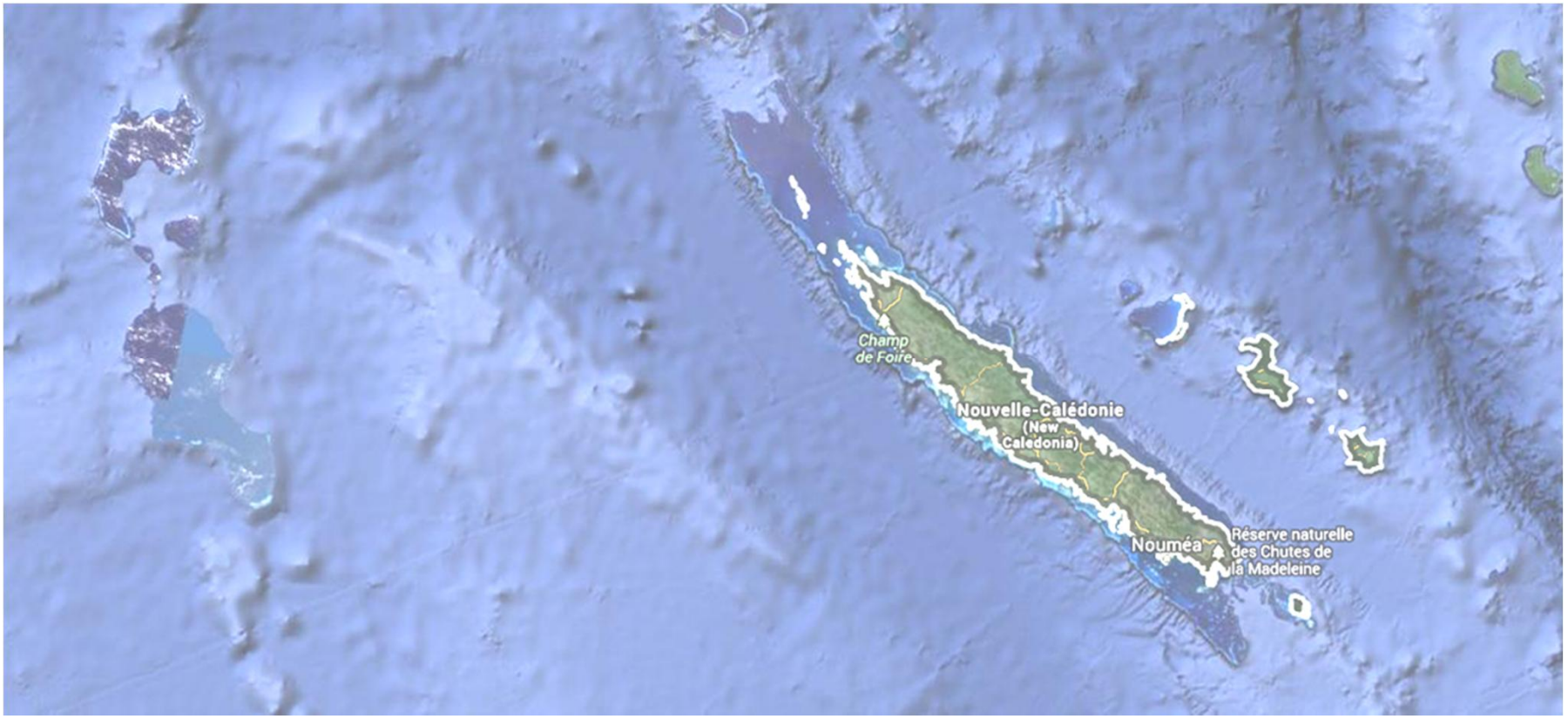
I mpact of the coral-reef barrier in the fonctionning of a narrow coral-reef lagoon.

E xemple in the Ouano coral reef lagoon (N ew Calédonia)



Boundary conditions identification

Determination of the lagoon/ocean exchange along coral-reef

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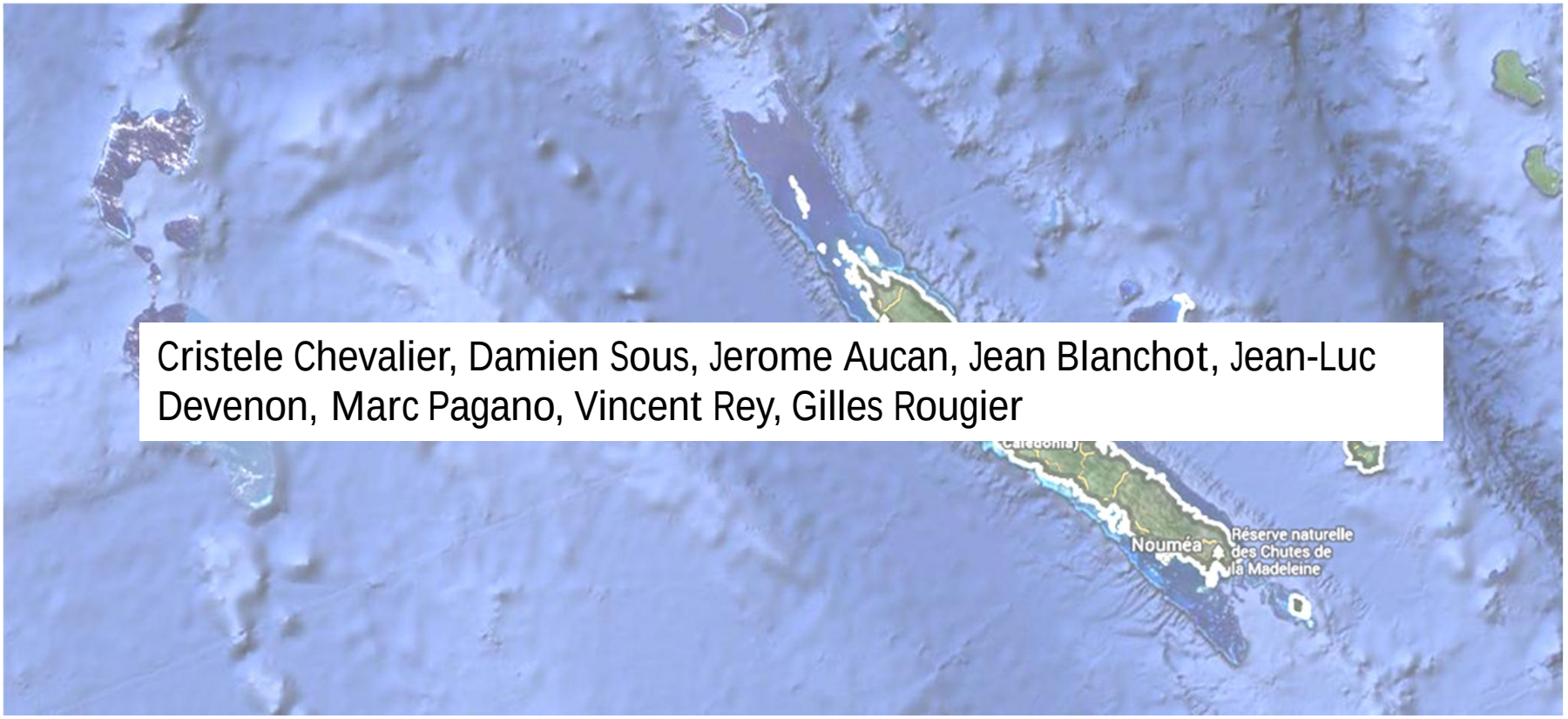


Cristele Chevalier, Damien Sous, Jerome Aucan, Jean Blanchot, Jean-Luc Devenon, Marc Pagano, Vincent Rey, Gilles Rougier

Boundary conditions identification

Determination of the lagoon/ocean exchange along coral-reef

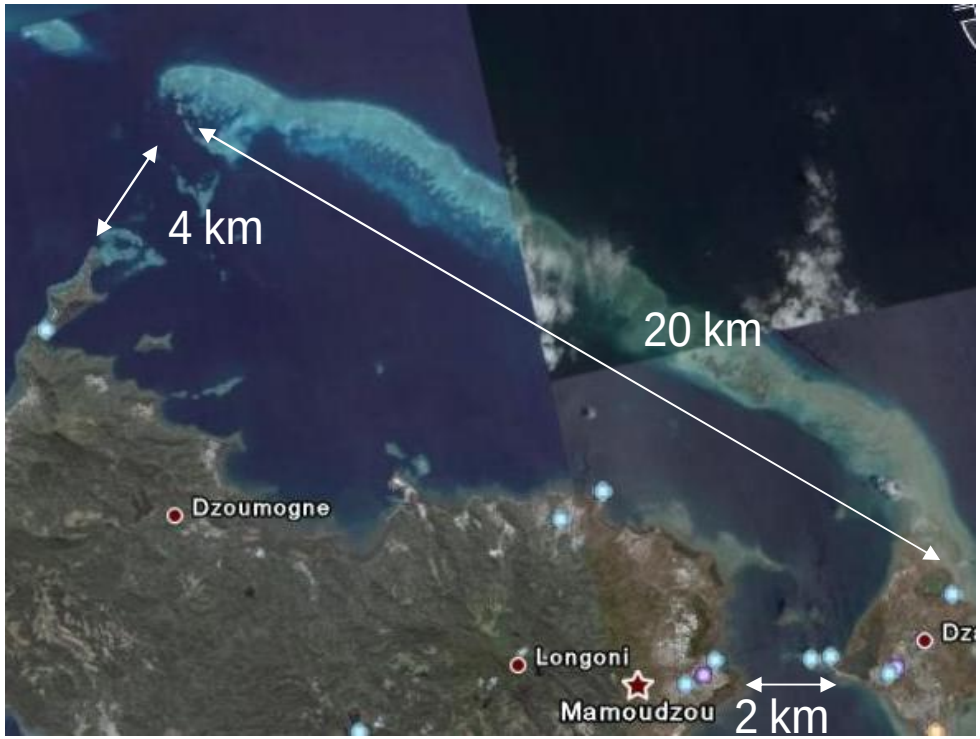
Narrow coral reef lagoon

What do I mean with a narrow coral reef lagoon ?

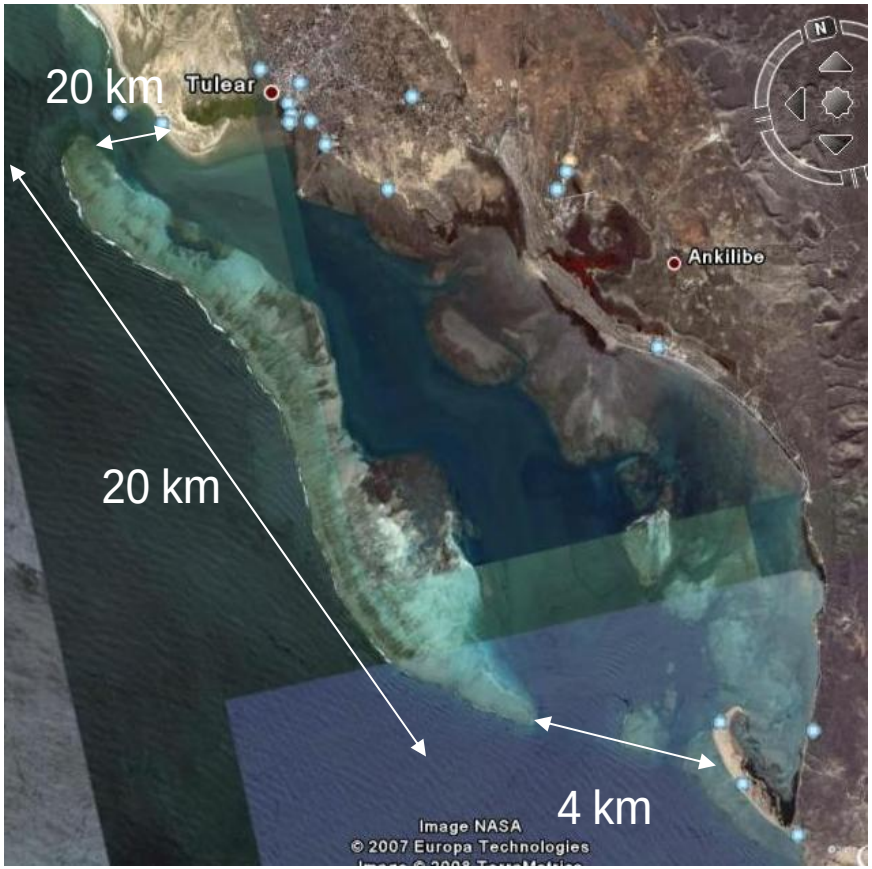
length >> width

Small passages << coral reef barrier length

Mayotte



Tuléar (Madagascar)



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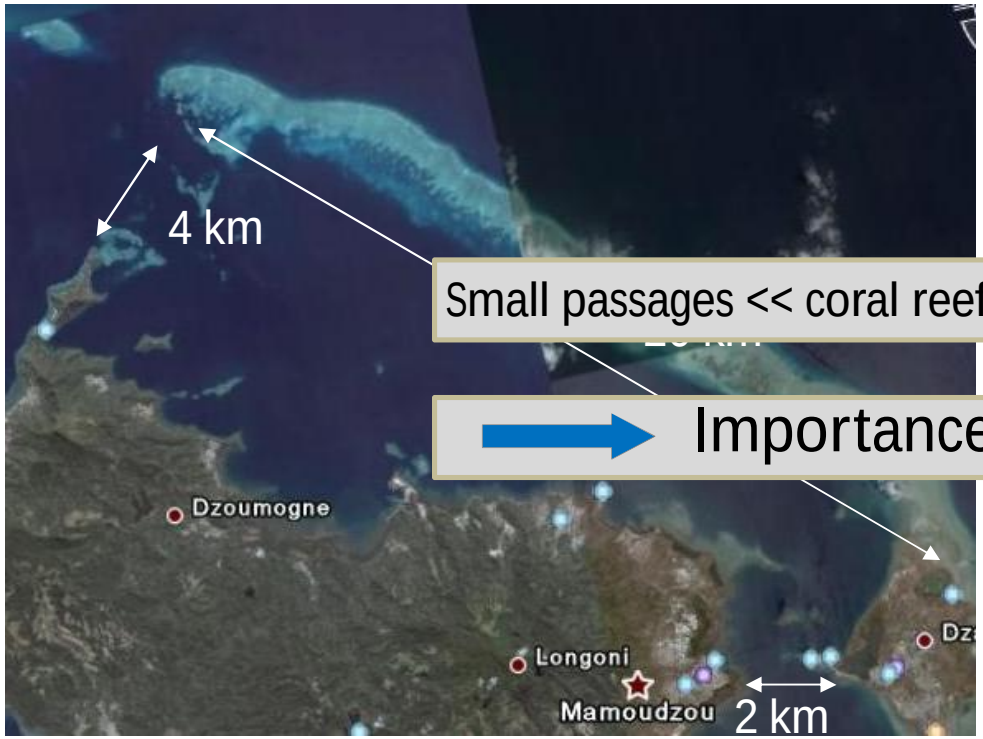

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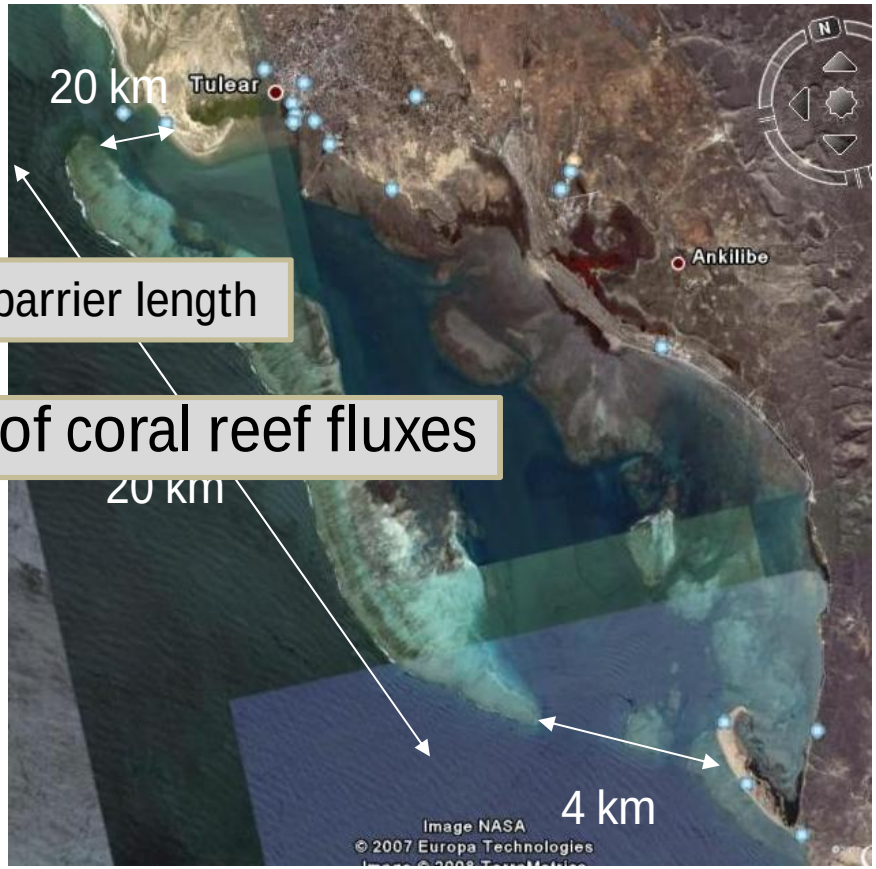


Small passages << coral reef barrier length

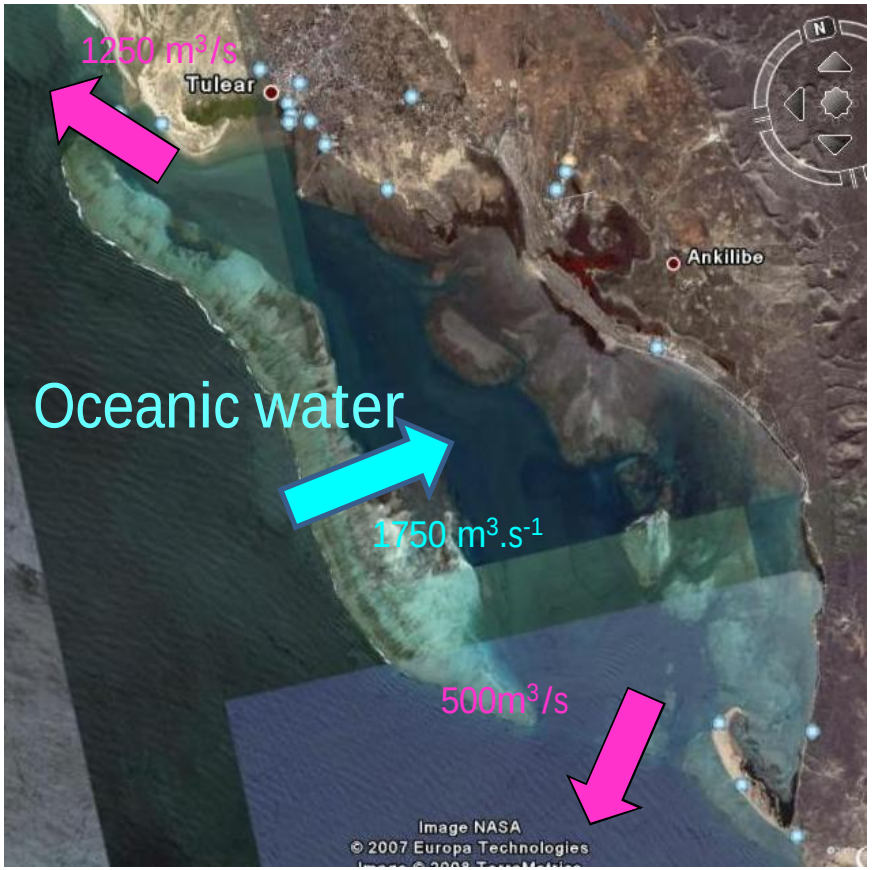
Importance of coral reef fluxes

Narrow coral reef lagoon

For example :

Mayotte :

Tulear :



Complex dynamics

Motivations

Motivation:
Whereas ocean around New Caledonia is poor (Oligotrophe), lagoon who surrounds the island is a high spot of biodiversity.

We want to understand why

Objectives:
We want to understand their role in the high productivity of the water in New Caledonia littoral.

Understand the reef of cross-reef fluxes on lagoon dynamics

Then we have to

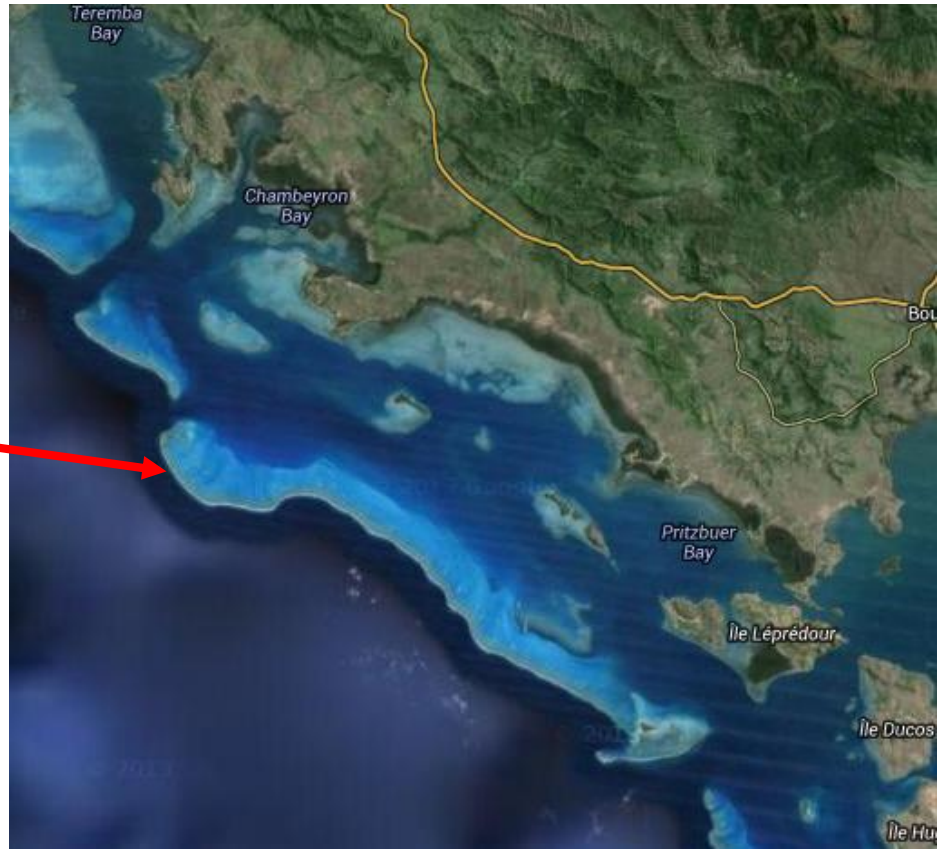
Identify boundary conditions
Determine the lagoon/ocean exchange s along coral-reef

Methodology

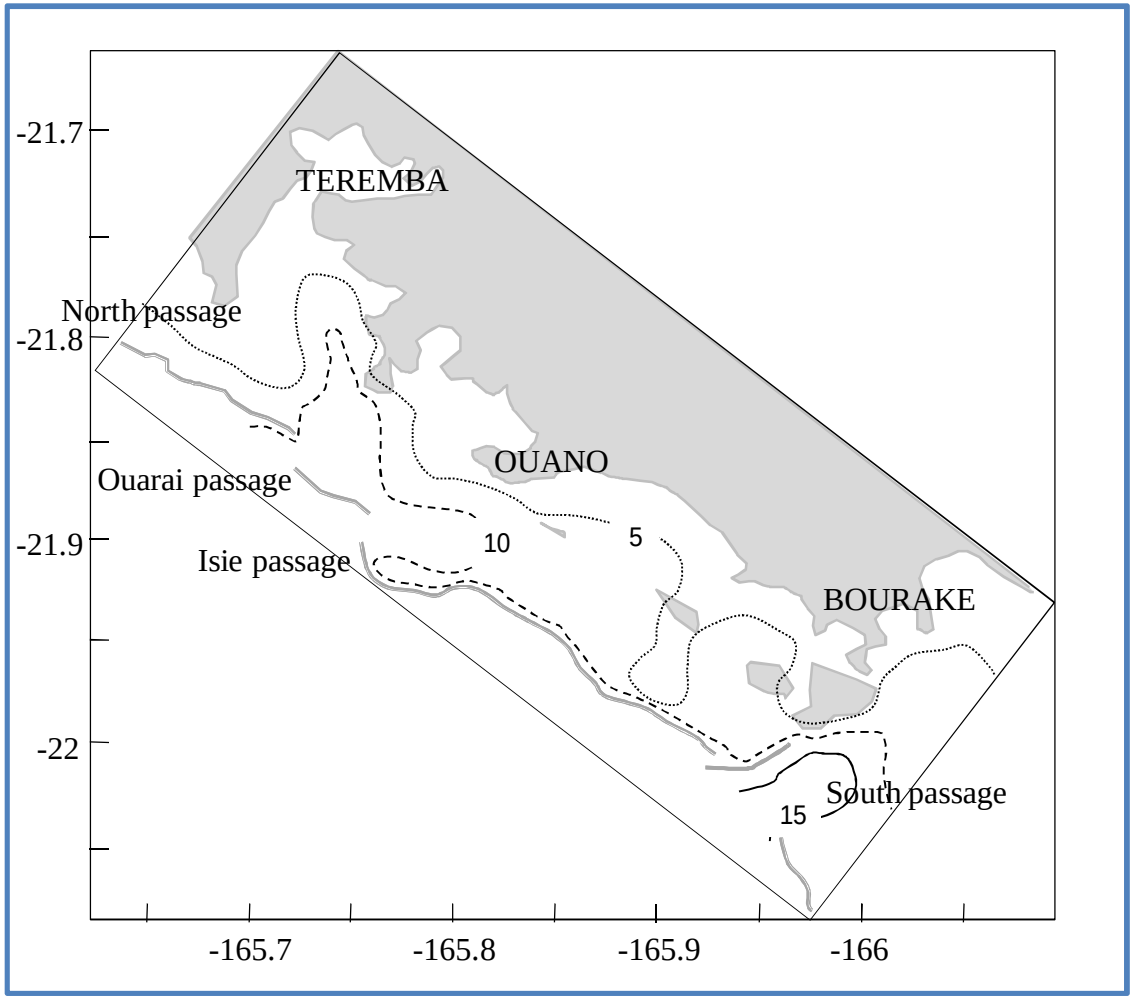
- Methodology:
  - Coupling Model and in-situ measurements:
    - Field surveys has been conducted in 2011 and 2013
    - Numerical tests are performed to evaluate the impact of cross-reef fluxes on this circulation.
  - Biological measurements

Ouano lagoon

We choose the Ouano lagoon as example :



Ouano lagoon



4 openings :

Reef passages connected to the ocean:

- Isie passage
- Ouarai passage

Channel between reef and coast :

- North passage
- South passage

Reef barrier : 20 km long

Ouano Lagoon :

Size : 20 * 10 km

Mean depth : 10 m

Ouano Lagoon / Ocean exchanges

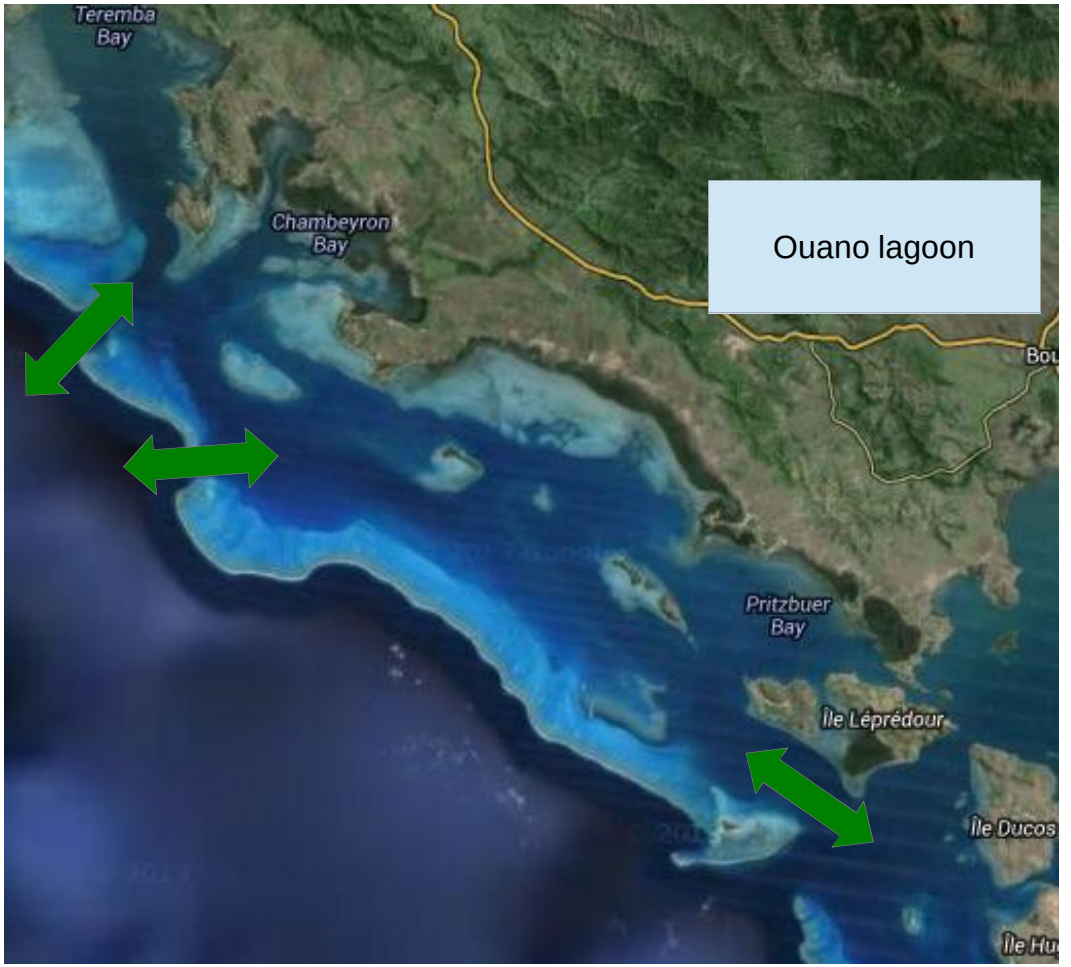
Lagoon / Ocean exchanges

through passages

Sections :

Section of passages :

L = 3 000 m, H = 10 m then 30 000 m²



Ouano Lagoon / Ocean exchanges

Lagoon / Ocean exchanges

through passages

above the coral reef

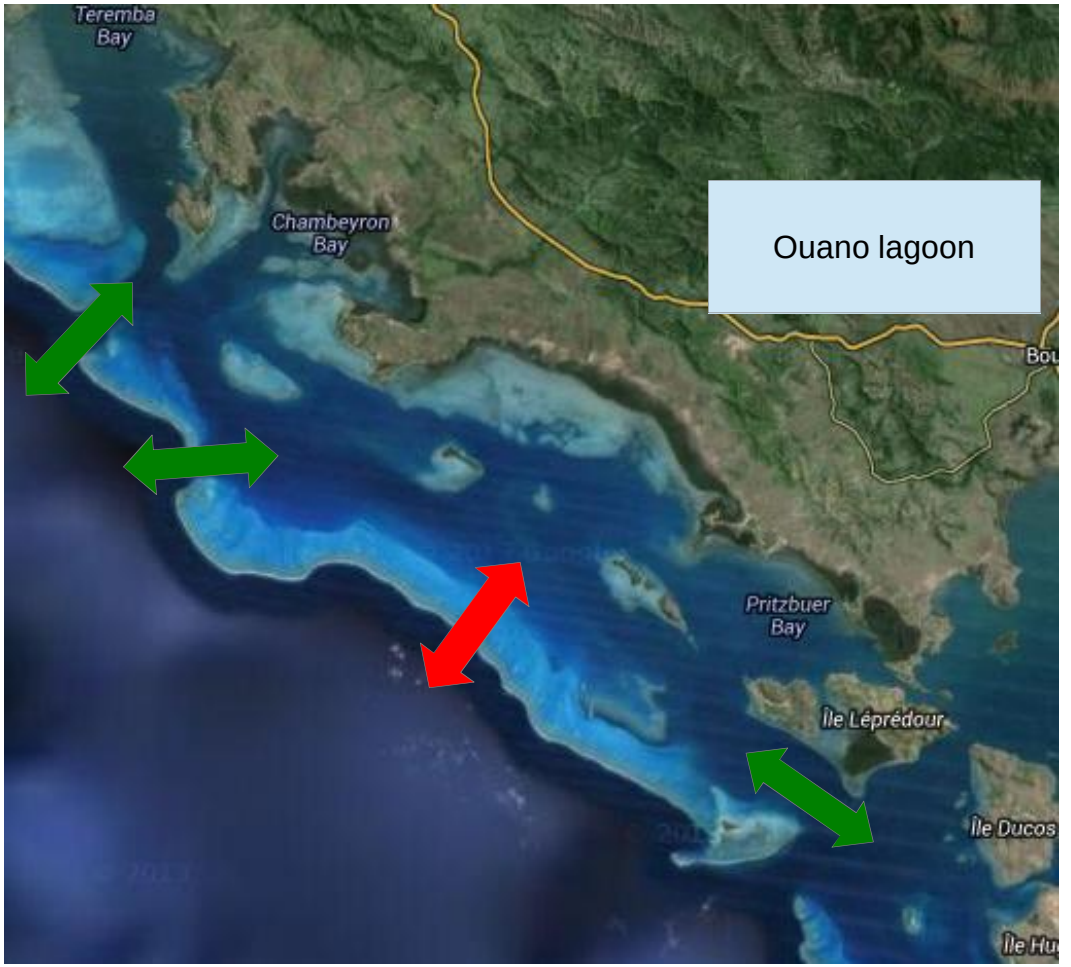
Sections :

Section of passages :

L = 3 000 m, H = 10 m then 30 000 m²

Section above the reef :

L = 20 000 m, H = 3 m then 60 000 m²

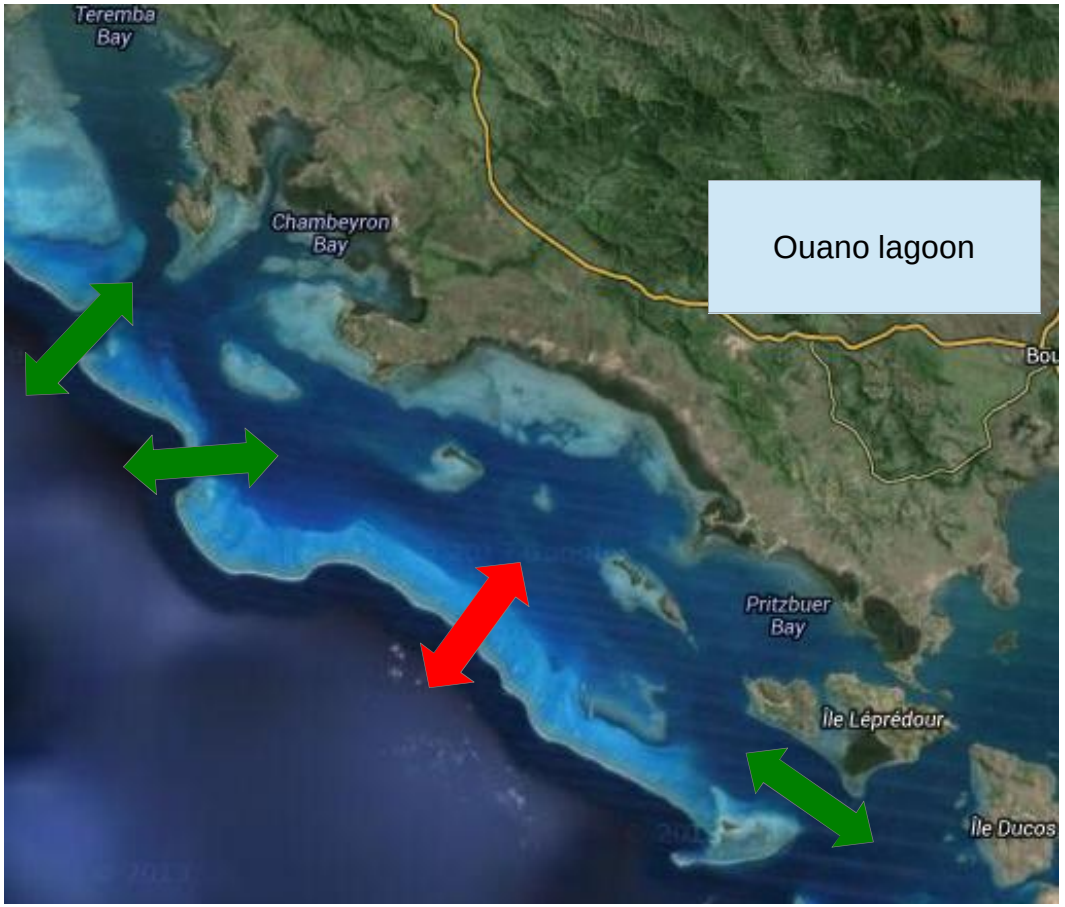


Ouano Lagoon / Ocean exchanges

Lagoon / Ocean exchanges

through passages

above the coral reef



Sections :

Section of passages :

L = 3 000 m, H = 10 m then 30 000 m²

Section above the reef :

L = 20 000 m, H = 3 m then 60 000 m²

It may have the same functionning as the narrow lagoon.

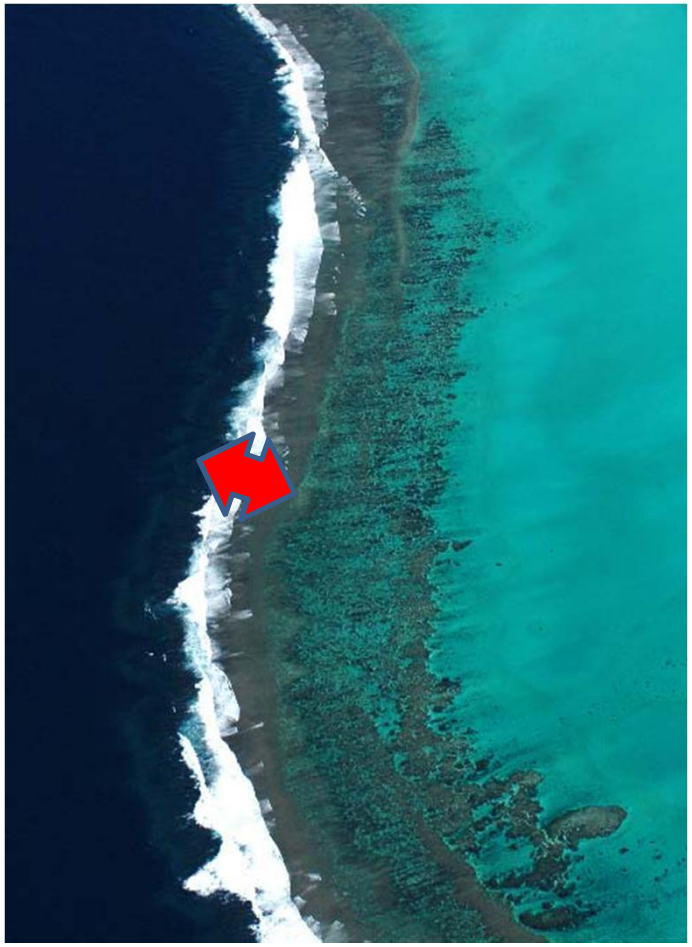
The coral reef barrier seems to play an important role in the Ouano lagoon circulation

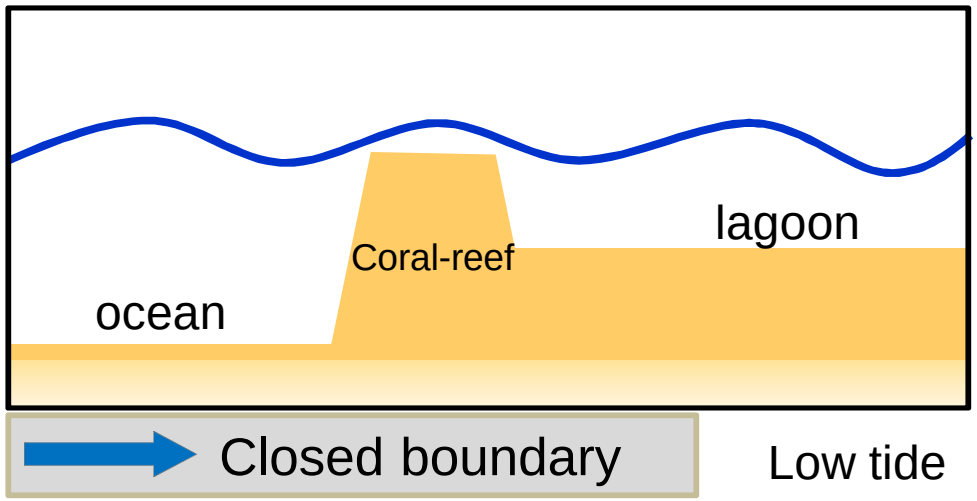
Plan

- Coral-reef barrier: a specific boundary condition
- Tools and results
- Coral reef impact on tidal circulation
- Coral reef impact on wave-driven circulation

Coral-reef boundary condition

With the Tide :



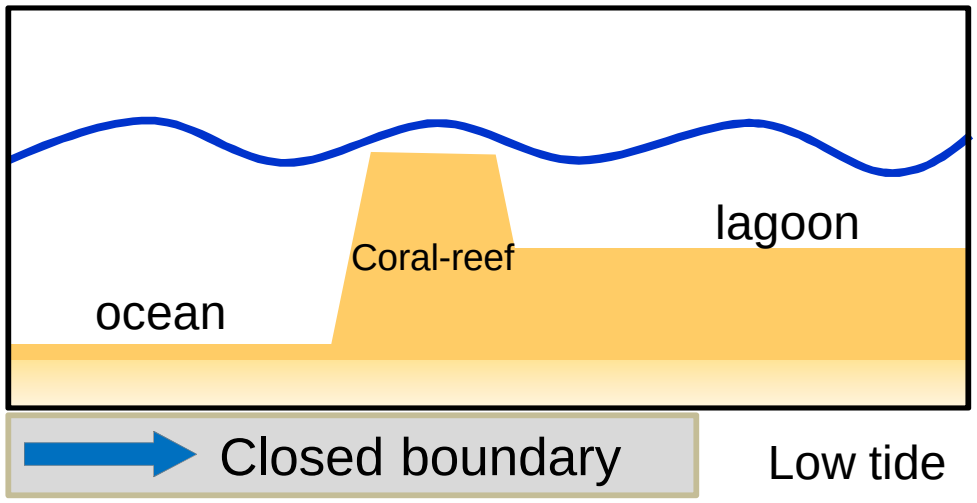


Closed boundary

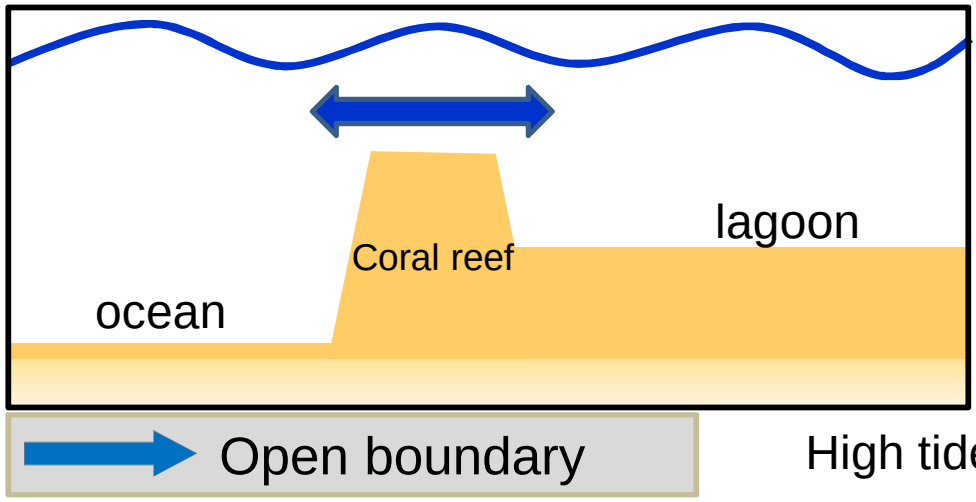
Low tide

Coral-reef boundary condition

With the Tide :



Low tide



High tide

Coral-reef boundary condition

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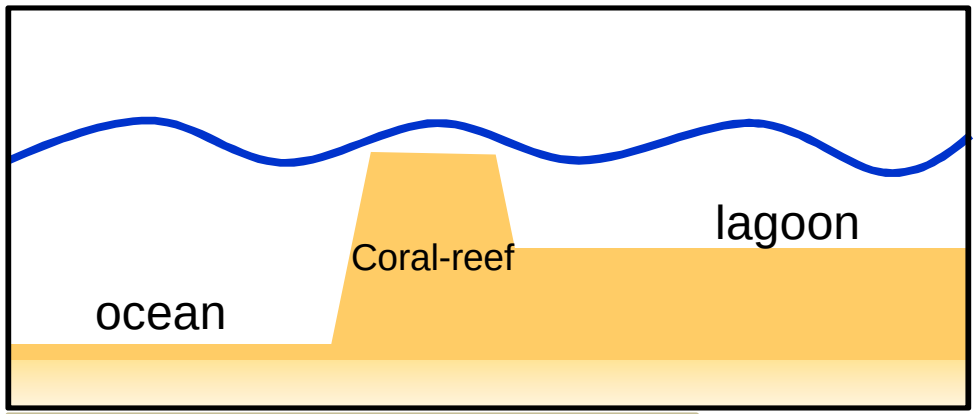
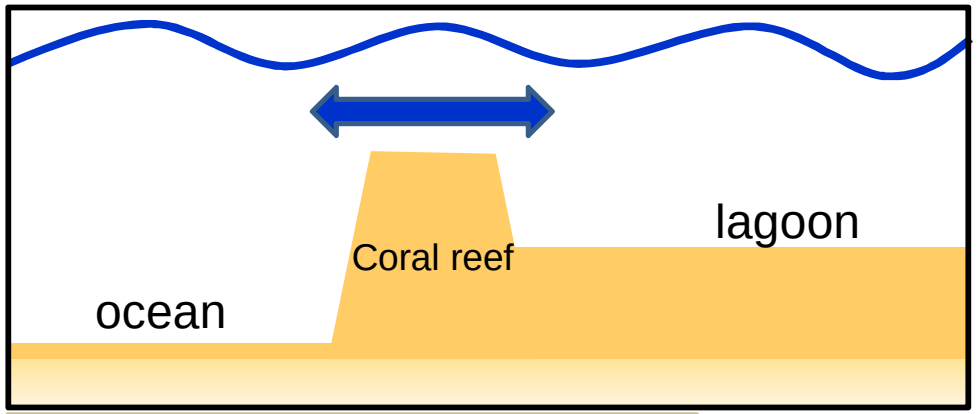


Closed boundary

Low tide



Open boundary

High tide

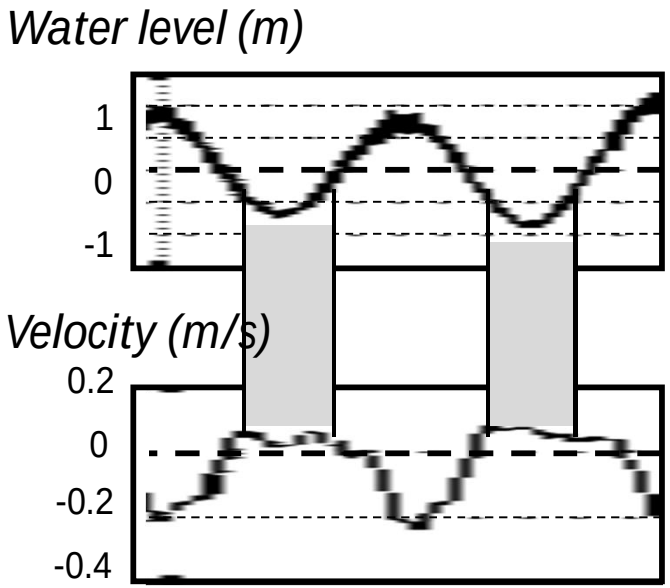
Boundary condition : opened or closed, alternatively with the tide

Coral-reef boundary condition

Tidal variability: exemples

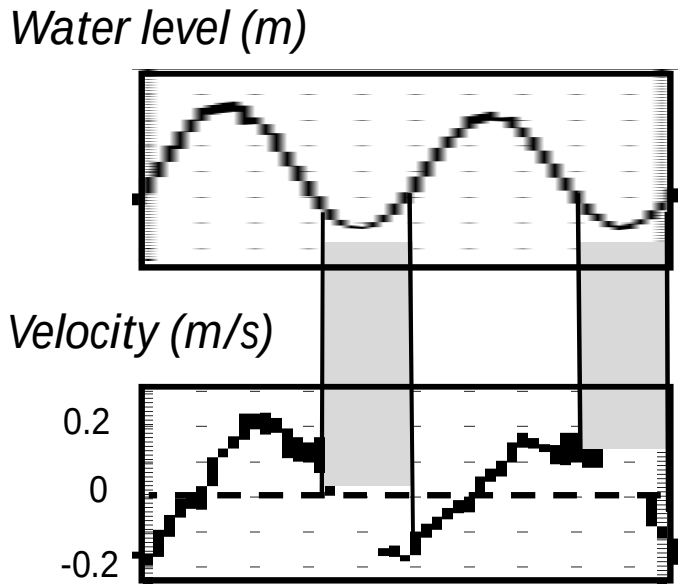
Mayotte:

Tide = propagative wave :



Tuléar:

Tide = stationnary wave :



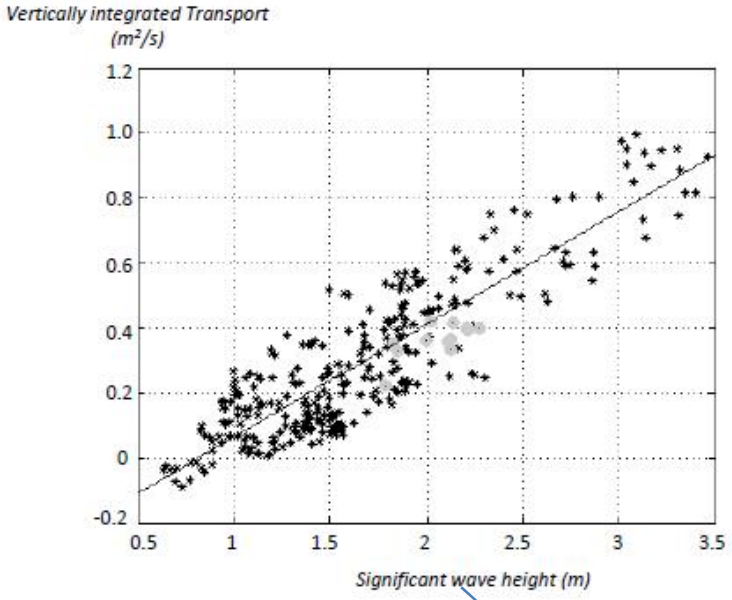
How is the tide in Ouano lagoon ?

Coral-reef boundary condition

Wave-driven current :

Tuléar :

On a reef transect



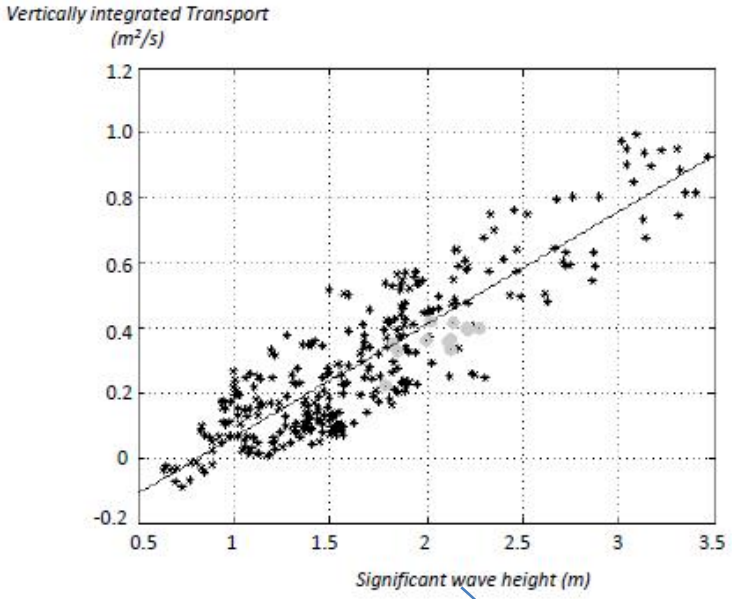
From wavewatch3

Coral-reef boundary condition

Wave-driven current :

Tuléar :

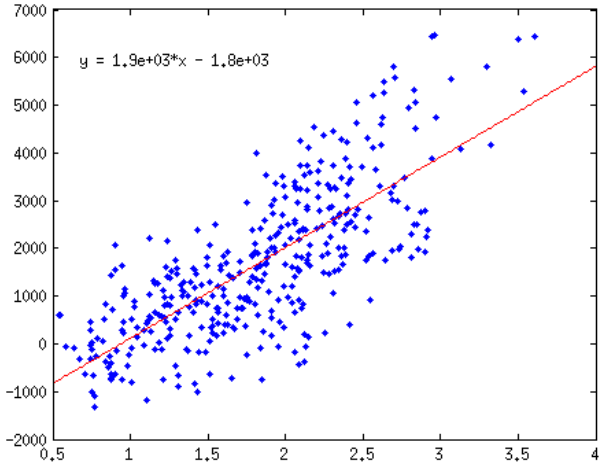
On a reef transect



From wavewatch3

Global fluxes

Global fluxes



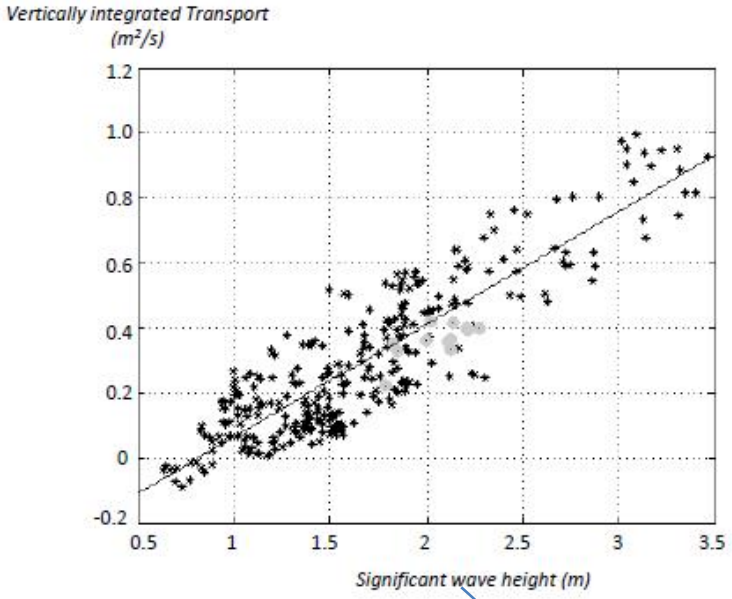
Wave from wavewatch3

Coral-reef boundary condition

Wave-driven current :

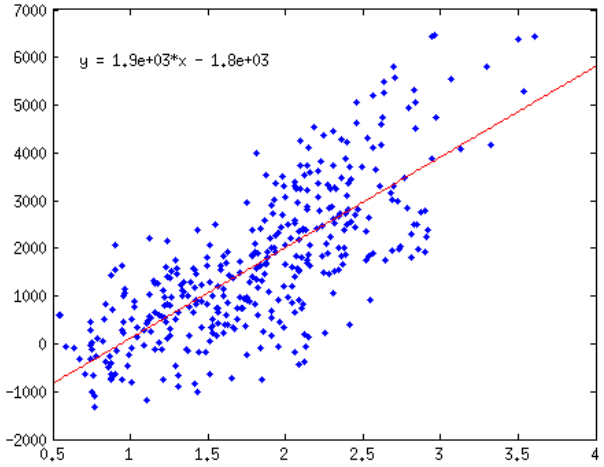
Tuléar :

On a reef transect



From wavewatch3

Global fluxes



Wave from wavewatch3

Global fluxes

Flux $_{\text{cross-reef}}$ = b1 * H – b2

With $b1 = 1900\ m^2.s^{-1}$ and $b2 = 1800 m^3.s^{-1}$

And H the significant height of the wave coming from From wavewatch3, ifremer

Coral-reef boundary condition

Bottom friction :

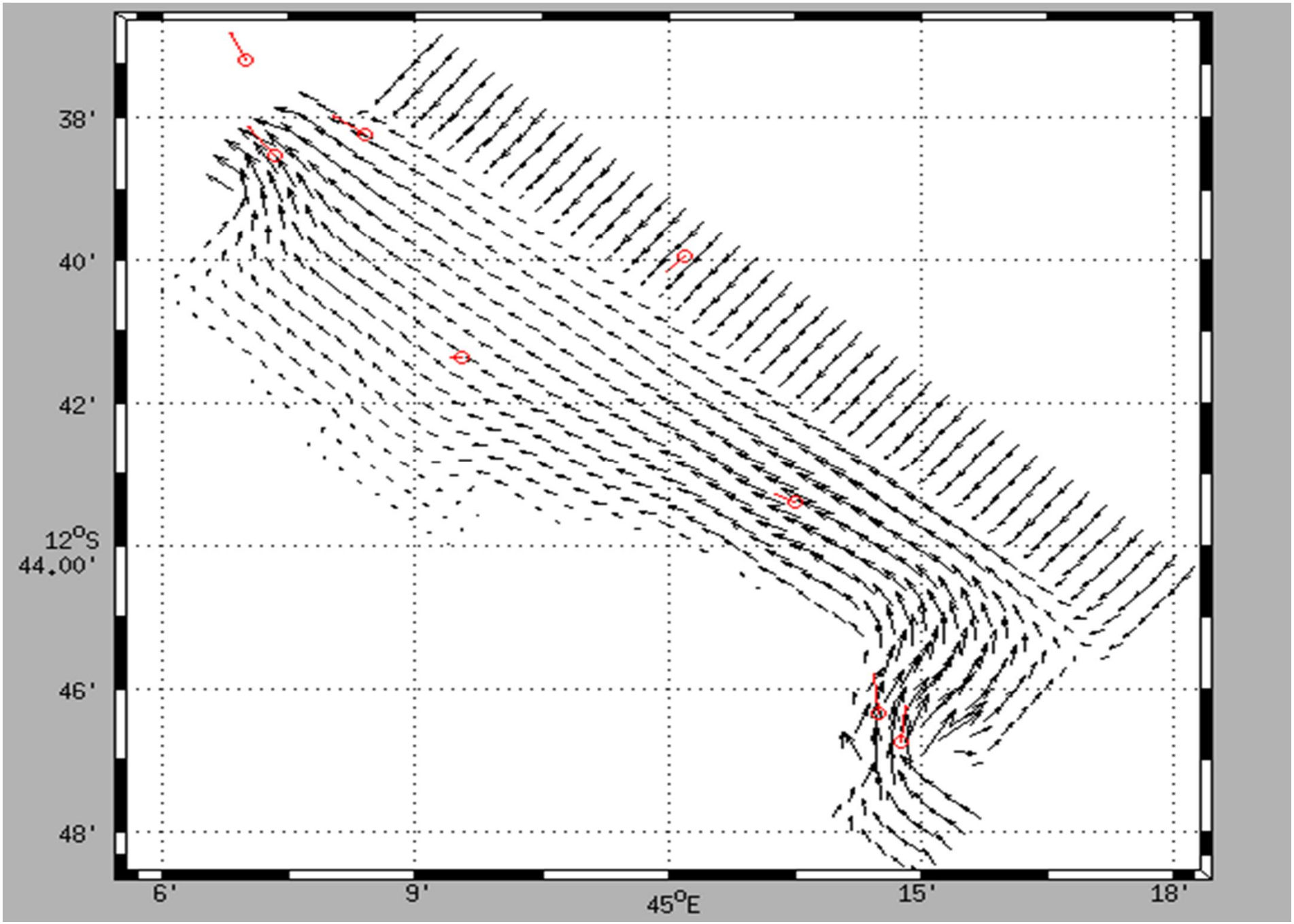
Bottom very rough → High bottom friction

Mayotte :

Bottom friction : quadratic formula $(\tau b^x, \tau b^y) = Cd * \sqrt{ub^2 + vb^2}$

Lagoon : bottom friction coefficient = 0.005

Reef: bottom friction coefficient = 0.3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40'
42'
12°S
44.00'
46'
48'
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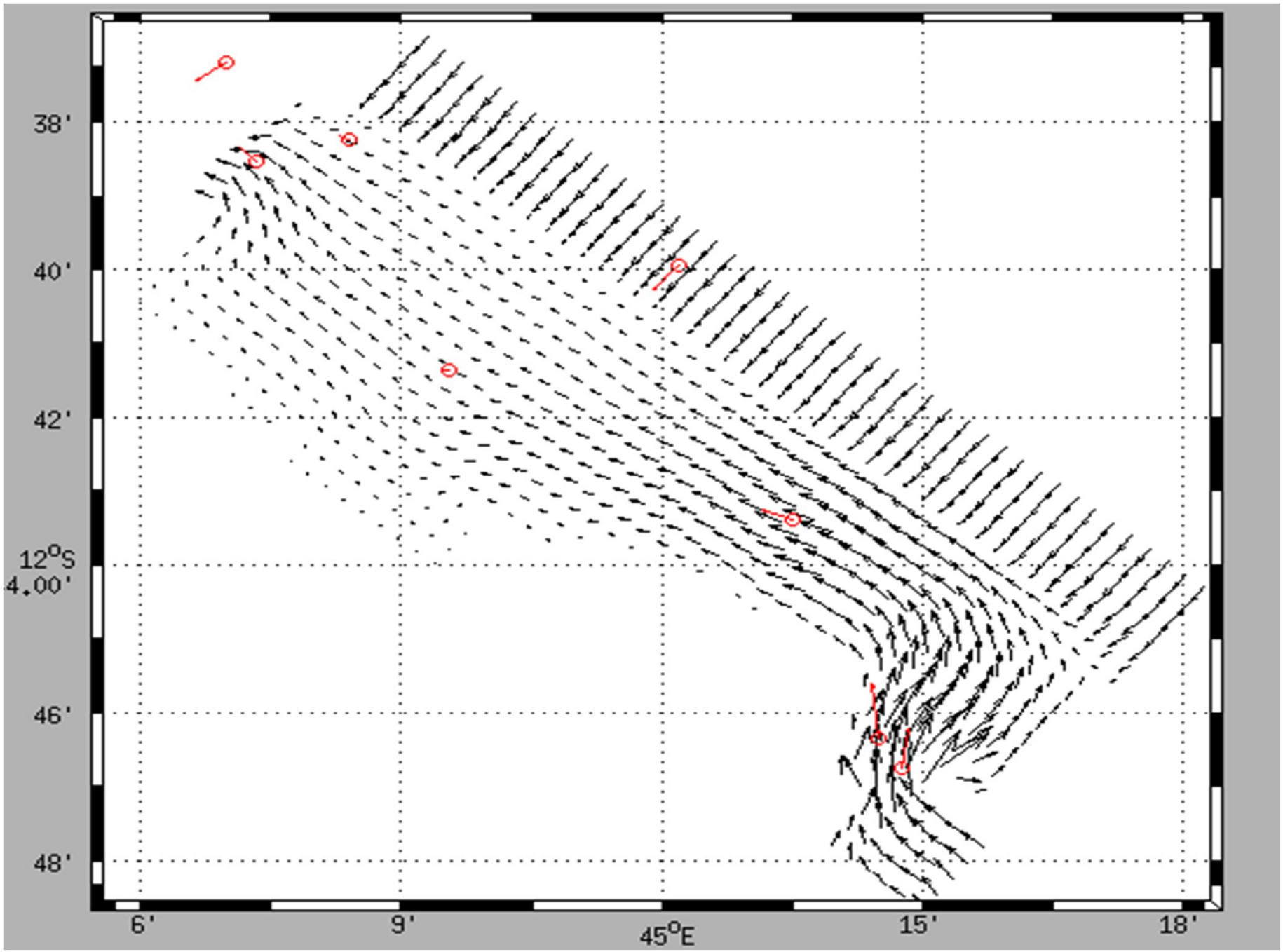
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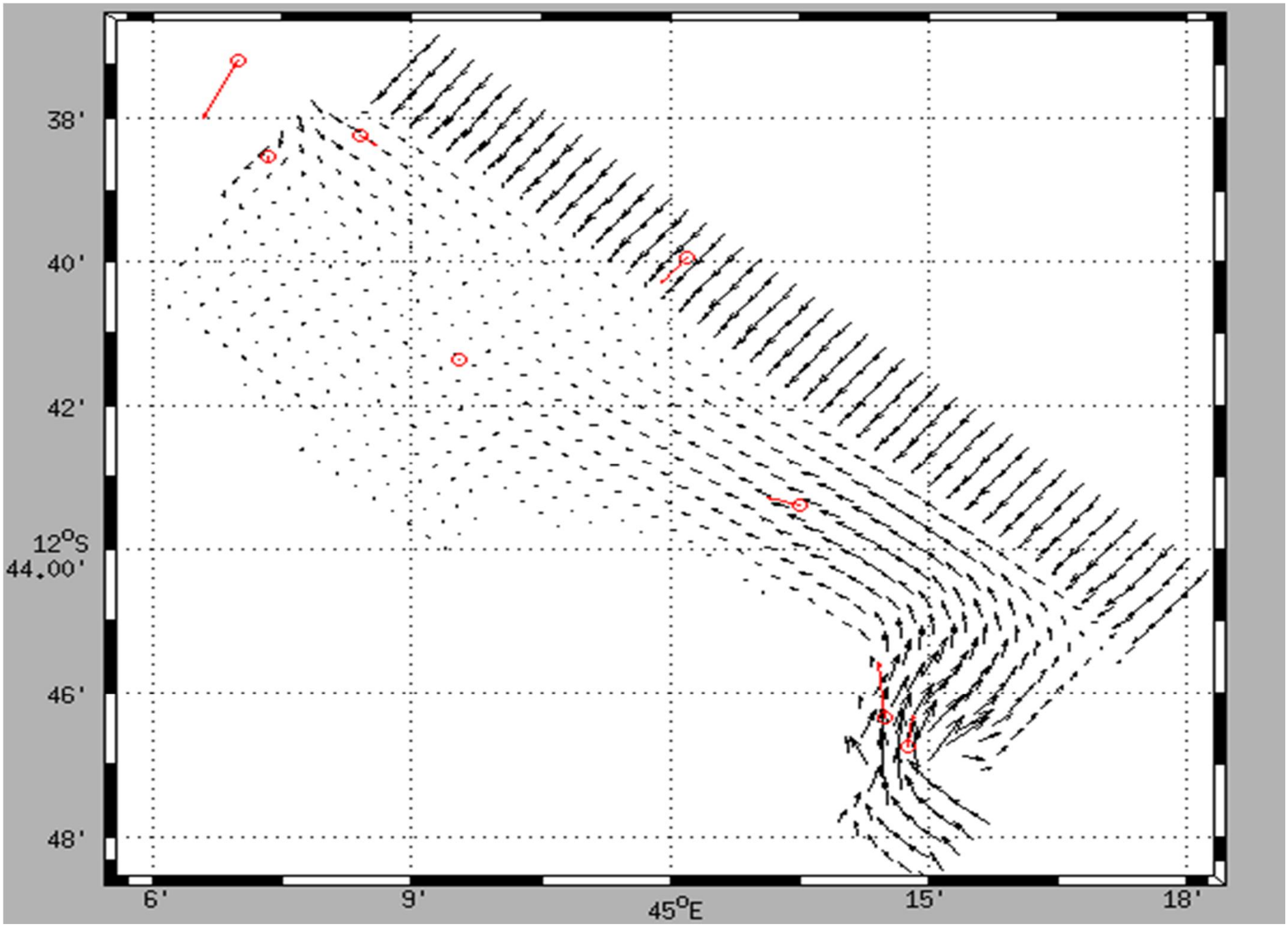
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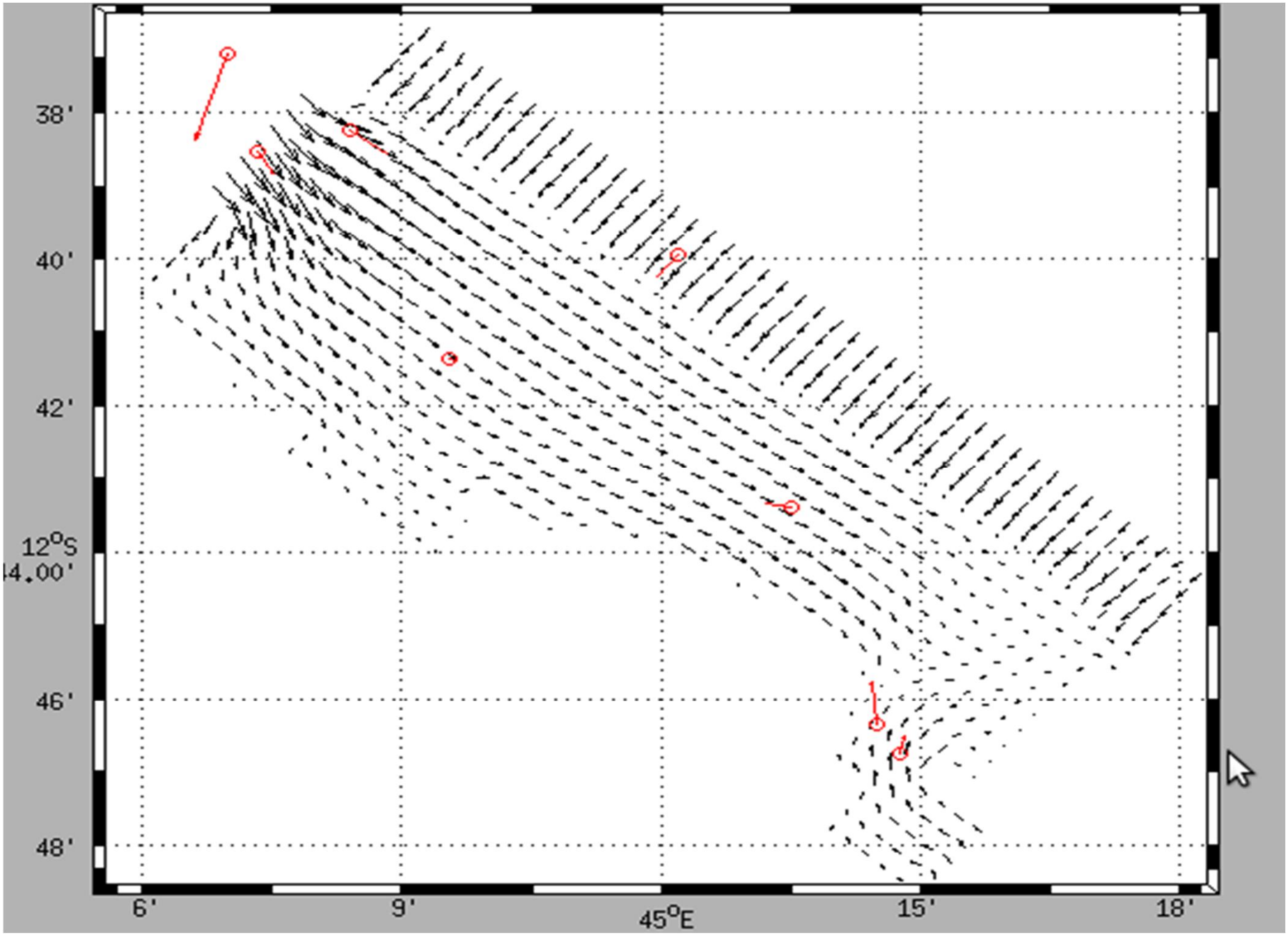
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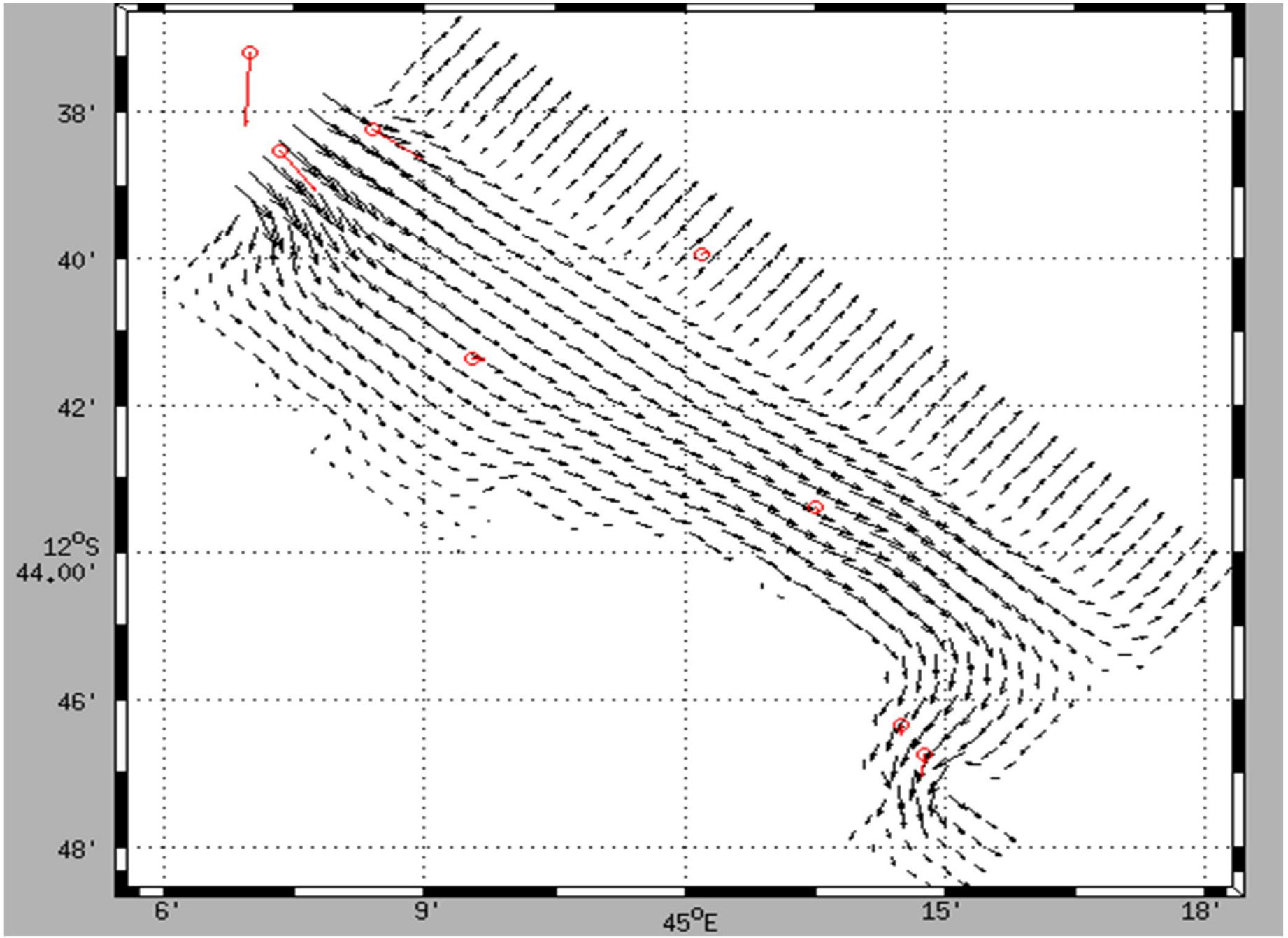
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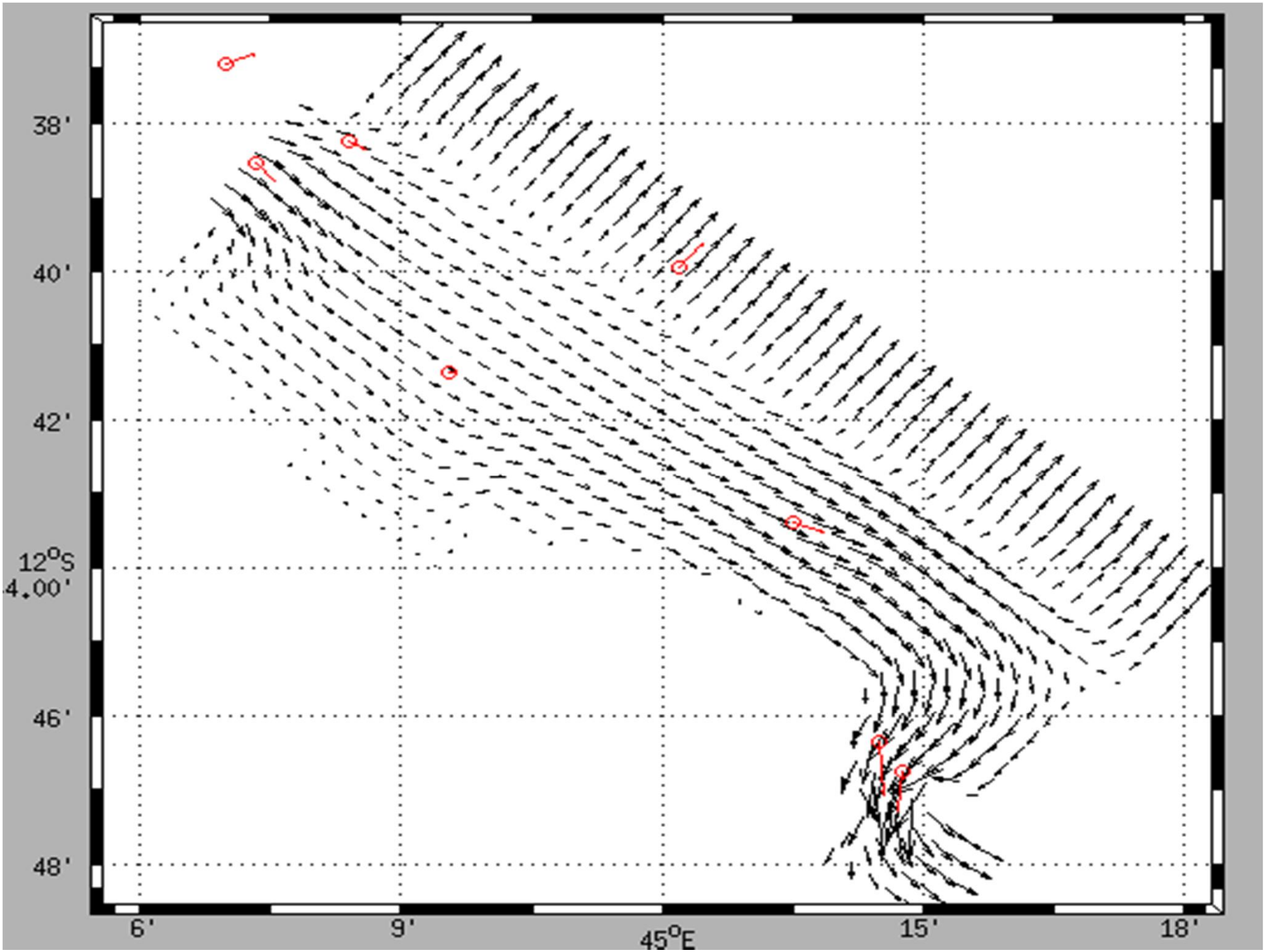
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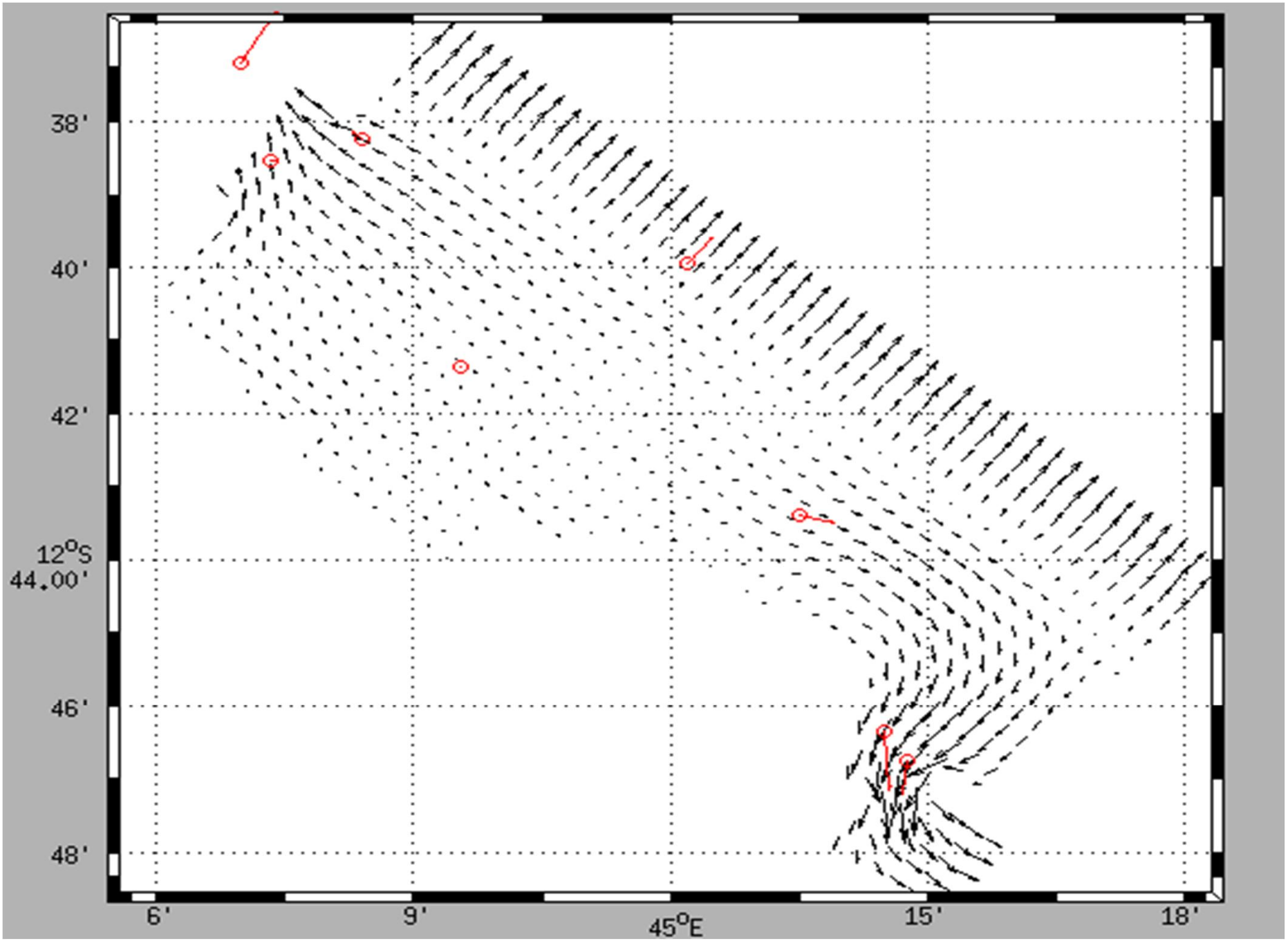
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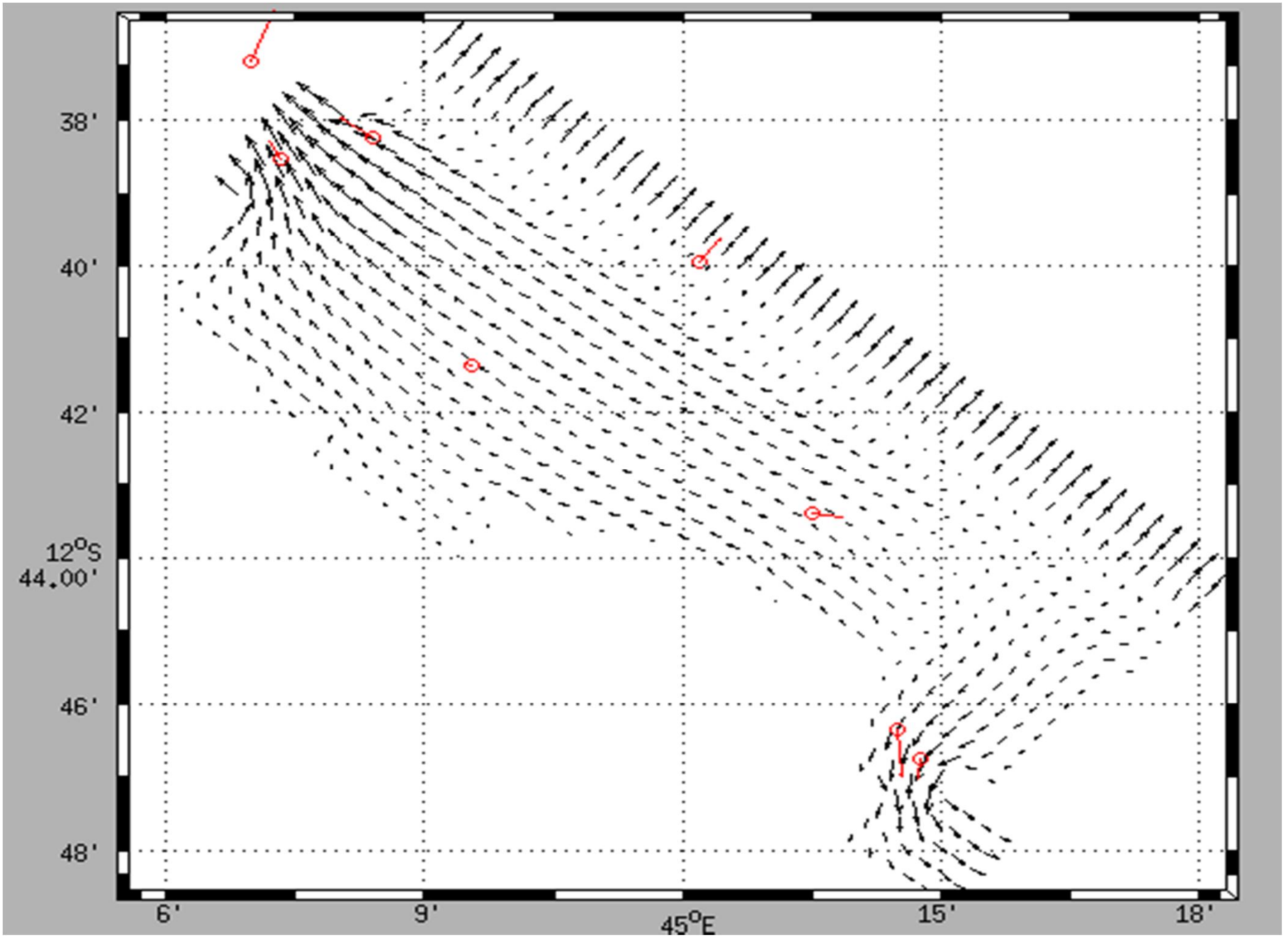
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With these experiences we decided to study Oauno lagoon...

A model : ROMS …

(Regional Ocean Modeling system)

Equations :

Primitive equations in an Earth-centered rotating environment

- Boussinesq approximation;
- hydrostatic vertical momentum balance.

Discretization :

- ***Space discretization:***

  Arakawa-C grid combined
  Sigma-coordinates in the vertical direction
  free-surface ocean model

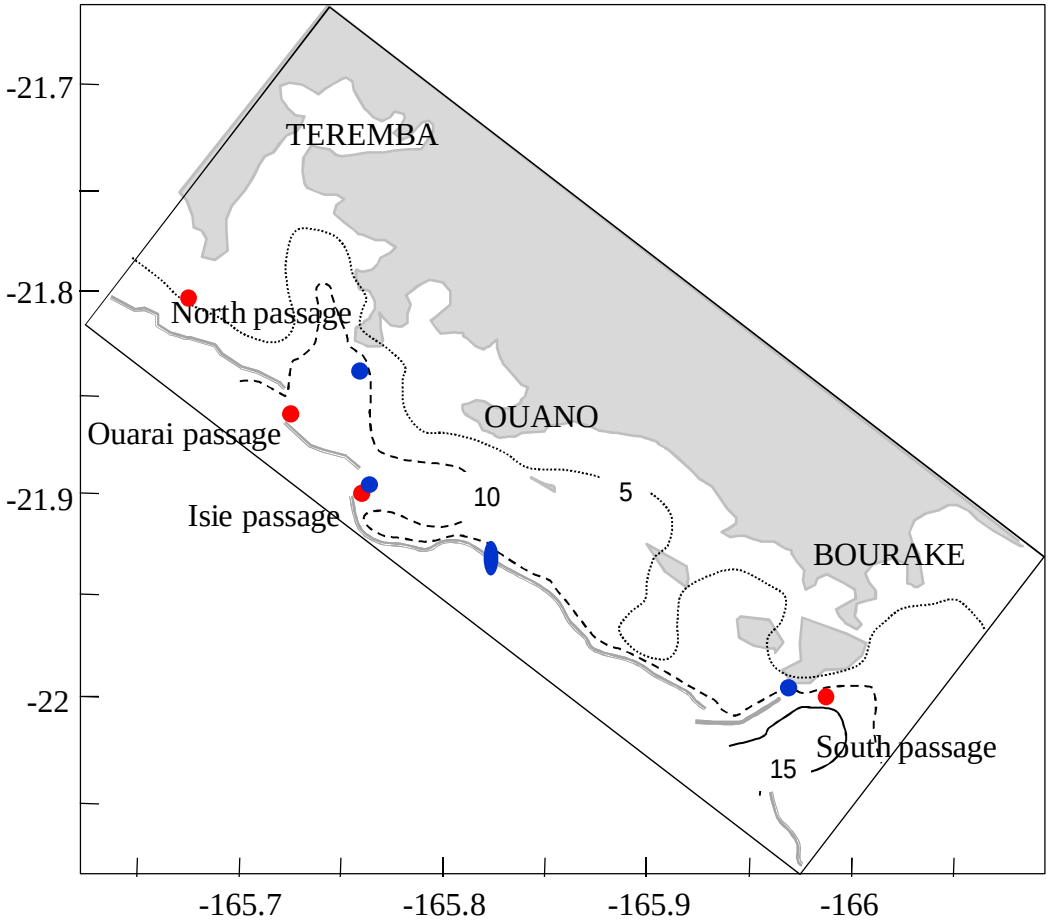
- ***Time discretization:*** Split-explicit

Methodology

Finite difference method
Parametrisation of the unresolved physical vertical subgrid-scale processes *(turbulent viscosity and diffusivity).*

And two Field suveys

- APTE (Juillet-aout 2011)
- OLE (Aout-Décembre 2013)



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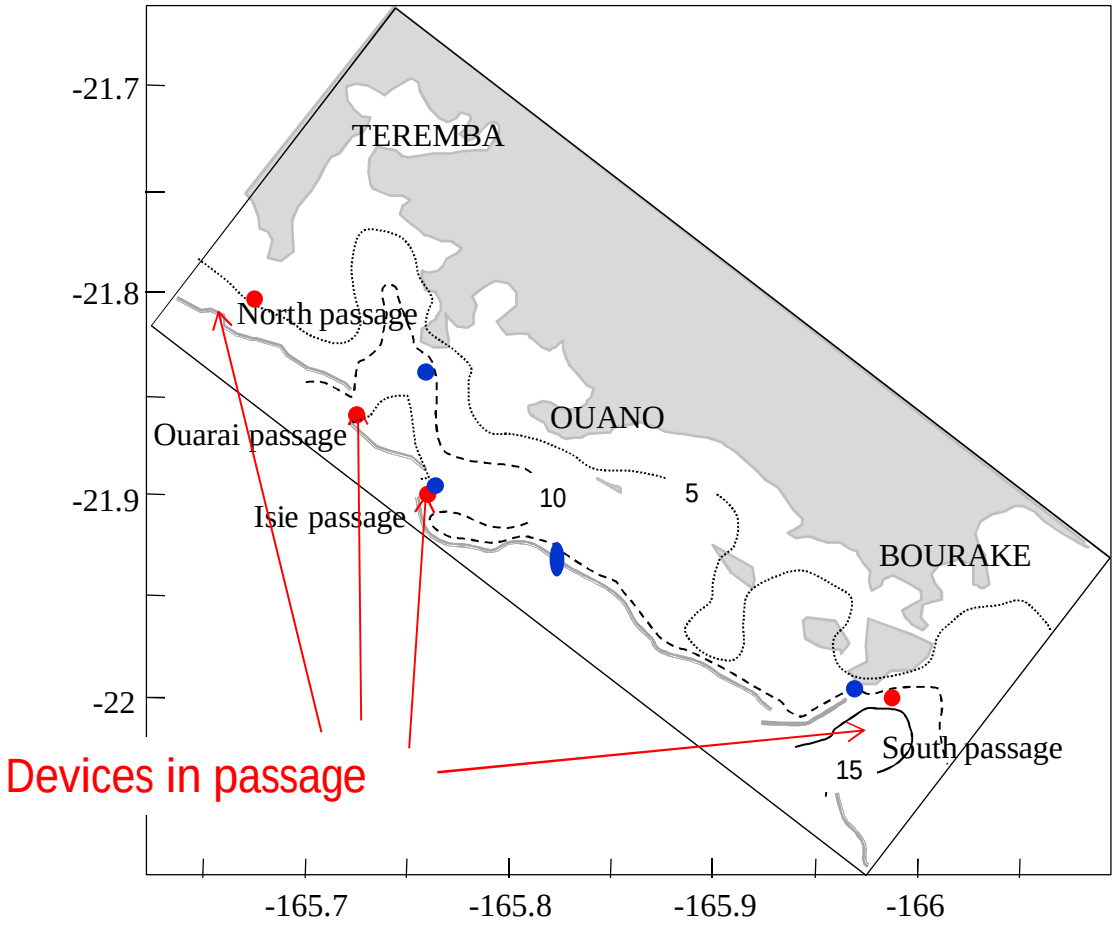

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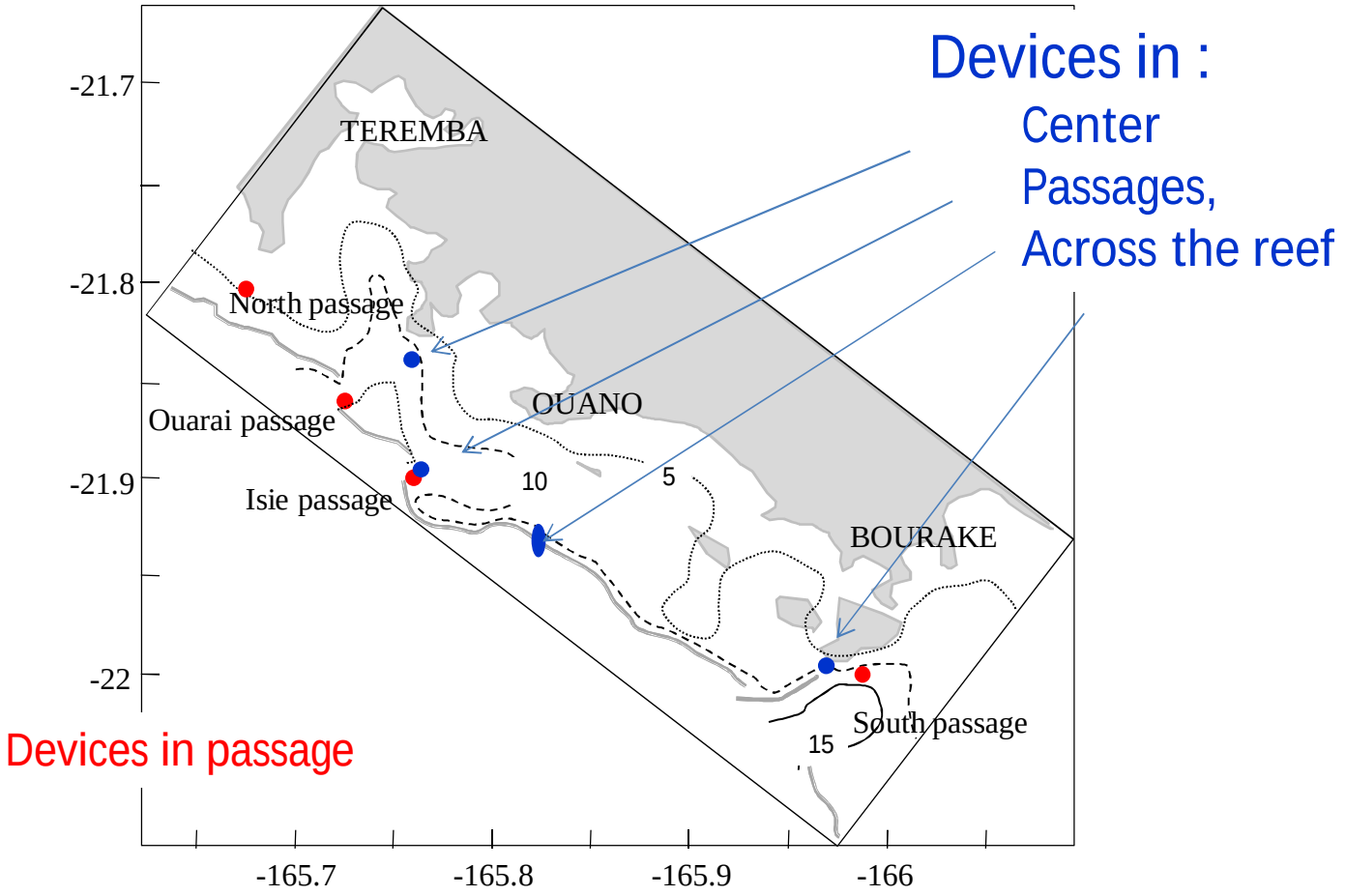

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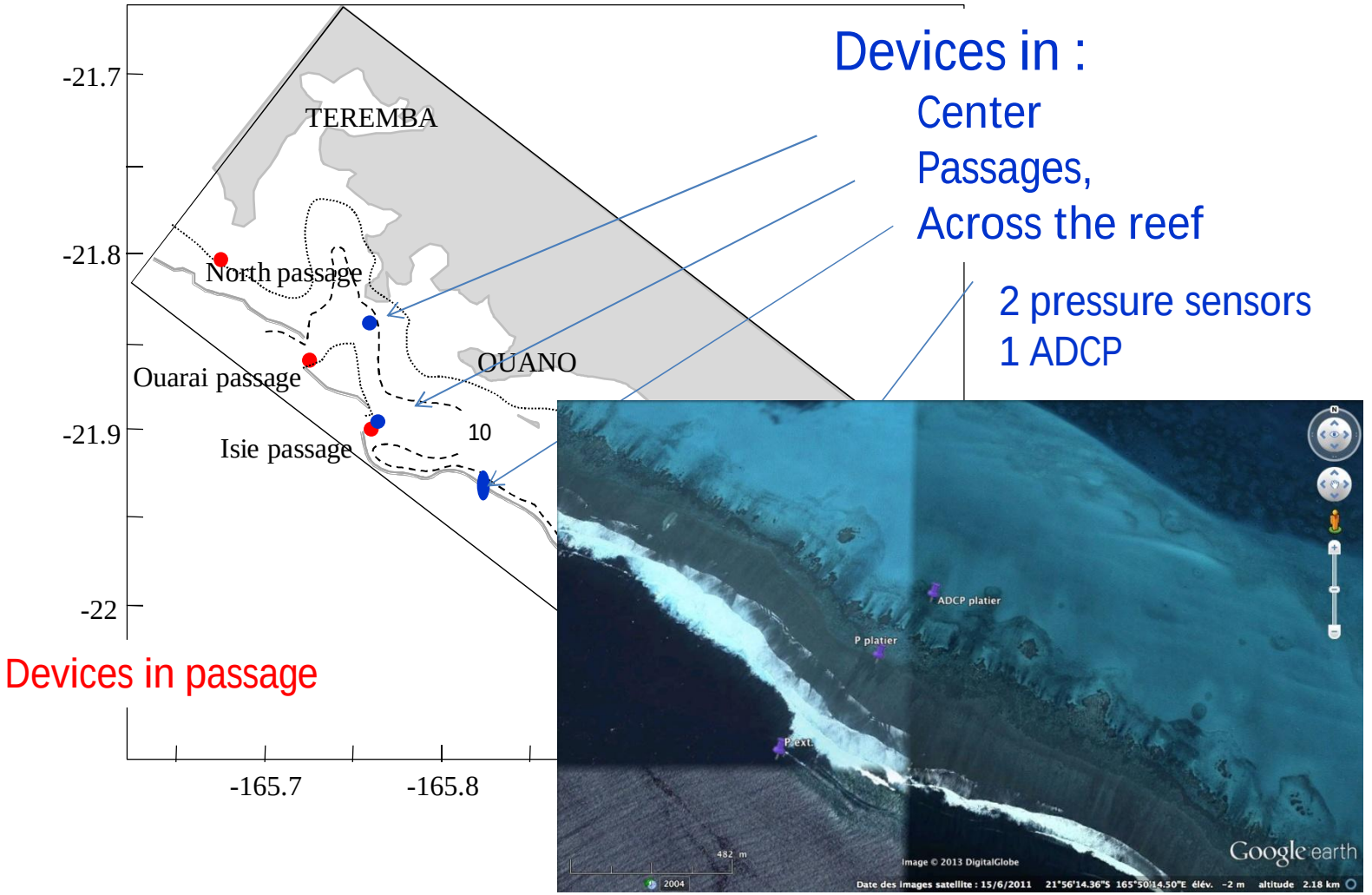
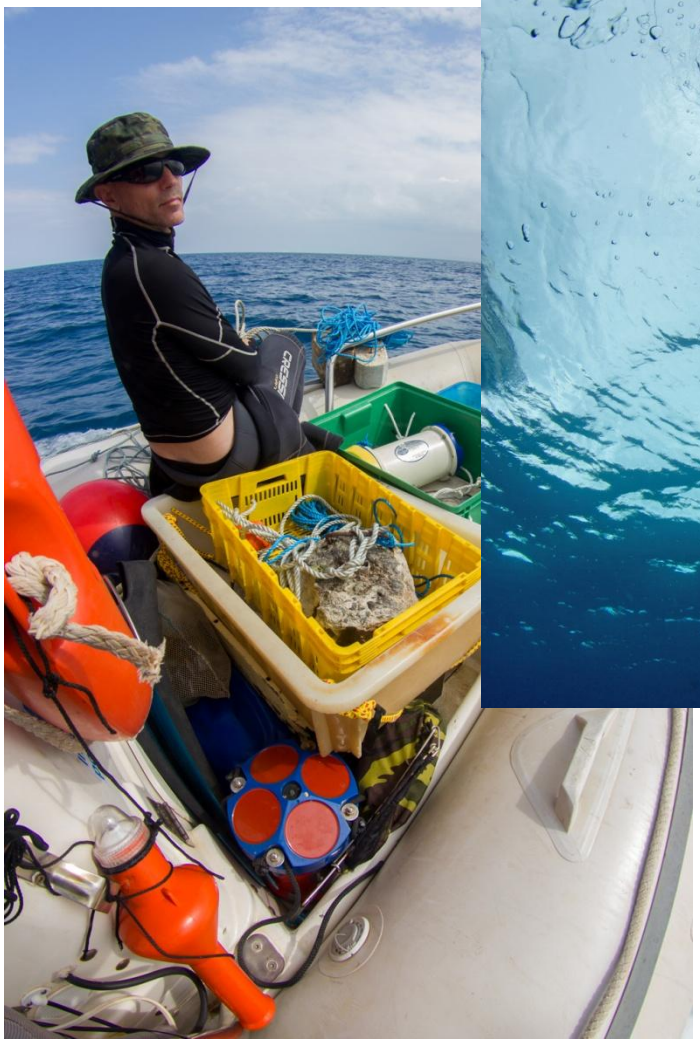


How ?

A zodiac

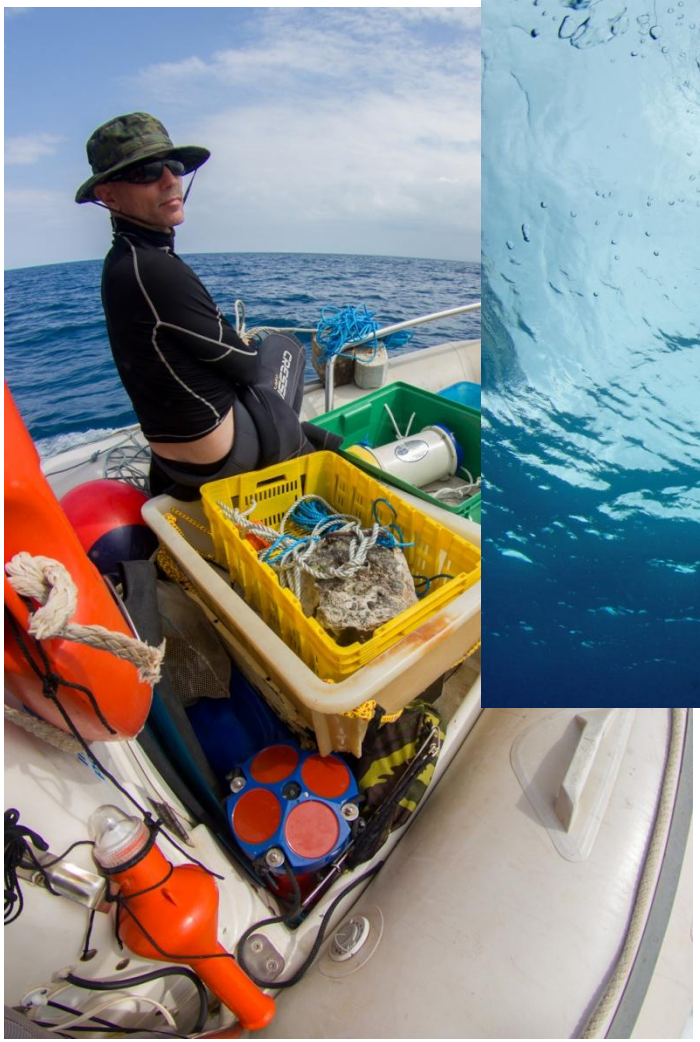
How ?



A zodiac

And two divers

How ?



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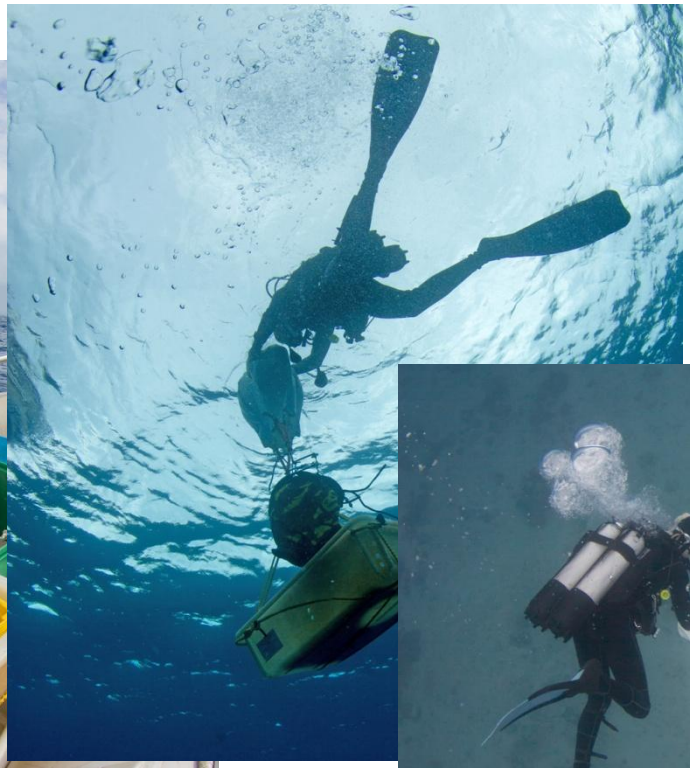

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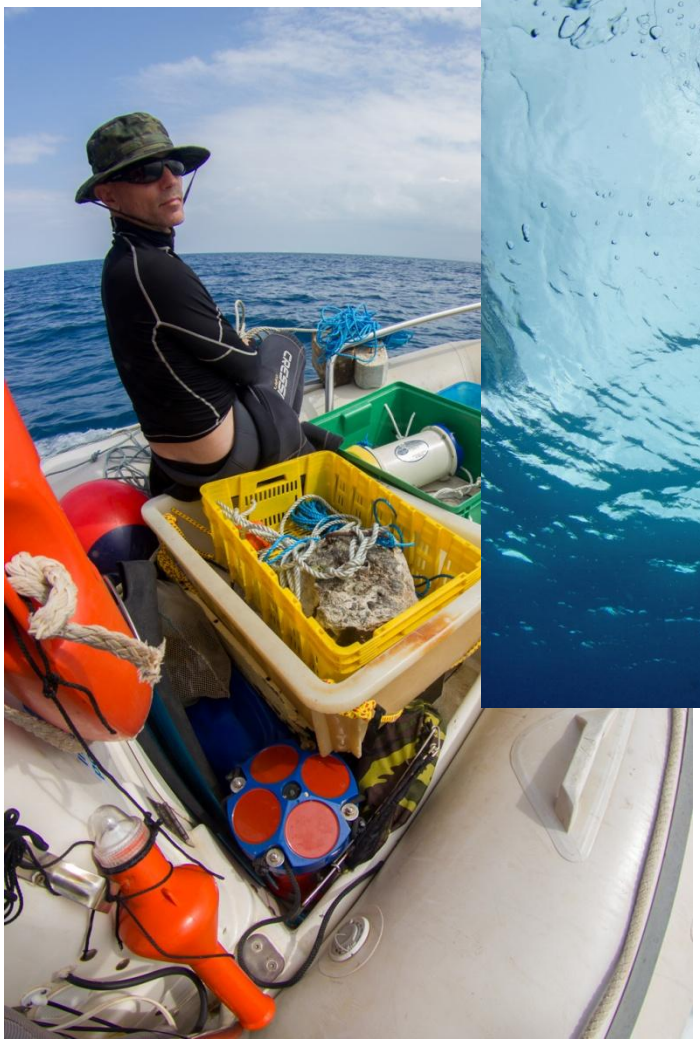

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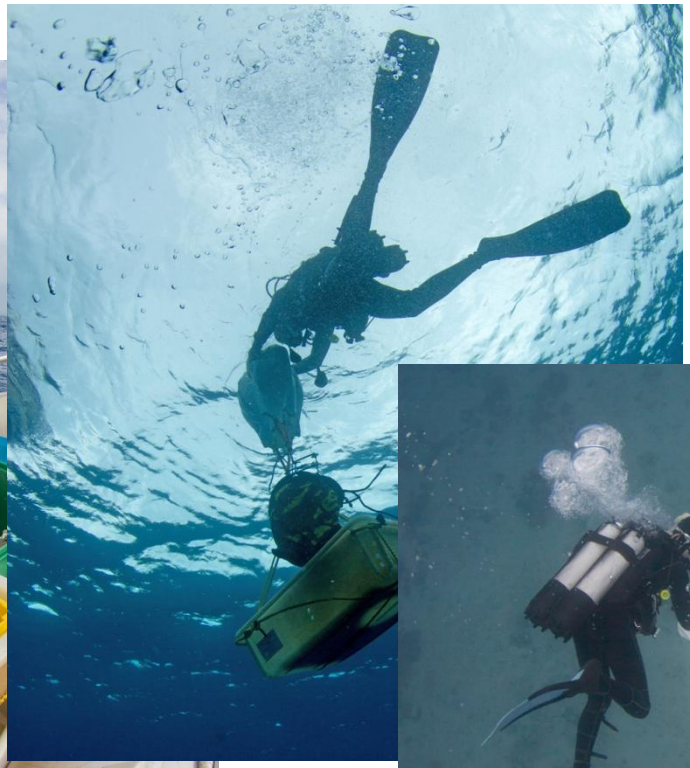

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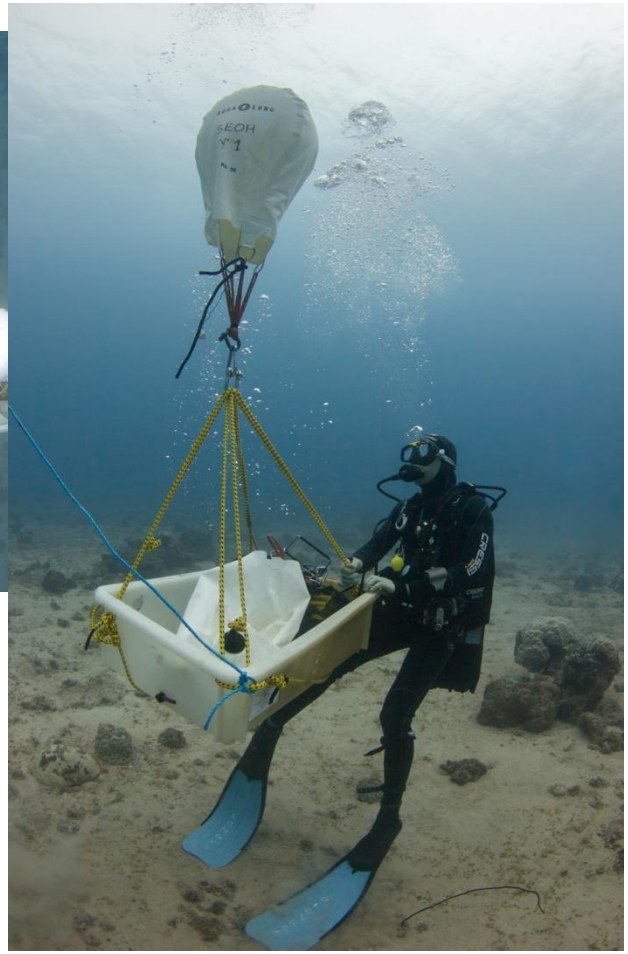
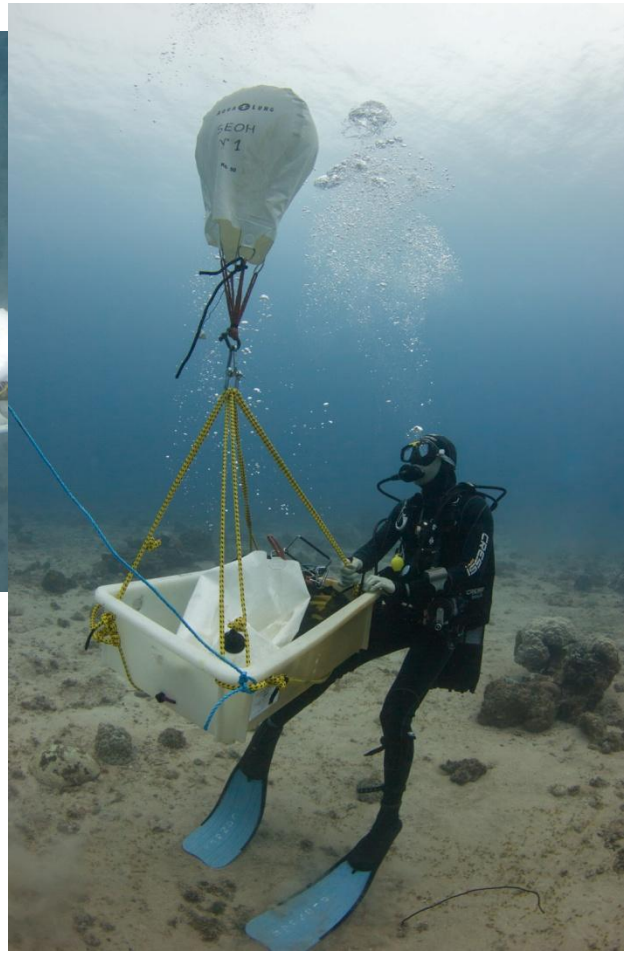


Light cruise

A zodiac

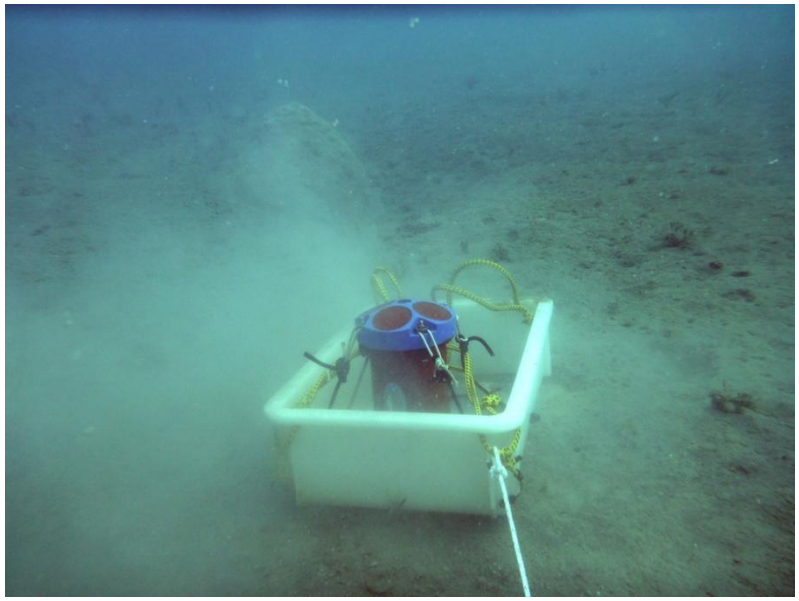
The ADCP was fixed

And two divers



How ?

And the device stays for few months



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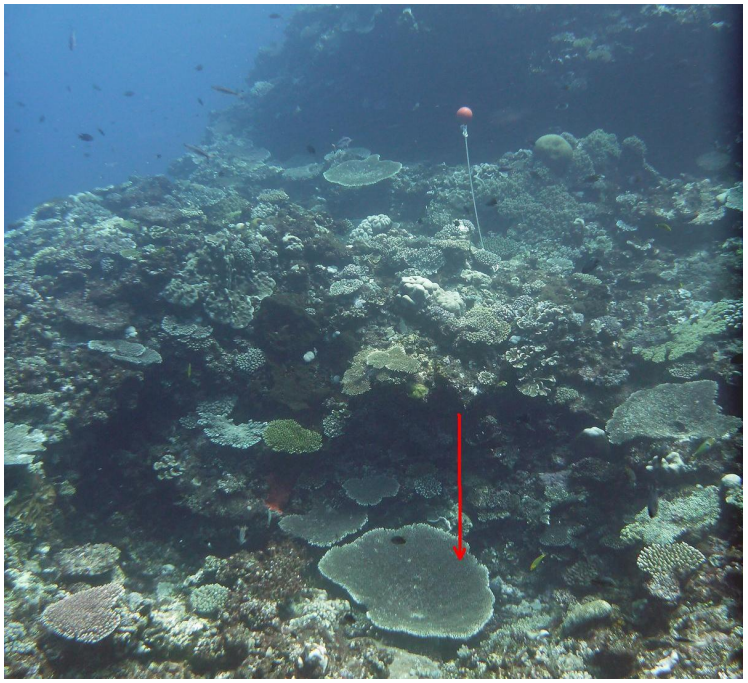
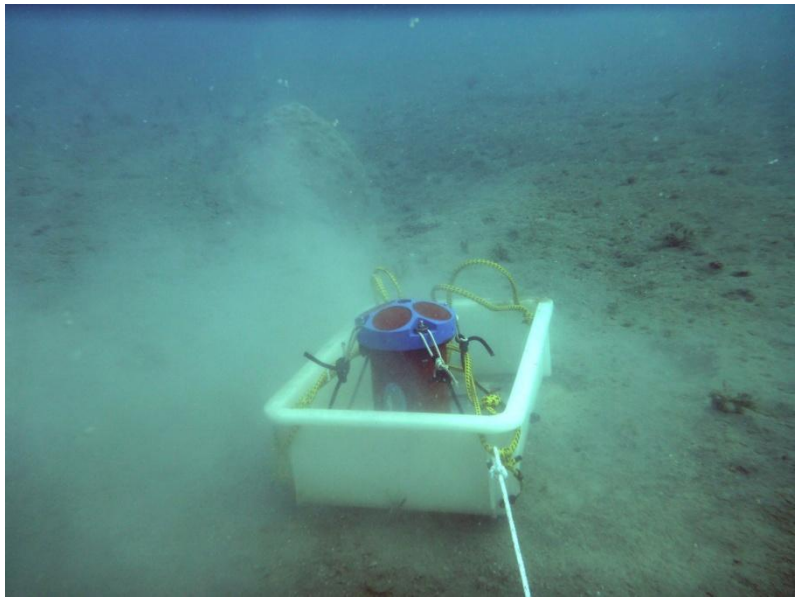
And the device stays for few months

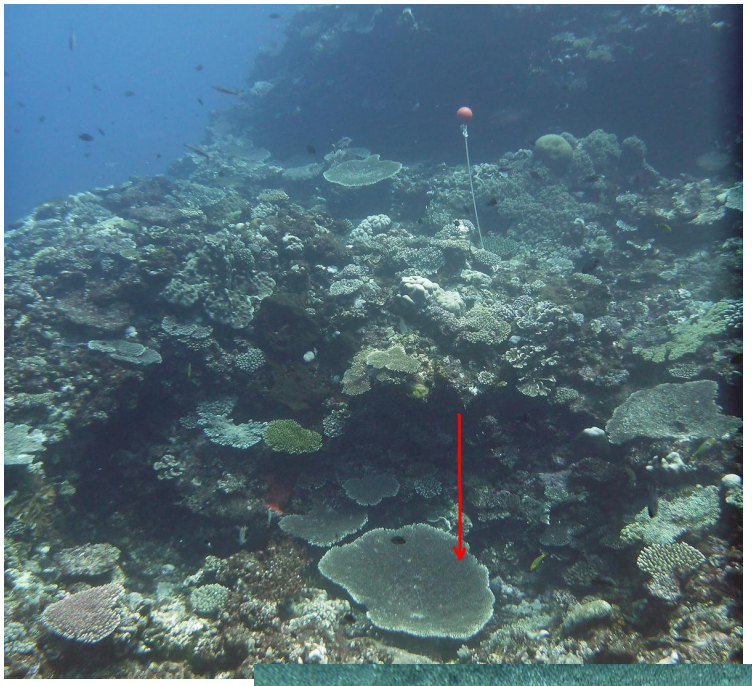


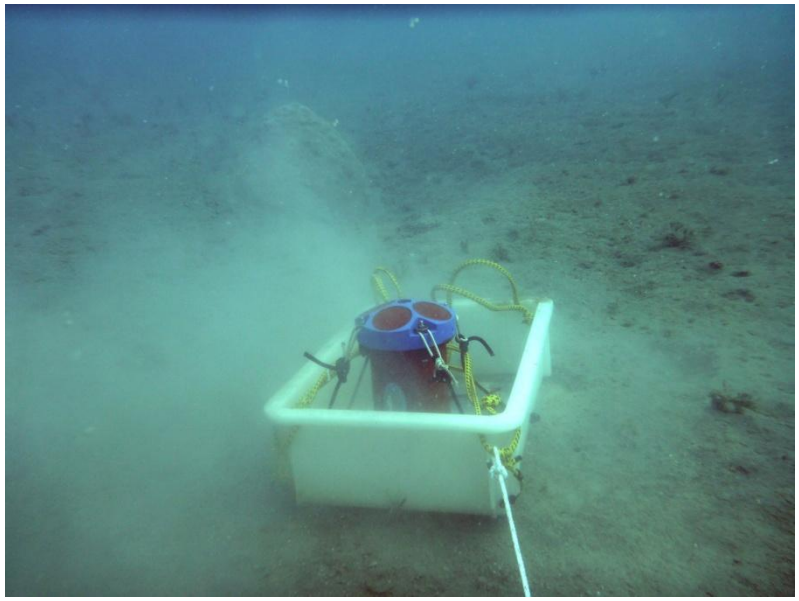


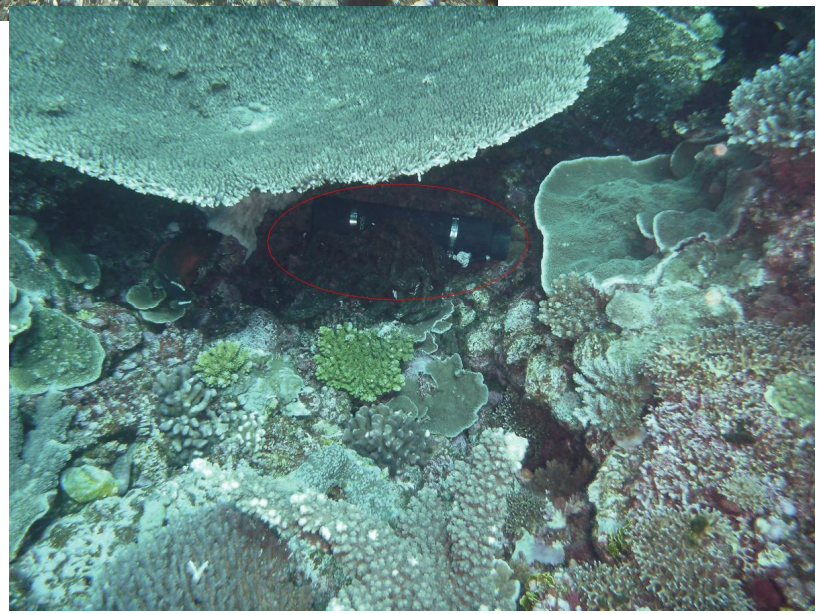
Similar set up for pressure device

How ?

And the device stays for few months



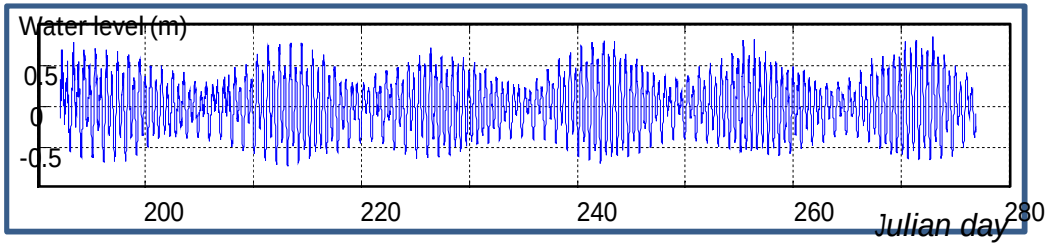




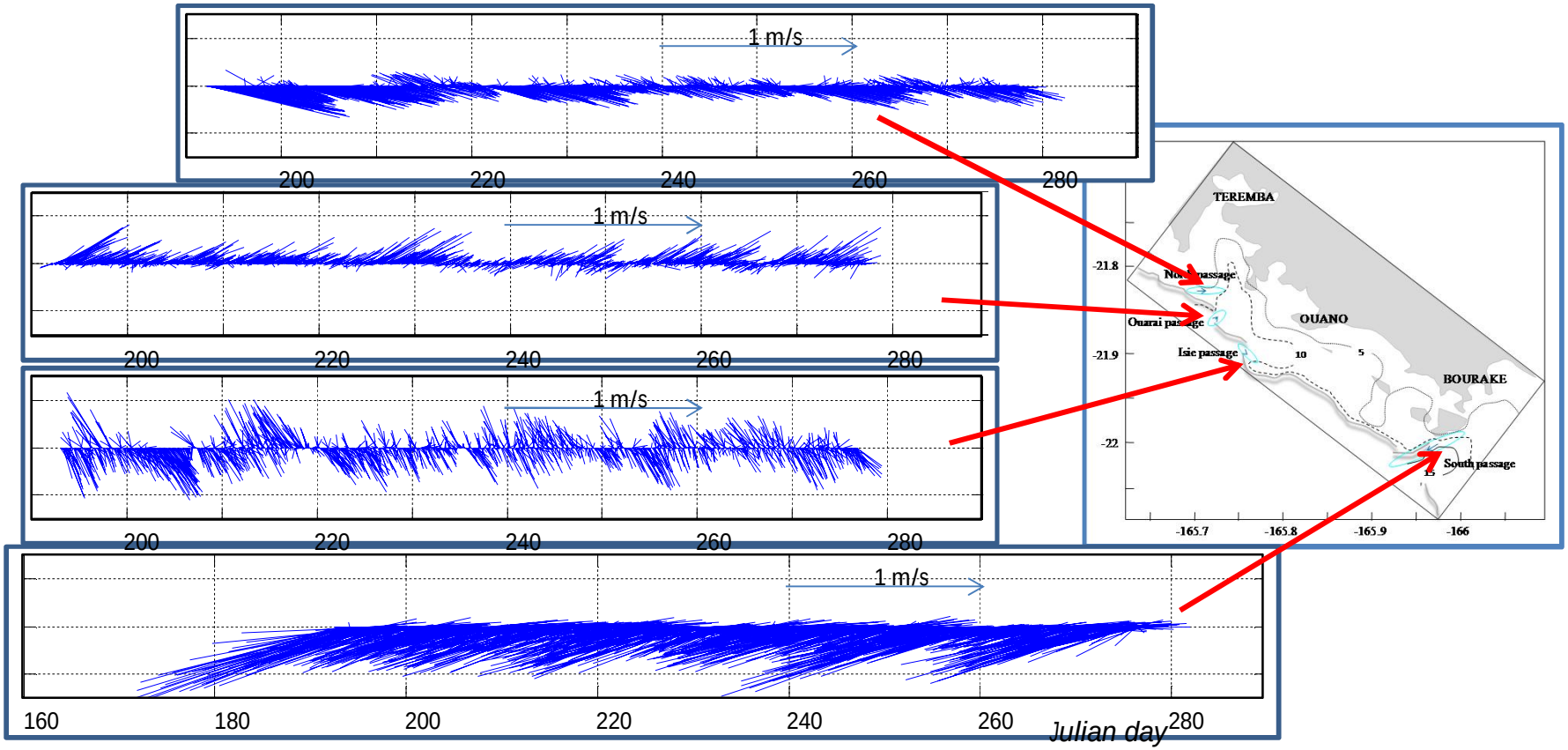
Similar set up for pressure device

Results : Apte (2011)

Water-level :

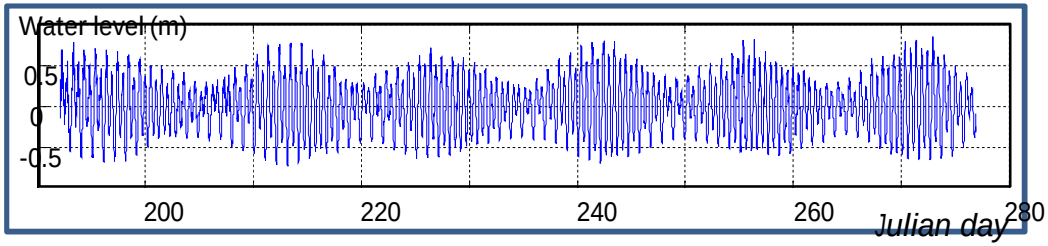


Velocity

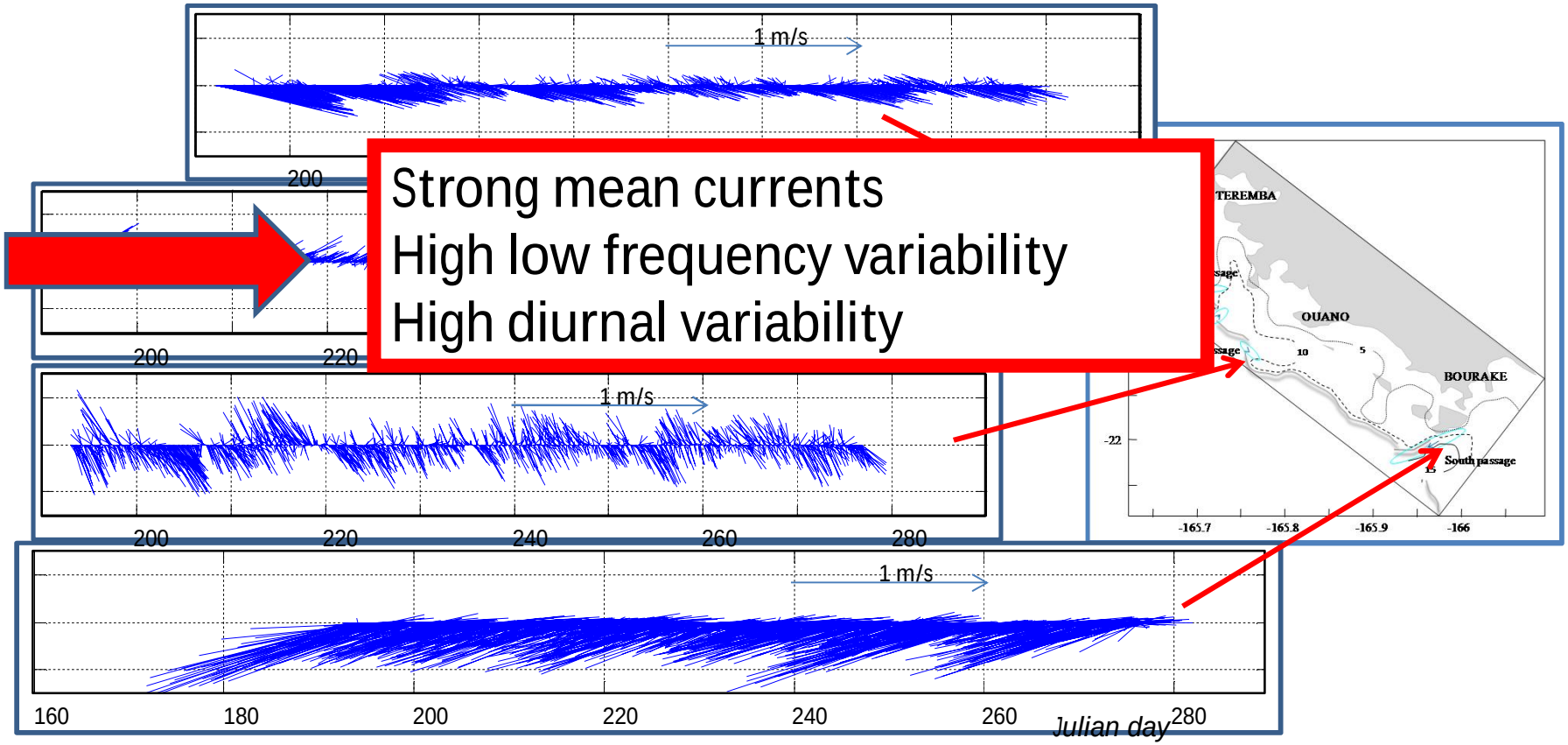


Results : Apte (2011)

Water-level :



Velocity

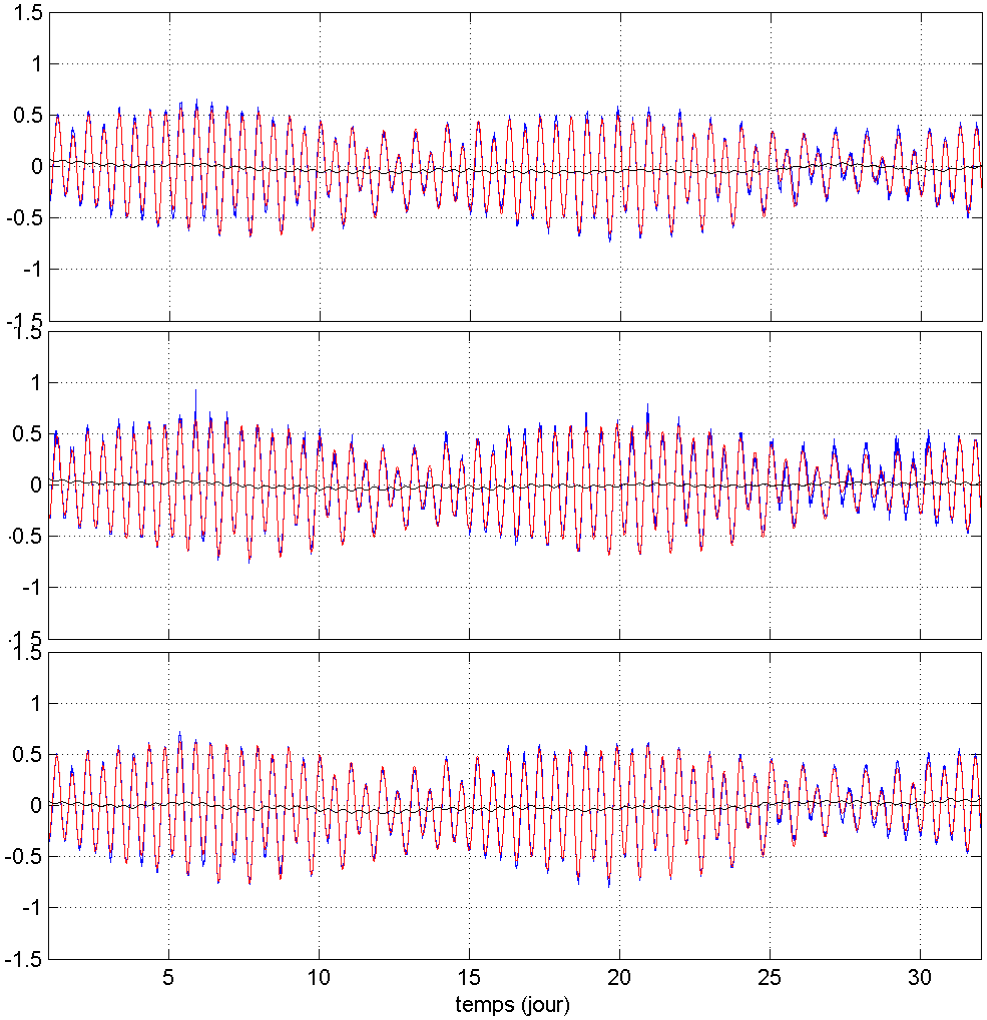


Strong mean currents
High low frequency variability
High diurnal variability

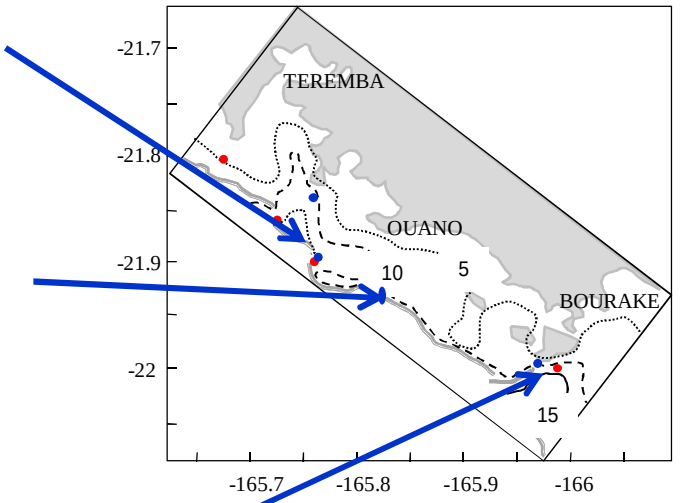
Results : OLE (2013)

Water level

October 2013



In passages :



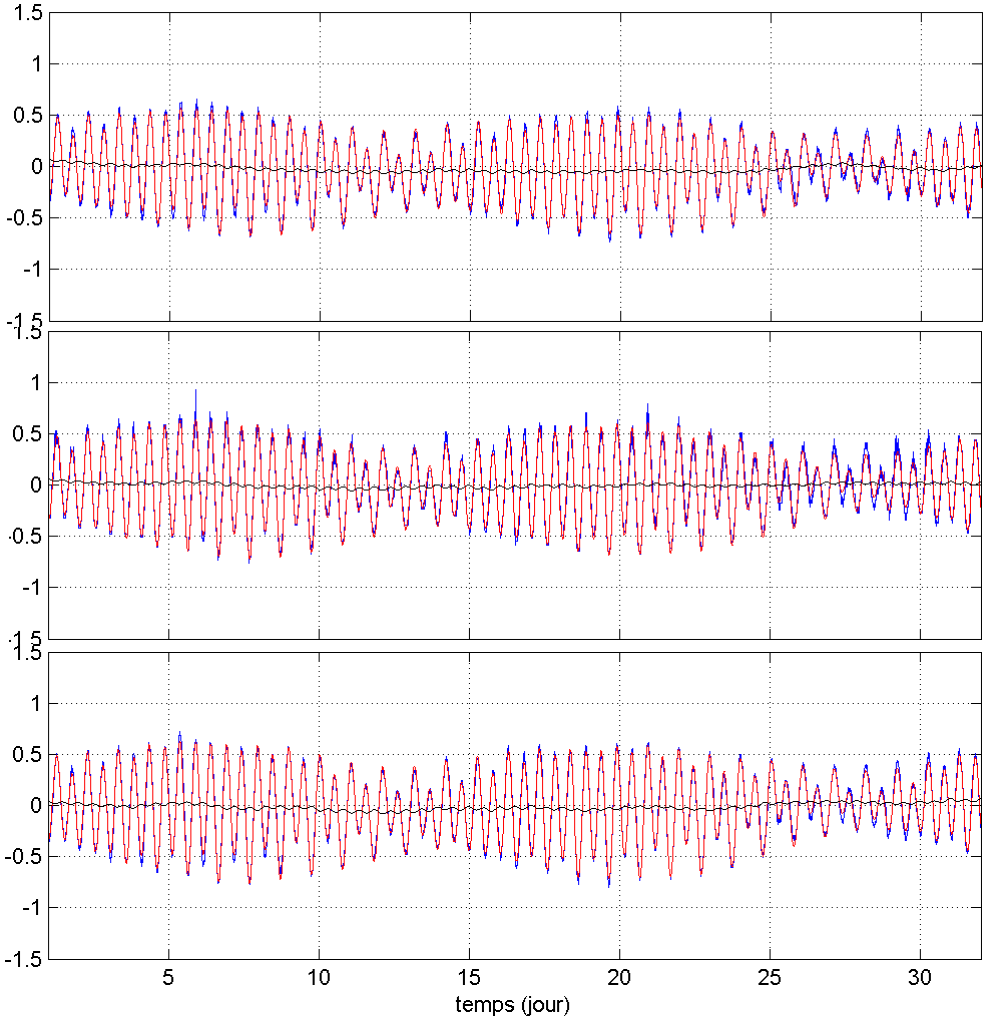
Blue : signal

Red: tidal signal

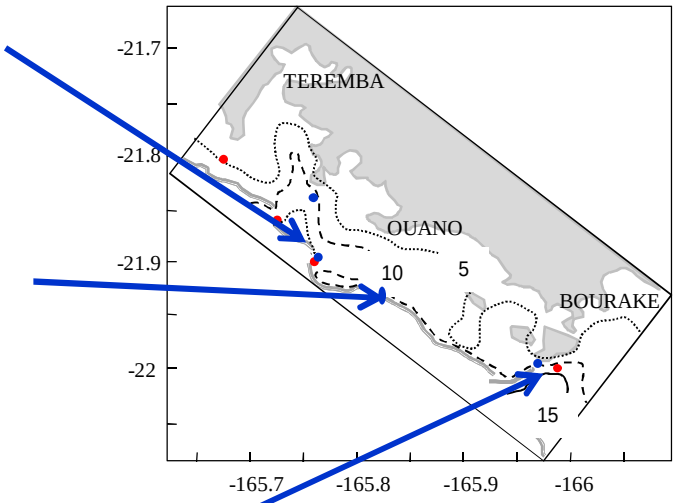
Results : OLE (2013)

Water level

October 2013



In passages :
Mainly tidal signal

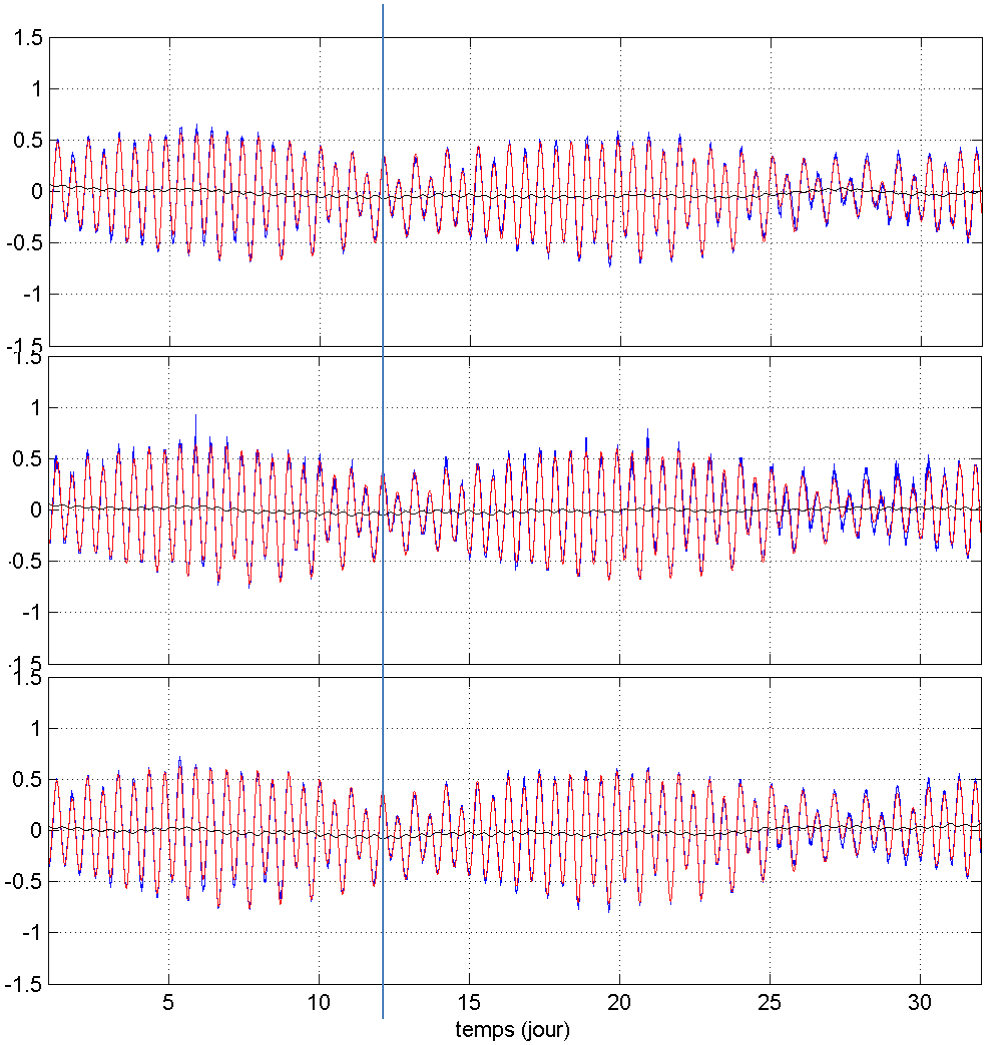


Blue : signal
Red: tidal signal

Results : OLE (2013)

Water level

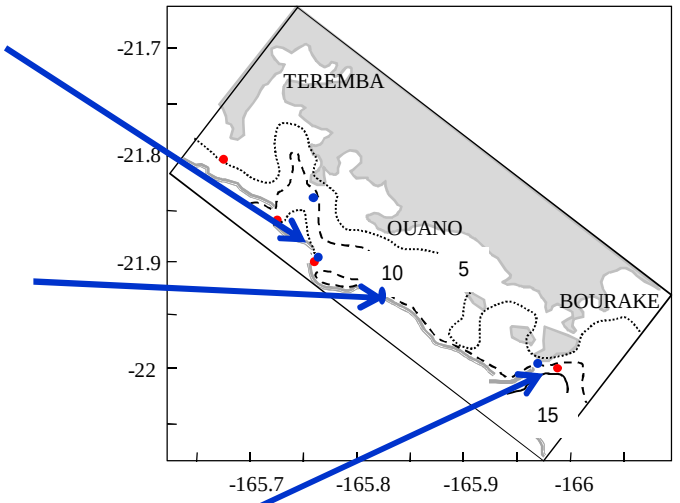
October 2013



In passages :

Mainly tidal signal

Quite in phase



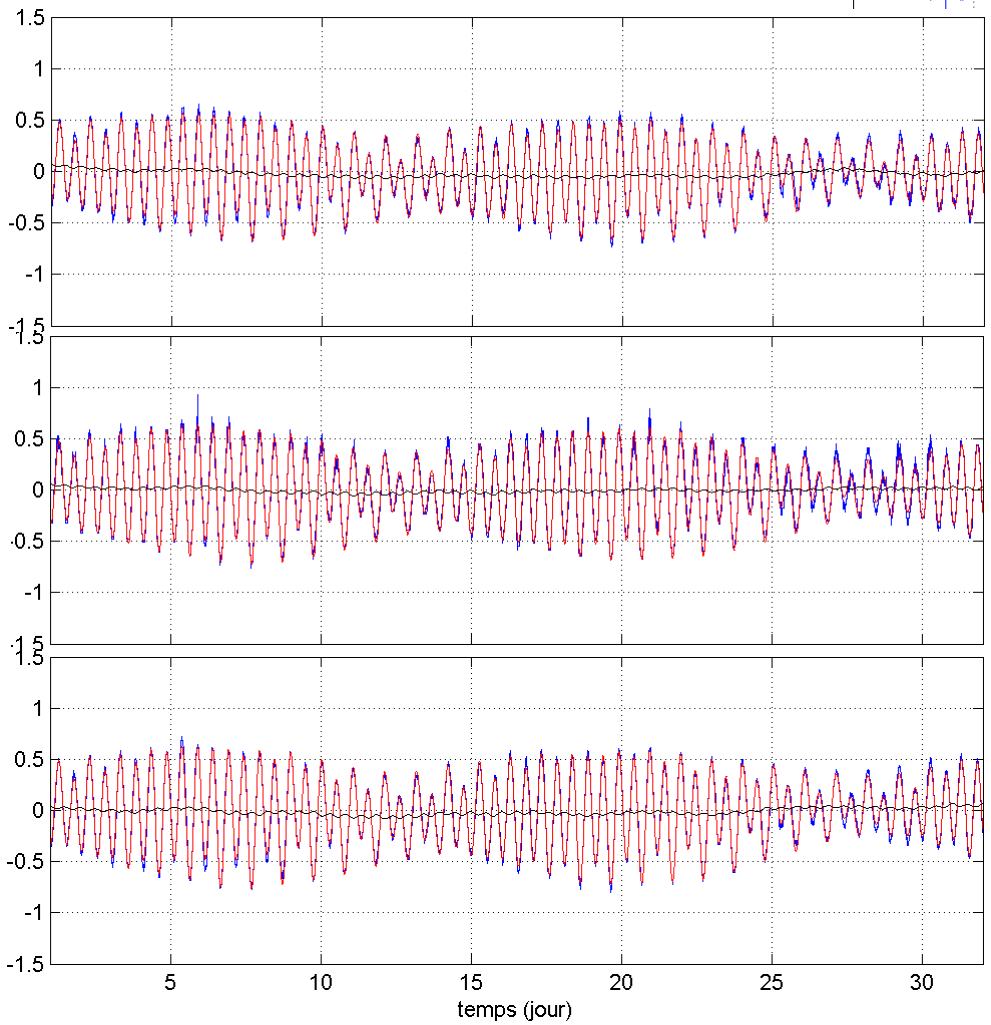
Blue : signal

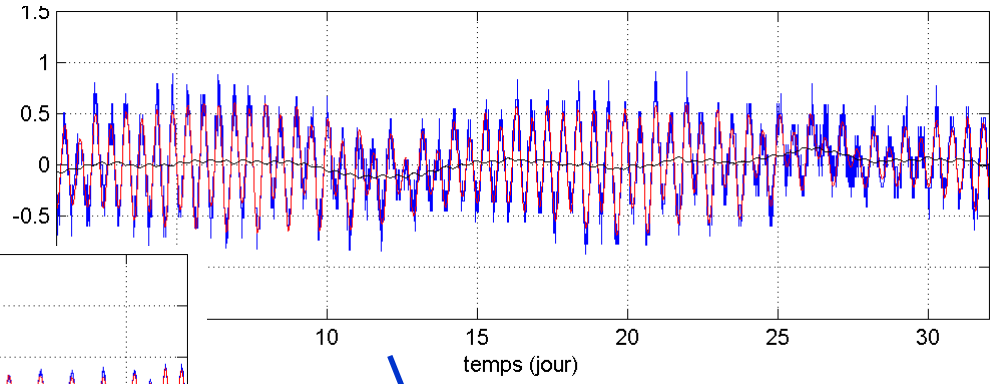
Red: tidal signal

Results : OLE (2013)

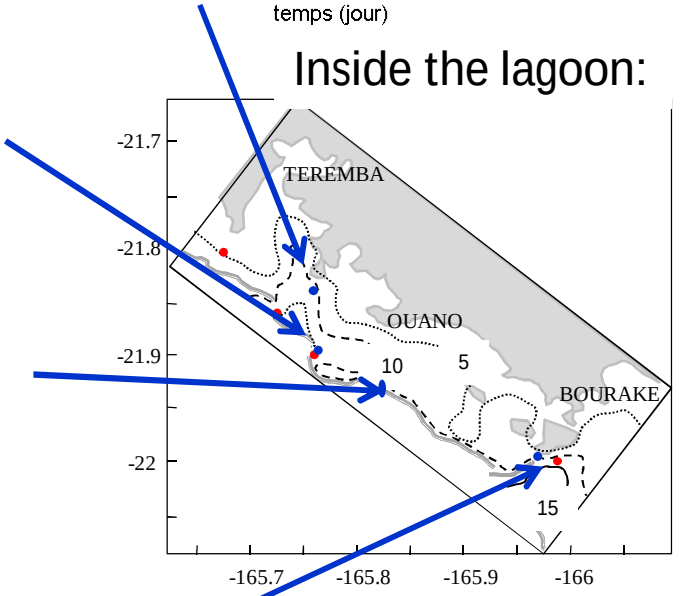
Water level

October 2013





Inside the lagoon:



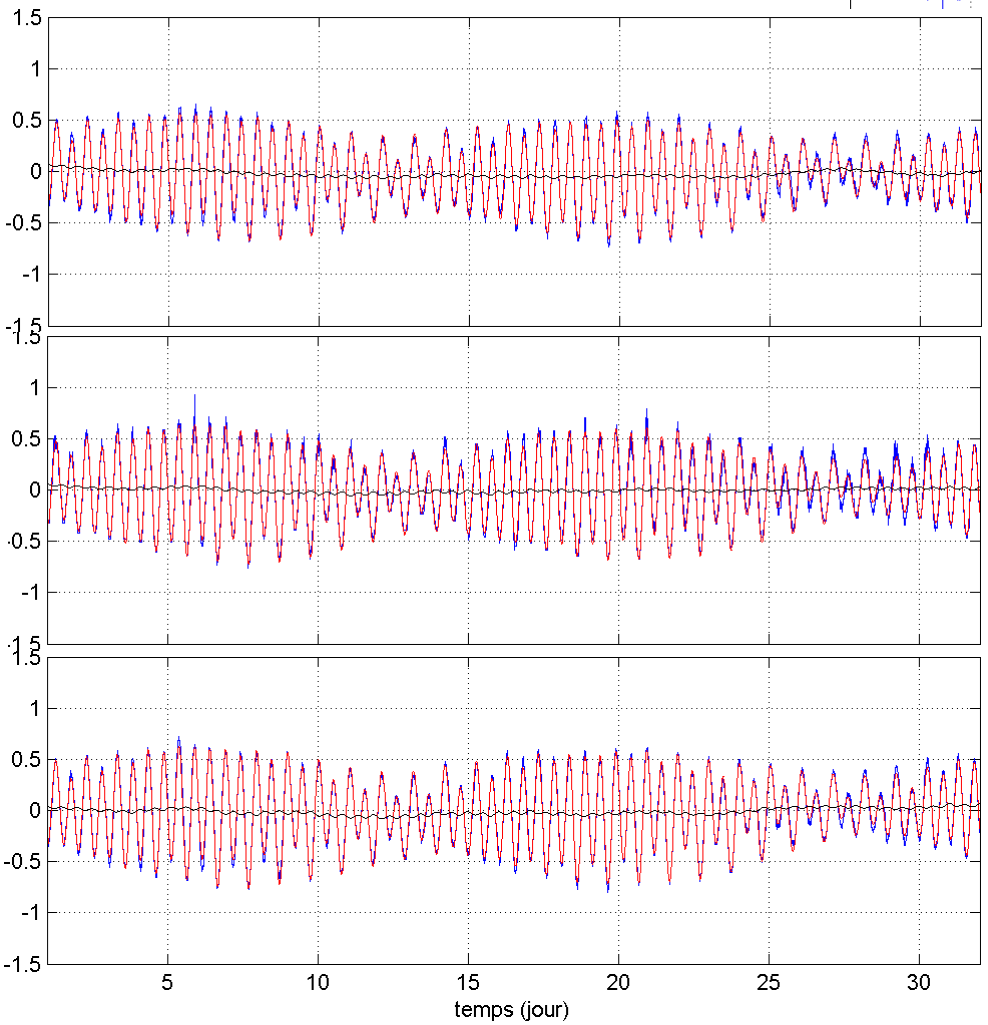
Blue : signal

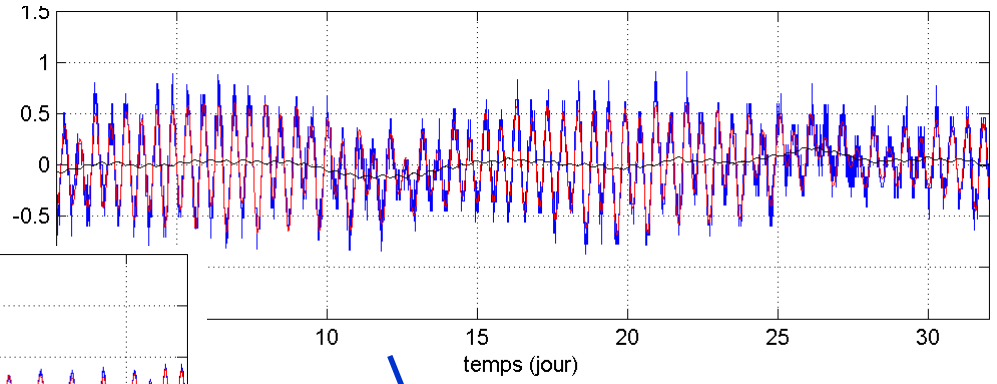
Red: tidal signal

Results : OLE (2013)

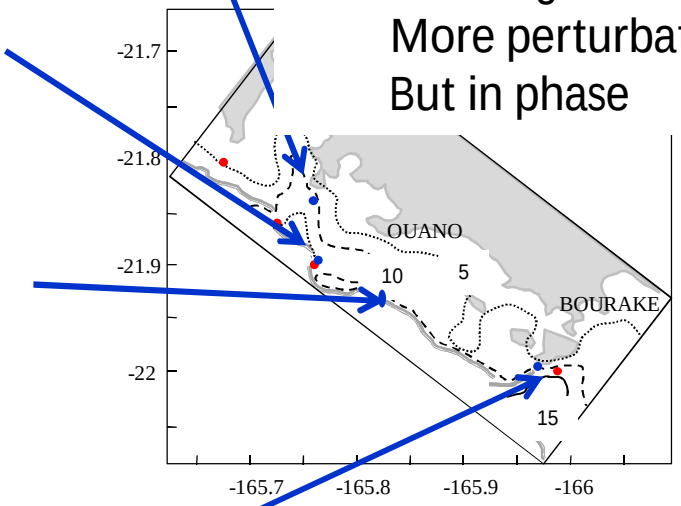
Water level

October 2013





Inside the lagoon:
More perturbated
But in phase



Blue : signal
Red: tidal signal

Results : OLE (2013)

Strange data :

Whereas the tide is quite in phase inside the lagoon, we can observe a phase lag of about 20 minutes outside the reef and inside the reef

Where is the error ?

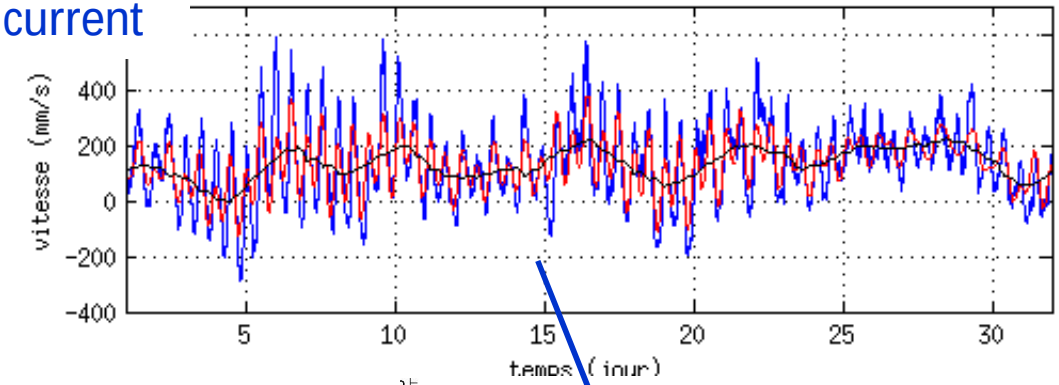
Results : OLE (2013)

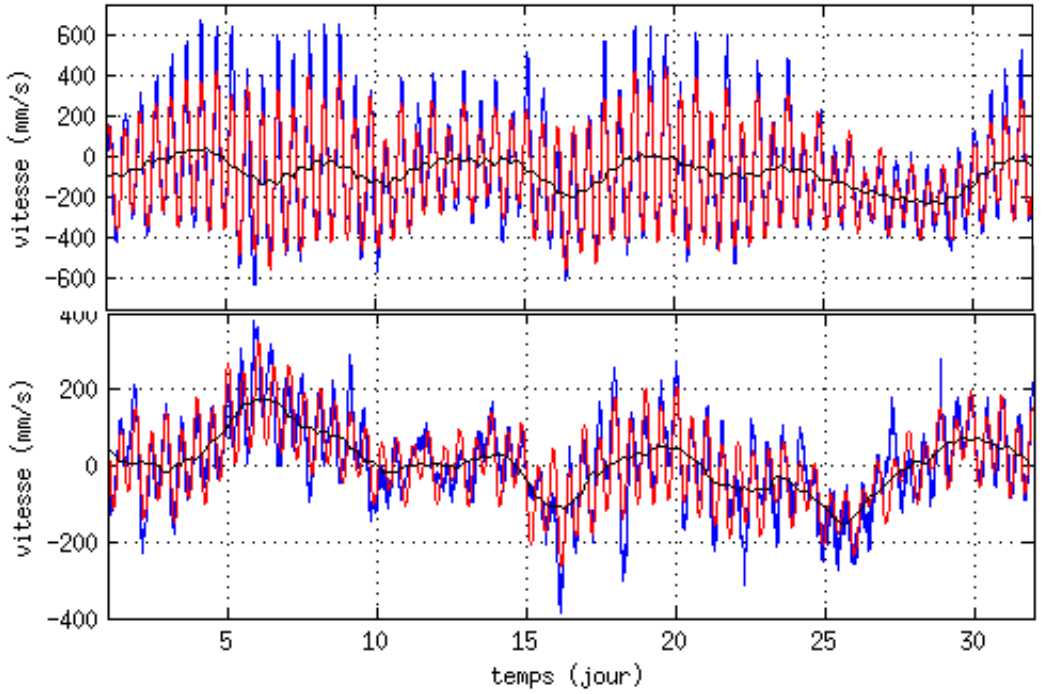
Current :

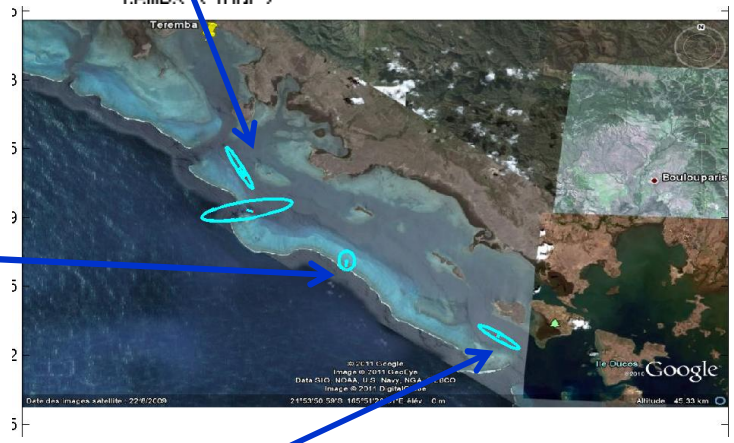
Results : OLE (2013)

Current :
velocities in the main direction of the current

October 2013





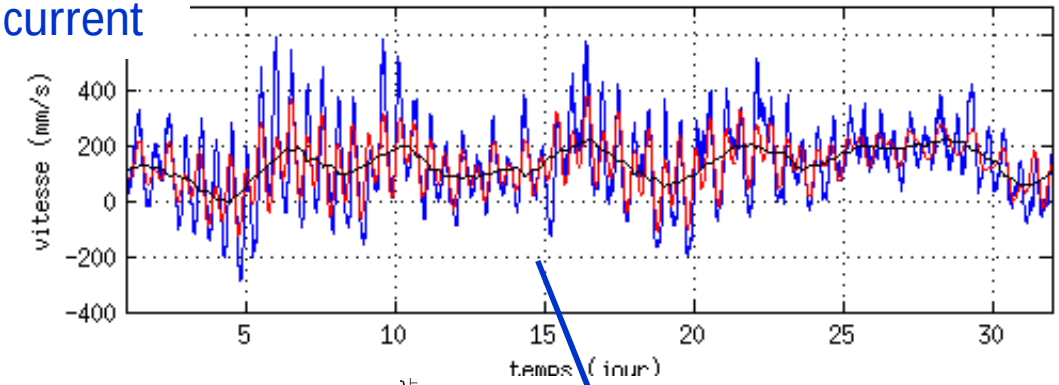


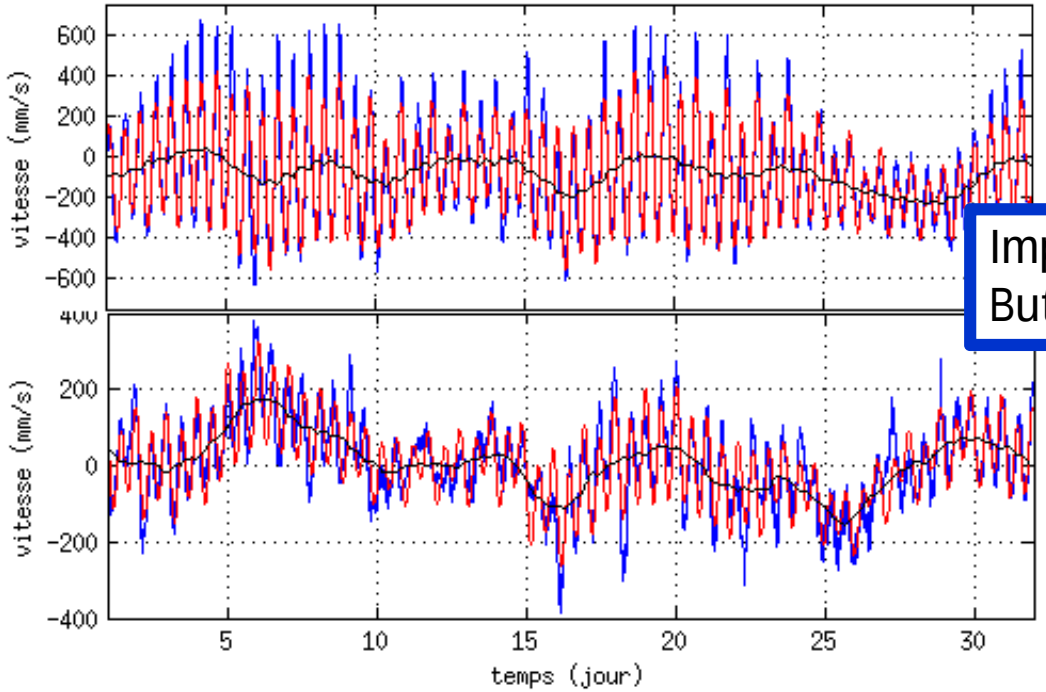
Blue : signal
Red: tidal signal

Results : OLE (2013)

Current :
velocities in the main direction of the current

October 2013





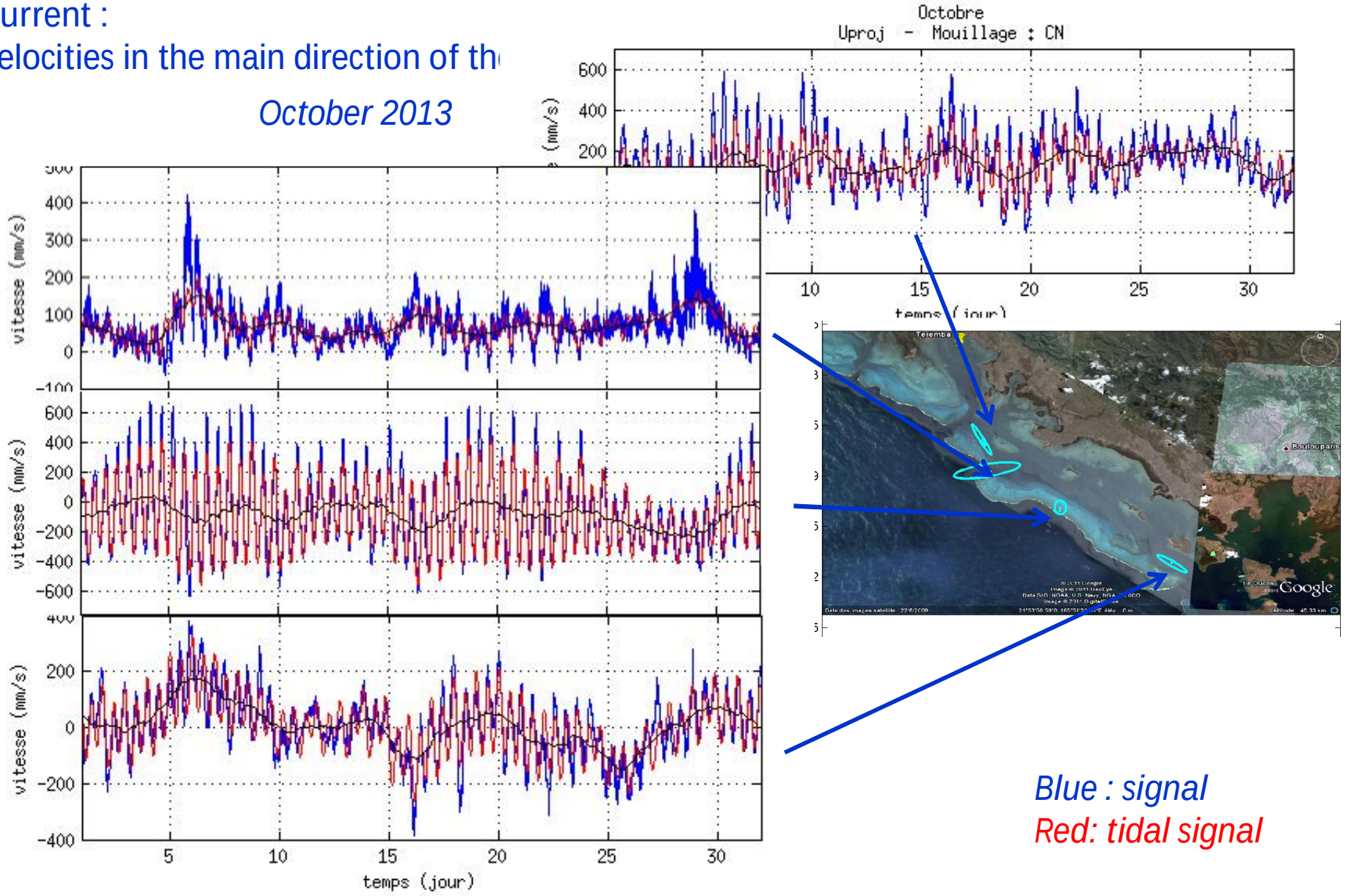
Important tidal signal
But also important low frequency variability

Blue : signal
Red: tidal signal

Results : OLE (2013)

Current :
velocities in the main direction of th

October 2013

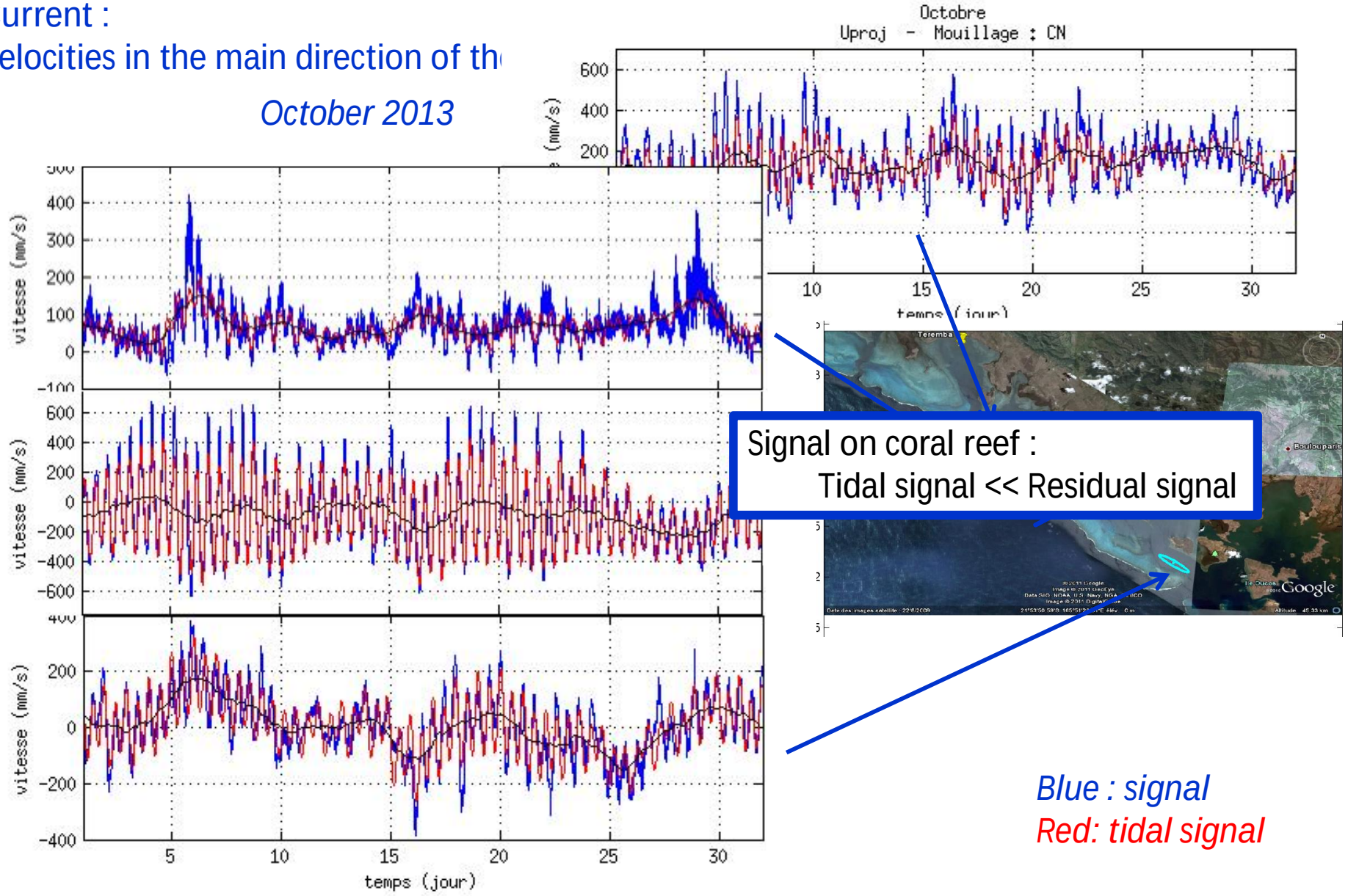


Blue : signal
Red: tidal signal

Results : OLE (2013)

Current :
velocities in the main direction of th

October 2013



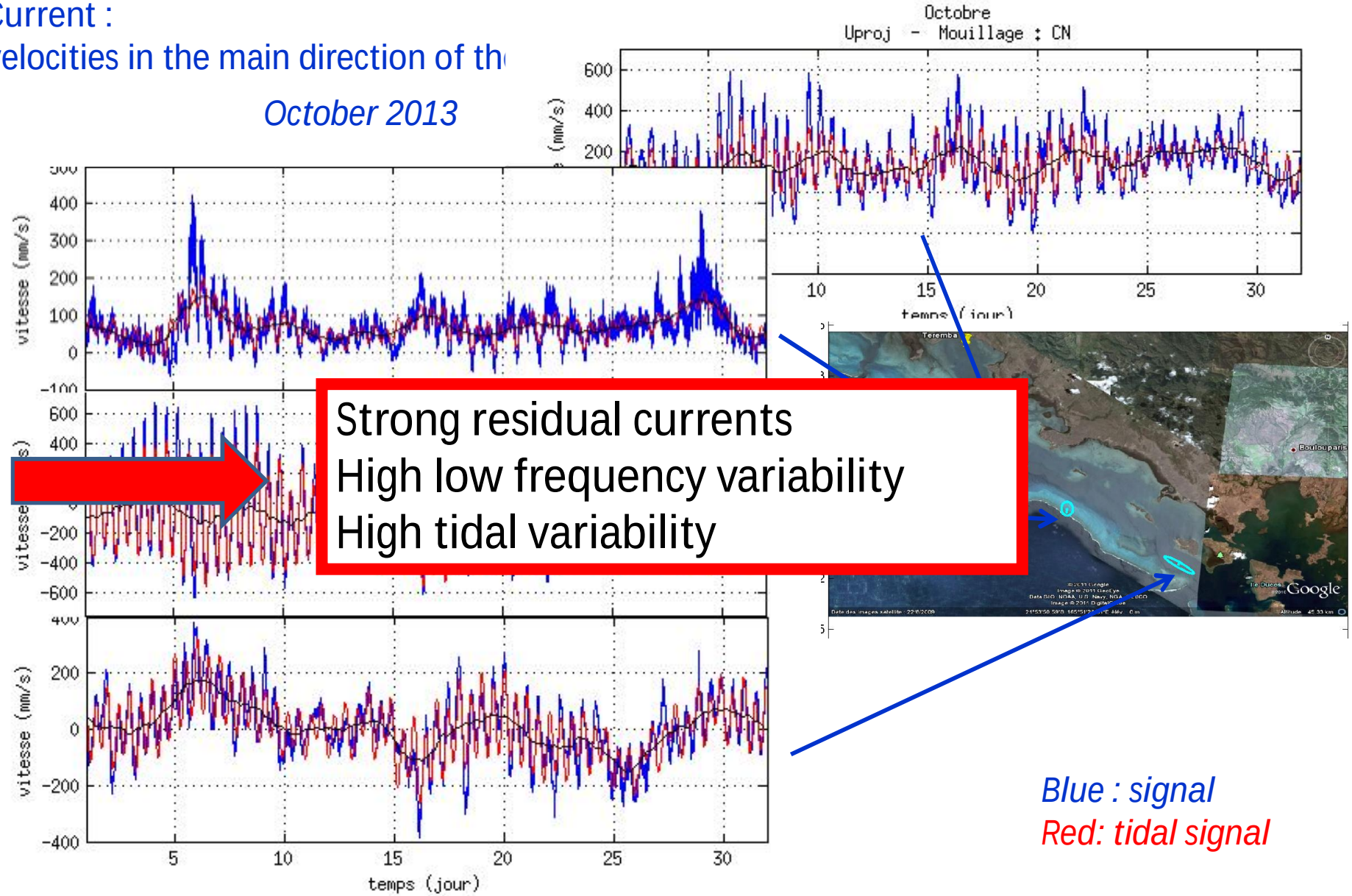
Signal on coral reef :
Tidal signal << Residual signal

Blue : signal
Red: tidal signal

Results : OLE (2013)

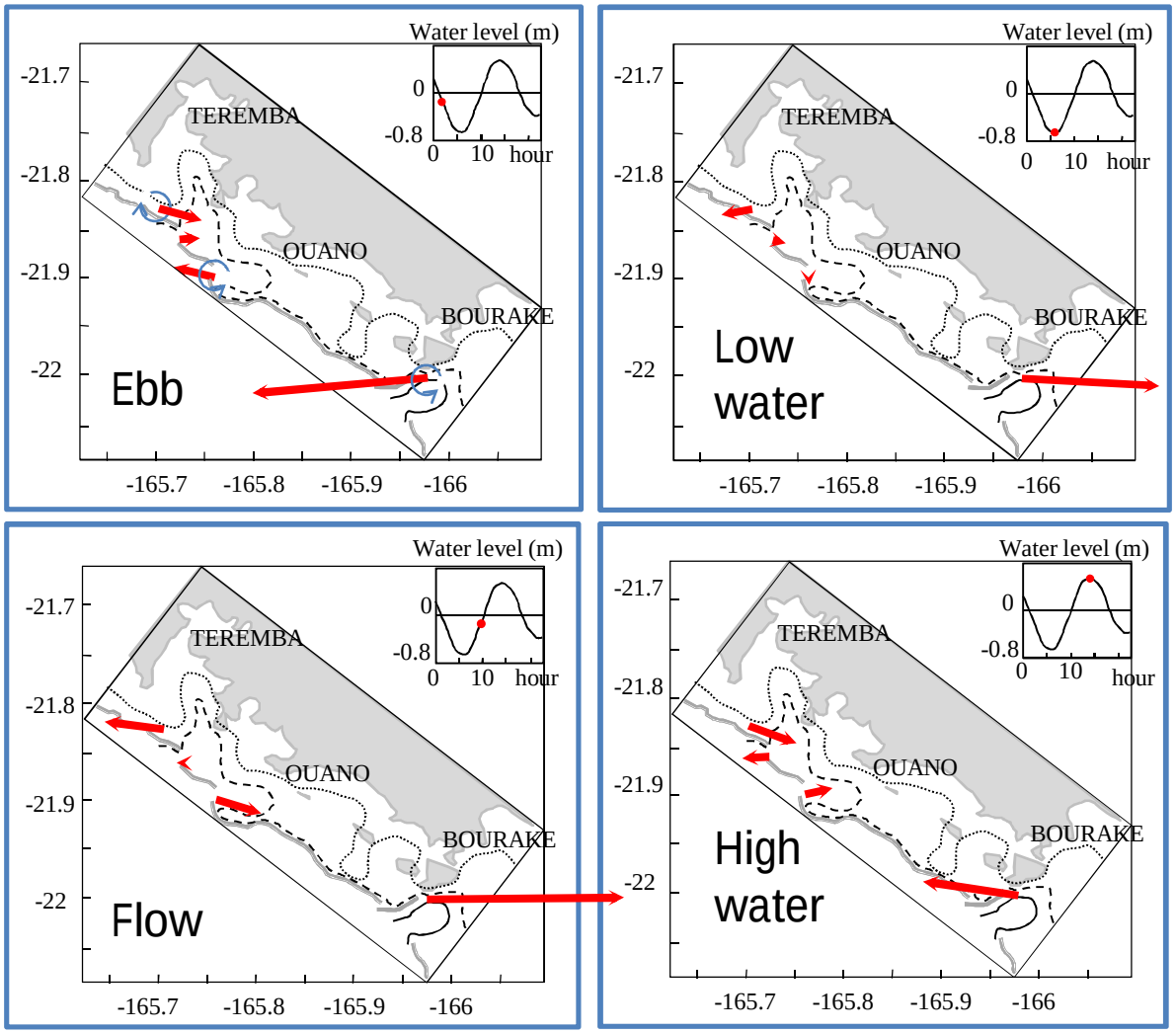
Current :
velocities in the main direction of th

October 2013



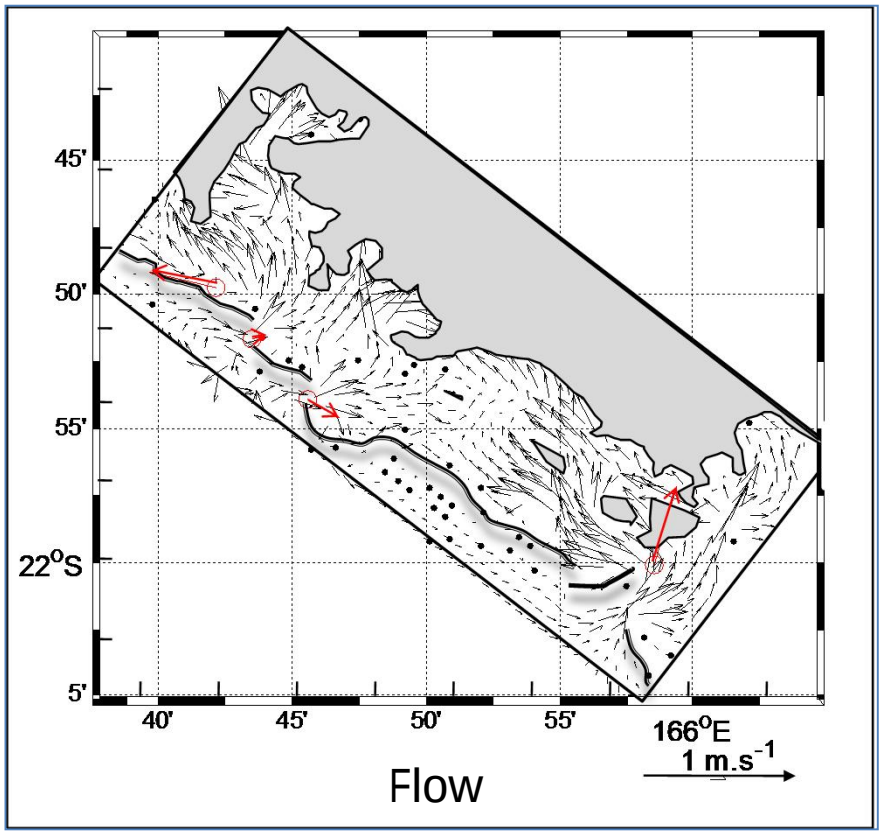
Blue : signal
Red: tidal signal

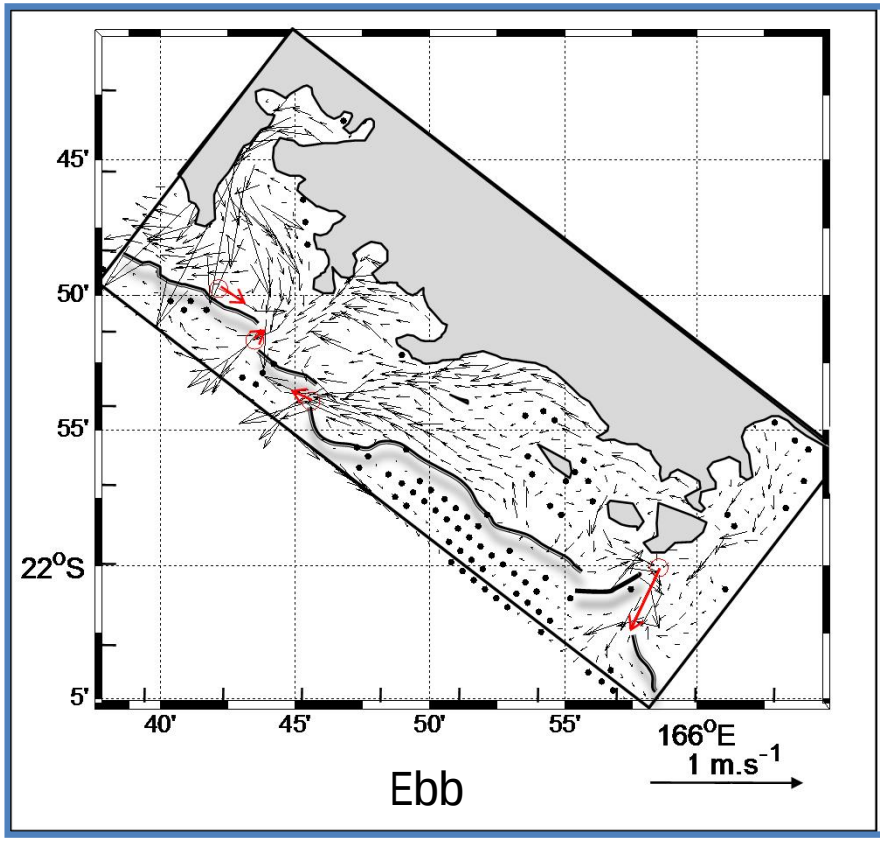
Tidal functionning : Apte (2011)



Tidal current during a cycle of spring tide

Modelisation of this tidal circulation

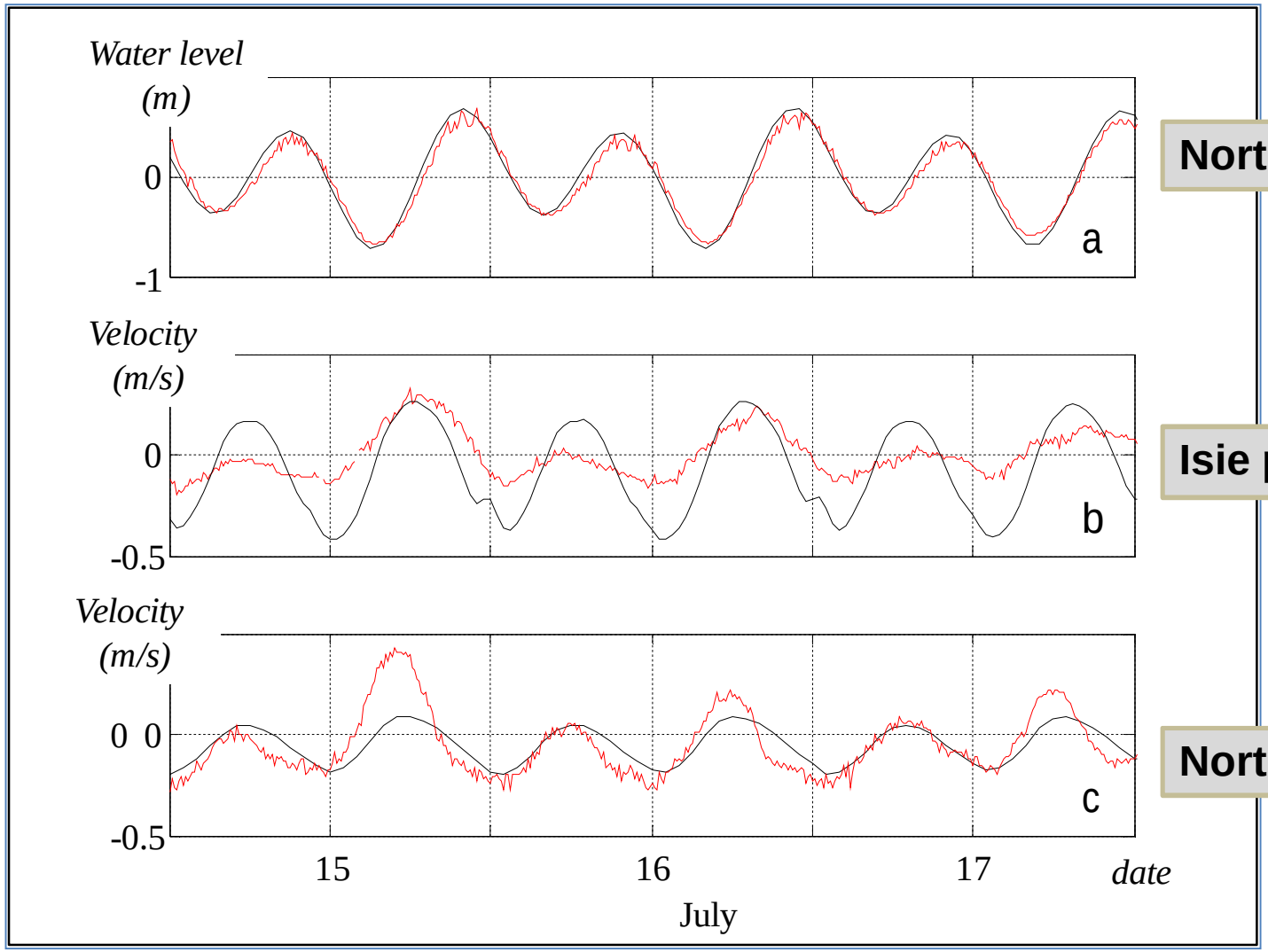




Comparison Model / data the 16 July 2011

Red quiver : data - Black quiver model results

Model results // in-situ data



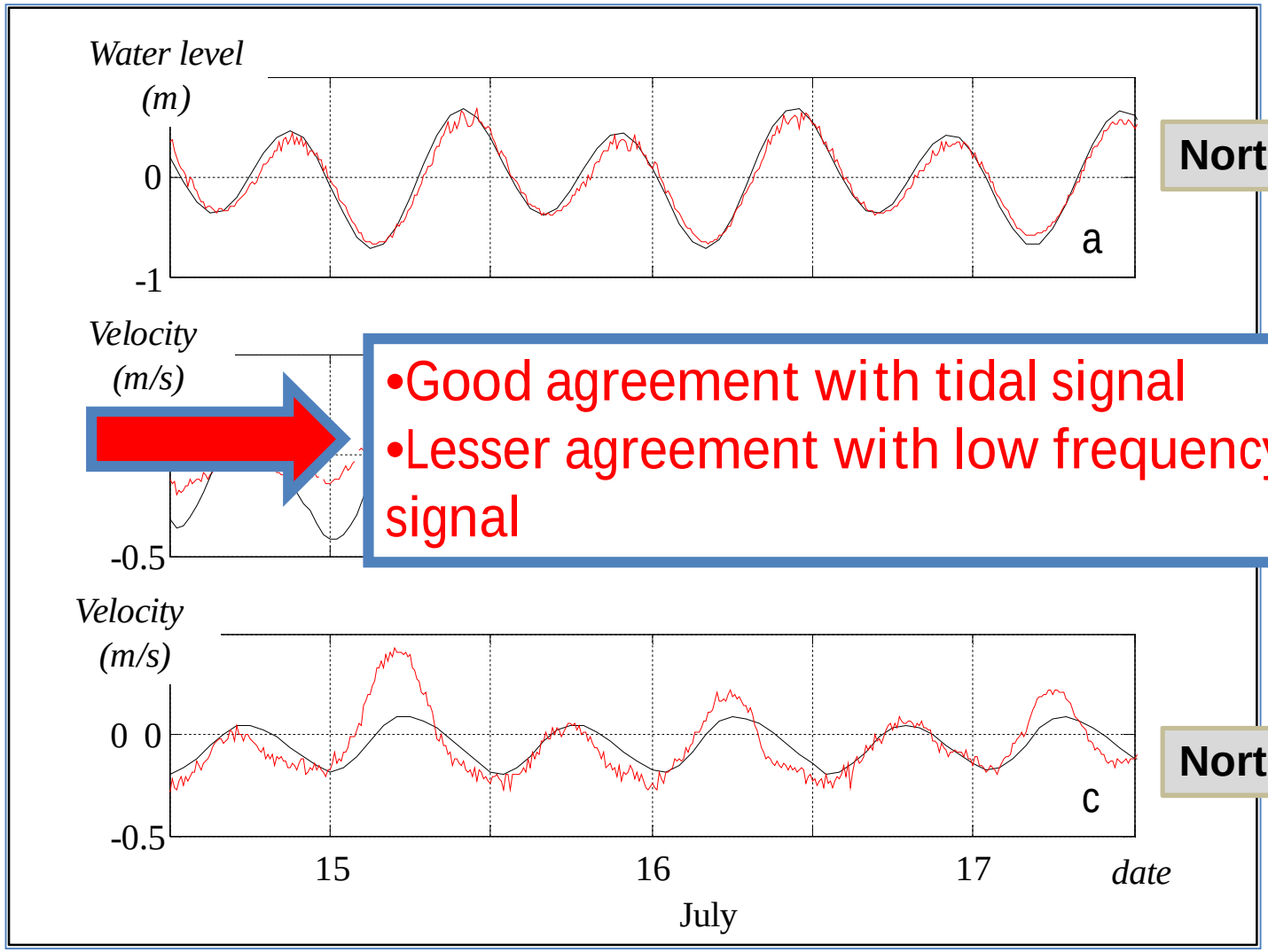
North Passage:

Isie passe :

North Passage:

Comparison Model results (black line) / in-situ data (red line) :

Model results // in-situ data



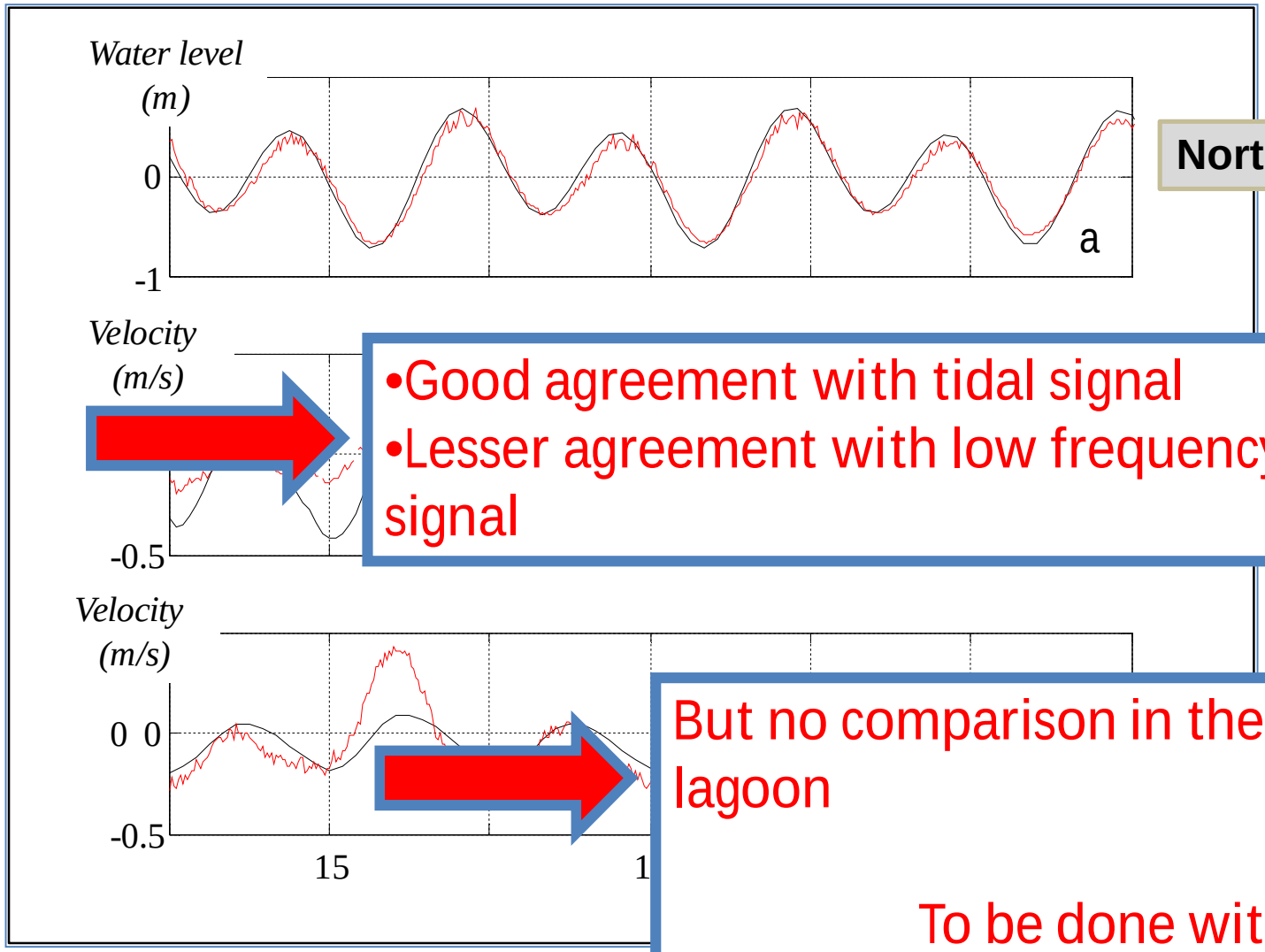
North Passage:

- Good agreement with tidal signal
- Lesser agreement with low frequency signal

North Passage:

Comparison Model results (black line) / in-situ data (red line) :

Model results // in-situ data



North Passage:

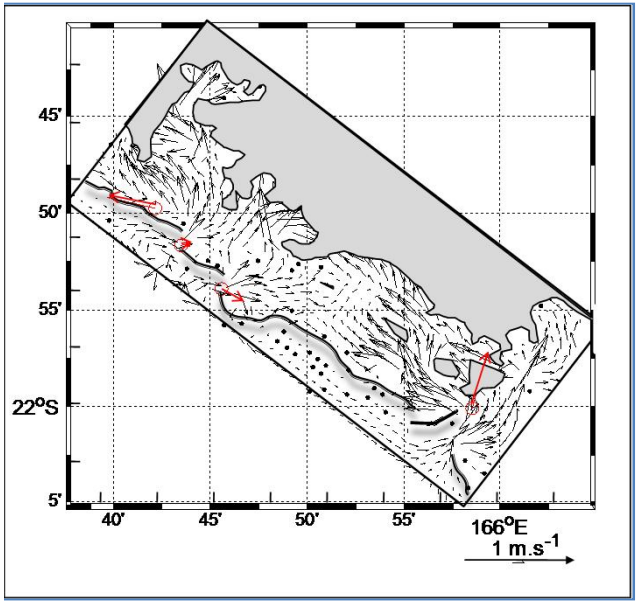
- Good agreement with tidal signal
- Lesser agreement with low frequency signal

But no comparison in the middle of the lagoon

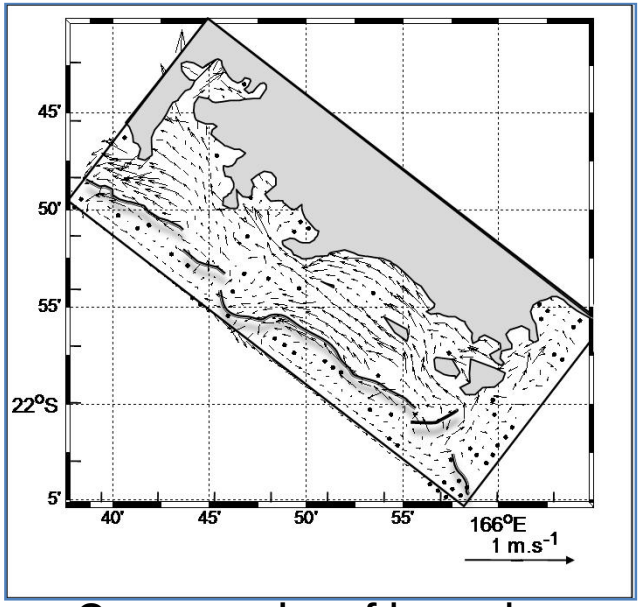
To be done with data from OLE

Comparison Model results (black line) / in-situ data (red line) :

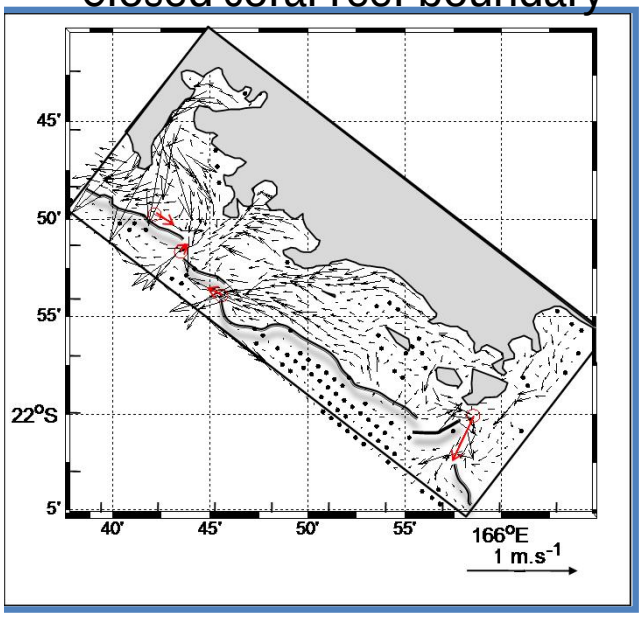
Coral reef boundary on tidal circulation

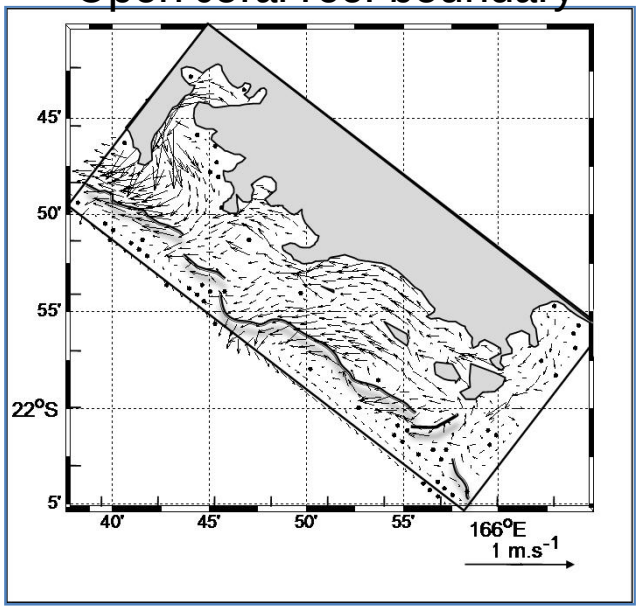


Closed coral reef boundary



Open coral reef boundary



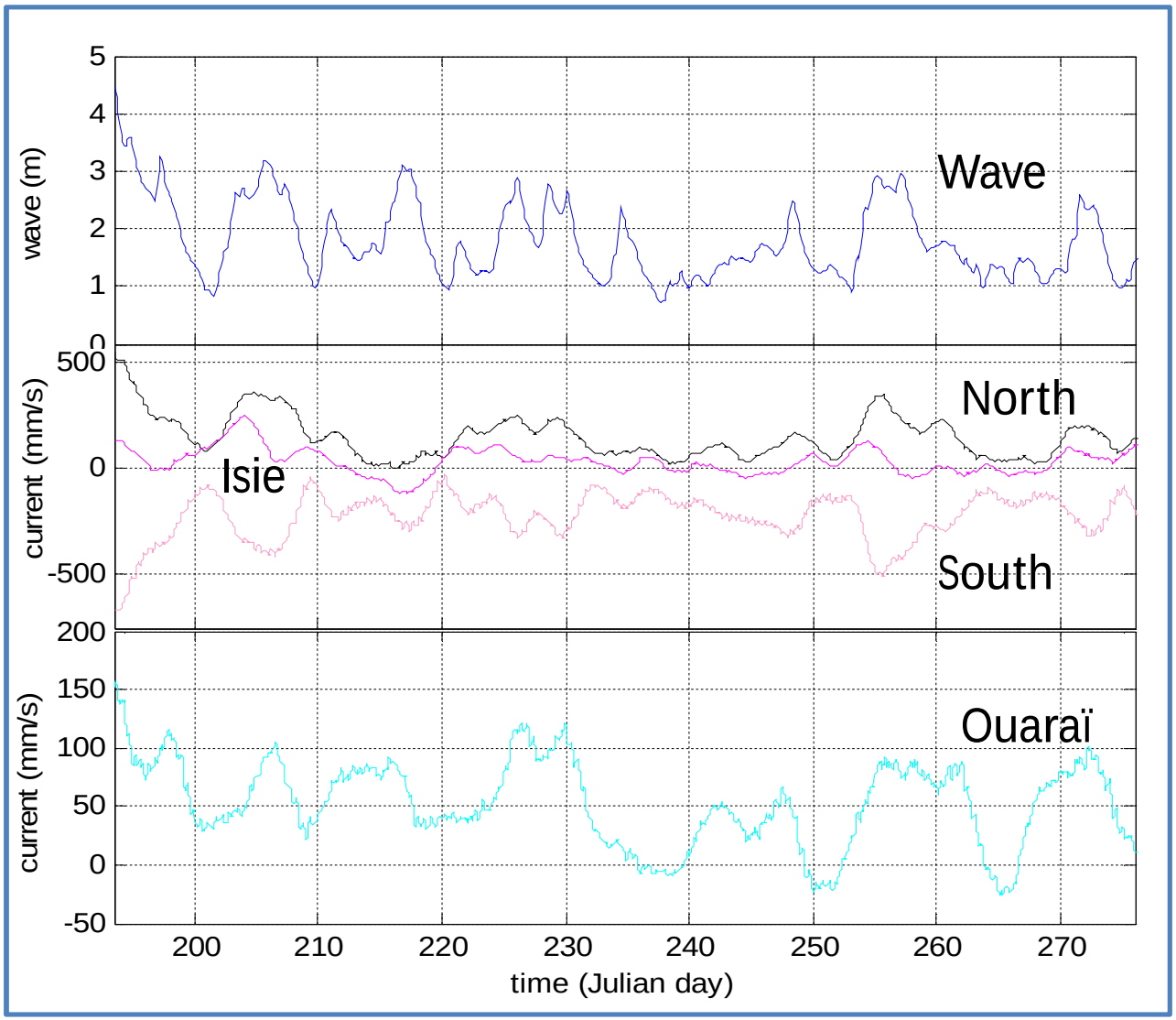


- Main characteristic of circulation is maintained
- Circulation is more homogenous inside the lagoon

- Main modifications :
  - ✓near reef
  - ✓ in passes :

  Reduce tidal fluctuation

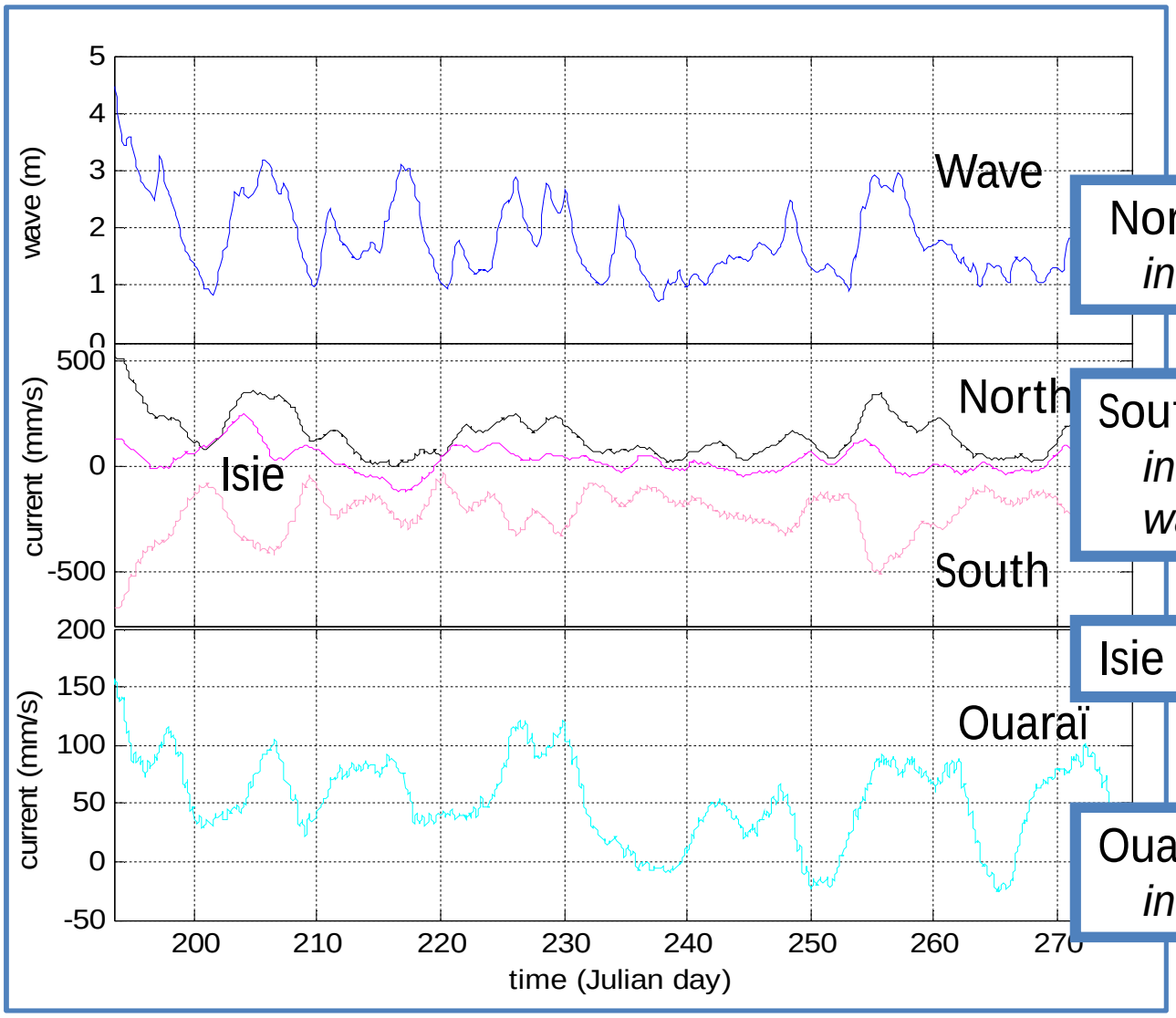
Low frequency variability : Wave impact



Two-days-averaged current and waves

Current in the main direction, positiv when enters

Low frequency variability : Wave impact



North : high correlation
increase of inflow due to waves

South : inverse correlation
increase of outflow due to waves

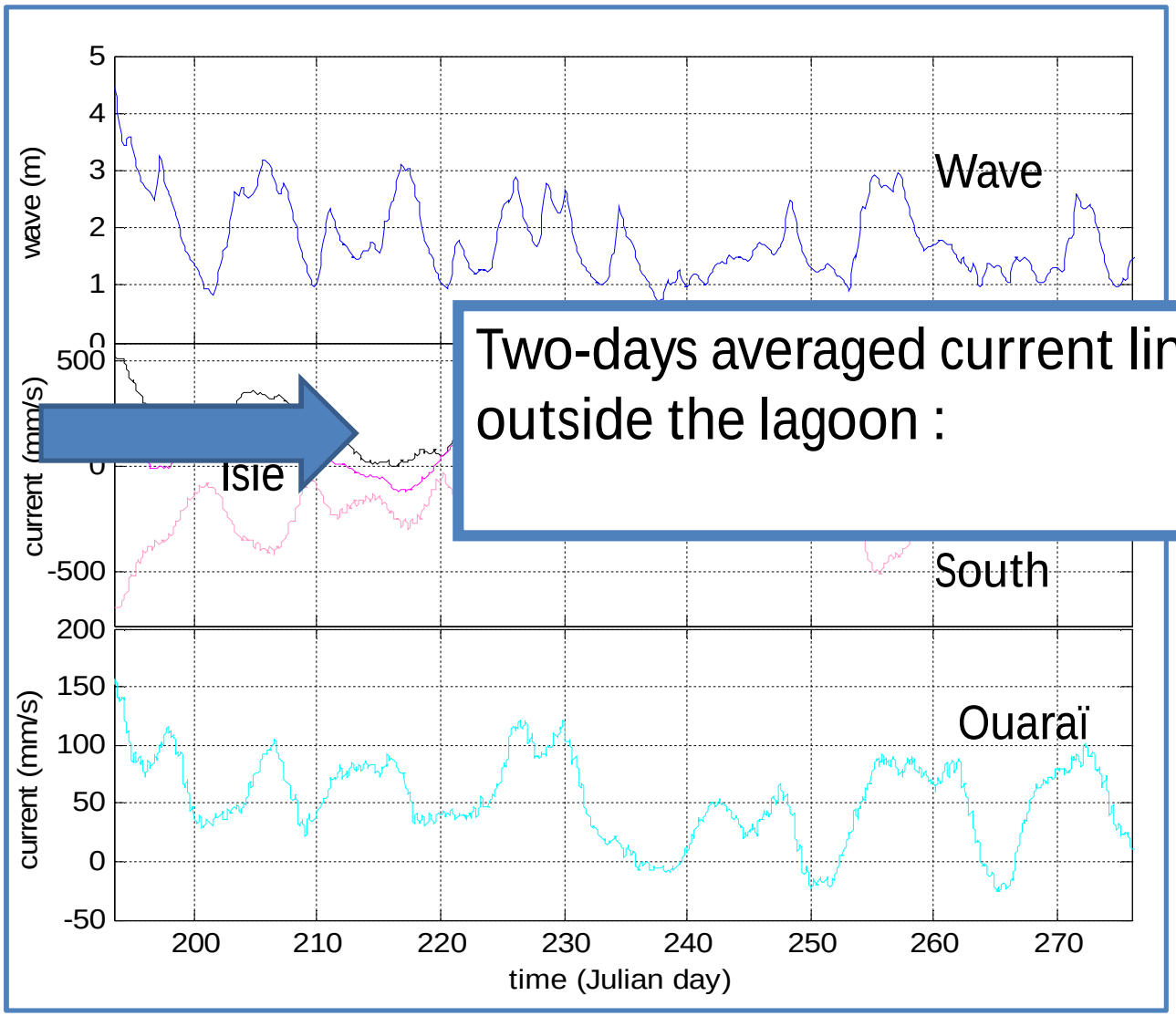
Isie : lower correlation

Ouarai: high correlation
increase of inflow due to waves

Two-days-averaged current and waves

Current in the main direction, positiv when enters

Low frequency variability : Wave impact

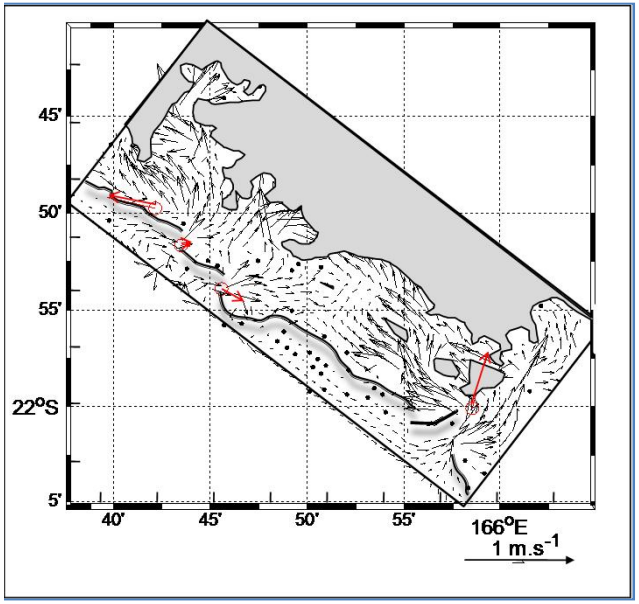


Two-days averaged current linked with waves outside the lagoon :

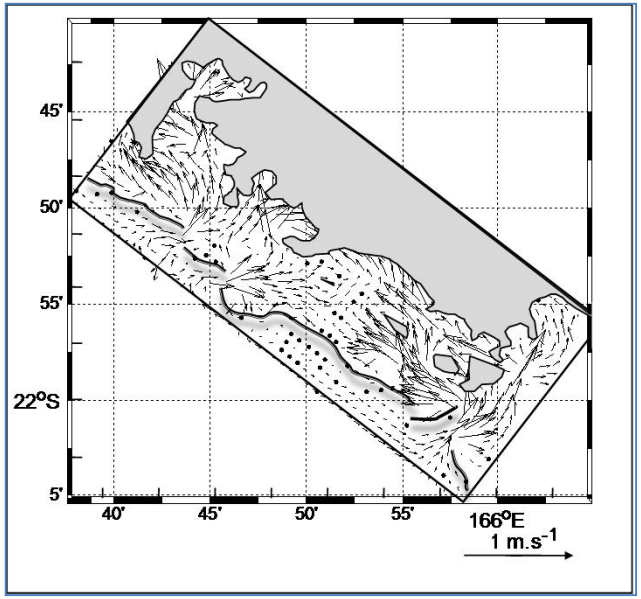
Two-days-averaged current and waves

Current in the main direction, positiv when enters

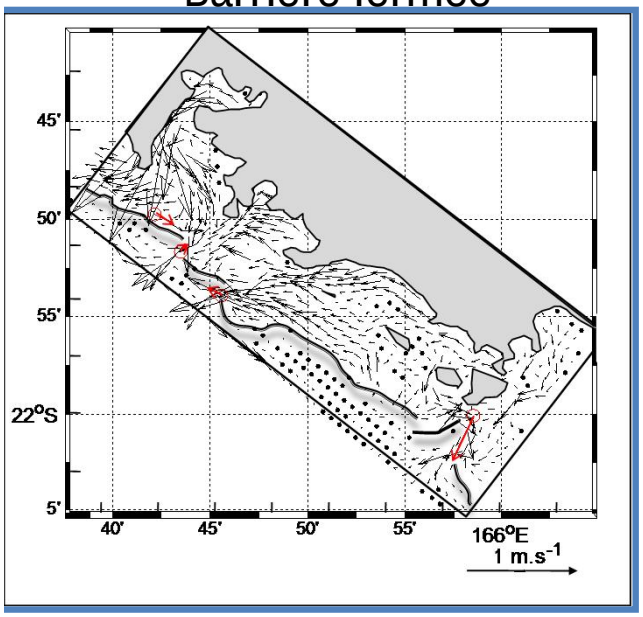
Wave impact

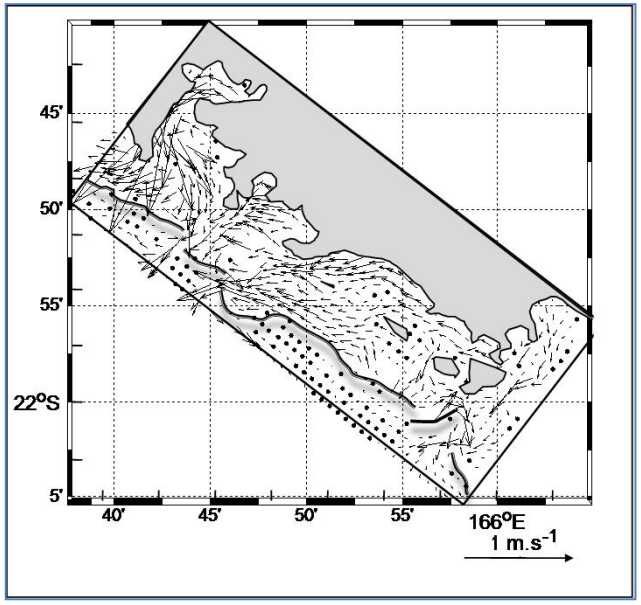


Barrière fermée



Flux simulant l'effet de la houle





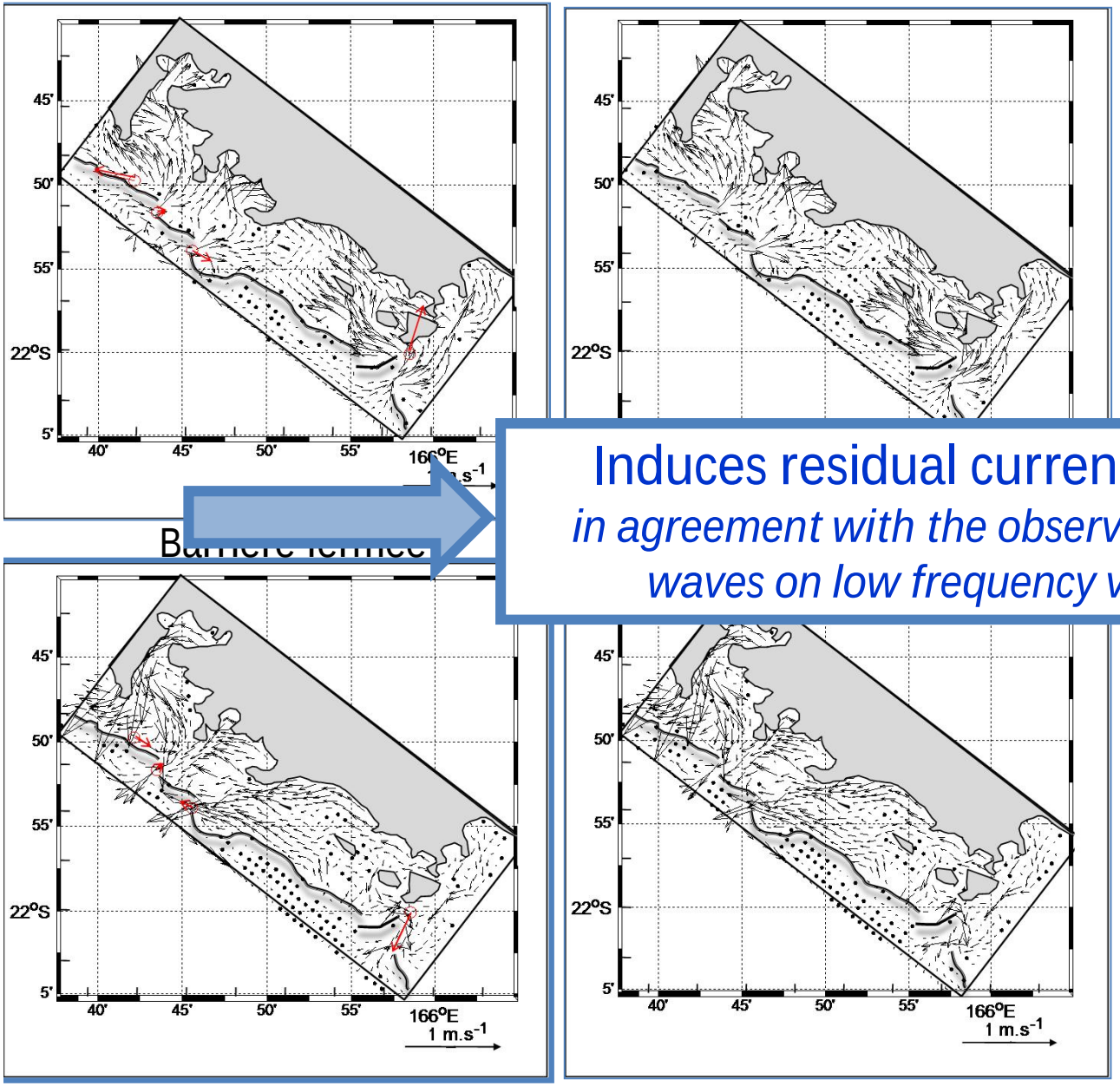
Hypothesis :

- Similar to the reference simulation
- Cross-reef inflow of about 25 $m^3.s^{-1}$ representing wave-driven flow

- Main characteristic of circulation is maintained

- Main modifications :
  - ✓near reef
  - ✓ in passes : *increase of outflow during ebb*

Wave impact



Induces residual current in passes

in agreement with the observed impact of waves on low frequency variability

Hypothesis :

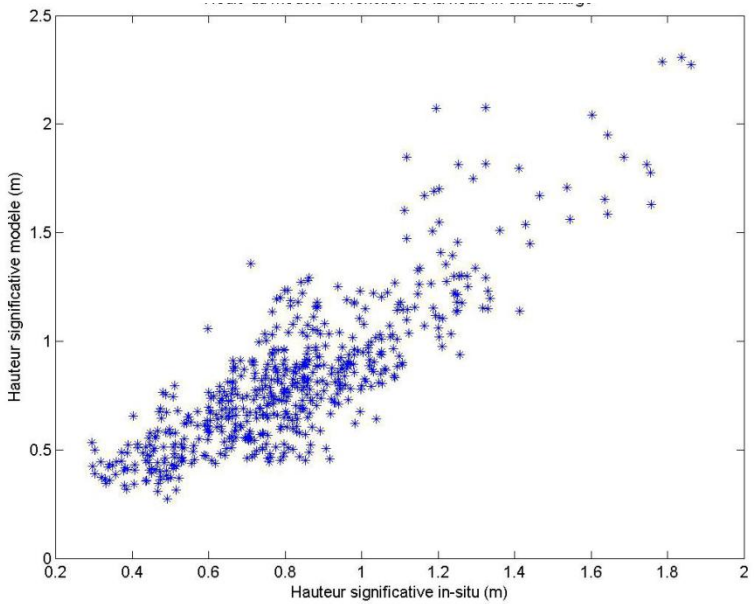
- Similar to the reference simulation
- Cross-reef inflow of about 25 $m^3.s^{-1}$ representing wave-driven flow

istic of circulation is maintained

- Main modifications :
  - ✓near reef
  - ✓ in passes : *increase of outflow during ebb*

Wave impact

On Coral reef : Wave height versus Current



High correlation :

But how to explain ?

Wave impact

How can we modelise the wave impact ?

Nouméa:

Bonneton, 2007

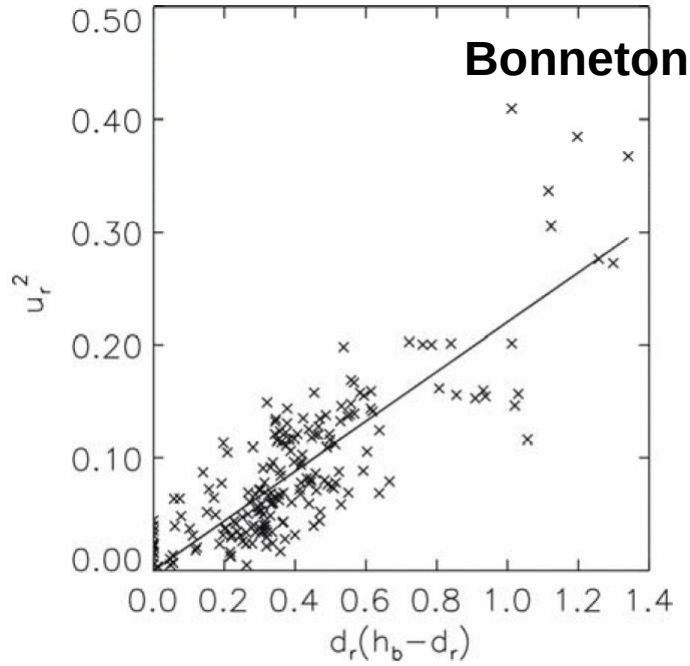
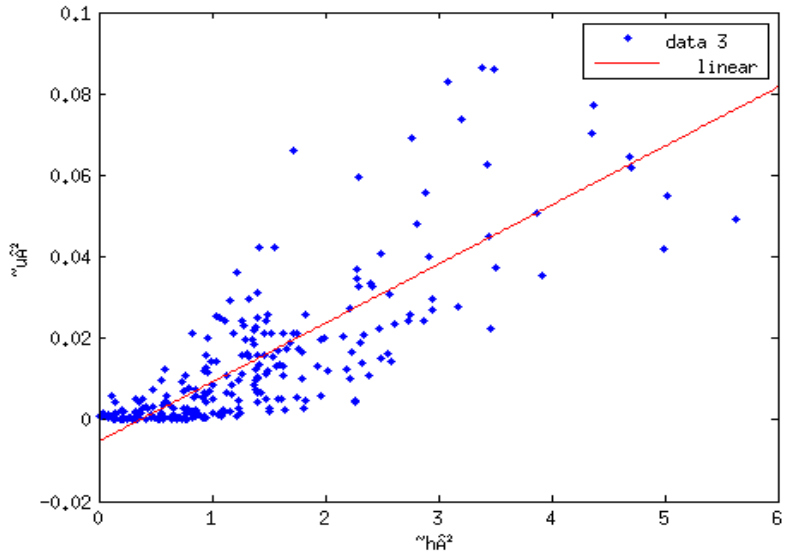


Figure 7. Square of the cross reef current u_r as a function of d_r (h_b-d_r), from data acquired between day 2 and day 7. The solid line is a least squares best fit, $u_r^2=0.22d_r$ (h_b-d_r), with a correlation coefficient of 0.83.

Ouano :



Where is the trouble ?

Coral-reef boundary condition

Houle :

I thought :

Wave-driven Current appears when wave is broken

Then

when hc ~ hs/2 > h

Coral-reef boundary condition

Houle :

I thought :

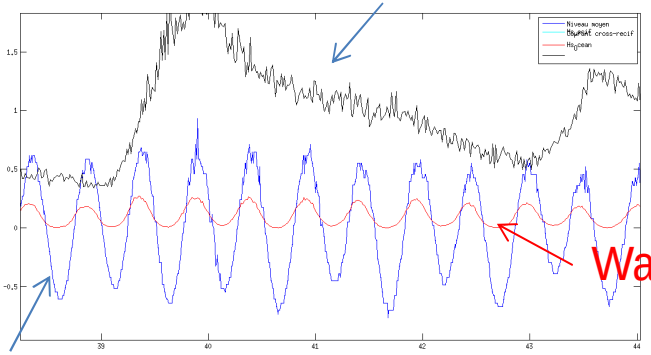
Wave-driven Current appears when wave is broken

Then

when hc ~ hs/2 > h

But here :

Wave height



Wave on the reef

Mean water level

Wave on the reef decrease at low tide and increase and high tide

Coral-reef boundary condition

Houle :

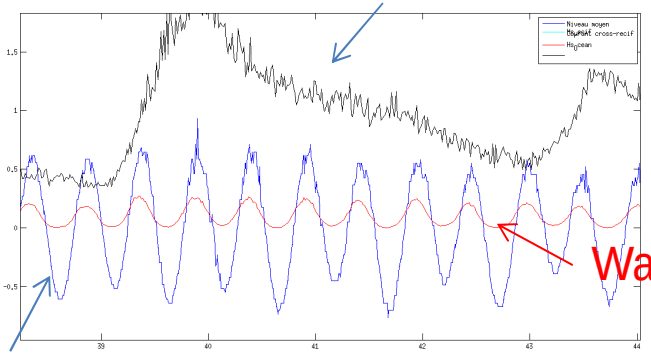
I thought :

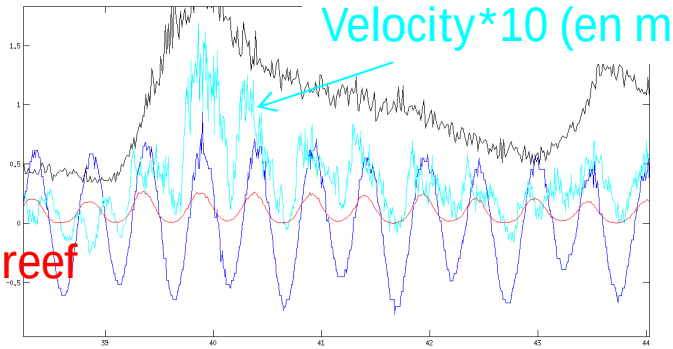
Wave-driven Current appears when wave is broken

Then

when hc ~ hs/2 > h

But here :

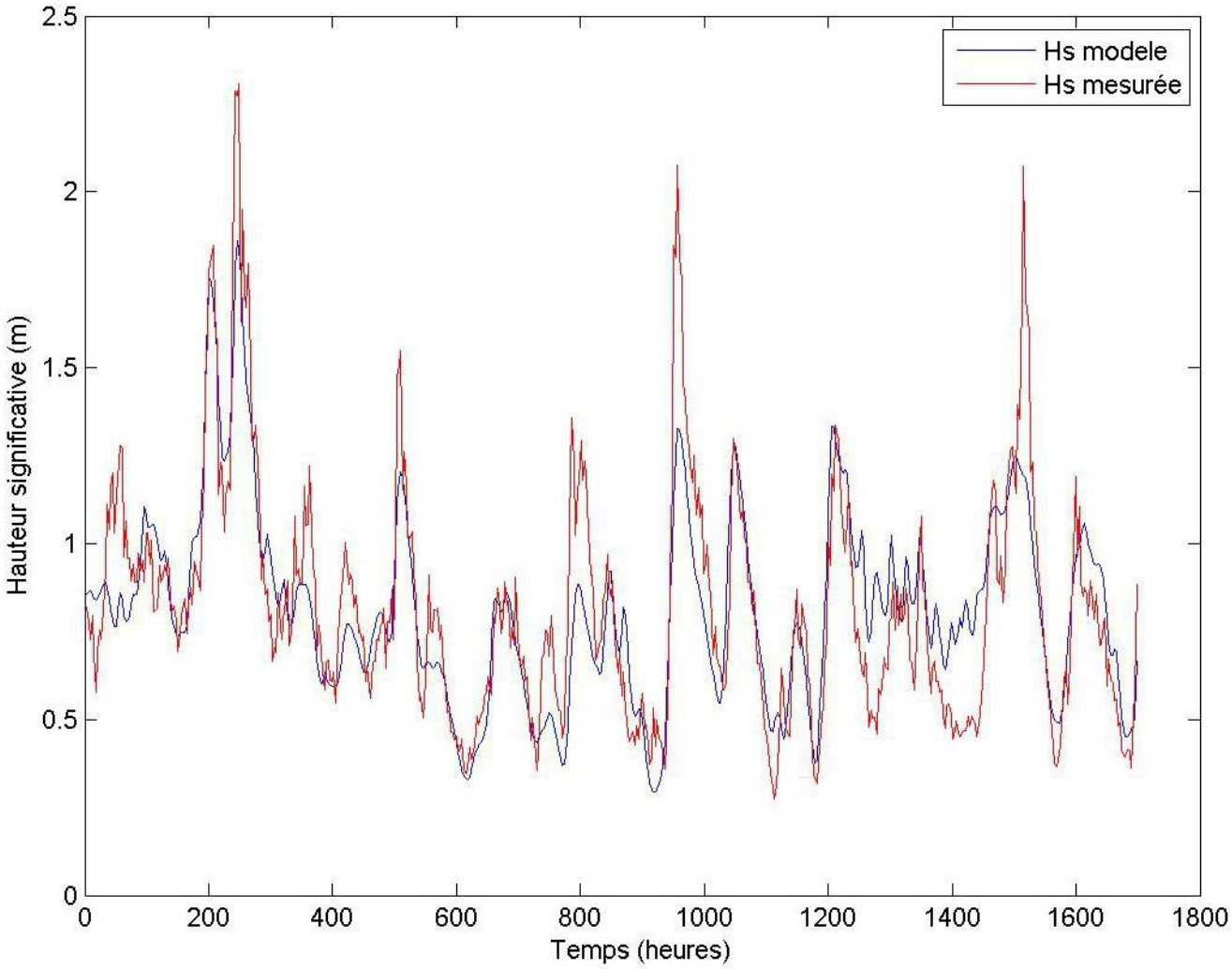




Current seems to be correlated to wave on the reef Then it decreases at low water and increase and high water

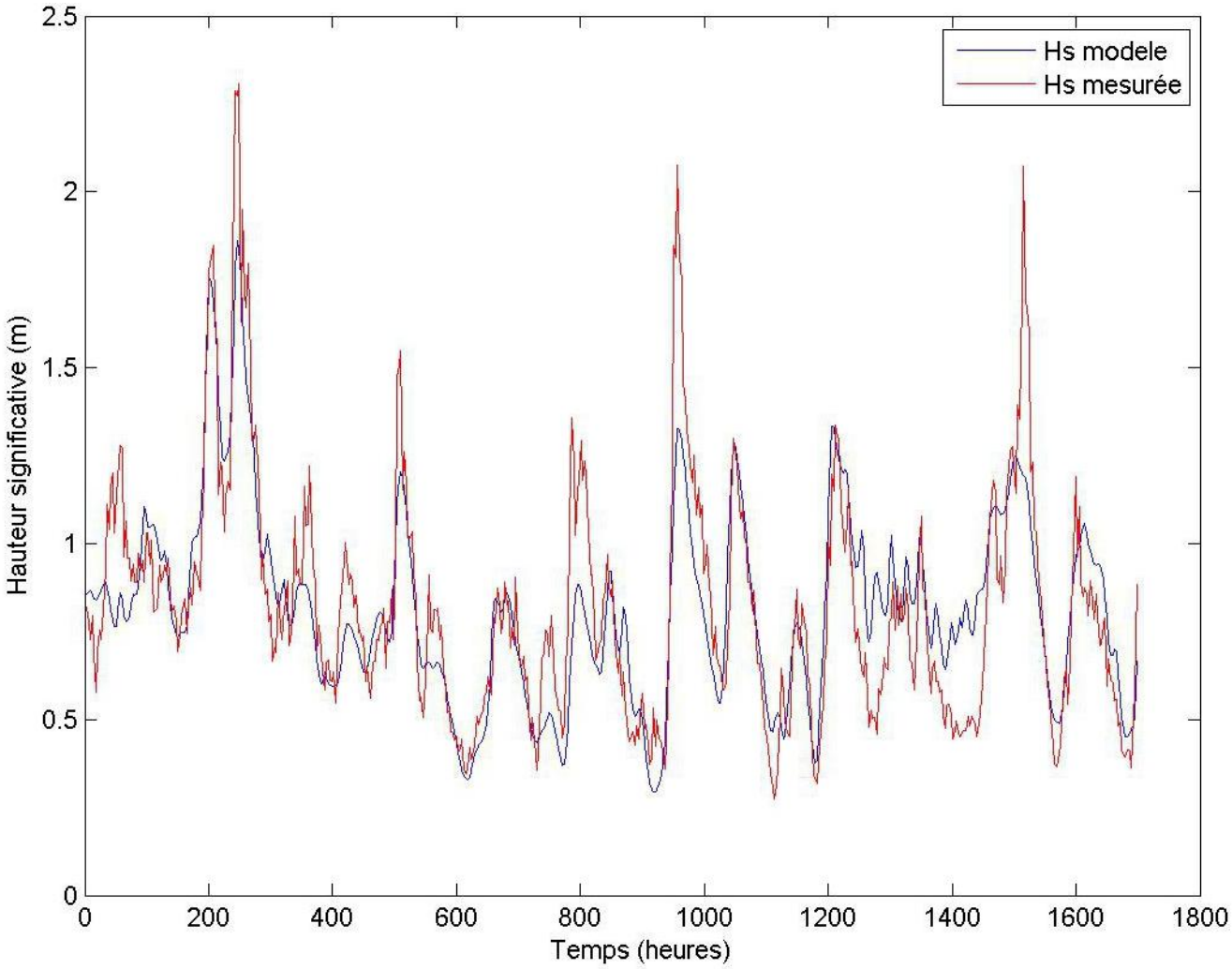
Wave impact

Comparison : Wavewatch Model versus in-situ Data



Wave impact

Comparison : Wavewatch Model versus in-situ Data

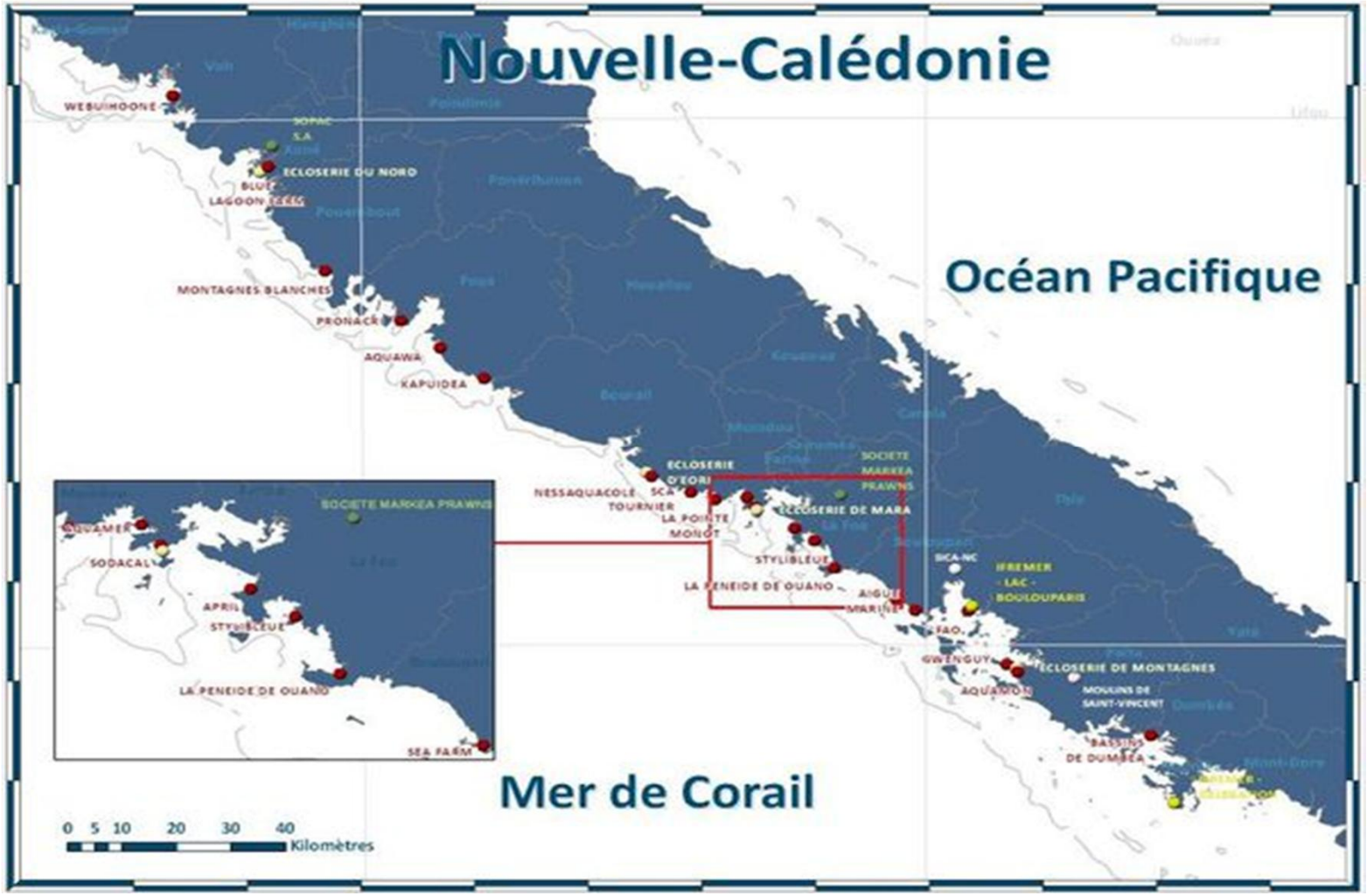


Very good agreement

To conclude :

- We have a lot of work to do…
- The coral reef barrier is not a simple boundary
  - Not a wall as it was long time considered
  - Wave does not create constant fluxes, but the wave-driven fluxes also depend from the tide
  - Cross-reef tidal current exists and must be taken into account
  - It is necessary to determine the bottom friction above coral reef

Thank you ...


Nouvelle-Calédonie
Océan Pacifique
Mer de Corail
WEBUIHOONE
SOPAC S.A
ECLOSERIE DU NORD
BLUE LAGOON FARM
MONTAGNES BLANCHES
PRONACE
AQUAWA
KAPUIDEA
ECLOSERIE D'EON
NESSAQUACOLE SCA
TOURNIER
LA POINTE MONOT
SOCIETE MARKEA PRAWNS
ECLOSERIE DE MARA
STYLIBLEUE
LA PENEIDE DE OUANO
AIGUE MARINE
BICA-NC
IFREMER - LAC - BOULOUPARIS
FAO
GWENGUY
AQUAMON
ECLOSERIE DE MONTAGNES
MOULINS DE SAINT-VINCENT
BASSINS DE DUMBEA
OUAMER
SODACAL
APRIL
SEA FARM
0 5 10 20 30 40
Kilomètres