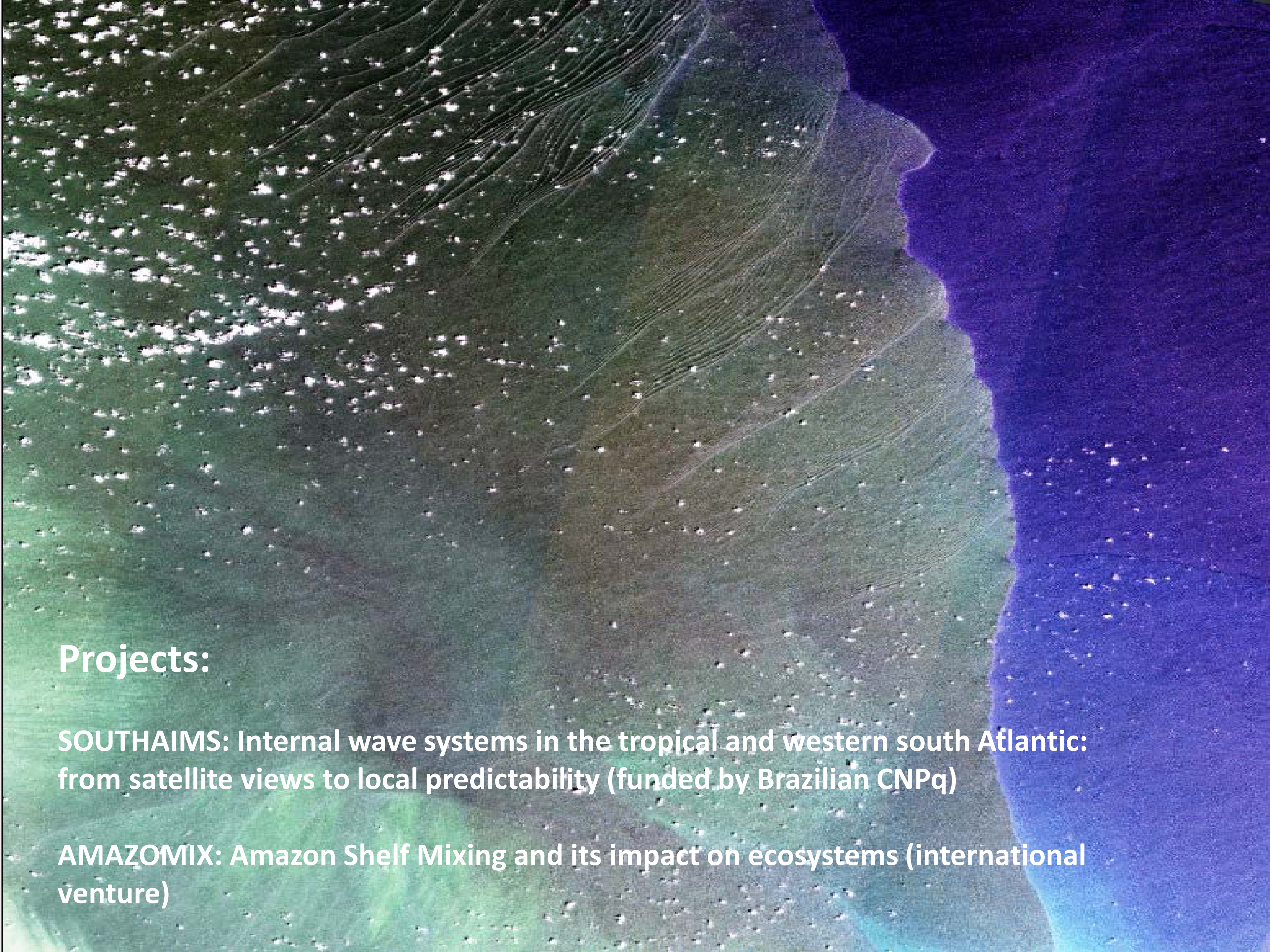
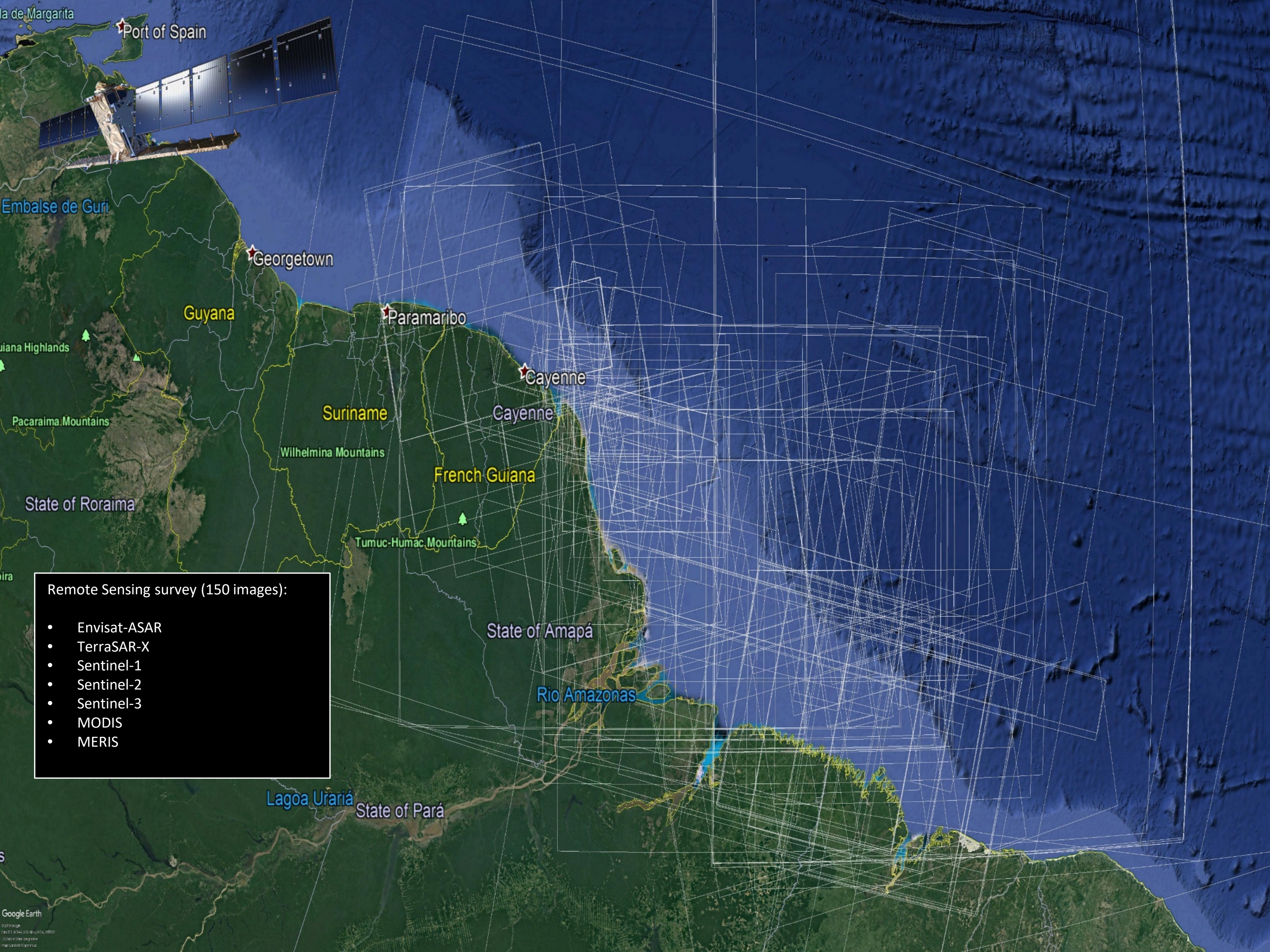
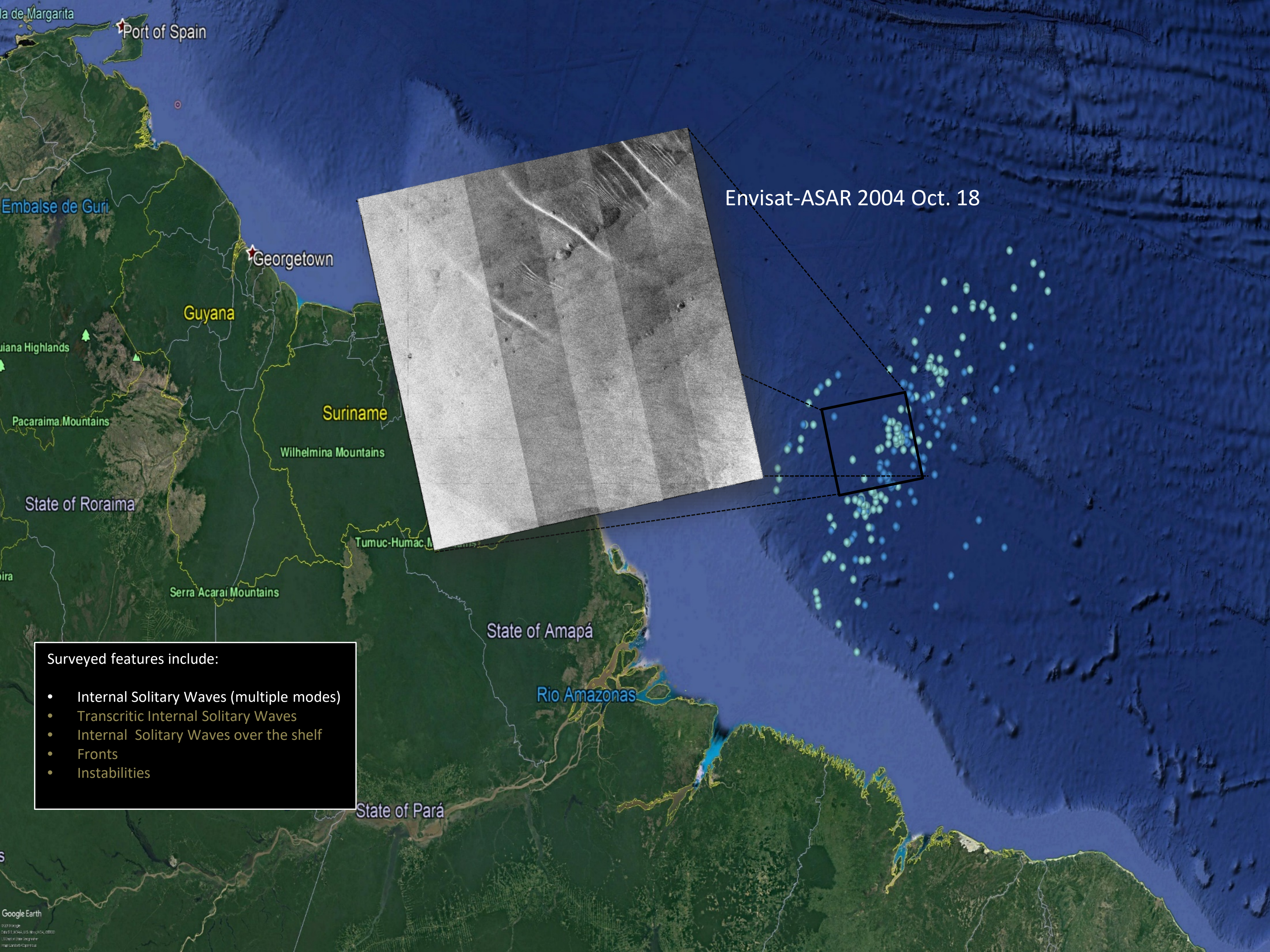
Observing and predicting internal wave interactions between the Amazon plume and the equatorial currents in the tropical West Atlantic

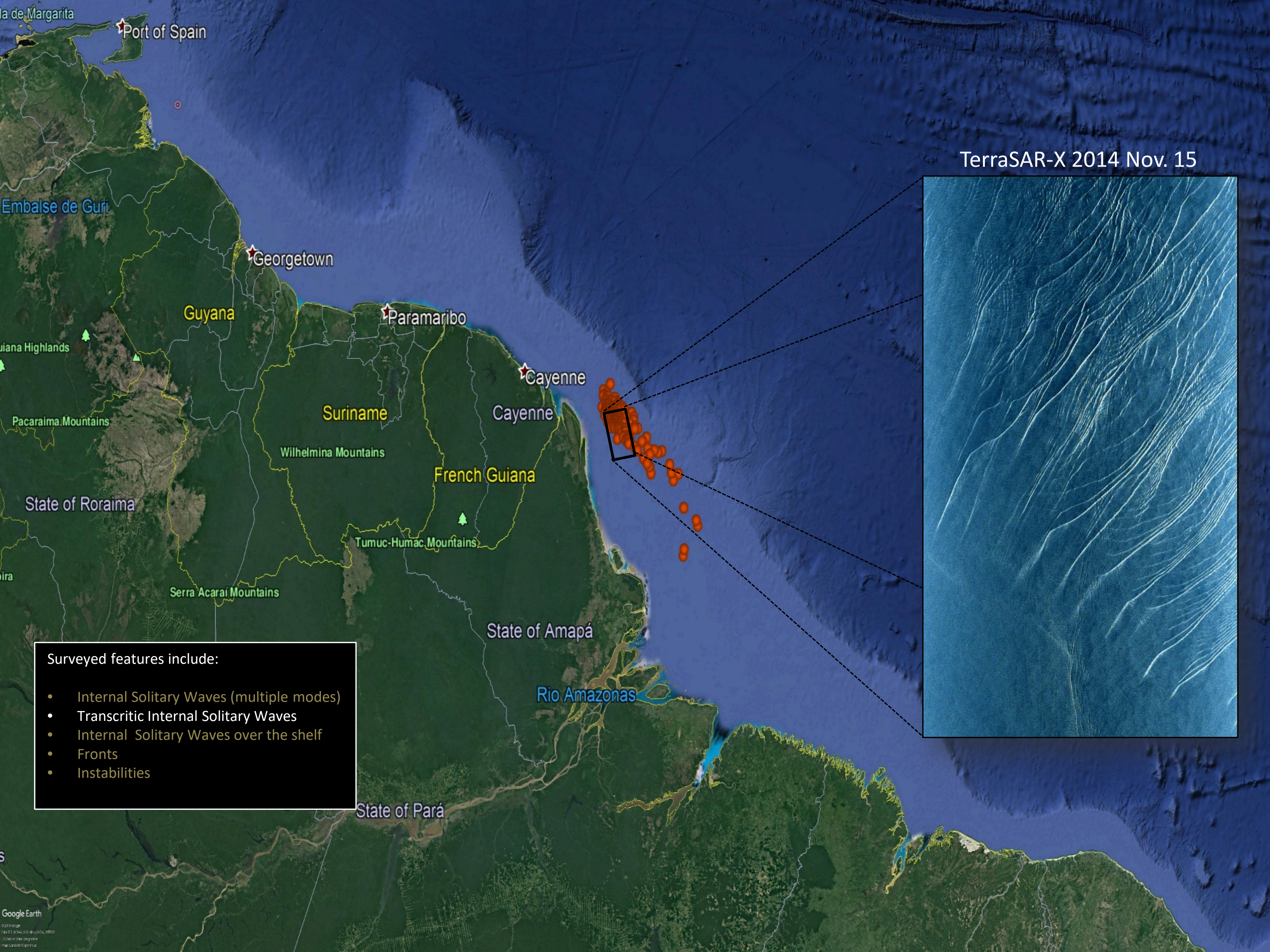
José da Silva (jdasilva@fc.up.pt), with contributions from: J.M. Magalhaes, A. Koch-Larrouy, M.C. Buijsman, G. Jeans, A.M. Santos-Ferreira, C.A.E. Garcia

Atlantic from Space, 23-25 Jan, 2019. NOC Southampton (UK)


Projects:
SOUTHAIMS: Internal wave systems in the tropical and western south Atlantic: from satellite views to local predictability (funded by Brazilian CNPq)
AMAZOMIX: Amazon Shelf Mixing and its impact on ecosystems (international venture)


Port of Spain
Embalse de Guri
Georgetown
Guyana
Paramaribo
Cayenne
Suriname
Cayenne
Pacaraima Mountains
Wilhelmina Mountains
French Guiana
State of Roraima
Tumuc-Humac Mountains
State of Amapá
Rio Amazonas
Lagoa Urariá
State of Pará
Google Earth
Remote Sensing survey (150 images):
- Envisat-ASAR
- TerraSAR-X
- Sentinel-1
- Sentinel-2
- Sentinel-3
- MODIS
- MERIS


Port of Spain
Embalse de Guri
Georgetown
Guyana
Pacaraima Mountains
Suriname
Wilhelmina Mountains
State of Roraima
Serra Acaraí Mountains
State of Amapá
Rio Amazonas
State of Pará
Google Earth
Envisat-ASAR 2004 Oct. 18
Surveyed features include:
• Internal Solitary Waves (multiple modes)
• Transcritic Internal Solitary Waves
• Internal Solitary Waves over the shelf
• Fronts
• Instabilities


TerraSAR-X 2014 Nov. 15
Port of Spain
Embalse de Guri
Georgetown
Guyana
Paramaribo
Cayenne
Suriname
Cayenne
Pacaraima Mountains
Wilhelmina Mountains
French Guiana
State of Roraima
Tumuc-Humac Mountains
Serra Acaraí Mountains
State of Amapá
Rio Amazonas
State of Pará
Google Earth
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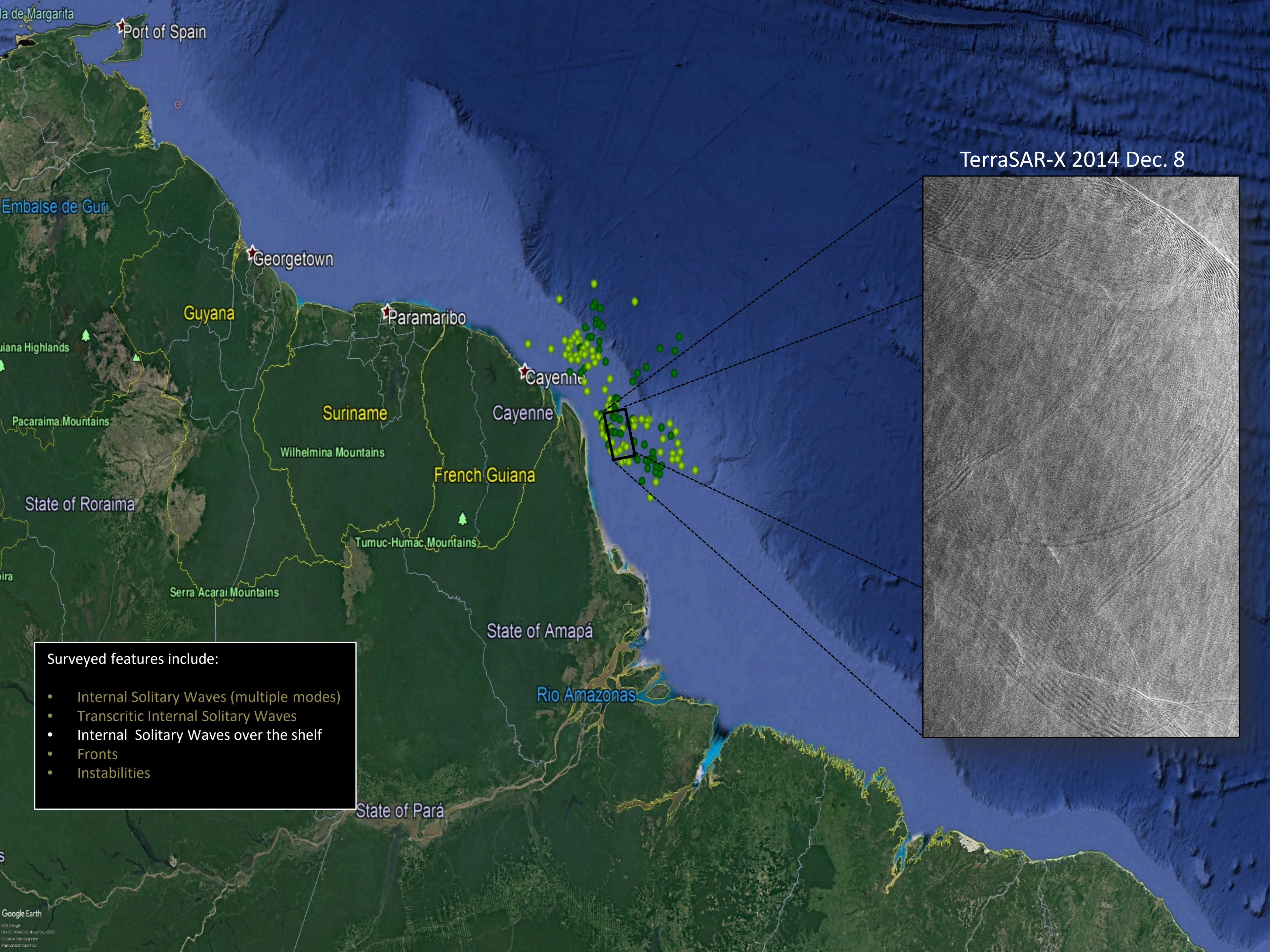
TerraSAR-X 2014 Dec. 8
Port of Spain
Embalse de Guri
Georgetown
Guyana
Paramaribo
Cayenne
Suriname
Cayenne
Pacaraima Mountains
Wilhelmina Mountains
French Guiana
State of Roraima
Tumuc-Humac Mountains
Serra Acaraí Mountains
State of Amapá
Rio Amazonas
State of Pará
Google Earth
Surveyed features include:
Internal Solitary Waves (multiple modes)
Transcritic Internal Solitary Waves
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Fronts
Instabilities

Sentinel-2 2017 Oct. 16
Port of Spain
Embalse de Guri
Georgetown
Guyana
Paramaribo
Cayenne
Suriname
Cayenne
Pacaraima Mountains
Wilhelmina Mountains
French Guiana
State of Roraima
Tumuc-Humac Mountains
Serra Acaraí Mountains
State of Amapá
Rio Amazonas
State of Pará
Google Earth
Surveyed features include:
- Internal Solitary Waves (multiple modes)
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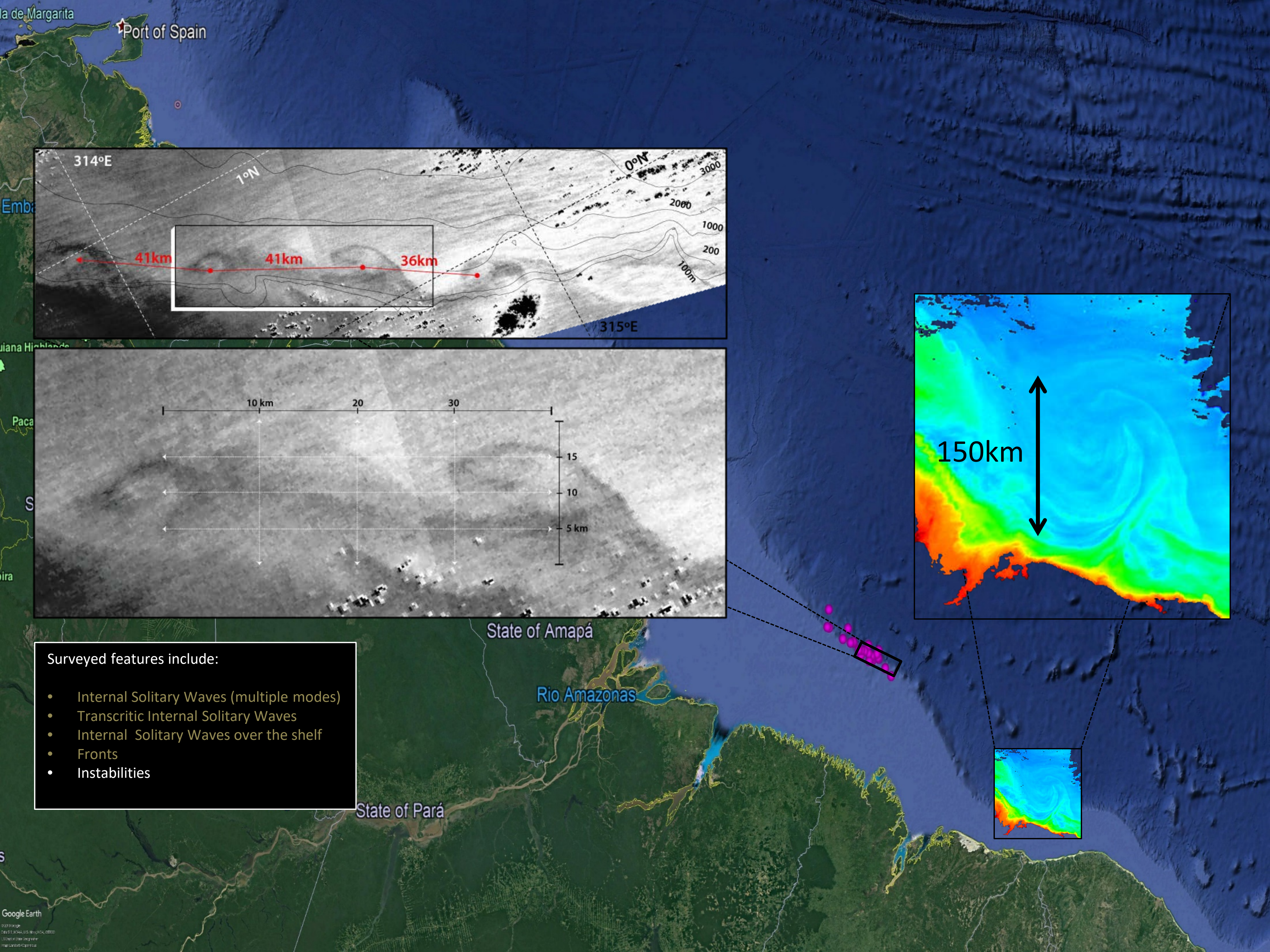
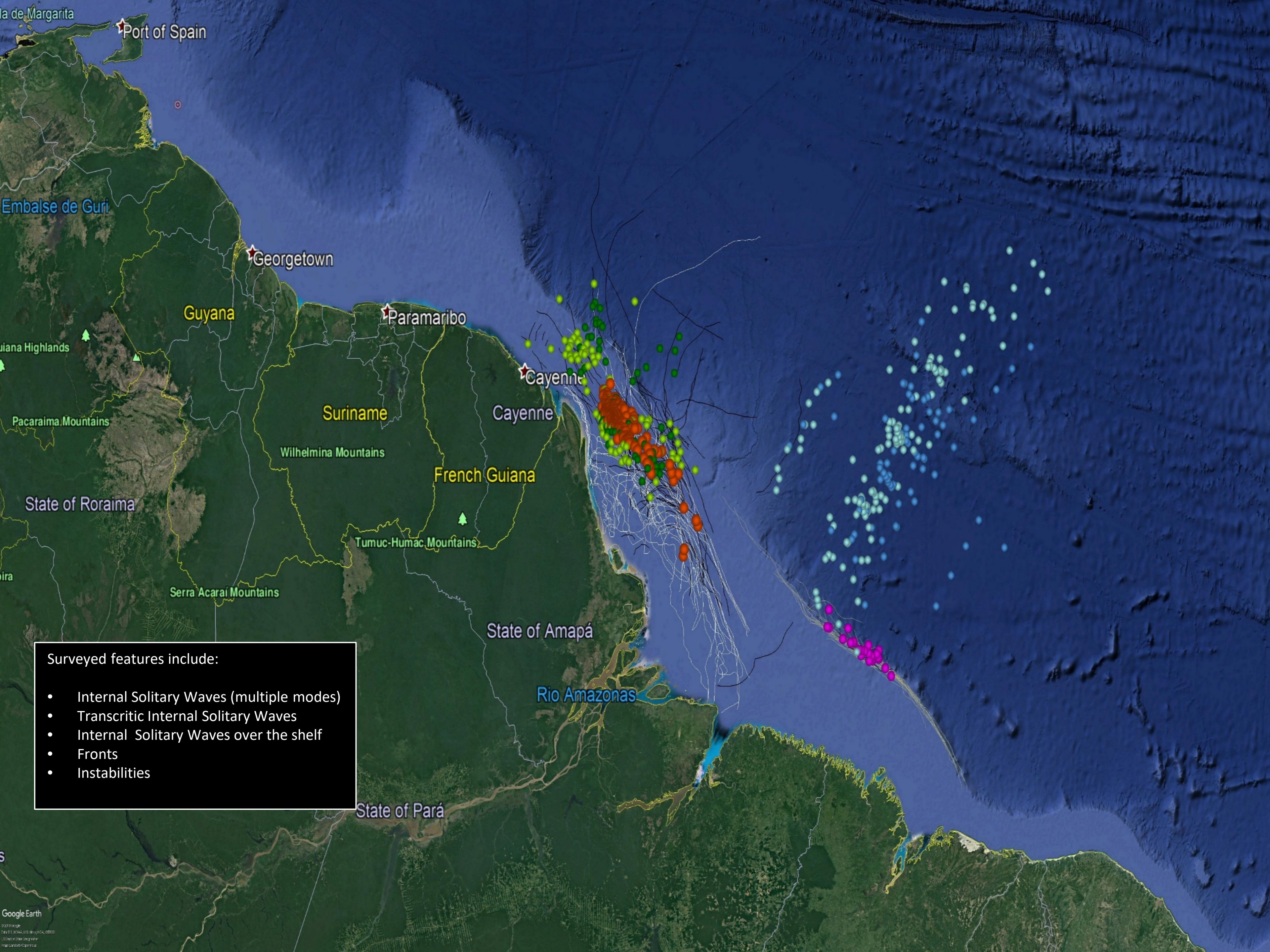
- Internal Solitary Waves over the shelf
- Fronts
- Instabilities


Port of Spain
314ºE
1ºN
0ºN
3000
2000
1000
200
100m
41km
41km
36km
315ºE
10 km
20
30
15
10
5 km
150km
State of Amapá
Rio Amazonas
State of Pará
Surveyed features include:
- Internal Solitary Waves (multiple modes)
- Transcritic Internal Solitary Waves
- Internal Solitary Waves over the shelf
- Fronts
- Instabilities
Google Earth



Port of Spain
Embalse de Guri
Georgetown
Guyana
Paramaribo
Suriname
Cayenne
Cayenne
Pacaraima Mountains
Wilhelmina Mountains
French Guiana
State of Roraima
Tumuc-Humac Mountains
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State of Amapá
Rio Amazonas
State of Pará
Google Earth
Surveyed features include:
• Internal Solitary Waves (multiple modes)
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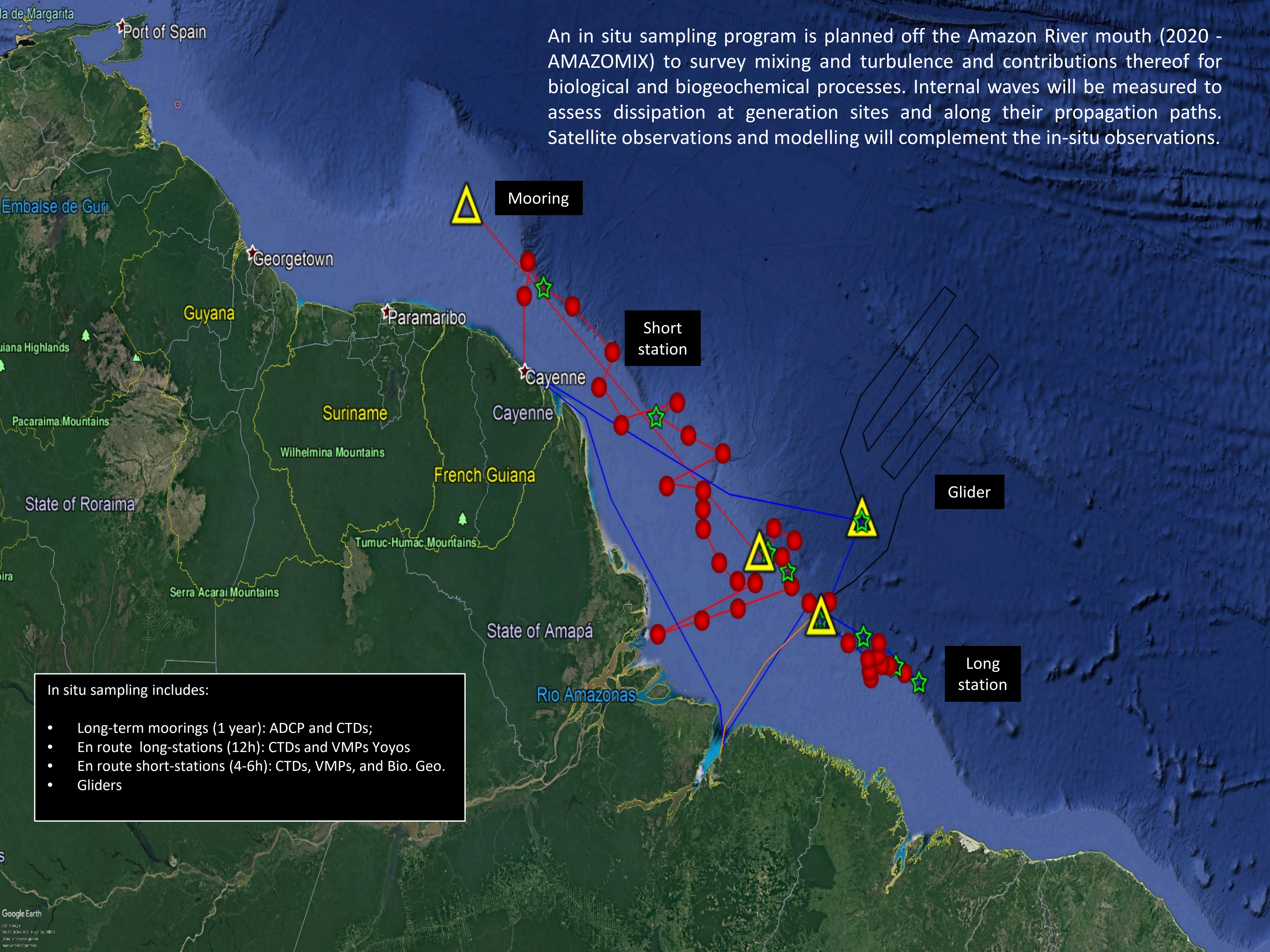
• Internal Solitary Waves over the shelf
• Fronts
• Instabilities

An in situ sampling program is planned off the Amazon River mouth (2020 - AMAZOMIX) to survey mixing and turbulence and contributions thereof for biological and biogeochemical processes. Internal waves will be measured to assess dissipation at generation sites and along their propagation paths. Satellite observations and modelling will complement the in-situ observations.



In situ sampling includes:

- Long-term moorings (1 year): ADCP and CTDs;
- En route long-stations (12h): CTDs and VMPs Yoyos
- En route short-stations (4-6h): CTDs, VMPs, and Bio. Geo.
- Gliders

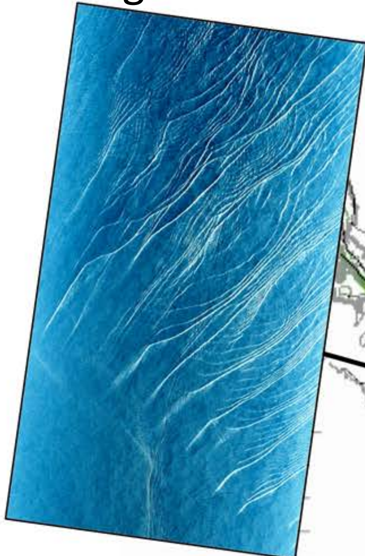
AMAZON SHELF MIXING AND ITS IMPACT ON ECOSYSTEMS

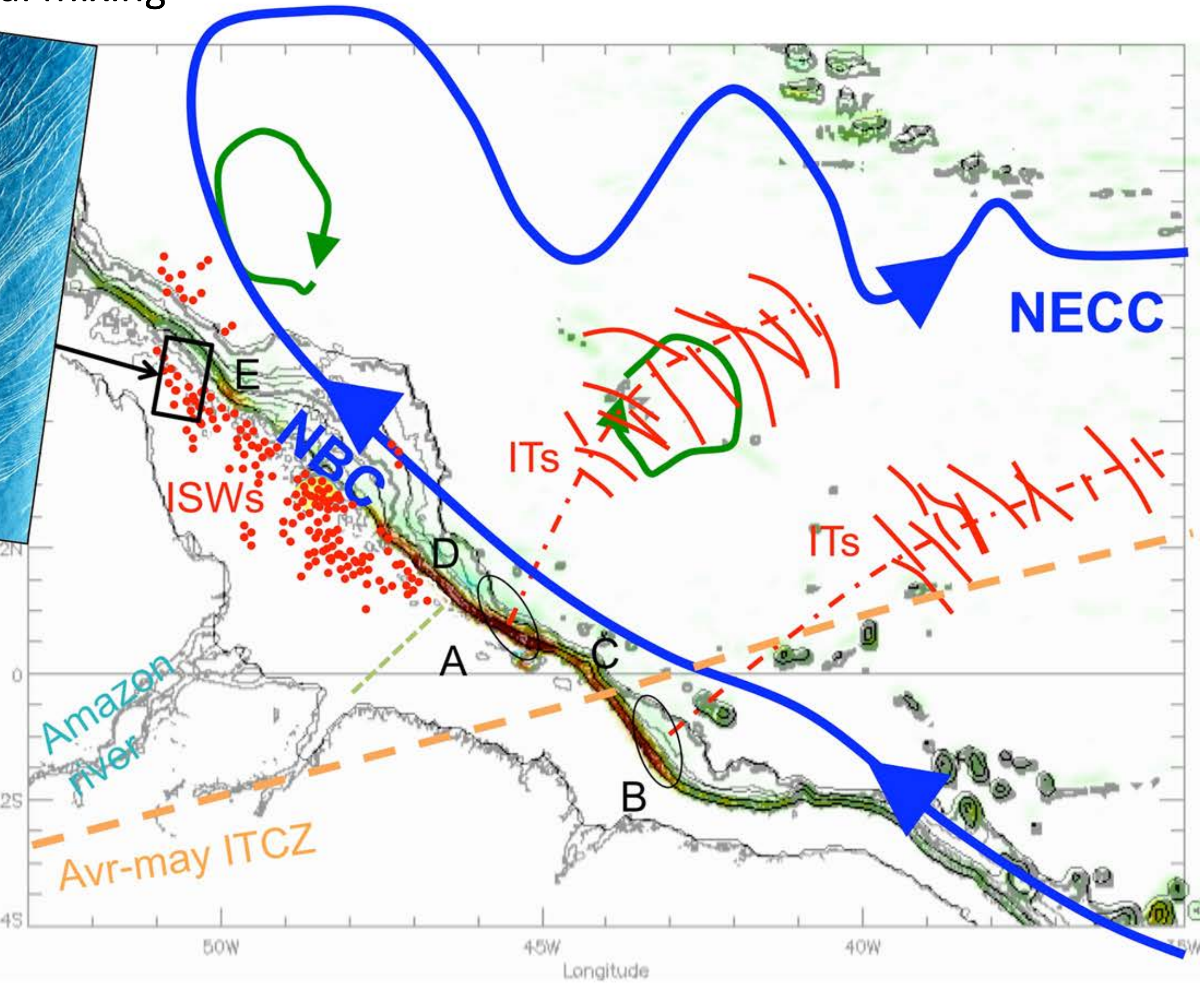
AMAZOMIX

- **France :** A. Koch-Larrouy (IRD), A. Bertrand (IRD), V. Vantrepotte (LOG), I. Dadou (LEGOS), J.F. Ternon (MARBEC), F. Lyard (LEGOS), F. Hernandez (LEGOS), L. Carrere (CLS), J. Jouanno (LEGOS), L. Stemmann (IMEV), T. Desclaux (LEGOS/UFPE ?)
- **Guyana:** F. Blanchard (LEEISA)
- **Brazil :** M. Araujo (UFPE), A. Costa Da Silva (UFPE), M. Silva (UFPE), R. Swchamborn (UFPE), S. Neumann Leitão (UFPE), F. Lucena-Frédou (UFRPE), T. Frédou (UFRPE), M. Kampel (INPE), J. Lee (UFPA), V. Isaac (UFPA), M. Rollnic (UFPA), S. Monteiro (UFPA), J. E. Martilleni Filho (UFPA), P. Calil (FURG)
- **Portugal : José da Silva,** J. Magalhaes (FCUP.)
- **USA:** M. Buijsman (Univ. of Southern Mississippi), A. Subramaniam (Lamont), J.P. Montoya (GATECH)

Charaterization of dissipation and propagation of Internal waves on the Amazon Shelf

- Internal waves generation on the shelf and shelf break
- Some propagate others not
- This will induce strong vertical mixing





Questions :

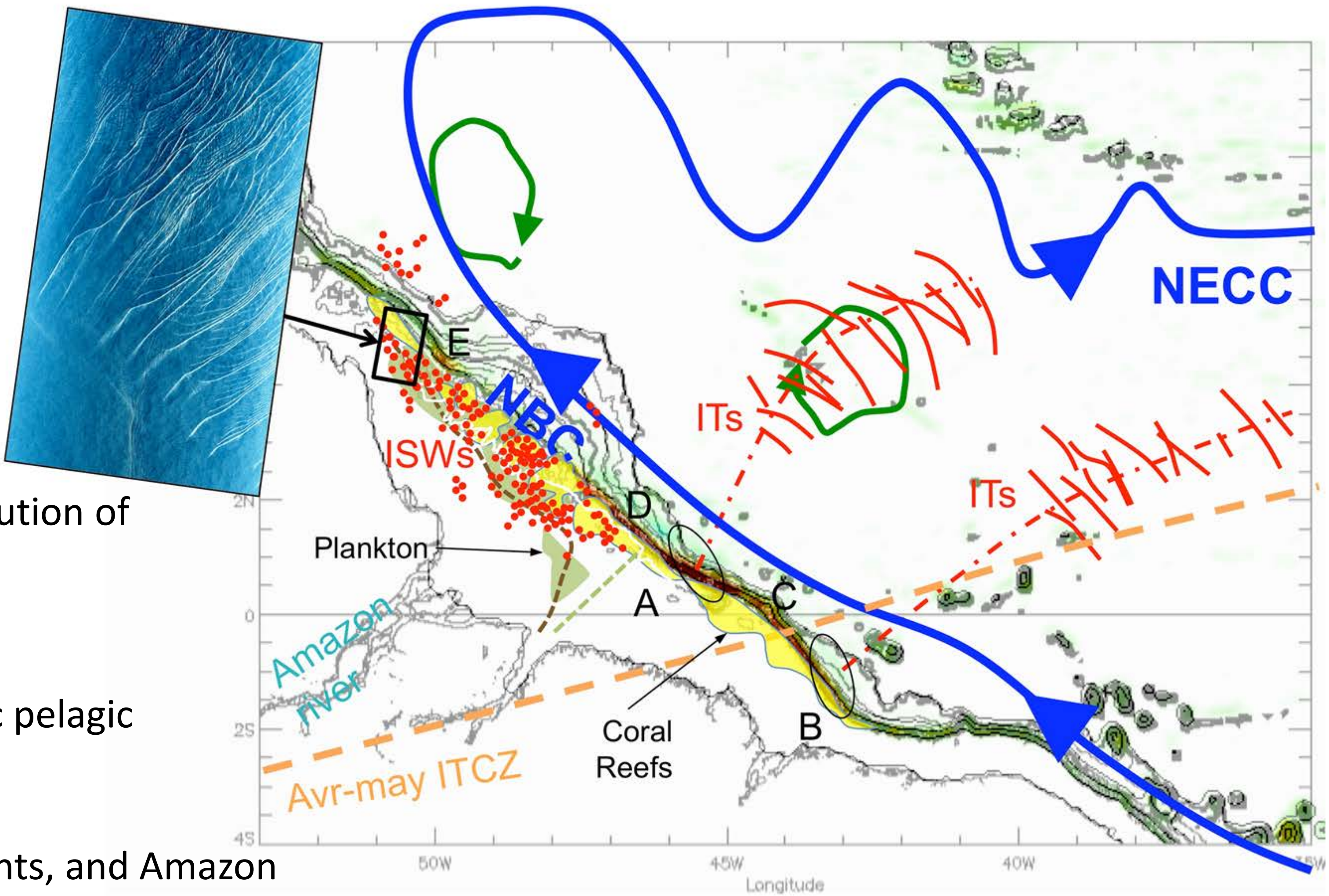
Dissipation local vs. far away from generation sites?

Intensity of dissipation? Could it reach the surface ?

Interaction with the current and eddies ?

Impact of mixing on biogeochemitry and ecosystem

Coral reefs and Planckton bloom may be influenced by this mixing
They might also be influenced by the Amazon River Plume and the currents



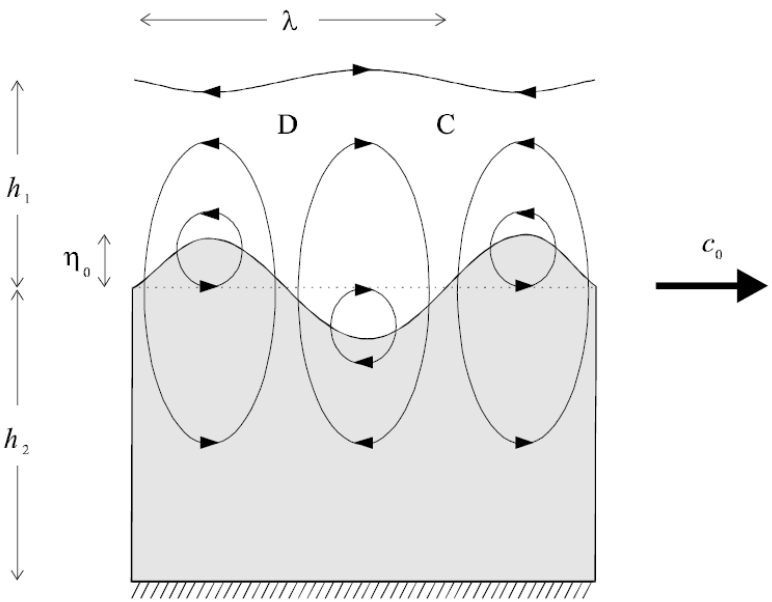
Questions :

What is the distribution of
- Nutrients
- Oxygen
- Plankton
- Meso and benthic pelagic

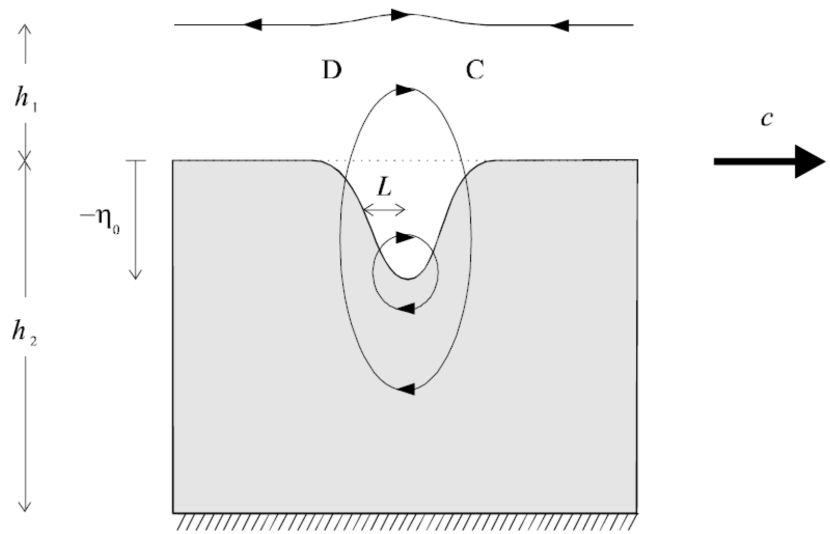
How mixing, currents, and Amazon plume influence the ecosystem ?

INTERNAL SOLITARY WAVES OR INTERNAL SOLITONS

Internal Waves



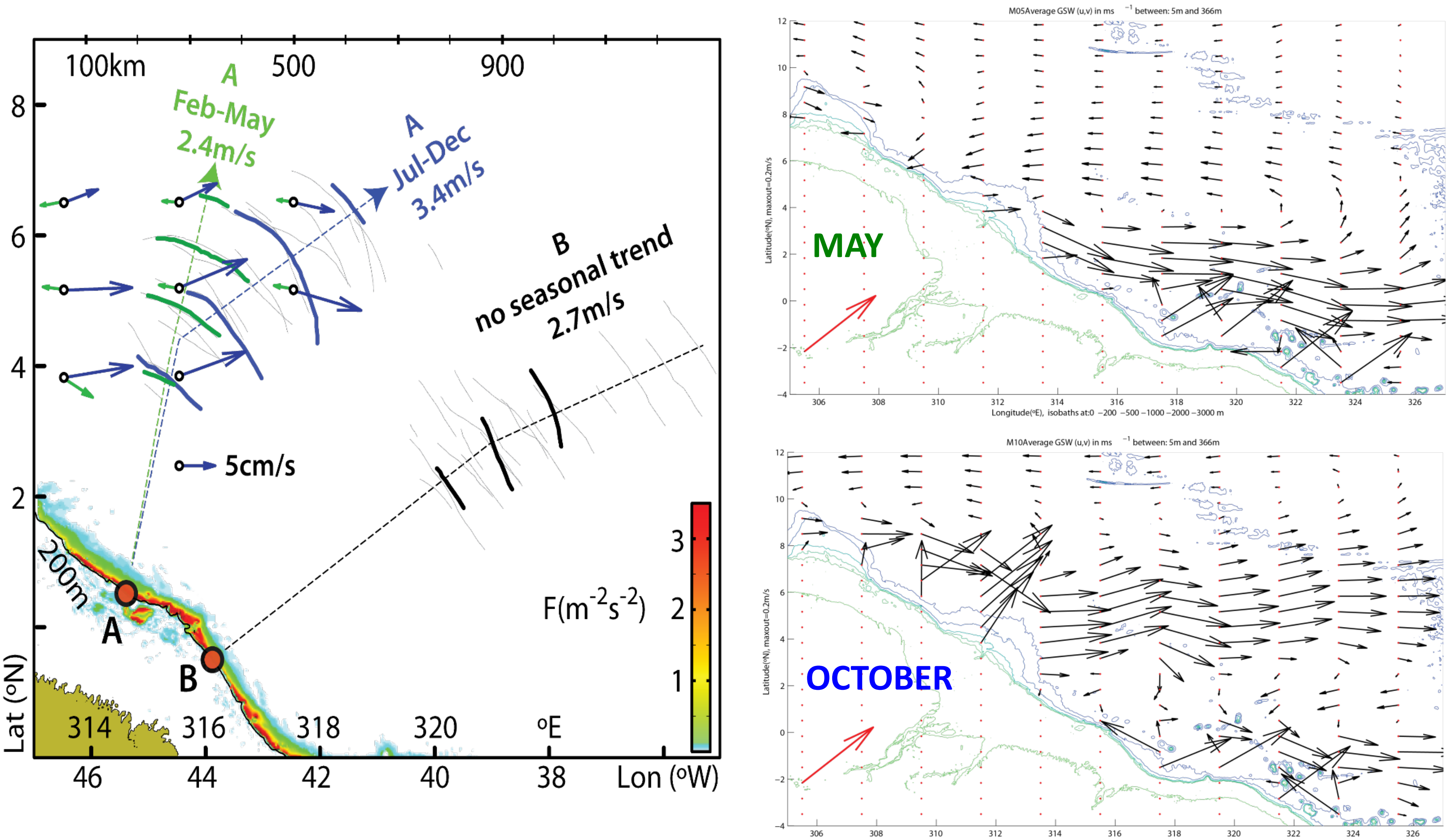
Soliton



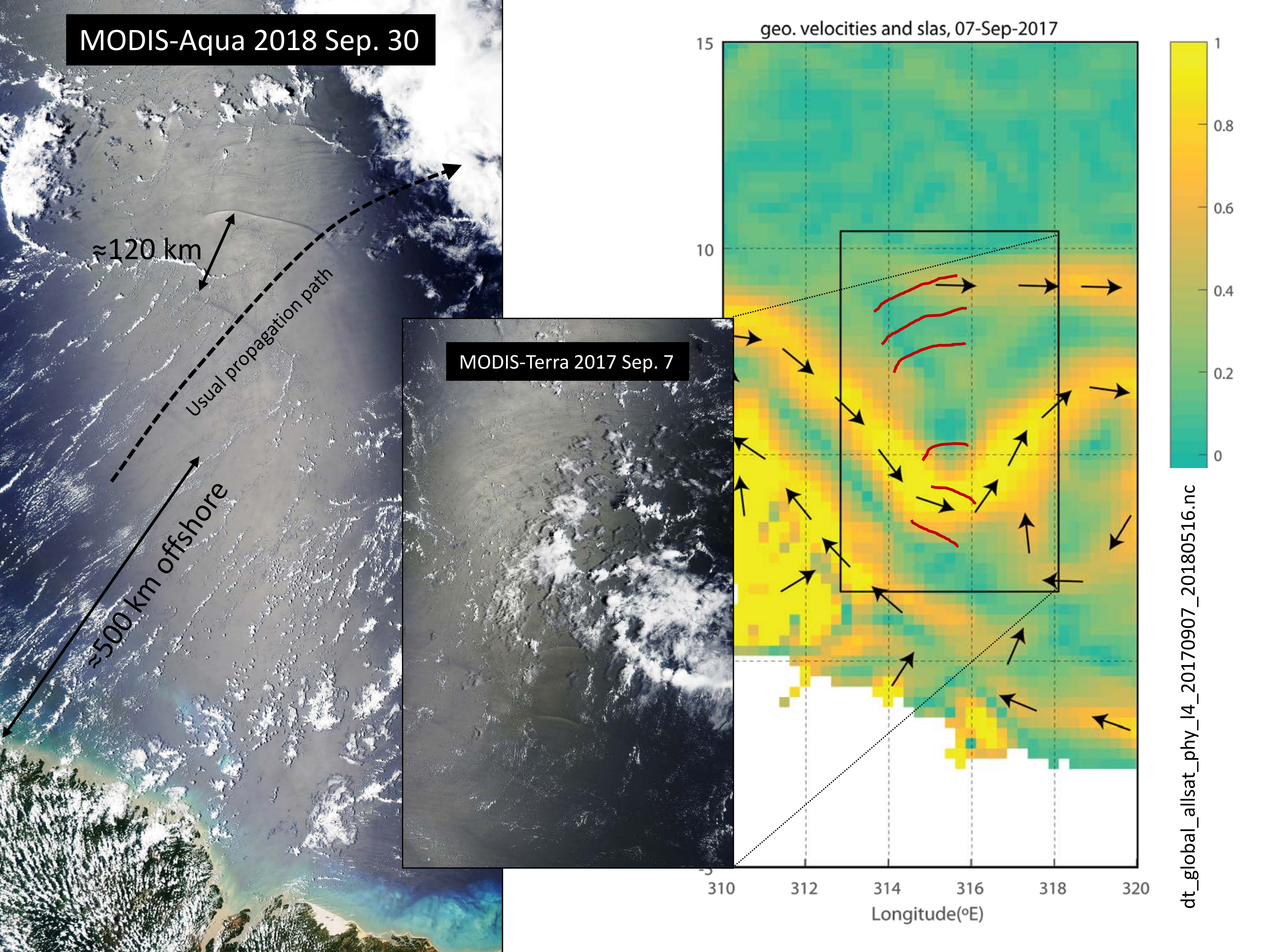
Orbital velocities classified as currents in metocean

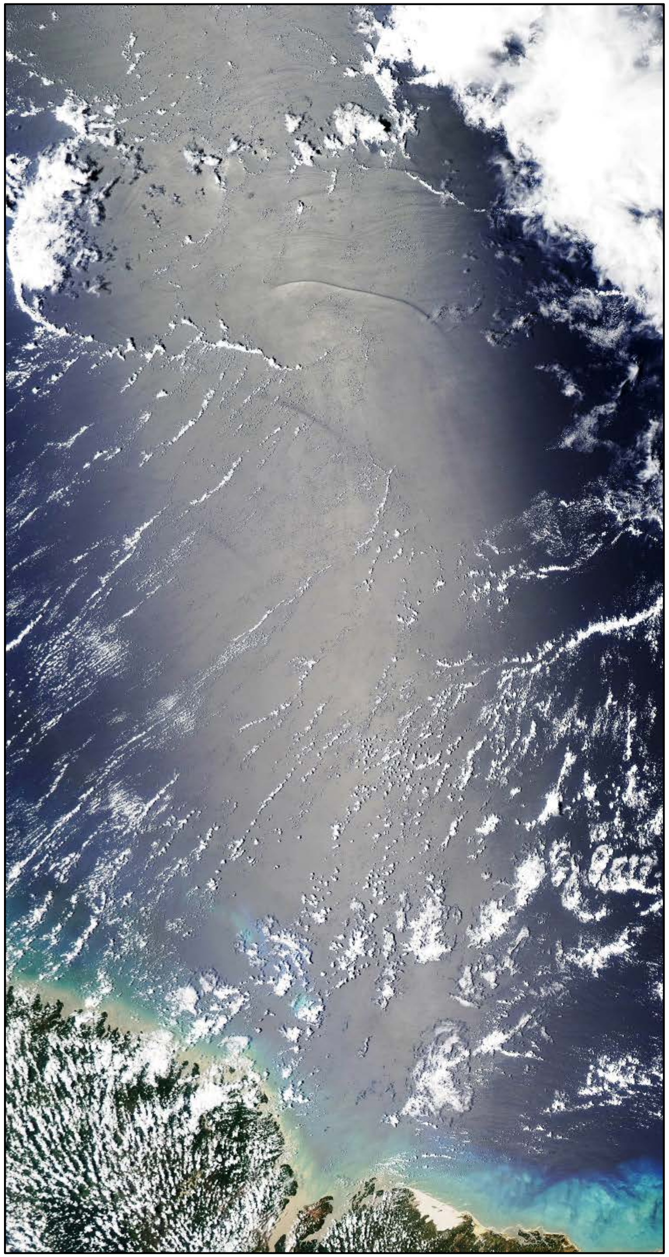
TYPICAL LARGE SOLITON CHARACTERISTICS

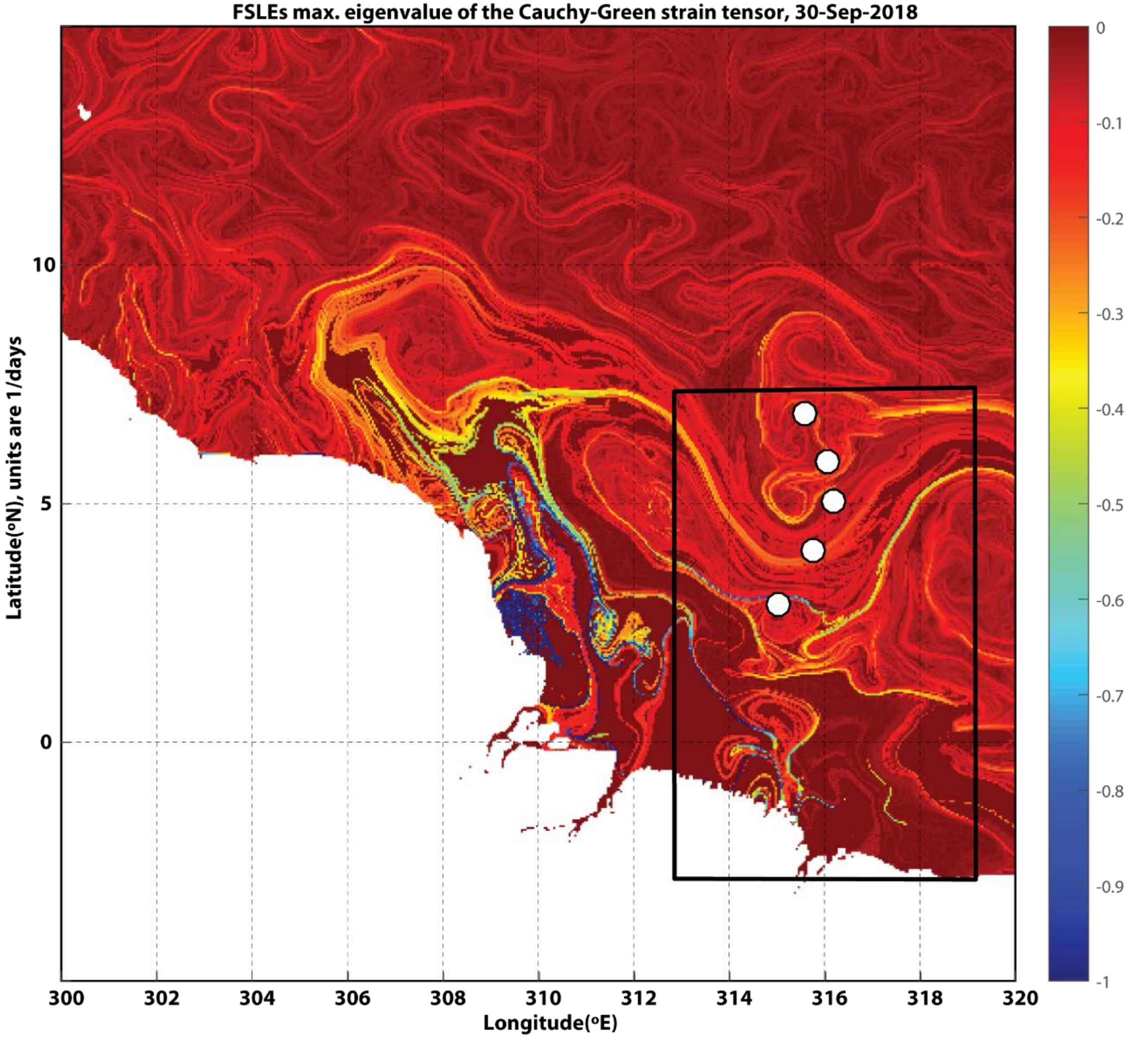
Amplitude	50m to 150m
Horizontal velocity	0.5m/s to 2.0m/s
Vertical velocity	about 1/3 horizontal velocities (0.7 m/s)
Other submesoscale Processes	typical vertical velocities: 0.03 m/s
Length scale	few hundred m to a few km
Duration	15 to 45 minutes
Crest length	200km to 250km (in study region)
Vertical heat fluxes	up to 1000 times more than background
Remote Sensing	SAR imaging and SAR altimetry



100km
500
900
A
Feb-May
2.4m/s
A
Jul-Dec
3.4m/s
B
no seasonal trend
2.7m/s
5cm/s
200m
A
B
F(m-2s-2)
Lat (oN)
Lon (oW)
oE
MAY
OCTOBER
M05Average GSW (u,v) in ms −1 between: 5m and 366m
M10Average GSW (u,v) in ms −1 between: 5m and 366m
Latitude(ºN), maxout=0.2m/s
Longitude(ºE), isobaths at:0 −200 −500 −1000 −2000 −3000 m


MODIS-Aqua 2018 Sep. 30
≈120 km
Usual propagation path
≈500 km offshore
MODIS-Terra 2017 Sep. 7
geo. velocities and slas, 07-Sep-2017
15
10
310
312
314
316
318
320
Longitude(°E)
1
0.8
0.6
0.4
0.2
0
dt_global_allsat_phy_l4_20170907_20180516.nc





- Lagrangian diagnostics (Finite Size Lyapunov Exponents): transport barriers and trajectories of passive tracers
- Predict some structures that are below the altimetric resolution (sub-mesoscale); e.g. interactions of the flow with postbloom chlorophyll and in situ production (nutrients renewals)

More details at: https://www.aviso.altimetry.fr/en/data/products/value-added-products/fsle-finite-size-lyapunov-exponents/fsle-description.html

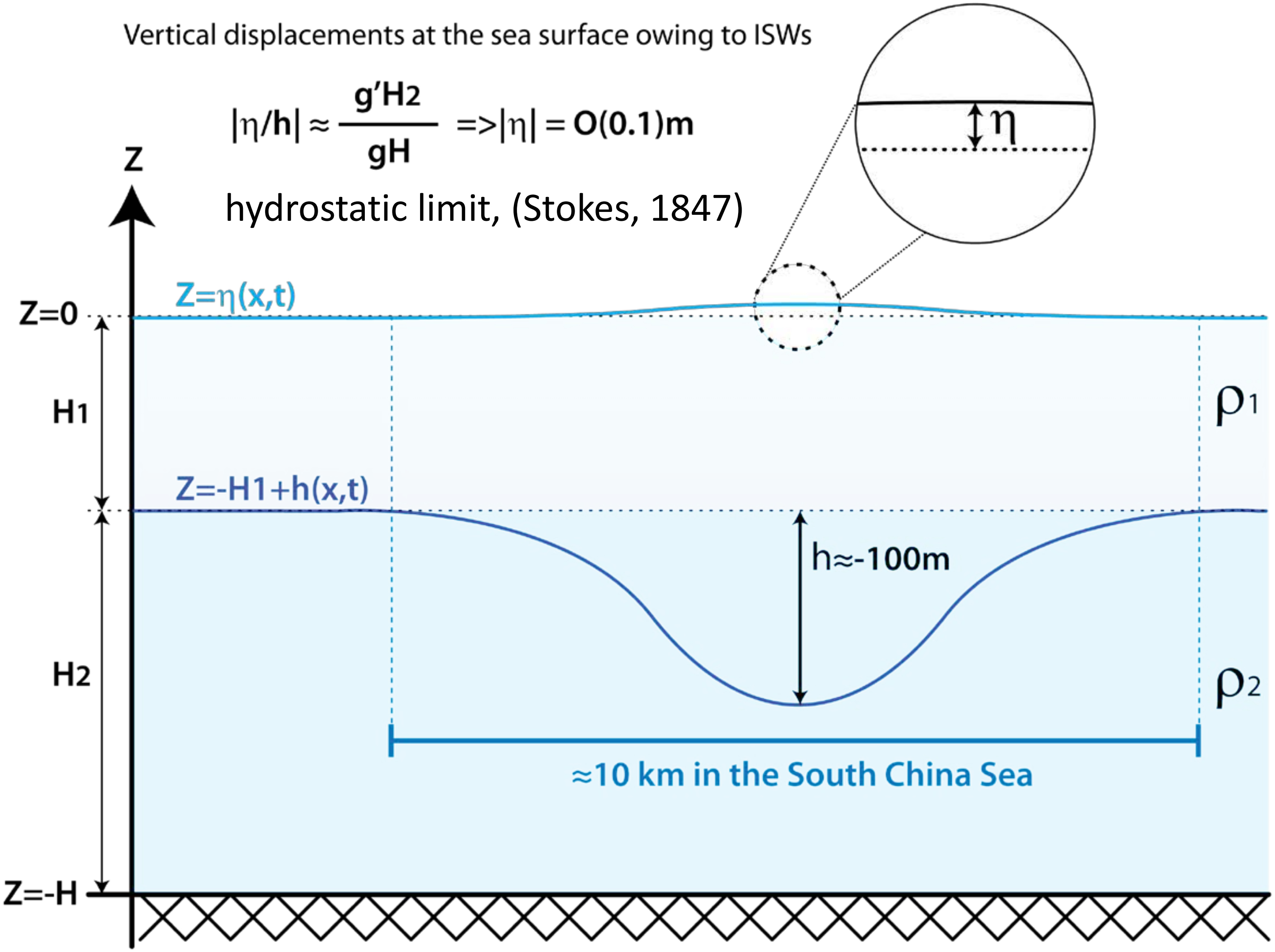
Quantification of Soliton Velocities
Simple Two Layer Theory

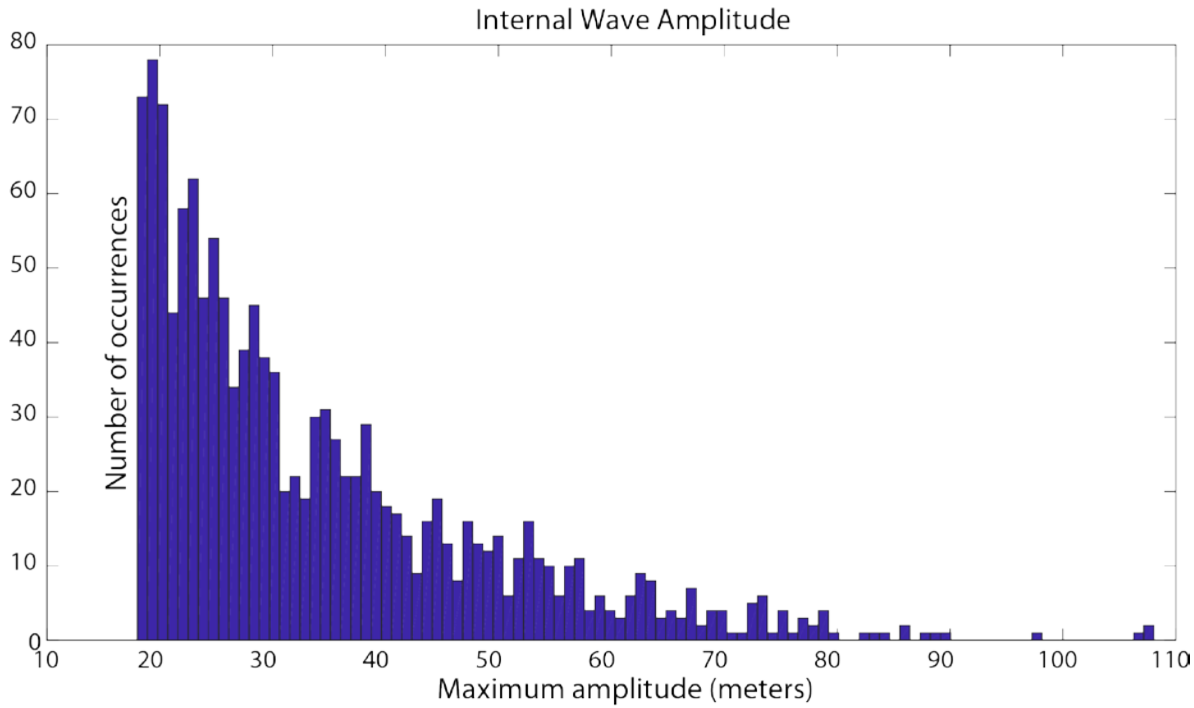
Stratification **Amplitude**

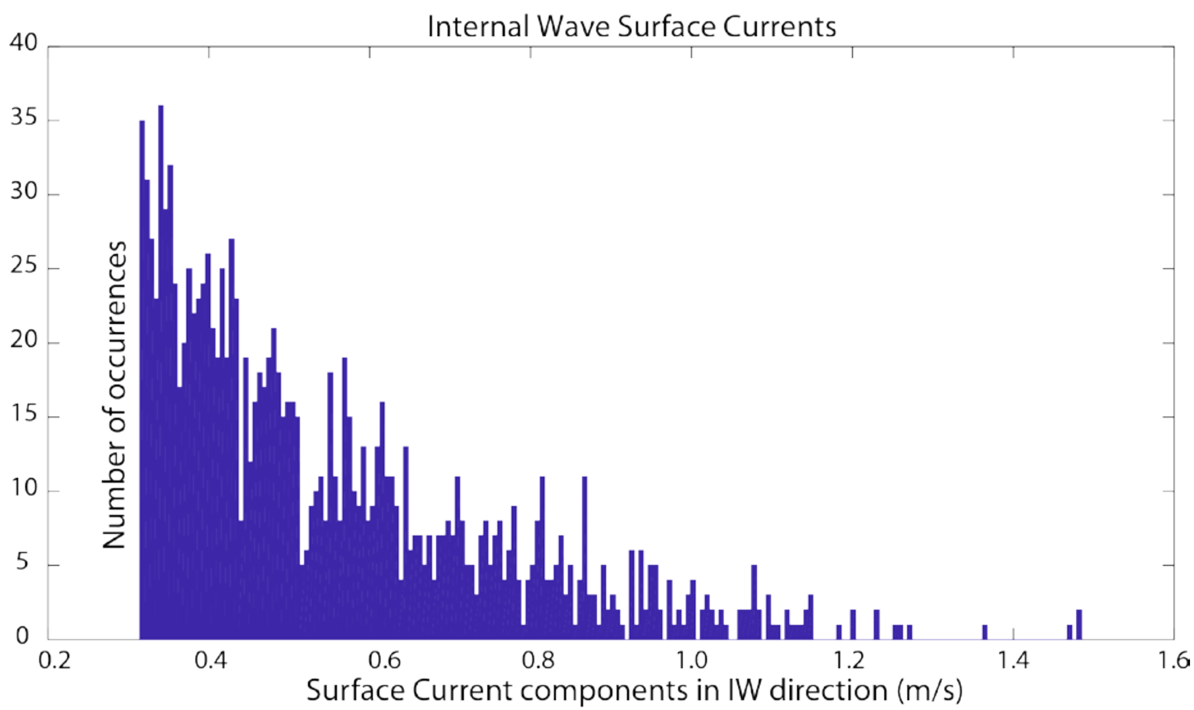
$$u_1 = \frac{c\,\eta}{(h_1 + \eta)}$$

Stratification **Amplitude**

Along-track Satellite SAR altimetry (Sentinel-3 missions)




Internal Wave Amplitude
Number of occurrences
Maximum amplitude (meters)
0
10
20
30
40
50
60
70
80
90
100
110


Internal Wave Surface Currents
Number of occurrences
Surface Current components in IW direction (m/s)
0
5
10
15
20
25
30
35
40
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

Conclusions & recomendations:

- The generation, propagation and dissipation of internal wave energy is an important factor relating to ocean climate, specially in the tropical Atlantic where some of the largest waves in the world interact with currents involved in the AMOC;

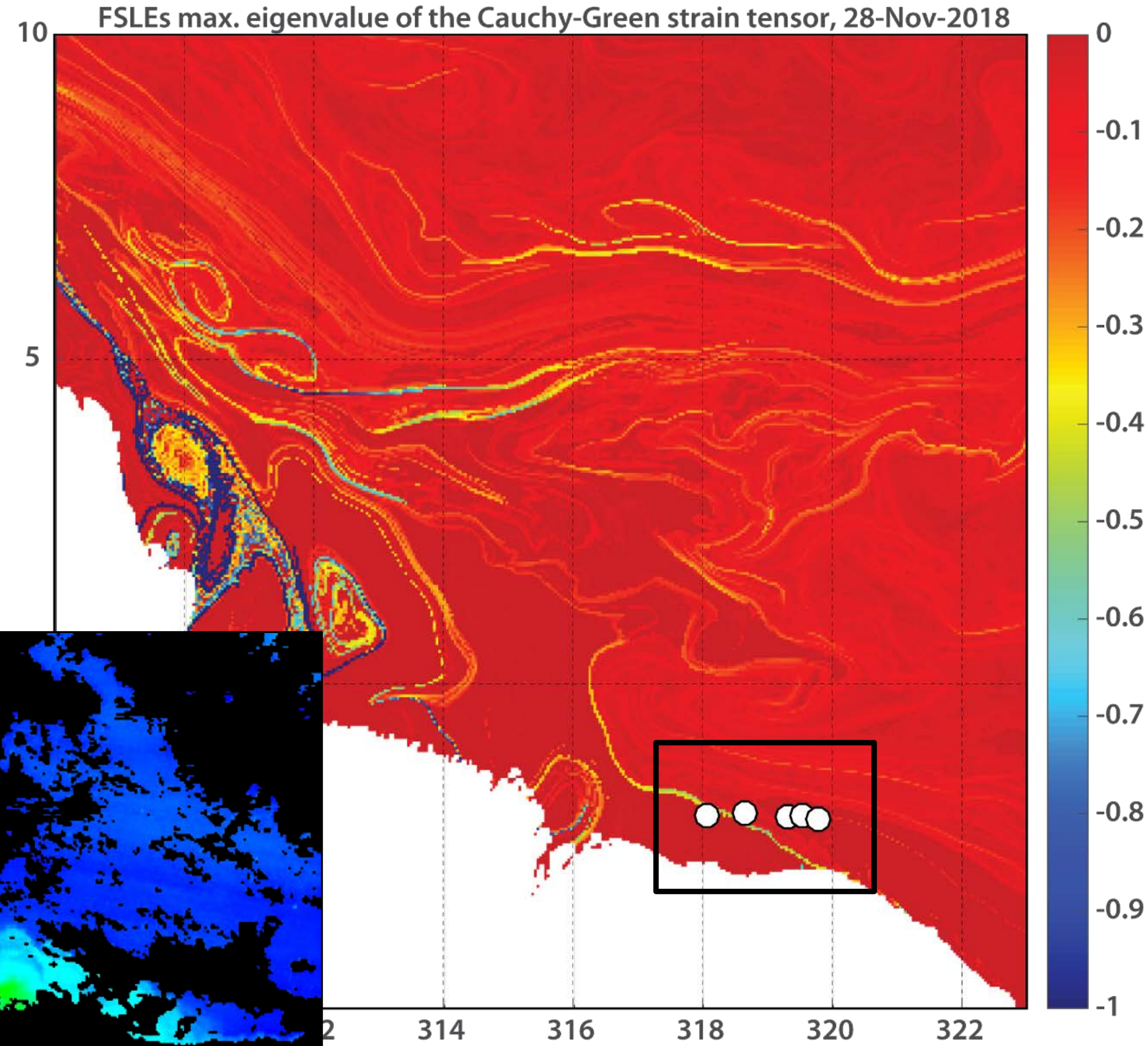
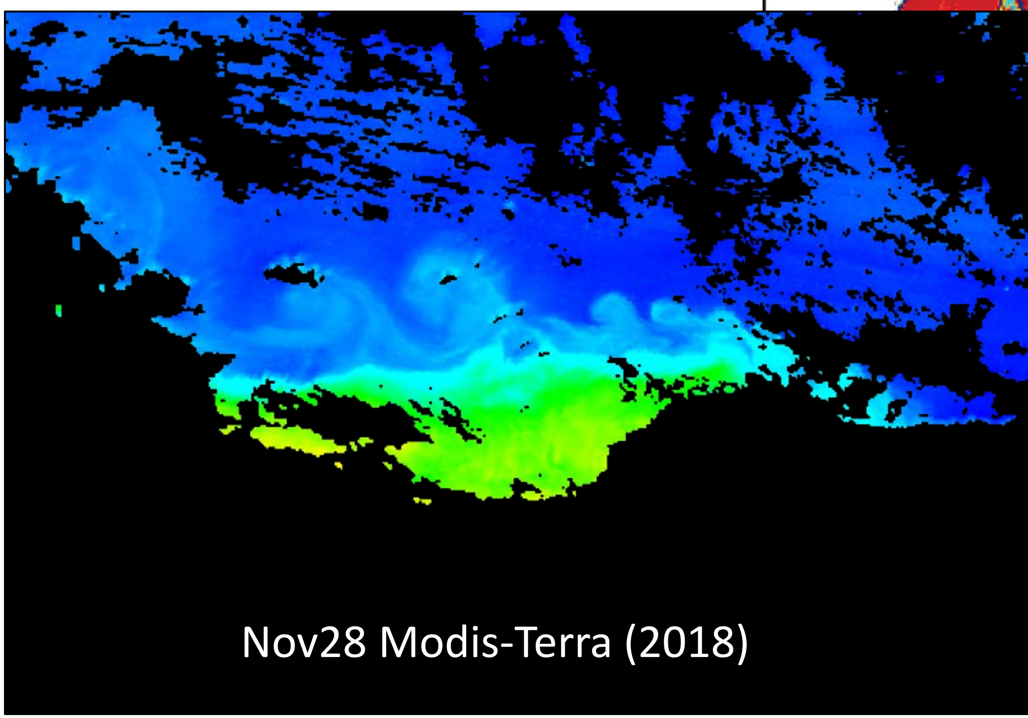
- A new method is available to estimate and predict internal wave amplitudes and propagation in the tropical Atlantic Ocean, based on new generation of satellite altimeters (SAR technique);

- Need support to conduct *in situ* experiments near in the tropical Atlantic, specially near the equator band, where singularities (rotation/Coriollis) prevent the full understanding and predictability of currents and internal waves;

- Algorithms for retrieving IW parameters (such as amplitudes and current profiles) are available, but need tunning/validation with in situ data for more widely applications;

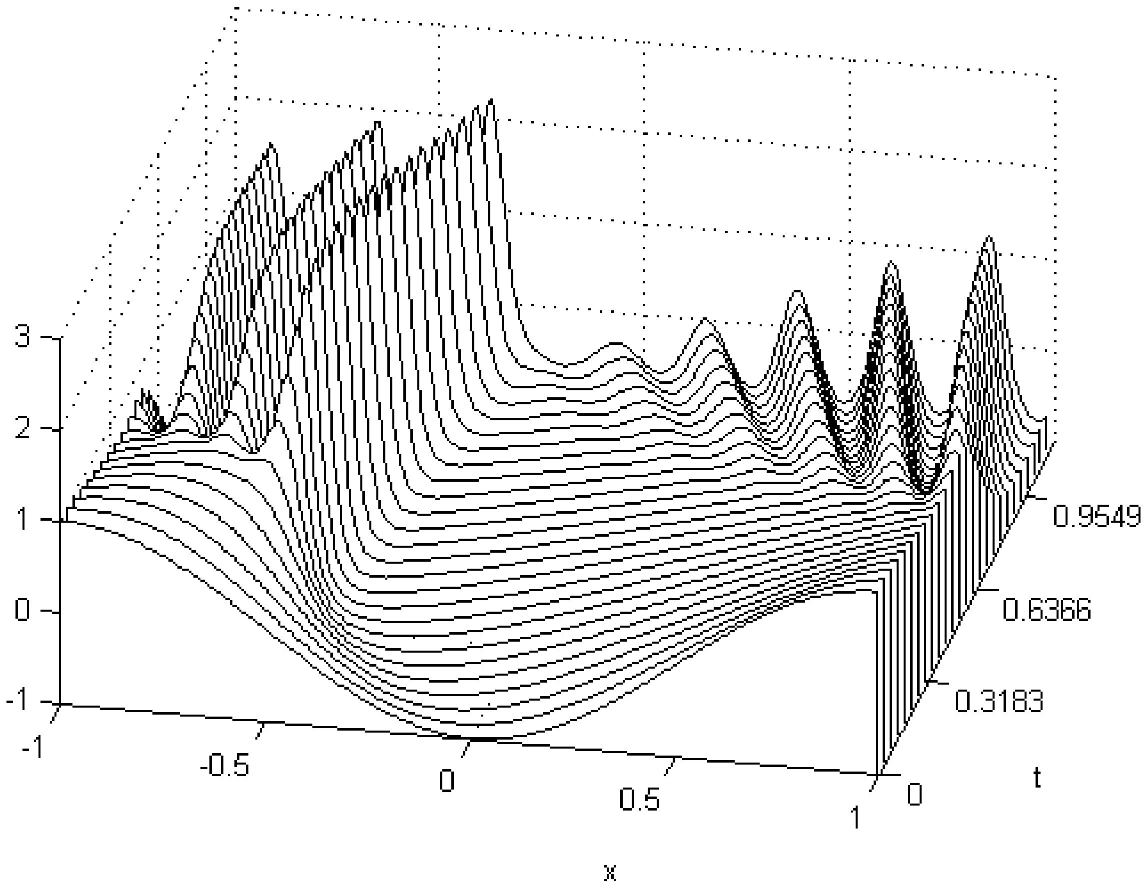
Thank you!

Extra Slides


FSLEs max. eigenvalue of the Cauchy-Green strain tensor, 28-Nov-2018
10
5
2
314
316
318
320
322
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1

Nov28 Modis-Terra (2018)

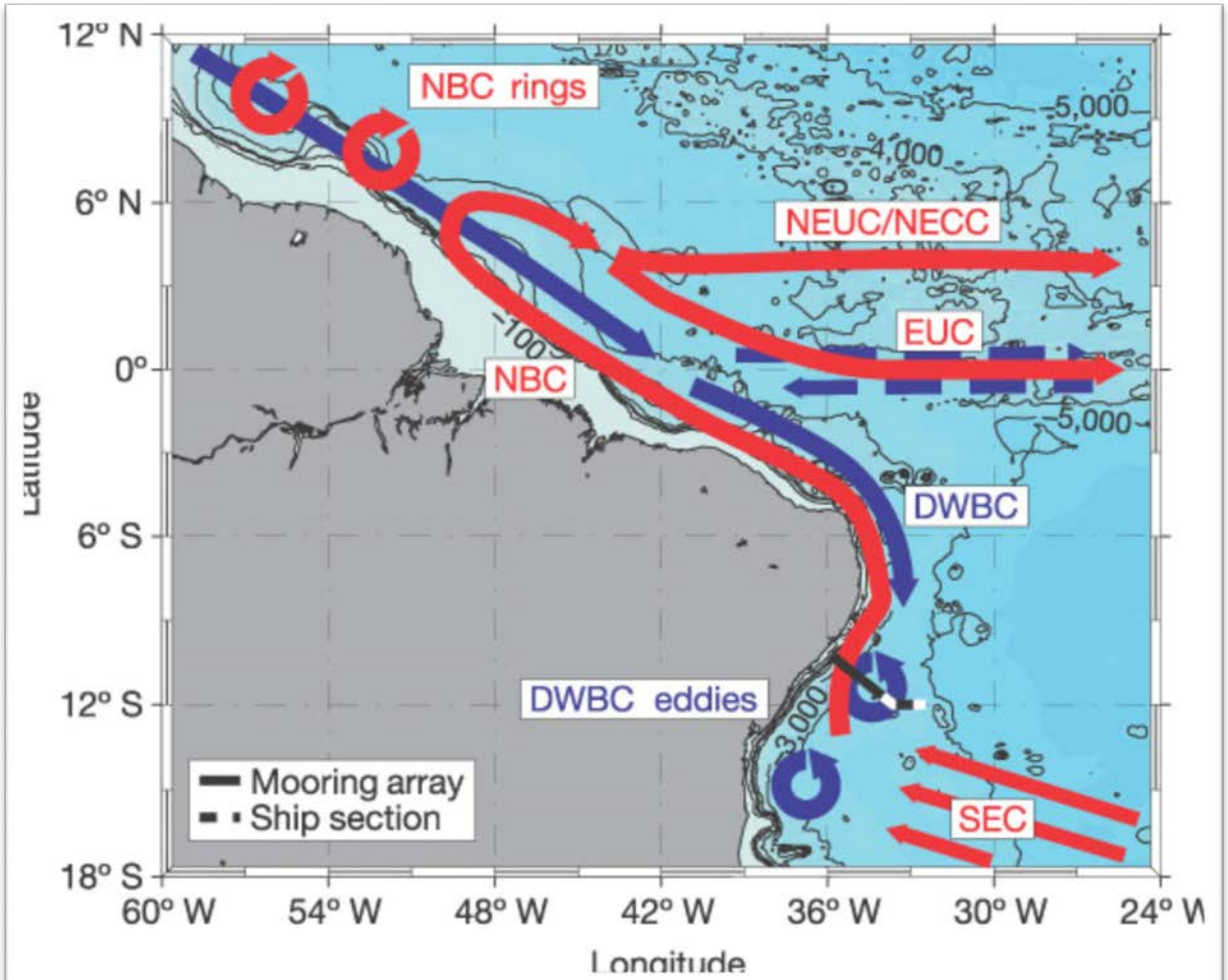
Internal Wave Generation Slides

“*Internal tide release*” may be considered as “*the nonlinear evolution of the internal tide*”, also denominated “*nonlinear desintegration of the internal tide*”.



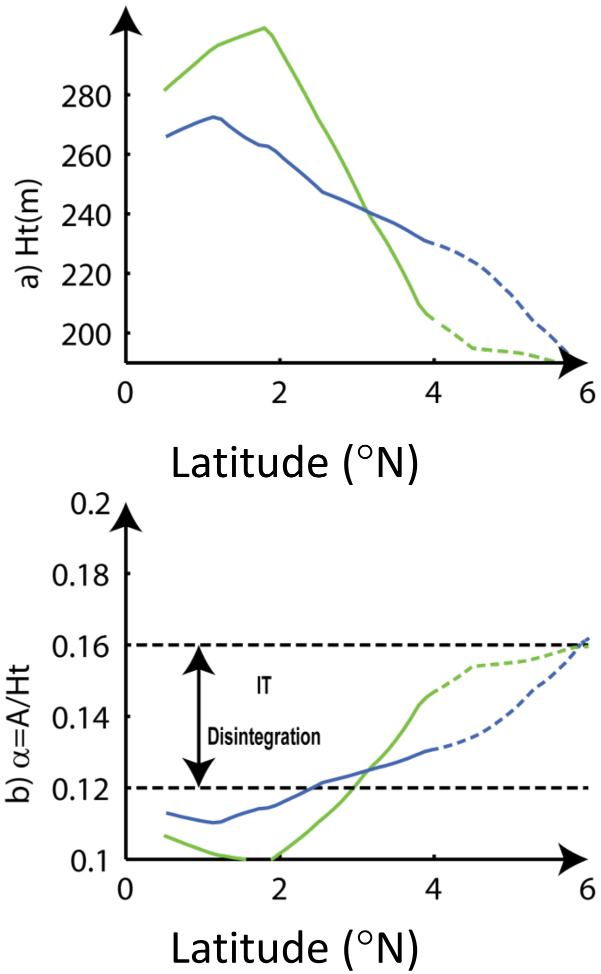
which may be viewed as, another “facet” of the nonlinear desintegration of Zabusky-Kruskal’s waves.

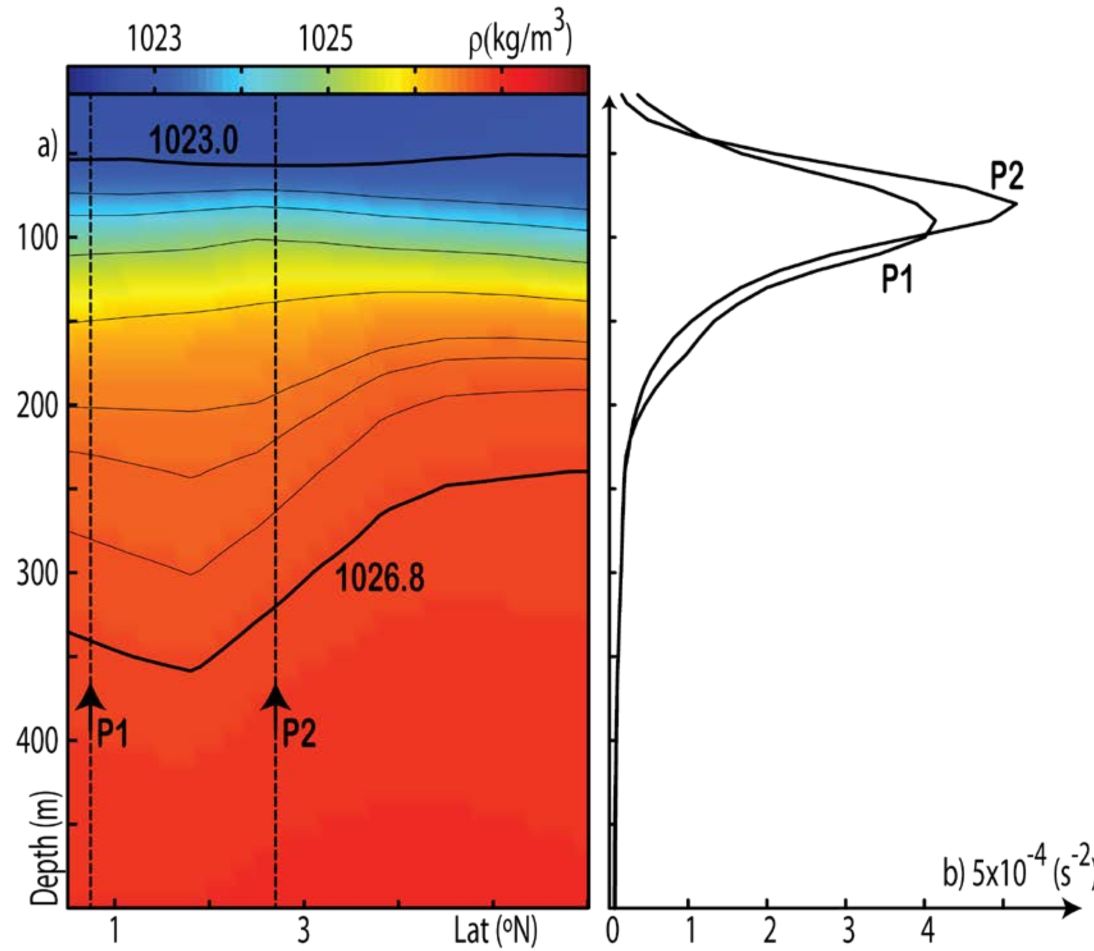
North **E**quatorial **C**ounter **C**urrent (NECC) shows large variability on multiple time scales, with a strong annual cycle (e.g. Garzoli and Katz 1983) and evidence of interannual fluctuations; Hence, a challange to build a predictable model of ISWs.



Schematic representation of mean currents in the tropical Atlantic with warm-water pathways in red and deep water (DW) pathways in blue. Indicated are the south equatorial current (SEC), the north Brazil current (NBC), the equatorial undercurrent (EUC), the north equatorial undercurrent (NEUC) merged with the north equatorial counter current (NECC) and the DWBC with alternating zonal flows marked at the Equator.

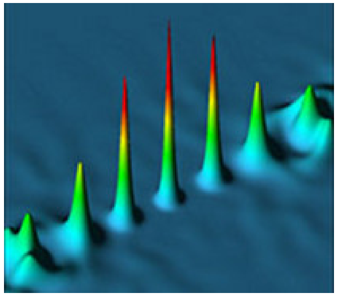
Dengler et al. 2004


a) Ht(m)
280
260
240
220
200
0
2
4
6
Latitude (°N)
b) α=A/Ht
0.2
0.18
0.16
0.14
0.12
0.1
IT
Disintegration
0
2
4
6
Latitude (°N)


1023
1025
ρ(kg/m3)
a)
1023.0
100
200
300
400
1026.8
P1
P2
Depth (m)
1
3
Lat (oN)
P2
P1
b) 5x10-4 (s-2)
0
1
2
3
4

Nonlinear parameter

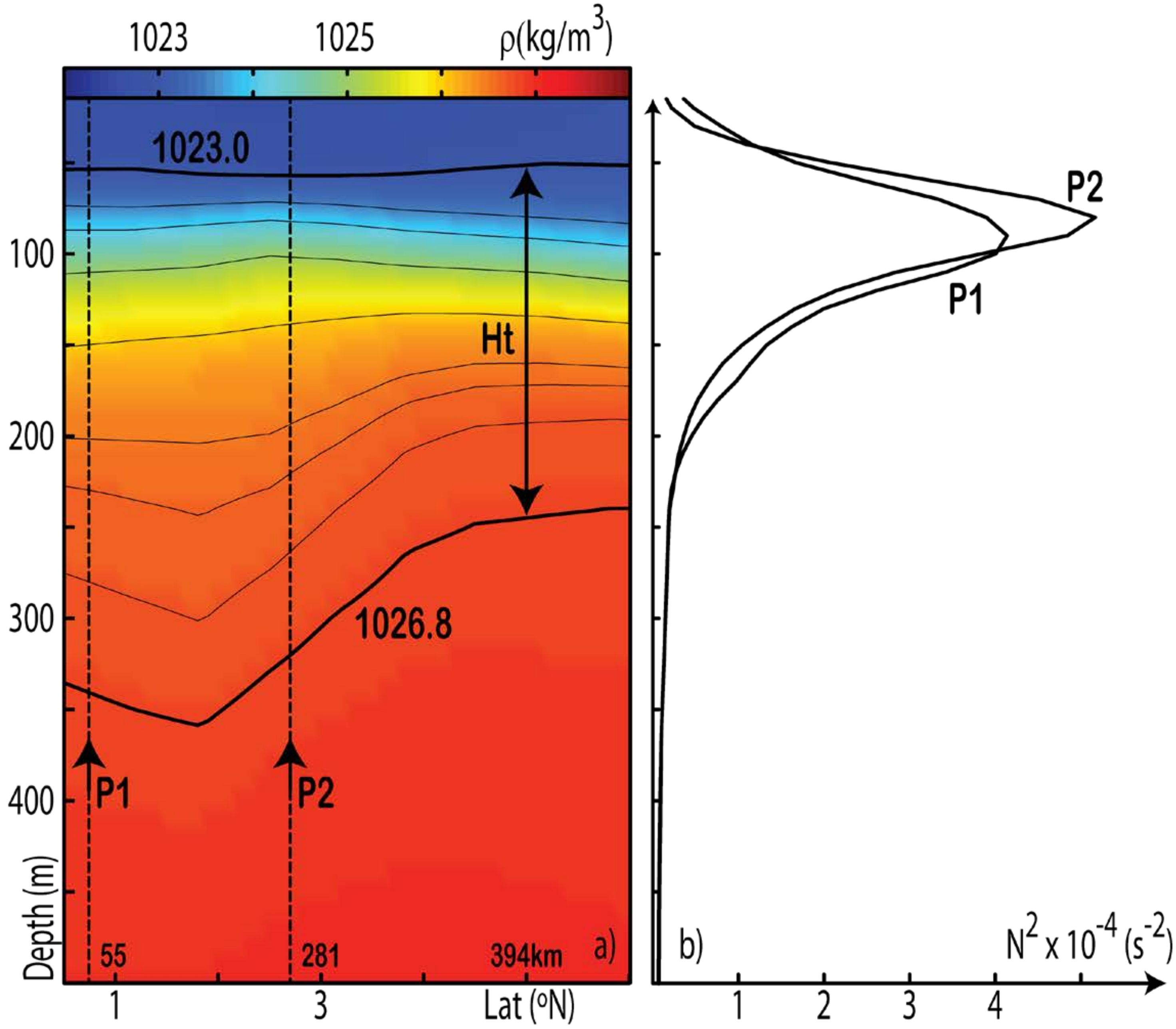
$$\alpha = \frac{A}{H_t}$$



Frequency dispersion term

$$\delta = \left(\frac{H_t}{L}\right)^2$$

$H_t \searrow \quad \alpha \nearrow \quad L \searrow \quad \delta \nearrow$



From Magalhaes, da Silva and M.C. Buijsman, 2016 (Ocean Sciences)