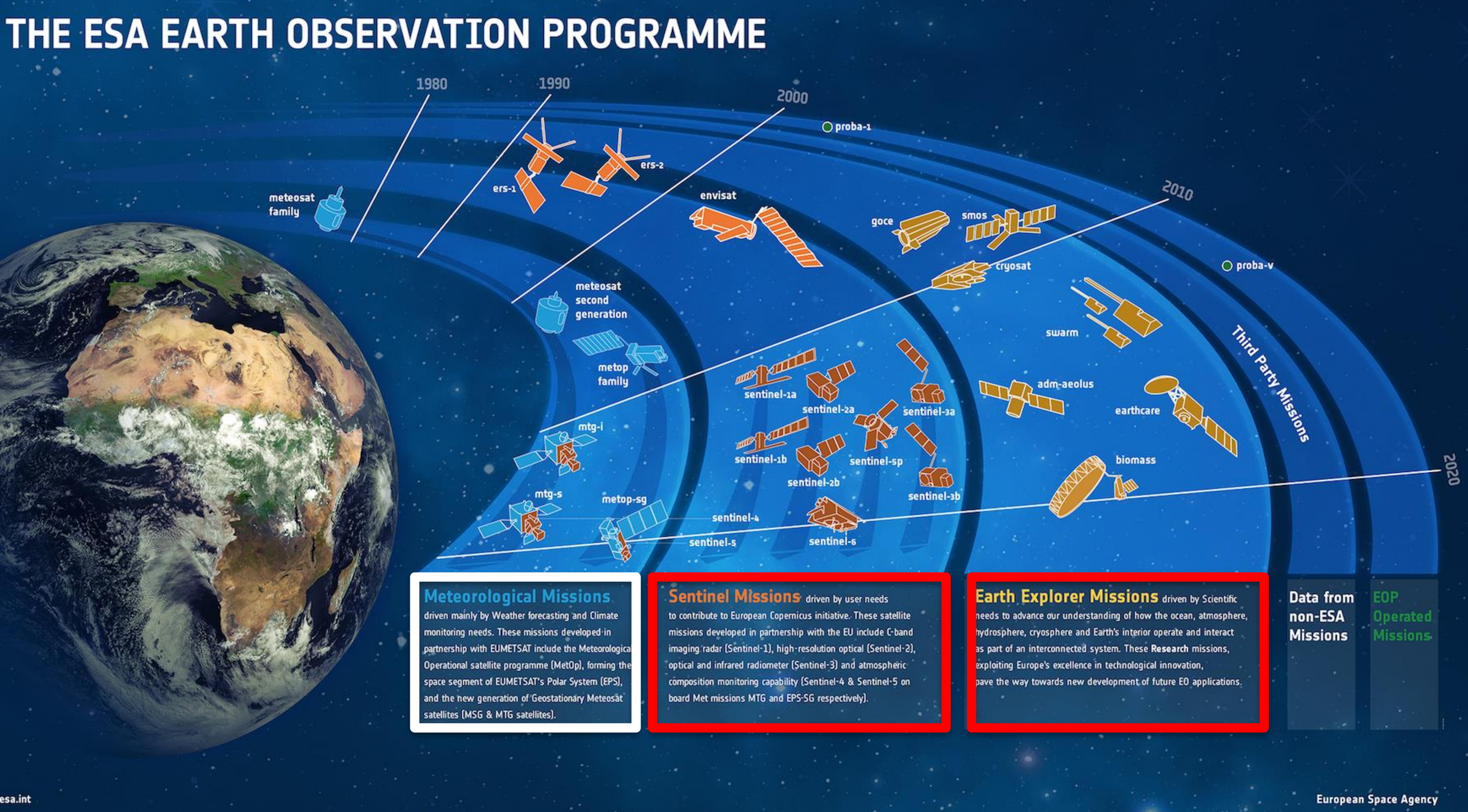
Walter Munk, Woods Hole Oceanographic Institute, 2000


CURRENT STATUS: DROGUED AND UNDROGUED DRIFTERS
November 26, 2018
DROGUED: 787
UNDROGUED: 629
buoys= 1416
NOAA/AOML
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0°
30°E

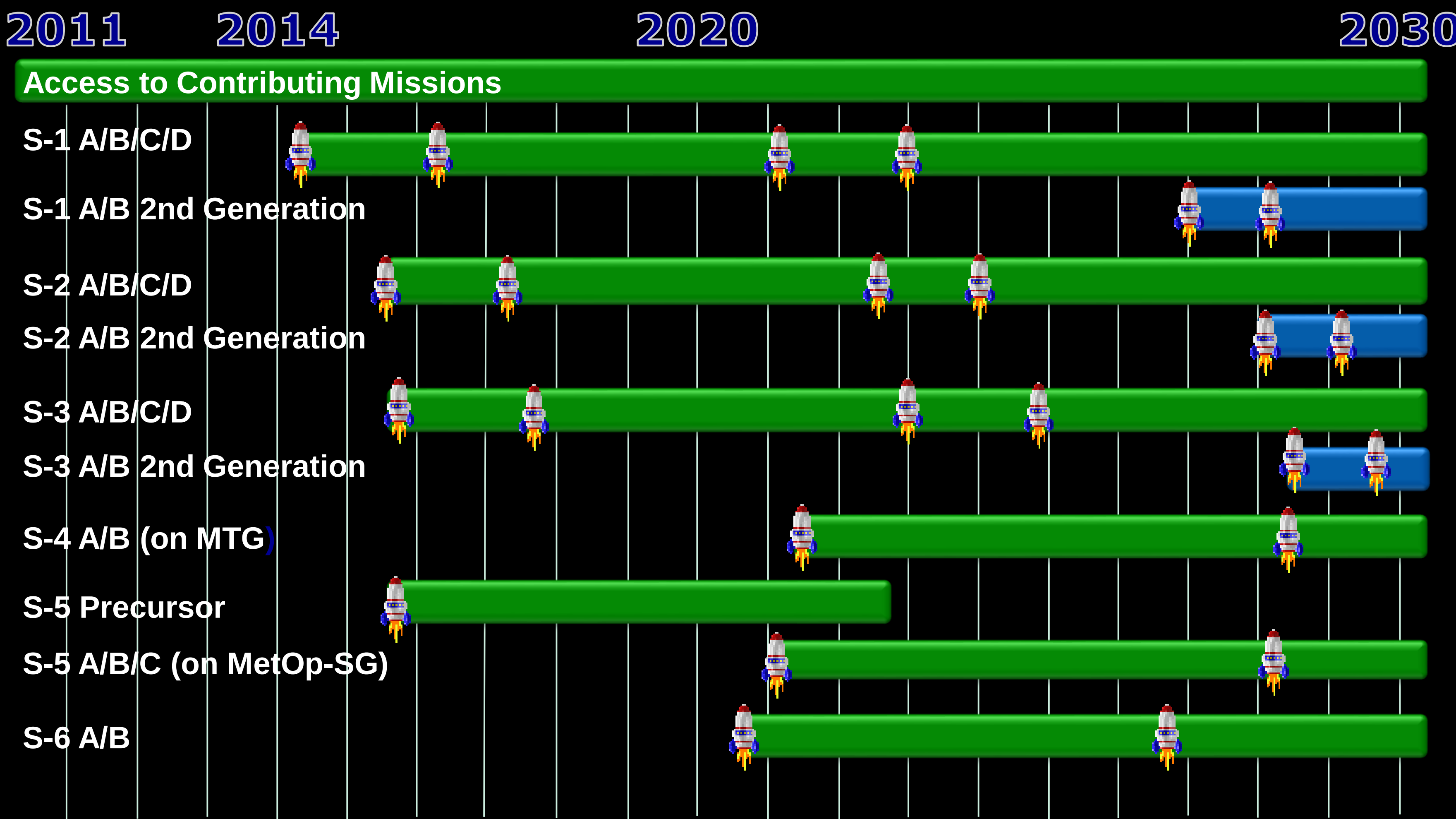

STATUS OF GLOBAL DRIFTER ARRAY
November 26, 2018
All drifters have SST
SST only: 653
SLP: 741
SAL: 18
WIND: 4
IRIDIUM: 1210
ARGOS: 206
buoys= 1416
NOAA/AOML
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0°
30°E


3956 Floats
3-Dec-2018
60°N
30°N
0°
30°S
60°S
60°E
120°E
180°
120°W
60°W
0°

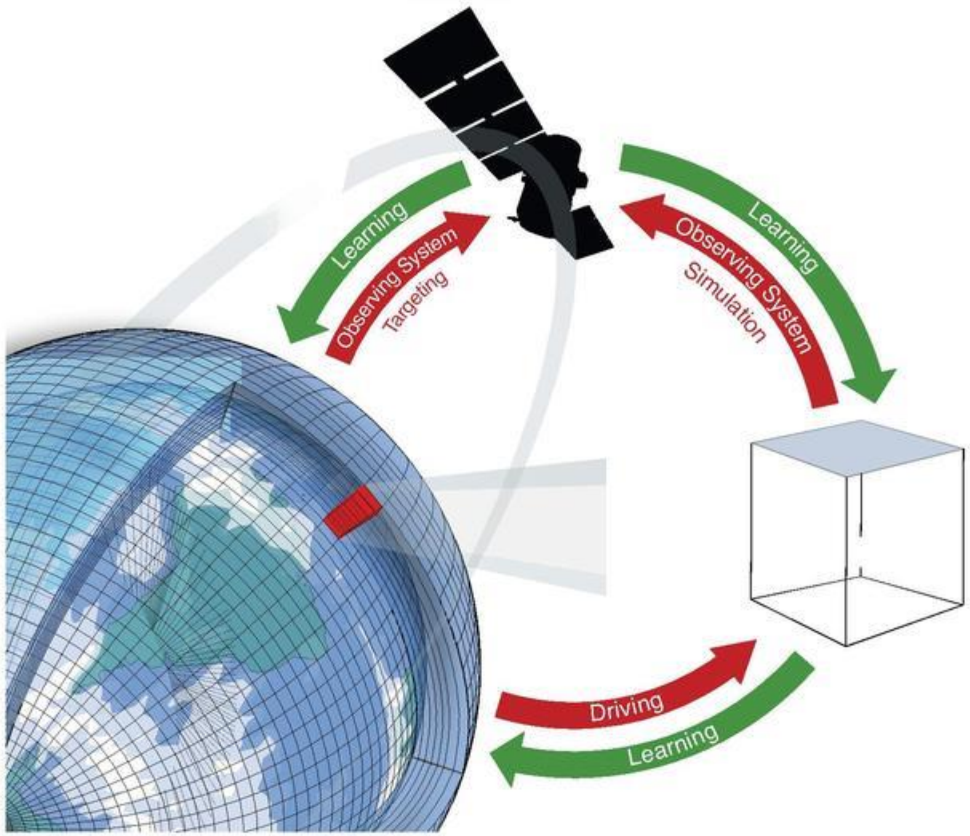
Three Pillars of ESA Earth Observation



… with a long-term operational perspective



Goal is a hierarchical system that integrates data and models (and can also be used to design observing systems)



Optimized sampling for multi-scale dynamics

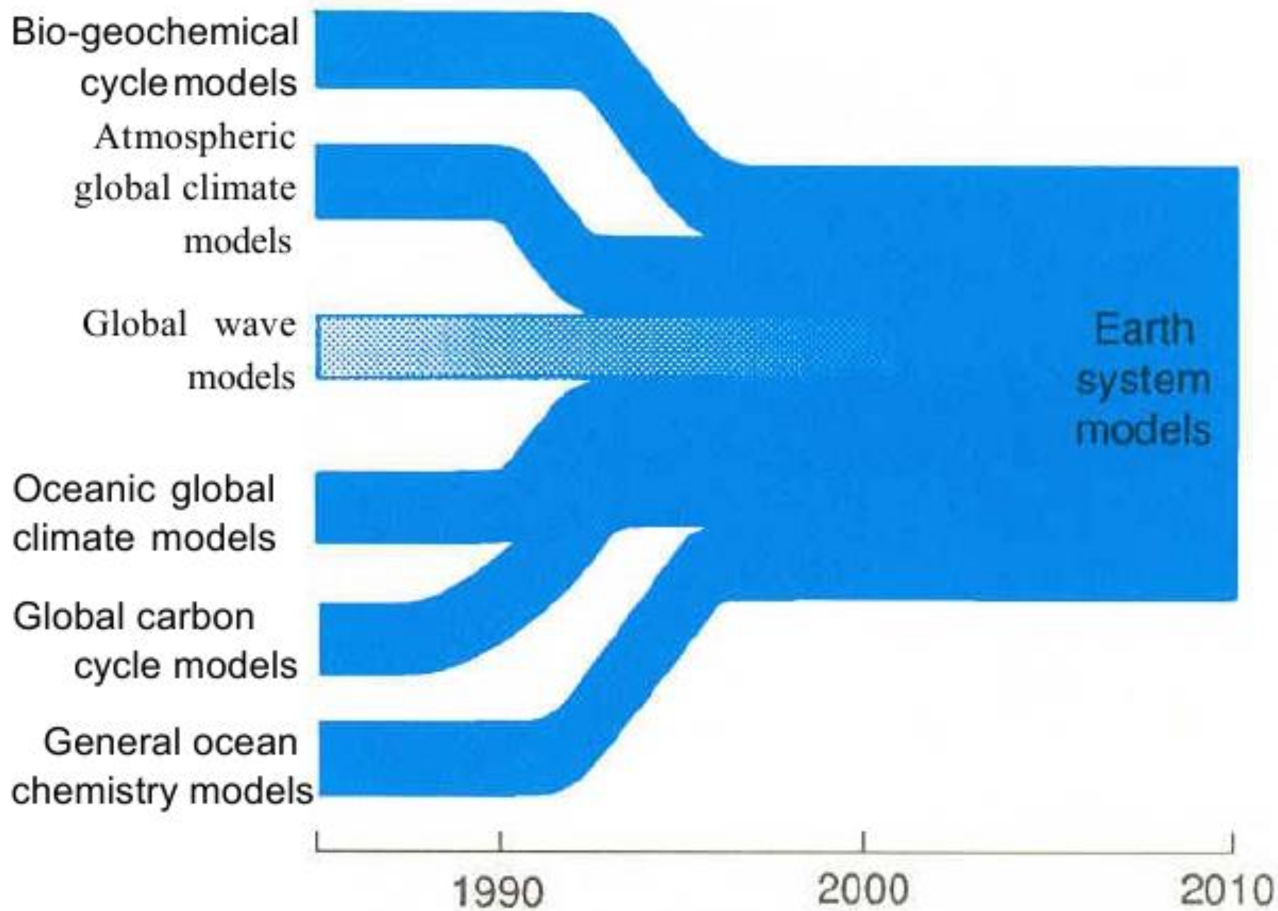
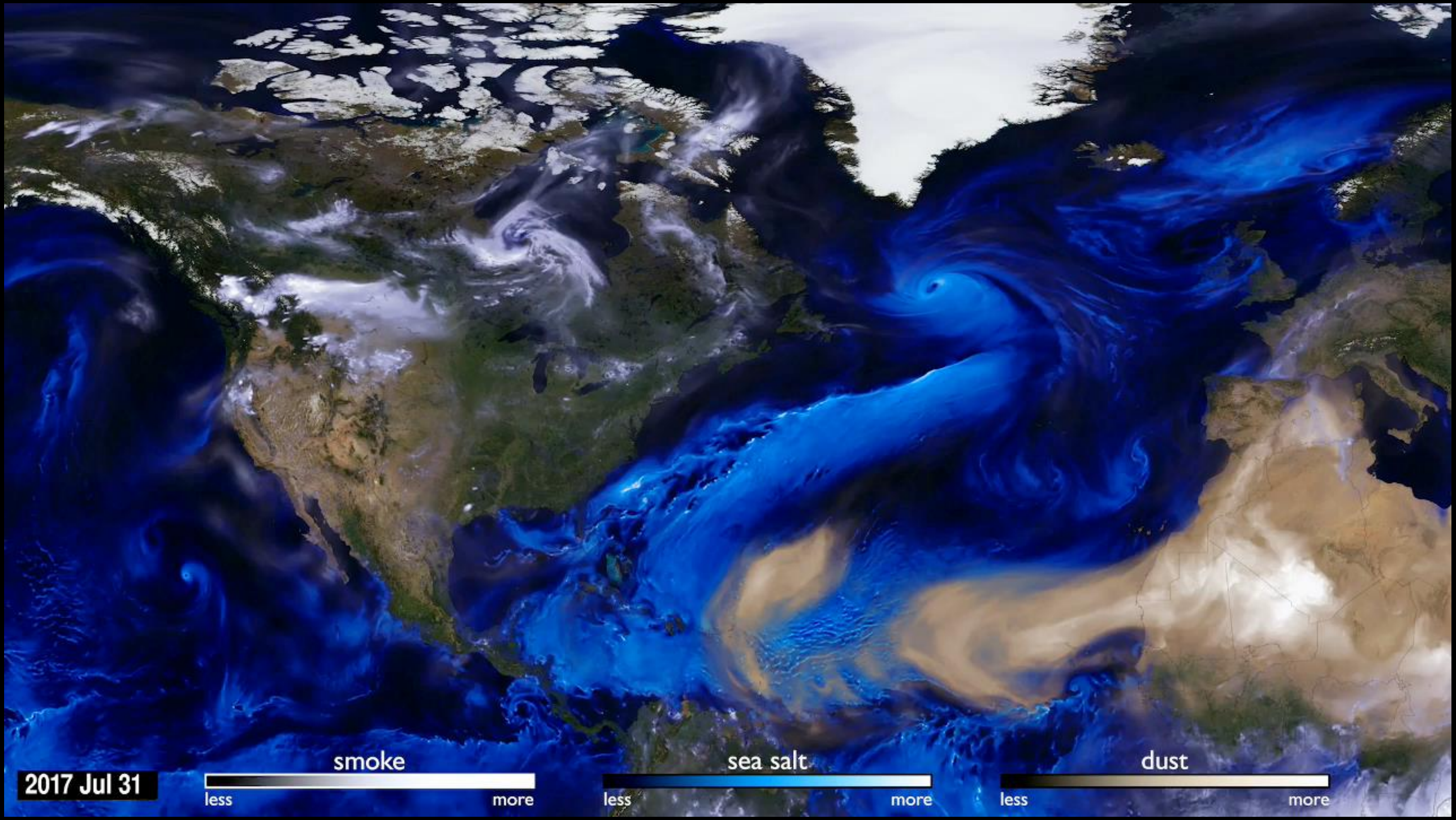
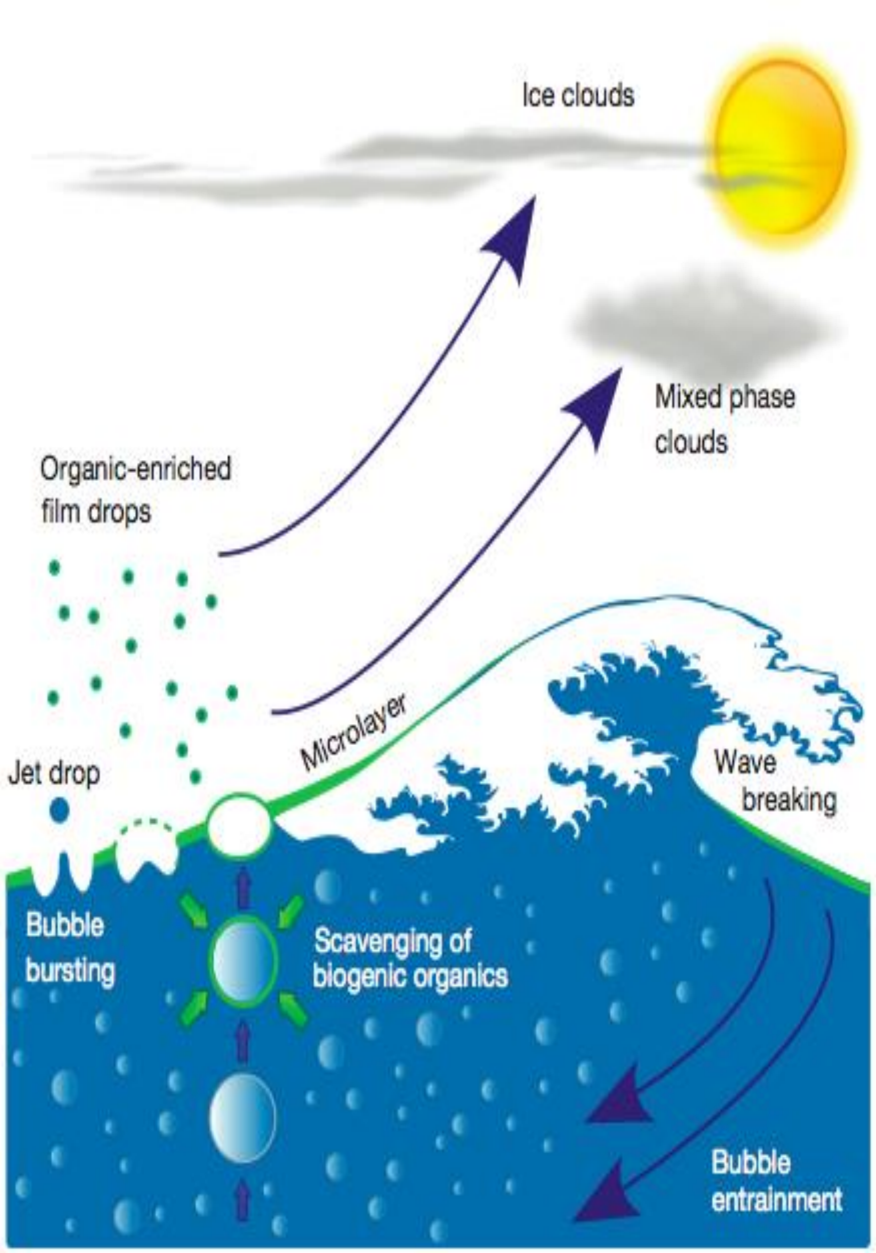


Figure 1. Future role of wave models as an essential coupling component for ocean-atmosphere-carbon-cycle models developed in the context ot the World Climate and Global Change programs.


2017 Jul 31
smoke
less
more
sea salt
less
more
dust
less
more



Sea-spray aerosol particles enriched in organic material are possibly generated when the air-sea interface is bursting

Ocean remote sensing: a privileged view

- Spatially detailed
  - Spatial resolution from meters to Kms
  - A synoptic picture that is 100 km - 10 000 km wide
- Regularly repeated
  - Revisit intervals between 30 min. and 35 days
  - Continuously repeated over years to decades
- Global coverage
  - Satellites see the parts where ships rarely go
  - Single-sensor consistency - no intercalibration uncertainties
- Measures parameters that cannot be observed in situ
  - Surface roughness at short length scales (2-50 cm)
  - Surface slope (a few cm over 100s of kilometres)

Ocean remote sensing: ew

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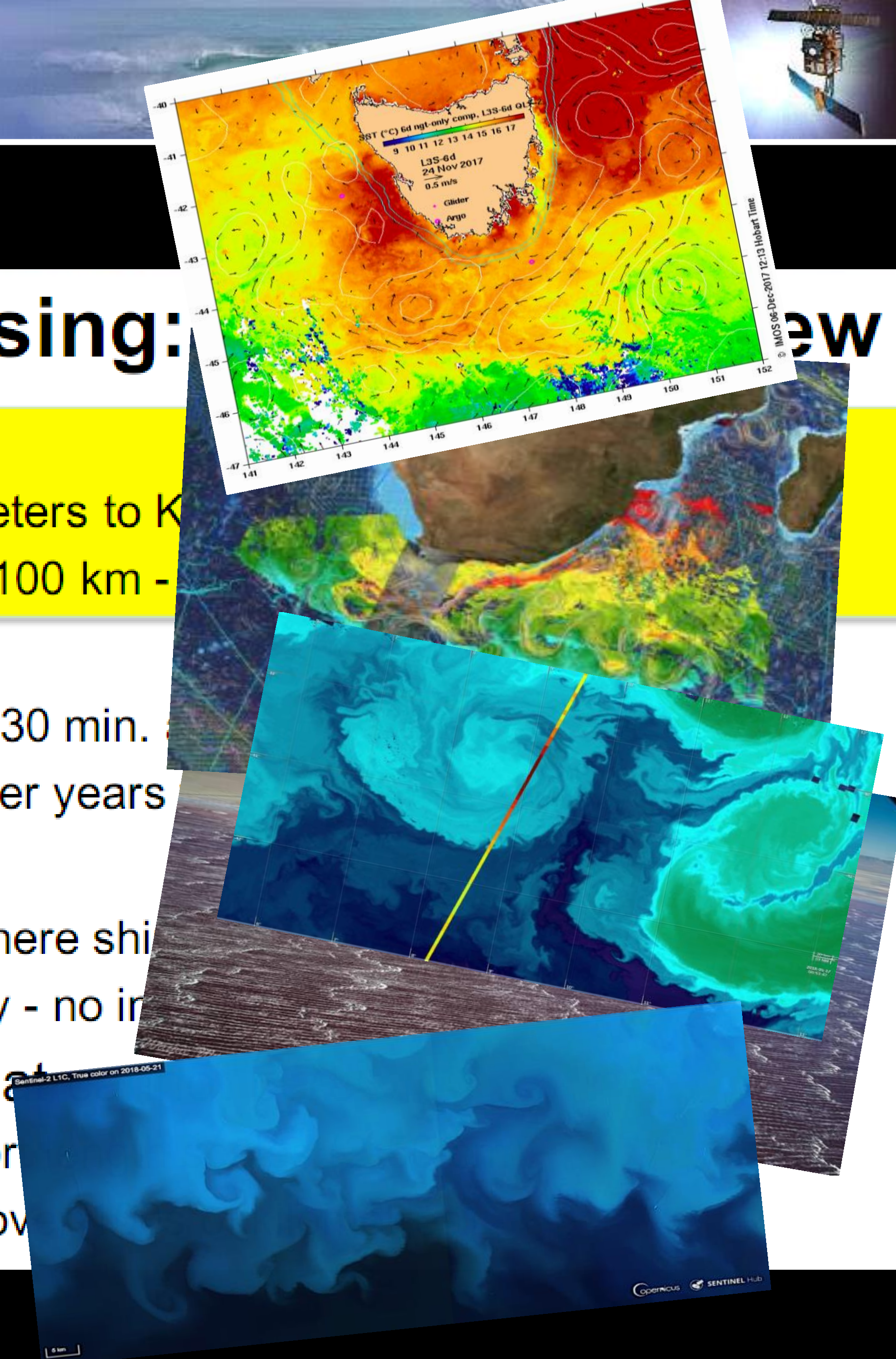
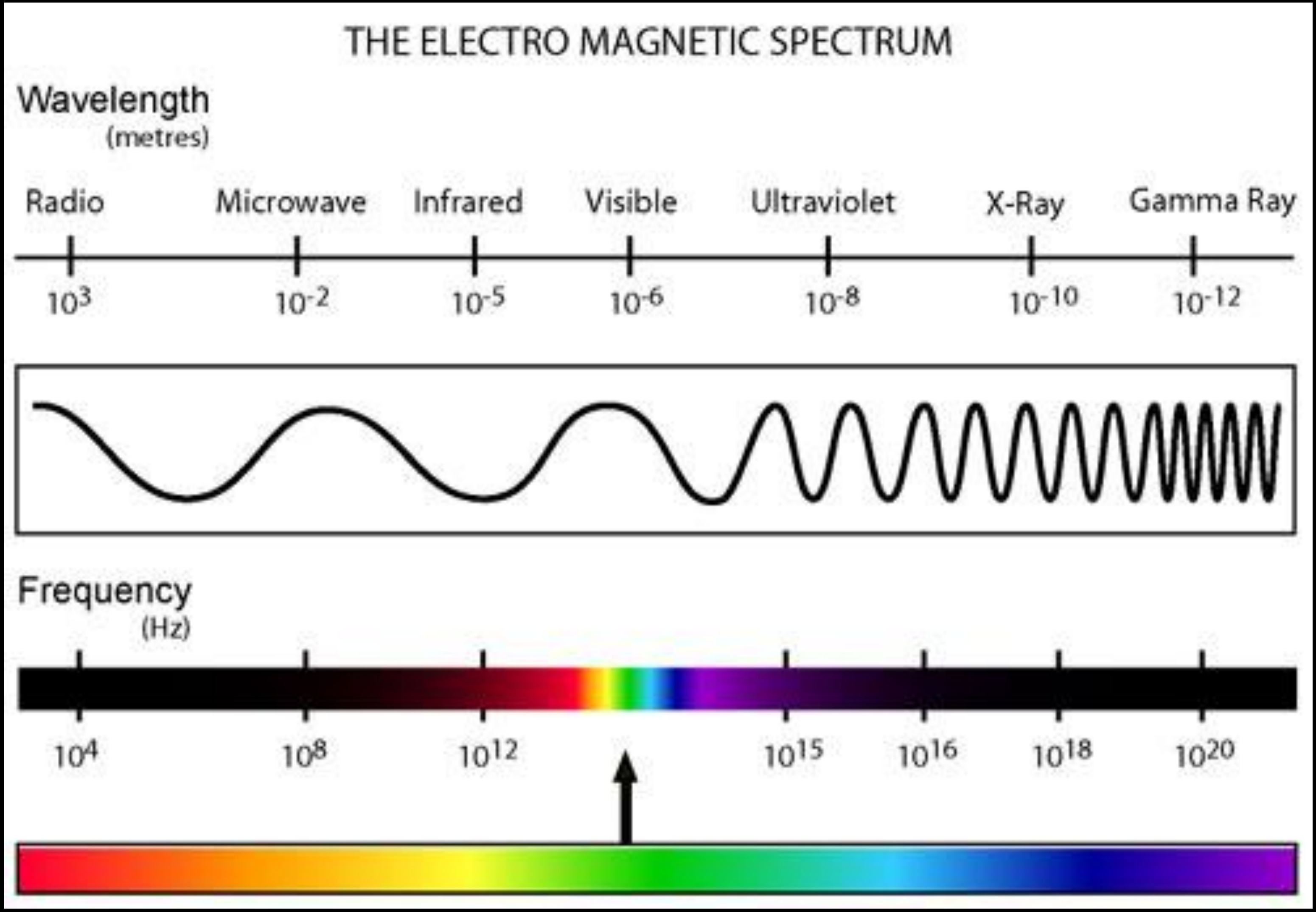
  - Surface slope (a few cm ov




THE ELECTRO MAGNETIC SPECTRUM
Wavelength
(metres)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-Ray
Gamma Ray
10^{3}
10^{-2}
10^{-5}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
Frequency
(Hz)
10^{4}
10^{8}
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}

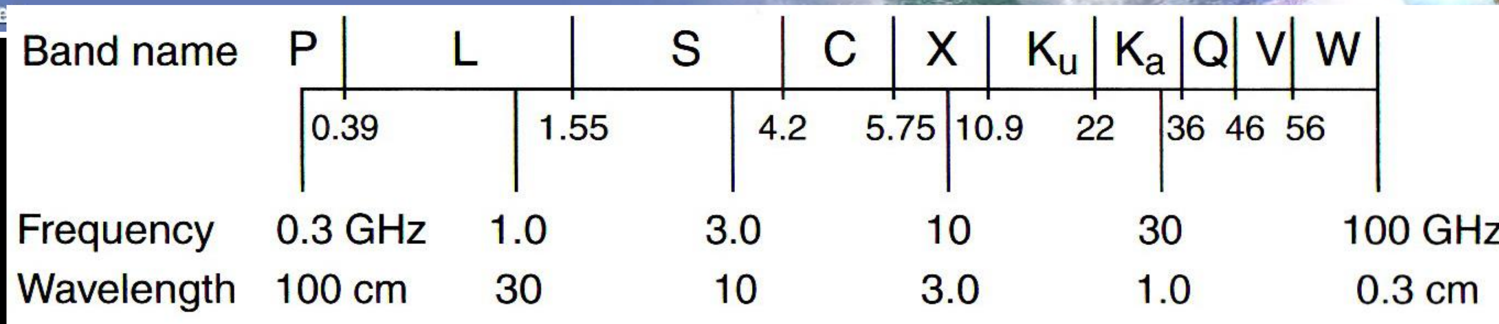


Table 2.1. Band letter designations used in microwave remote sensing.

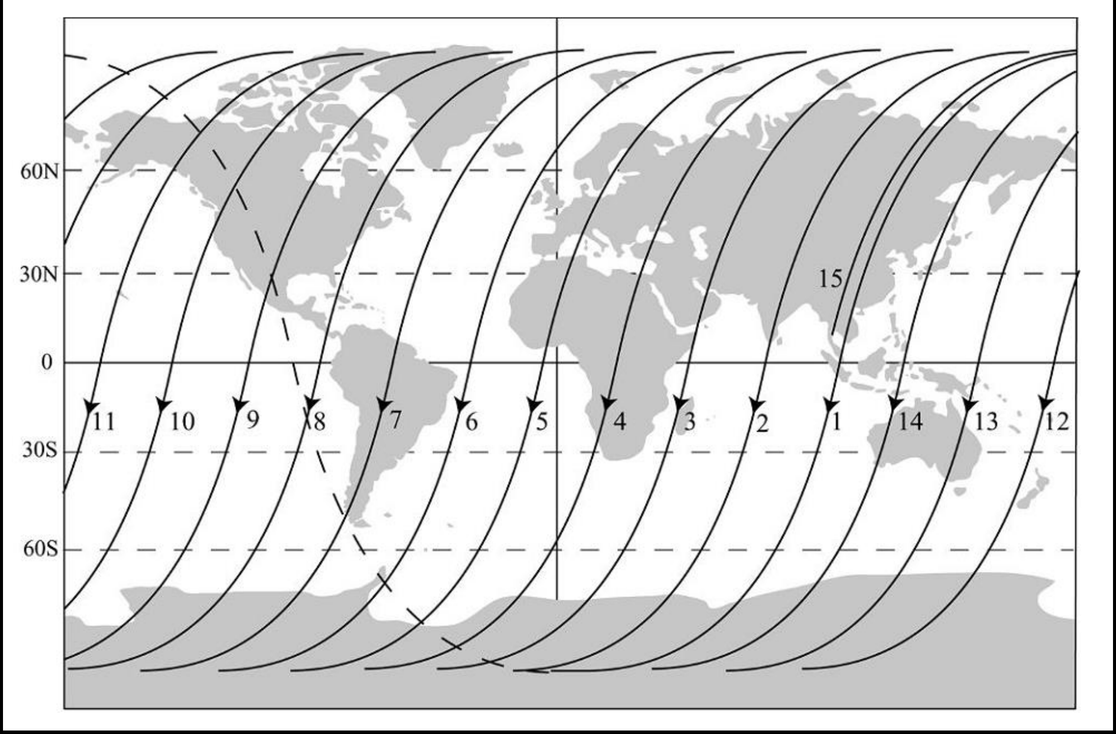
Band	Frequency (GHz)	Wavelength
P	0.225–0.390	76.9–133 cm
L	0.390–1.55	19.35–76.9 cm
S	1.55–4.20	7.14–19.35 cm
C	4.20–5.75	5.22–7.14 cm
X	5.75–10.9	2.75–5.22 cm
K_u	10.9–22.0	1.36–2.75 cm
K_a	22.0–36.0	8.33–13.6 mm
Q	36.0–46.0	6.52–8.33 mm
V	46.0–56.0	5.36–6.52 mm
W	56.0–100	3.0–5.36 mm

Satellite orbits

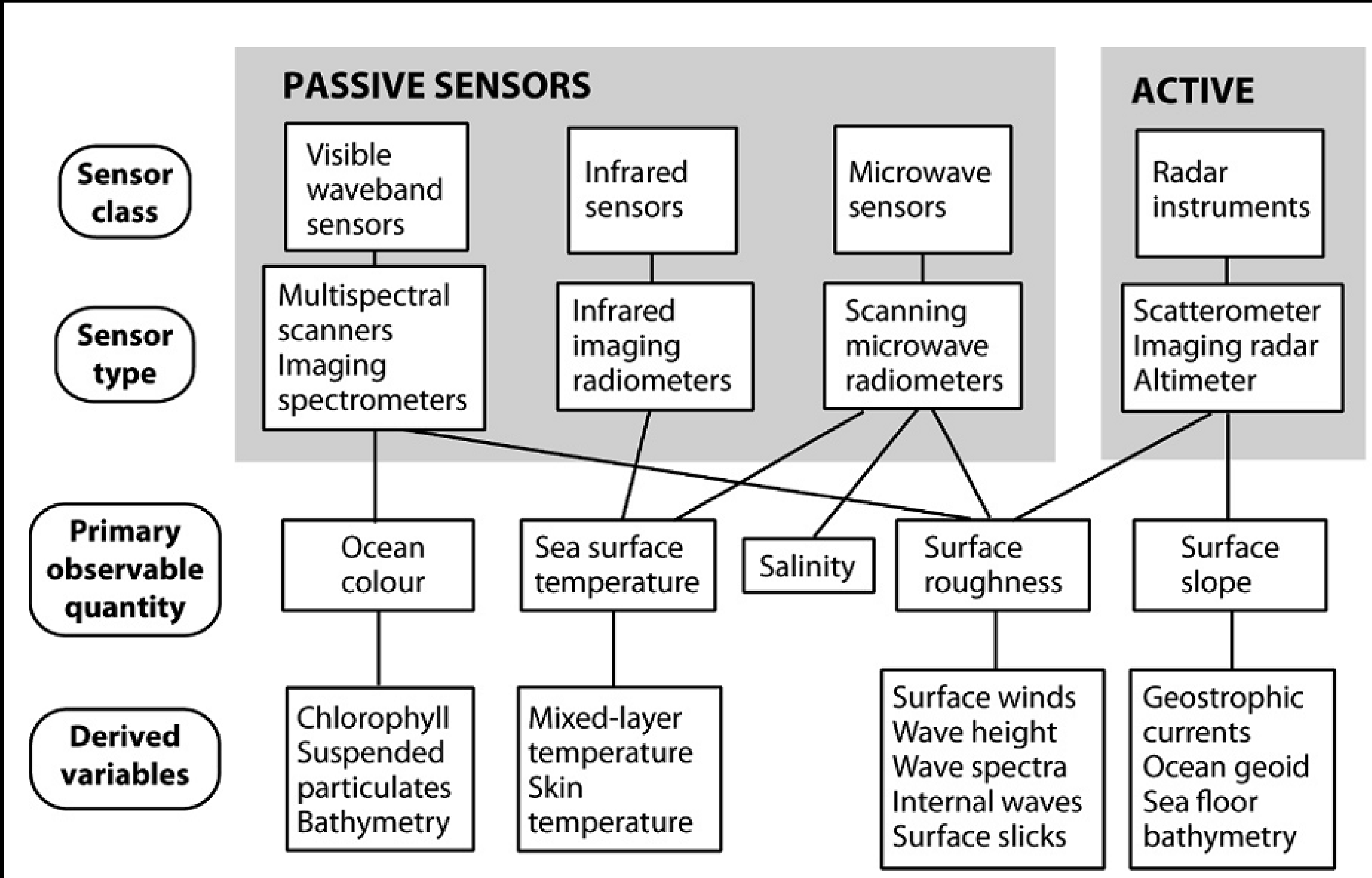
•Geostationary sensors typically offer a revisit interval of less than 30 min and spatial resolution of 1 to 5 km.

•The polar orbiting sensor cover the whole Earth in a single day if it is the swath at least 2700 km.

• Each point on the Earth surface is viewed once from descending track and once from ascending track.

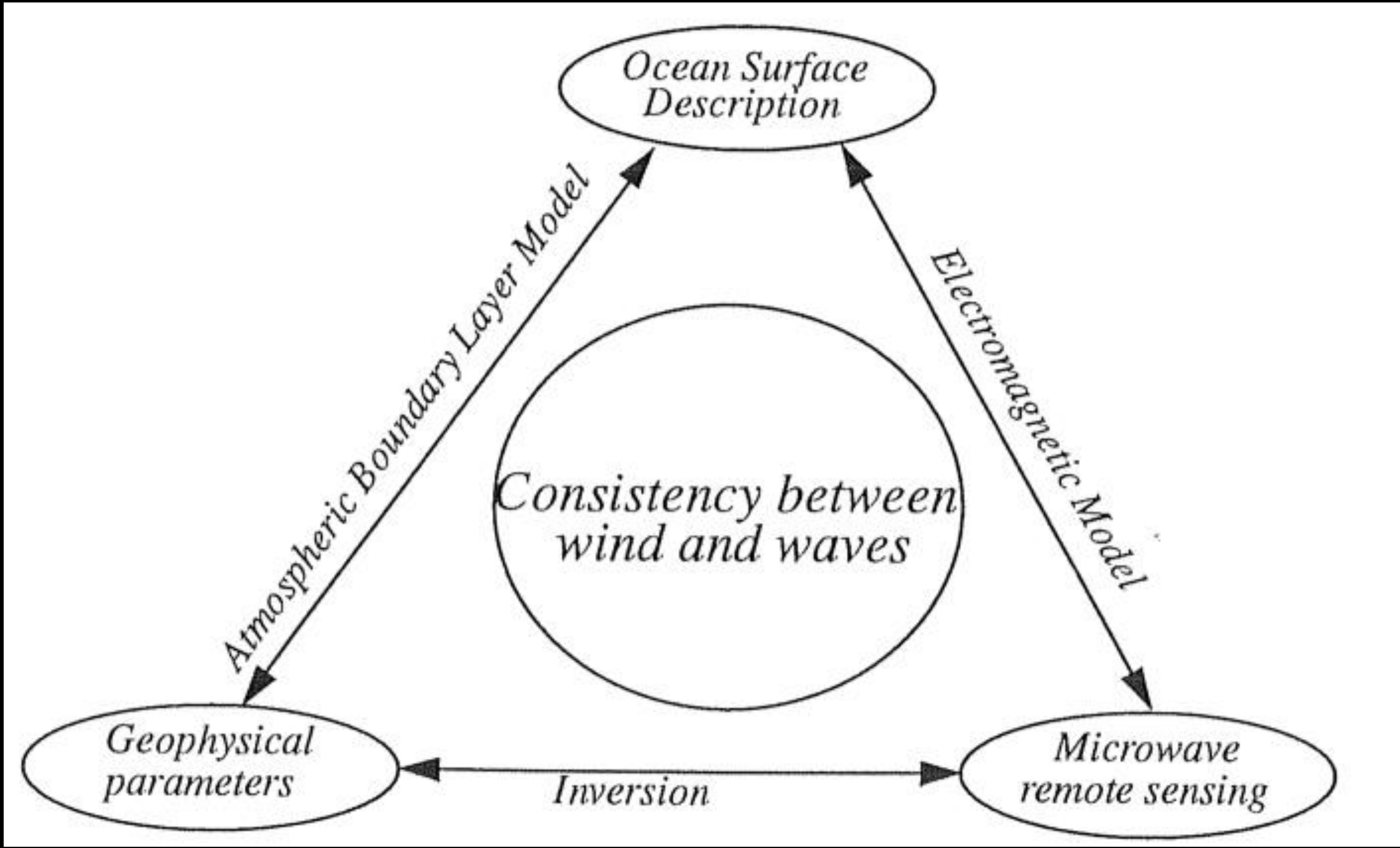


Ground track of a typical near-polar, low-Earth orbit, showing all the descending passes for one day and one ascending pass (dashed).

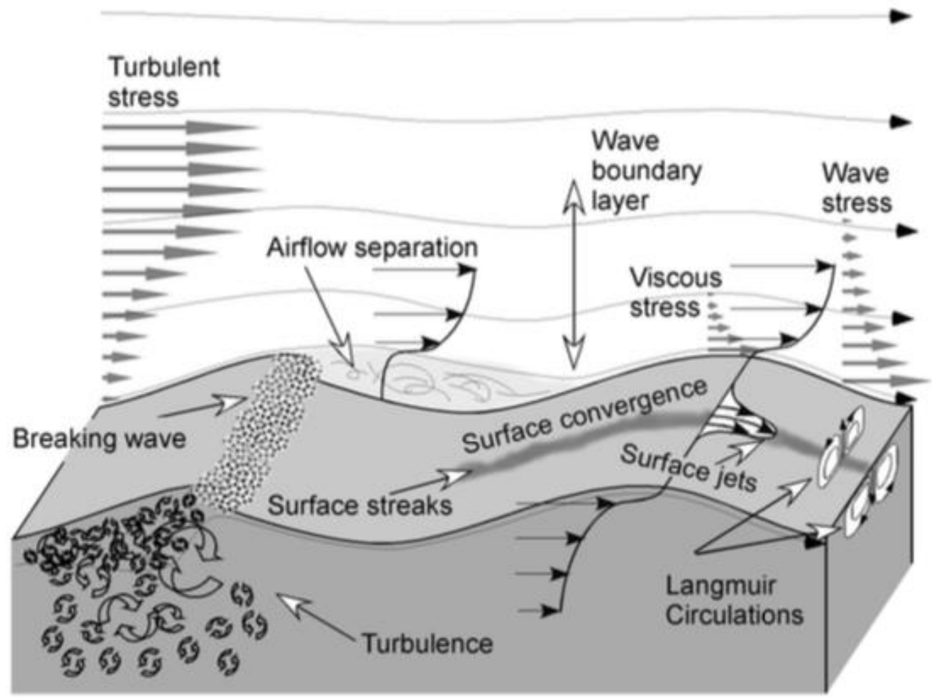


Schematic illustrating the different remote-sensing methods and classes of sensors used in satellite oceanography, along with their applications (from Robinson, 2004).

Foremost, to understand the satellite sensor initial capability (sensor physics and spatio-temporal sampling) ->A consistent approach (T. Elfouhaily, 1997)

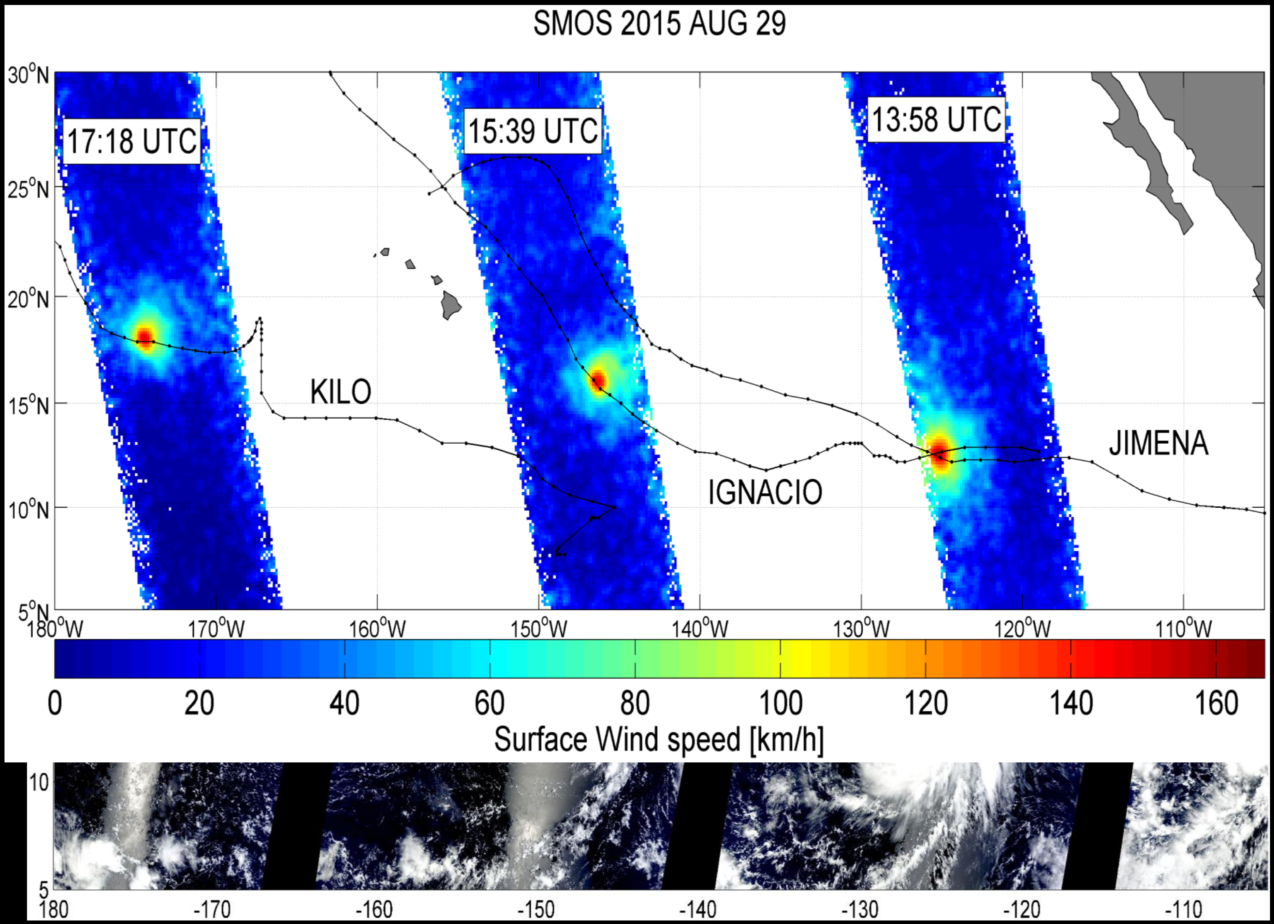


[redacted]

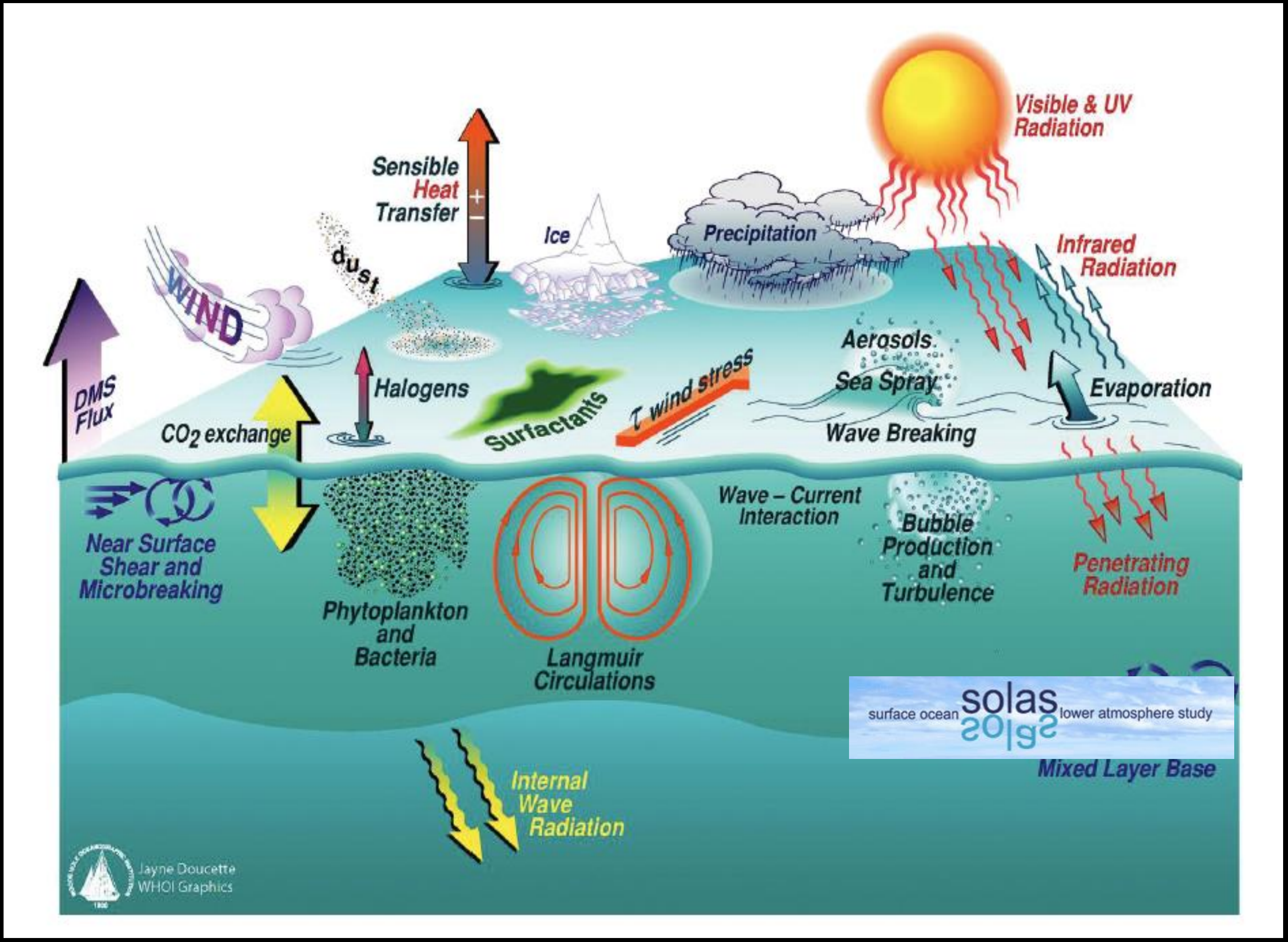


[redacted]

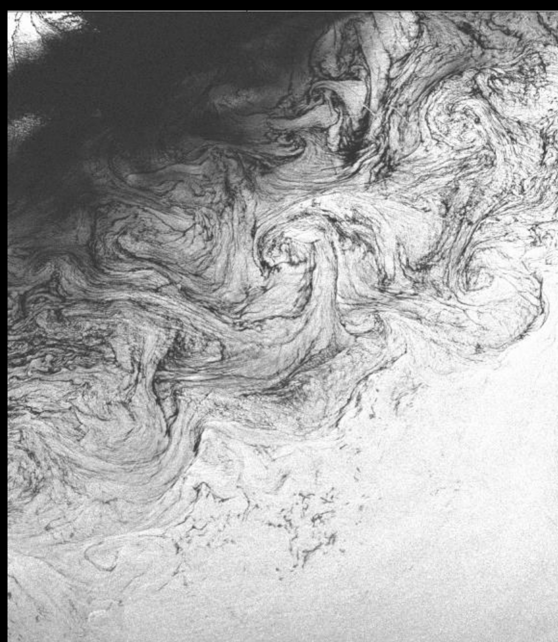
Signatures of 3 co-evolving 2015 major Hurricanes from 22 Aug to 9 Sep in the East and Central tropical Pacific as seen from SMOS, SMAP and AMSR-2 observations (beyond others)

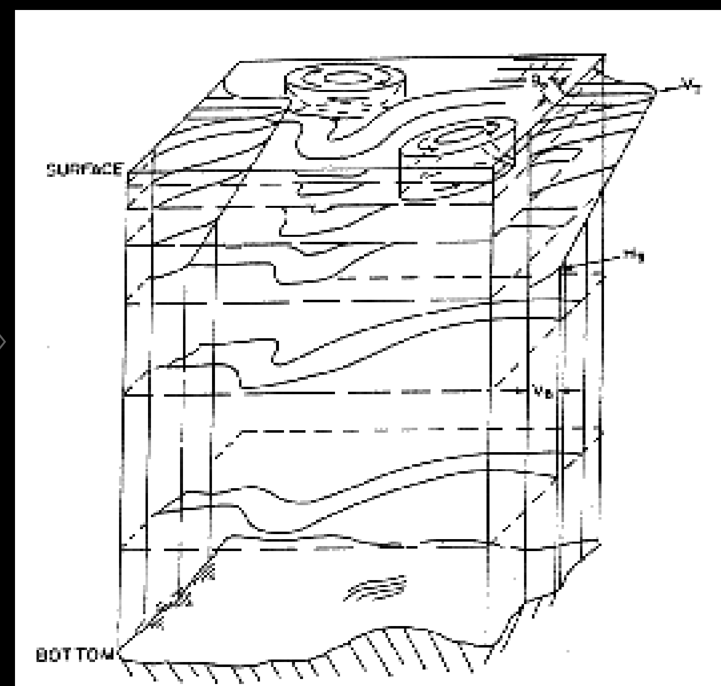


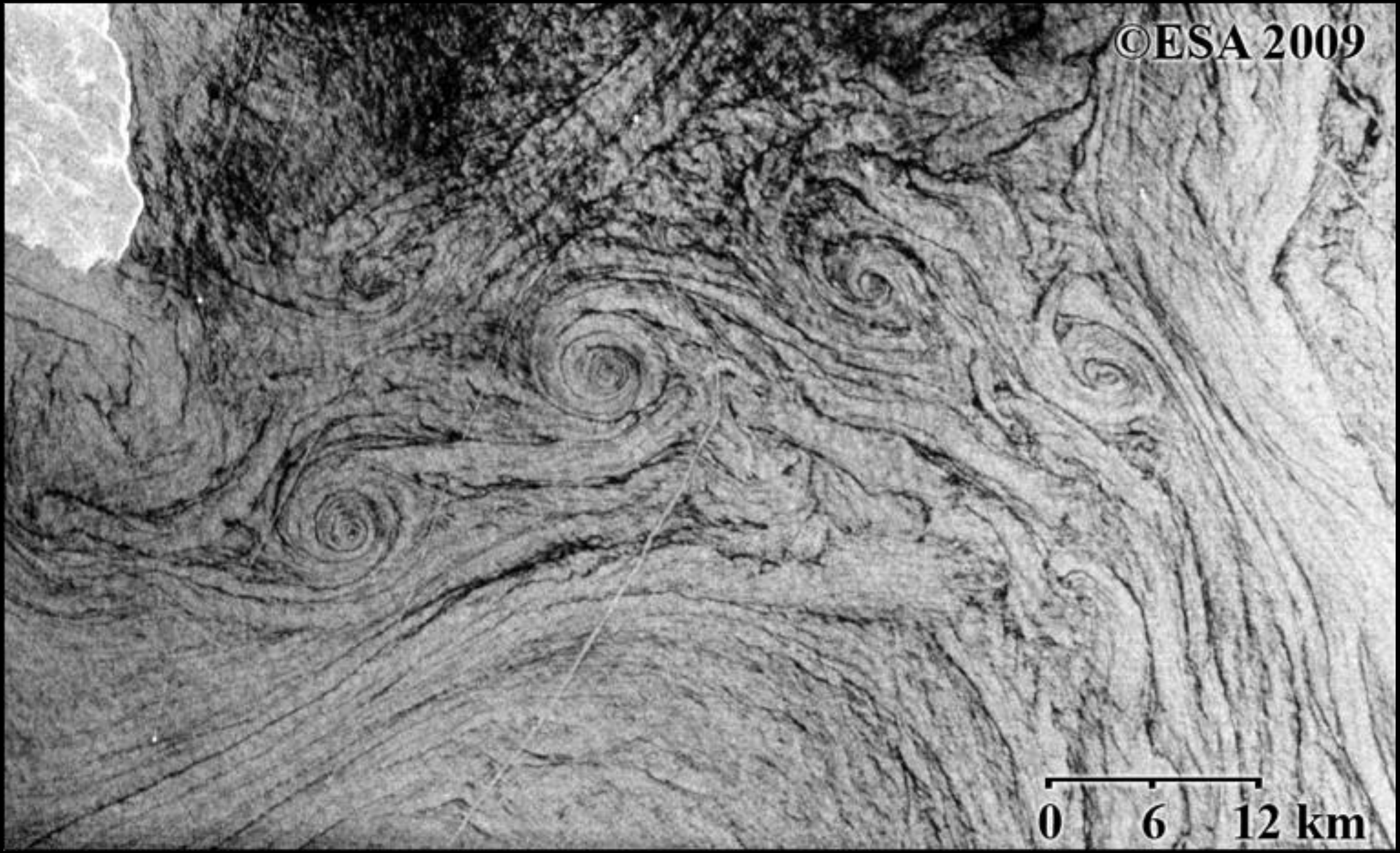
Satellite instruments generally measure 2D surface expressions of 4D structures

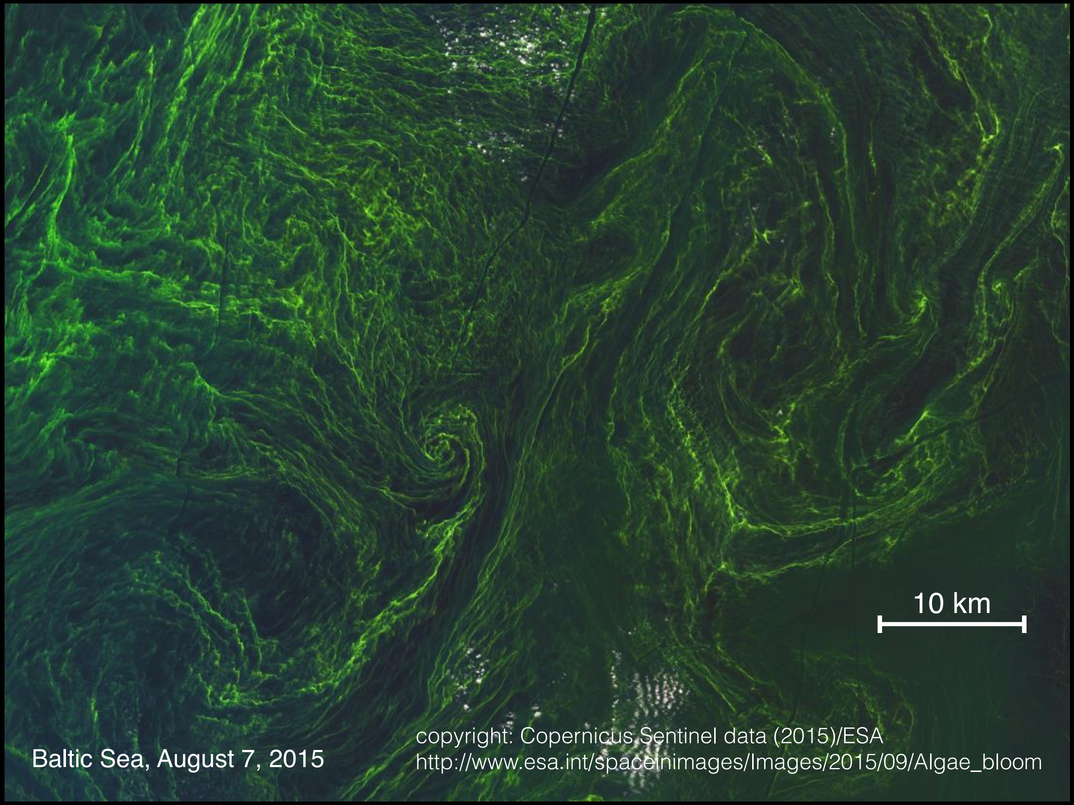


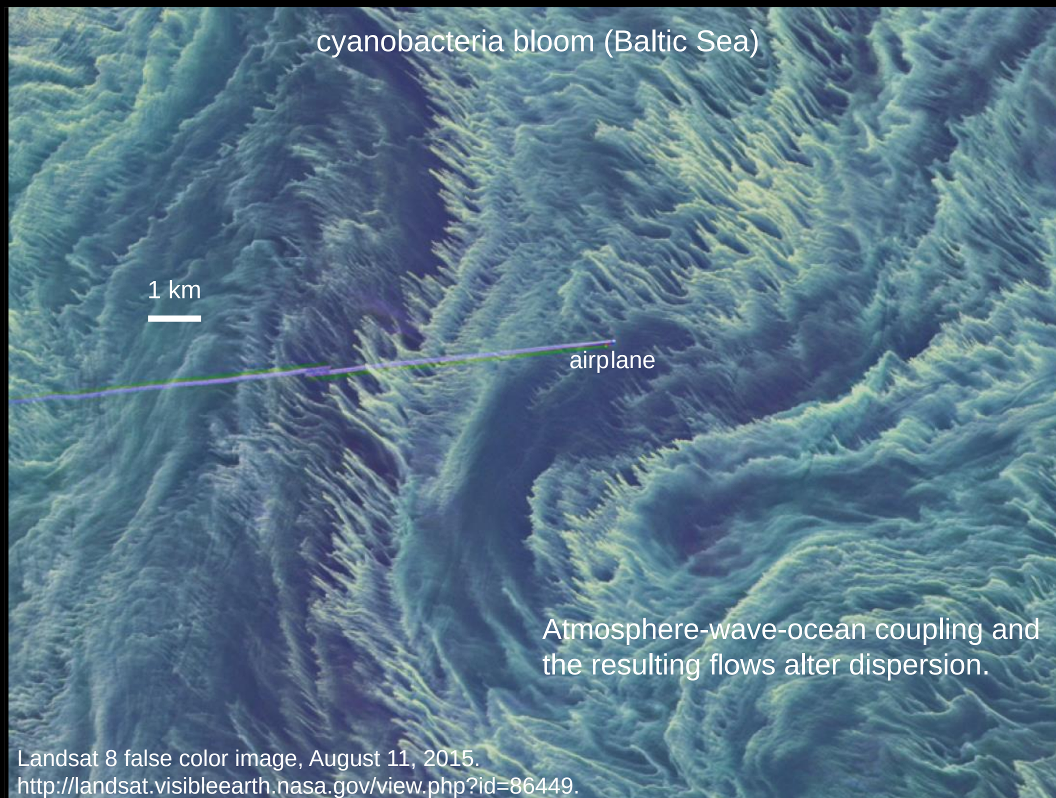
Sub-mesoscale (10 km eddies) and high resolution radar sea surface roughness variations





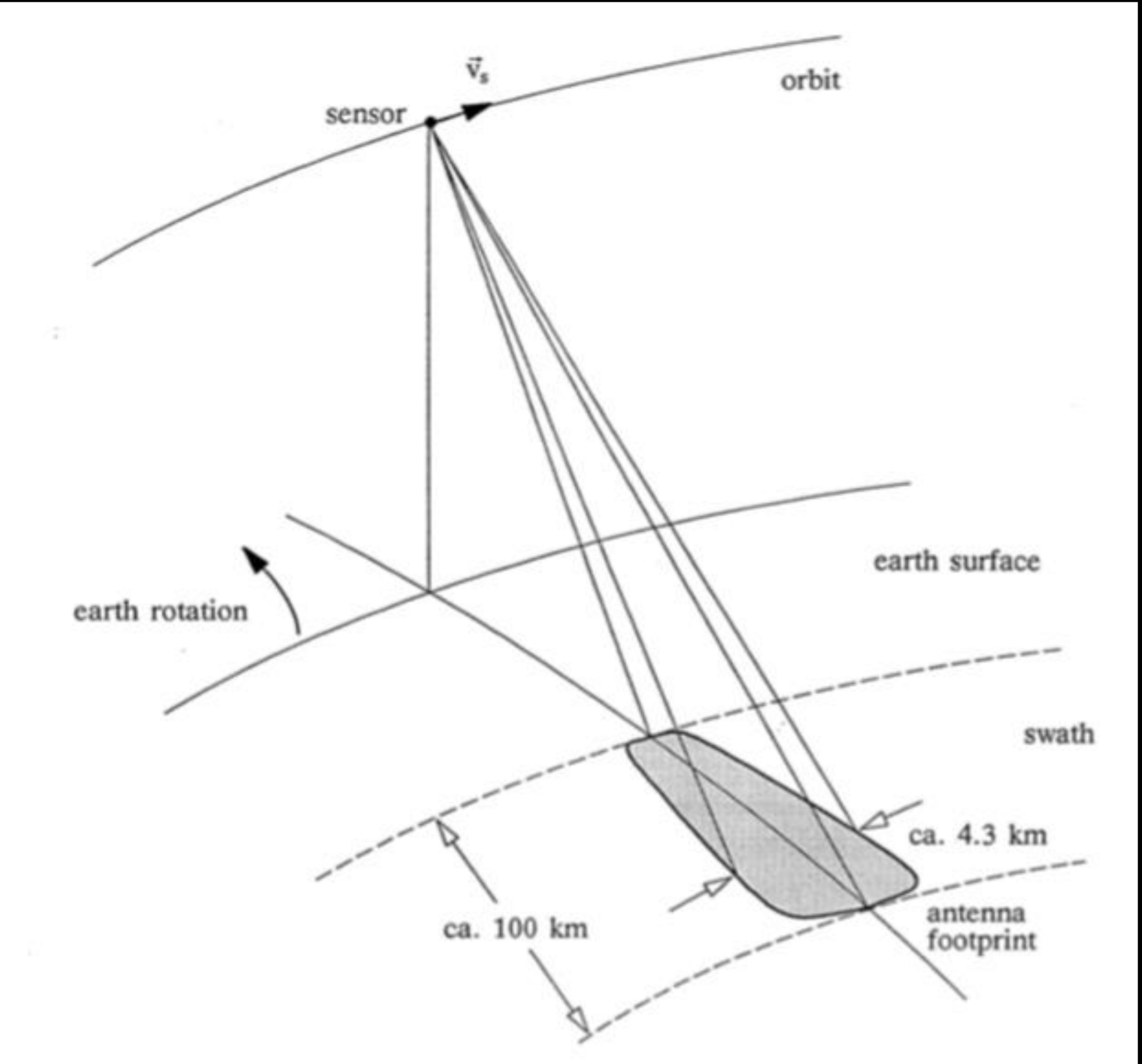

©ESA 2009
0 6 12 km


10 km
Baltic Sea, August 7, 2015
copyright: Copernicus Sentinel data (2015)/ESA
http://www.esa.int/spaceinimages/Images/2015/09/Algae_bloom



Landsat 8 false color image, August 11, 2015.
http://landsat.visibleearth.nasa.gov/view.php?id=86449.

Sensor Geometry: the SAR case



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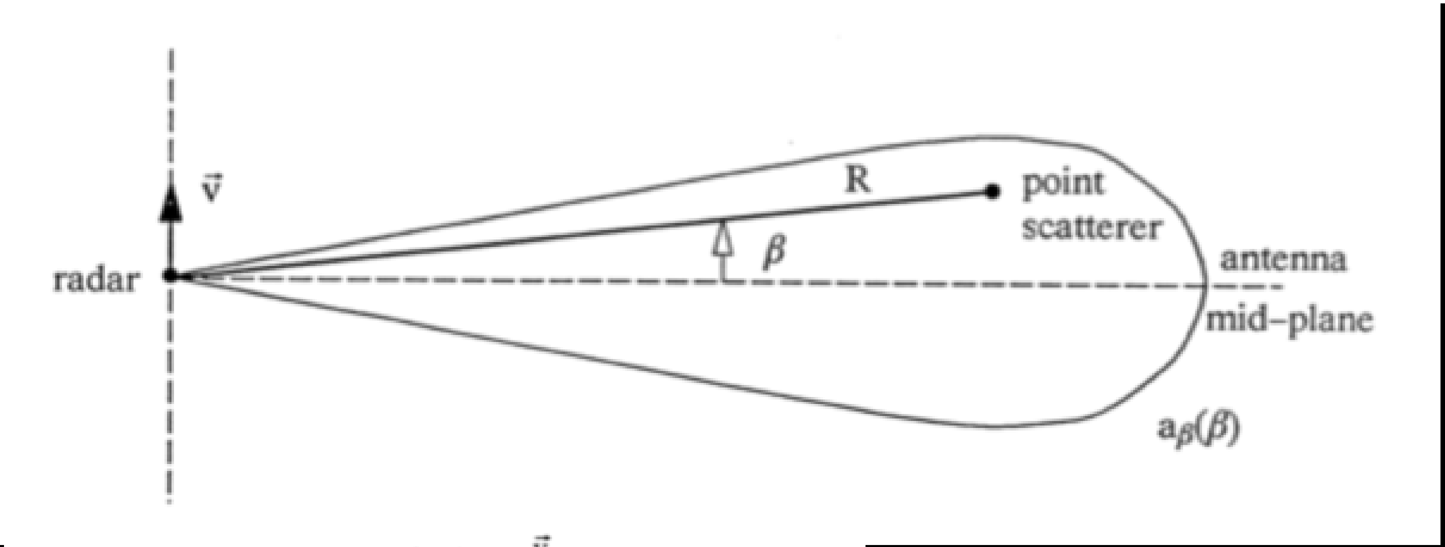
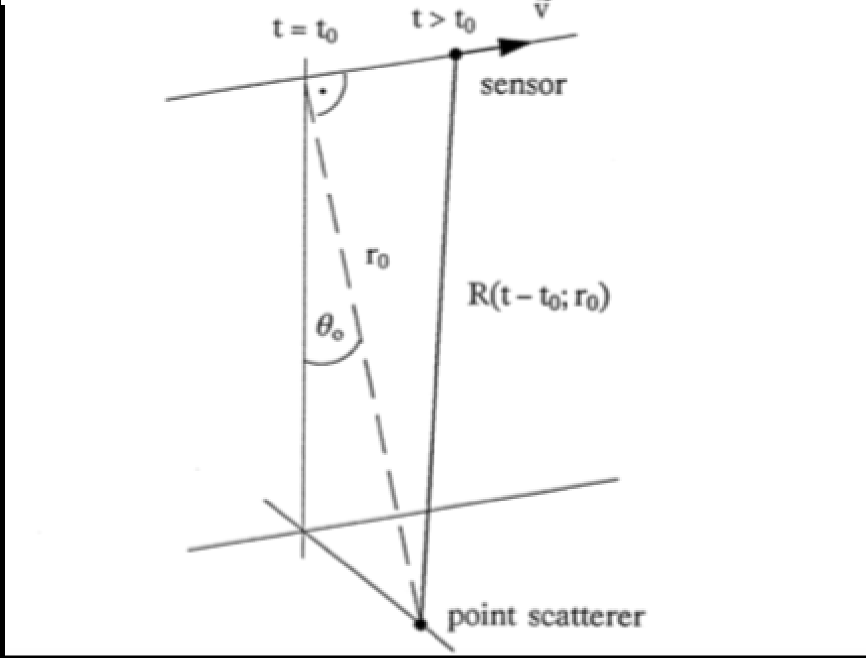
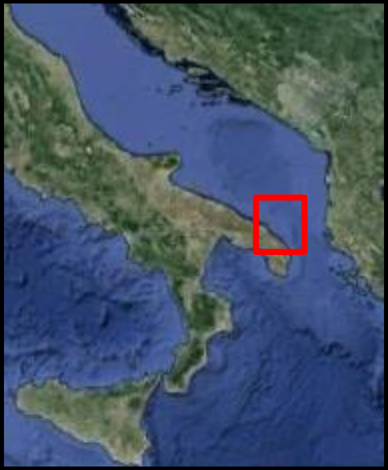




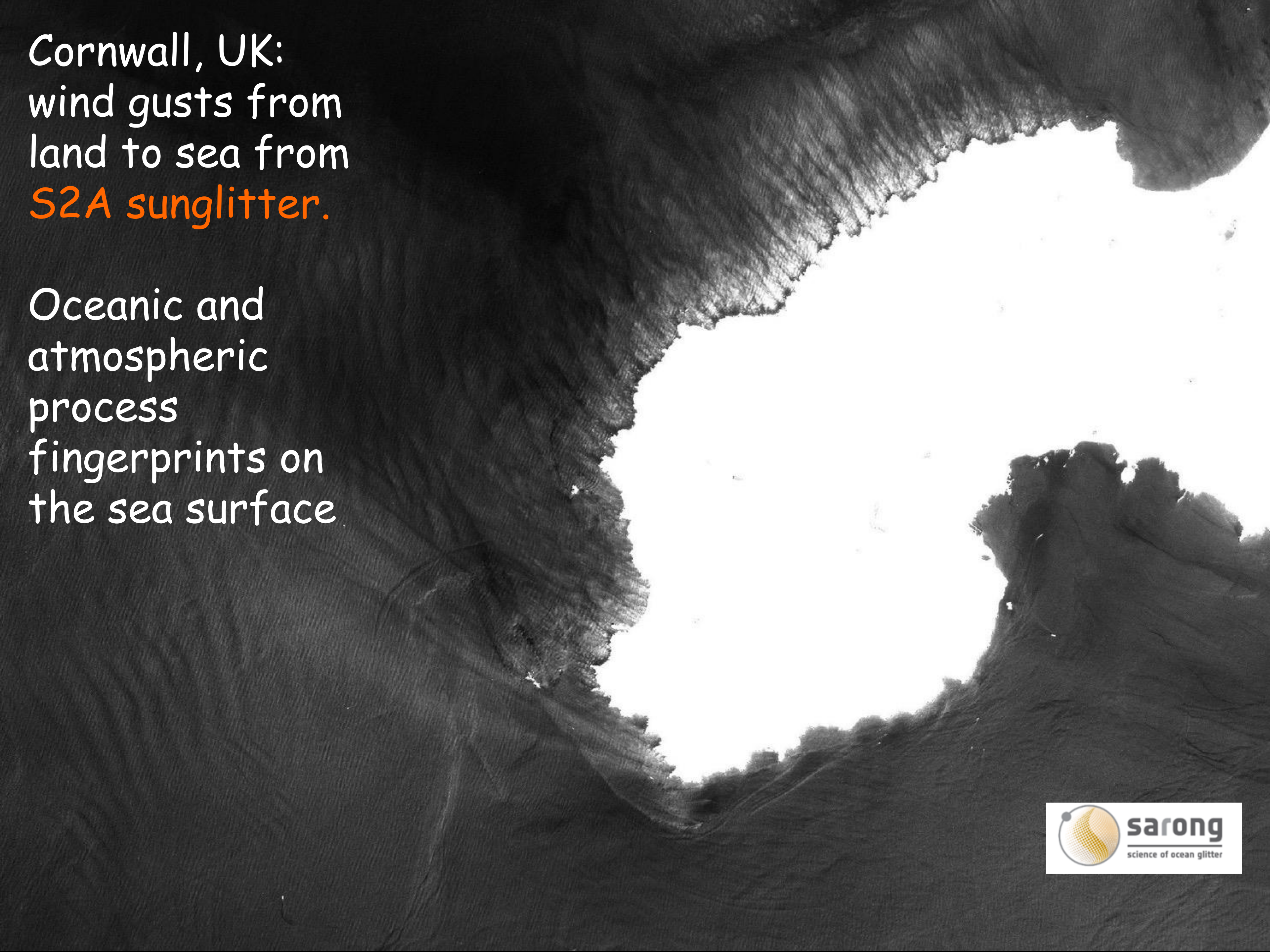
Sentinel-1

Sentinel-1: Oil Discharge

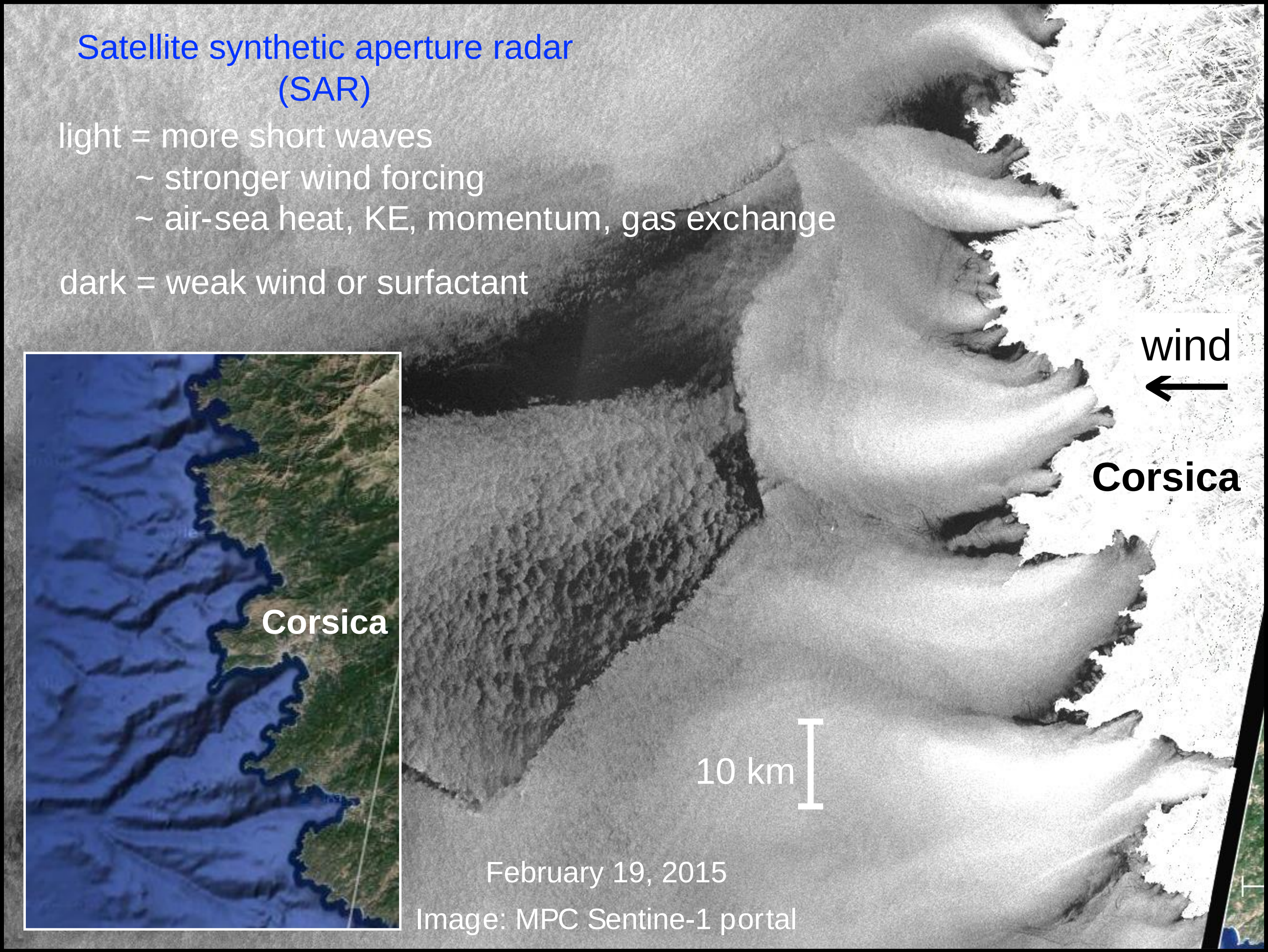


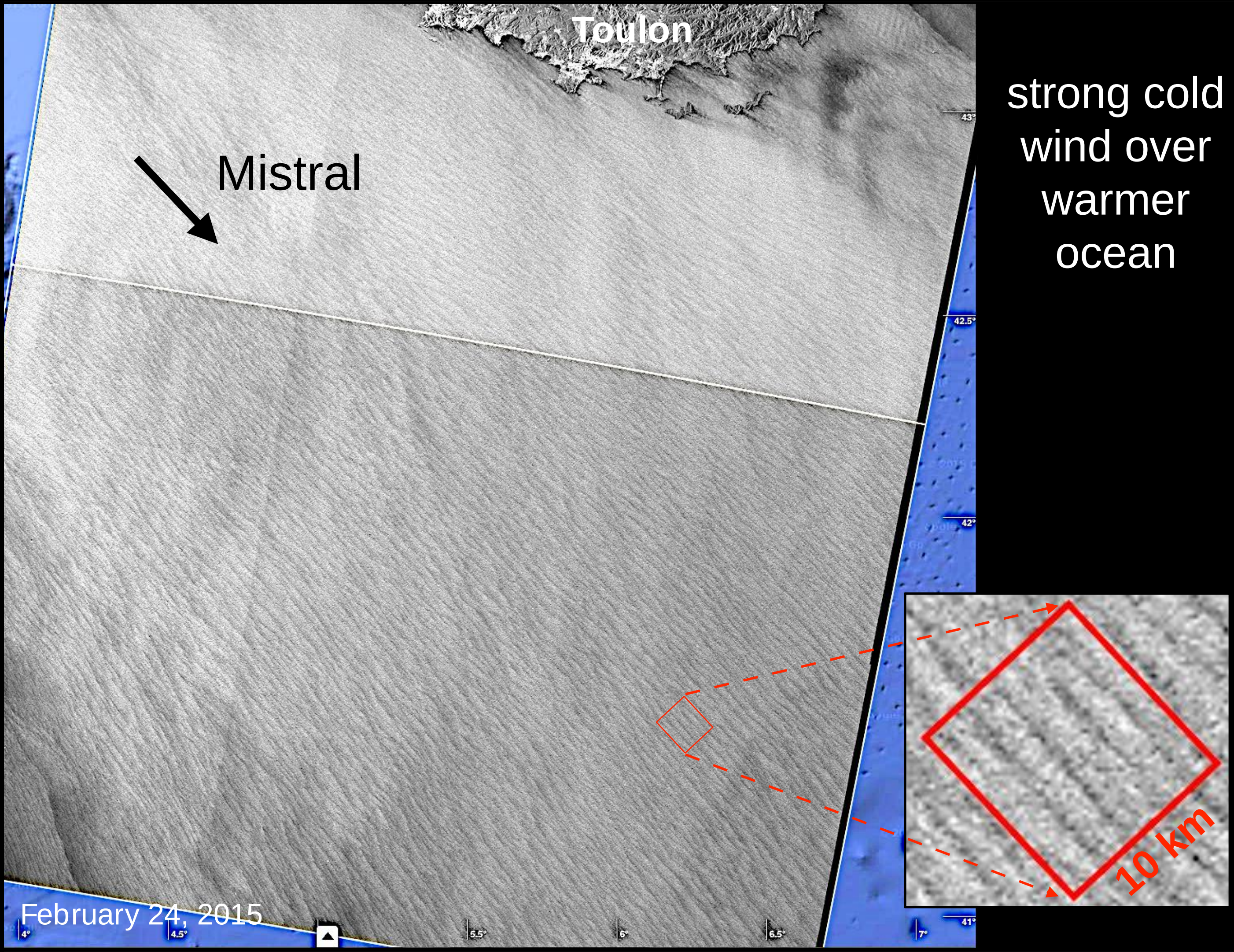
Cornwall, UK:
wind gusts from land to sea from S2A sunglitter.

Oceanic and atmospheric process fingerprints on the sea surface

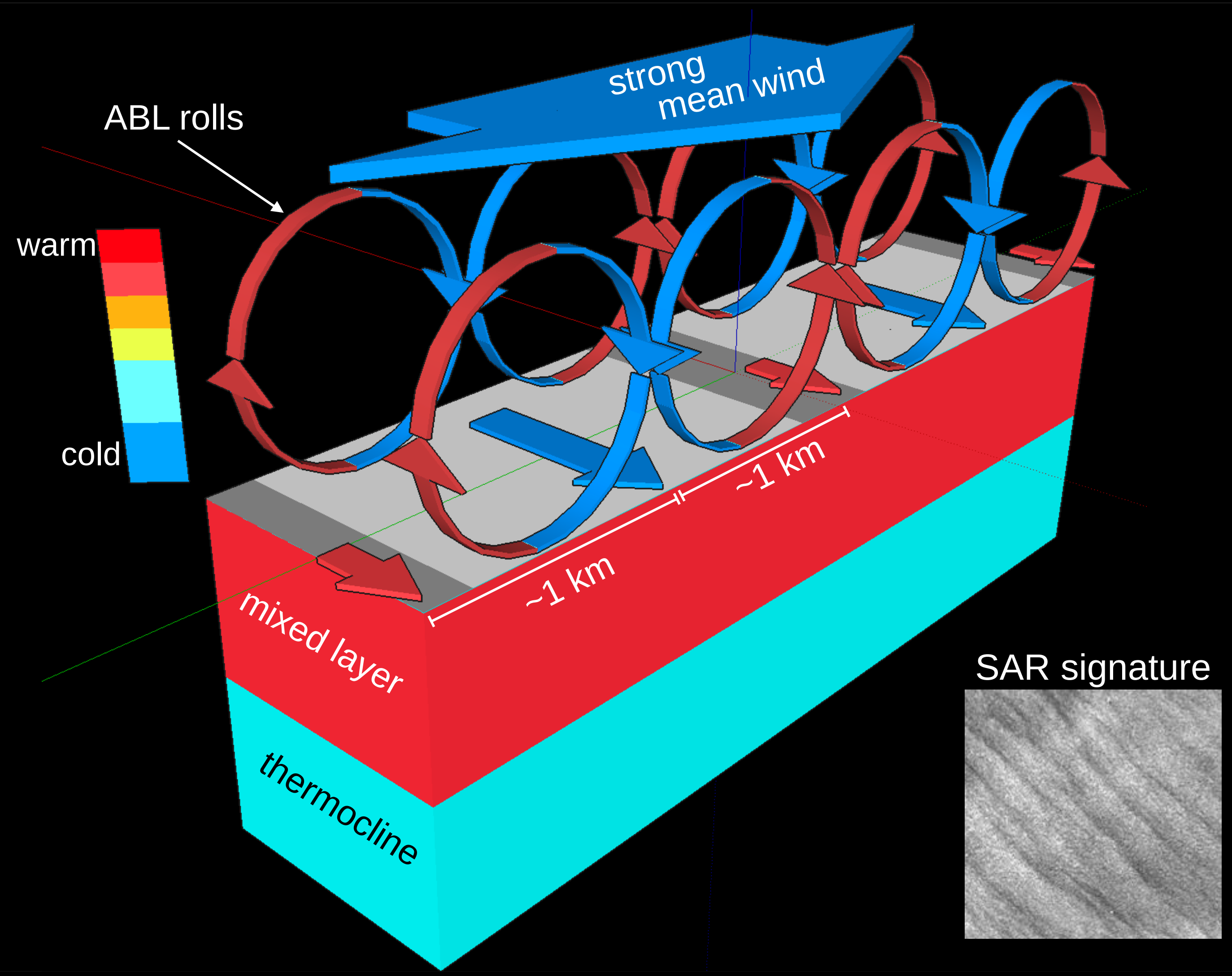


sarong
science of ocean glitter

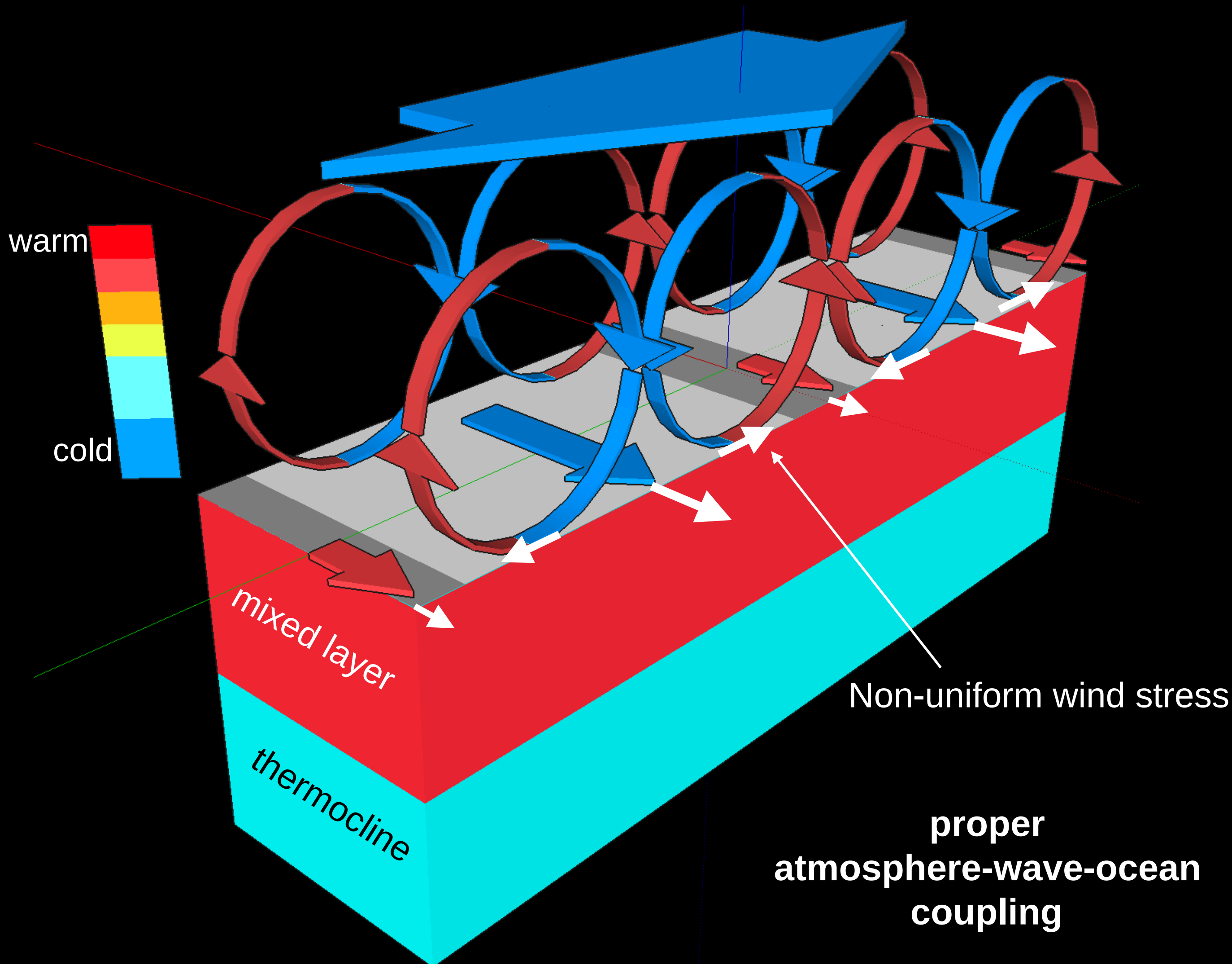

Satellite synthetic aperture radar
(SAR)
light = more short waves
~ stronger wind forcing
~ air-sea heat, KE, momentum, gas exchange
dark = weak wind or surfactant
Corsica
wind
Corsica
10 km
February 19, 2015
Image: MPC Sentine-1 portal



strong cold wind over warmer ocean

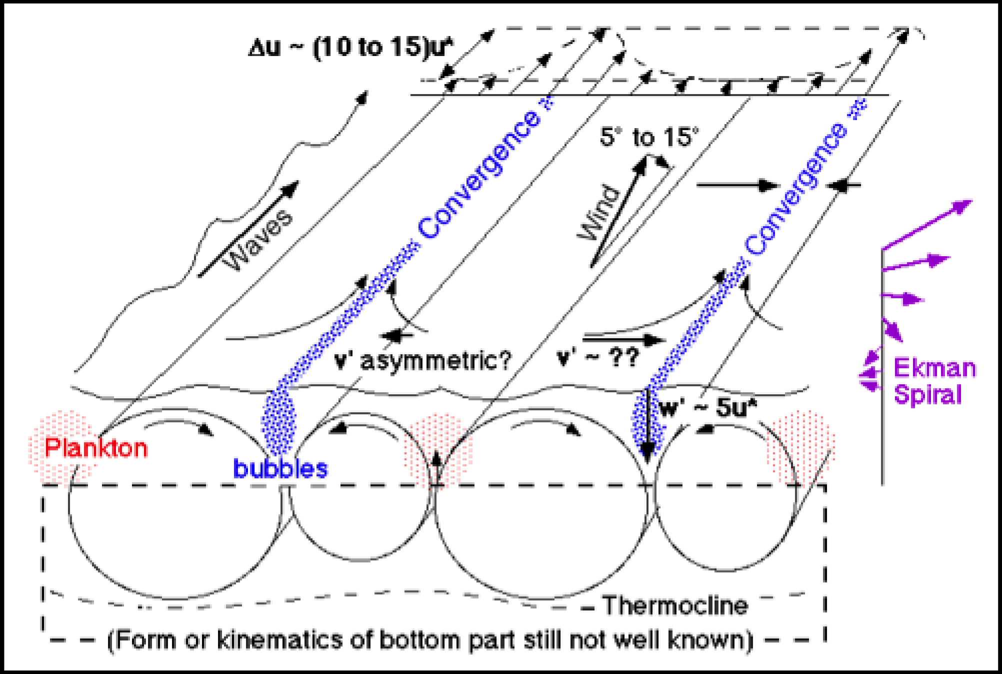


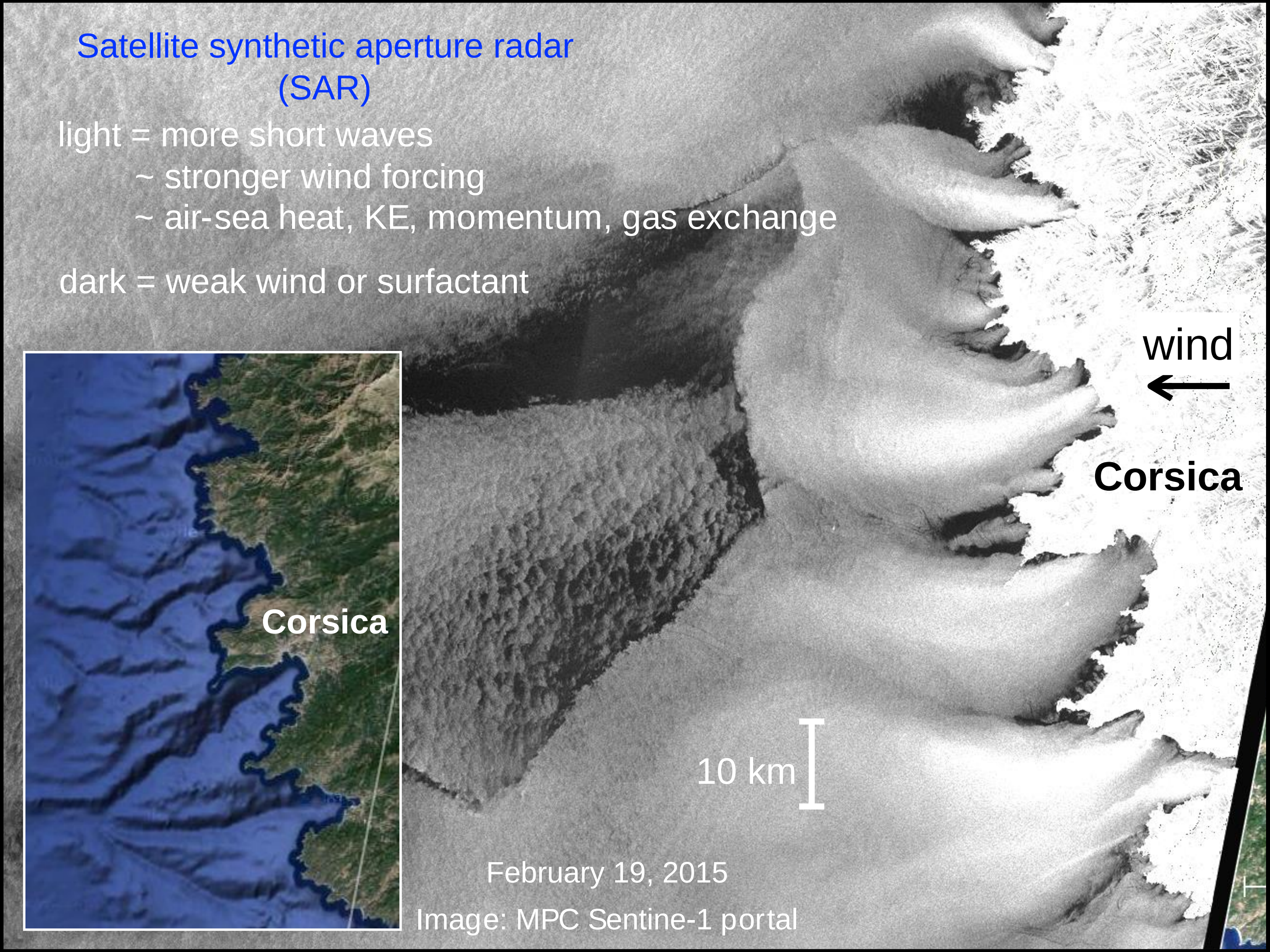
strong
mean wind
ABL rolls
warm
cold
~1 km
~1 km
mixed layer
thermocline
SAR signature



proper atmosphere-wave-ocean coupling

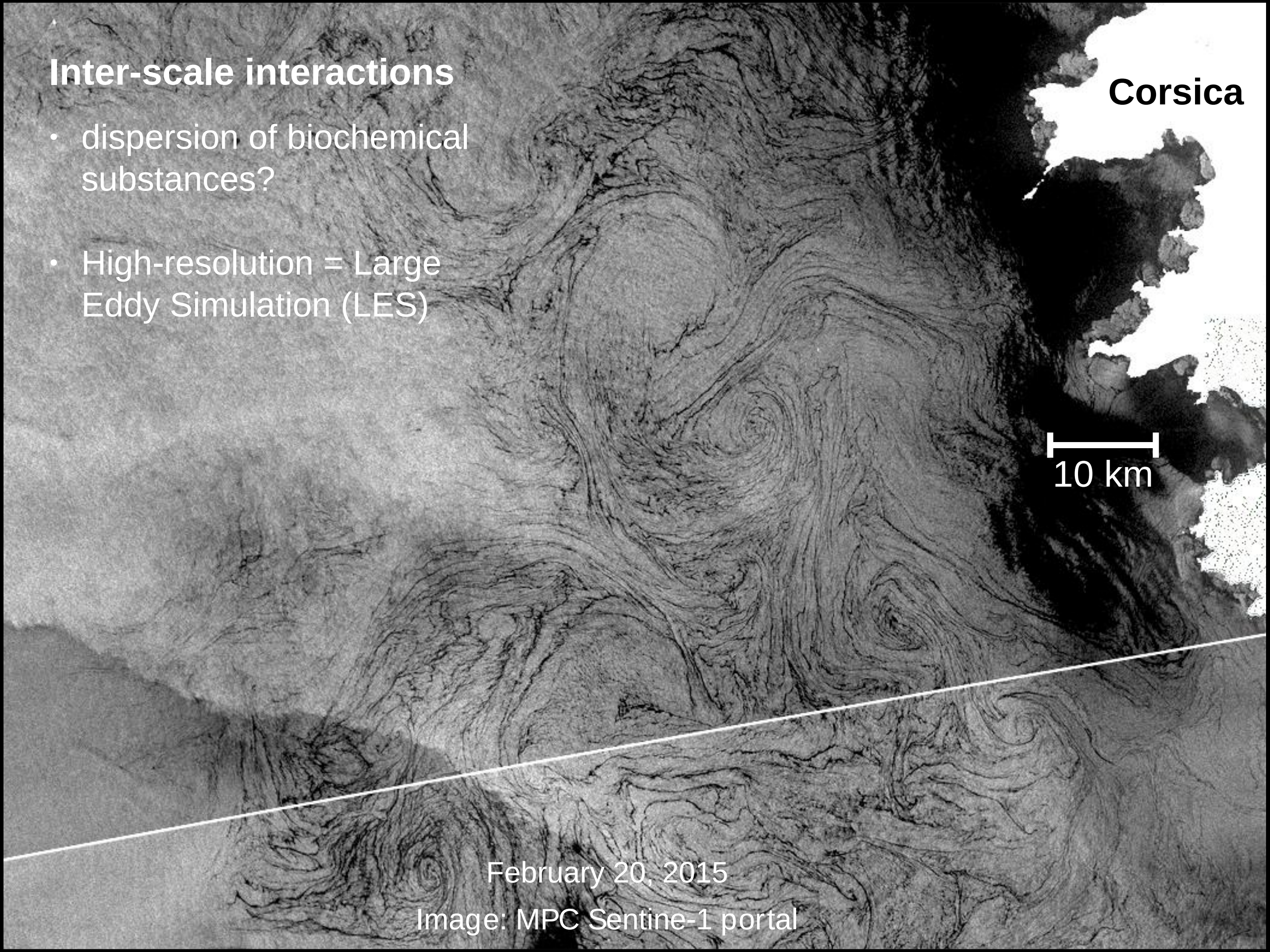
Schematic illustration of the Langmuir circulation (first described by Langmuir, 1938). The separation scale of the convergence zones are typically 10-100 m




Satellite synthetic aperture radar
(SAR)
light = more short waves
~ stronger wind forcing
~ air-sea heat, KE, momentum, gas exchange
dark = weak wind or surfactant
wind
Corsica
Corsica
10 km
February 19, 2015
Image: MPC Sentine-1 portal

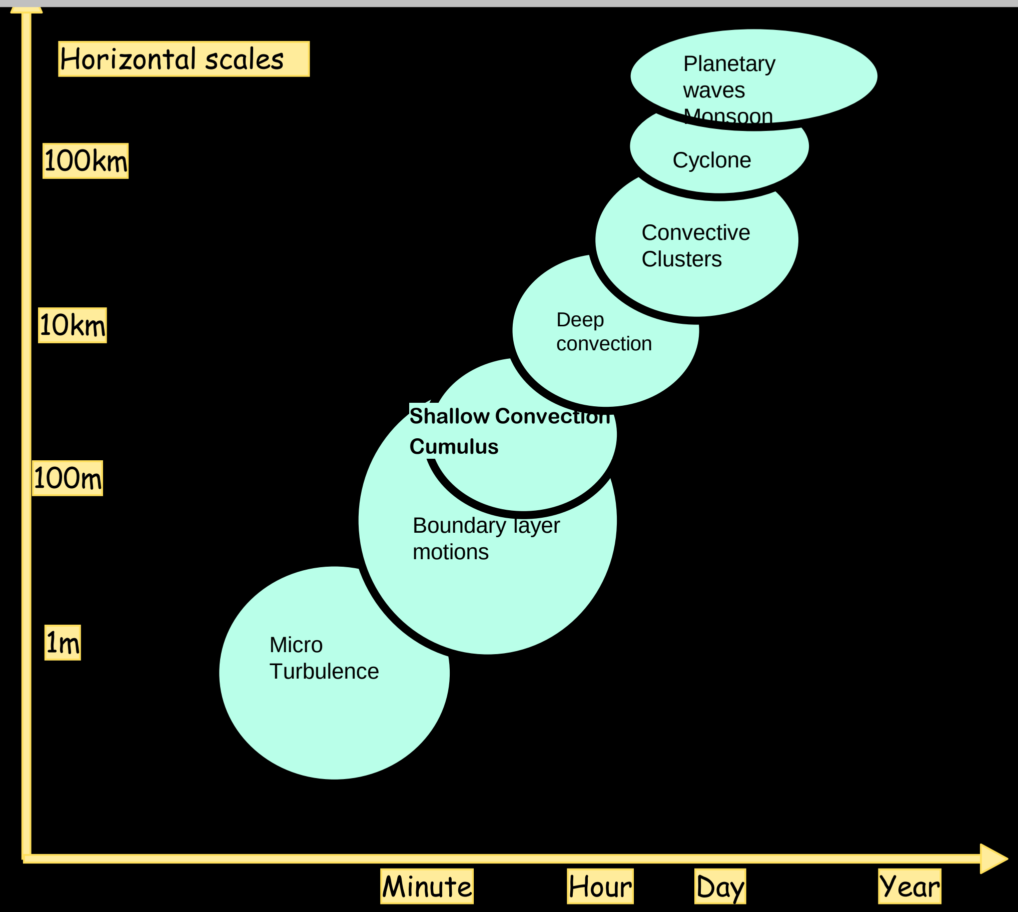
Inter-scale interactions

- dispersion of biochemical substances?
- High-resolution = Large Eddy Simulation (LES)

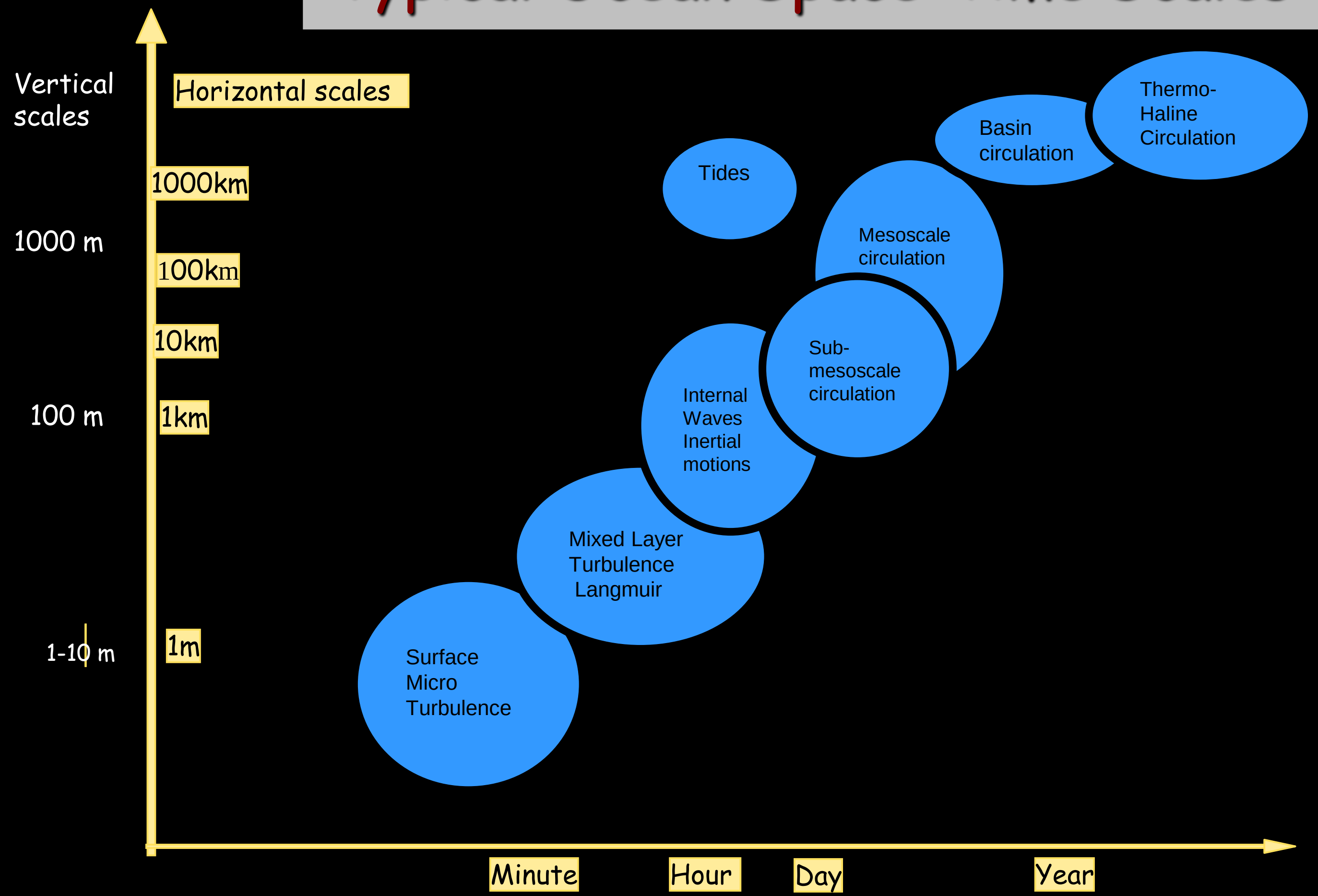


February 20, 2015
Image: MPC Sentine-1 portal

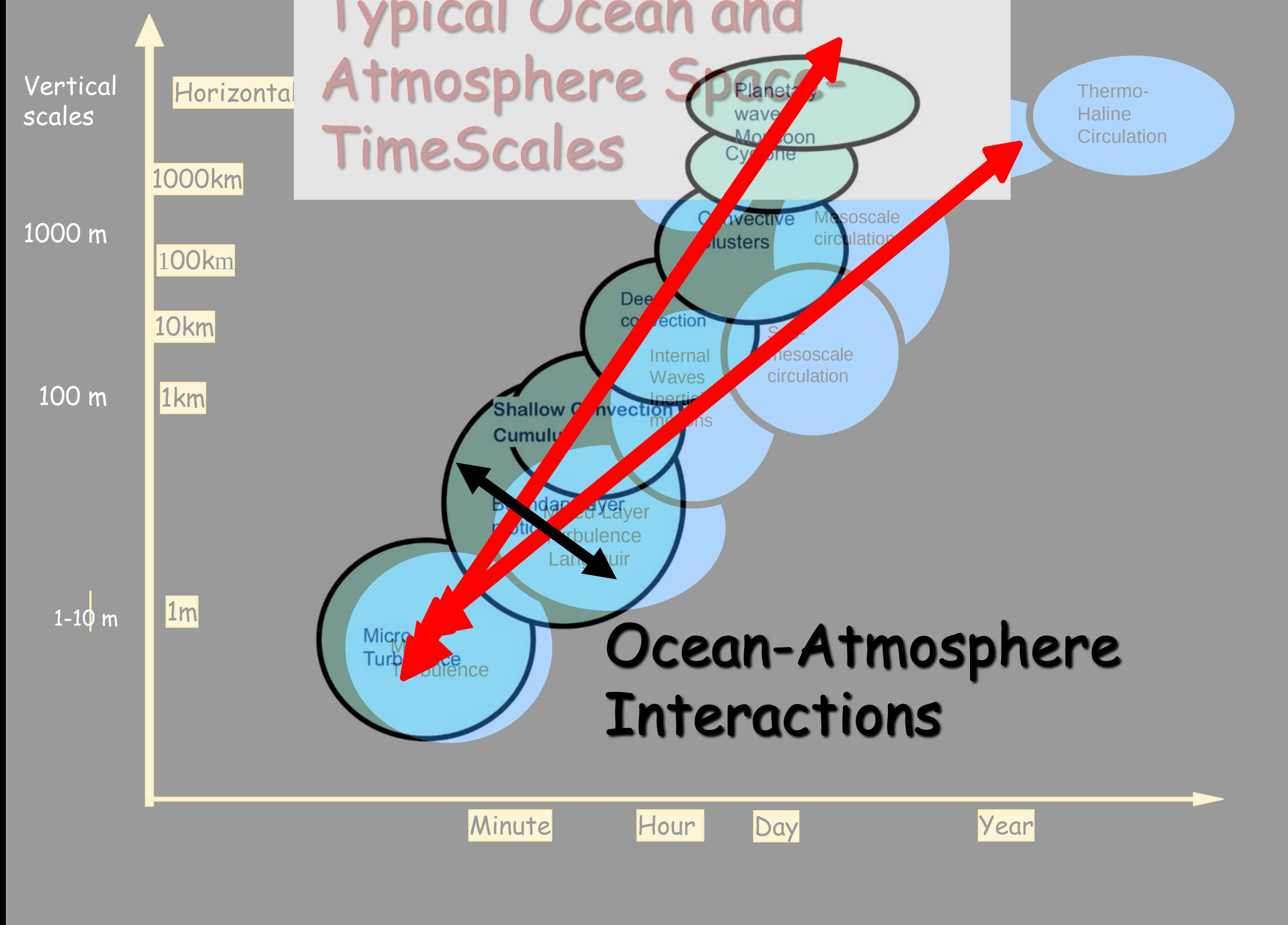
Typical Atmosphere Space-Time scales

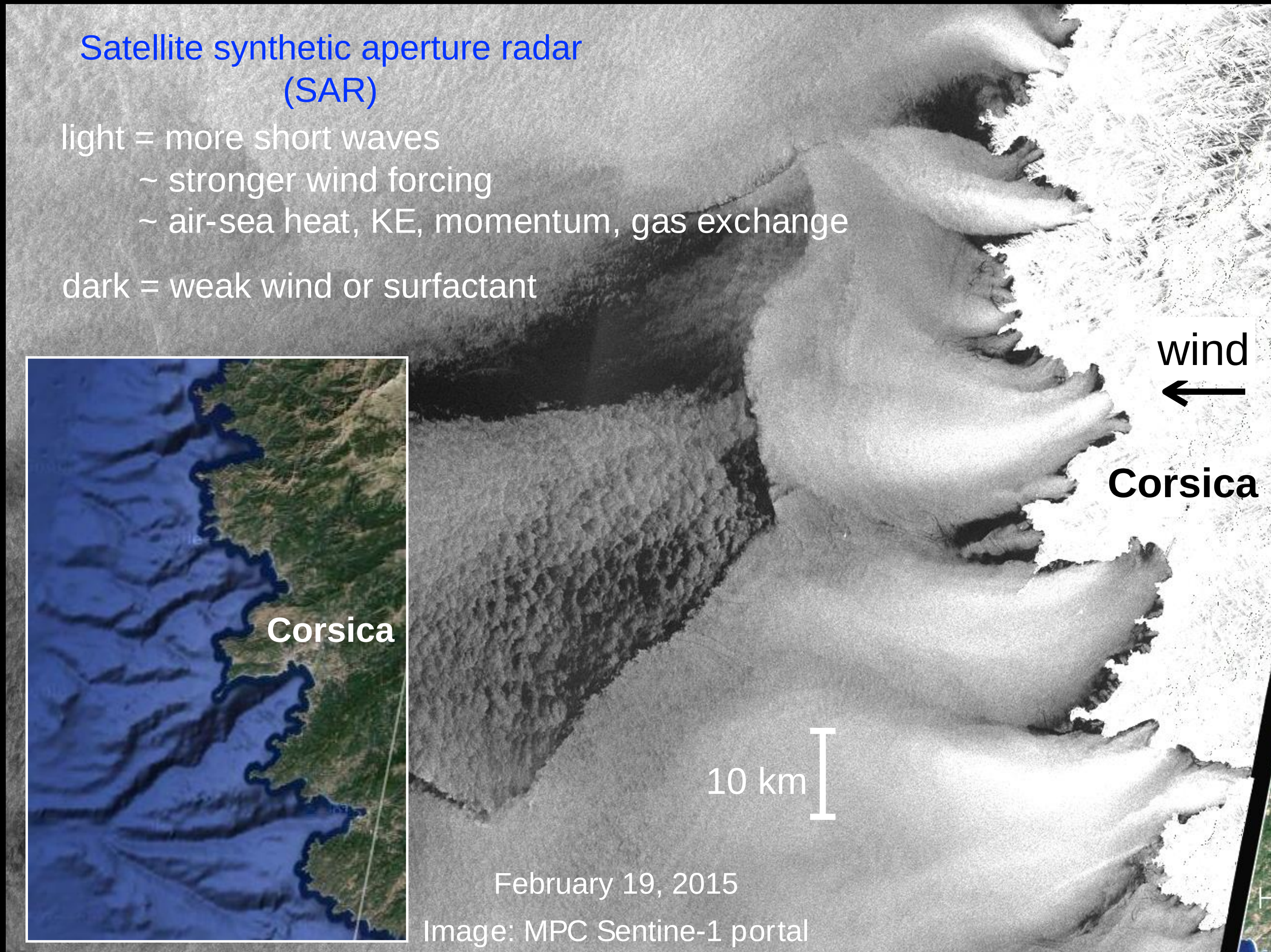


Typical Ocean Space-Time Scales



Typical Ocean and Atmosphere Space-TimeScales




Satellite synthetic aperture radar
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Corsica
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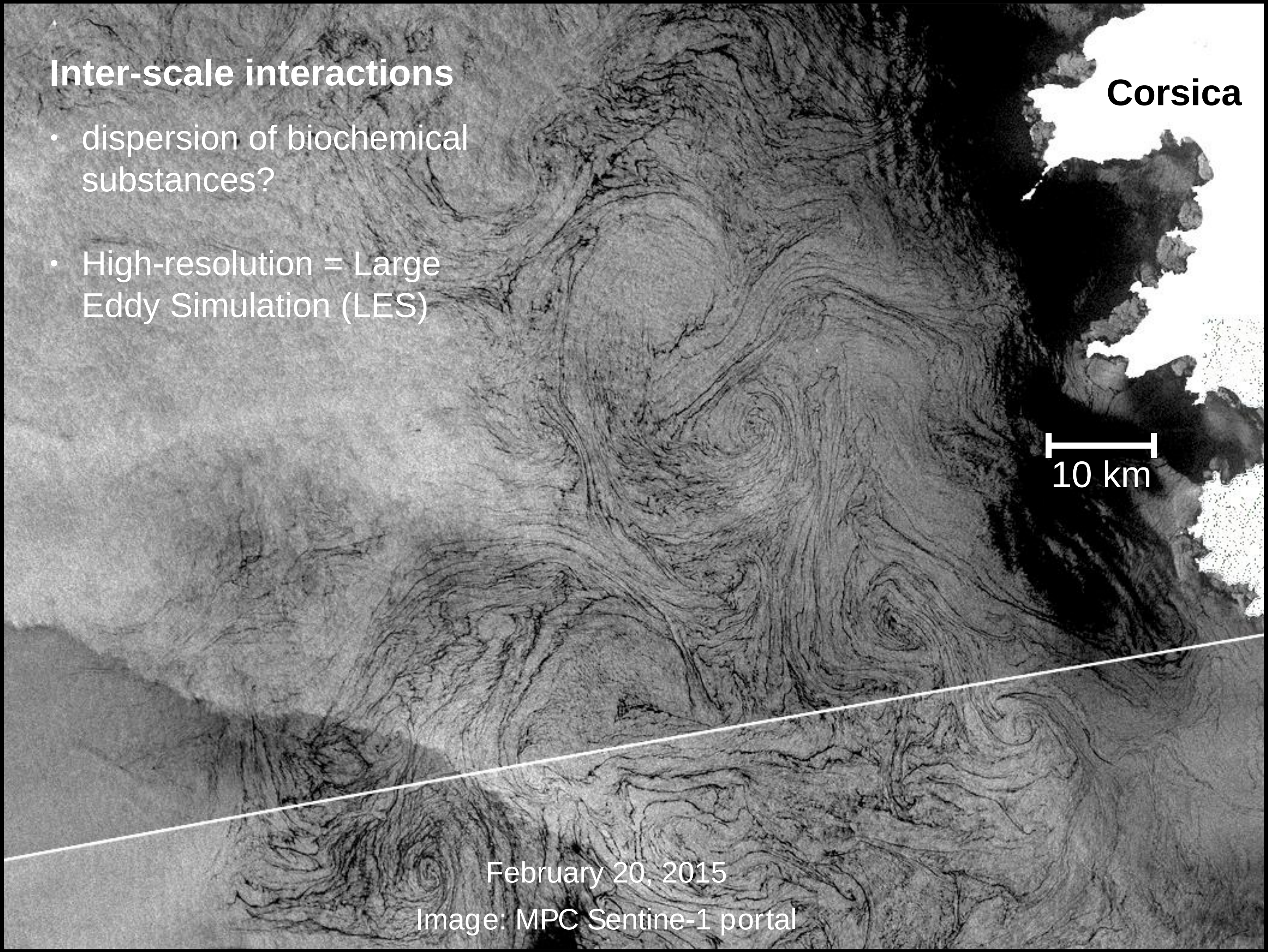
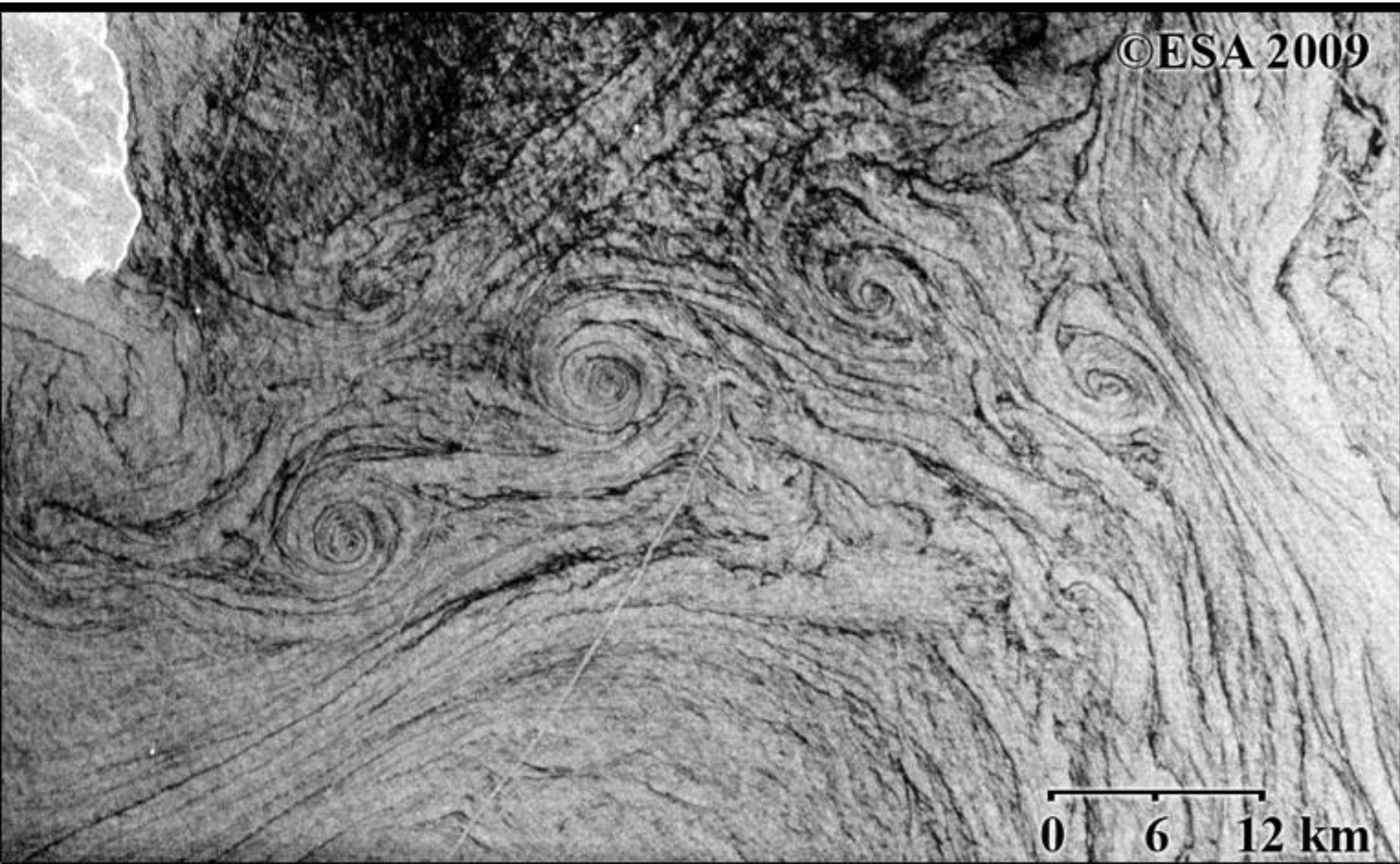
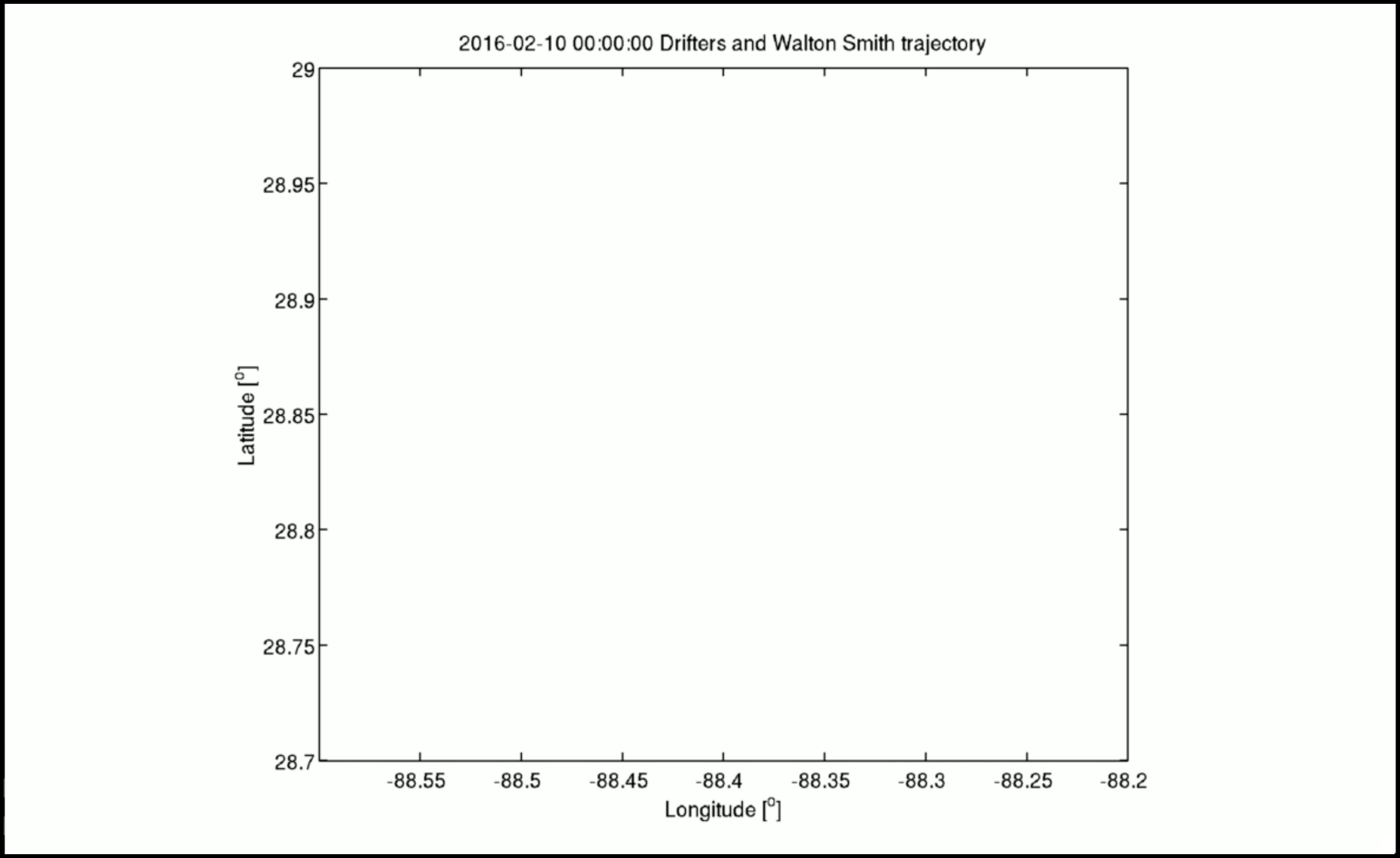
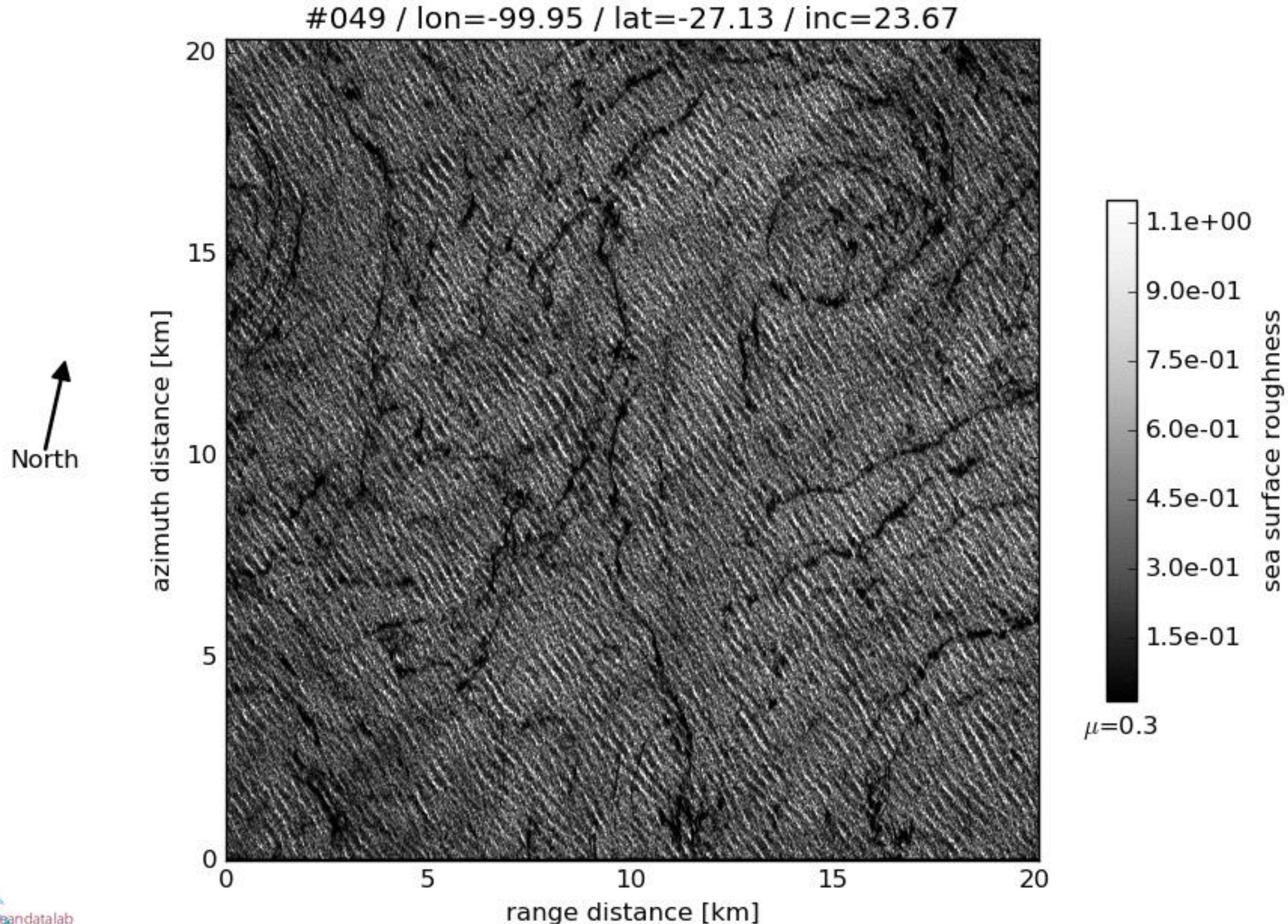


February 20, 2015
Image: MPC Sentine-1 portal


©ESA 2009
0
6
12 km

Intense deformation field at oceanic front inferred from directional sea surface roughness observations

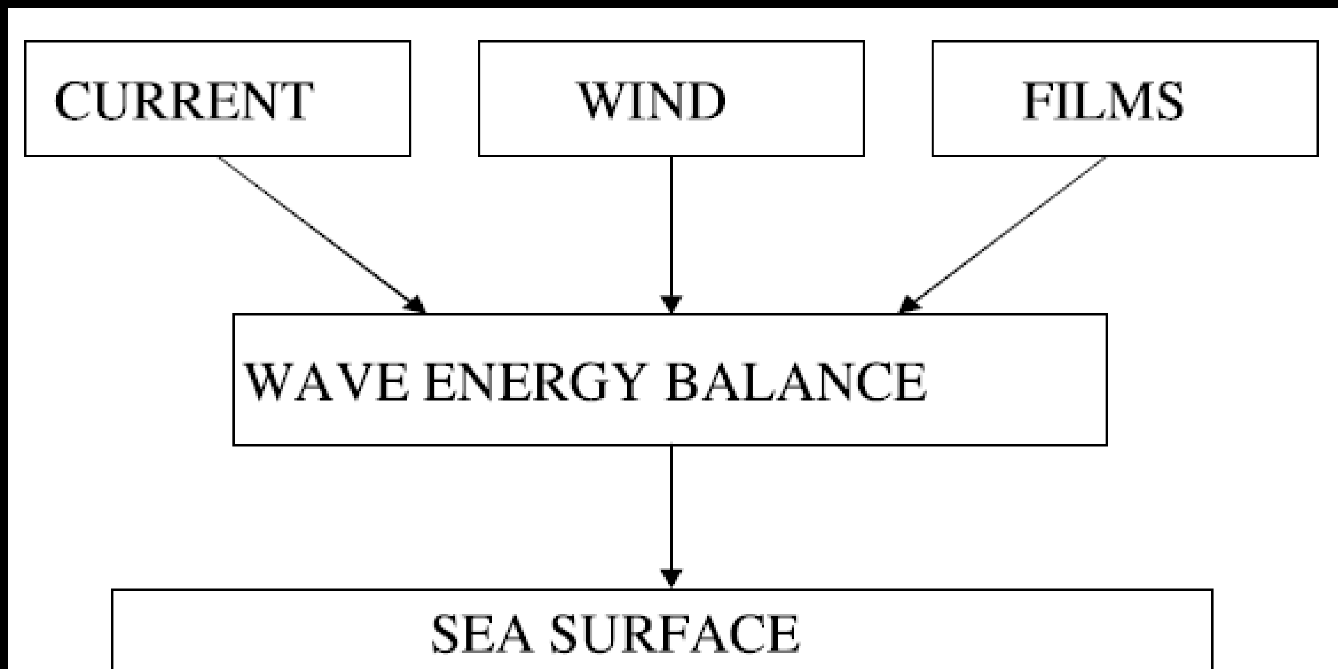



#049 / lon=-99.95 / lat=-27.13 / inc=23.67
azimuth distance [km]
range distance [km]
0
5
10
15
20
sea surface roughness
1.1e+00
9.0e-01
7.5e-01
6.0e-01
4.5e-01
3.0e-01
1.5e-01
μ=0.3
North

Sea Surface Roughness changes: interpretation framework

$$\frac{\partial N(\mathbf{k})}{\partial t} + \left(c_{gi} + u_i\right)\frac{\partial N(\mathbf{k})}{\partial x_i} - k_j \frac{\partial u_j}{\partial x_i}\frac{\partial N(\mathbf{k})}{\partial k_i} = Q(\mathbf{k})/\omega$$

$$Q(\mathbf{k}) = \beta_\nu(\mathbf{k})\omega E(\mathbf{k}) - D(\mathbf{k}) - Q^{nl}(\mathbf{k}) + Q^{wb}(\mathbf{k})$$



$$\partial\tilde{N}(\mathbf{k})/\partial t + c_{gi}\partial\tilde{N}(\mathbf{k})/\partial x_i$$
$$= \omega^2 k^{-5}\left[\omega^{-1} m_k^{ij} u_{i,j} B_0 - \tilde{B}/\tau + \tilde{\beta} B_0 + \tilde{I}_{sw}\right]$$

$$m_k^{ij} = k_j \partial \ \ln \ N_0/\partial k_i$$

LETTRE XX.

De M. Jean Spooner,
A. B. S.[t] John's Cambridge.

Gênes 1.[er] Mai 1822.

Vous m'avez fait l'honneur, M. le Baron, de me demander un extrait du mémoire que j'ai pris la liberté de vous communiquer relativement à un phénomène lumineux qui se montre sur la mer lorsque le soleil ou la lune y donnent dessus (*), et que vous voulez avoir la bonté d'insérer dans votre *Correspondance*

L'équation en question est:

$$\frac{a^2}{a^2+x^2+y^2}+\frac{2\cos. Z a}{\sqrt{a^2+x^2+y^2}}+\cos.^2 Z=\frac{2.\cos.^2 J+2\cos.^2 J.a.\cos. Z}{\sqrt{a^2+x^2+y^2}}-\frac{2\cos. J\sin. Z.x}{\sqrt{a^2+x^2+y^2}}.$$

Par la quatrième observation.

$$A^2=\frac{.0000013+.0005593+.0585262}{2+.0005593-1.9281164}=\frac{.0590868}{.0724429}$$

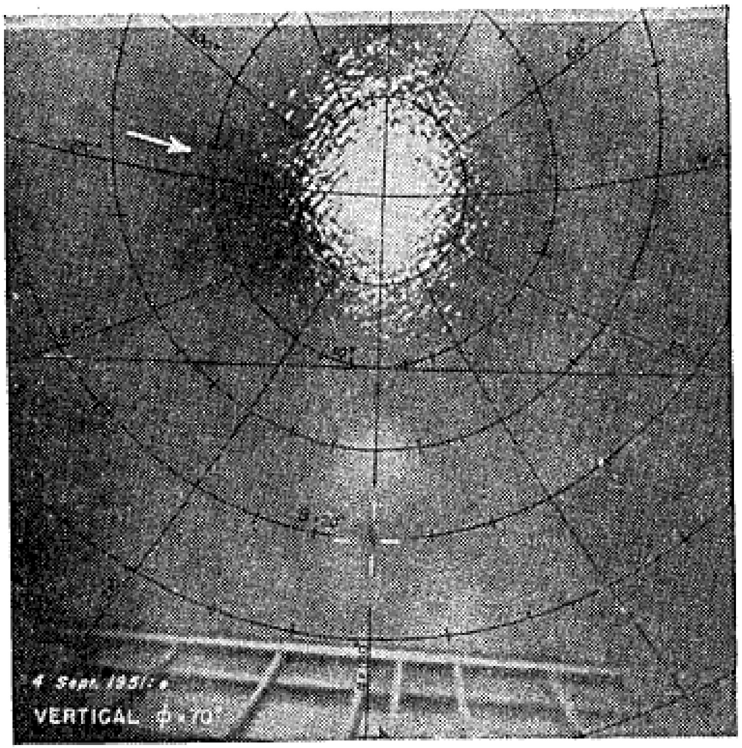
De-là, log. $A=\bar{1}.95574725=$ log. cosin. de $25^\circ\ 26'$.

JOURNAL OF THE OPTICAL SOCIETY OF AMERICA VOLUME 44, NUMBER 11 NOVEMBER, 1954

Measurement of the Roughness of the Sea Surface from Photographs of the Sun's Glitter

CHARLES COX AND WALTER MUNK
Scripps Institution of Oceanography, La Jolla, California*

(Received April 28, 1954)



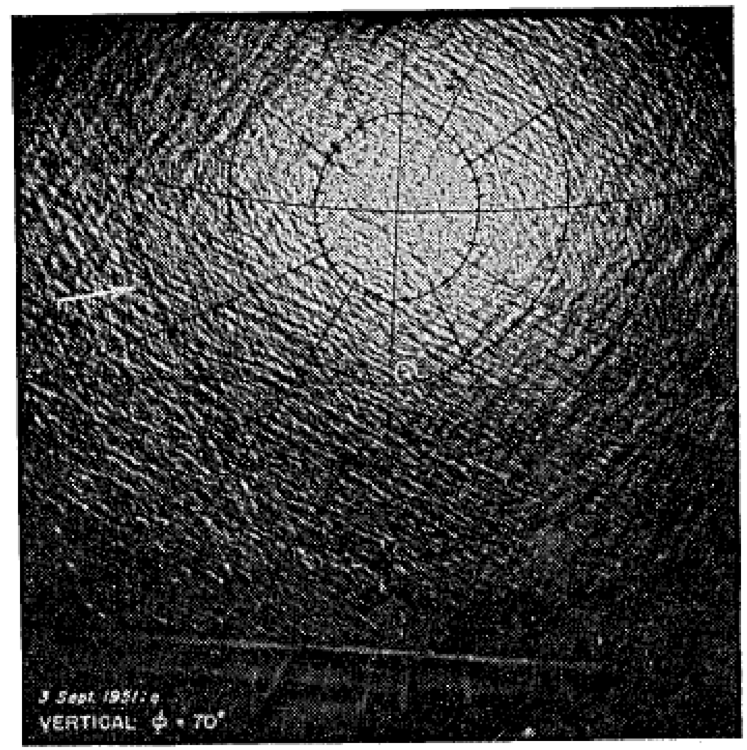
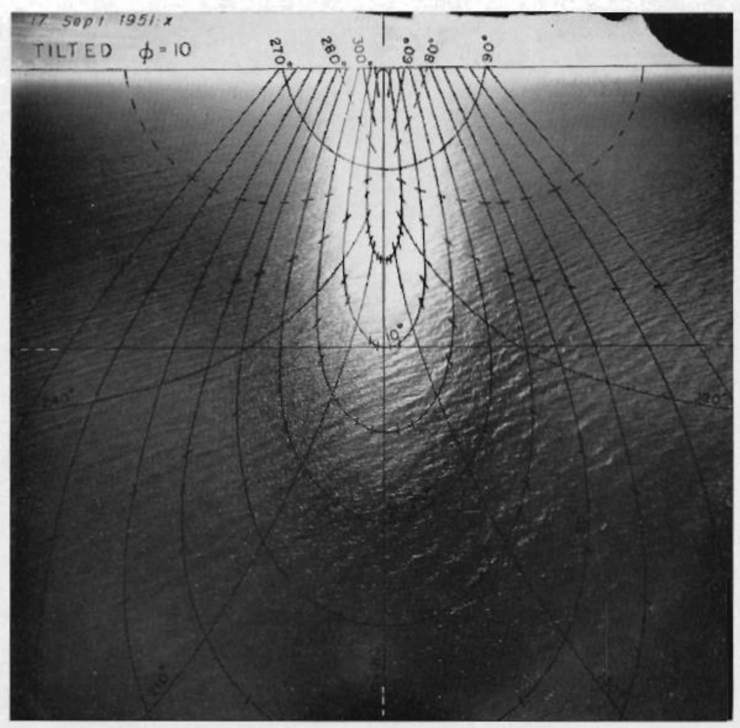


FIG. 1. Glitter patterns photographed by aerial camera pointing vertically downward at solar elevation of $\phi=70°$. The superimposed grids consist of lines of constant slope azimuth α (radial) drawn for every 30°, and of constant tilt β (closed) for every 5°. Grids have been translated and rotated to allow for roll, pitch, and yaw of plane. Shadow of plane can barely be seen along $\alpha=180°$ within white cross. White arrow shows wind direction. *Left:* water surface covered by natural slick, wind 1.8 m sec^{-1}, rms tilt $\sigma=0.0022$. *Right:* clean surface, wind 8.6 m sec^{-1}, $\sigma=0.045$. The vessel *Reverie* is within white circle.

Cox and Munk (1956)



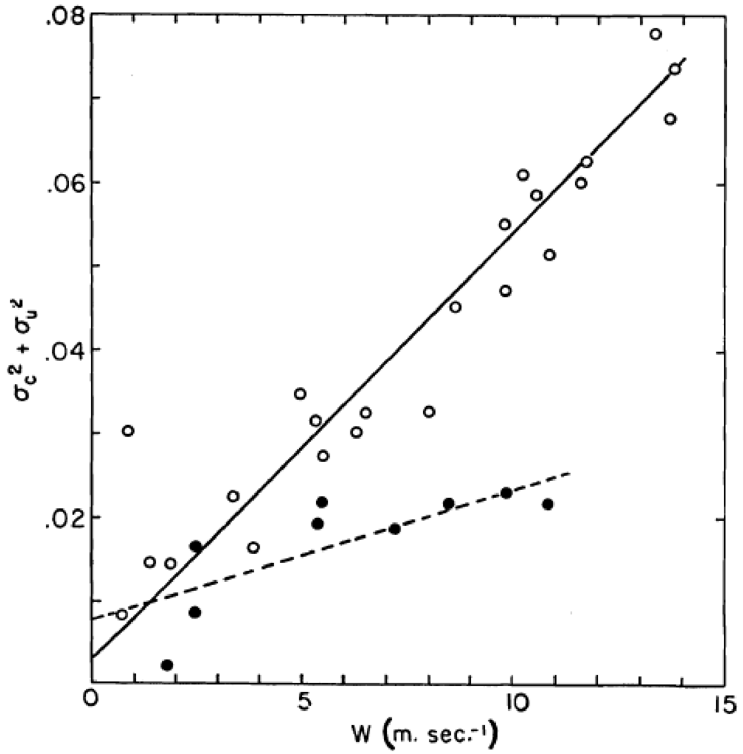
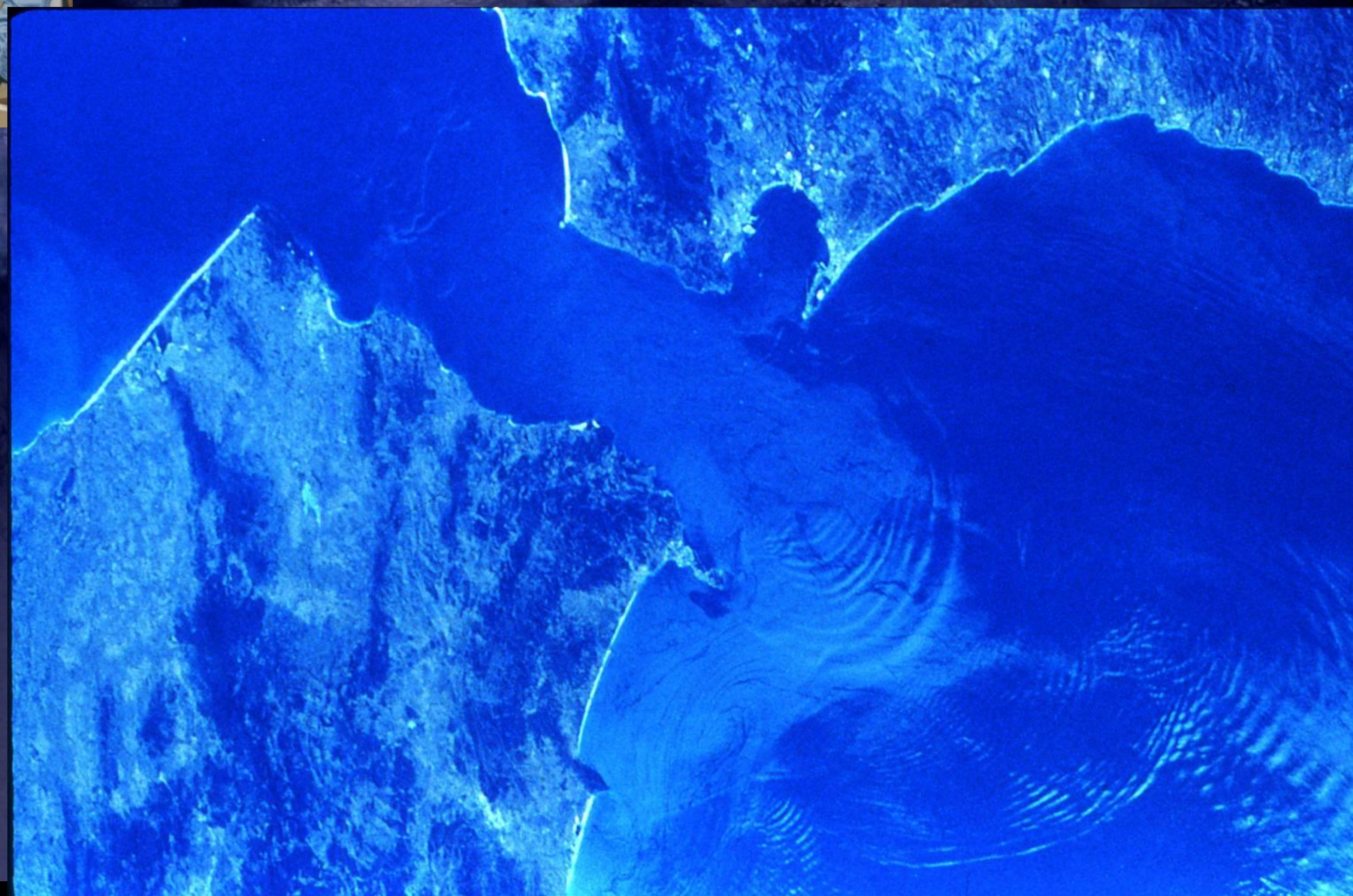
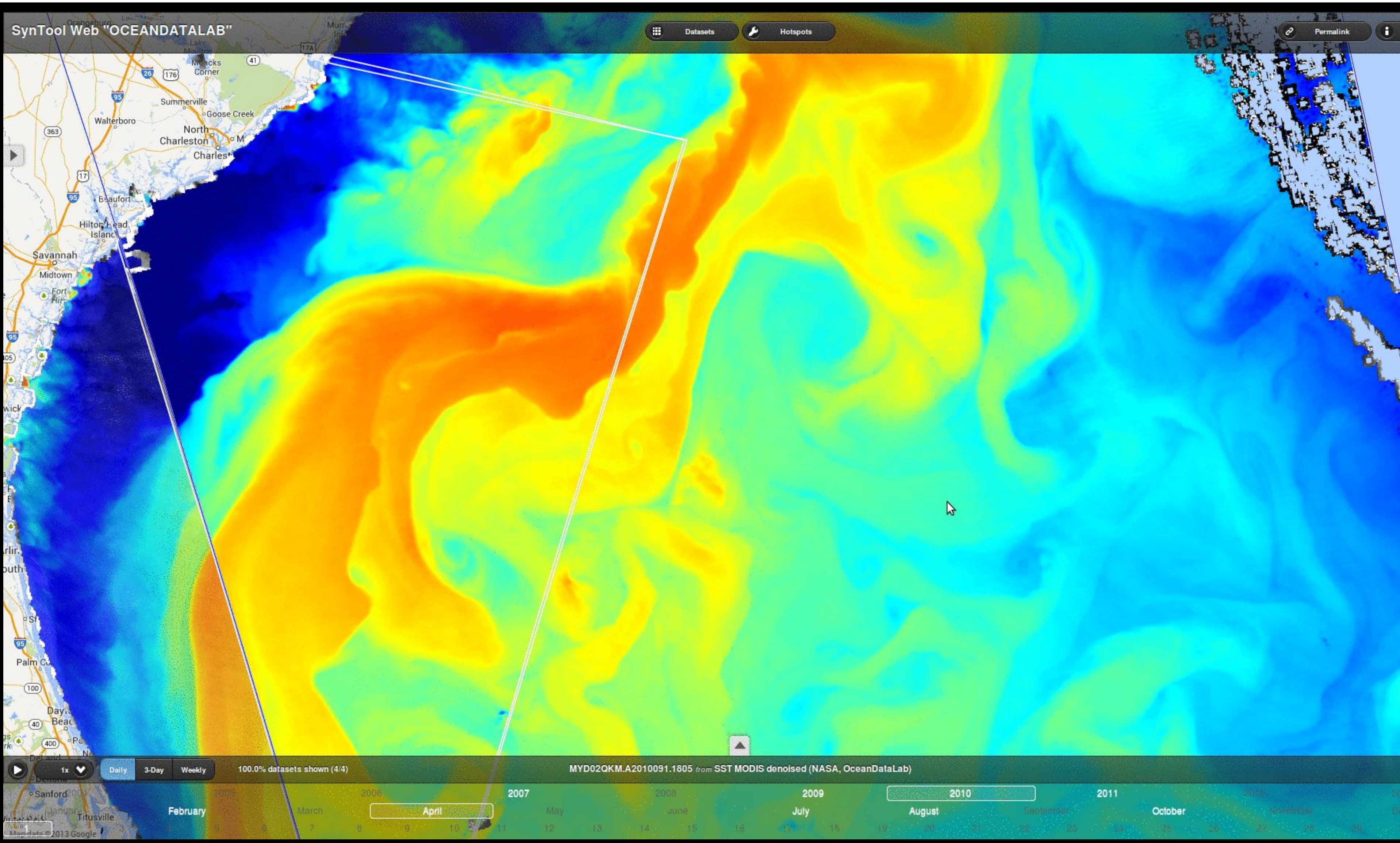


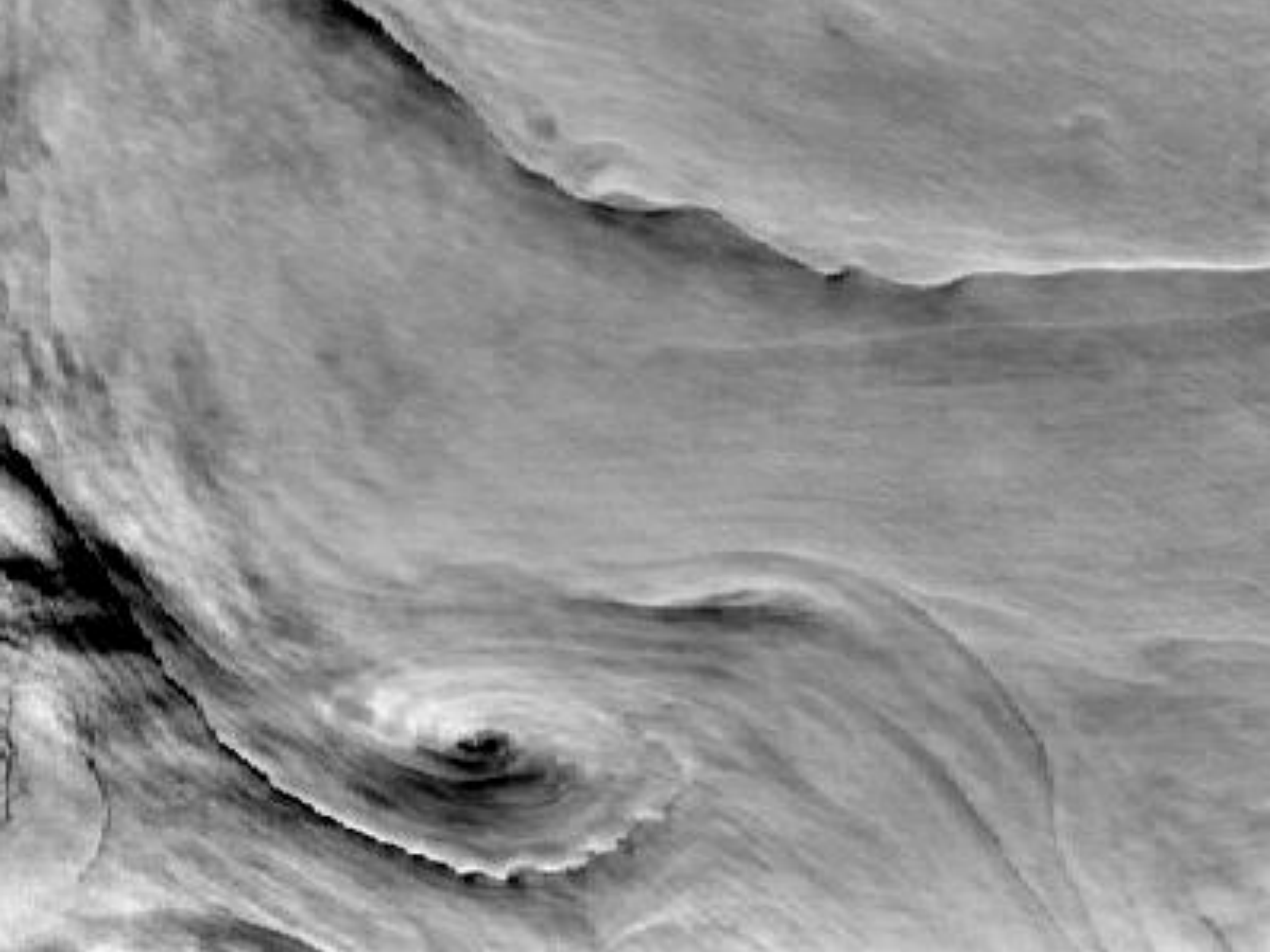
Fig. 13. Mean square slope components and their sum as functions of the wind speed W measured 41 ft. above sea level. The plot includes all analyzed data for clean sea surfaces (open circles) and slick surfaces (solid circles). Continuous lines are regression lines for clean surfaces; dashed lines for slick surfaces.

Paul Desmond Scully-Power
NASA’s astronaut

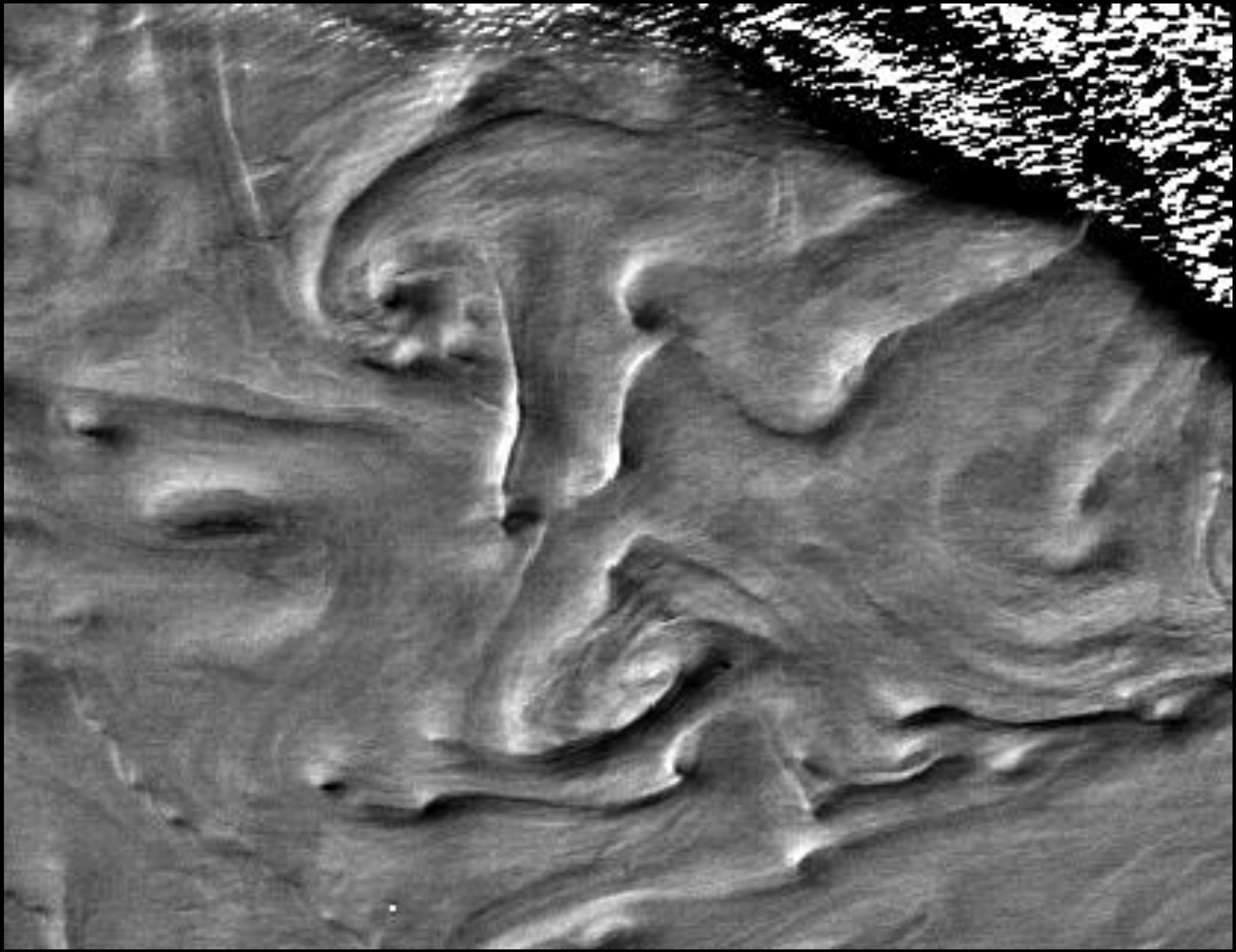


Gulf Stream roughness changes

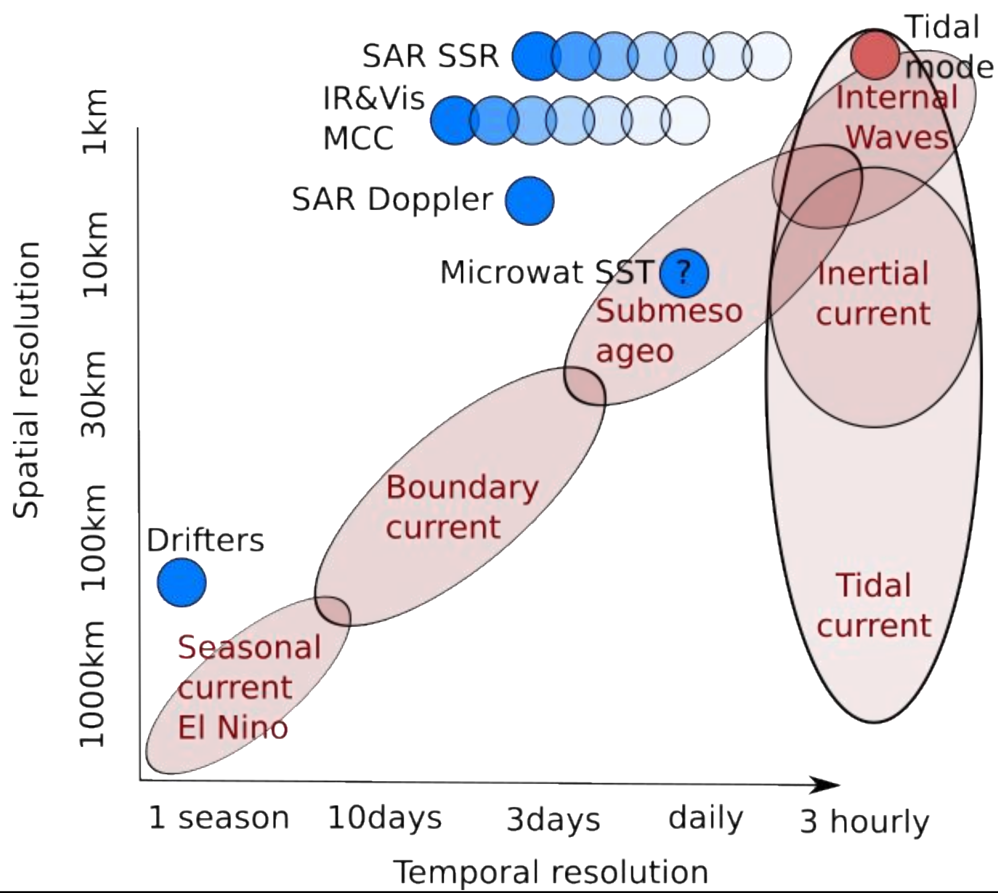

SynTool Web "OCEANDATALAB"
Datasets
Hotspots
Permalink
Summerville
Goose Creek
Walterboro
North Charleston
Charleston
Beaufort
Hilton Head Island
Savannah
Midtown
Palm Coast
Sanford
Titusville
1x
Daily
3-Day
Weekly
100.0% datasets shown (4/4)
MYD02QKM.A2010091.1805 from SST MODIS denoised (NASA, OceanDataLab)
2007
2009
2010
2011
February
April
July
August
October
Map data ©2013 Google

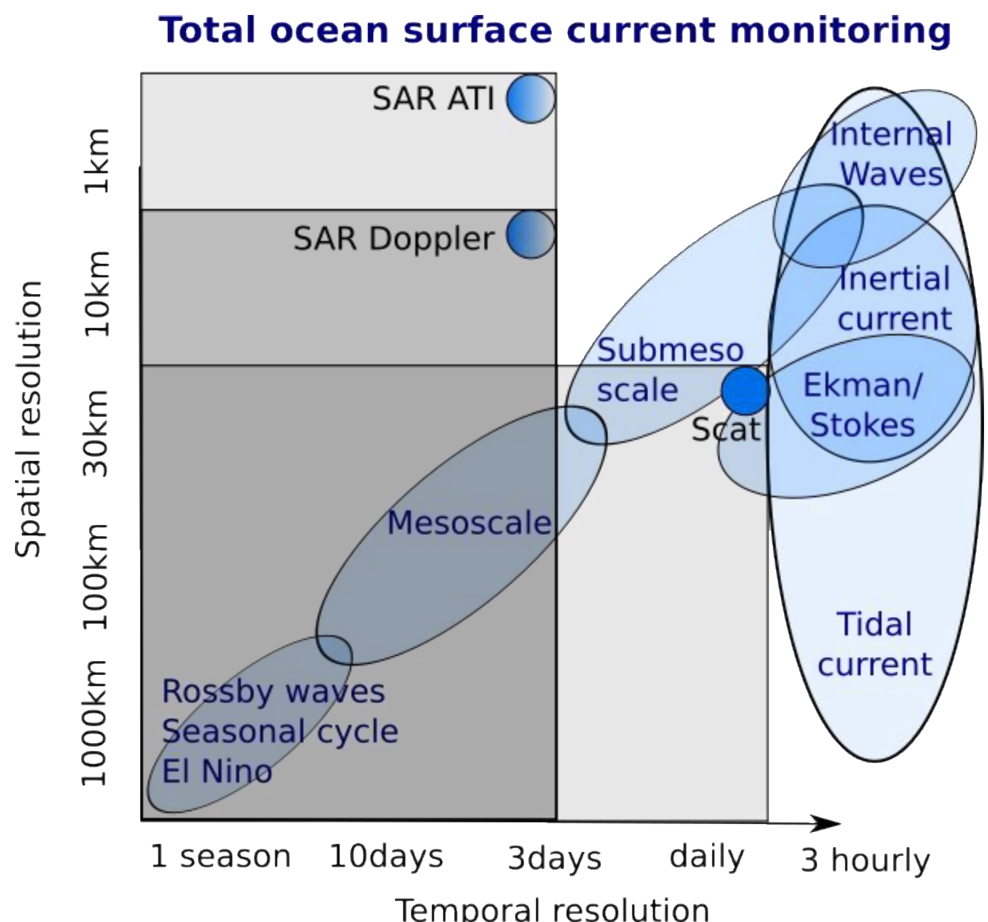


Miso Turbulence (Mediterranean Sea) : pearl-necklace evidences



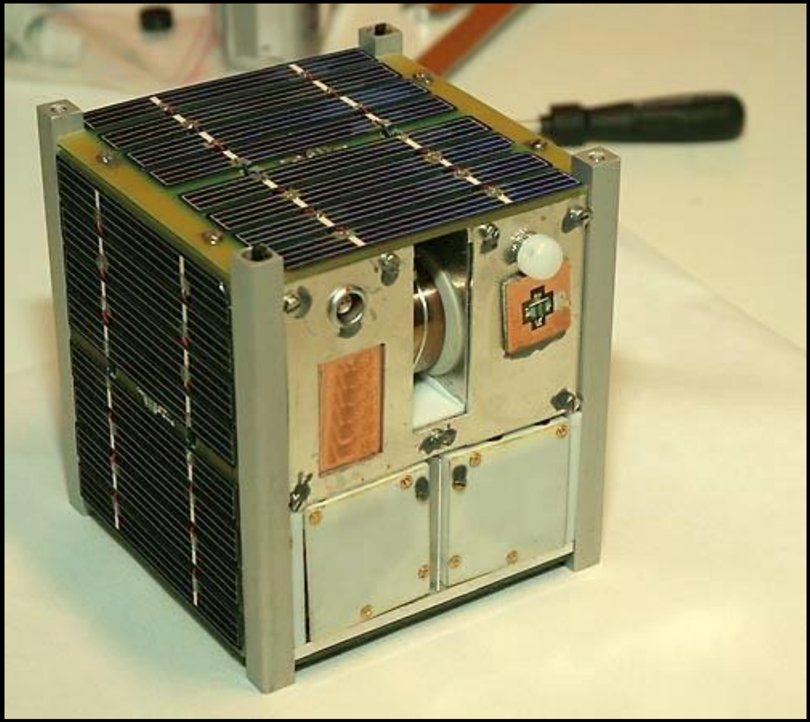
Upper ocean ageostrophic current monitoring

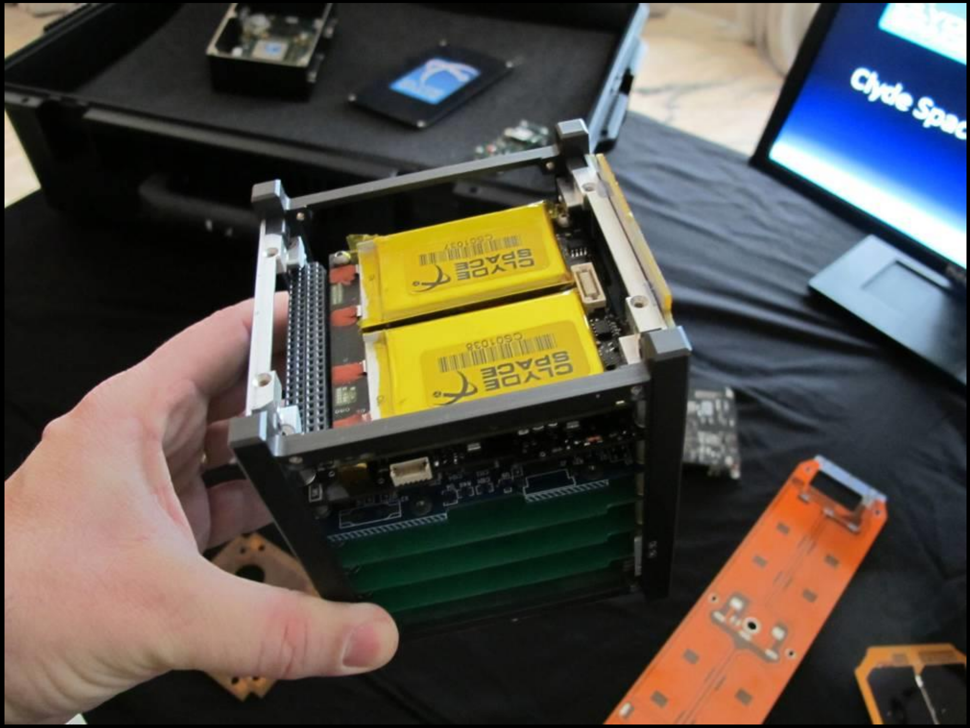



Total ocean surface current monitoring
SAR ATI
SAR Doppler
Internal Waves
Inertial current
Submeso scale
Ekman/ Stokes
Scat
Mesoscale
Tidal current
Rossby waves
Seasonal cycle
El Nino
Spatial resolution
1km
10km
30km
100km
1000km
1 season
10days
3days
daily
3 hourly
Temporal resolution

New Era - Nanosatellites - CubeSat

A **CubeSat** is a type of miniaturized satellite for space research that usually has a volume of exactly 10 cm cube, and mass of no more than 1.33 kilograms.

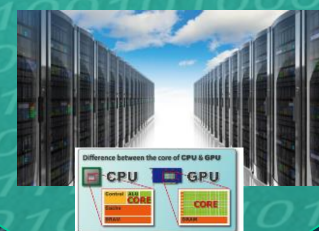




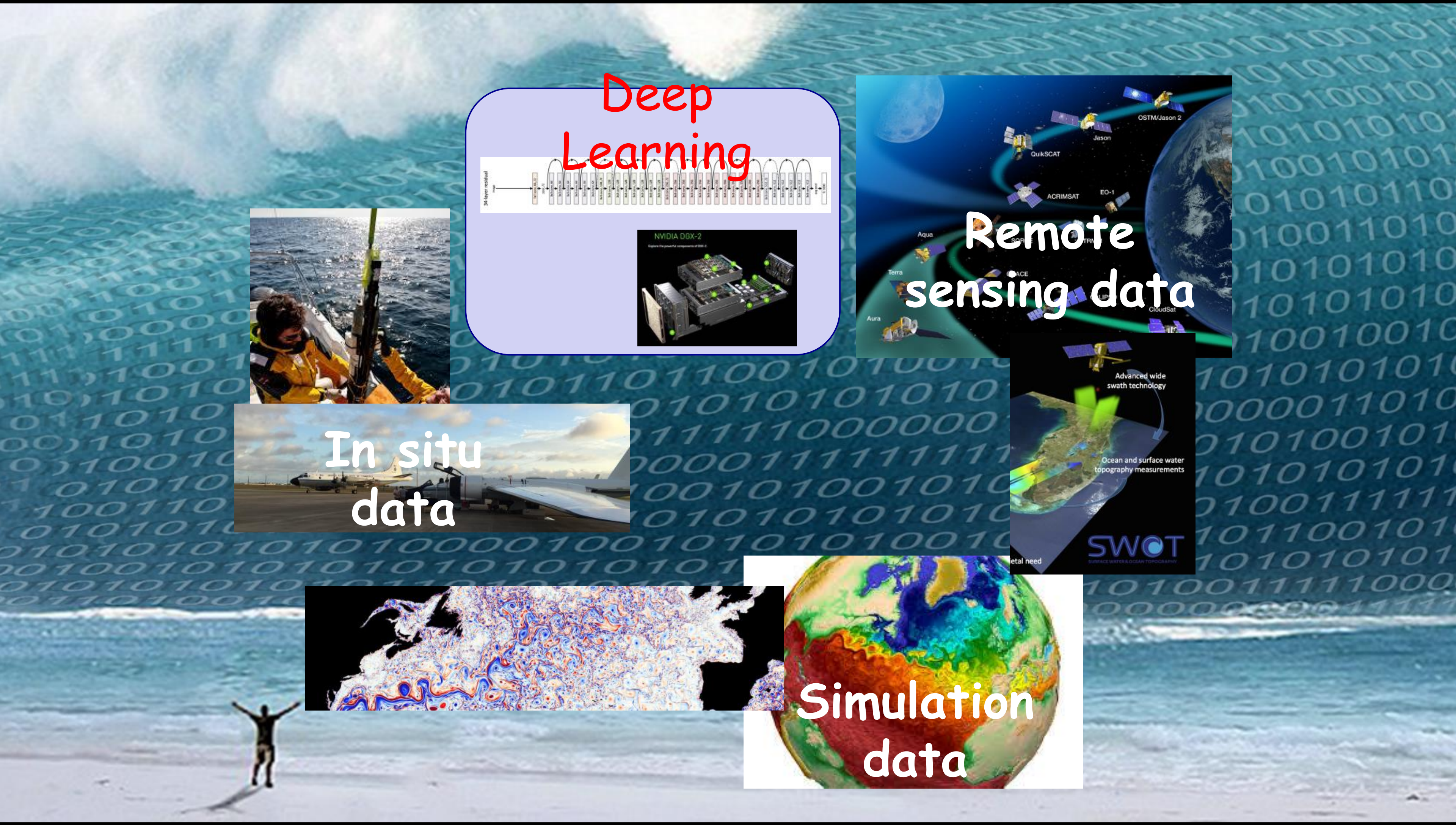
Big Data & AI/Data Science

Data

Big data infrastructure



DL/AI



Deep Learning
NVIDIA DGX-2
OSTM/Jason 2
Jason
QuikSCAT
ACRIMSAT
EO-1
Aqua
Terra
Aura
CloudSat
Remote sensing data
Advanced wide swath technology
Ocean and surface water topography measurements
SWOT
In situ data
Simulation data

Numerous questions and challenges

Some of the Living Planet Challenges to better assess the existing pressures on the marine environment (e.g. overfishing, pollution, habitat destruction, ...) potentially leading to increased risks to global food security, economic prosperity, …

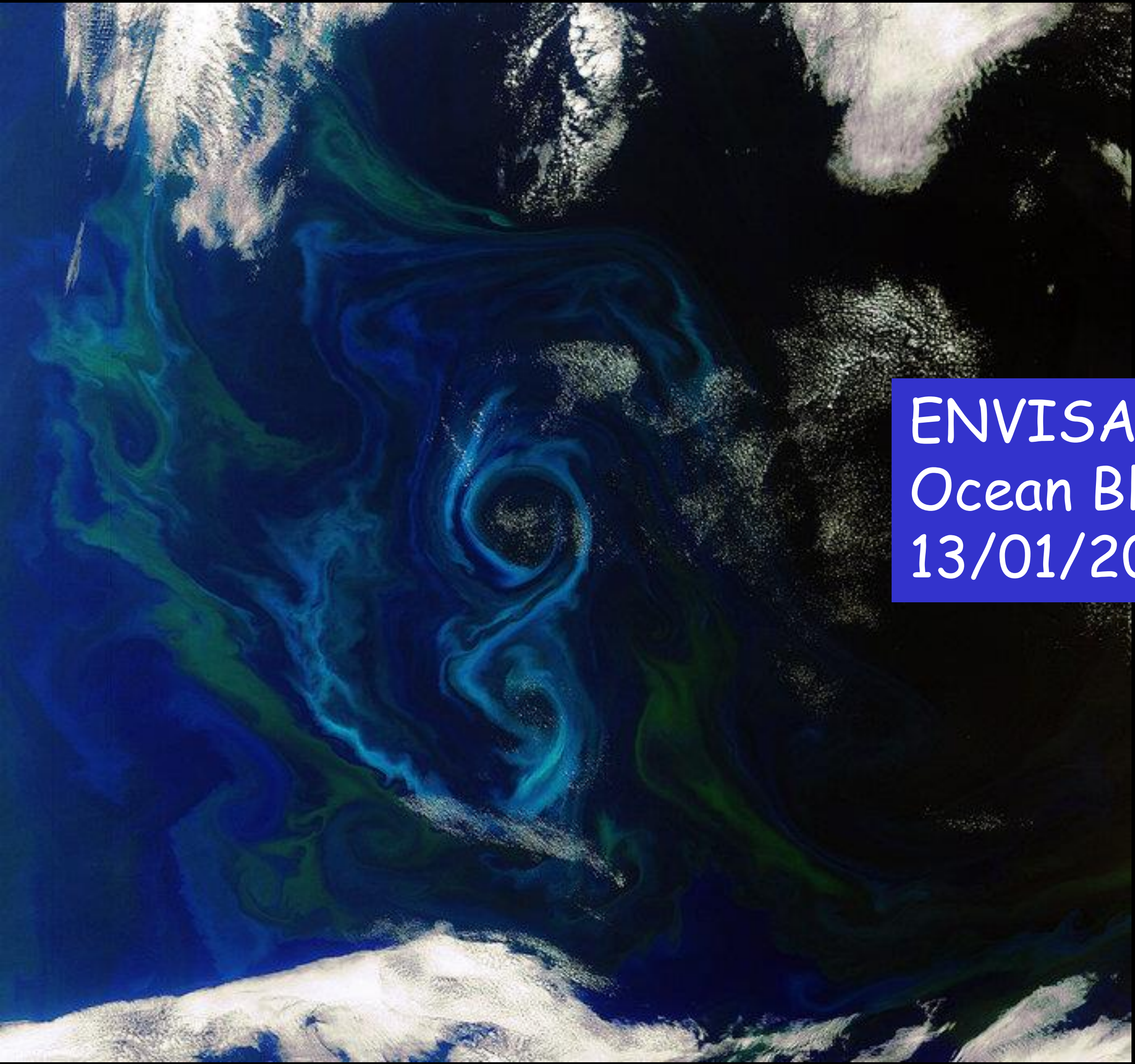
Evolution of coastal ocean systems including the interactions with land in response to natural and human-induced environmental perturbations

Mesoscale and submesoscale circulation and the role of the vertical ocean pump and its impact on energy transport and biogeochemical cycles

Response of the marine ecosystem and associated ecosystem services to natural and anthropogenic changes,

Physical and biogeochemical air/sea interaction processes on different spatio-temporal scales and their fundamental role in weather and climate

Sea level changes from global to coastal scales and from days (e.g. storm surges) to centuries (e.g. climate change)



ENVISAT MERIS Southern Ocean Bloom 13/01/2012

Numerous questions and challenges :

How can we map the distribution of marine plastic Debris?

Has the Agulhas current strengthened in the last 5 years?

Is the surface circulation of the Black Sea and in the Mediterranean Sea stable?

How is the Arctic Ocean changing ?

How is marine biodiversity changing, locally, regionally, globally ?

What is the extent of ocean acidification ?

Are western boundary currents changing, the Gulf Stream ?

How can ship routing be optimised ?

Why and where is regional sea level changing?

How are our coastal regions changing?

How can we map estuary systems from space?

Most observations are not yet sufficiently explored and used, limited to 'low-hanging fruits', and necessity to better optimize analysis to reveal multi-scale dynamics

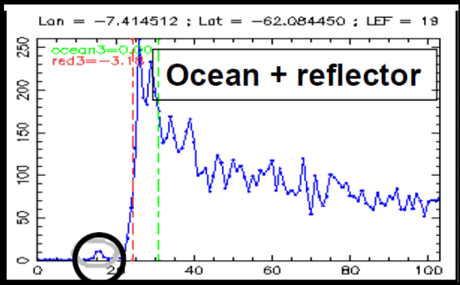
- … Synergy between high and medium resolution observations to reveal mean states and trends, near-surface ocean-atmosphere dynamics, local and non-local interactions, convergence/divergence surface fronts and numerous roughness contrasts

Atmospheric and Oceanic observations generally produce high quality data, but it is often too sparse (many gaps where information is missing, and/or often too local in both space and time)

How can we use observed data in combination with the physical knowledge of stochastic processes in nonlinear dynamical systems to estimate and model those effects on the variability of computationally resolvable scales of motion that are caused by the small, rapid, unresolvable scales of fluid motion that upscaling in data assimilation leaves out?

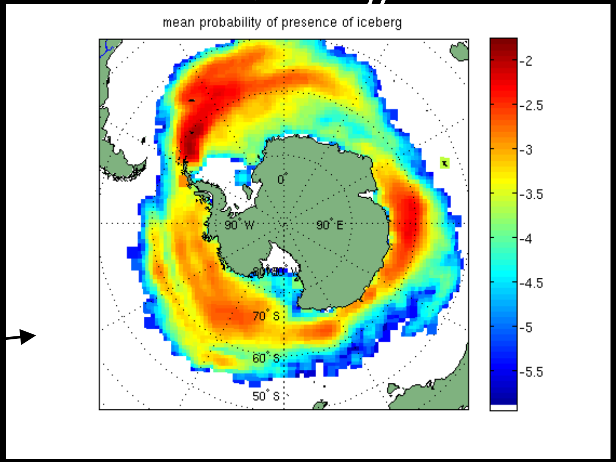
Extracting new knowledge

Analysis of altimeter wave forms :
ERS 1 & 2, Envisat, Jason 1 & 2, Cryosat, AltiKa (12 TB)

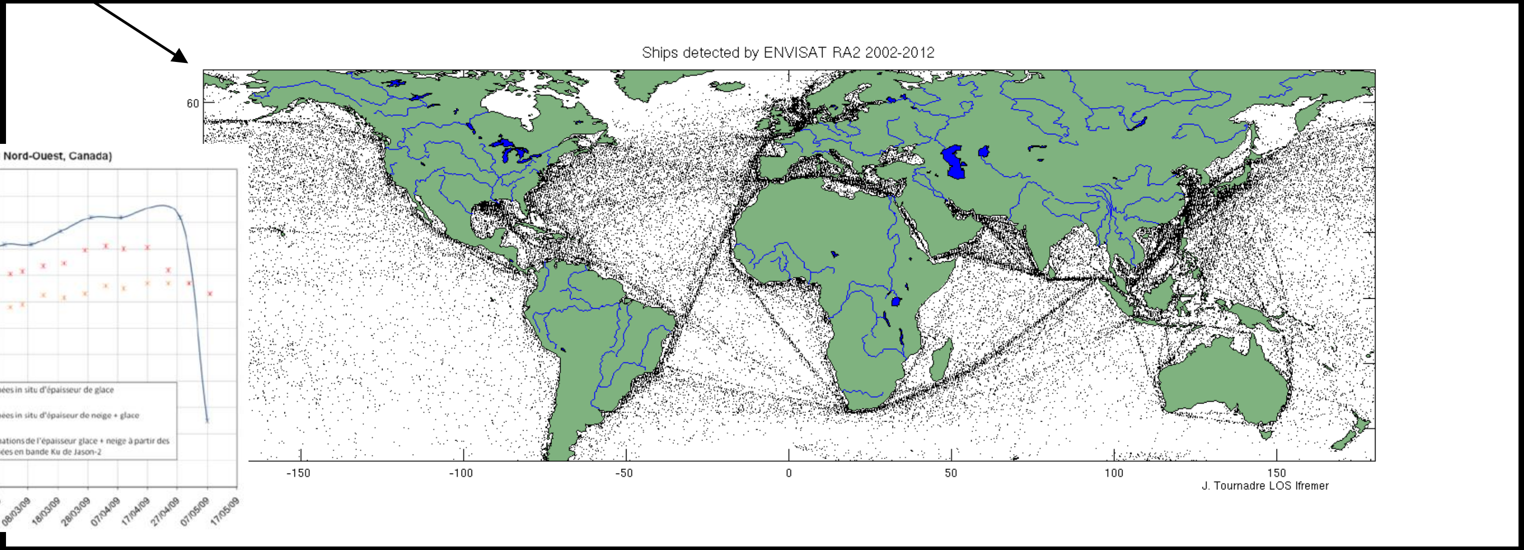


Disposing of a sandbox with permanent access to all data and processing power greatly ease bridging the gap between initial idea and full demonstration / long term assessment

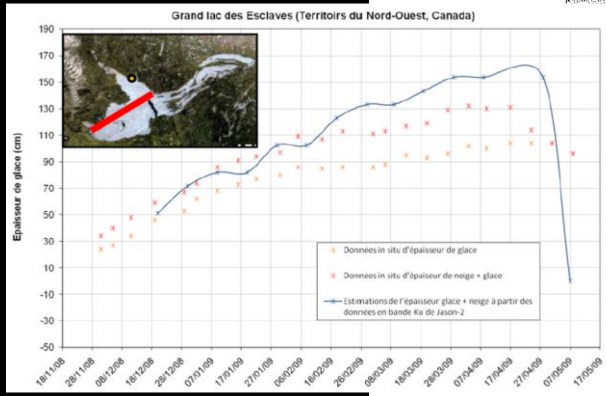
Iceberg detection & climatology

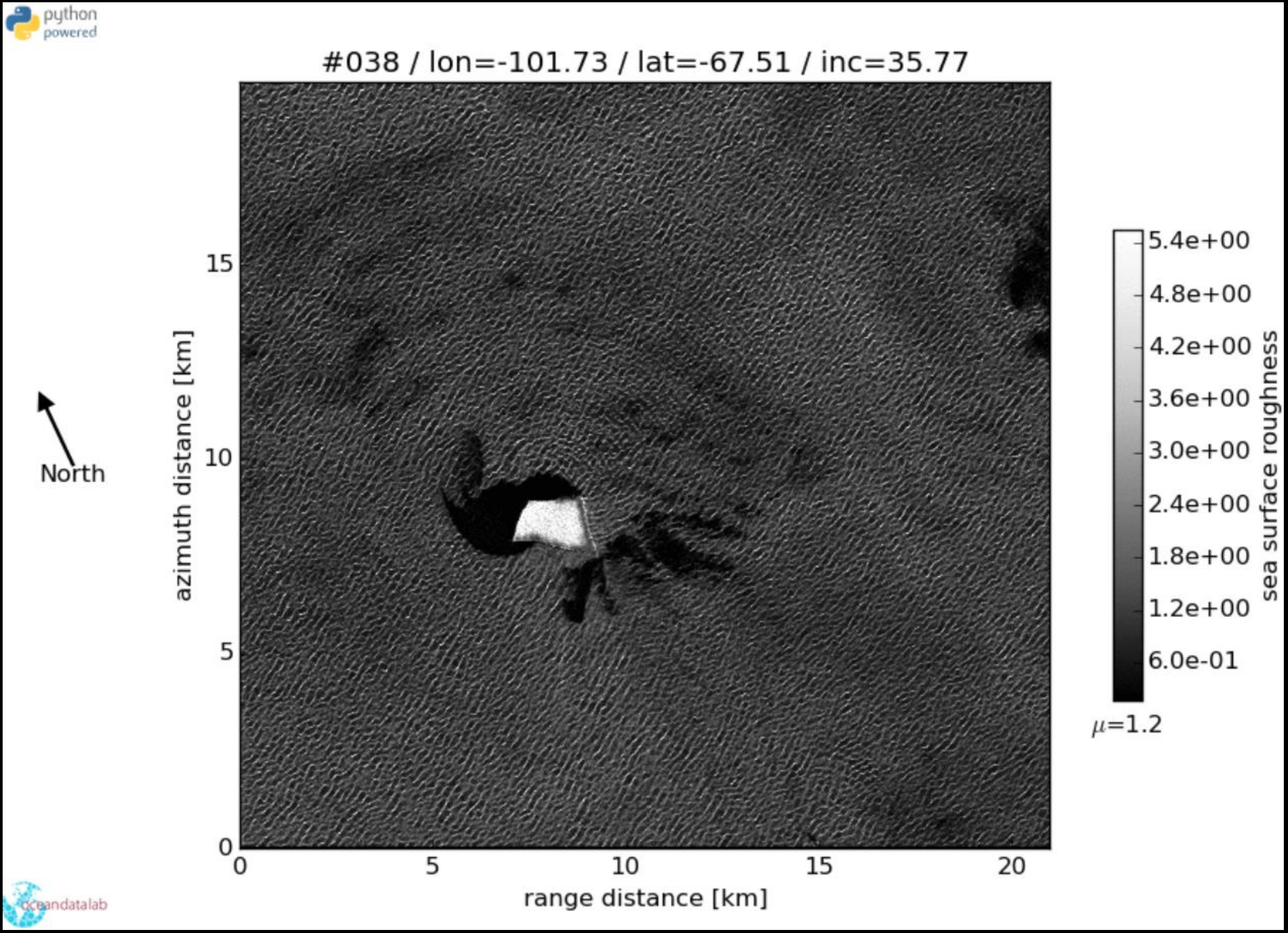


Ship detection



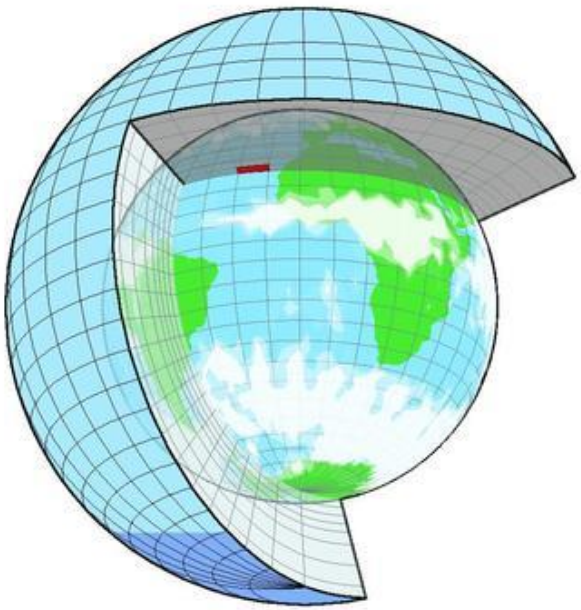
Lake ice thickness



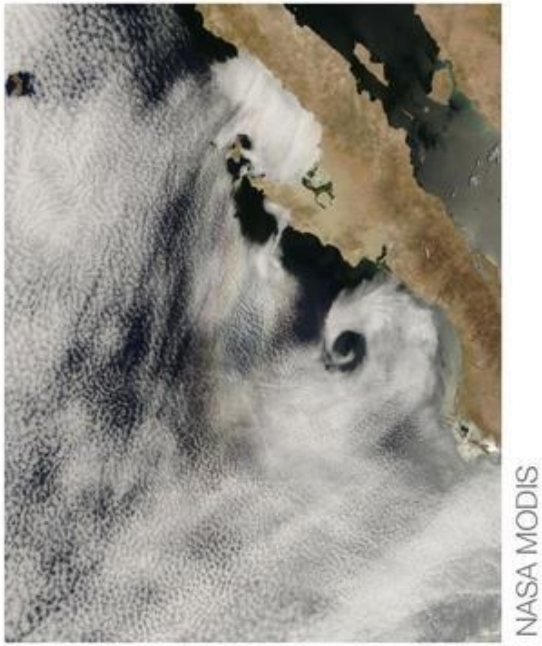


#038 / lon=-101.73 / lat=-67.51 / inc=35.77
North
azimuth distance [km]
range distance [km]
0
5
10
15
20
sea surface roughness
5.4e+00
4.8e+00
4.2e+00
3.6e+00
3.0e+00
2.4e+00
1.8e+00
1.2e+00
6.0e-01
μ=1.2
python powered
oceandatalab

Climate models are too coarse to resolve clouds

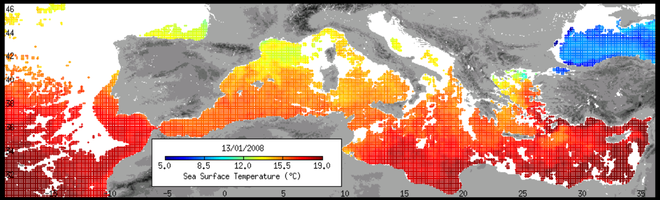


Global model:
~100 km resolution

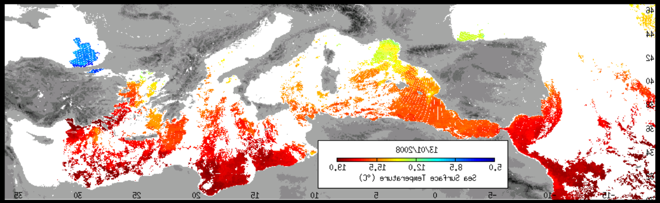


Cloud scales: ~10-100 m

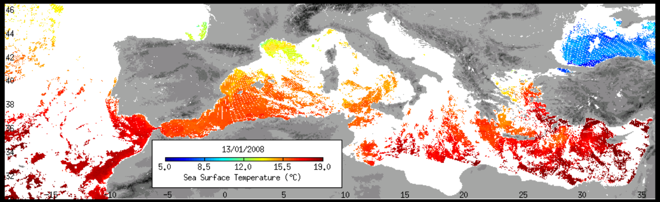
SST



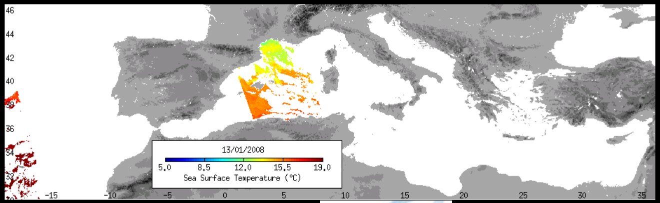
MSG/SEVIRI (10km, 3 heures)



SAF O&SI NAR pour AVHRR17 (2km, 2 passes/jour)

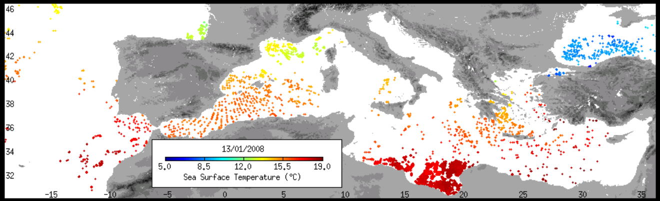


SAF O&SI NAR18 pour AVHRR17 (2km, 2 passes/jour)

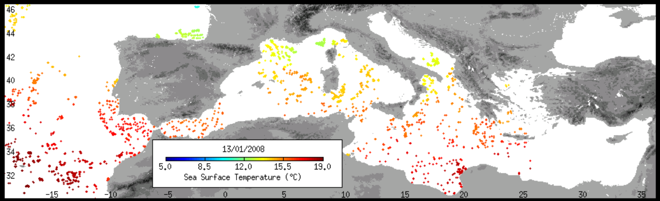


AT

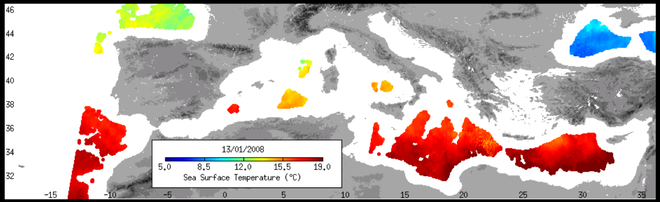
1 jour



Avhrr 18



Avhrr 17

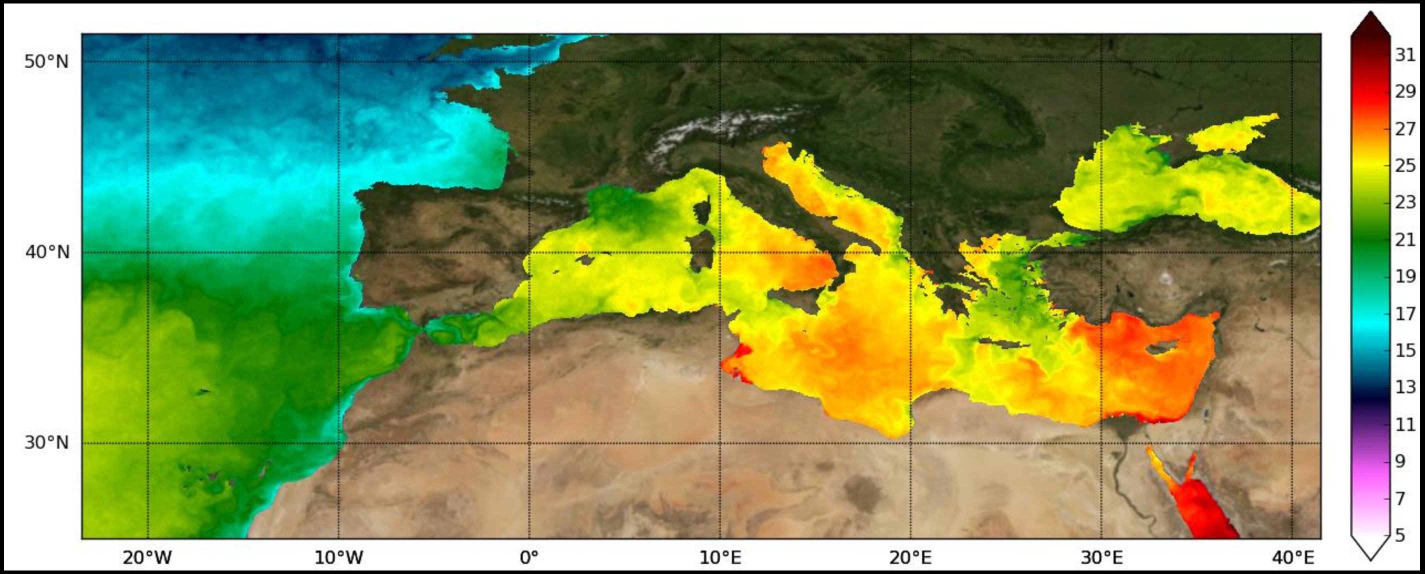


ENVISAT/AATSR (1 km, 14-15 orbites/jour)

⇒ Multi-satellite product

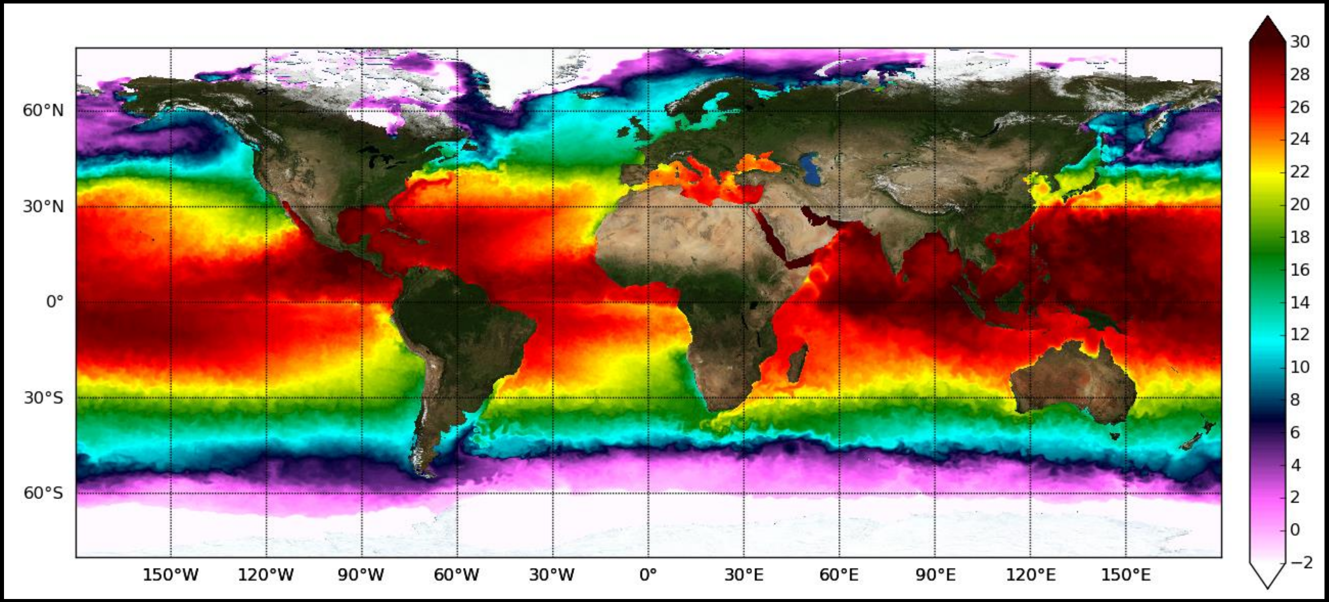
Sea surface temperature

High resolution daily product 2006-present, 2 km resolution



projet ESA Medspiration

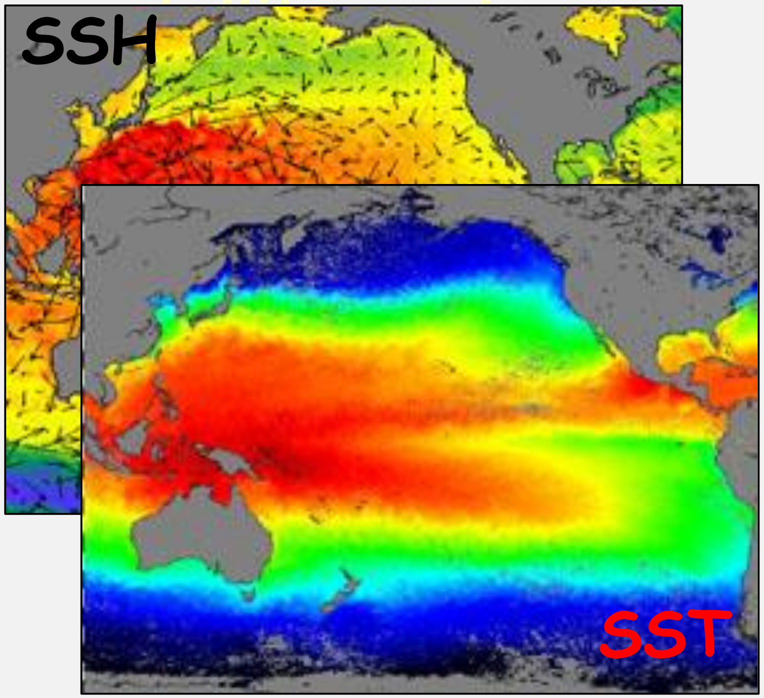
Global SST



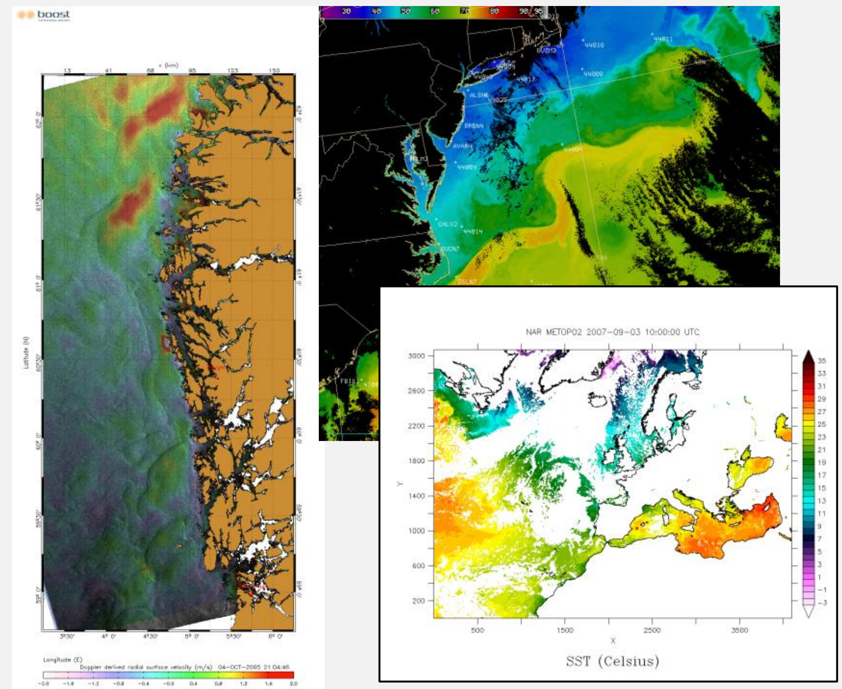
Global reanalysis 2006-present
at 10 km resolution

High-resolution satellite ocean sensing

From low-resolution ……………. to high-resolution



Low-resolution: ~25km (0.25°) eg,
Altimetry (SSH), Radiometer (SST)



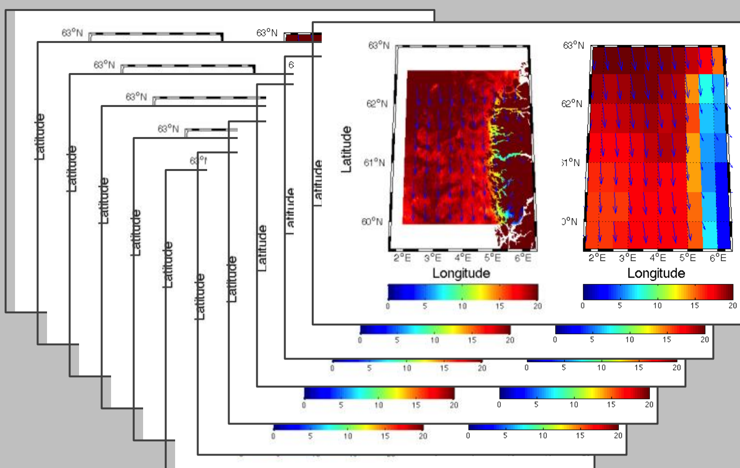
High-resolution: 1-4km (0.01°) or < 1km
SAR, Infrared (SST), Ocean Colour

Key issue

How to deliver daily high-resolution geophysical field at regional/global scale from the the irregular space-time sampling of high-resolution sensors

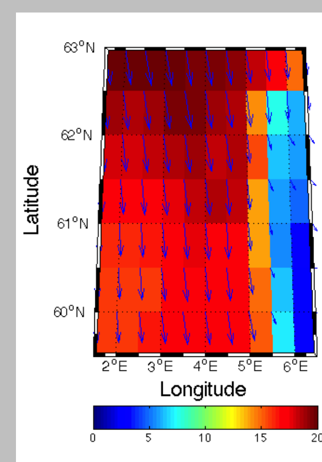
Emulating the OCEAN at high-resoluton from multi-scale/multi-sensor databases

HR observations are irregularly sampled in space and time. But …. 1) low resolution observations are generally available and 2) we should learn a lot from past joint HR/LR observations.

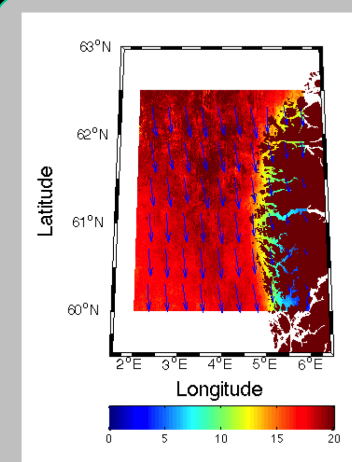


Database of past LR/HR observations

+



New LR observation

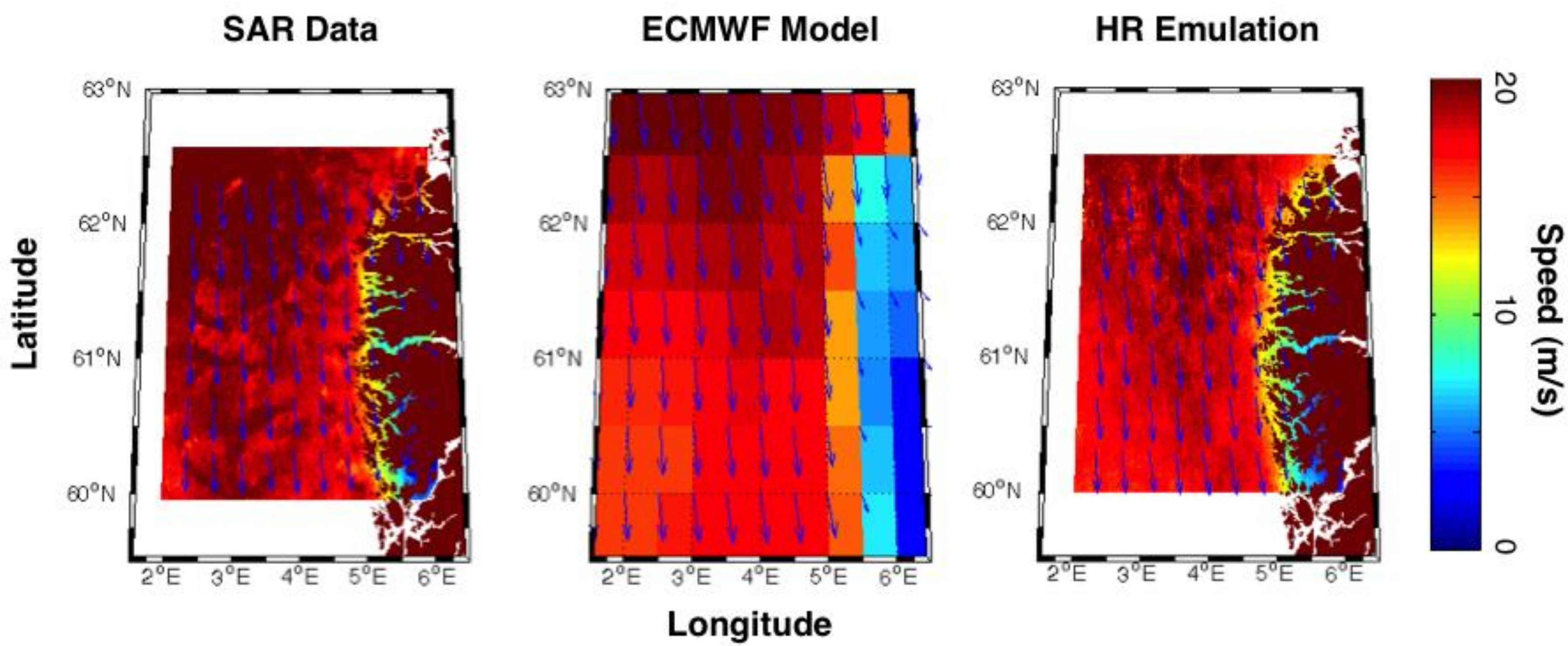


New HR observation

Key objective: learning new multi-scale/multi-modal representations of ocean dynamics from multi-sensor remote sensing archives

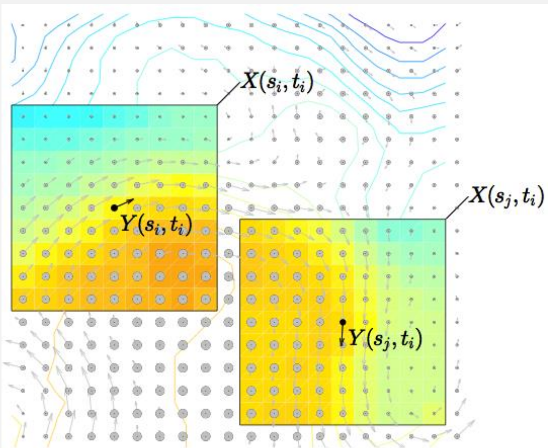
Multi-scale/multi-modal representations of ocean dynamics from remote sensing archives

Wind fields:



Learning ECMWF-to-SAR transfer functions for HR wind field emulation

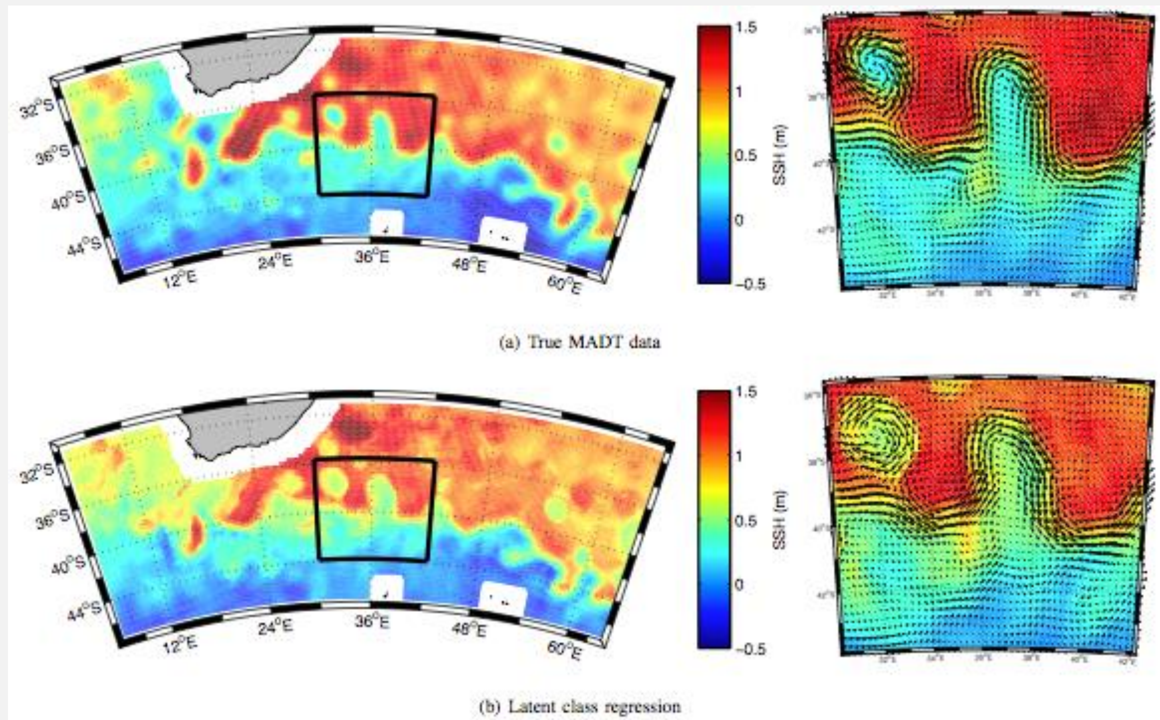
Multi-scale/multi-modal representations of ocean dynamics from remote sensing archives



SQG-like assumption: local relationships between local SST patches and sea surface currents

Learning from joint SST-SSH observations

Application to AMSR/SST-AVISO/SSH

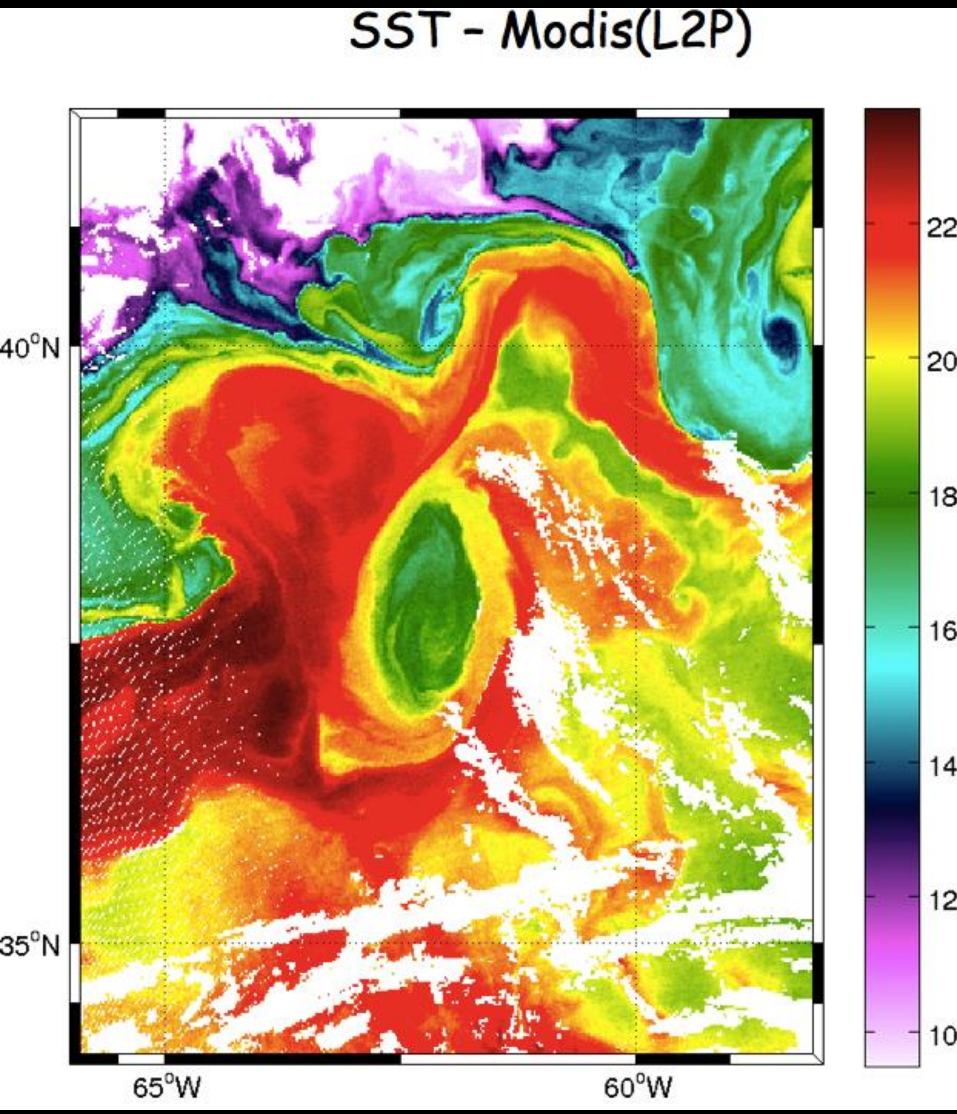


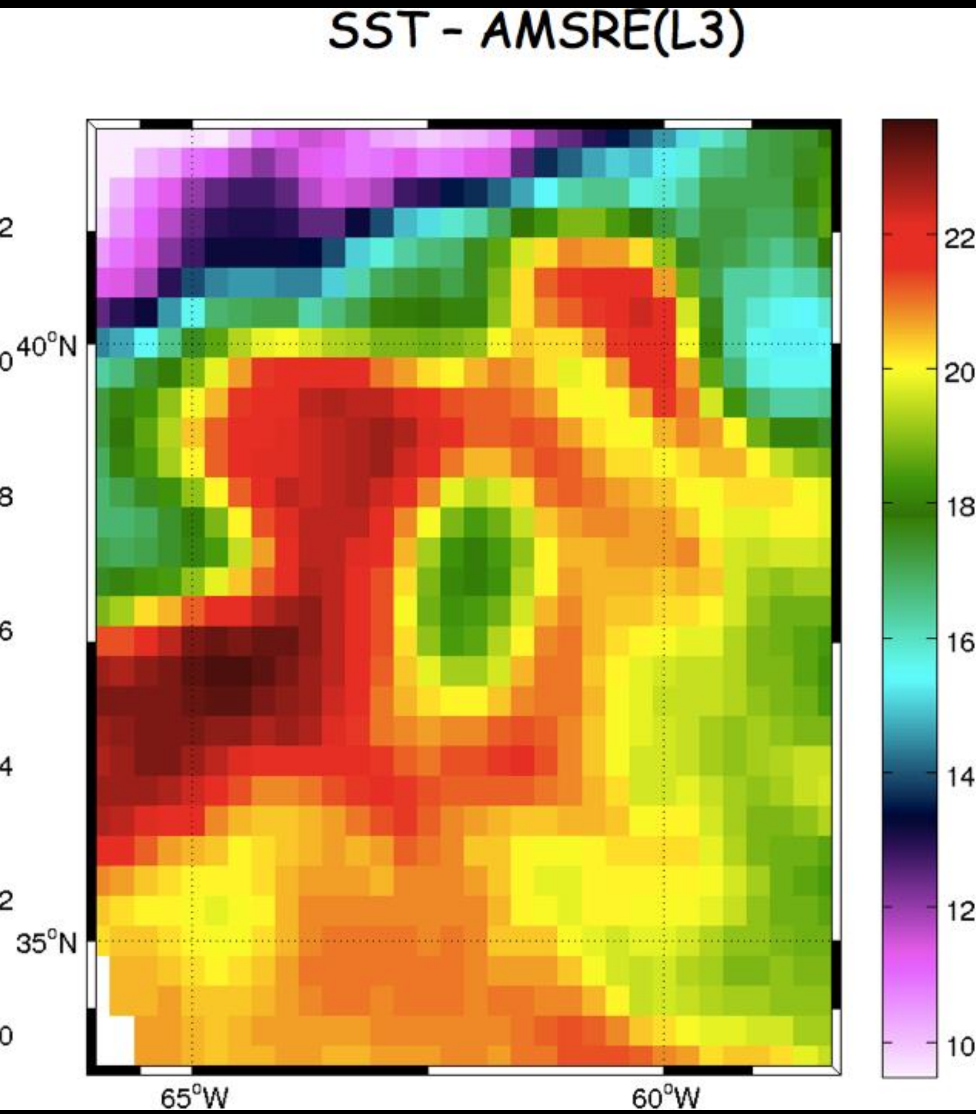
(a) True MADT data

(b) Latent class regression

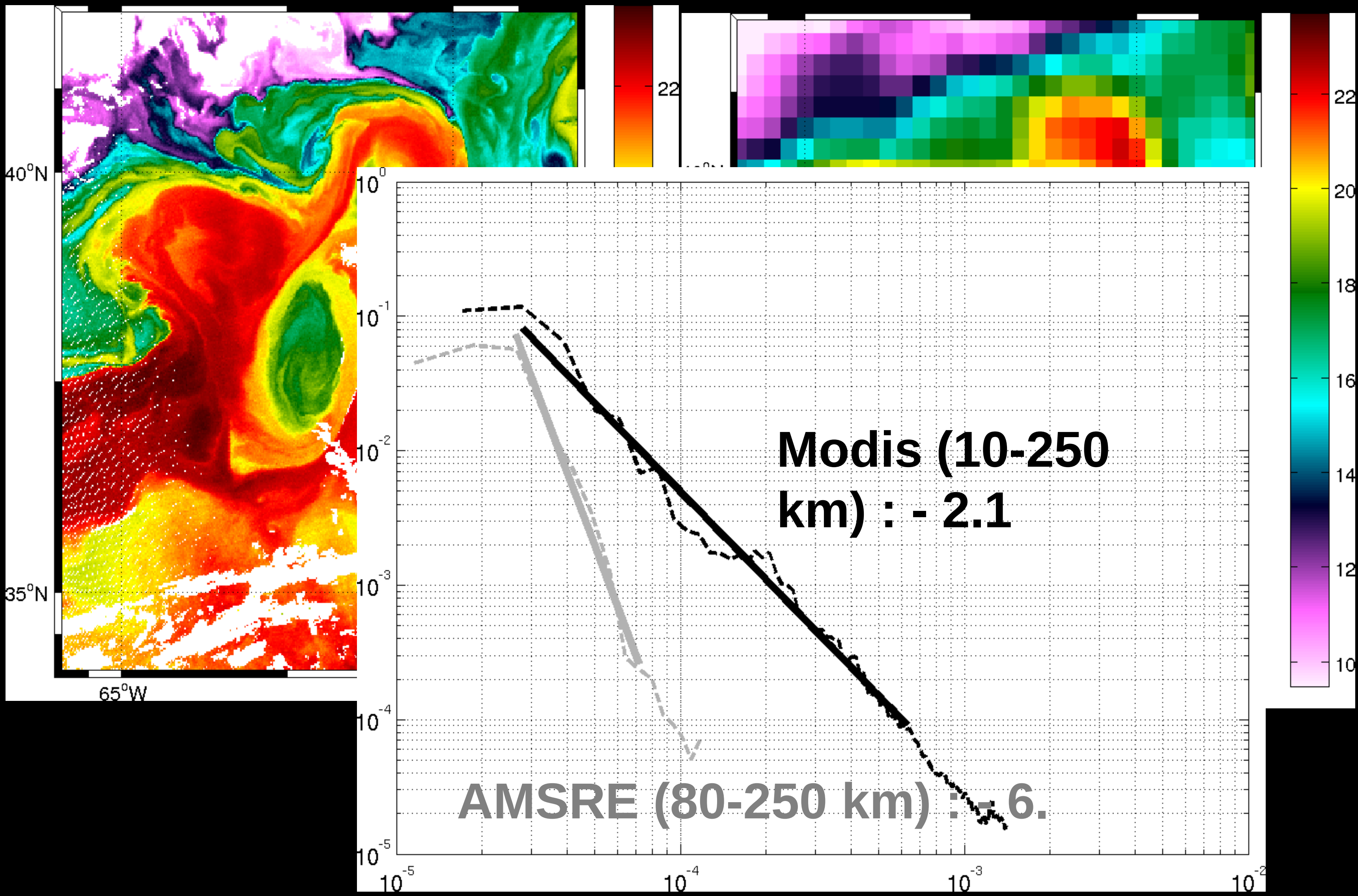
Towards high-resolution sea surface currents from a joint SST-SSH analysis

Small scales / mesoscale





Characterizing the submesoscale - Spectral approach



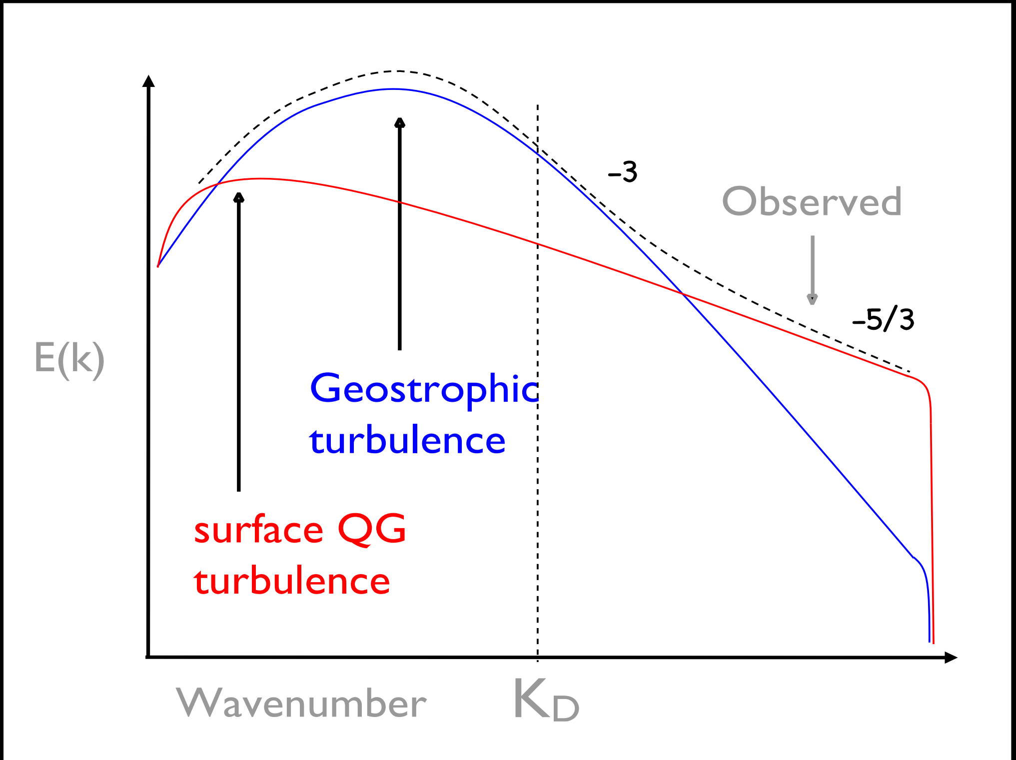
Tracer mixing depends on KE spectrum

$$E(k) \sim k^{-\alpha}$$

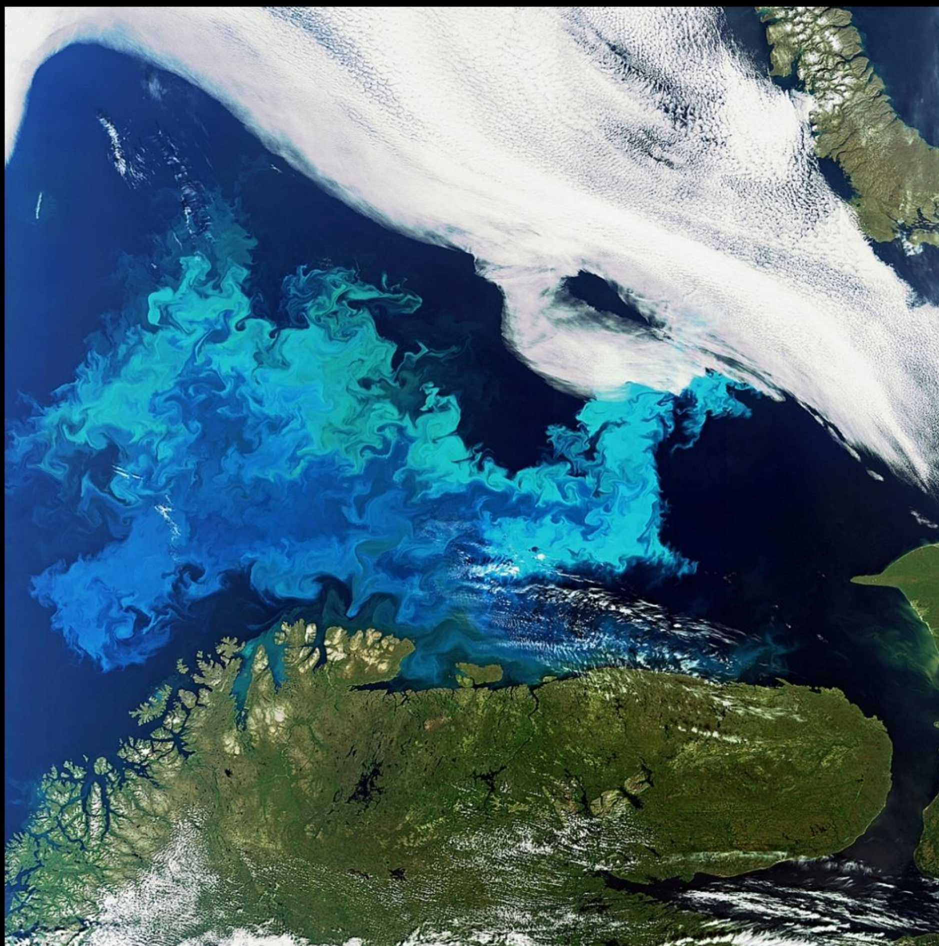
α>3 : **spectrally nonlocal**: stirring set by large scales

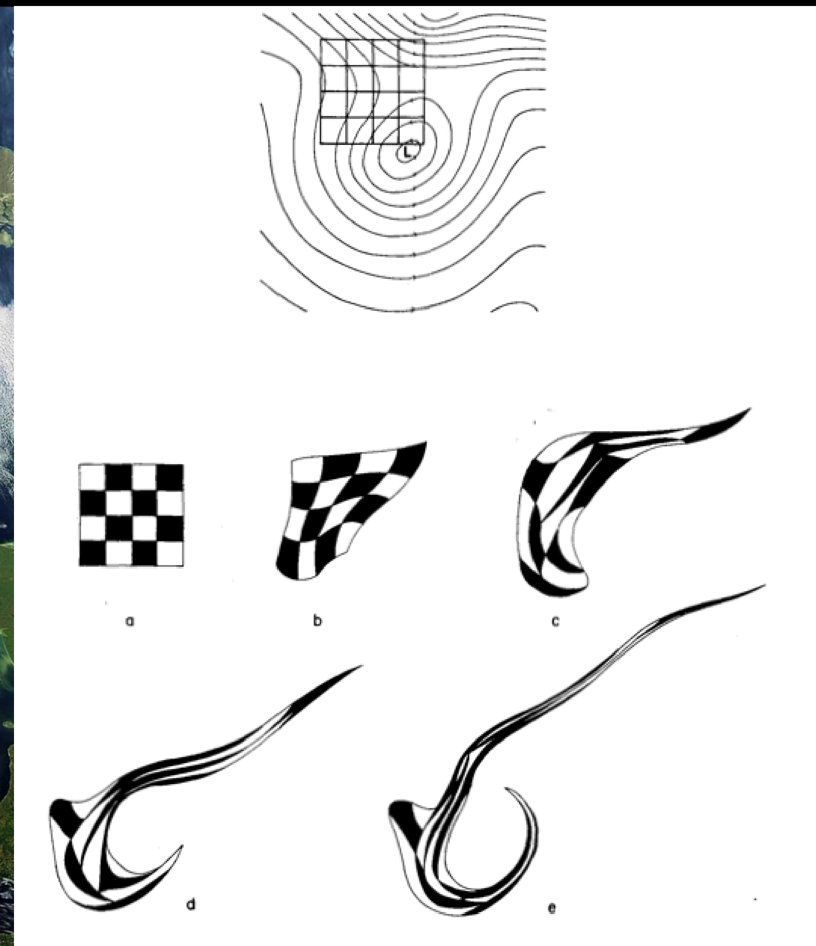
α<3 : **spectrally local**: stirring set by local scales

- Simple proxy model: surface quasigeostrophic turbulence
- Dynamics driven by surface density anomalies (zero interior PV)

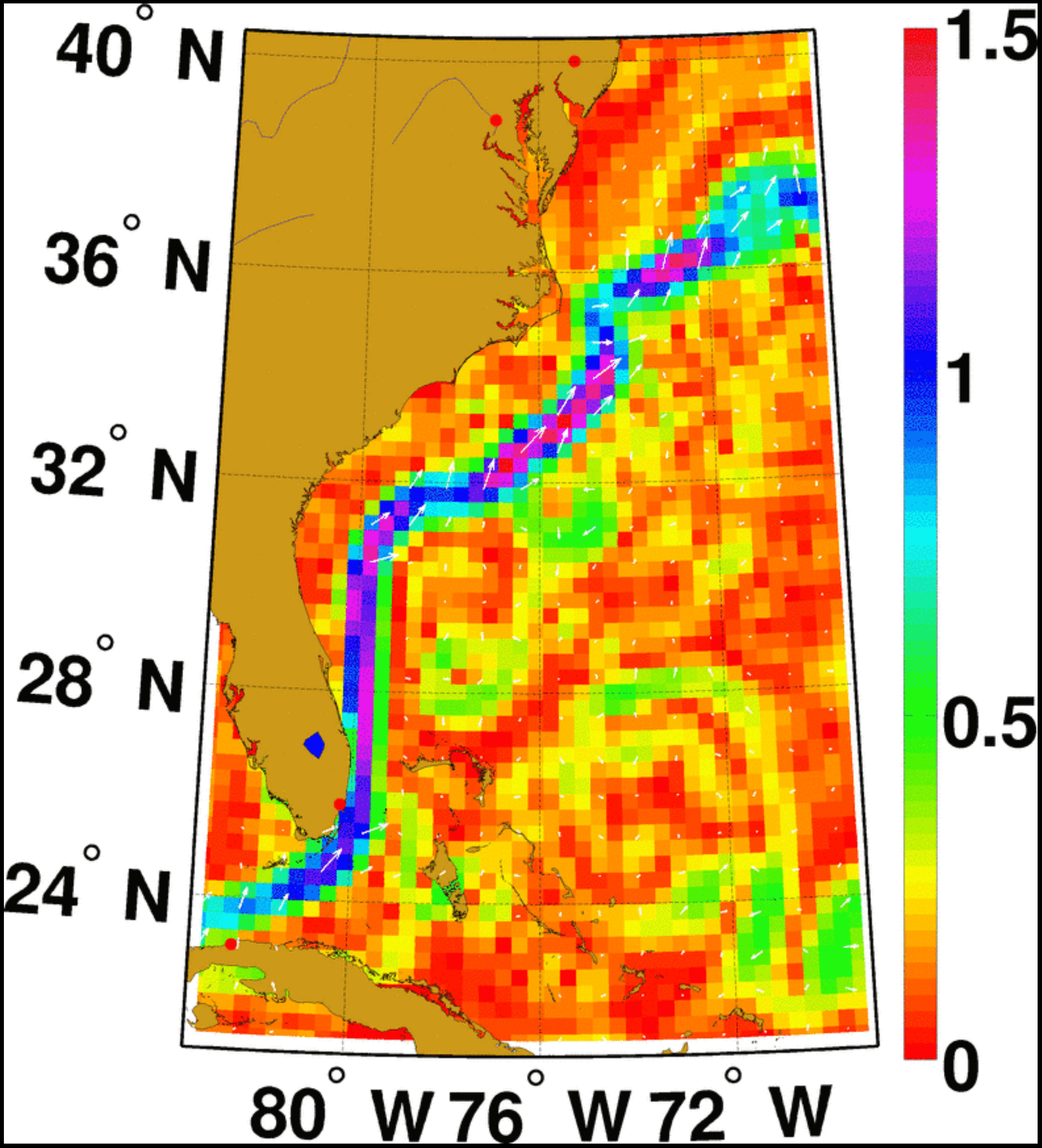


Stirring and mixing : interplay and scale interactions

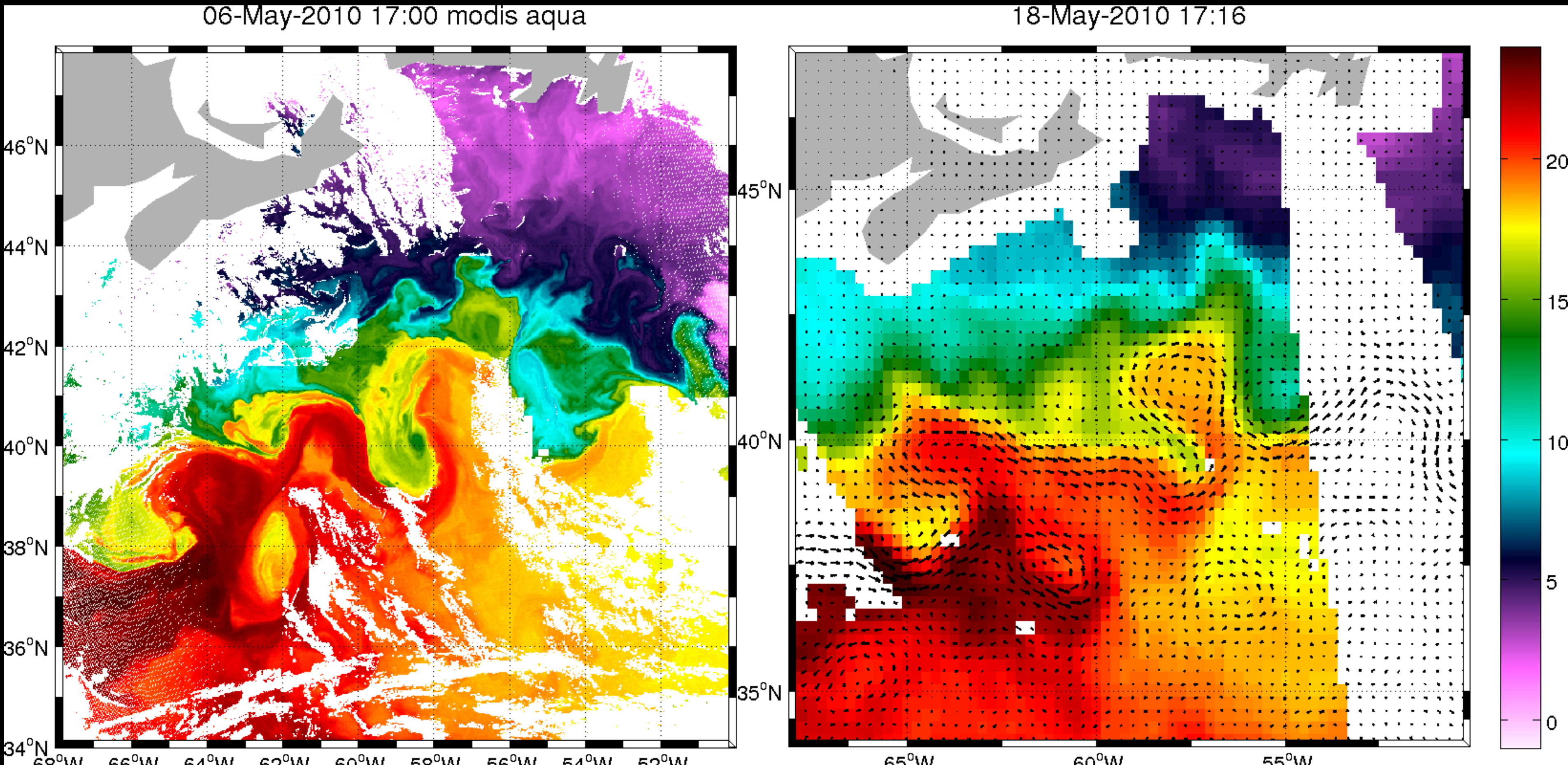




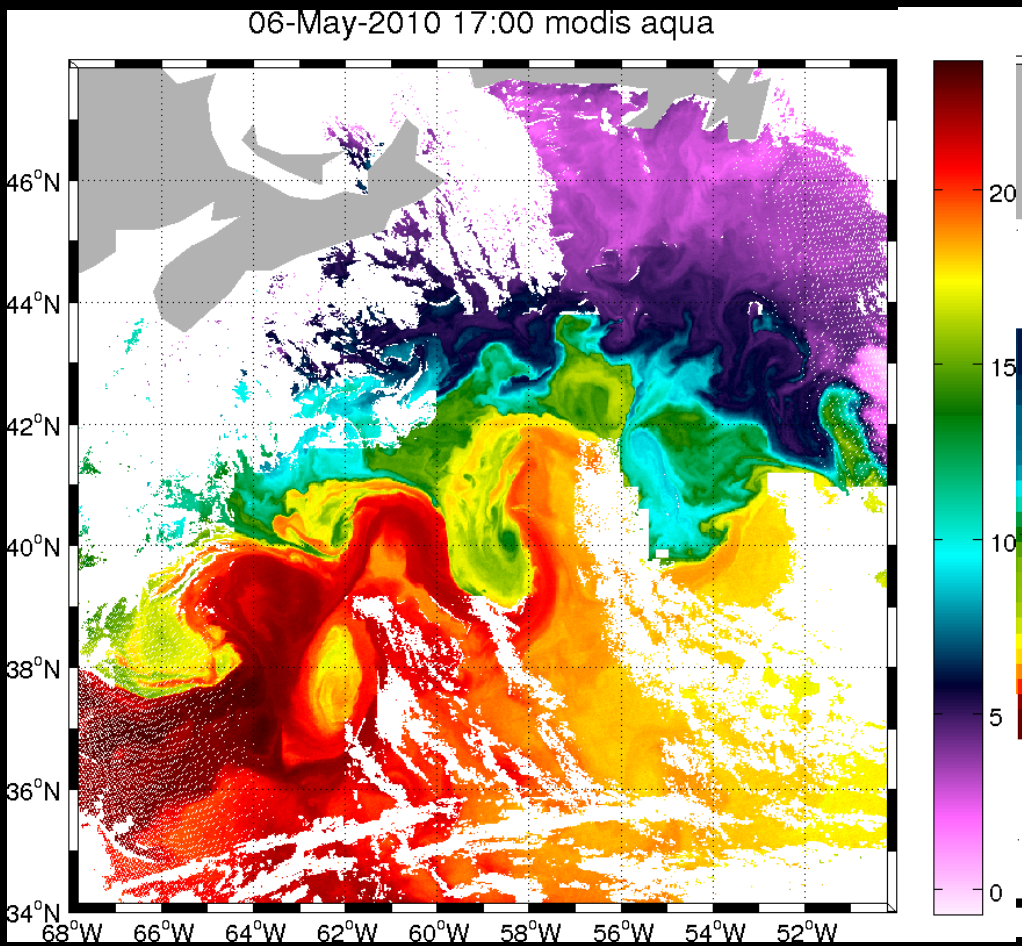
31Mar/07Apr (2010)
MODIS vs Altimetry-derived velocity field

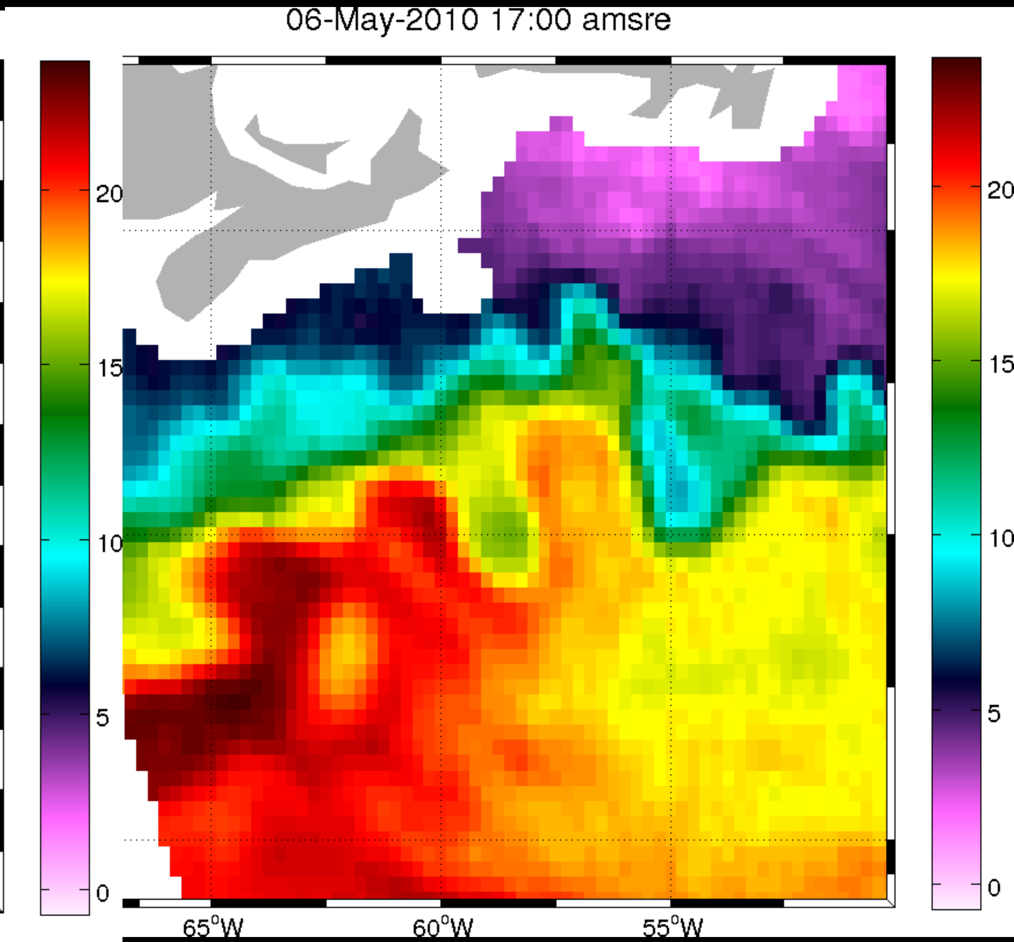


Small scales / mesoscale

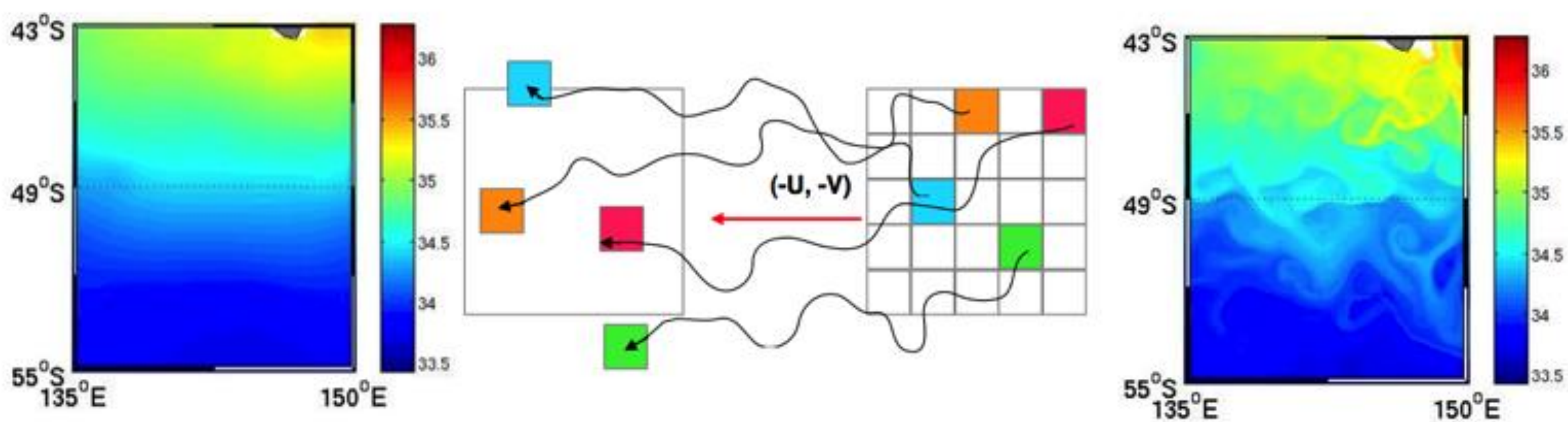


Small scales / mesoscale

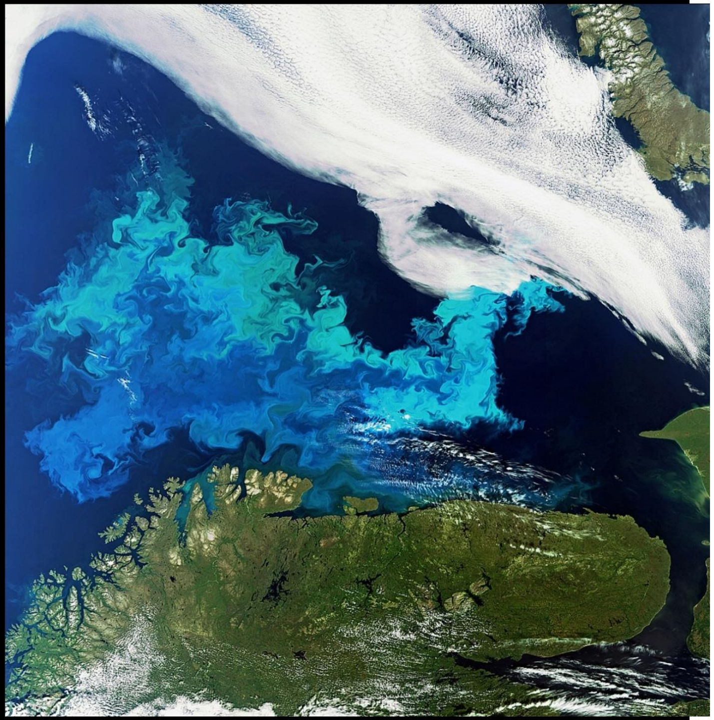


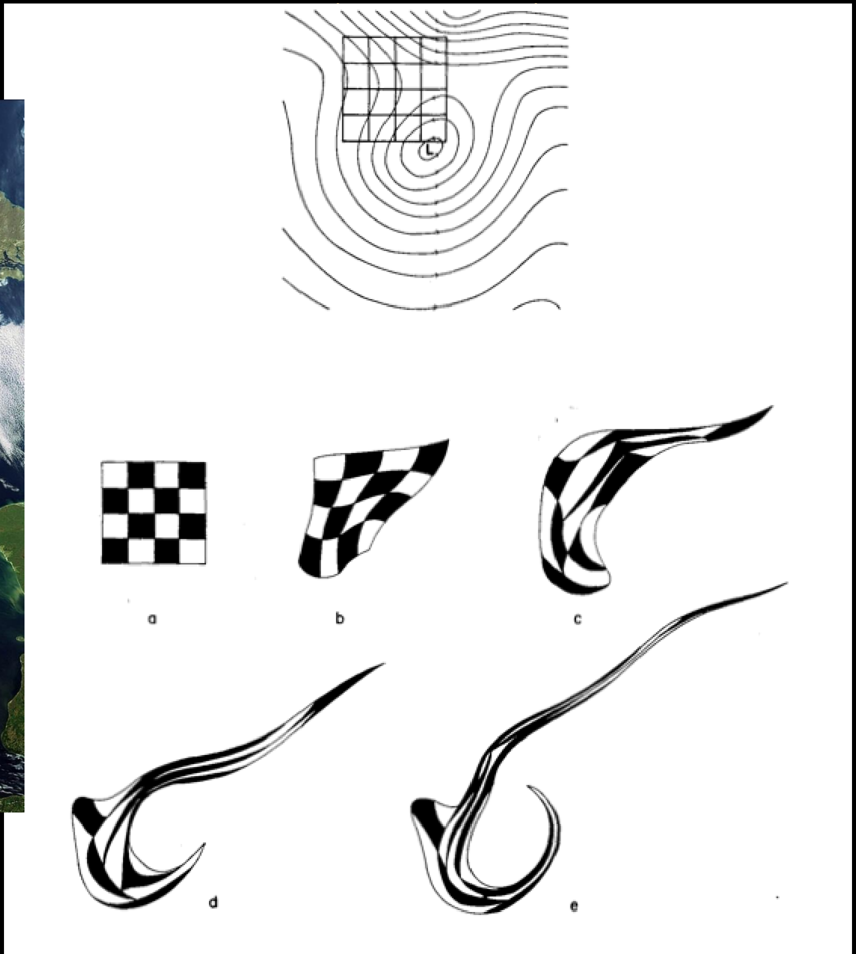


Lagrangian advection to dynamically interpolate large-scale tracer (sea surface temperature field, left) onto a high-resolution product (right). Particle trajectories computed using altimetry-derived velocities (AVISO, weekly 1/3°) with 3 hours time steps

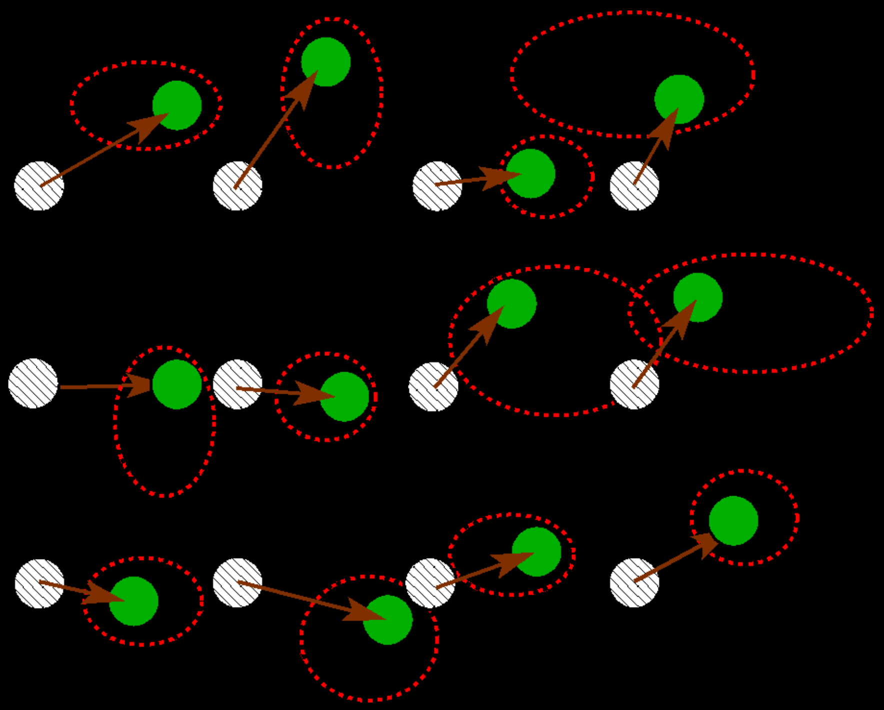


Stirring and mixing : interplay and scale





Observed data in combination with the physical knowledge of stochastic processes in nonlinear dynamical systems



Large scales:

$\boldsymbol{w}$

Small scales:

$\boldsymbol{\sigma}\dot{B}$

Variance tensor:

$\boldsymbol{a} = \boldsymbol{a}(\boldsymbol{x},\boldsymbol{x}) = \dfrac{\mathbb{E}\{\boldsymbol{\sigma} dB\,(\boldsymbol{\sigma} dB)^T\}}{dt}$

Advection of tracer Θ

Multiplicative random forcing

Balanced energy exchanges

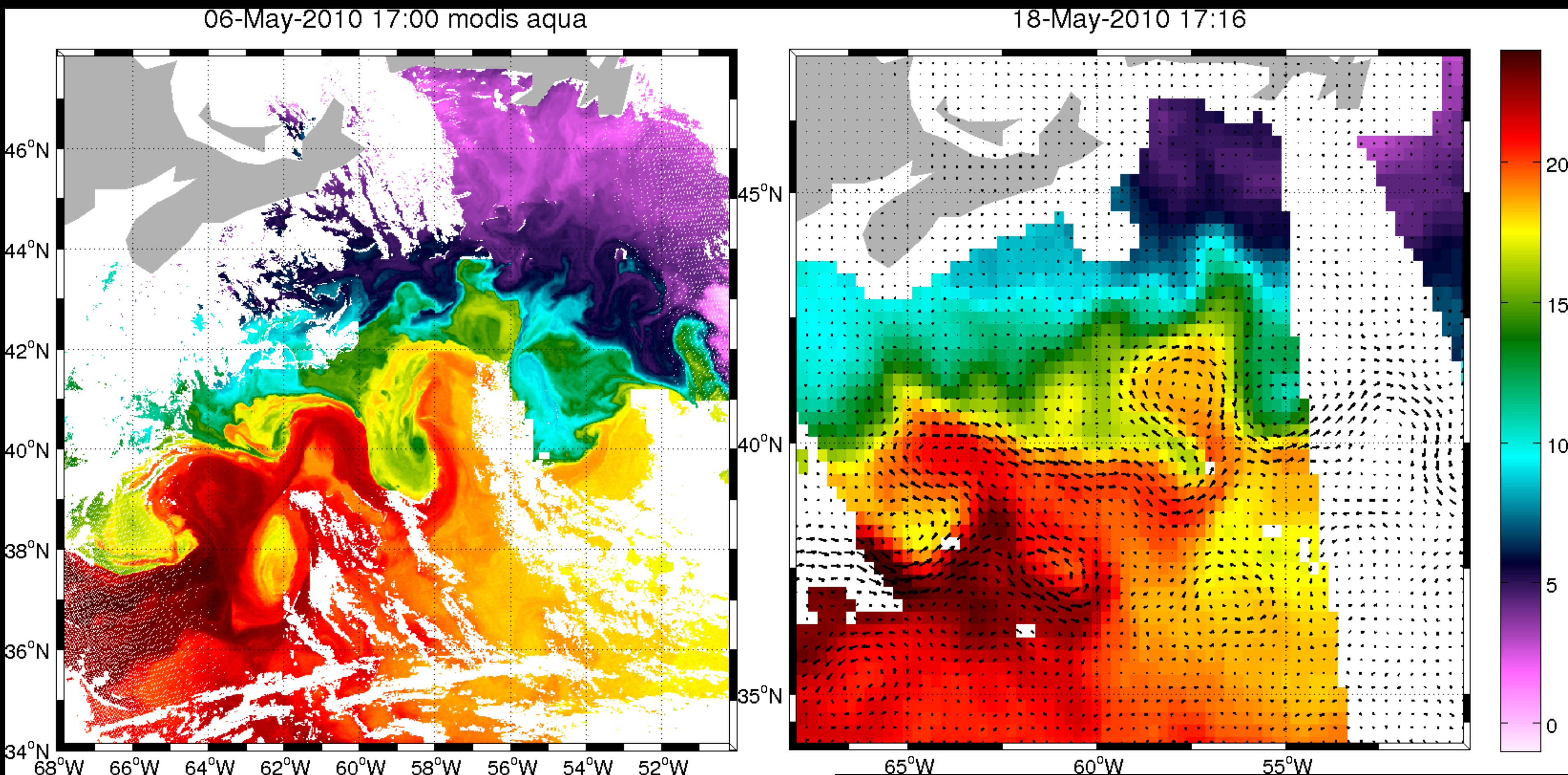
Advection

Diffusion

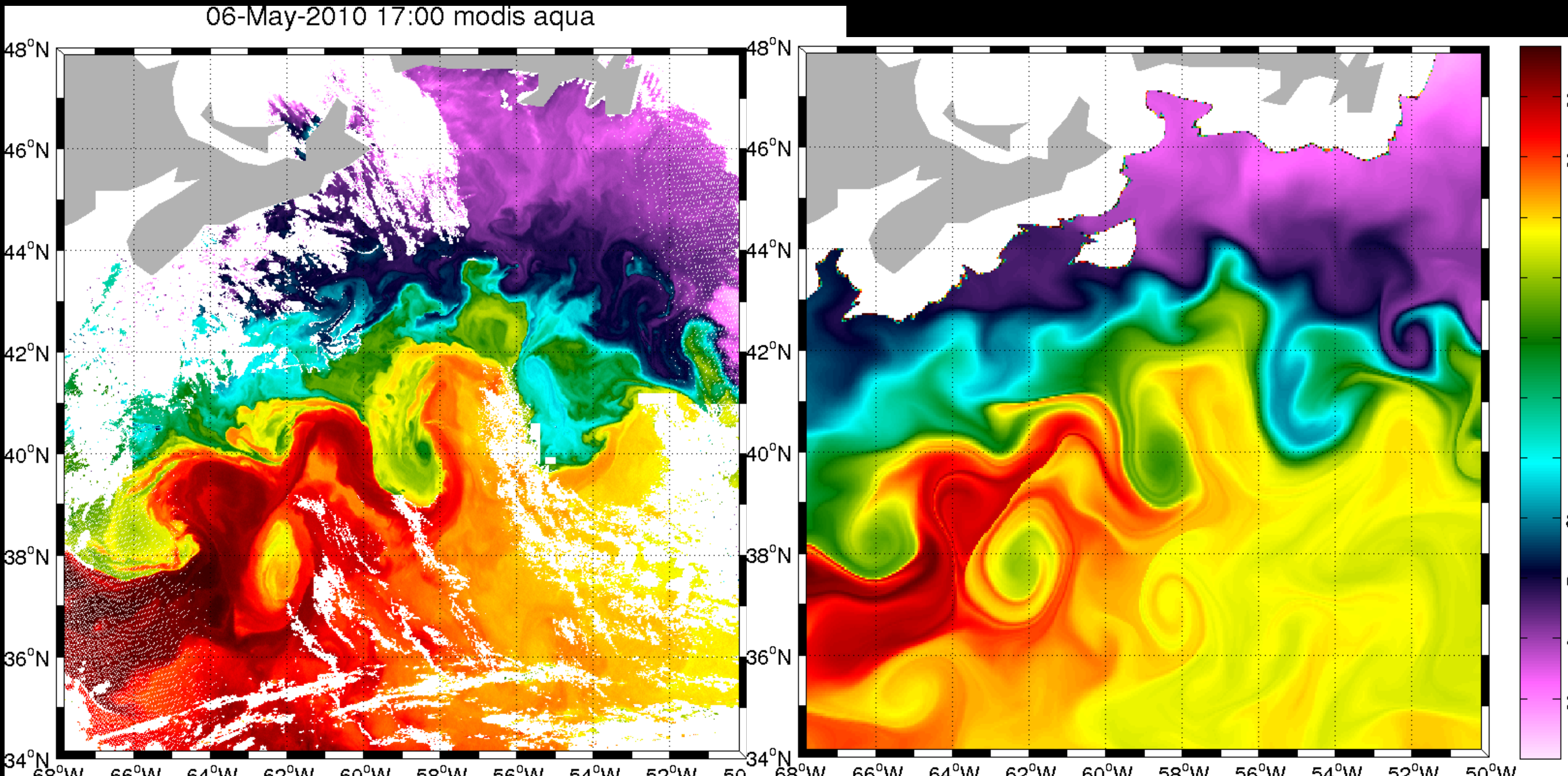
$$\partial_t \Theta + \boldsymbol{w}^{\star} \cdot \boldsymbol{\nabla}\Theta + \boldsymbol{\sigma}\dot{B} \cdot \boldsymbol{\nabla}\Theta = \boldsymbol{\nabla} \cdot \left(\frac{1}{2}\boldsymbol{a}\boldsymbol{\nabla}\Theta\right)$$

Drift correction

Small scales / mesoscale



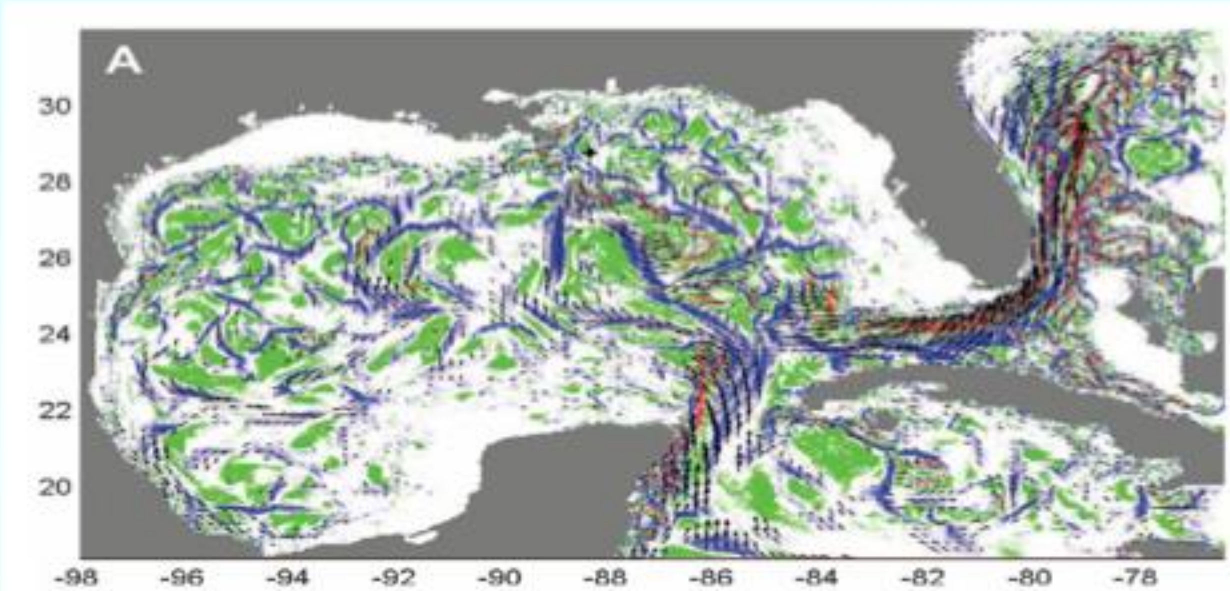
Small scales / mesoscale



Application to Oil Spills Detection

Deepwater Horizon
May 24, 2010
Terra/MODIS

The blended satellite products allow to estimate the impact of surface currents on the biogeochemical transport, on the dispersion of pollutants and oil spills



Forecast of oil spill dispersion in the Gulf of Mexico on 25 june 2010: red and blue show regions of strong oil dispersion within 3 days. This diagnosis, based on altimetric data, compared well with what was observed (Mezic et al, Science, 2010).

However these satellite datasets (altimetric and microwave data) cannot capture ocean dynamics at scales smaller than 100 km because of the resolution (or/and noise level).

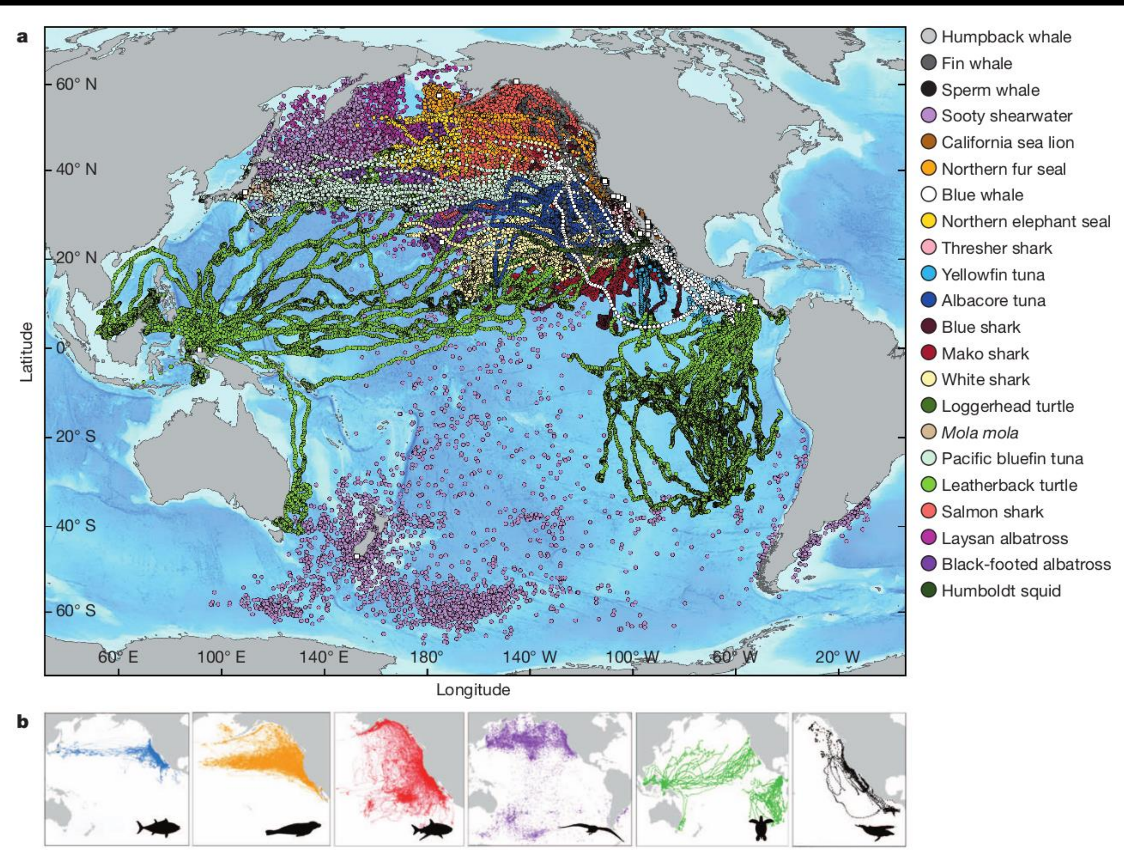
Altimetry for ecology : the invisible landscape

LETTER

doi:10.1038/nature10082

Tracking apex marine predator movements in a dynamic ocean

B. A. Block[1], I. D. Jonsen[2], S. J. Jorgensen[1], A. J. Winship[2], S. A. Shaffer[3], S. J. Bograd[4], E. L. Hazen[4], D. G. Foley[4], G. A. Breed[2,5], A.-L. Harrison[5], J. E. Ganong[1], A. Swithenbank[1], M. Castleton[1], H. Dewar[6], B. R. Mate[7], G. L. Shillinger[1], K. M. Schaefer[8], S. R. Benson[9], M. J. Weise[5], R. W. Henry[5] & D. P. Costa[5]

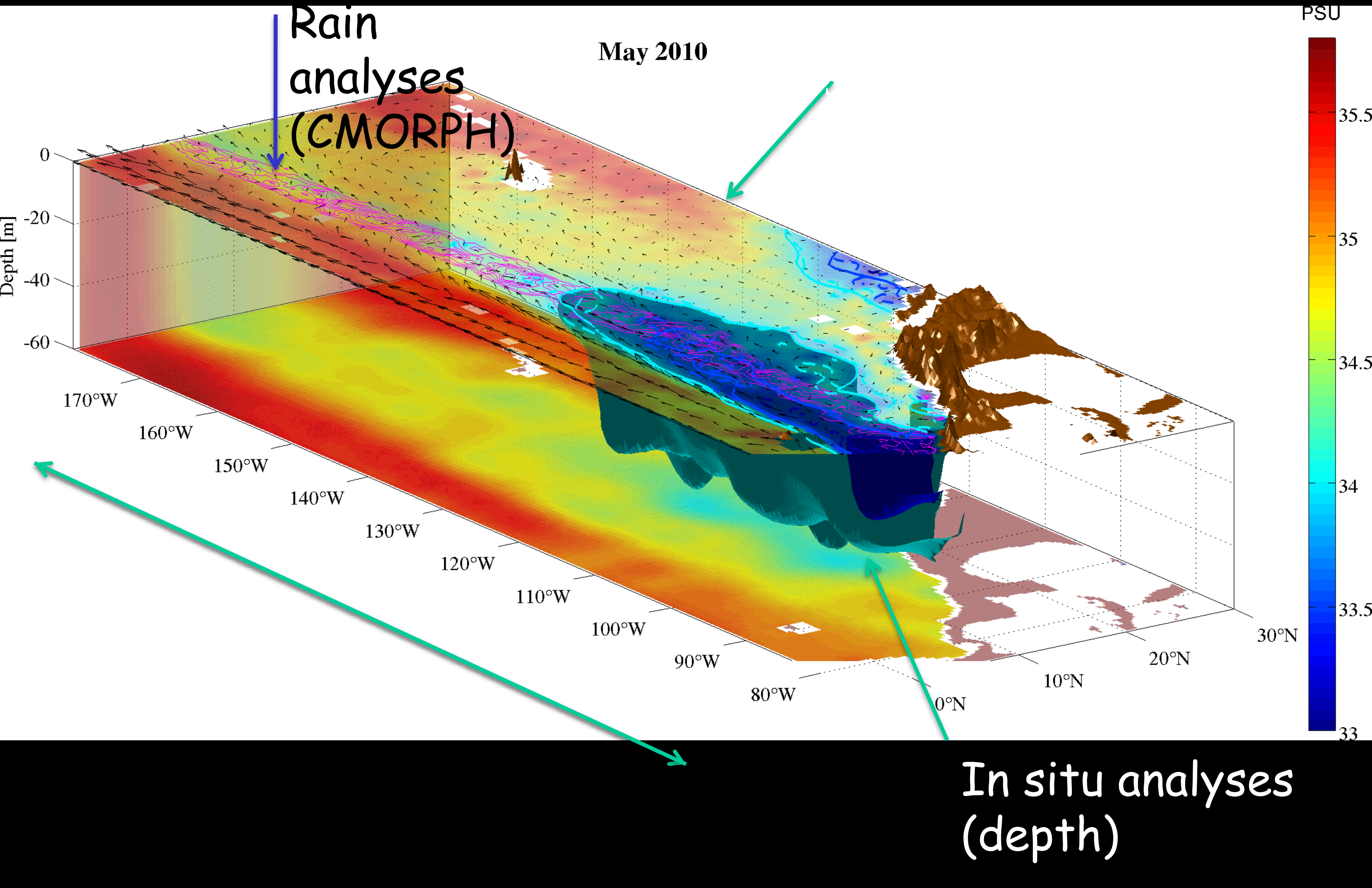


NATURE | VOL 475 | 7 JULY 2011

In their displacements, top predators encounter environmental heterogeneity at multiple scales.

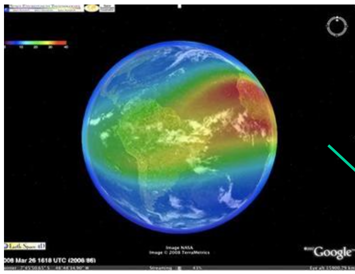
Until now, observations where sparse, and matched large-scale current information was enough

Eastern Pacific Freshpool & 3D monitoring of the pool



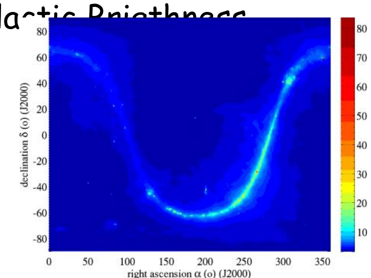
Sea Surface Salinity from Space

Ionosphere

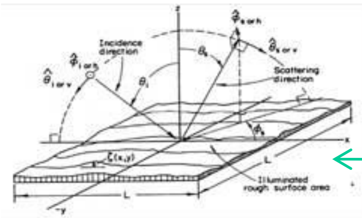


SMOS

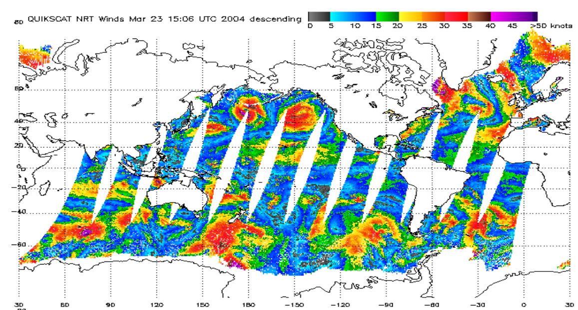
Galactic Brightness



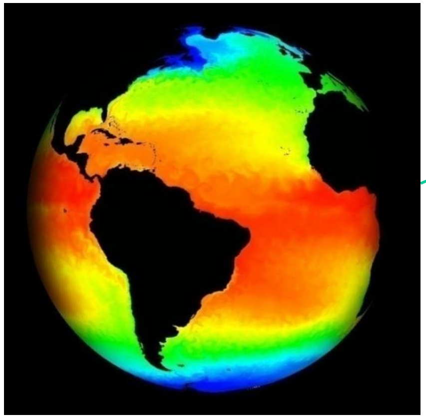
Electromagnetic Models



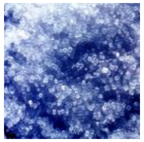
Ocean Surface Winds



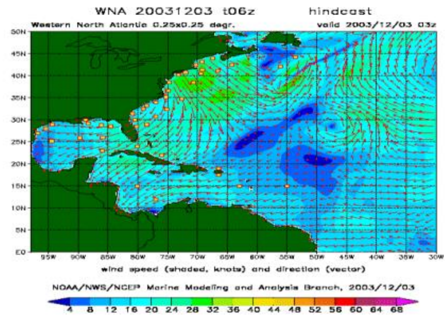
Sea Surface Temperature

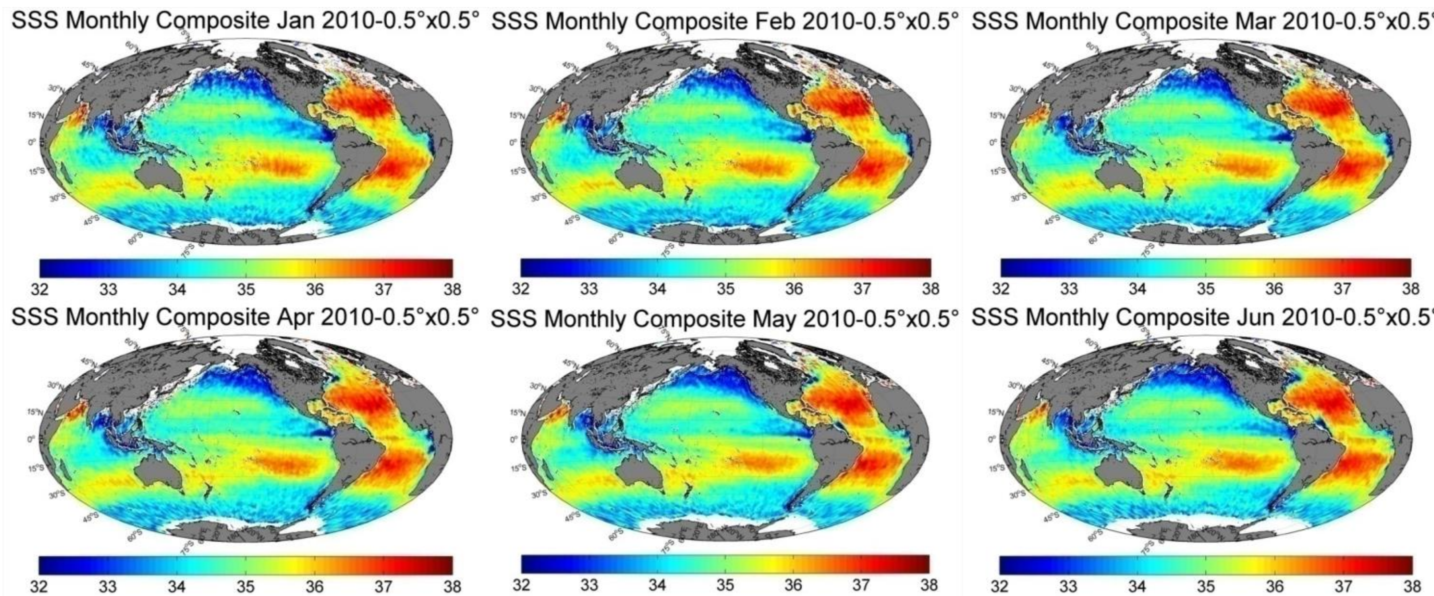


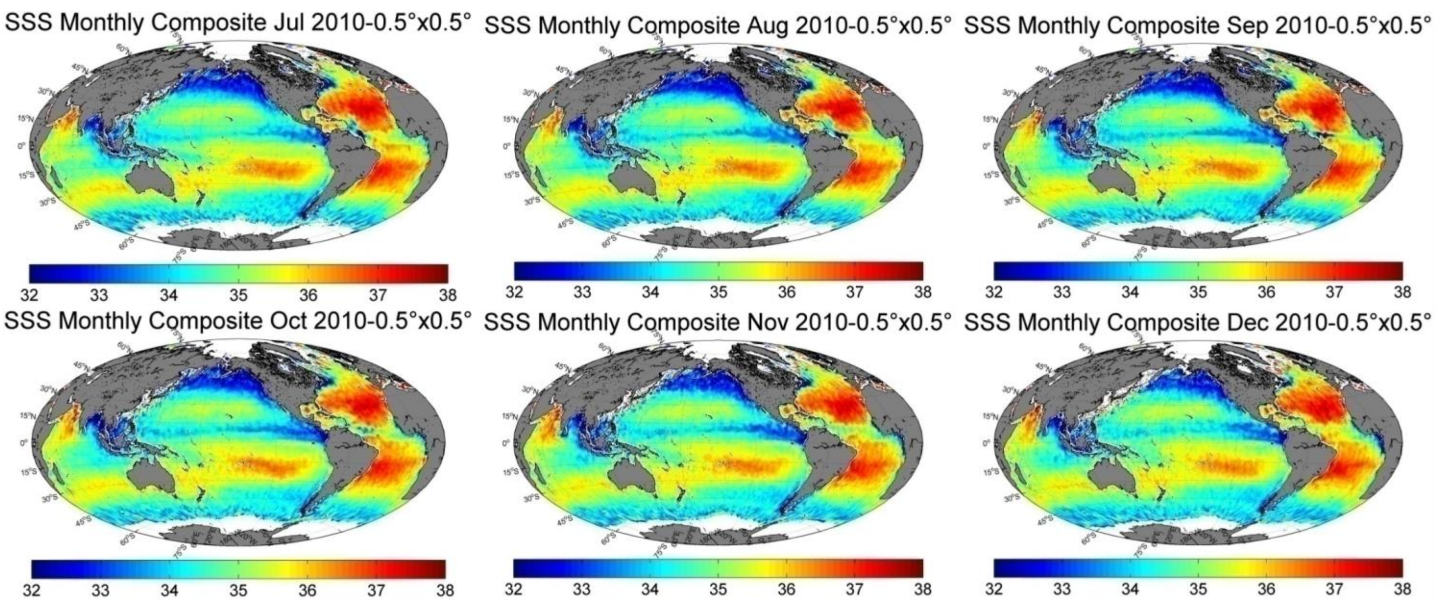
Sea Surface Salinity



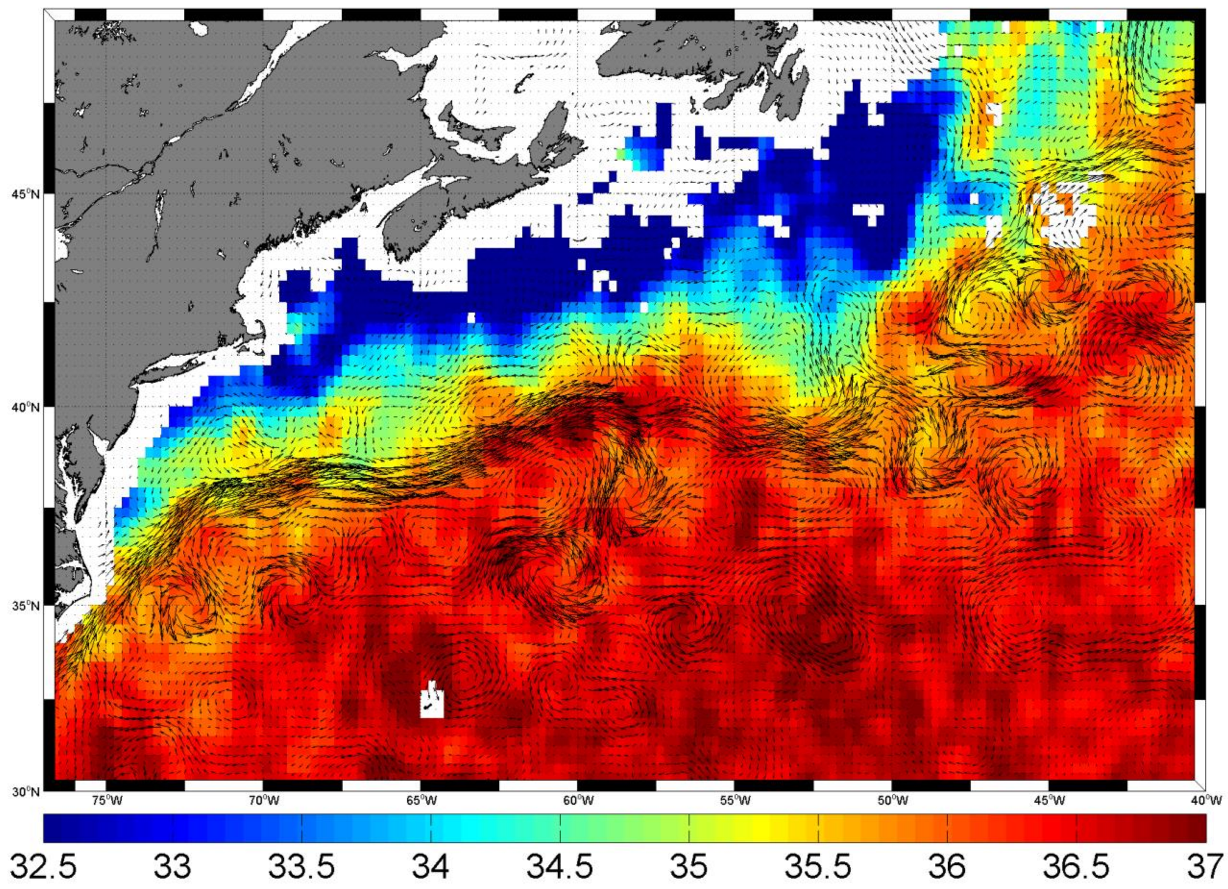
Sea State

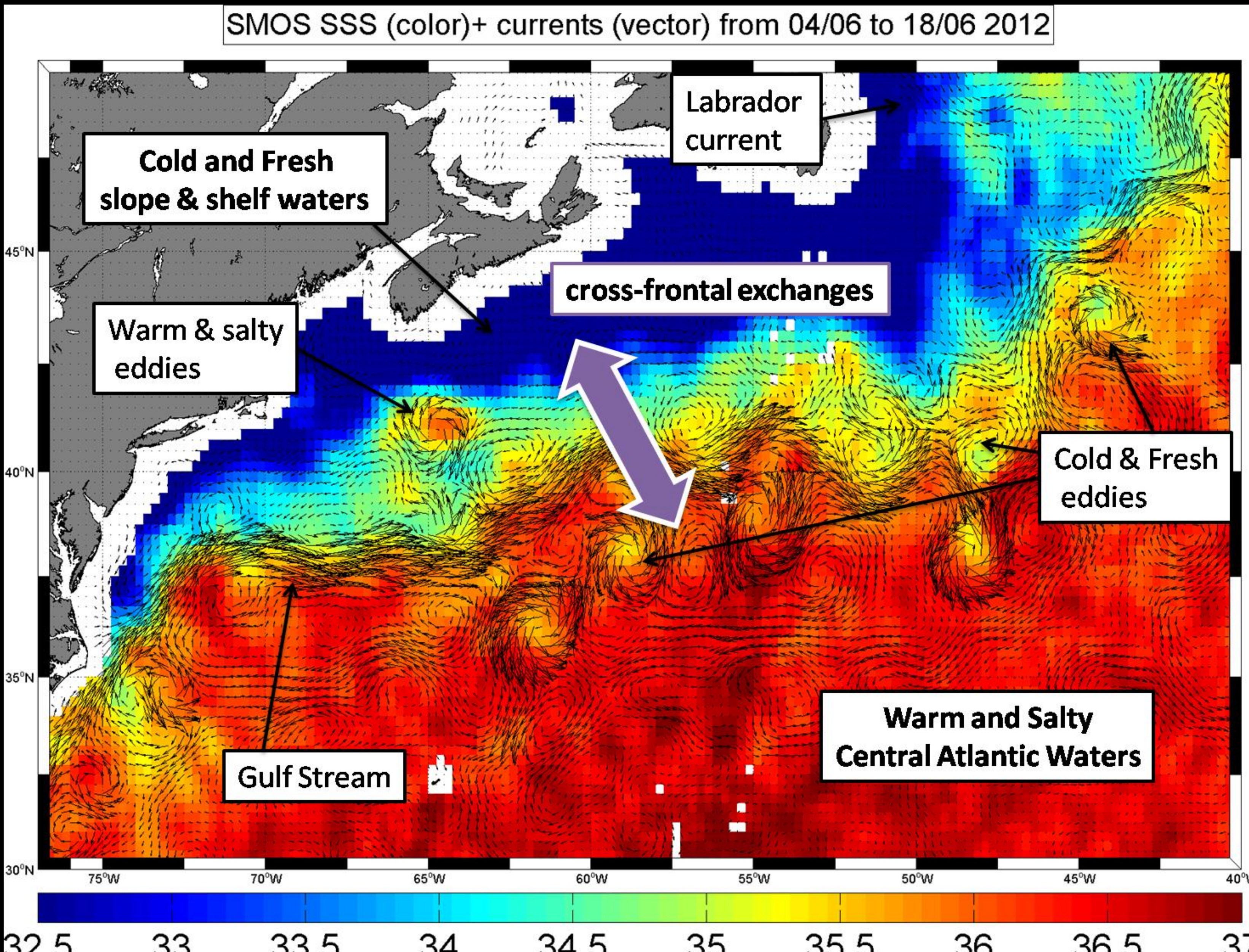



SSS Monthly Composite Jan 2010-0.5°x0.5°
SSS Monthly Composite Feb 2010-0.5°x0.5°
SSS Monthly Composite Mar 2010-0.5°x0.5°
SSS Monthly Composite Apr 2010-0.5°x0.5°
SSS Monthly Composite May 2010-0.5°x0.5°
SSS Monthly Composite Jun 2010-0.5°x0.5°
32 33 34 35 36 37 38

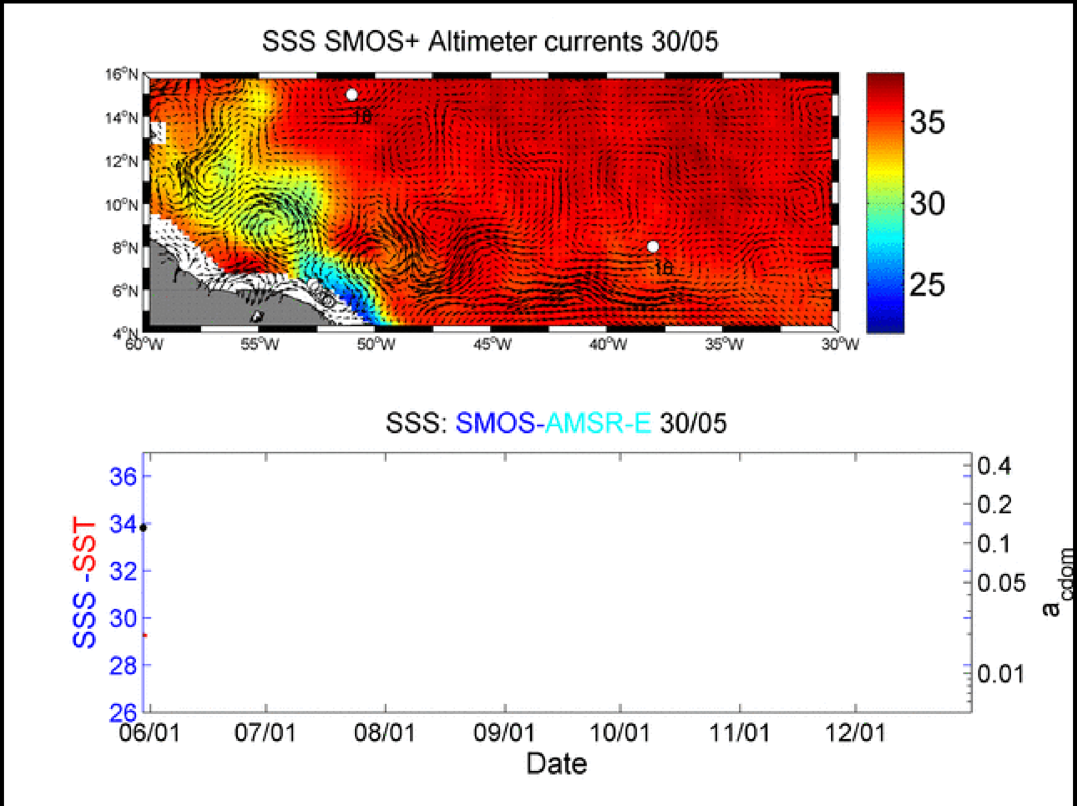

SSS Monthly Composite Jul 2010-0.5°x0.5°
32 33 34 35 36 37 38
SSS Monthly Composite Aug 2010-0.5°x0.5°
32 33 34 35 36 37 38
SSS Monthly Composite Sep 2010-0.5°x0.5°
32 33 34 35 36 37 38
SSS Monthly Composite Oct 2010-0.5°x0.5°
32 33 34 35 36 37 38
SSS Monthly Composite Nov 2010-0.5°x0.5°
32 33 34 35 36 37 38
SSS Monthly Composite Dec 2010-0.5°x0.5°
32 33 34 35 36 37 38

SMOS SSS (color)+ currents (vector) from 03/03 to 17/03 2012

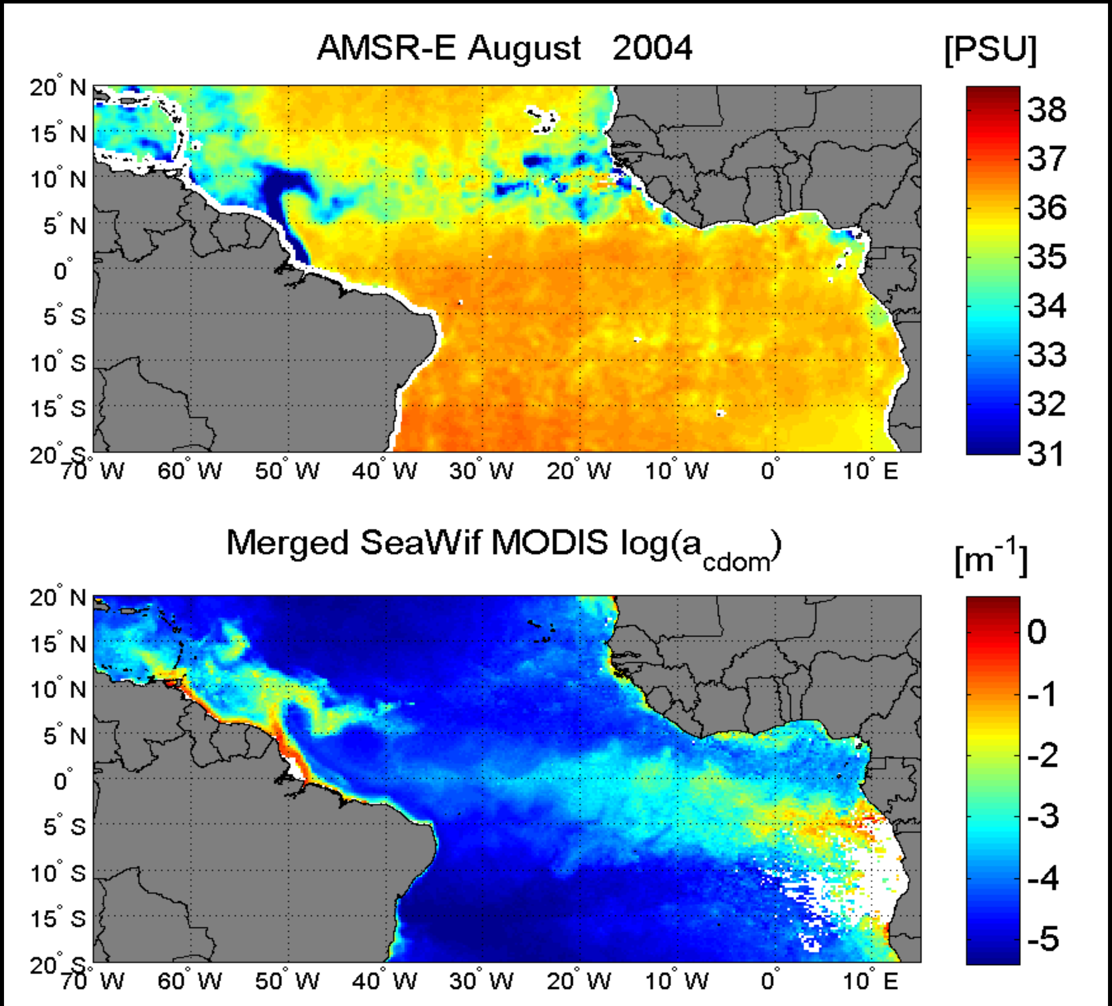



SMOS SSS (color)+ currents (vector) from 04/06 to 18/06 2012
Labrador current
Cold and Fresh slope & shelf waters
cross-frontal exchanges
Warm & salty eddies
Cold & Fresh eddies
Gulf Stream
Warm and Salty Central Atlantic Waters
45°N
40°N
35°N
30°N
75°W
70°W
65°W
60°W
55°W
50°W
45°W
40°W
32.5
33
33.5
34
34.5
35
35.5
36
36.5
37

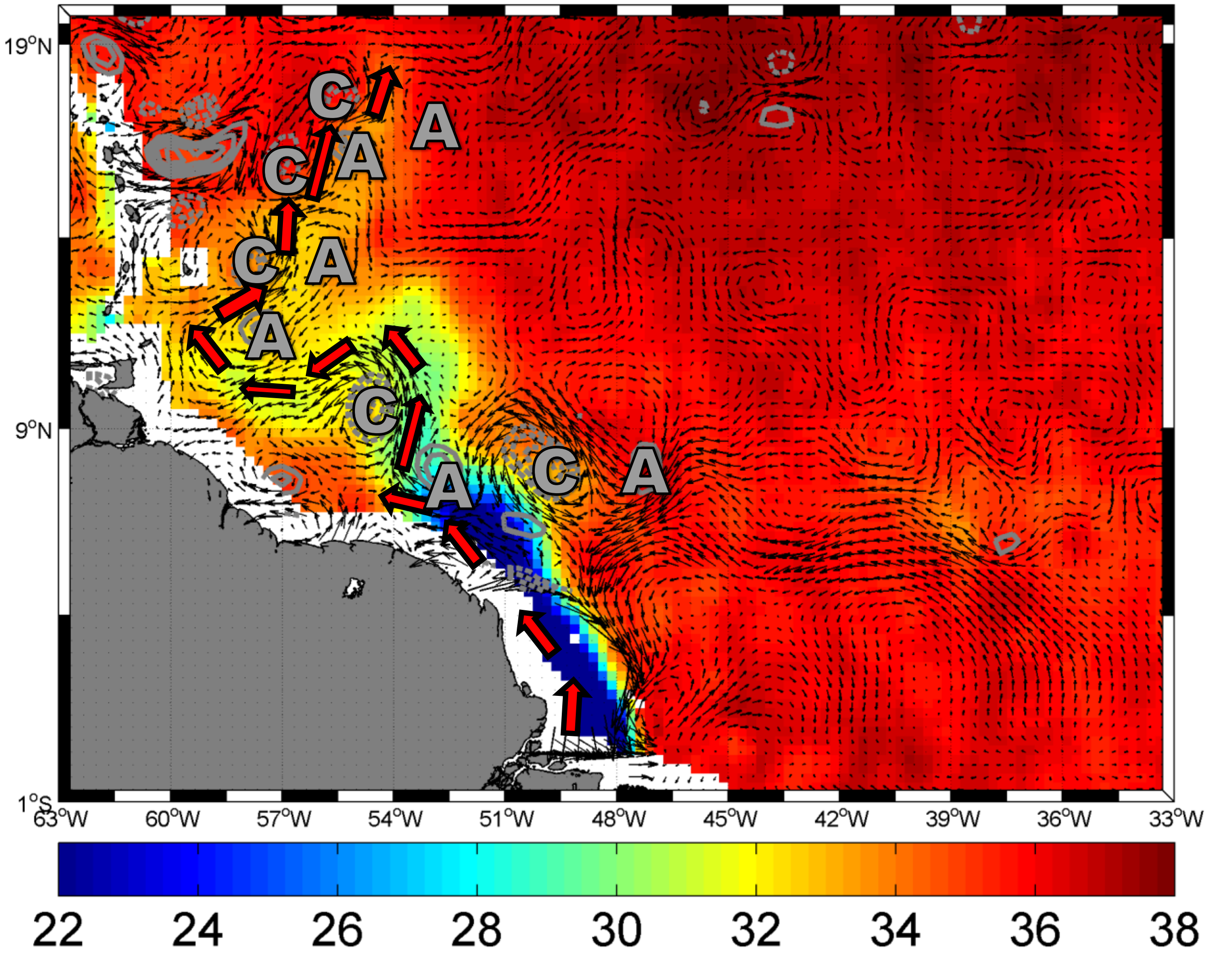
Synergy SSS (SMOS+AMSR-E)+Altimeter-derived surface currents +SST (GHRSST)+ Ocean Colour (CDOM MERIS/MODIS)



Lagrangian Optical-Physical properties


AMSR-E August 2004
[PSU]
38
37
36
35
34
33
32
31
Merged SeaWif MODIS log(a_{cdom})
[m^{-1}]
0
-1
-2
-3
-4
-5
20° N
15° N
10° N
5° N
0°
5° S
10° S
15° S
20° S
70° W
60° W
50° W
40° W
30° W
20° W
10° W
0°
10° E

SSS Averaged from Jun 04 through Jun 14



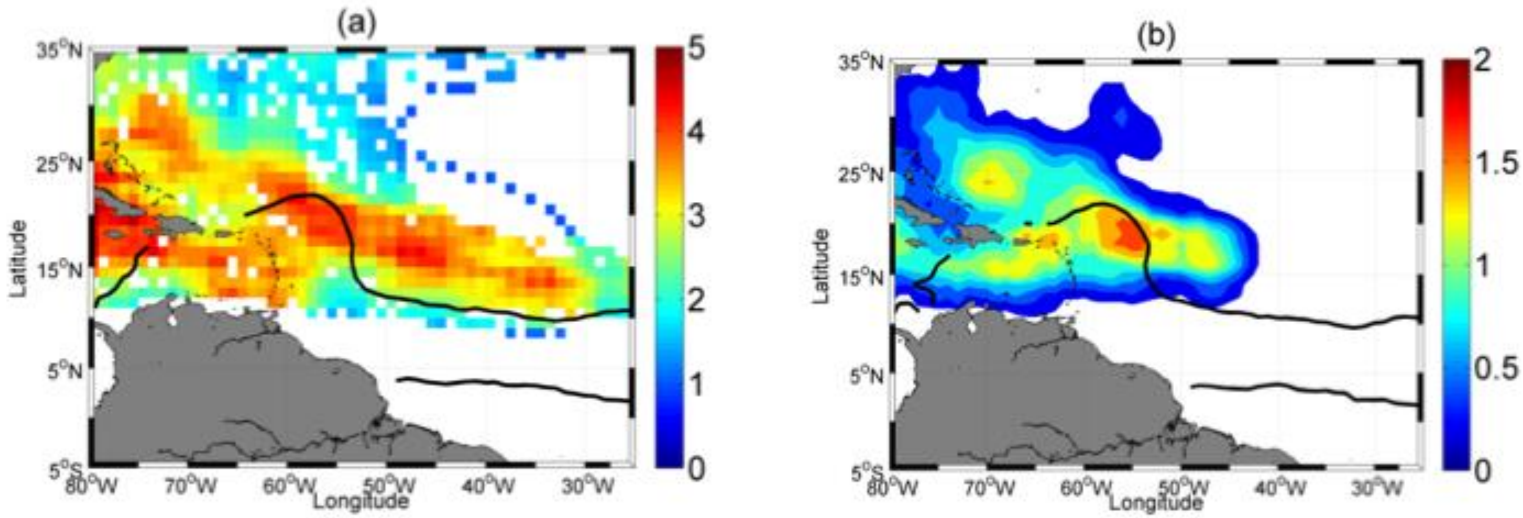
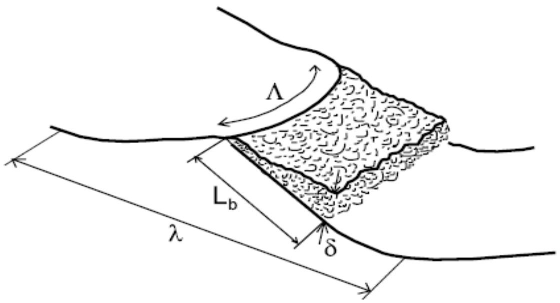


FIG.2 The number of 1950 through 2010 “best track” TC per one degree square (smoothed by a 3° x 3° block average) (a) that evolves as Cat 4-5 somewhere along their path and (b) that intensified locally to Cat 4-5. The black curve is showing the historical extent of the Amazon-Orinoco river plume during the hurricane peak season (August to October).

Passive Microwave measurements

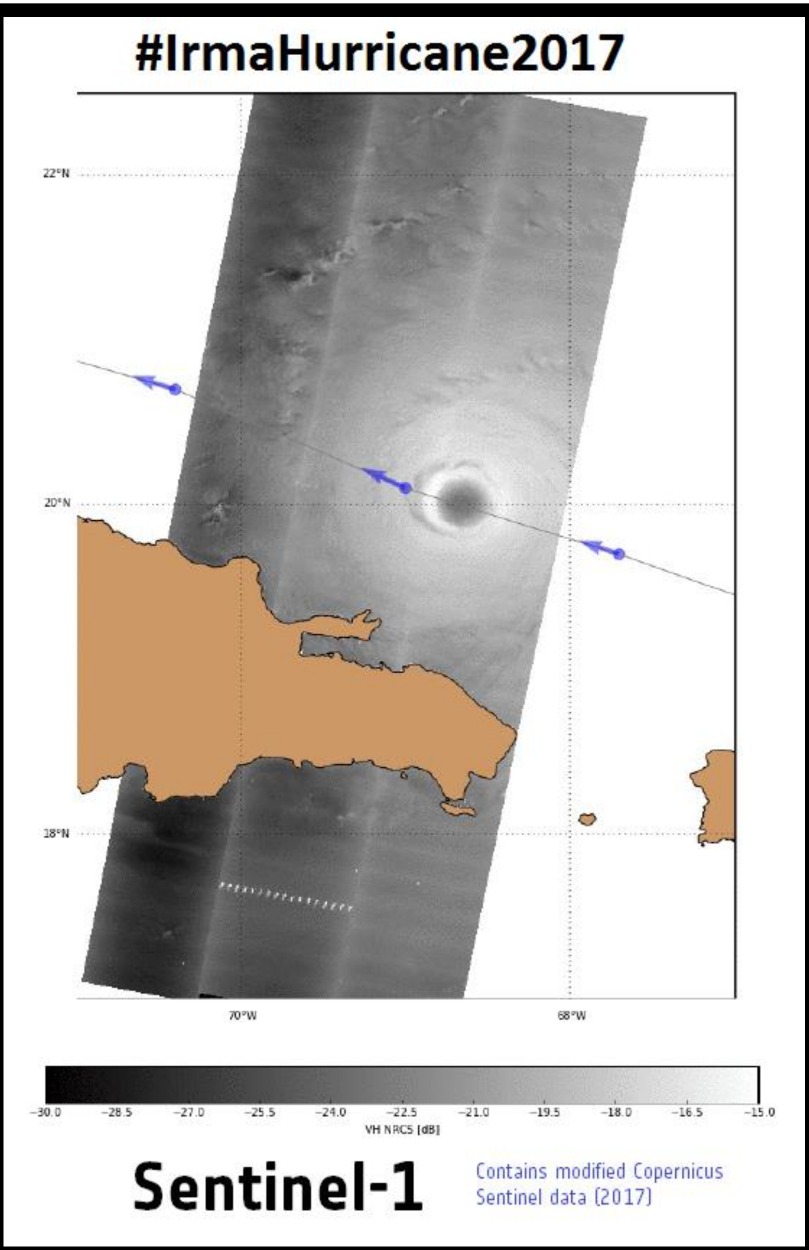


Semi-empirical model

-Self-similar breaker-scale distribution

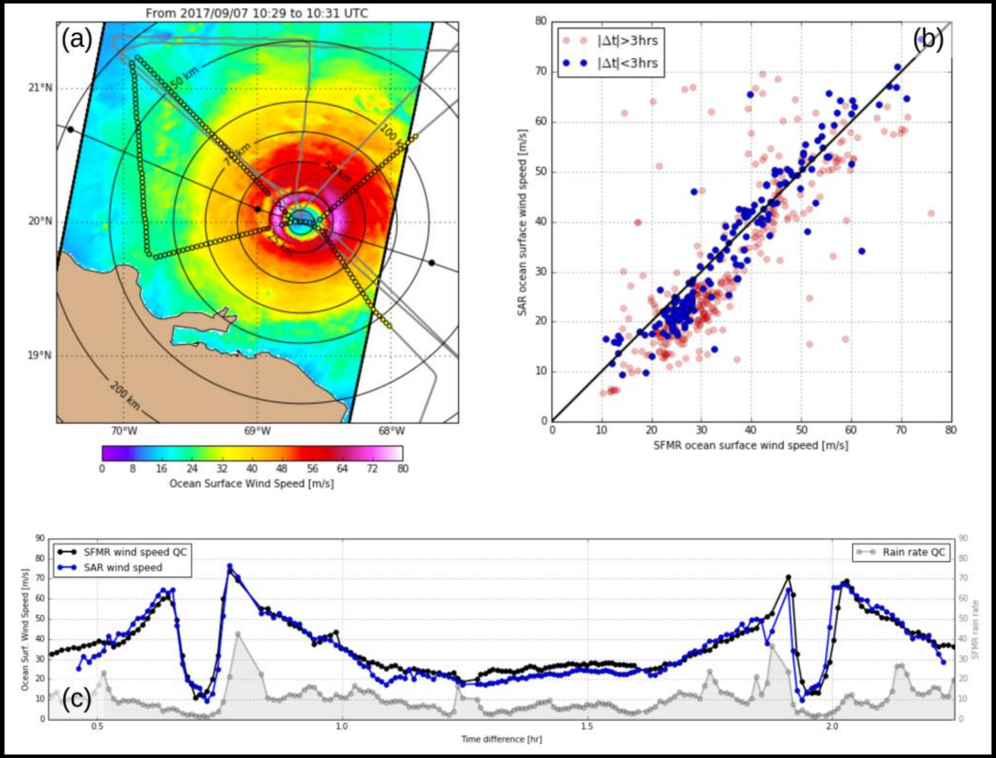
-Foam coverage and thickness

→ wavelength sensitivity


#IrmaHurricane2017
22°N
20°N
18°N
70°W
68°W
-30.0
-28.5
-27.0
-25.5
-24.0
-22.5
-21.0
-19.5
-18.0
-16.5
-15.0
VH NRCS [dB]
Sentinel-1
Contains modified Copernicus Sentinel data (2017)

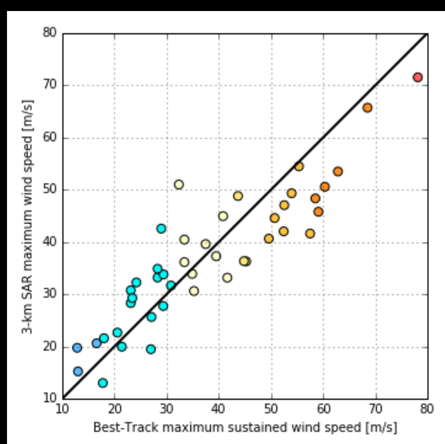
Ocean Surface Wind : C-Band Synthetic Aperture Radar

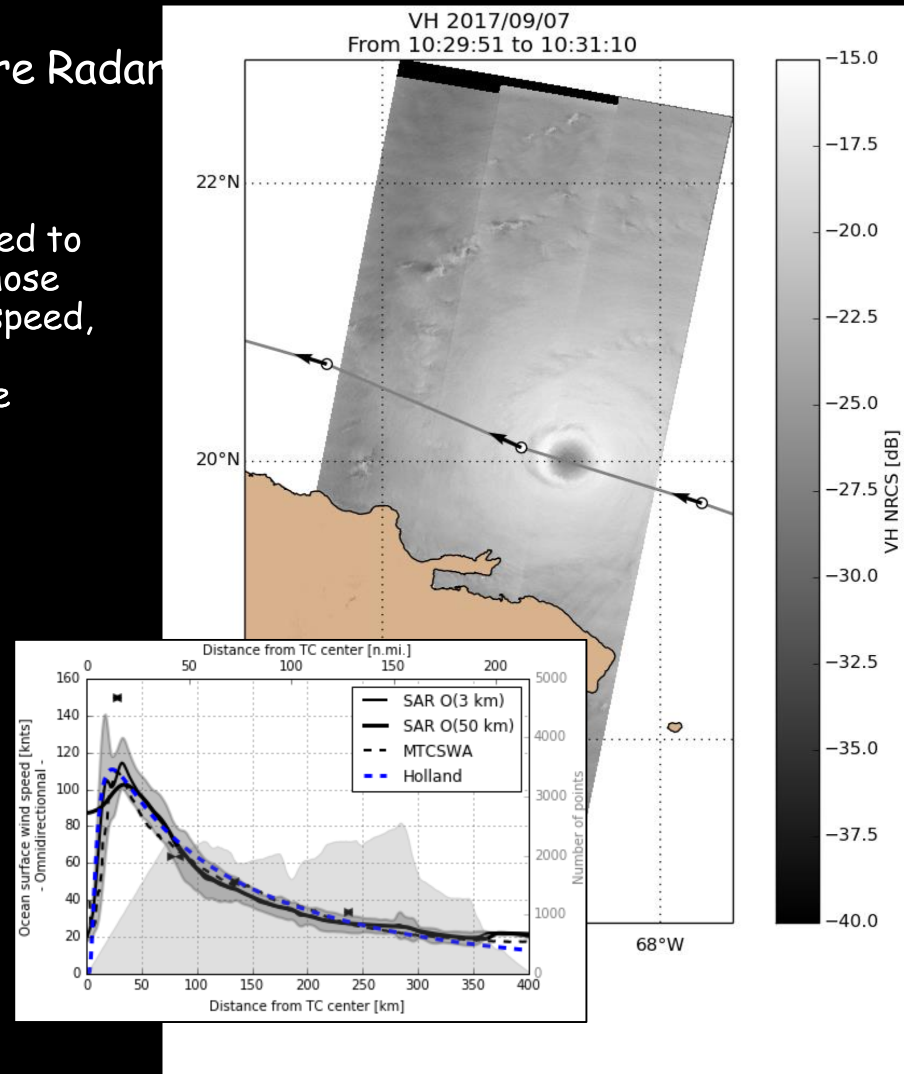
Signal	Intensity of backscatter signal (NRCS)
Resolution	1 km
Assets	Dual polarization: -Co-pol = less noise, sensitive to wind direction -Cross-pol = no saturation at high winds High resolution
Limitations	Not a large coverage, reduced opportunity to get acquisitions over TCs Impacts of rain and waves exist



Ocean Surface Wind : C-Band Synthetic Aperture Radar

Thanks to its high resolution C-Band SAR can be used to estimate Tropical Cyclones parameters, including those related to the inner core: radius of maximum wind speed, maximum wind speed, the inner core enthropy
This is complementary to radiometer large coverage



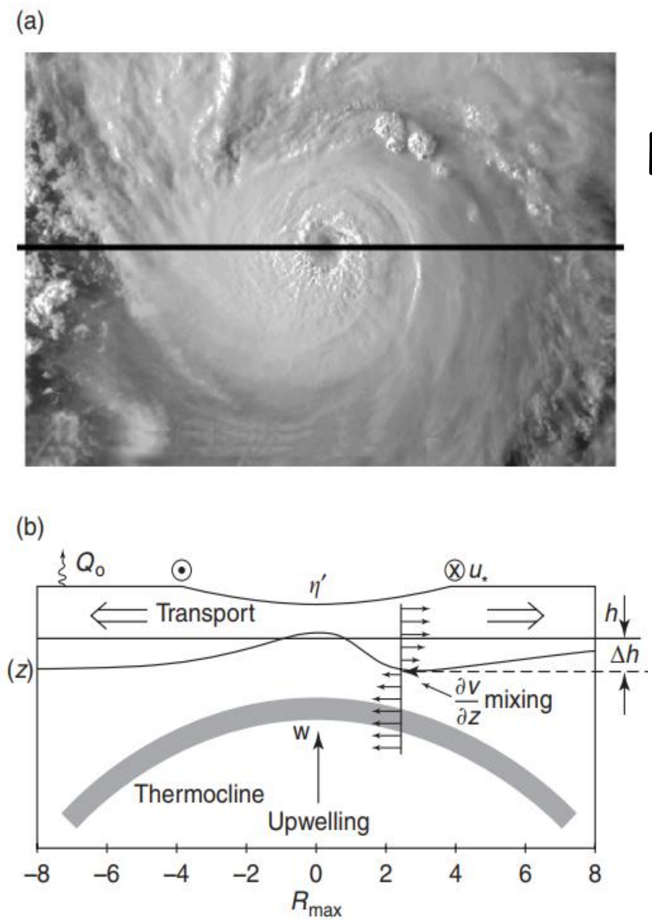


Upper ocean responses to extreme wind forcing by tropical cyclones remains a central problem in physical oceanography

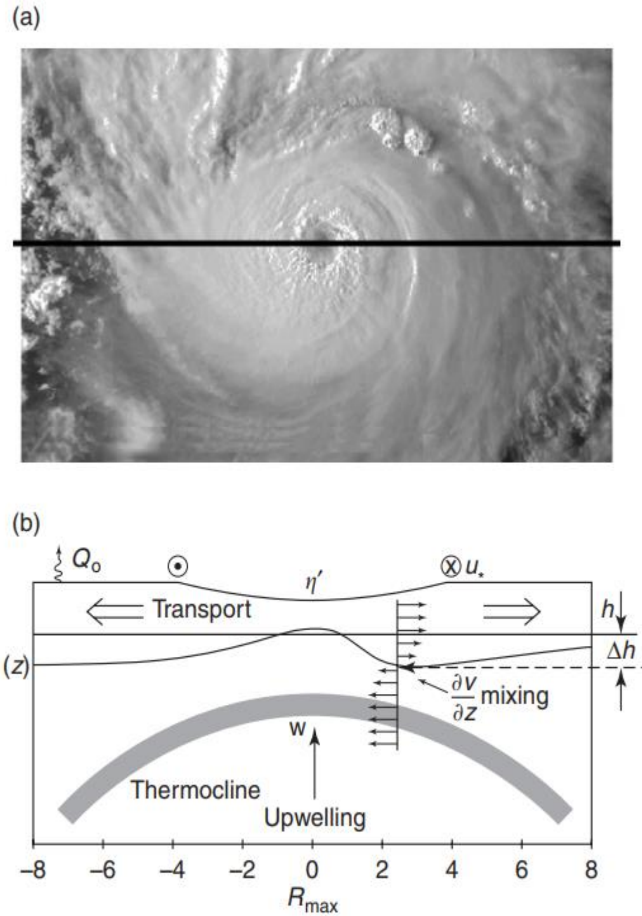
Parameterization of wind forcing at high-wind speeds is still a matter of debate and active research

To accurately model air-sea coupled processes, it is of central importance to quantify how efficiently surface winds and waves, within storm cores, increase the momentum of surface currents

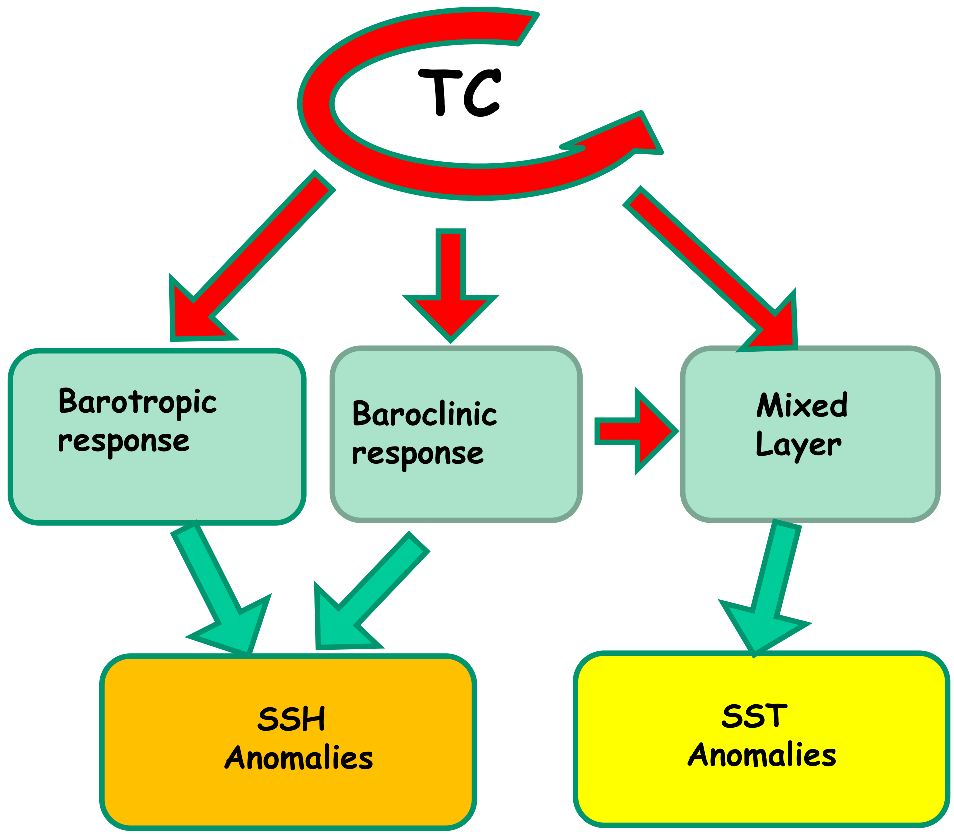
Energy transfer to upper currents mostly occurs in front of the extremes and is nearly balance with the increase in kinetic energy of the upper ocean currents



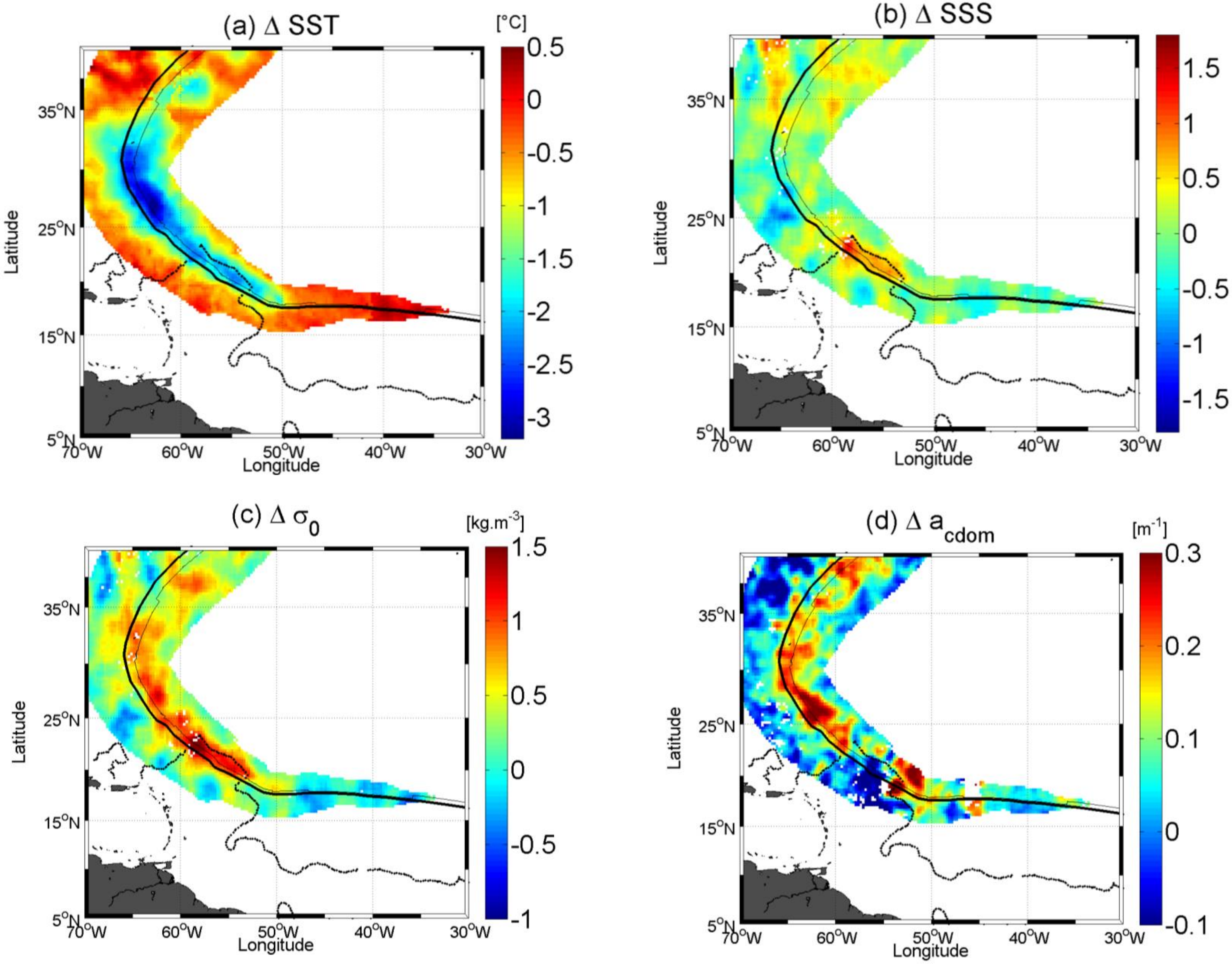
Far from the coasts, Extreme Events are opportunities of high scientific values to investigate how natural processes at their peaks can transfer energy and matter within and across boundaries, and to identify the mechanisms involved and their rates, jointly with their local and/or long term impacts



Simplified TC Wake Model

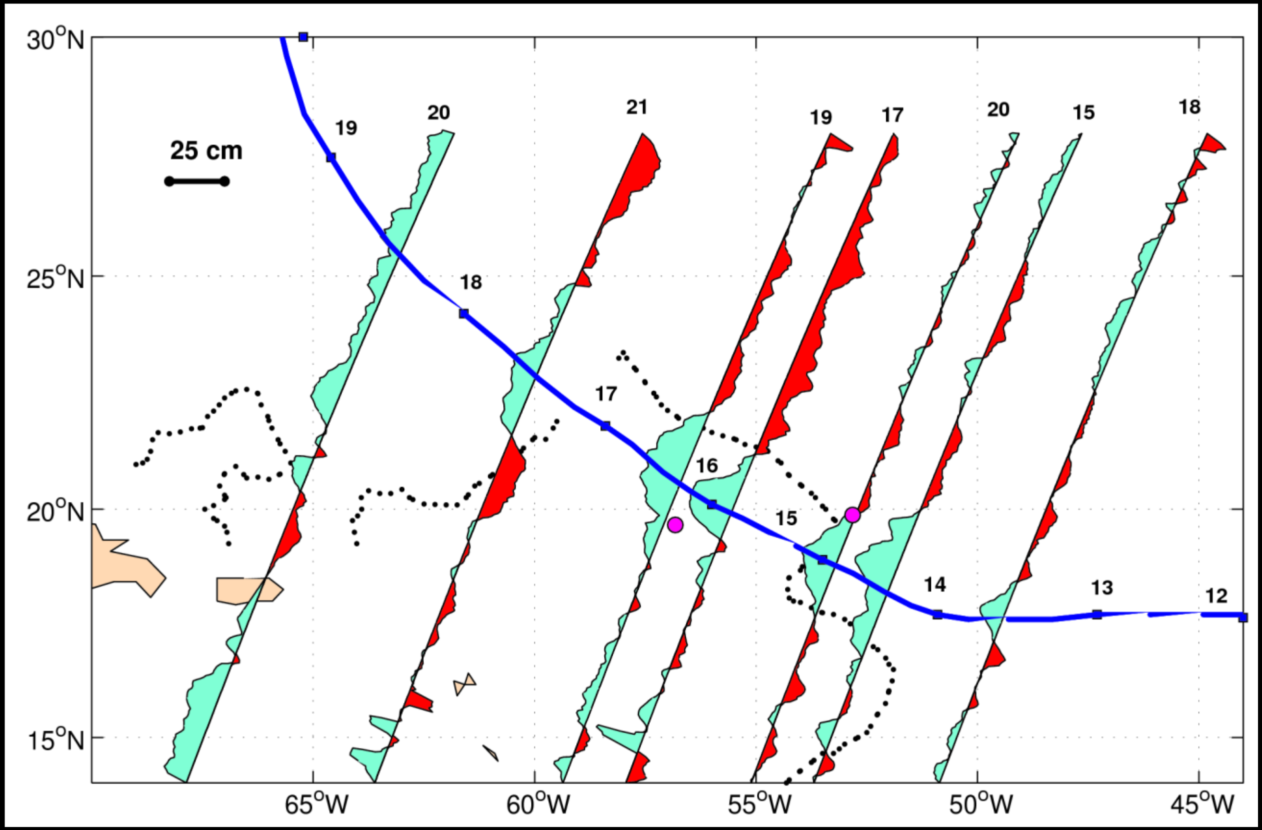


Surface signature wakes of Igor

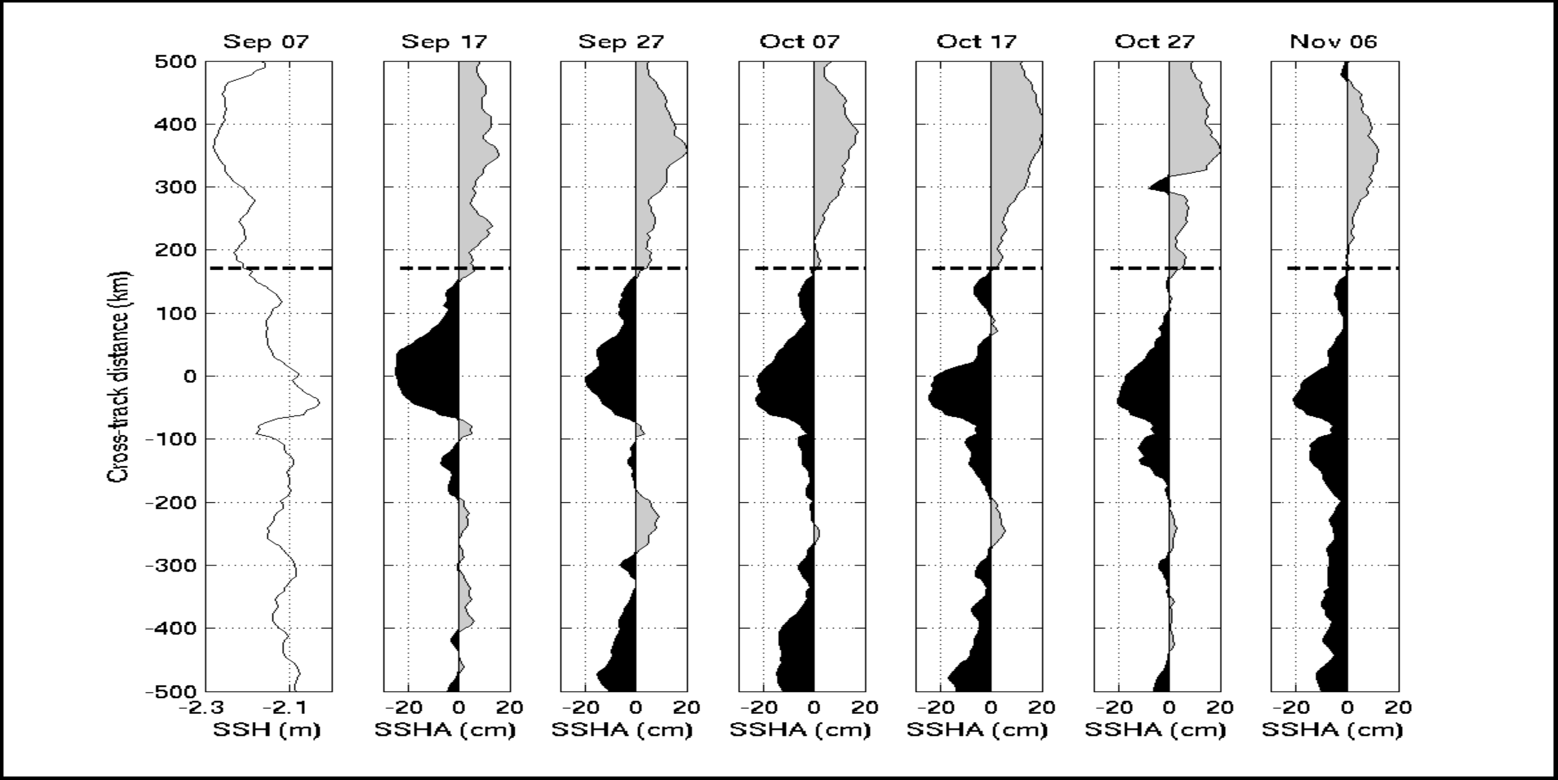


Six days of data centered on t_o-(+) 4 days have been averaged to construct the pre (post)-cyclonic quantities.

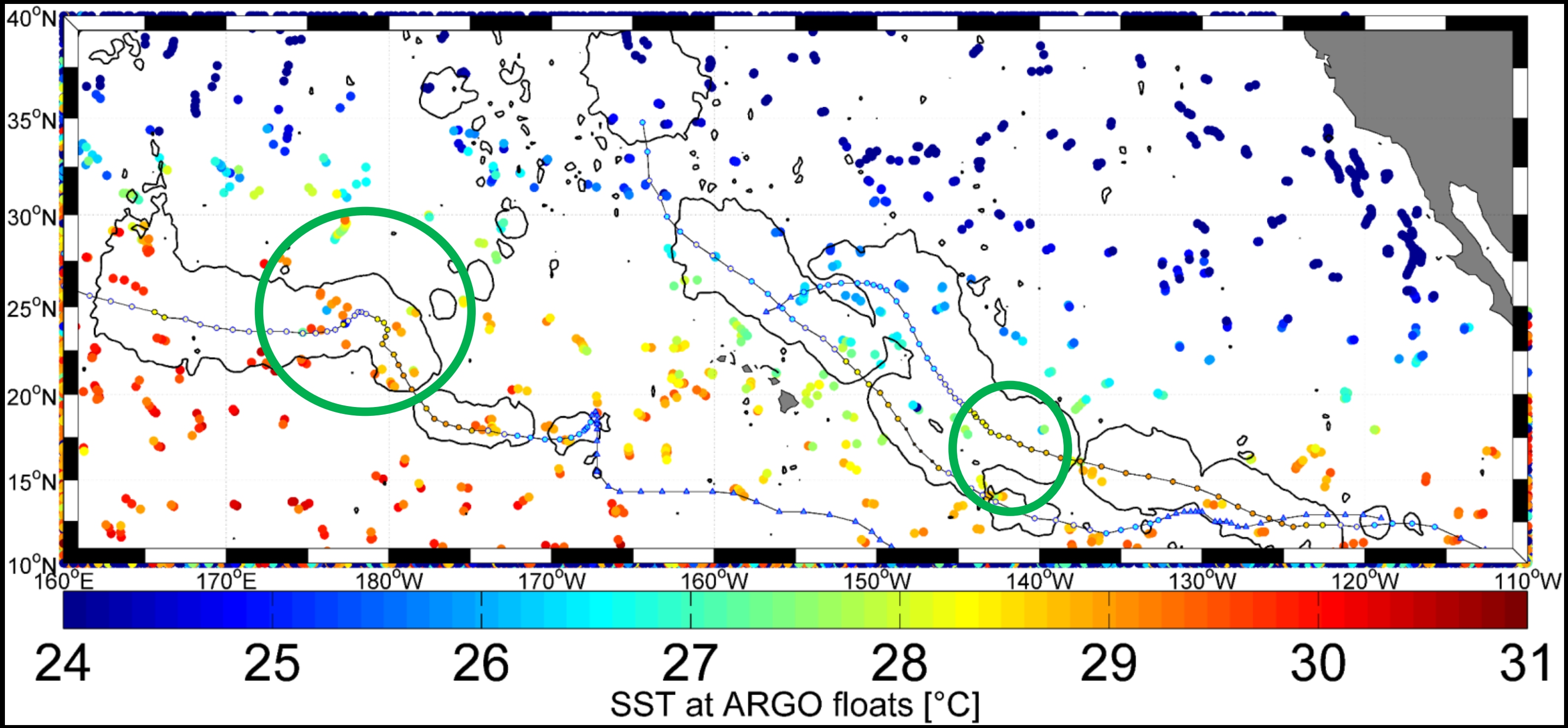
Surface altimeter SSH wakes of Igor



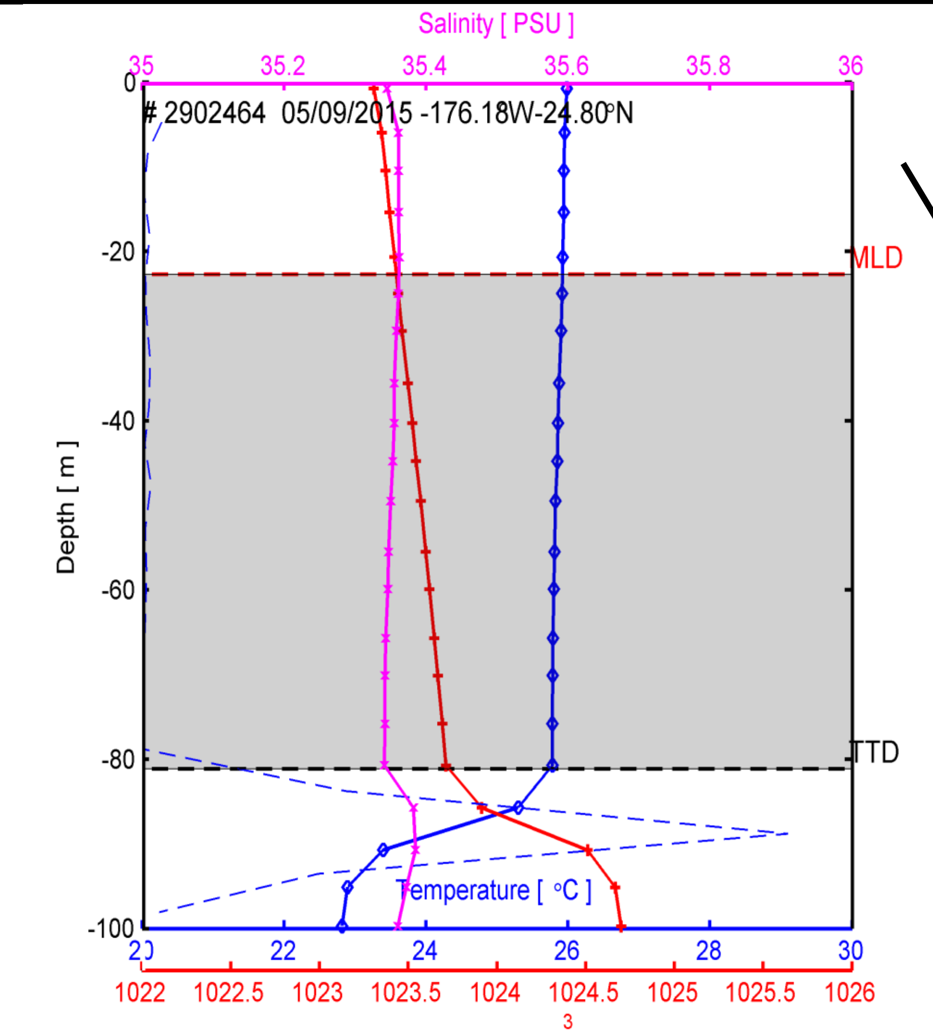
Surface SSH wake and persistency of Igor

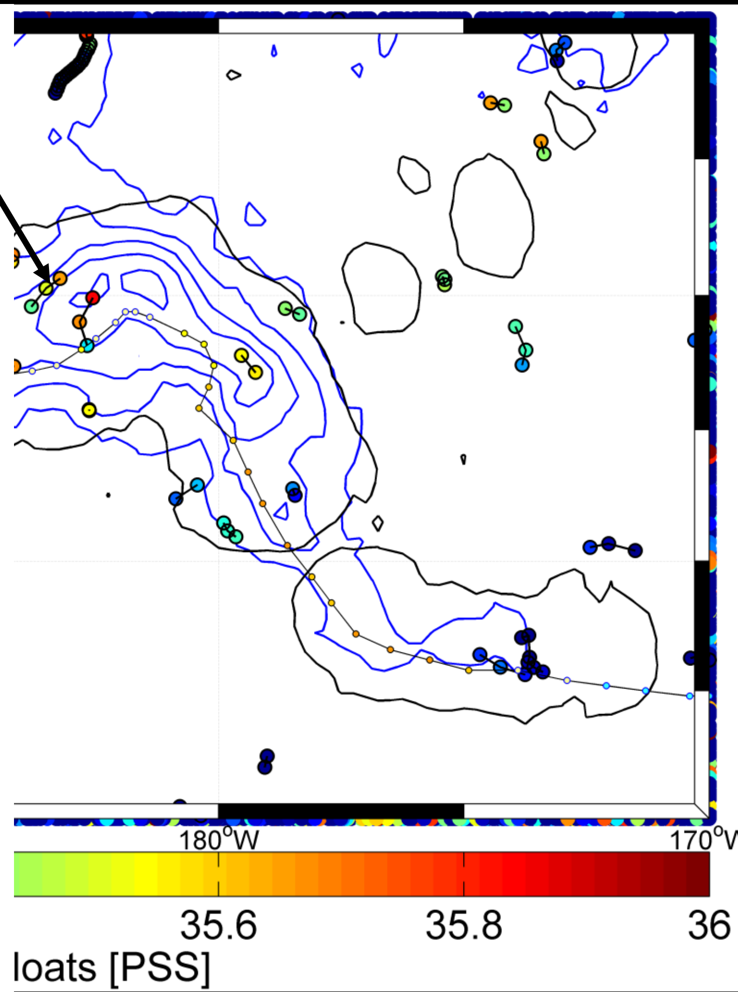


ARGO Floats

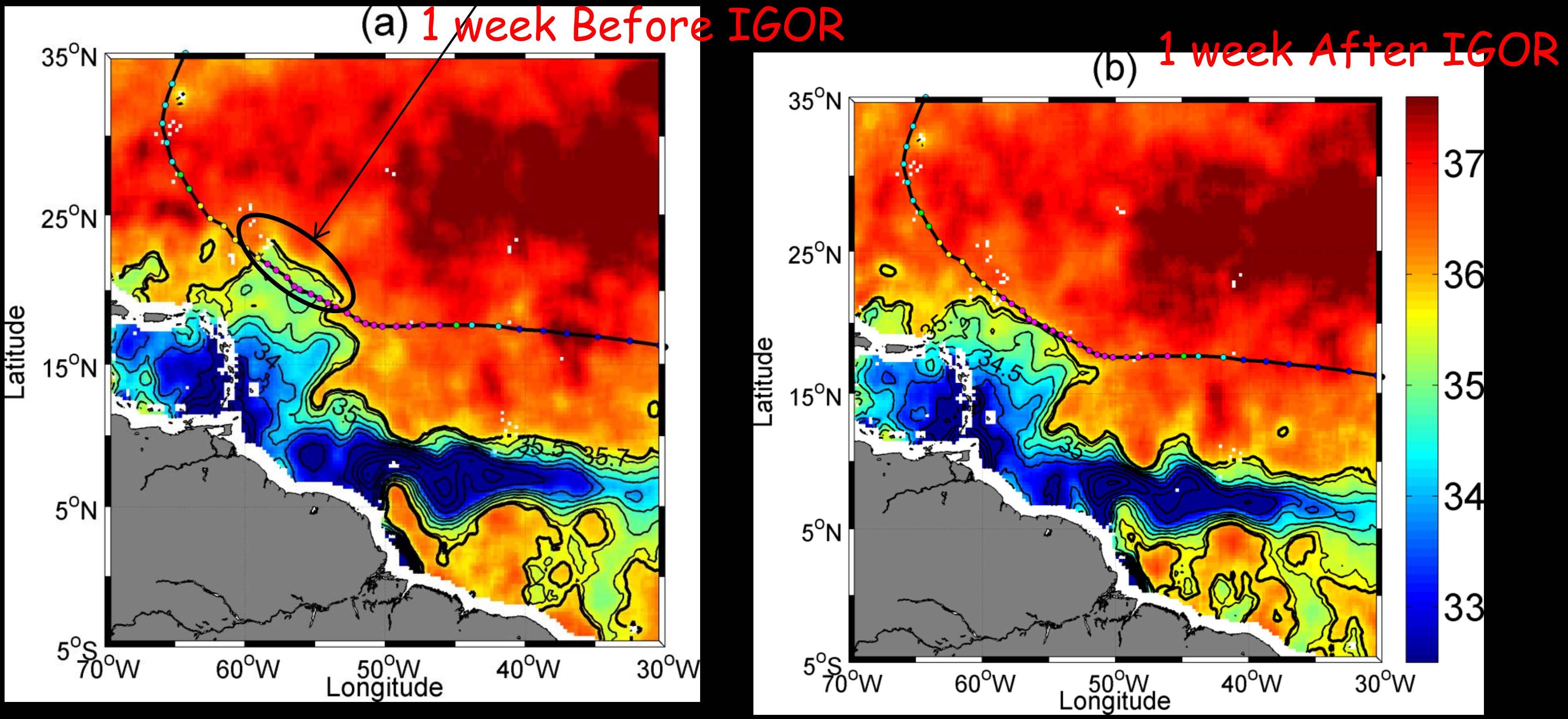


40°N
35°N
30°N
25°N
20°N
15°N
10°N
160°E
170°E
180°W
170°W
160°W
150°W
140°W
130°W
120°W
110°W
24
25
26
27
28
29
30
31
SST at ARGO floats [°C]


Salinity [PSU]
35
35.2
35.4
35.6
35.8
36
2902464 05/09/2015 -176.18W-24.80N
0
-20
-40
-60
-80
-100
MLD
TTD
Depth [m]
Temperature [°C]
20
22
24
26
28
30
1022
1022.5
1023
1023.5
1024
1024.5
1025
1025.5
1026
3


180°W
170°W
35.6
35.8
36
loats [PSS]

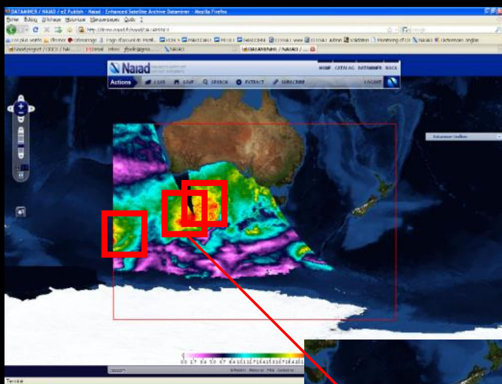
Surface area~ 89000 km^2> Lake Superior, the world largest freshwater lake: a transfer of 1 GTo of Salt in 5 days

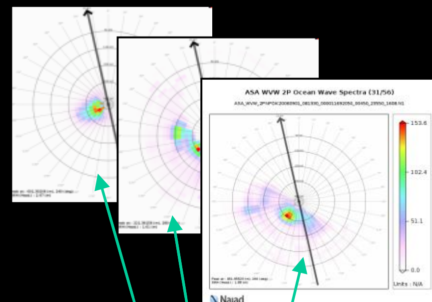


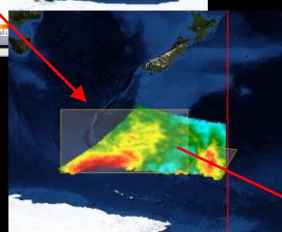
SMOS microwave satellite-derived SSS composite images of the Amazon plume region revealing the SSS conditions (a) before and (b) after the passing of Hurricane Igor, a category 5 hurricane that attained wind speeds of 136 knots in September 2010. Color-coded circles mark the successive hurricane eye positions and maximum 1-min sustained wind speed values in knots.
Seven days of data centered on (a) 10 Sep 2010 and (b) 22 Sep 2010 have been averaged to construct the SSS images, which are smoothed by a 1° x 1° block average.

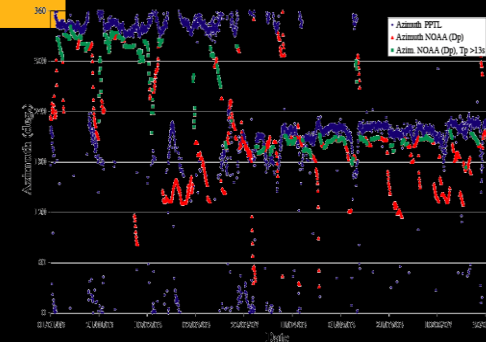
Big questions....

Are storms more numerous and intensifying with climate change ?



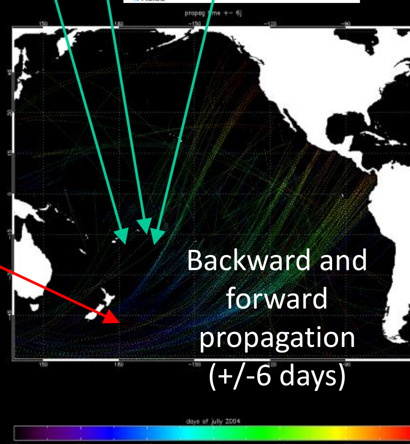






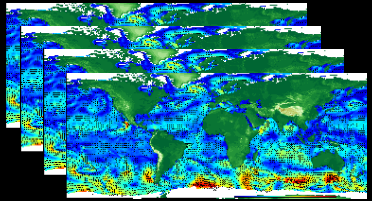
Seismic noise (50 years)

Scatterometer and SAR (20 years)

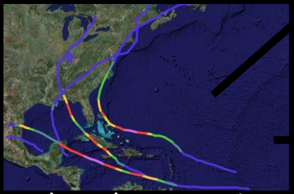


Backward and forward propagation (+/-6 days)

Buoys (30 years)

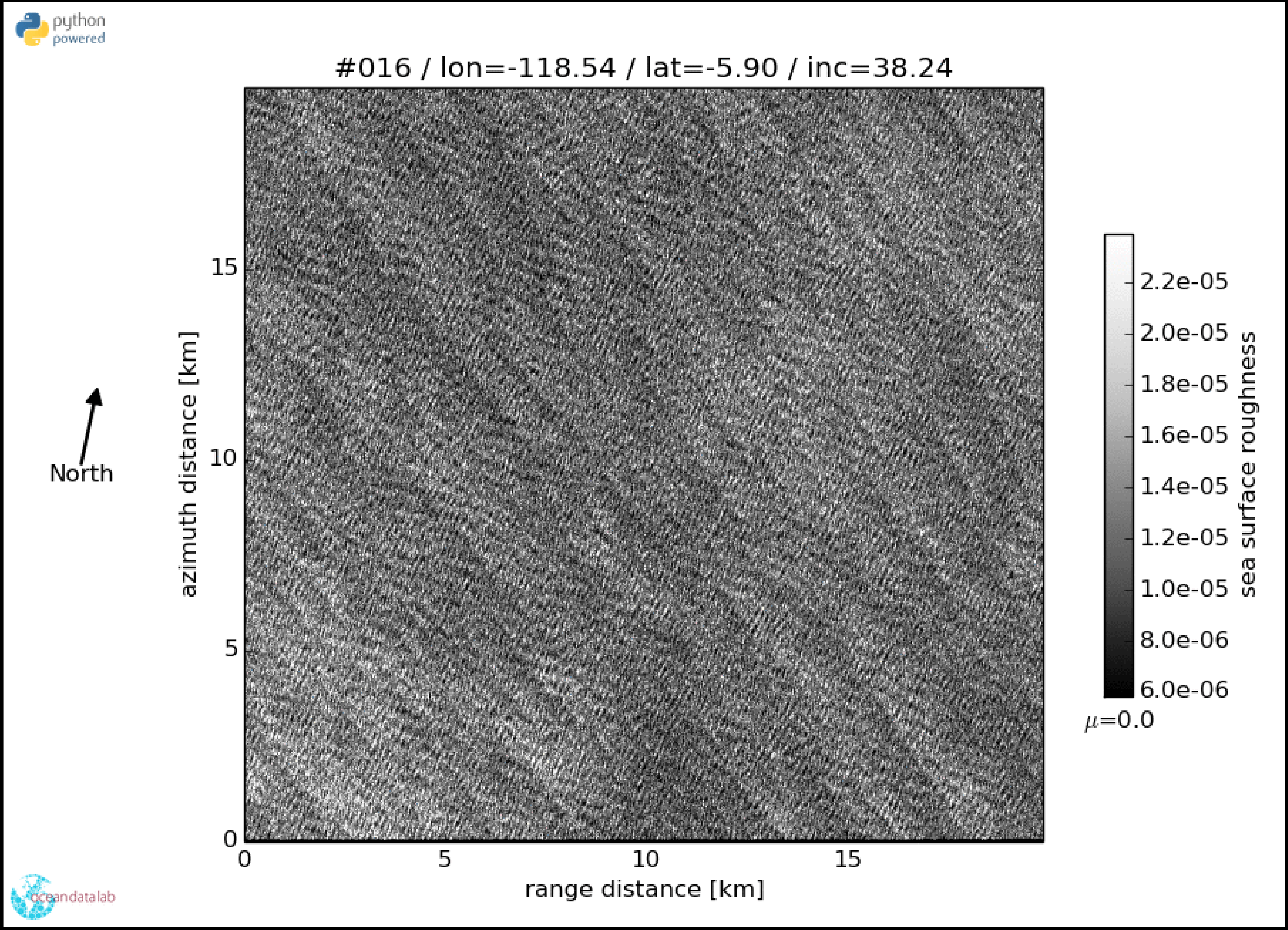


Weather model (25 years)

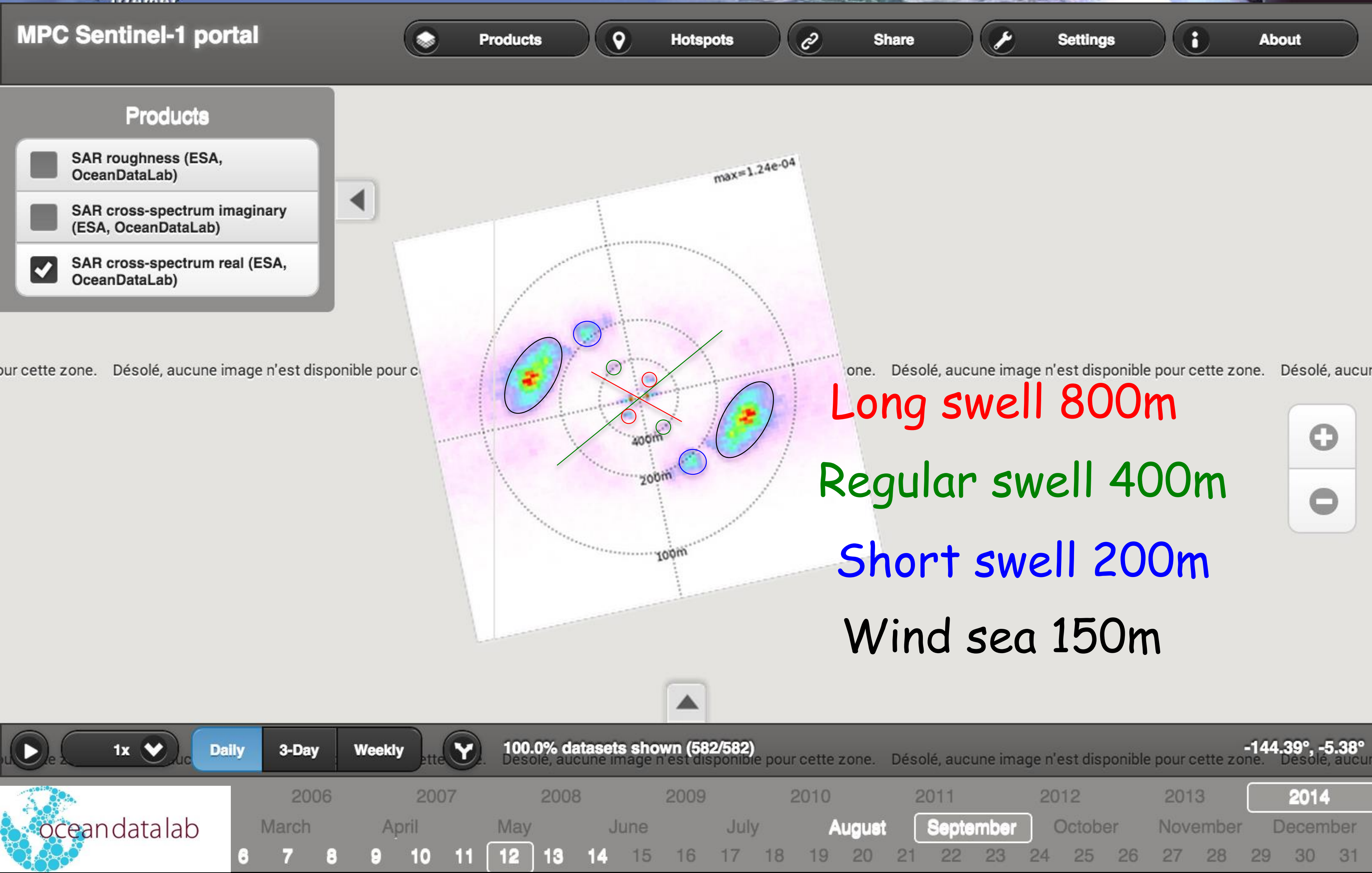


Feature and tracks extraction

S1 Imagette #016 from first track over Pacific



Forerunners Mid Pacific ocean : WV, VV pol, Sept 12



Long swell 800m

Regular swell 400m

Short swell 200m

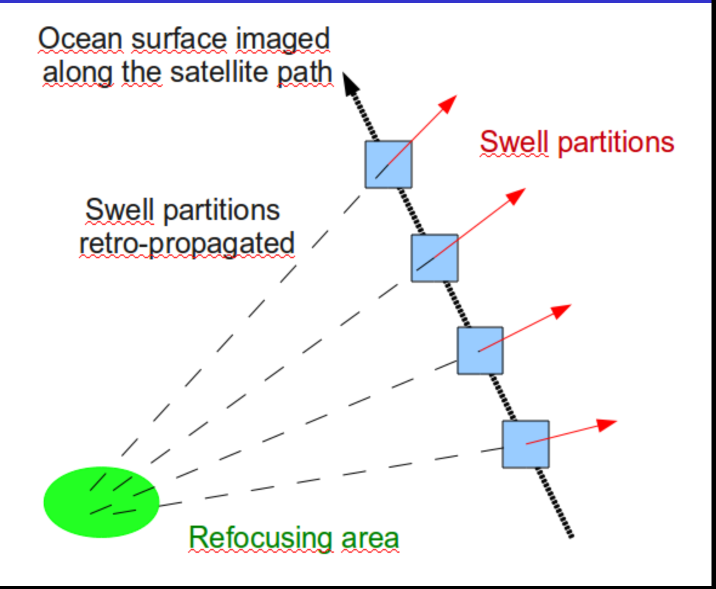
Wind sea 150m

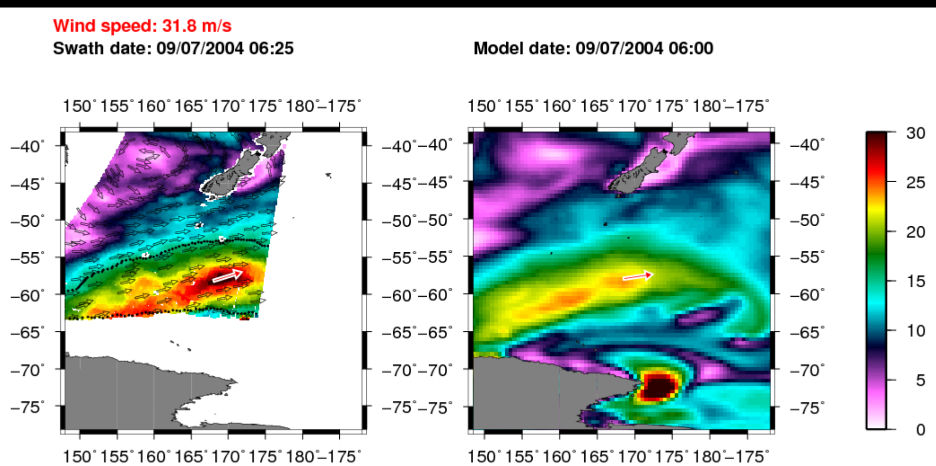
Identifying swell field source

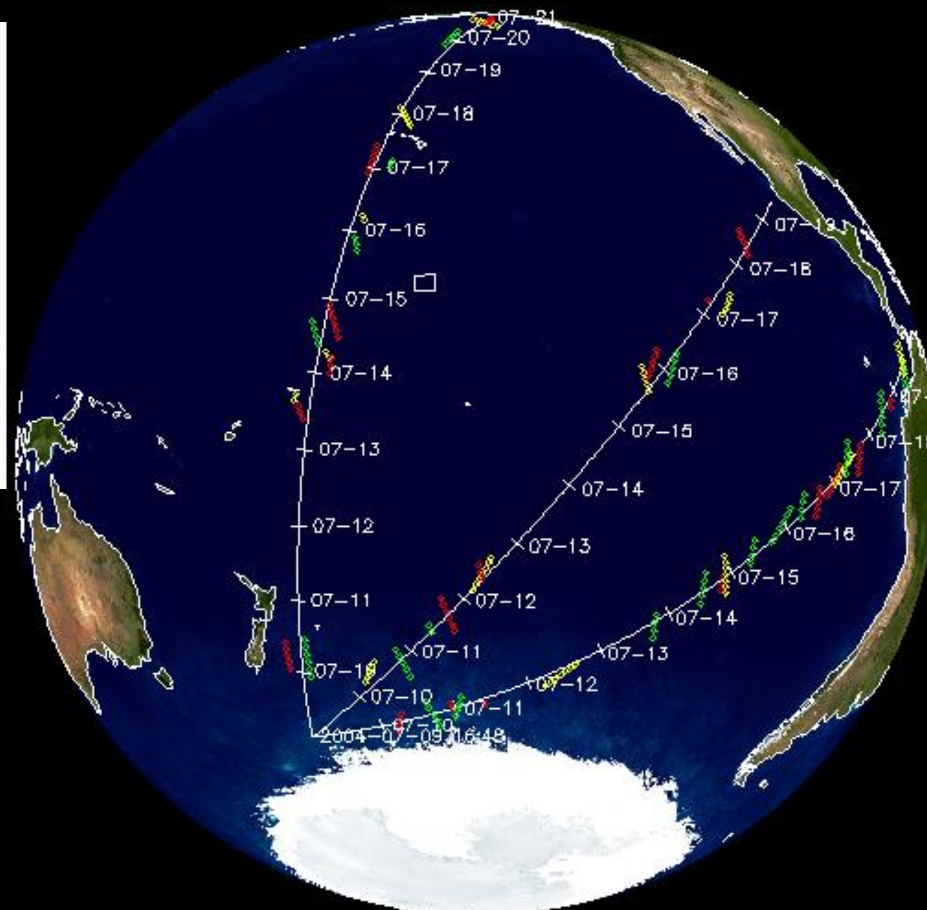
- Linear theory of swell propagation:
  - in open ocean, far from islands
  - swell propagates at group speed, $Cg=gT_p/4\pi$
  - along great circles of direction θ_p

→ compensate for sparse and track-based sampling of the swell partitions.

- Refocusing of the swell partitions
  - → converge in space and time to regions systematically (96% collocations) **coinciding with Storms events**

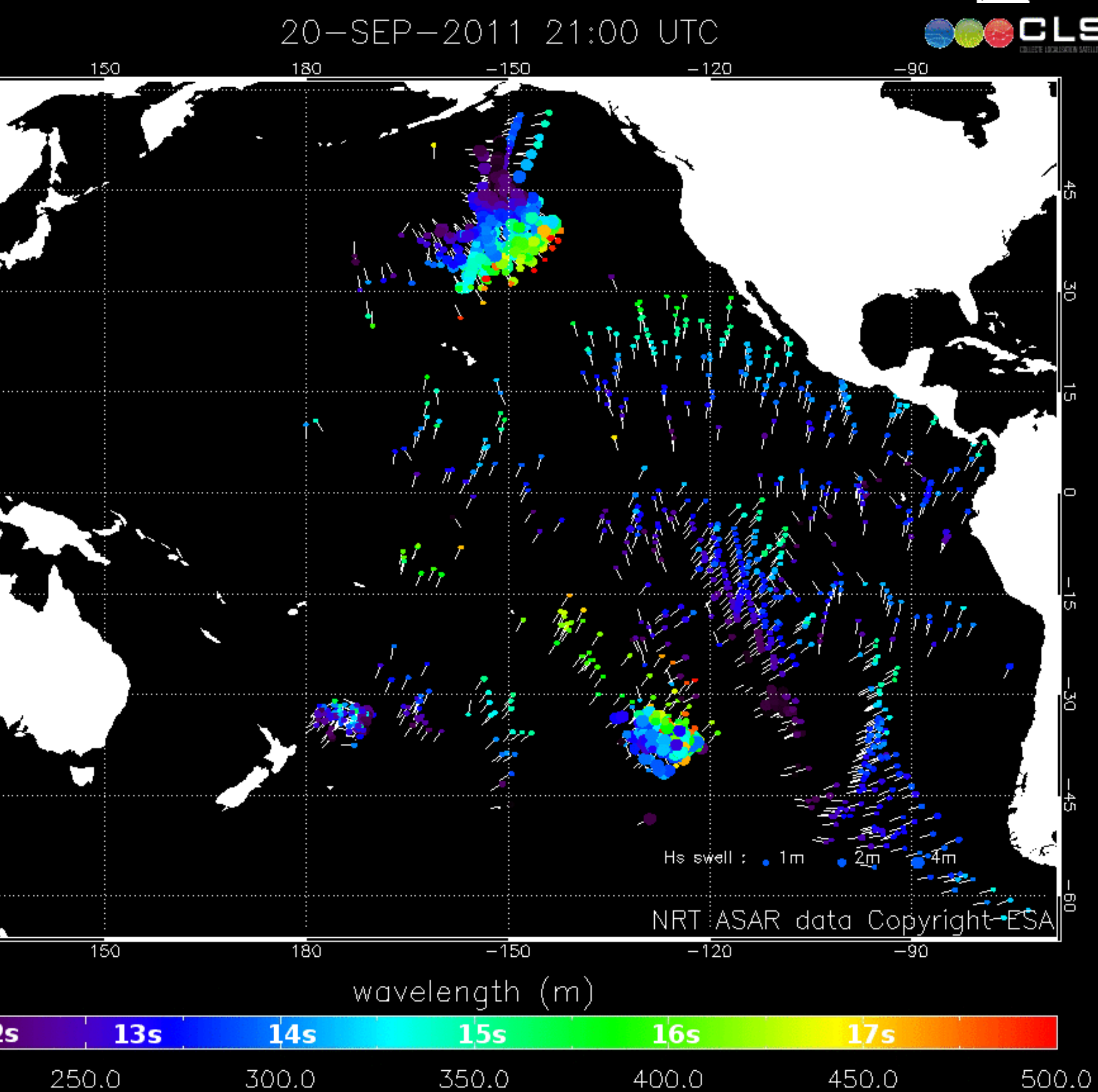




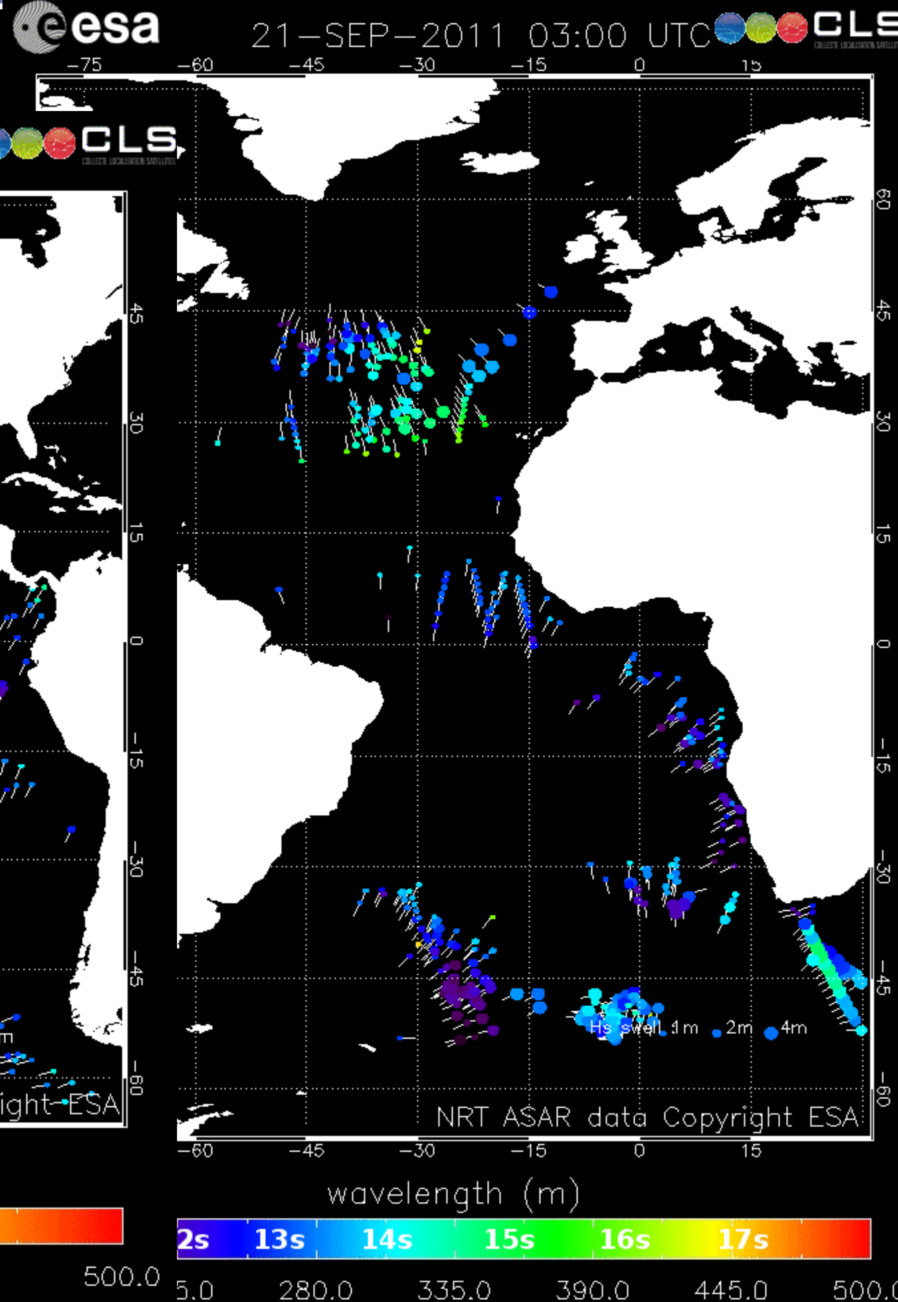


RED : ENVISAT ASAR
GREEN : ENVISAT RA2
YELLOW : JASON ALTIMETER

Fireworks



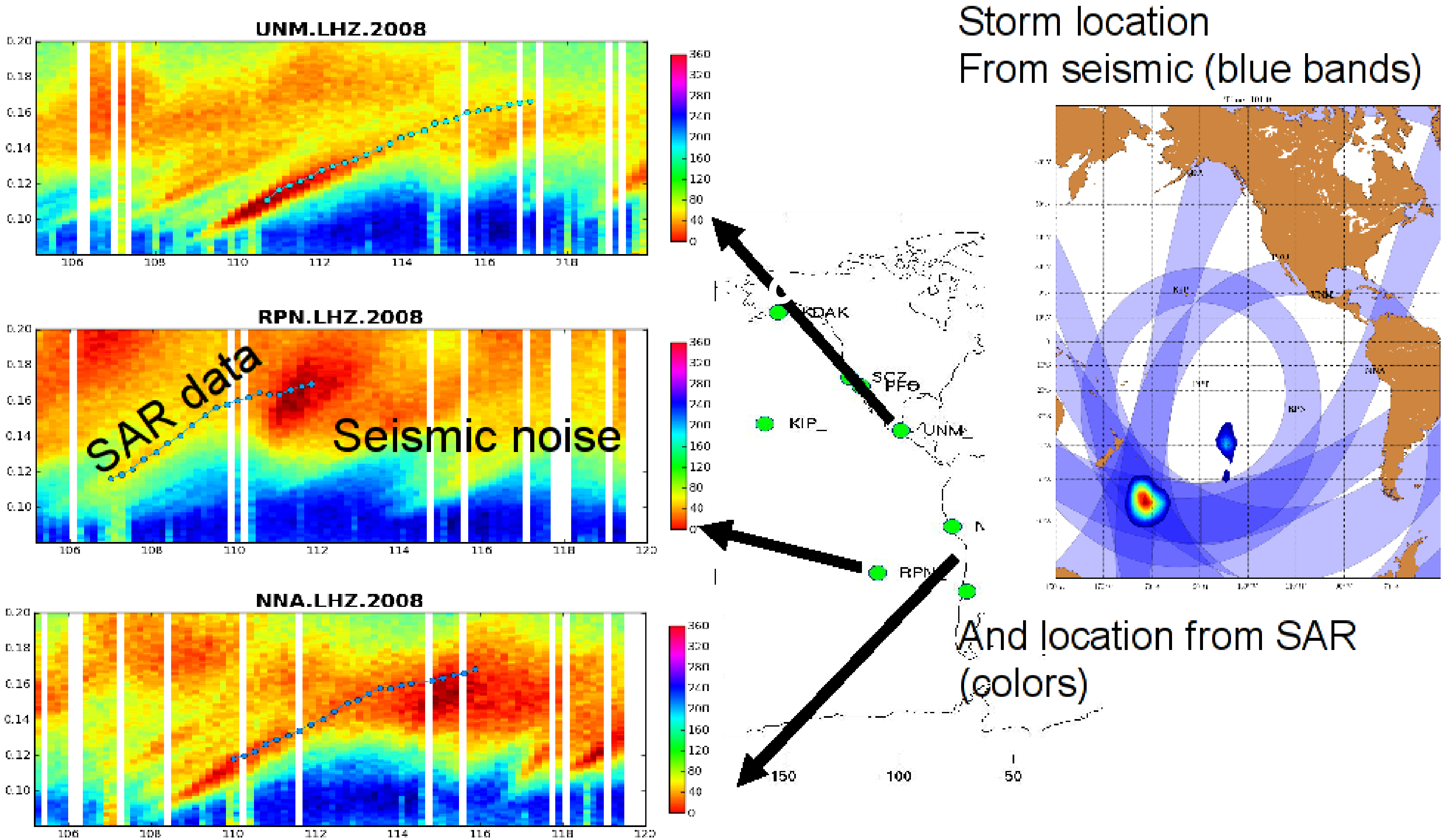
20-SEP-2011 21:00 UTC
CLS
150
180
-150
-120
-90
45
30
15
0
-15
-30
-45
-60
Hs swell : 1m 2m 4m
NRT ASAR data Copyright ESA
wavelength (m)
13s
14s
15s
16s
17s
250.0
300.0
350.0
400.0
450.0
500.0



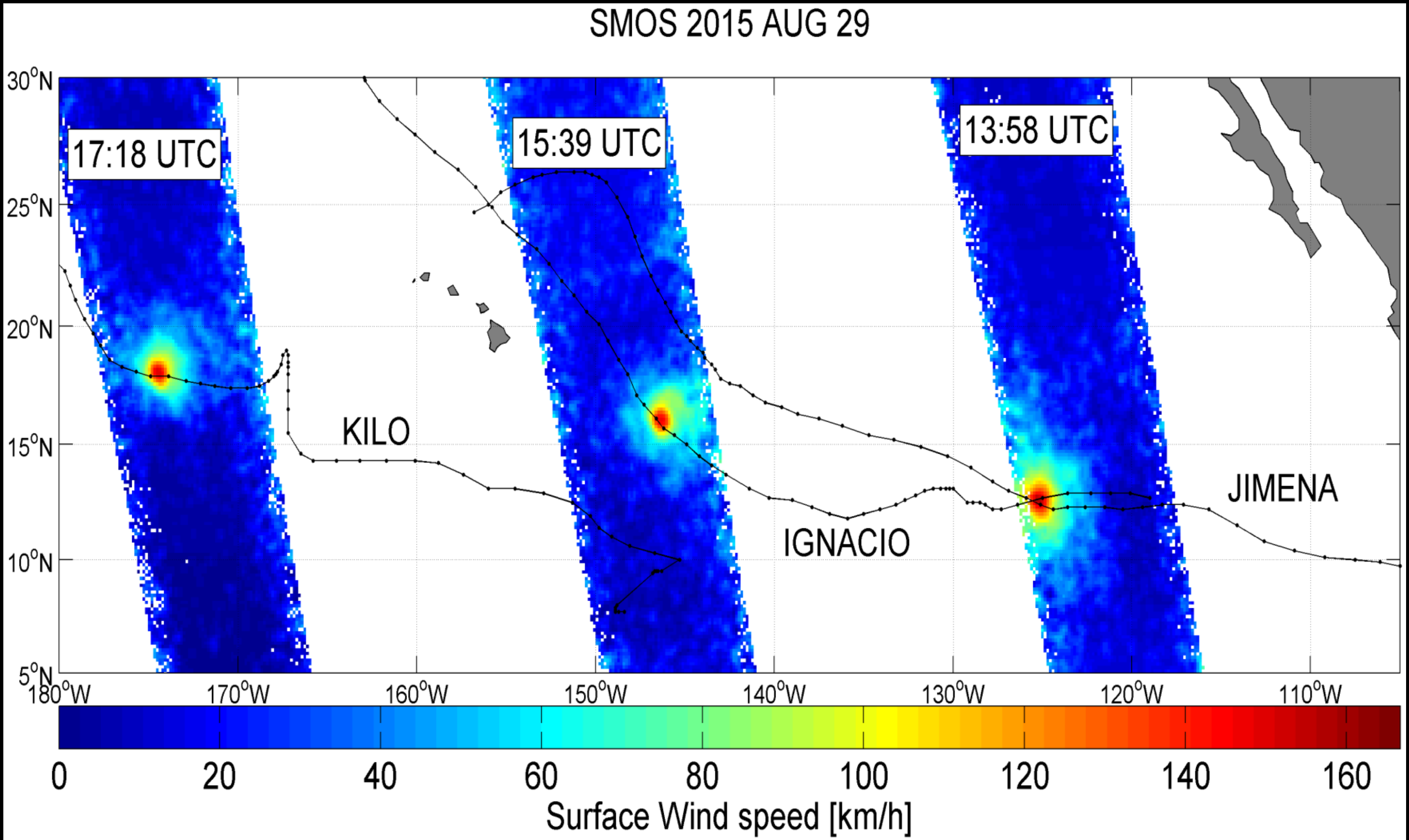
21-SEP-2011 03:00 UTC
-75
-60
-45
-30
-15
0
15
60
45
30
15
0
-15
-30
-45
-60
Hs swell 1m 2m 4m
NRT ASAR data Copyright ESA
wavelength (m)
2s
13s
14s
15s
16s
17s
5.0
280.0
335.0
390.0
445.0
500.0

Consistency and storm severity

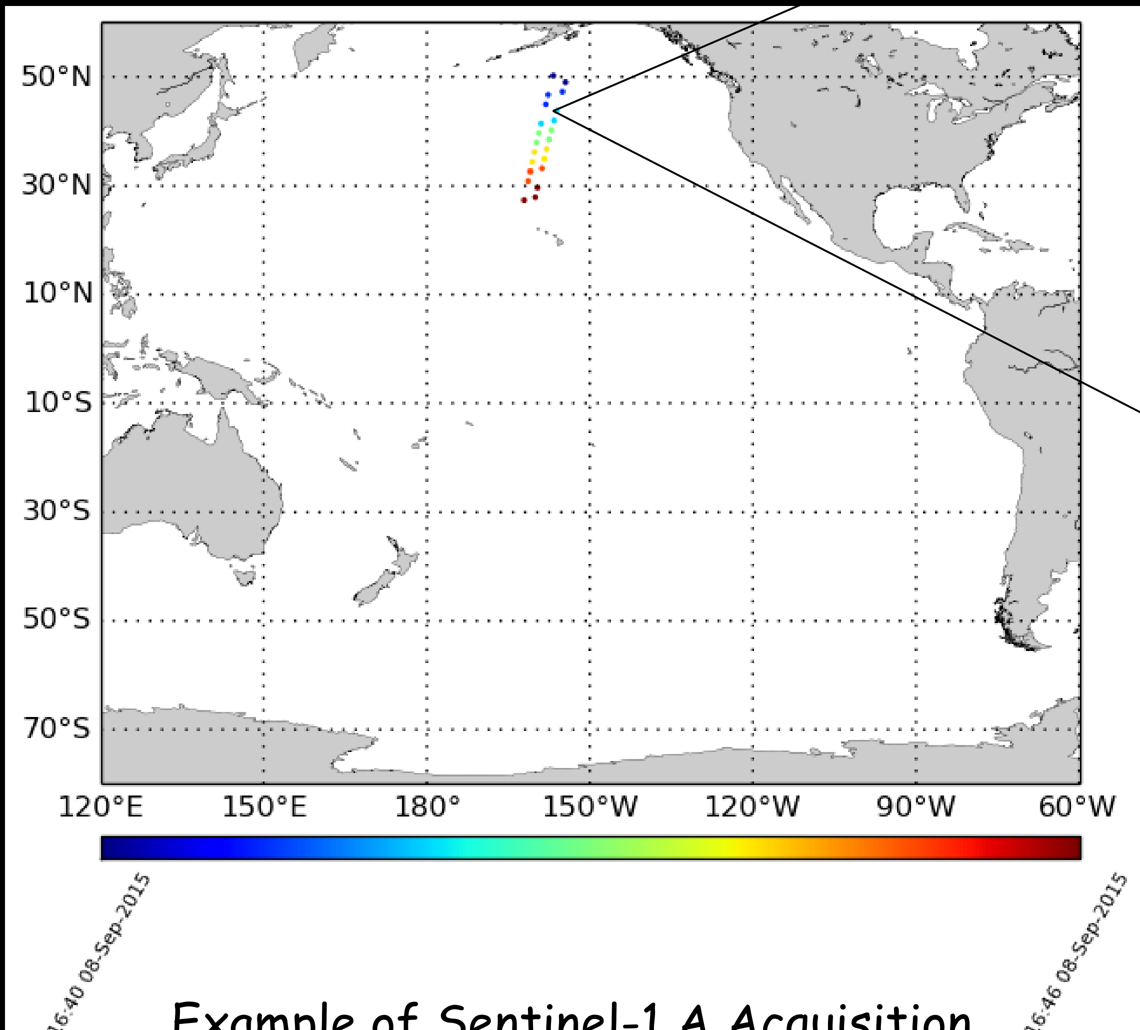
Example of seismic - SAR synergy



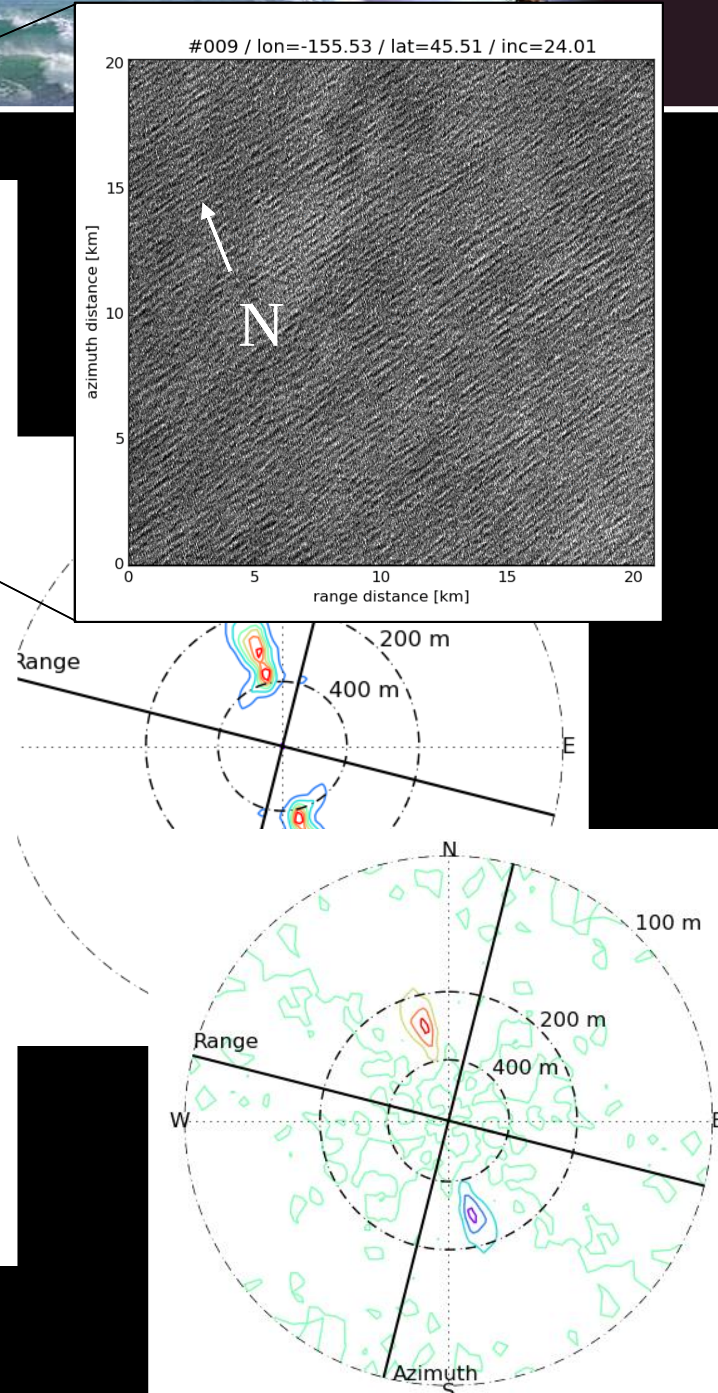
Signatures of 3 co-evolving 2015 major Hurricanes from 22 Aug to 9 Sep in the East and Central tropical Pacific as seen from SMOS, SMAP and AMSR-2 observations (beyond others)



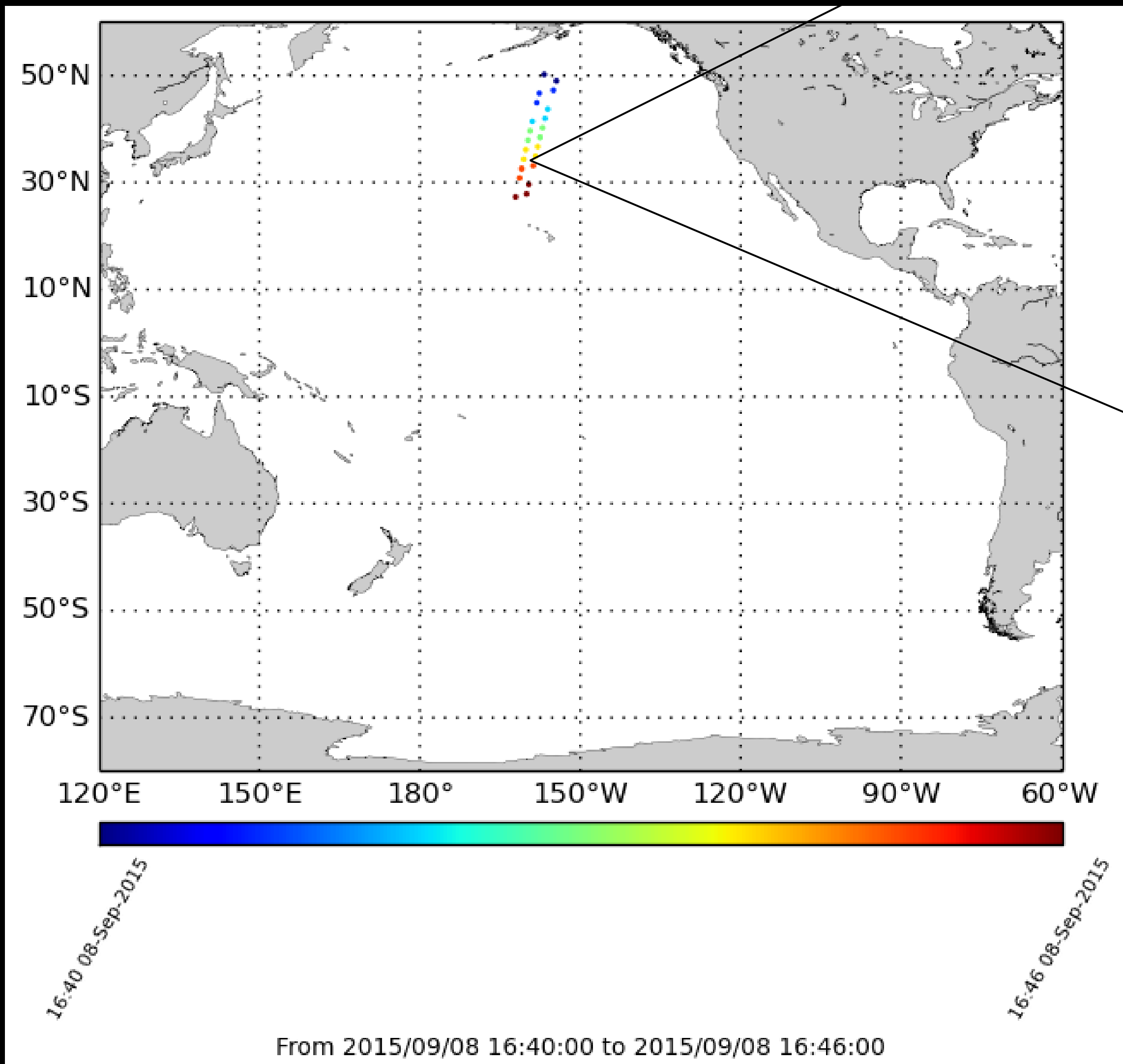
Jimena : wave generationx

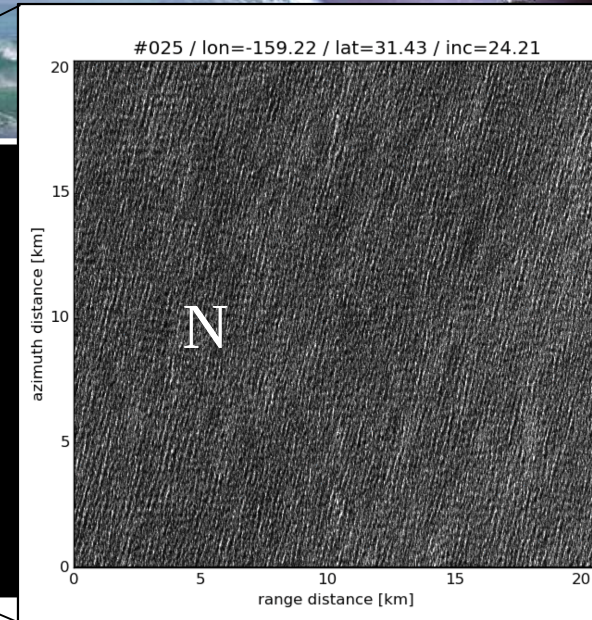


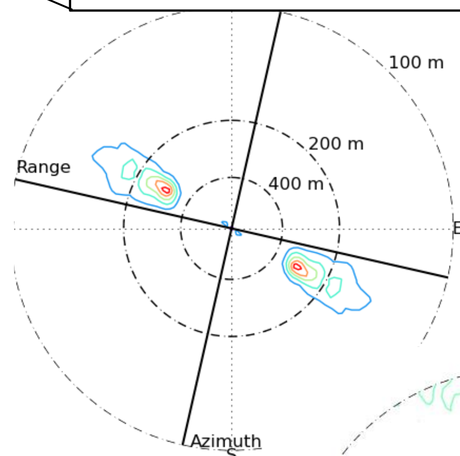
Example of Sentinel-1 A Acquisition
2015 Sept 8. From 16:40 to 16:46

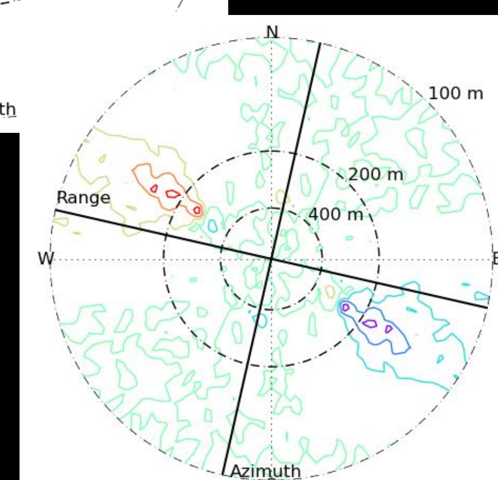


Jimena : wave generationx



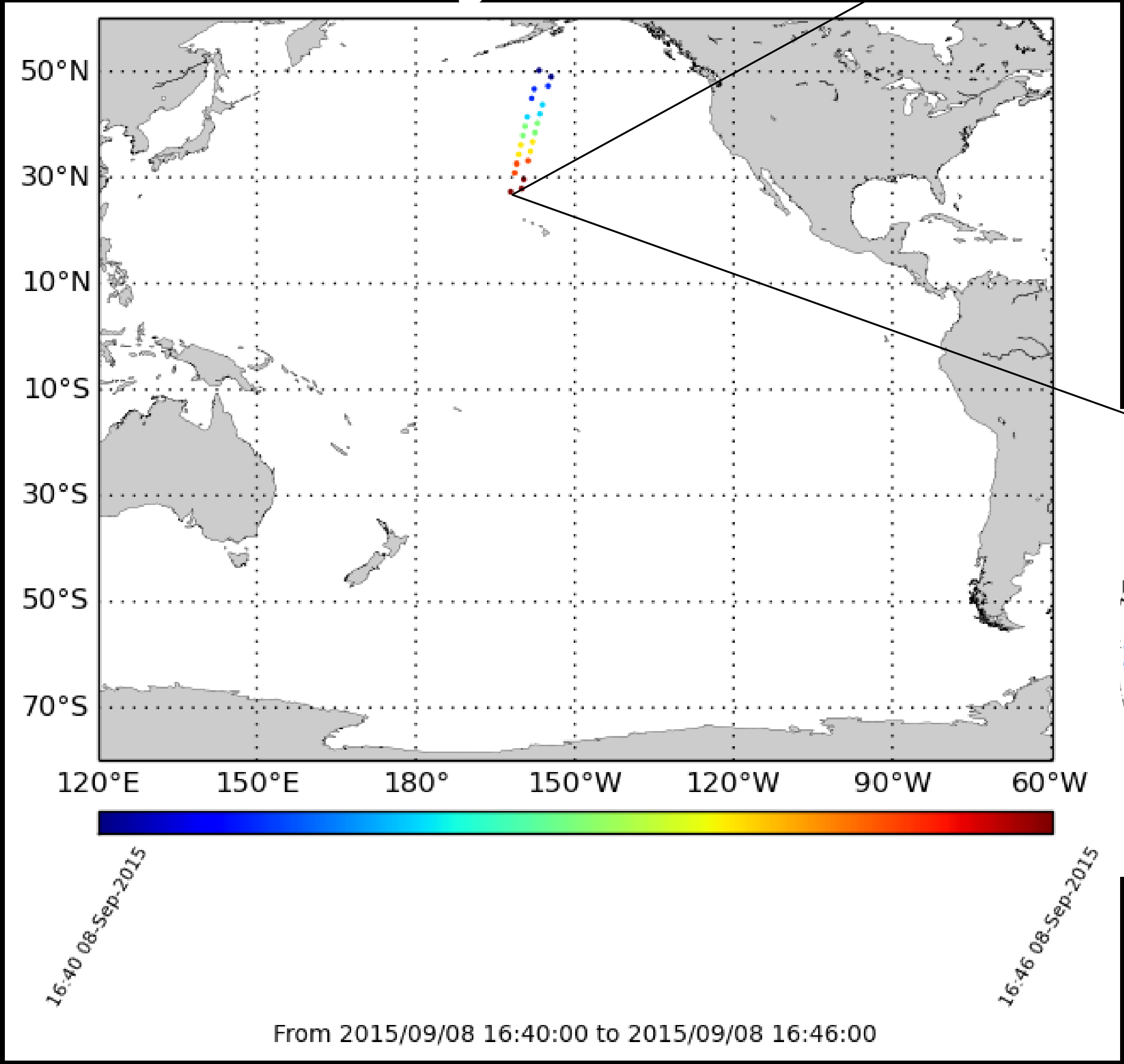


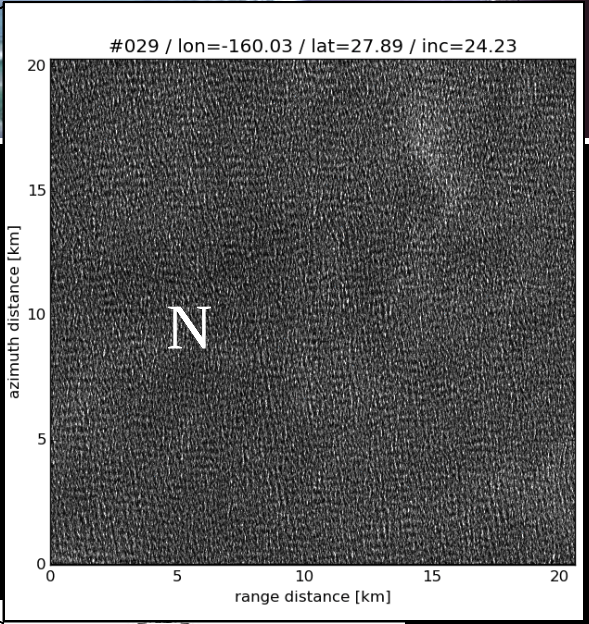


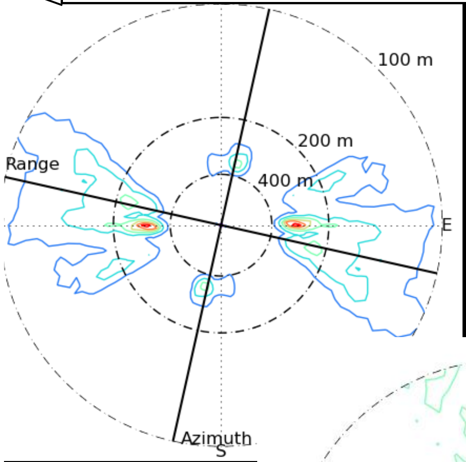


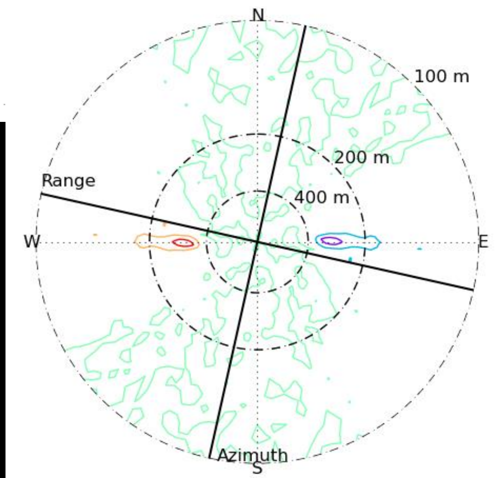
Example of Sentinel-1 A Acquisition
2015 Sept 8. From 16:40 to 16:46

Jimena : wave generationx



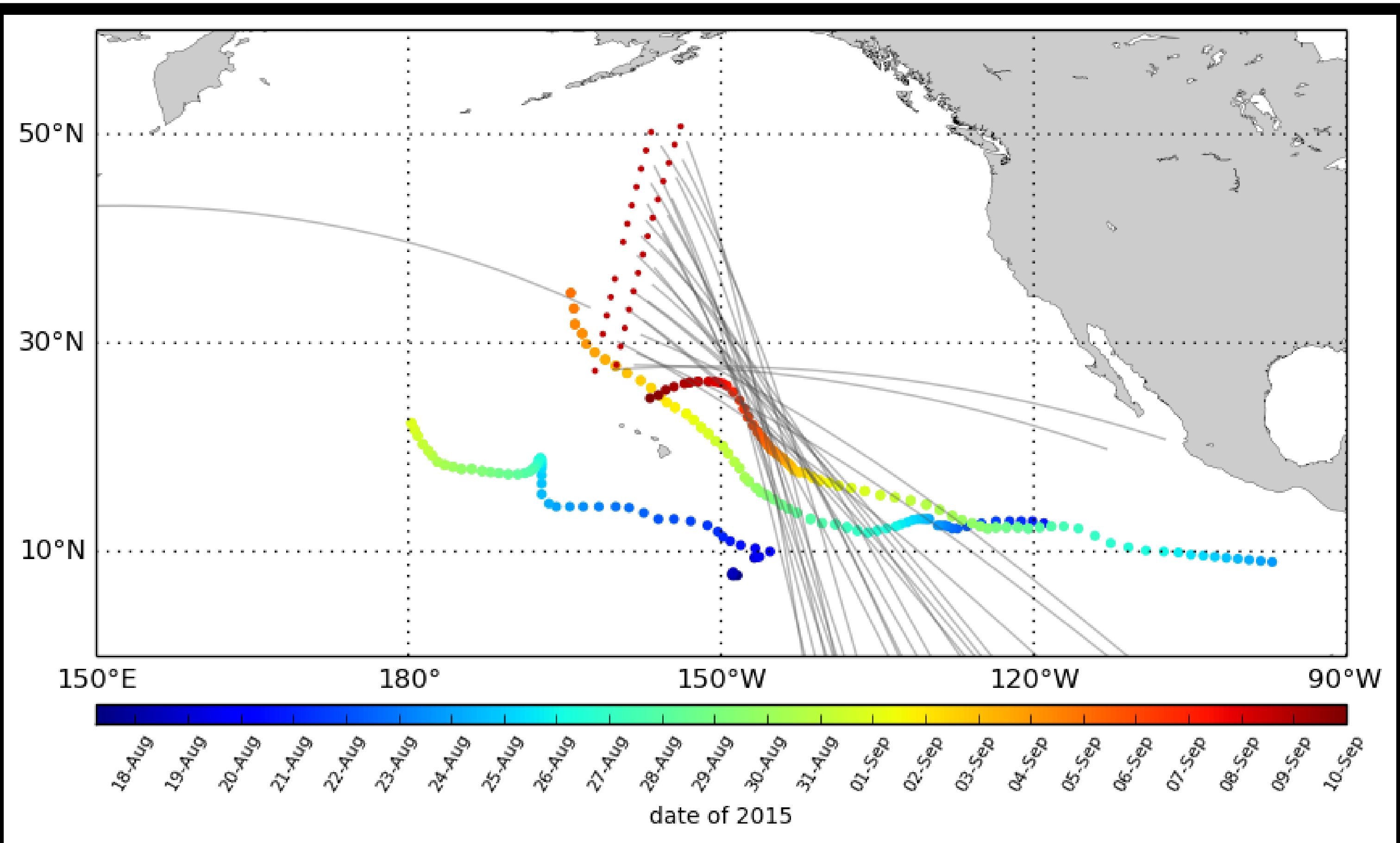






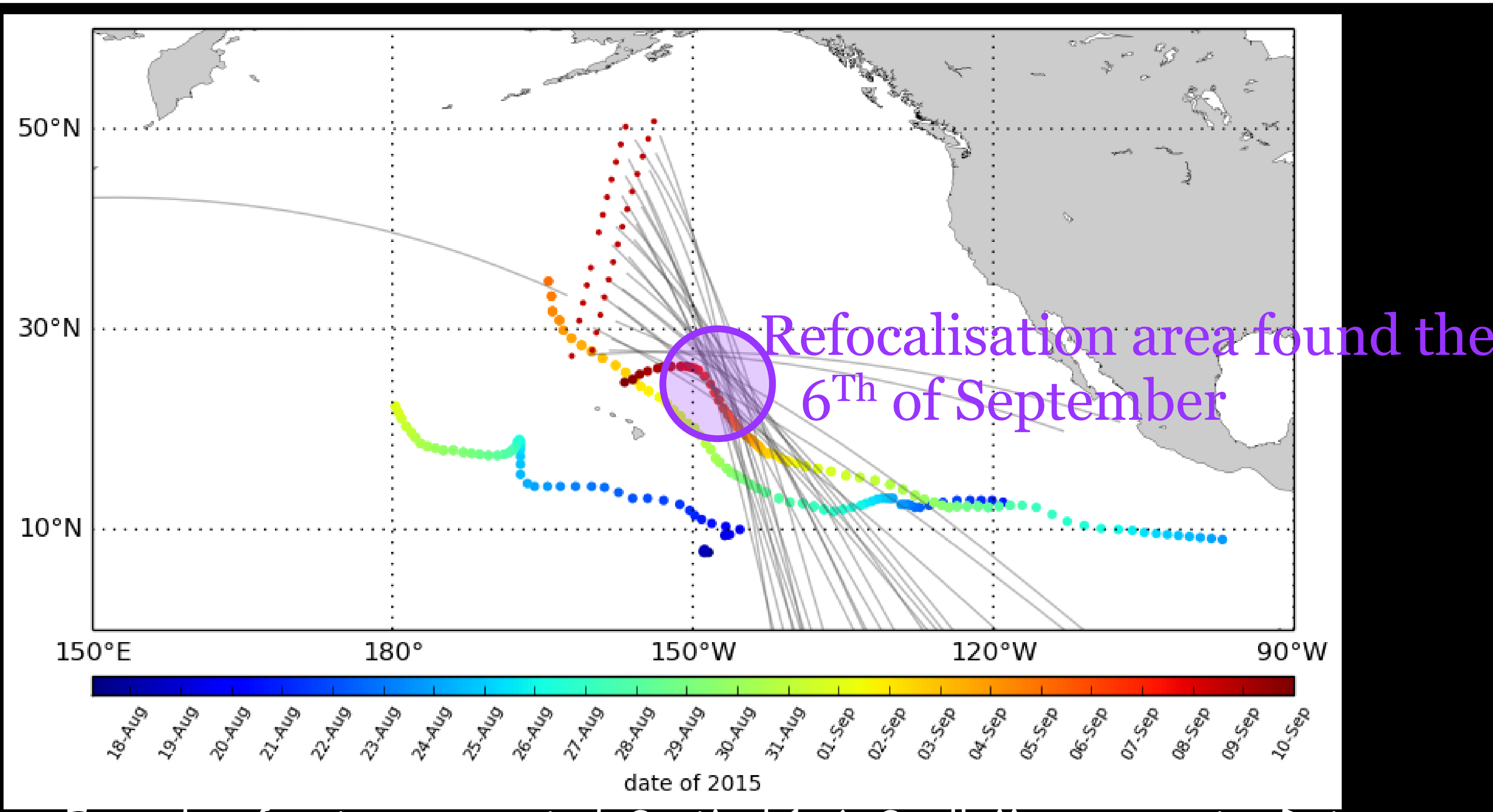
Example of Sentinel-1 A Acquisition
2015 Sept 8. From 16:40 to 16:46

Jimena : wave generationx



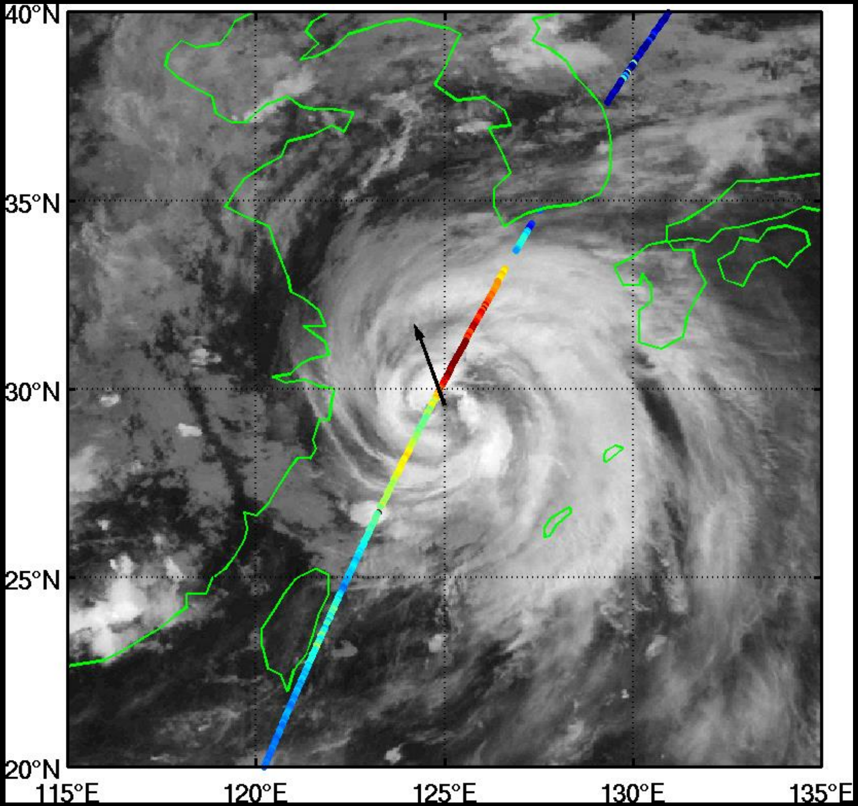
- Example of retro-propagated Sentinel-1 A Swell Measurements. Data acquired the 2015 Sept 8 16:40 to 16:46 UTC
- 3 tracks corresponding to the 3 hurricanes Kilo, Ignacio and Jimena (from left to right) are overplotted. Color code is time.

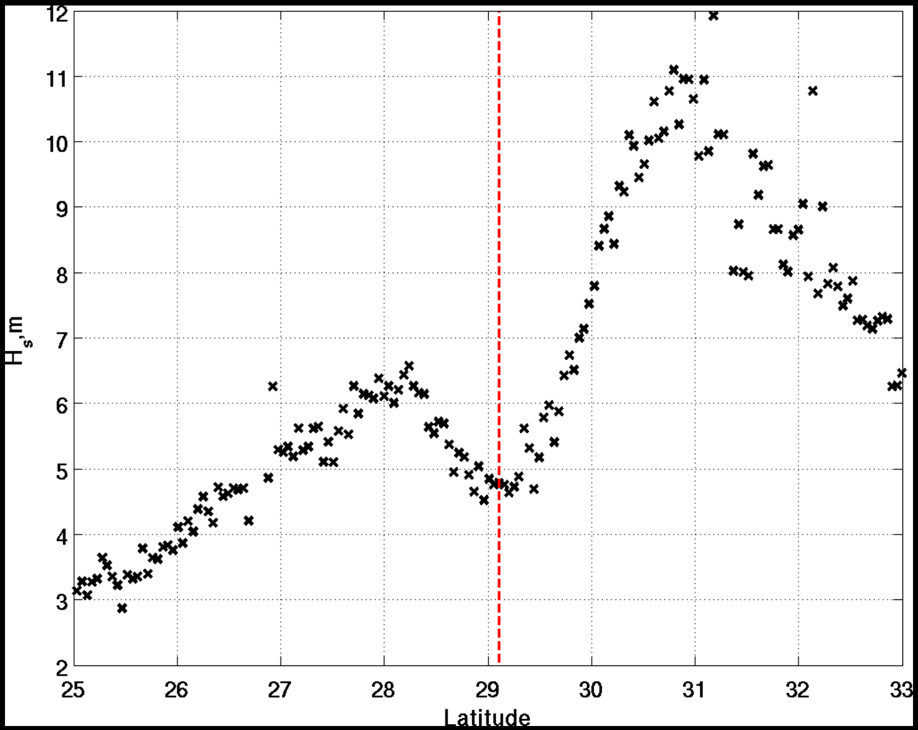
Jimena : wave generationx



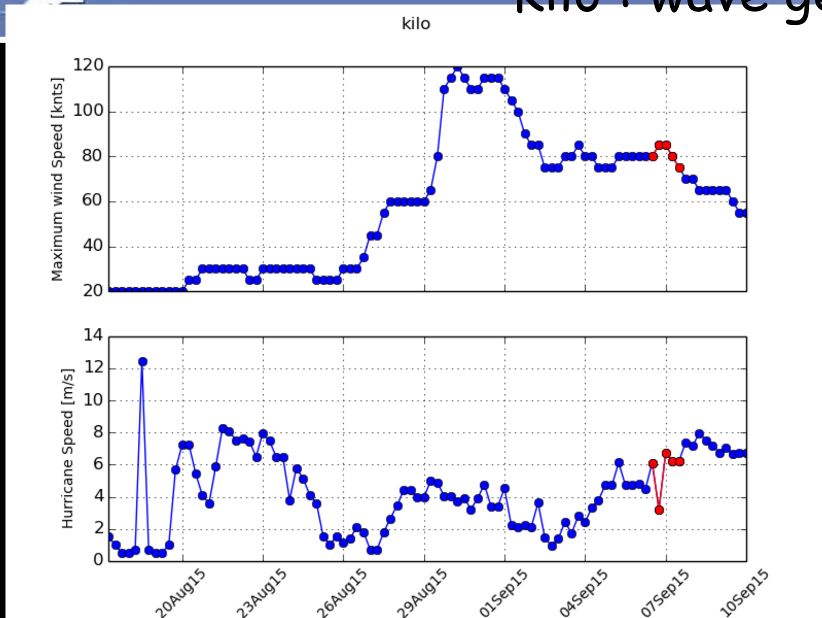
- Example of retro-propagated Sentinel-1 A Swell Measurements. Data acquired the 2015 Sept 8 16:40 to 16:46 UTC
- 3 tracks corresponding to the 3 hurricanes Kilo, Ignacio and Jimena (from left to right) are overplotted. Color code is time.
- Refocalisation area is found along the Jimena track the 6th of September. On the right hand side of the track.

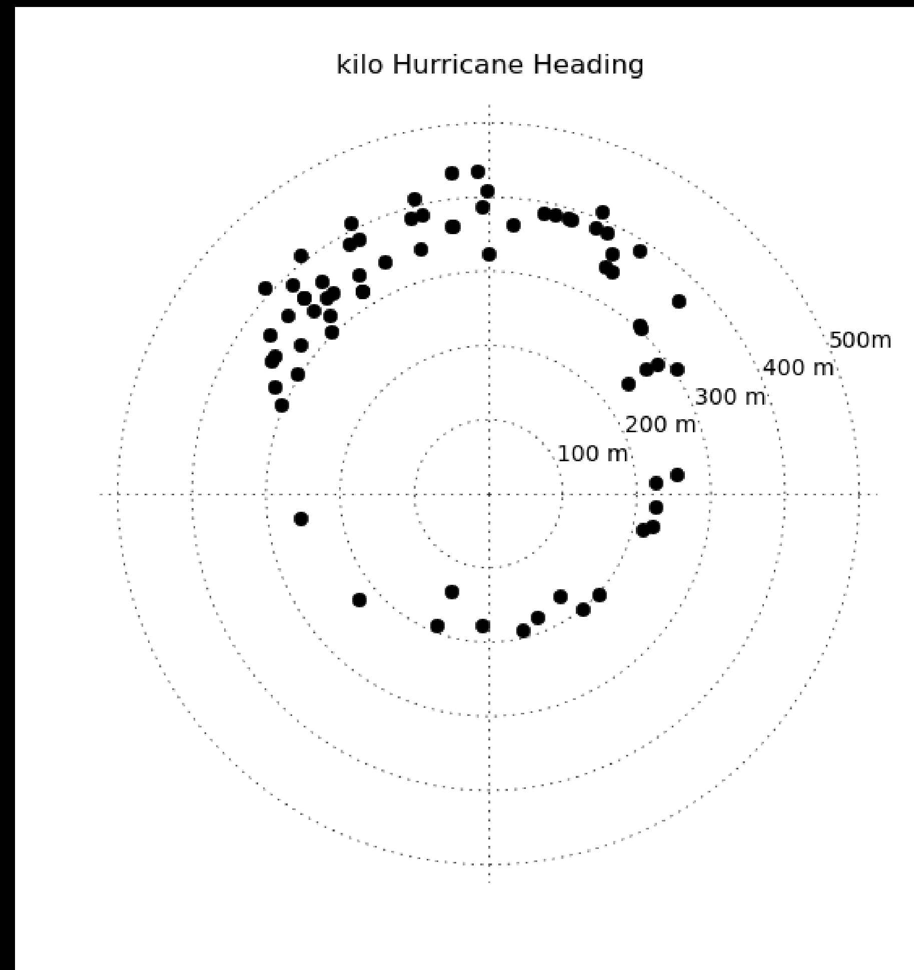
Trapped-fetch waves – distinctive feature of TC wave field

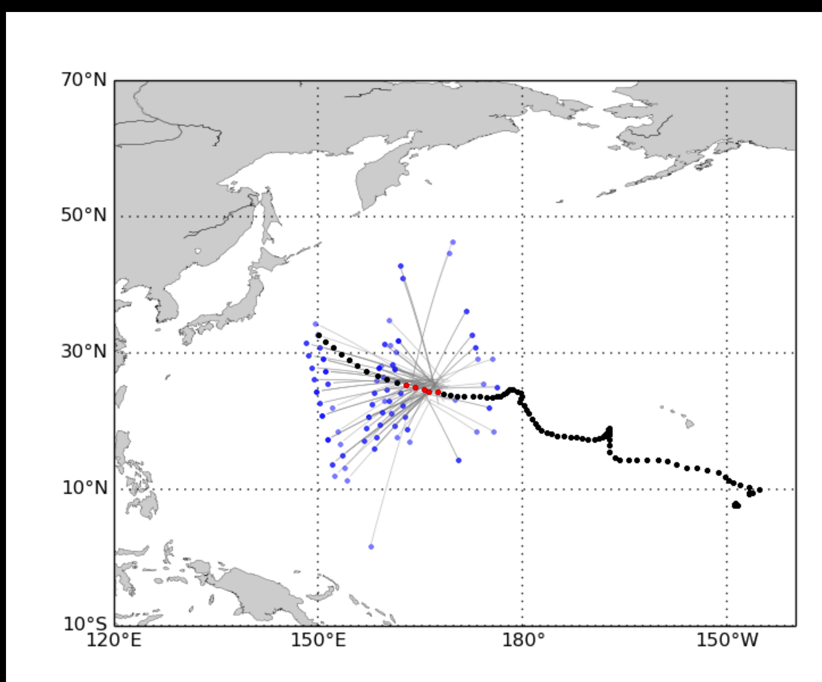




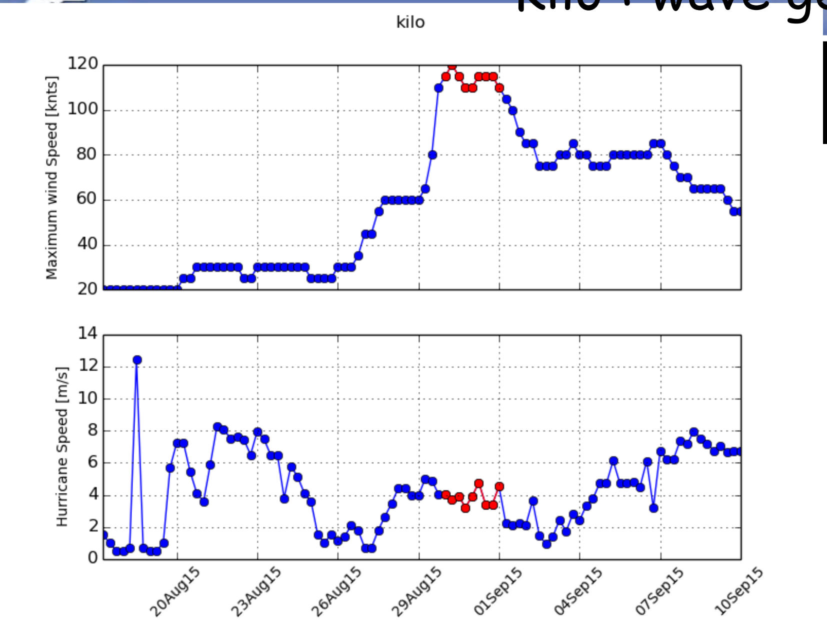
Kilo : wave generation

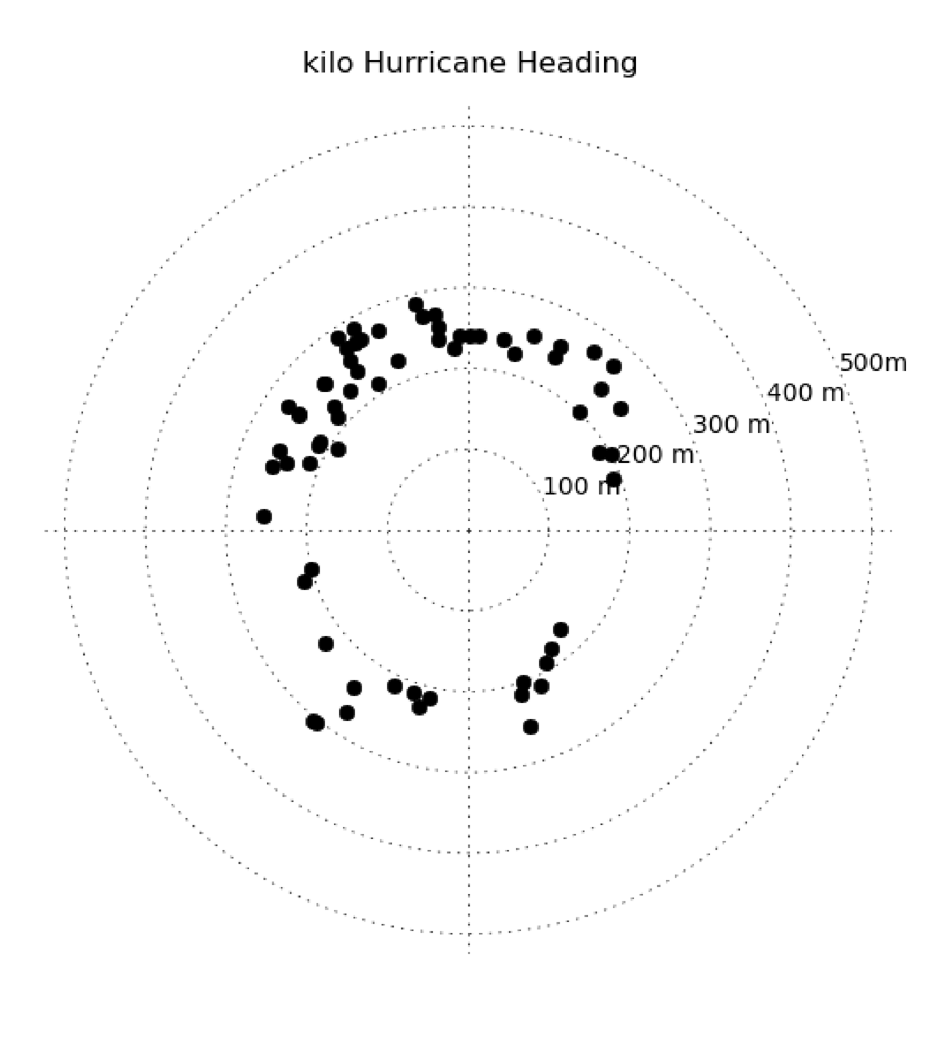


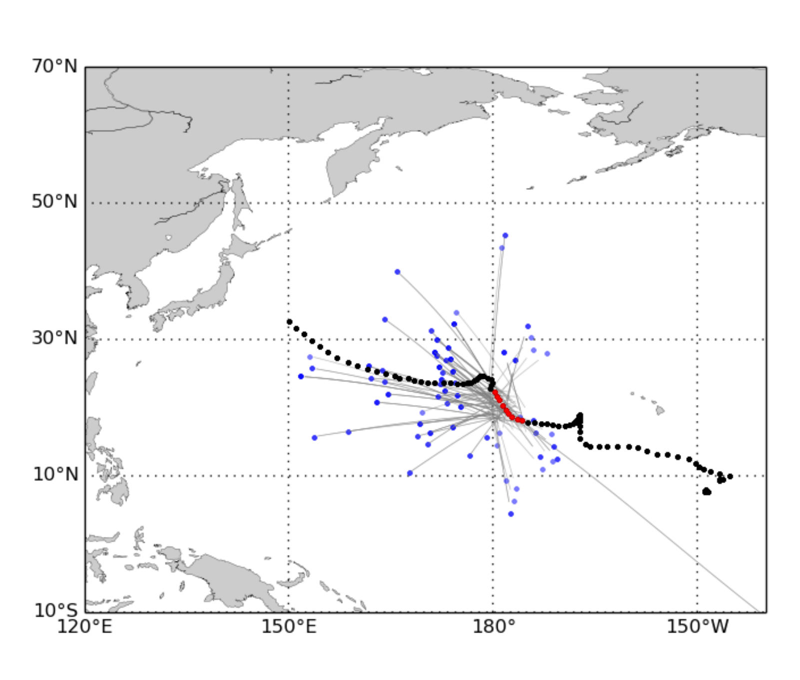




Kilo : wave generation







Main message …

- Today ideal instrument … (wide-swath, high-resolution, topography, roughness, Doppler, emissivity, reflectance, …) = the combined use of observations, including in situ measurements
- Very (too) large number of spatio-temporal scales under local and non-local interactions
- Improved technologies (instruments, resolution, computer capabilities, storage, dissemination) all contribute to improved combined analysis
- Theoretical frameworks and numerical simulations can be used to assess the causes and contexts of the different observations (including sensor physics, observability conditions and instrument capabilities), to refine dynamical/statistical gap filling methods
- New challenges, new altimeter instruments (SARAL, Sentinel-3, SWOT, …, CubeSat opportunities), possible new high-resolution microwave instruments (10-20 km), Doppler measurements to infer sea surface currents (SAR and/or RAR-SKIM or DopplerScat), and combined roughness contrasts as local quantitative proxies to trace strong surface gradient areas

Opening the Pandora's box ?

Archiving data leads to very large heterogeneous and multimodal databases

Data assimilation is growing in response to the growth of data collected, but (personal opinion) tremendous amounts of information still remain hidden in data archives.

Knowledge trees and complex algorithms are essential to avoid the Google's principle, i.e. pertinence = popularity

Research efforts to be concerned with the definition of adequate exploratory processes to detect relevant patterns in large, heterogeneous, multidimensional observation data sets with different resolutions to better approach complex spatial and/or temporal dynamics of the ocean system.

LETTRE XX.

De M. JEAN SPOONER,
A. B. S.[t] JOHN'S CAMBRIDGE.

Gênes 1.[er] Mai 1822.

Vous m'avez fait l'honneur, M. le Baron, de me demander un extrait du mémoire que j'ai pris la liberté de vous communiquer relativement à un phénomène lumineux qui se montre sur la mer lorsque le soleil ou la lune y donnent dessus (*), et que vous voulez avoir la bonté d'insérer dans votre *Correspondance*

L'équation en question est:

$$\frac{a^2}{a^2+x^2+y^2} + \frac{2\cos. Z a}{\sqrt{a^2+x^2+y^2}} + \cos.^2 Z = \frac{2.\cos.^2 J + 2\cos.^2 J . a . \cos. Z}{\sqrt{a^2+x^2+y^2}} - \frac{2\cos. J \sin. Z . x}{\sqrt{a^2+x^2+y^2}}.$$

Par la quatrième observation.

$$A^2 = \frac{.0000013 + .0005593 + .0585262}{2 + .0005593 - \bar{1}.9281164} = \frac{.0590868}{.0724429}$$

De-là, log. $A = \bar{1}.95574725 =$ log. cosin. de $25° \, 26'$.