OCASO Project

Tsunami Arrival Detection with High Frequency (HF) Radar Technology

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Oceanography Division – Instituto Hidrográfico, Marinha

5th December 2019

OCASO Project

OCASO : Observatório **C**osteiro **A**mbiental do **S**ud**O**este

Project Manager: Instituto Hidrográfico (IH)

Duration: 2017 - 2020

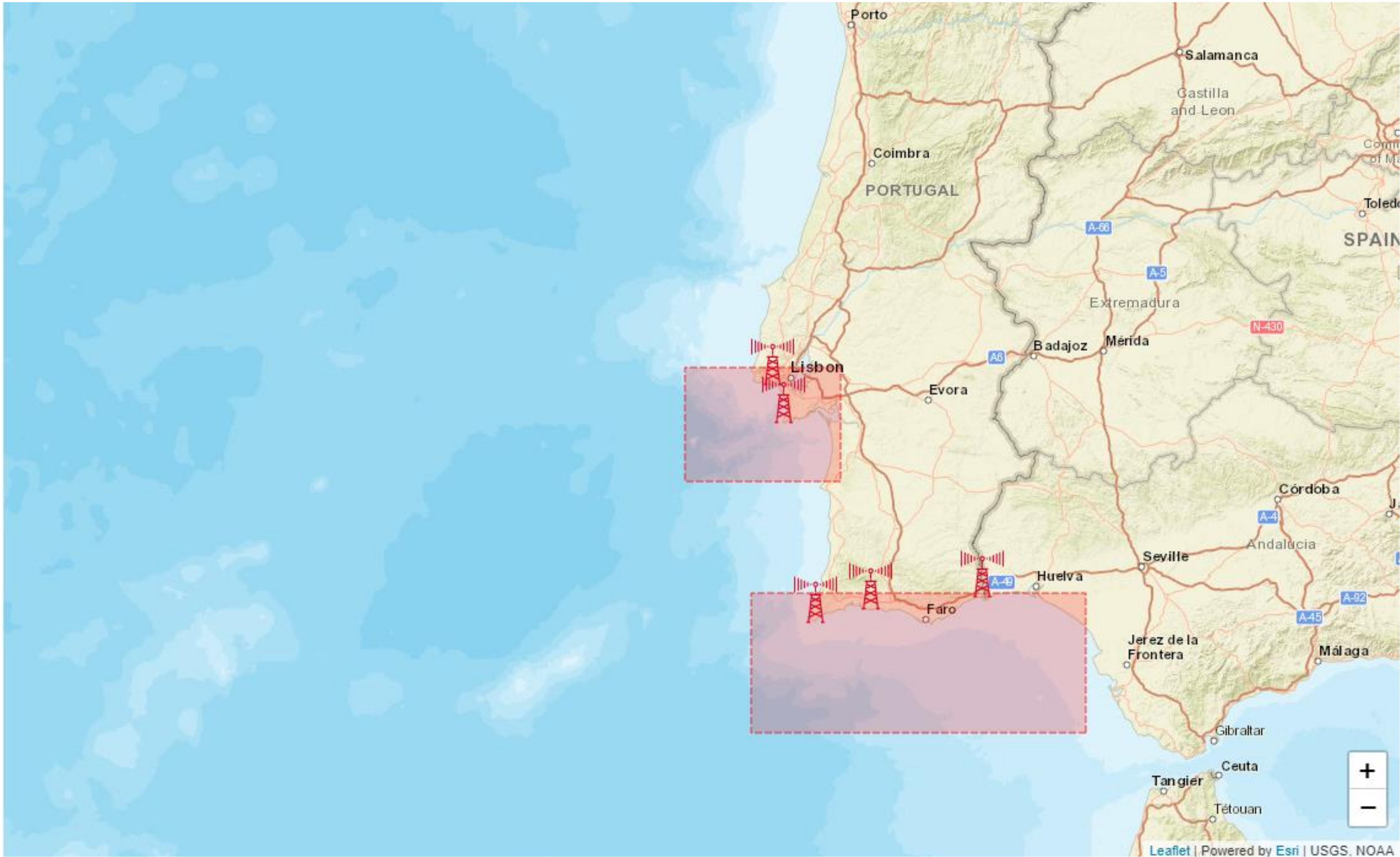
Goals:

- Establish a transboundary oceanographic observatory along the Southern region, taking advantage of the existing monitoring network.
- Monitorize and detect tsunamigenic activity, aiming to provide continuous information for the activities developped in the area, which are relevant for both countries' economies.

National HF Radar Network

5 HF RADARS / IH

- São Julião
- Cabo Espichel
- Sagres (SGTR)
- Alfanzina
- Monte Gordo



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RADAR ON RAIA
“Radares de alta frecuencia en el Observatorio RAIA”
Interreg
España - Portugal
RADAR ON RAIA
Raia | Observatorio Oceanográfico da Marxe Ibérica
www.marnaraia.com

What is RADAR ON RAIA?

Title: High frequency radars in the RAIA Observatory

Programme: Interreg V-A Spain-Portugal (POCTEP) 2014-2020 programme

Priority: Priority axis 1 “Intelligent growth through cross-border cooperation for the promotion of Innovation”

Total budget: 1.438.471,95€; FEDER grant: 1.078.853,96€

Duration: From 01/01/2018 to 31/12/2021

Partenership

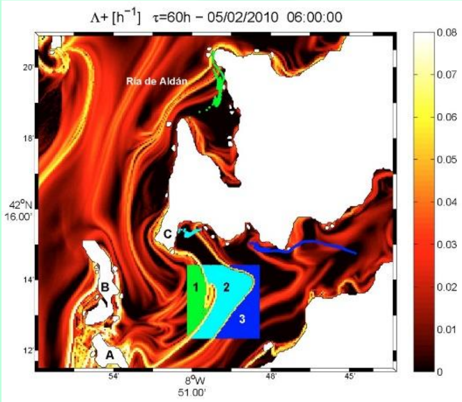
Background: Oceanic Observatory of the Iberian Margin (RAIA)

- Improve coastal observation in terms of meteo-oceanographic and water quality data.
- Provide high-resolution operational models (hydrodynamic and biogeochemical).
- Develop new technologies for ocean observation.
- Establish a common platform for management and distribution of data and products.
- Develop and implement a wide range of products and services for the end users.
- Provide data to the main European initiatives: Copernicus, EMODnet and SeaDataNet.

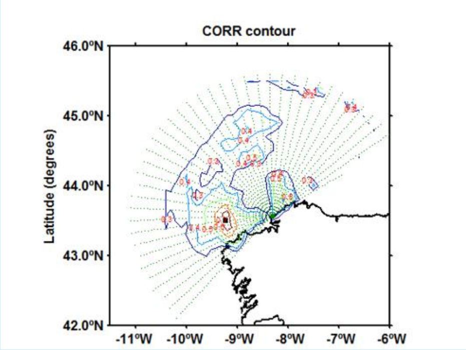
LINES OF WORK

1. Consolidation of a cross-border HF radar

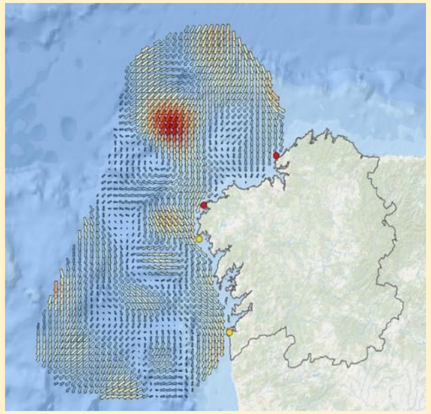
4. Products for end users



2. Data validation and management



3. Spatial Data Infrastructure



HF Radar

- Measurement of ocean surface currents and waves
- f = 3 – 30 MHz and λ = 10 – 100 m
- Distances offshore 100 – 200 km w/ resolution 3 – 12 km
- Precision: 10 cm/s current velocity and 10° current direction

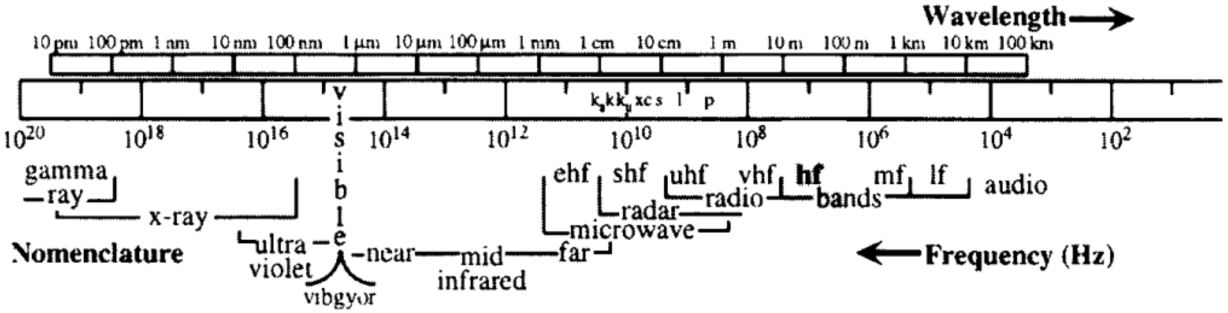
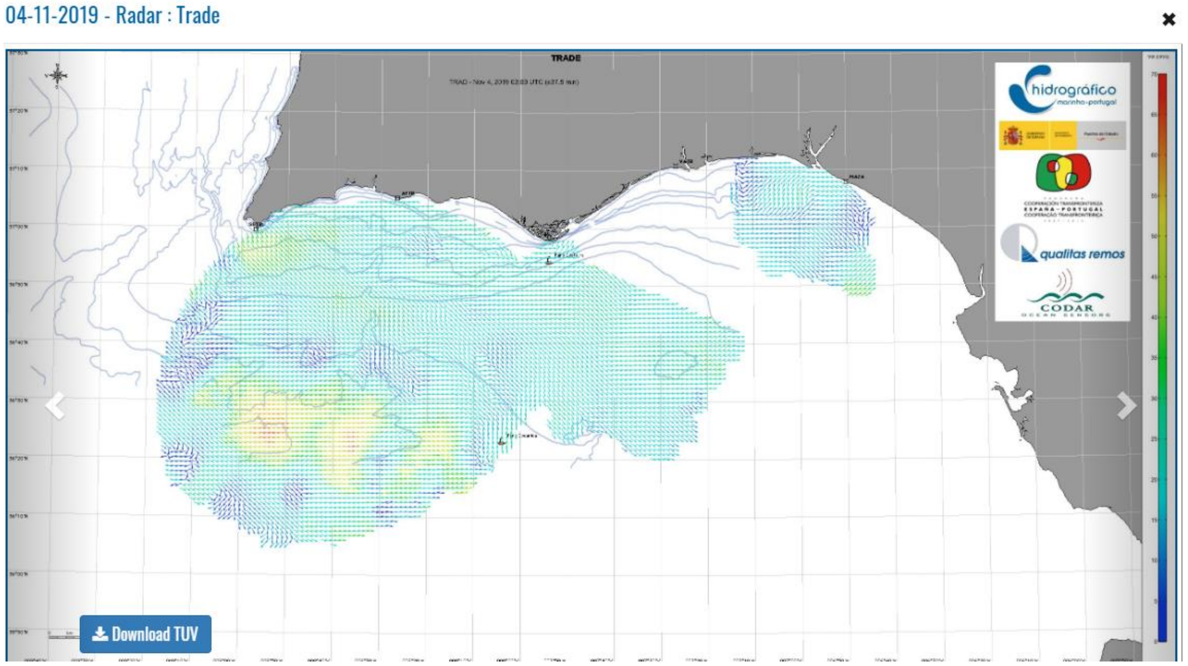


Fig. 1: Electromagnetic spectrum showing the HF band relative to other radio wave bands and the broader spectrum.

(Paduan & Graber 1997)



Tohoku Earthquake & Tsunami
11th Mar 2011

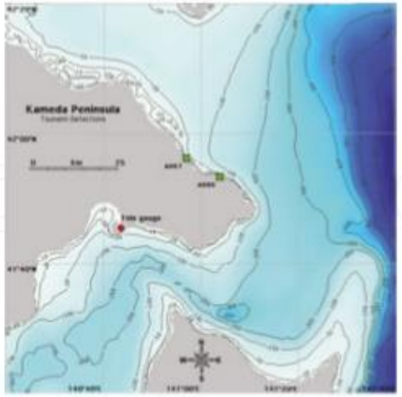


Figure 6. The location of the radars A087, A088, the tide gauge at Hakodate, and the offshore bathymetry.

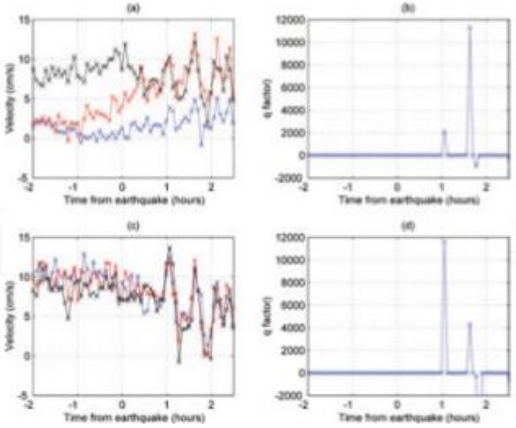


Figure 7. Perpendicular band velocities from A088 and derived q-factors. (a) Distance from radar: 0–2 km (blue), 2–4 km (red), and 4–6 km (black). (b) The q-factor for range 0–6 km. (c) Distance from radar: 6–8 km (blue), 8–10 km (red), and 10–12 km (black). (d) The q-factor for range 6–12 km.

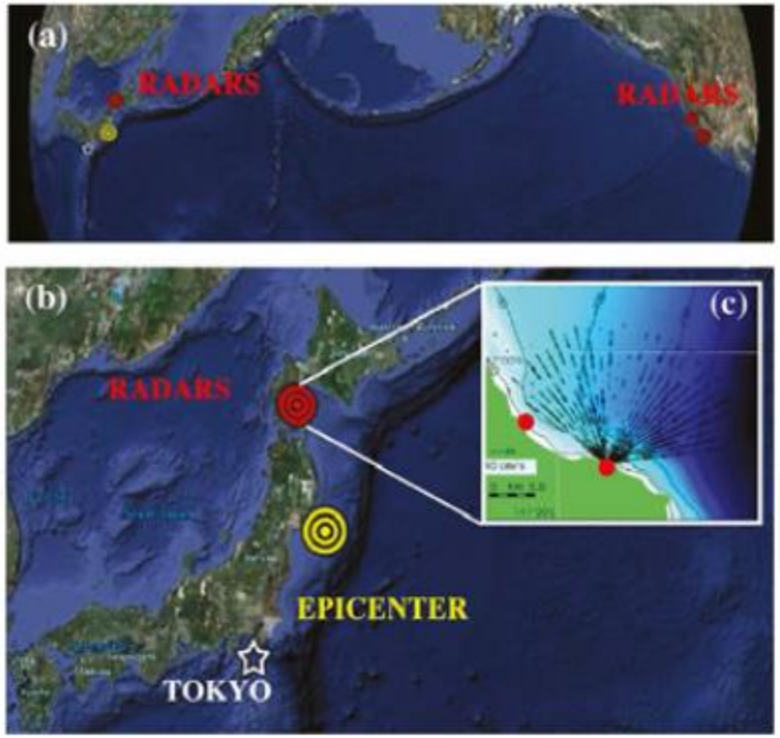


Figure 1. (a) The North Pacific Ocean showing the location of the radars that detected the tsunami. Abbreviated radar field names are as follows; corresponding geographic locations are given in Section 1. Japan: A087 and A088. USA: STV2, SEA1, YHS2, TRIN, GCVE, BML1, PREY, COMM, ESTR, and LUIS. (b) The location of the Japan earthquake and the radars in Hokkaido. (c) The bathymetry offshore from the radars and radial velocities measured by the Kinaoshi radar, March 11, 2011, 21:00 JST.

(Coastal Tsunami Warning with Deployed HF radar systems, by Lipa et al 2016)

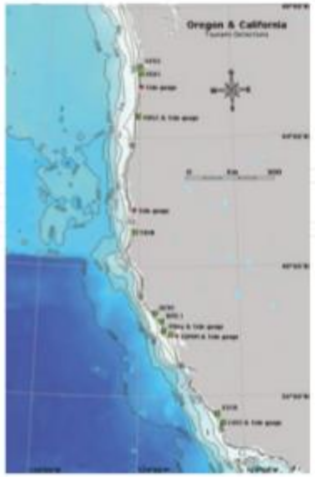


Figure 8. Locations of radars and tide gauges in California and Oregon. The offshore bathymetry indicates a narrow offshore continental shelf.

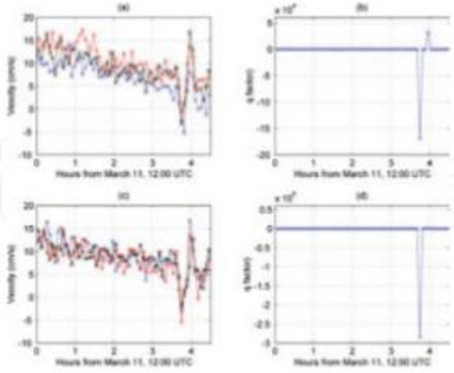


Figure 9. Perpendicular band velocities and derived q-factors from YHS2. (a) Distance from radar: 2–4 km (blue), 4–6 km (red), and 6–8 km (black). (b) The q-factor for range 2–8 km. (c) Distance from radar: 8–10 km (blue), 10–12 km (red), and 12–14 km (black). (d) The q-factor for range 8–14 km.

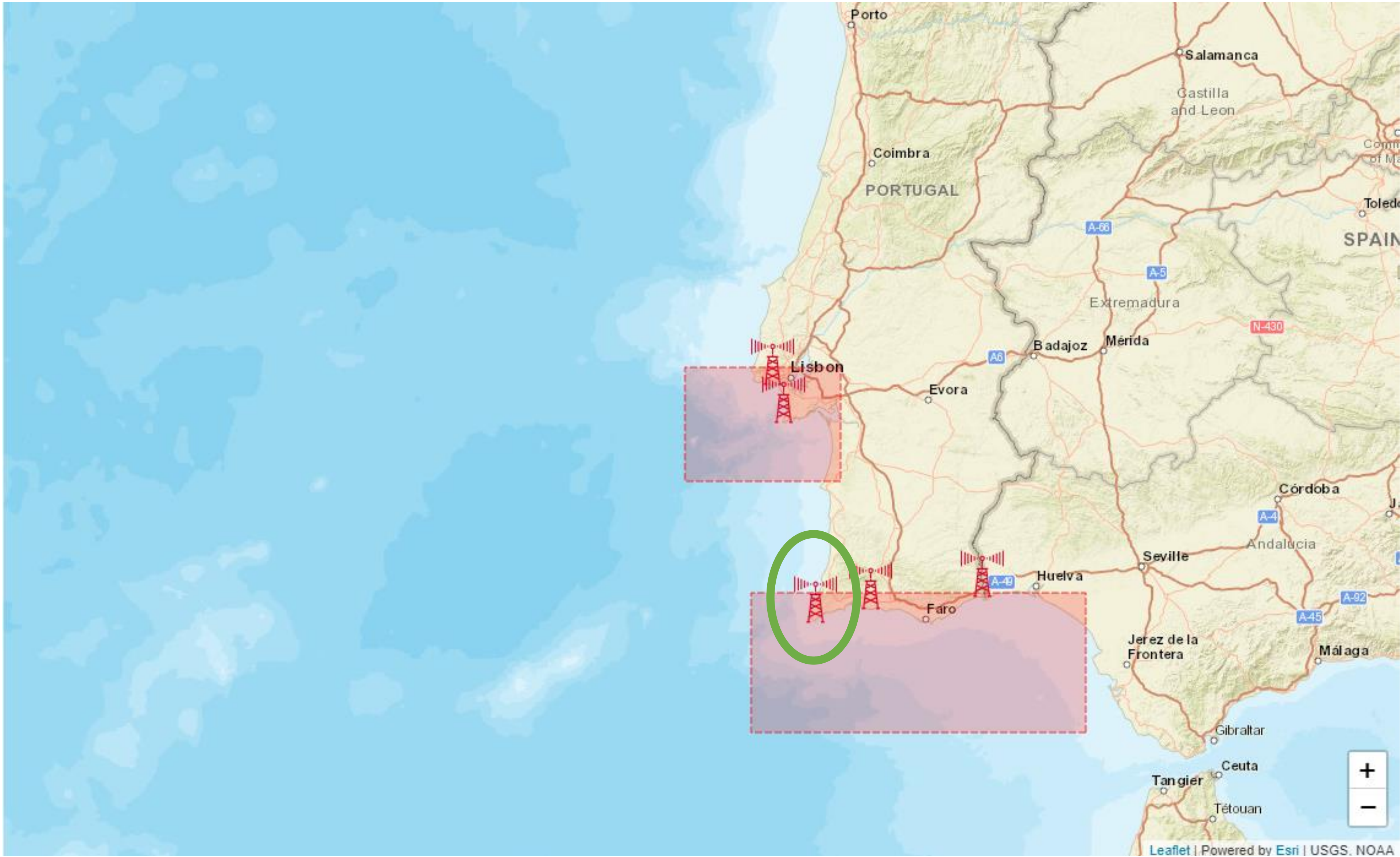
National HF Radar Network

5 HF RADARS / IH

Observing and reporting

- São Julião
- Cabo Espichel
- **Sagres (SGTR)**
- Alfanzina
- Monte Gordo

(The only) 1 HF Radar w/ tsunami detection module



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HF Radars NJ Coast, EUA

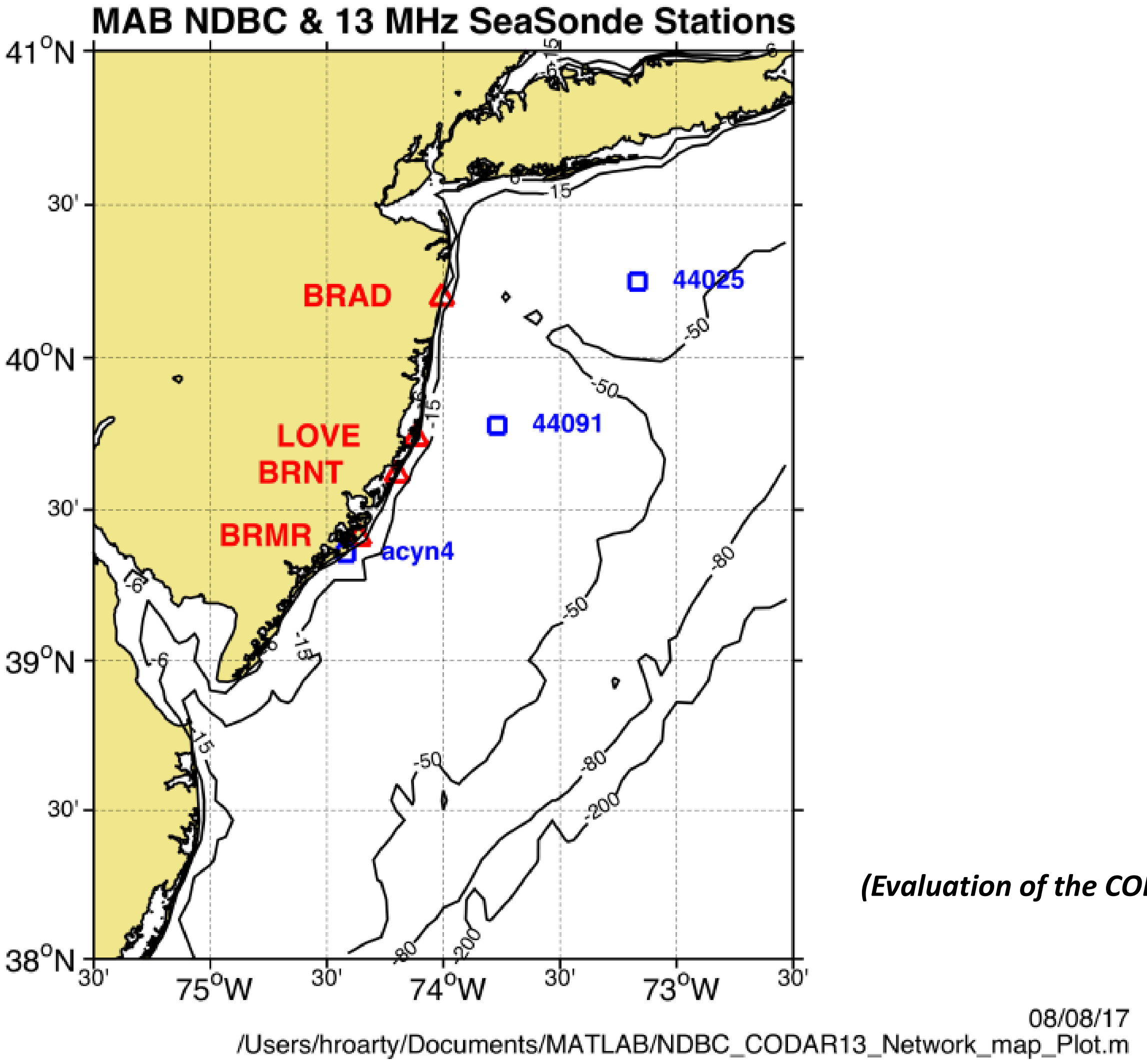


Figure 1: The coast of New Jersey showing the location of four HF radar stations (red triangle) used in the experiment. Location of NDBC stations 44025, 44091 and ACYN4 are also shown

4 HF Radars w/ CODAR tsunami detection module installed:

- BRAD
- LOVE
- BRNT
- BRMR

(Evaluation of the CODAR tsunami detection algorithm and software, by Roarty et al 2019)

Meteotsunami New Jersey
13th June 2013

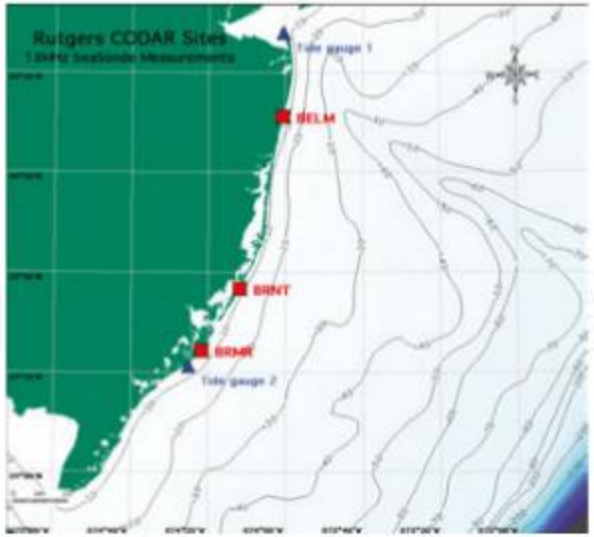


Figure 12. The radar stations at Brant Beach (BRNT), Brigantine (BRMR), and Belmar (BELM); the NOAA tide gauges at Sandy Hook (tide gauge 1) and Atlantic City (tide gauge 2) and the offshore bathymetry contours, with depths in meters.

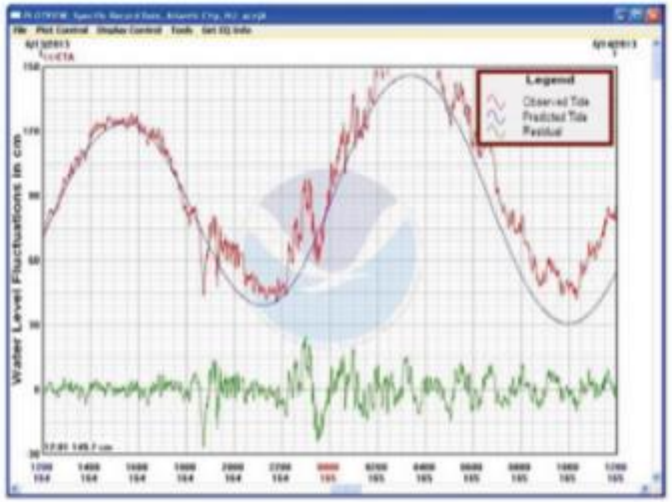


Figure 13. NOAA tide gauge observations June 13, 2013 at Atlantic City, NJ.

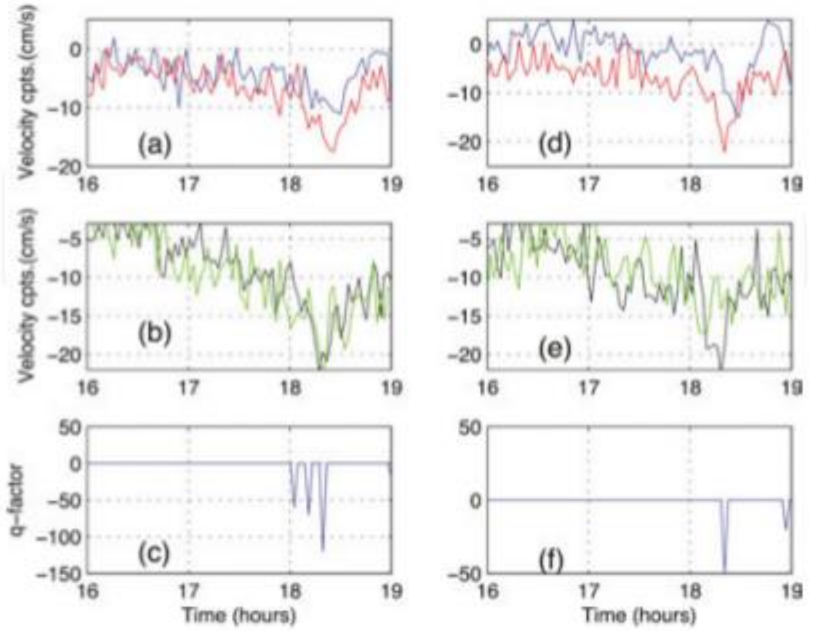
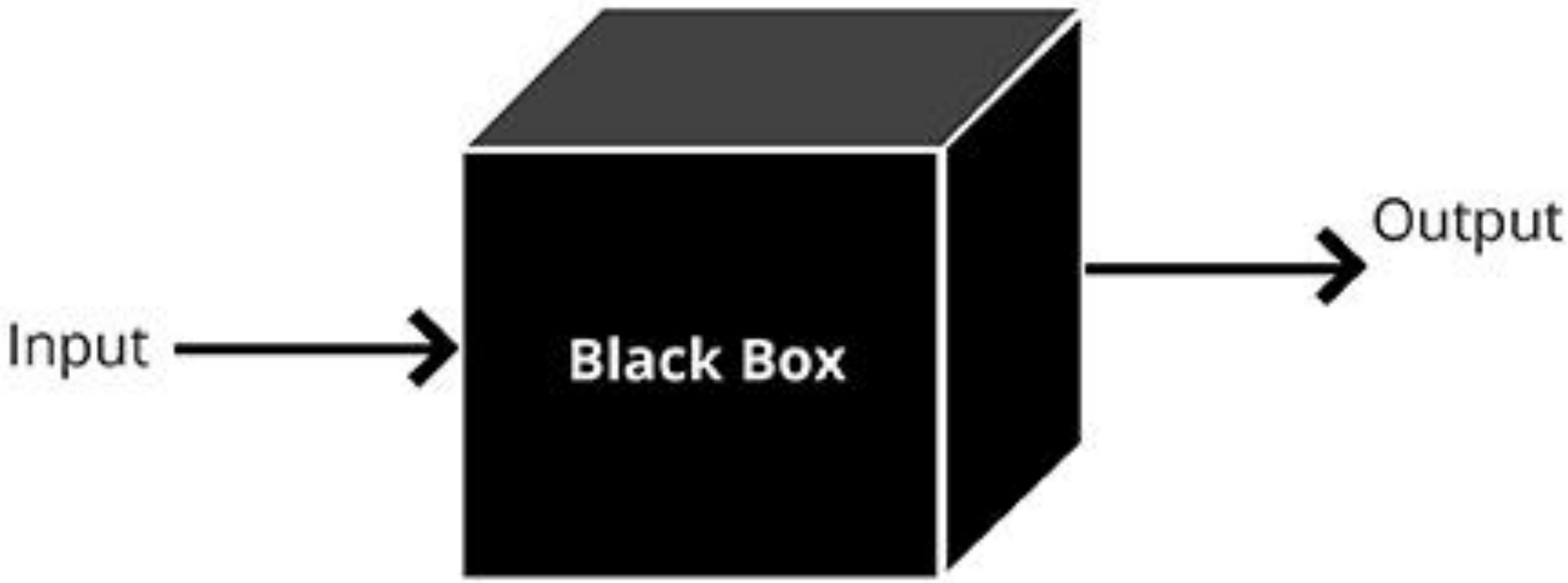


Figure 14. The meteotsunami arrival observed by radars BRNT and BRMR: band velocity components and the corresponding q-factors plotted against hours from 00:00 June 13, 2013. BRNT: (a) 6–8 km (blue), 8–10 km (red), (b) 10–12 km (black), 12–14 km (green), (c) Corresponding q-factors. BRMR: (d) 2–4 km (blue), 6–8 km (red), (e) 14–16 km (black), 20–22 km (green), (f) Corresponding q-factors.

(Coastal Tsunami Warning with Deployed HF radar systems, by Lipa et al 2016)

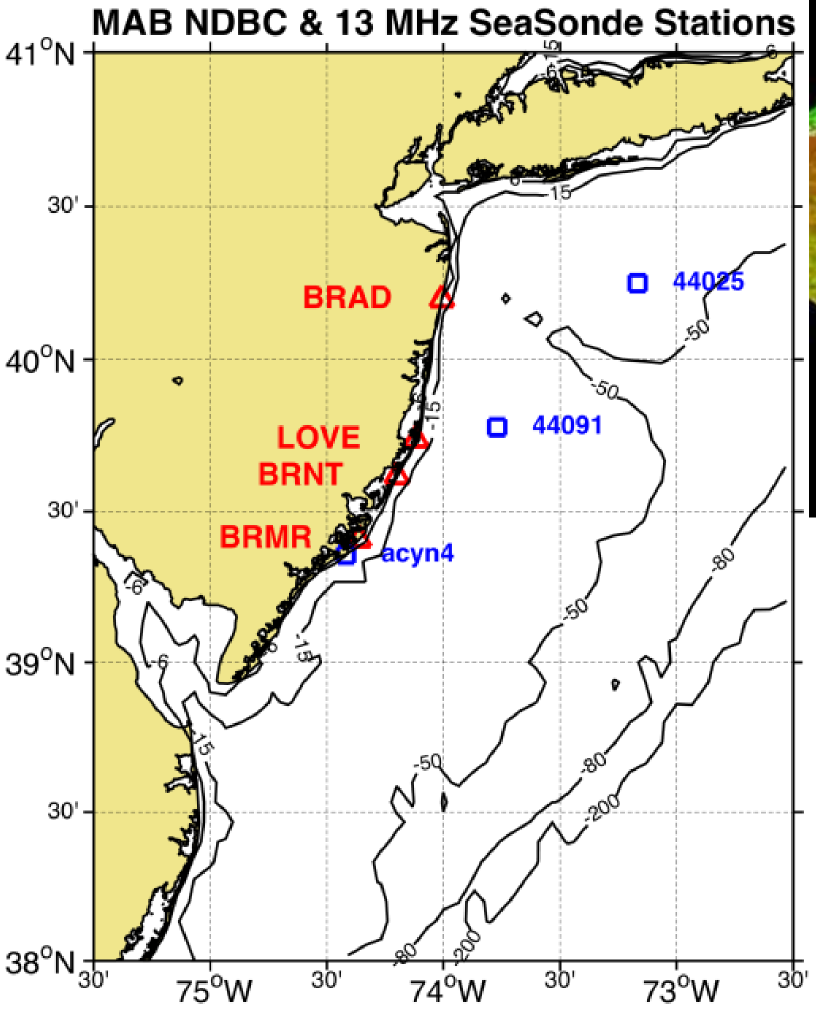
CODAR Seasonde Radar & Software



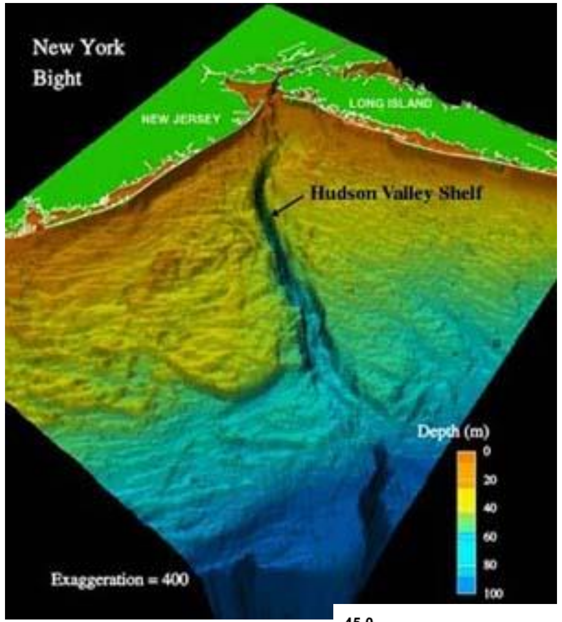
So how is tsunami detection being performed?

CODAR Seasonde Radar & Software

- Detects oncoming tsunami wave through its orbital velocity
- In SW, *H* increases but orbital velocities increase much faster
- Observed tsunami waves near field 2-50 km from coast
- Tsunami signal extracted from background current and noise by means of a qfactor PRA.



08/08/17
/Users/hroarty/Documents/MATLAB/NDBC_CODAR13_Network_map_Plot.m



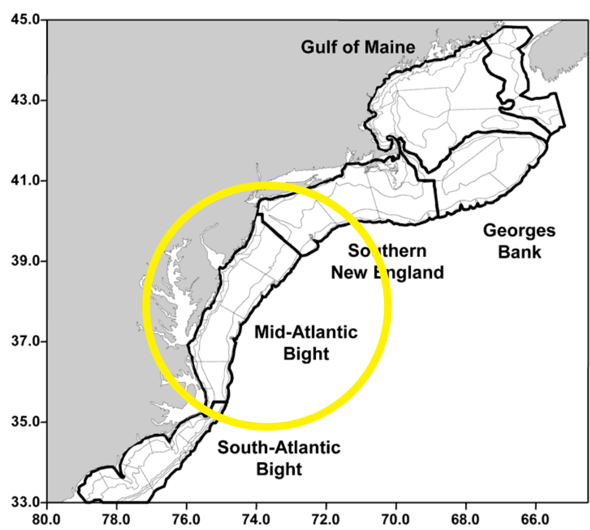


Figure 1: The coast of New Jersey showing the location of four HF radar stations (red triangle) used in the experiment. Location of NDBC stations 44025, 44091 and ACYN4 are also shown

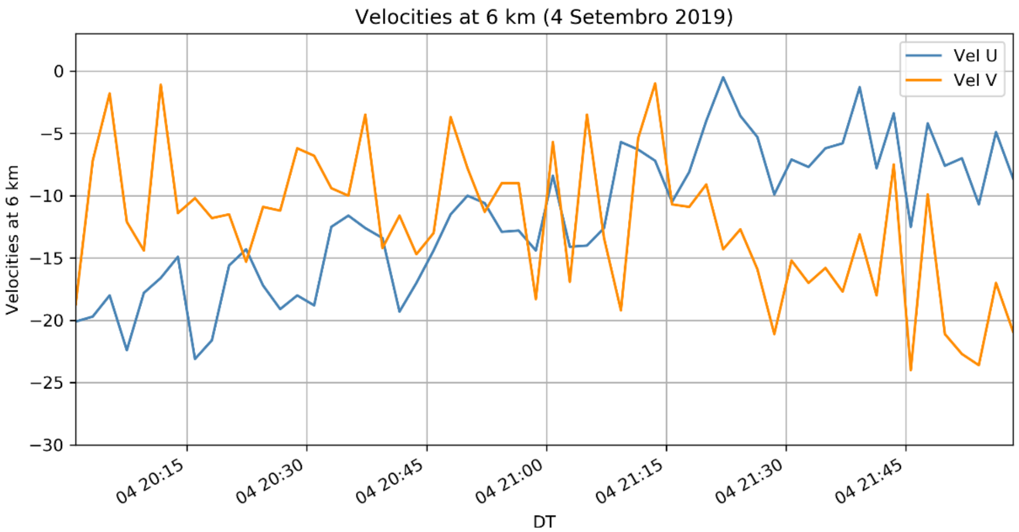
(Evaluation of the CODAR tsunami detection algorithm and software, by Roarty et al 2019)

CODAR Tsunami detection Method

- Calculate radial velocity maps from short-term radar cross spectra
- Radial velocities
  - Partitioned by 2 km strips, parallel to bathy contours
  - Resolved into components parallel & perpendicular depth contour
  - Resolved velocities in strip averaged to create time series (TS) on shore and along shore for each band

(Evaluation of the CODAR tsunami detection algorithm and software, by Roarty et al 2019)

Time series of Onshore and Along shore Velocities at HF Radar Sagres (SGTR)



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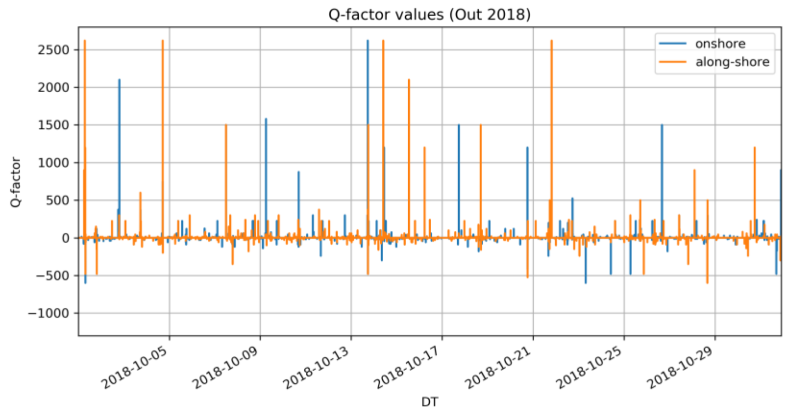
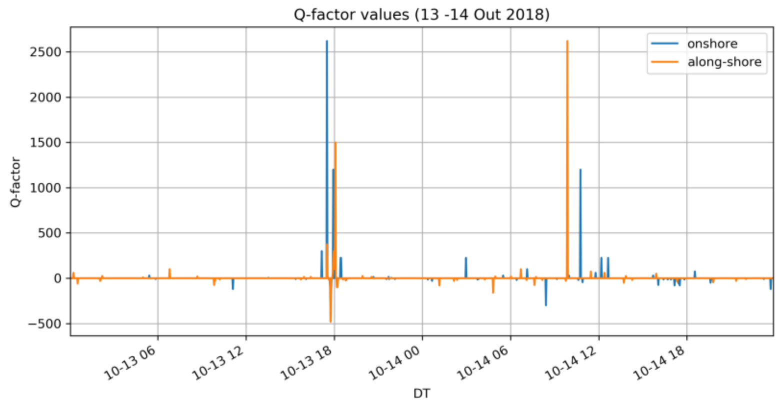
CODAR Tsunami detection Method

- Pattern recognition algorithm (PRA) applied to TS to detect tsunami waves
- Correlation in adjacent bands in nearby times
- Output of PRA is **Qfactor**
- **Qfactor** data derived from Doppler spectra collected every 128 seg

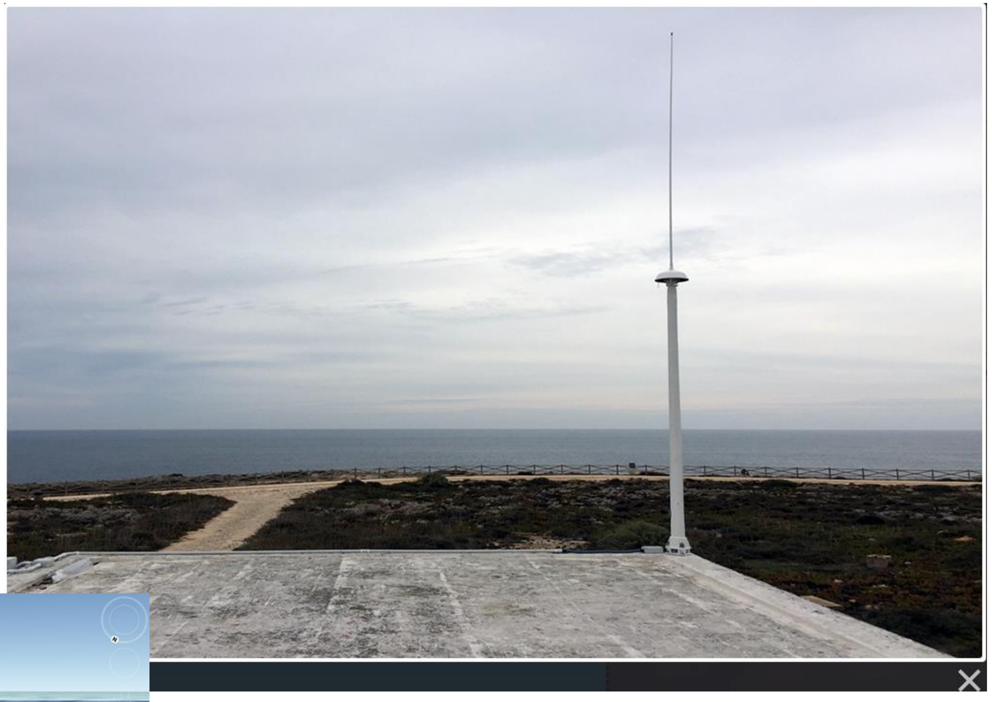
(Evaluation of the CODAR tsunami detection algorithm and software, by Roarty et al 2019)

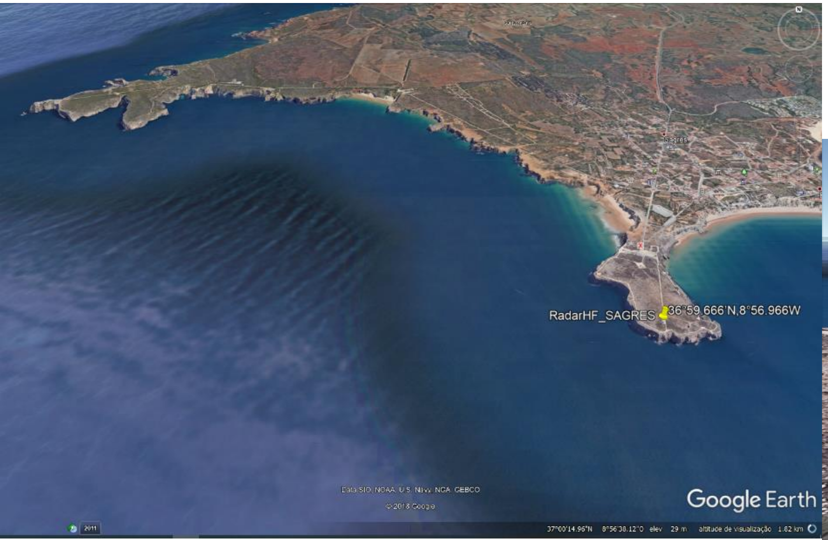




Operational Challenges and Limitations

- Tsunami current pattern id & analyzed within background currents: Probability of detection *Pd* ↑ limited by non-tsunami background current field
- Sources of variable random noise and radio interferences: Probability of False alarms *Pfa* ↓





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Operational Challenges and Limitations

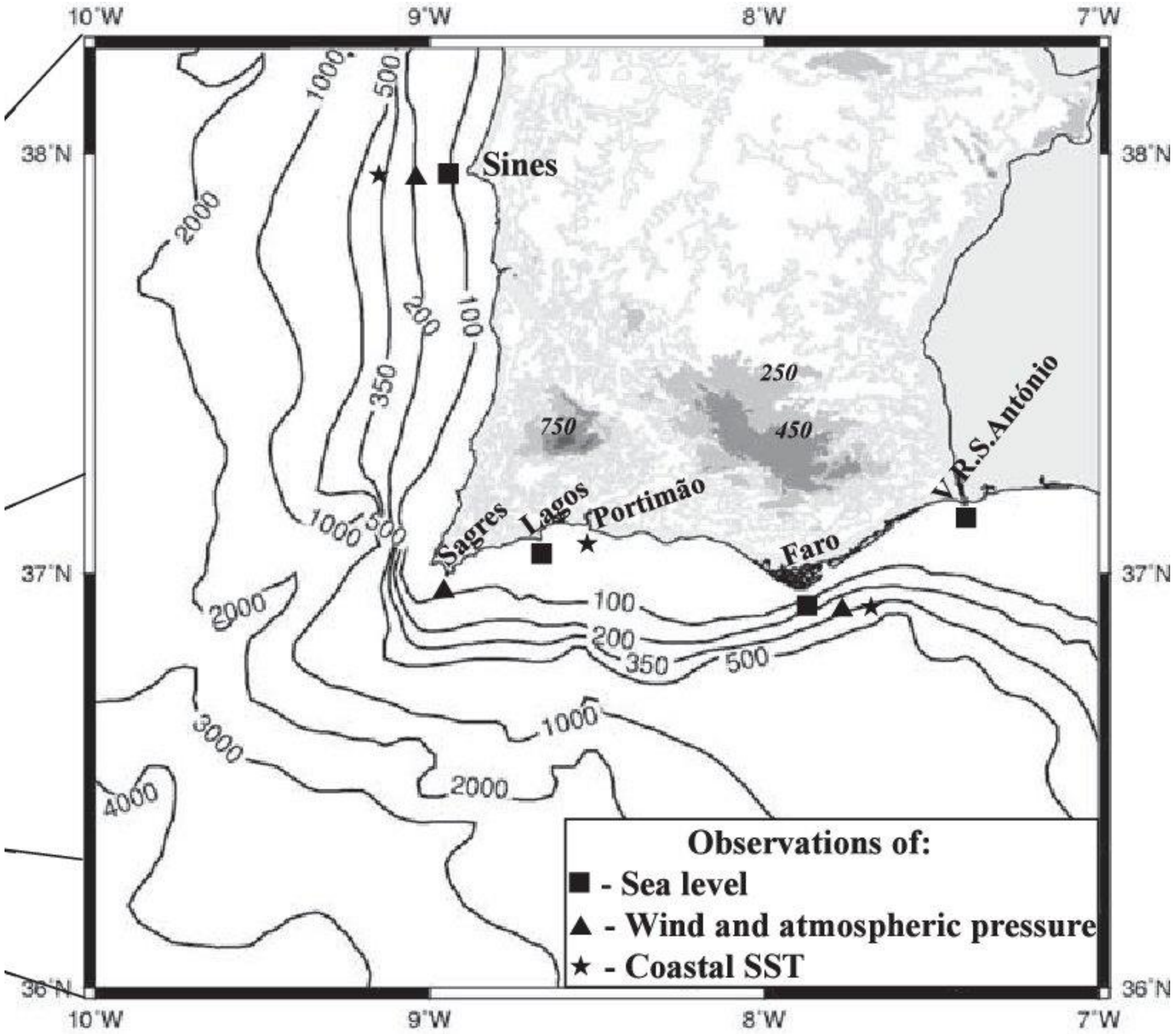
Maximum detection range and **warning time** (for given radar output power) limited by:

1) **tsunami intensity**

2) **bathymetry profile seaward of coastal radar location**

The shallower the continental shelf, the greater the detection distance and warning time

Barrick et al (2016), in IEEE



Relvas & Barton (2002), JGR

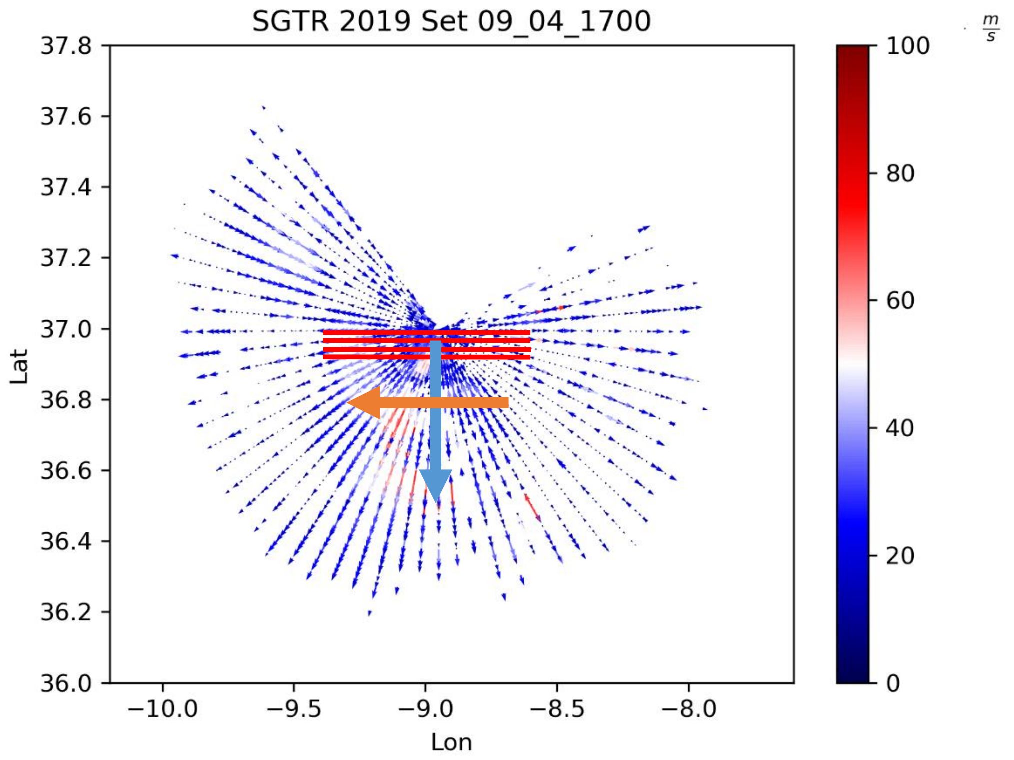
HF Radar Sagres

Tsunami detection module output:

- **Q-factor:**
  - Parameter that quantifies the presence of a tsunami wave
  - Spikes indicate possible incoming tsunami wave
  - Probabilistic index of tsunami occurrence

Detection **Onshore**: waves propagate perpendicularly to the coast

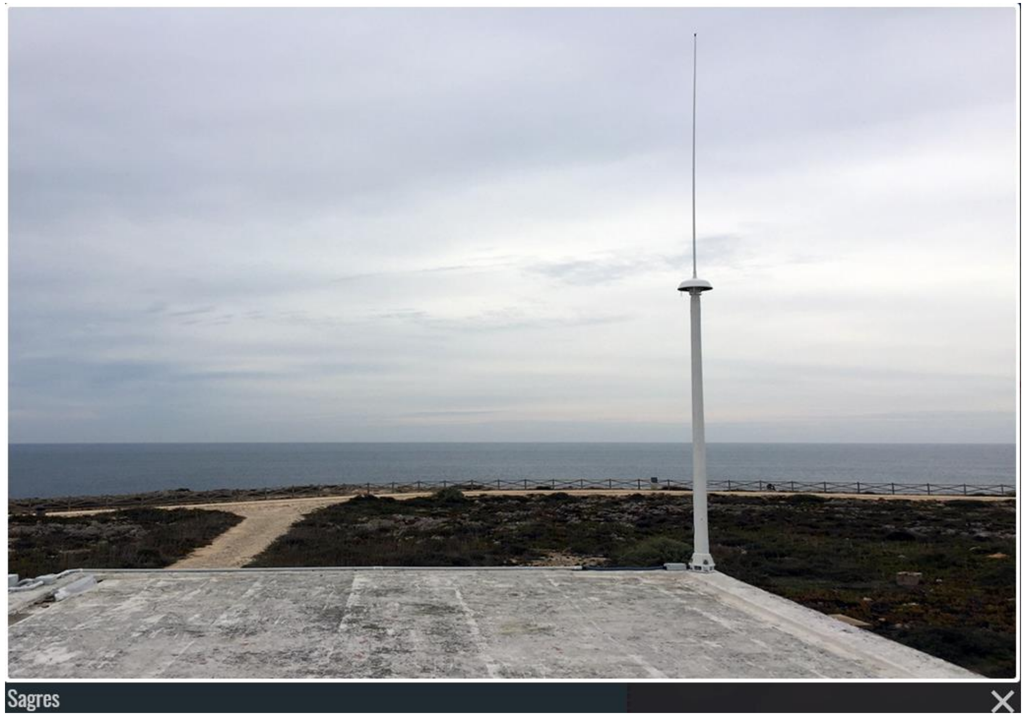
Detection **Along shore**: waves propagate parallel to the coast



OCASO Project

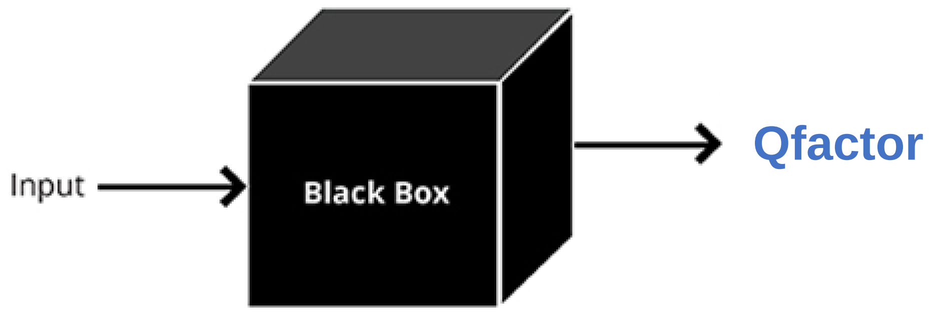
Sagres HF Radar

- **Establish adequate Q-factor threshold**
  - To issue tsunami warning
  - Distinguishable from other events
  - Minimizing false alarms
- Simulate possible tsunami scenarios impacting Portuguese Coast and map coastal impact (inundation, run-up, run-in, flow depth)
- Integrate HF radar tsunami detection capability in the Portuguese NTWS

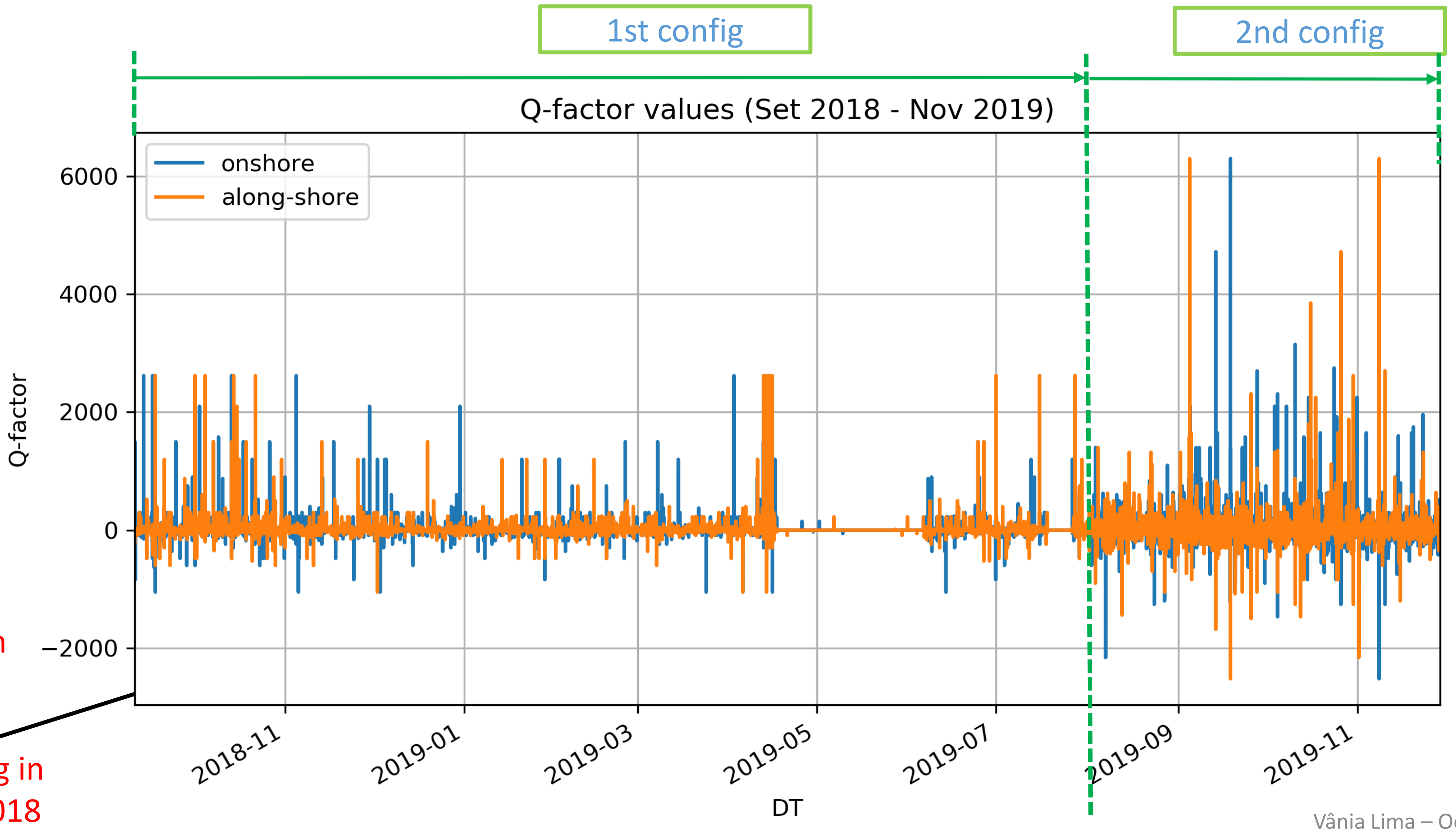


Evaluation of Data for Sagres HF Radar

- Analysis of Qfactor output from Sagres radar station
- Statistics and behaviour of Qfactor
- Determine appropriate threshold for Qfactor tsunami warning, minimizing false alarms



SGR HF radar / Q-factor Detection Data



HF Radar SAGRES Tsunami Detection Module Started Operating in 10-Set-2018

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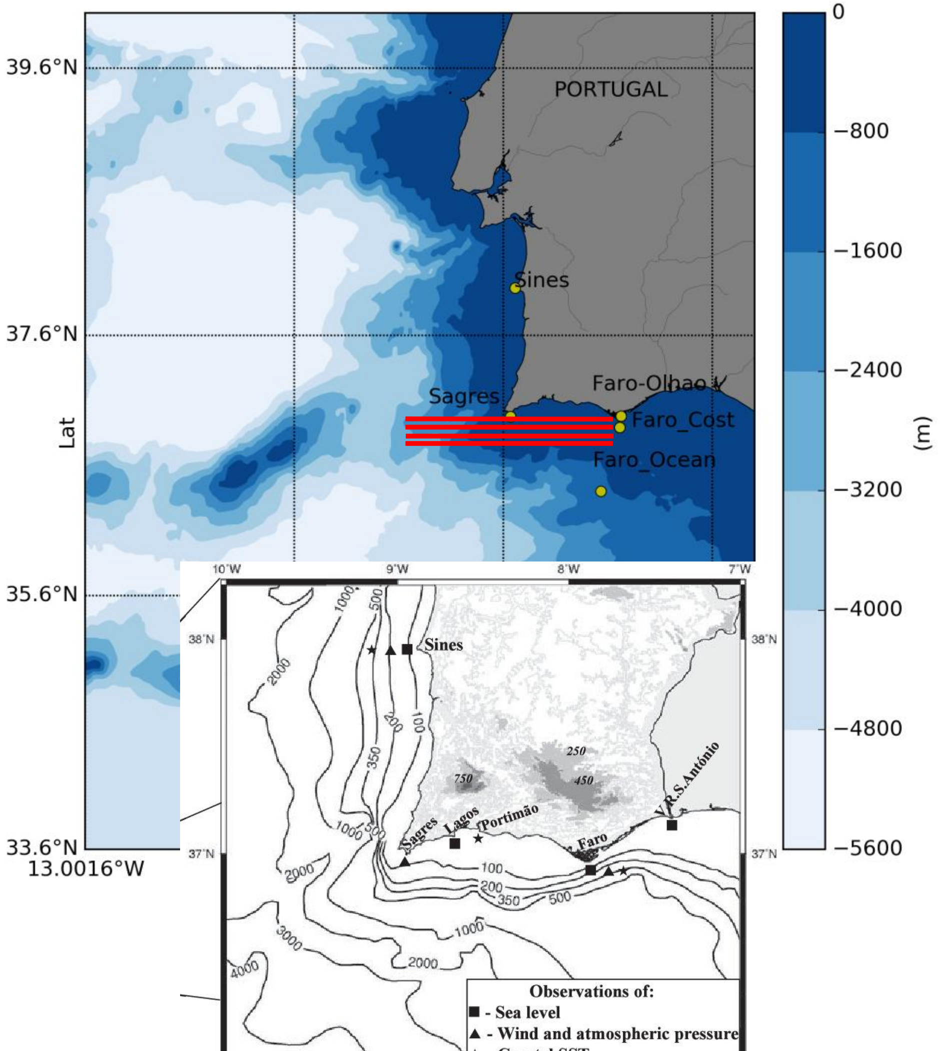
SGR HF radar / Q-factor Detection Data

1st CONFIG : *Sep 2018 – Jul 2019*

Strip Orientation (degrees True) : 0°
Strip Width: 6 km
Number of Strips: 10 *(0 to 54 km)*
Detection Background Span: 26 minutes

Qfactor Strips: 0 to 30 km



SGR HF radar / Q-factor Detection Data

2nd CONFIG: *Aug 2019 – present*

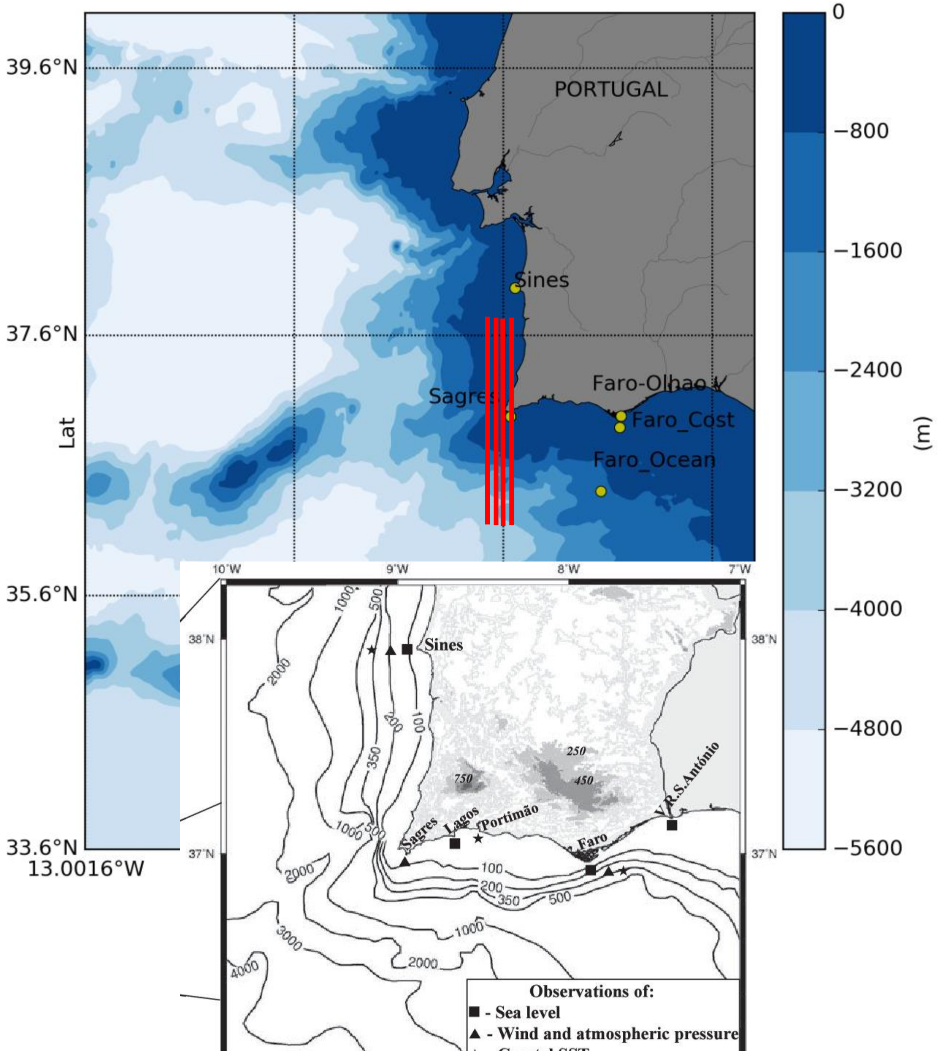
Strip Orientation (degrees True) : 270°

Strip Width: 2 km

Number of Strips: 12 *(0 to 24 km)*

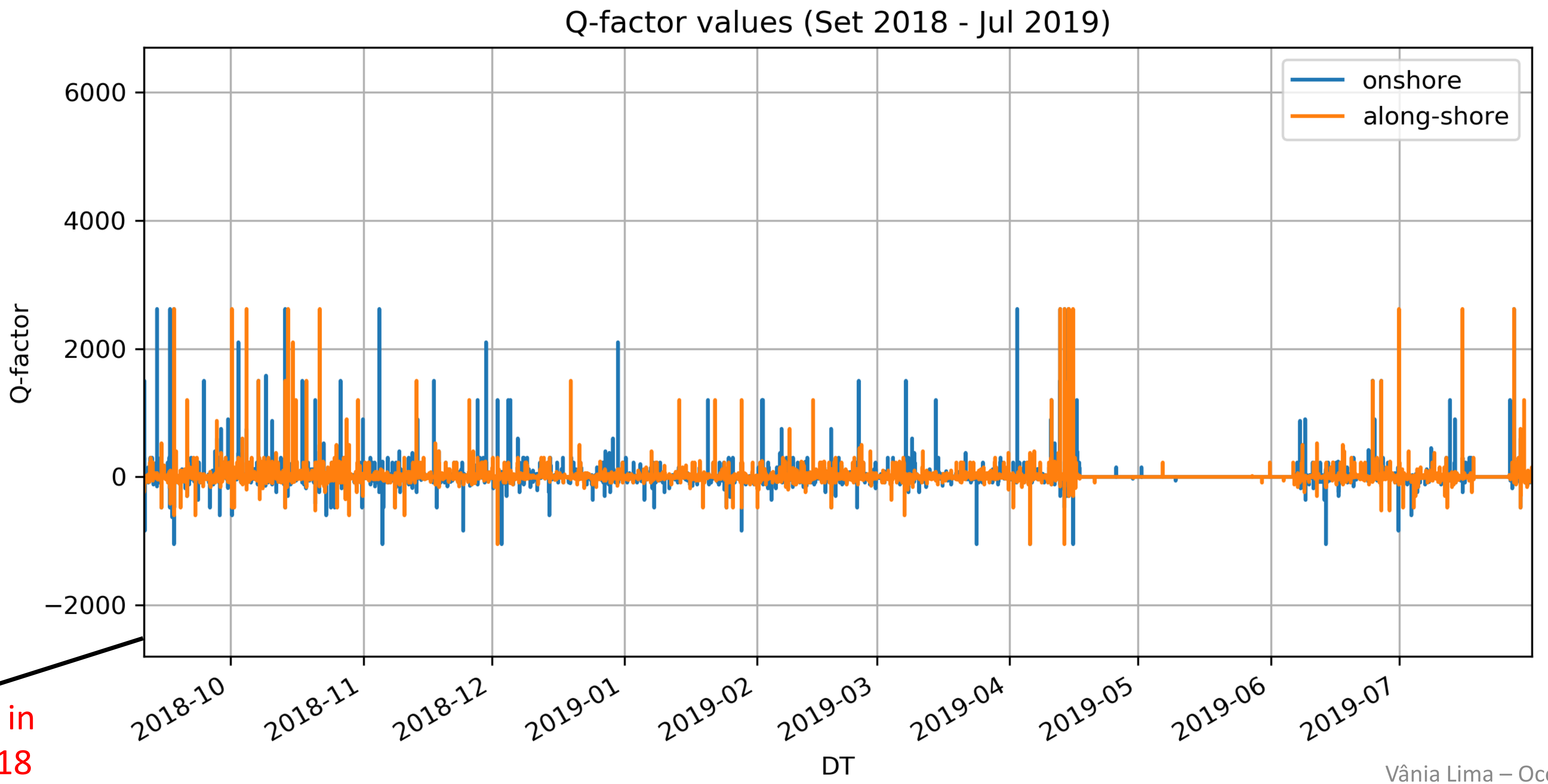
Detection Background Span: 26 minutes

Qfactor Strips: 0 to 14 km



SGR HF radar / Q-factor Detection Data

1st config



HF Radar SAGRES Tsunami Detection Module Started Operating in 10-Set-2018

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SGR HF radar / Q-factor Detection Data

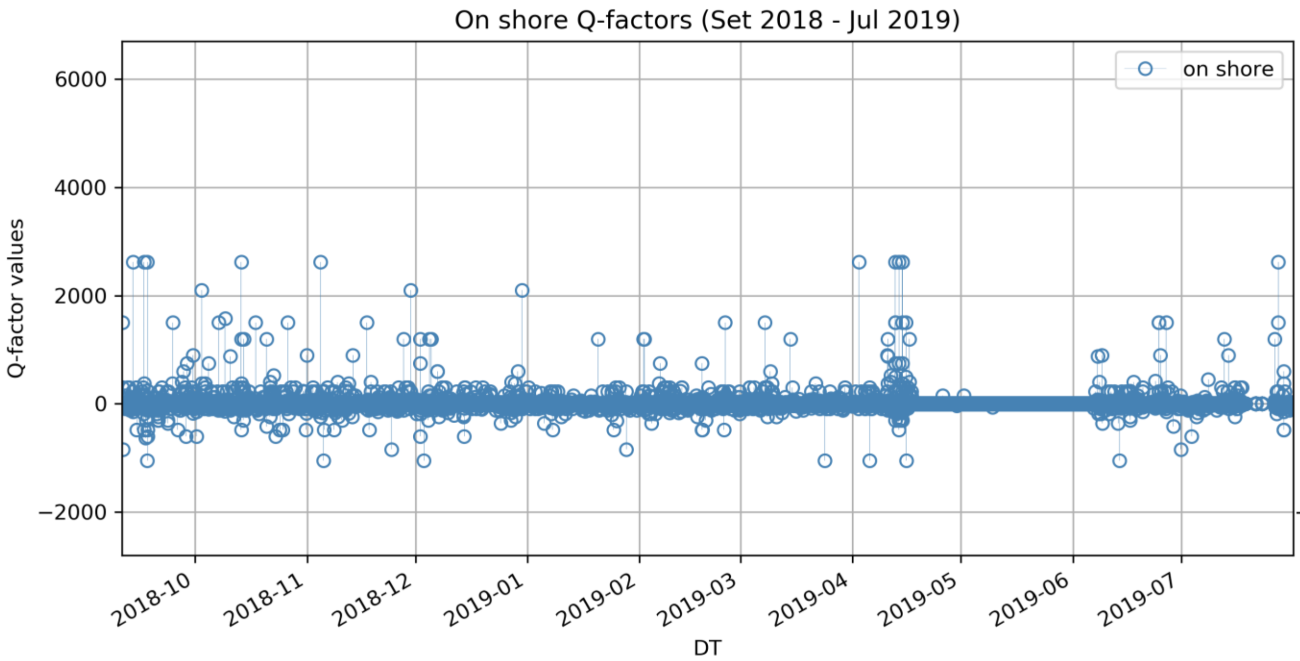
- Qfactor on shore and along shore values (Set 2018 – Jul 2019)

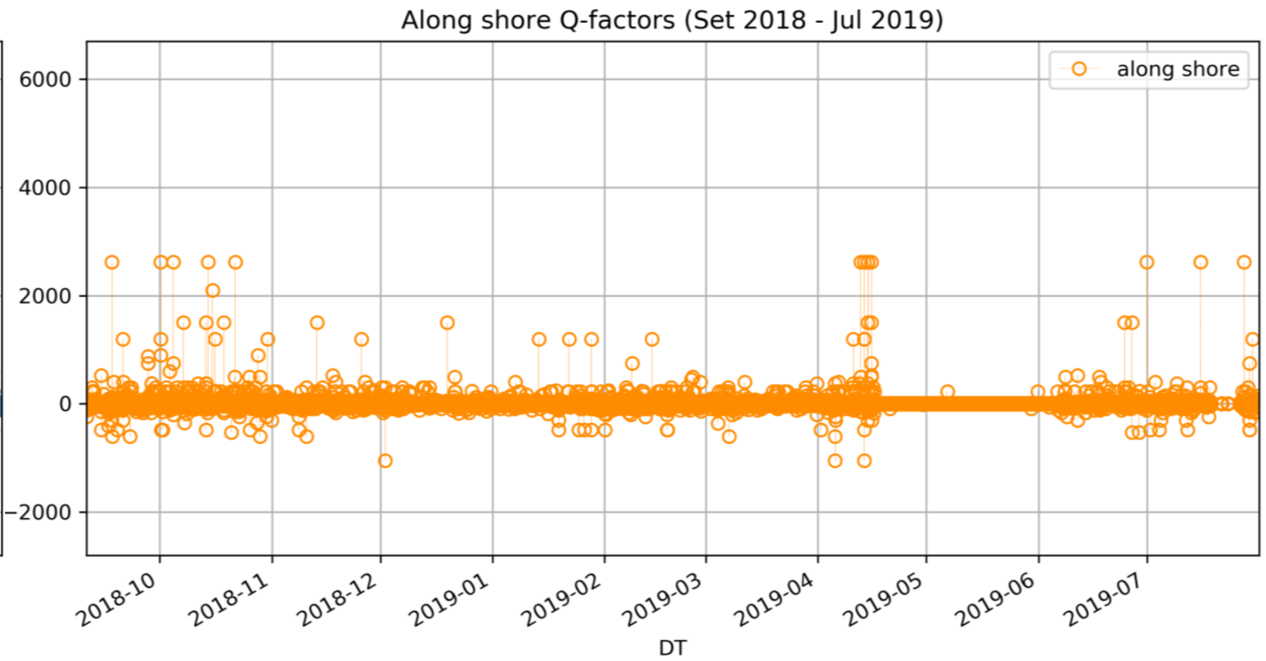
Qfactor		Value	No Ocurrances
On shore	Maximum	**2620**	11
	Minimum	**-1050**	7
Along shore	Maximum	**2620**	14
	Minimum	**-1050**	3

n = 212380

$\sigma_{onshore}$ = 31.4

$\sigma_{alongshore}$ = 29.4

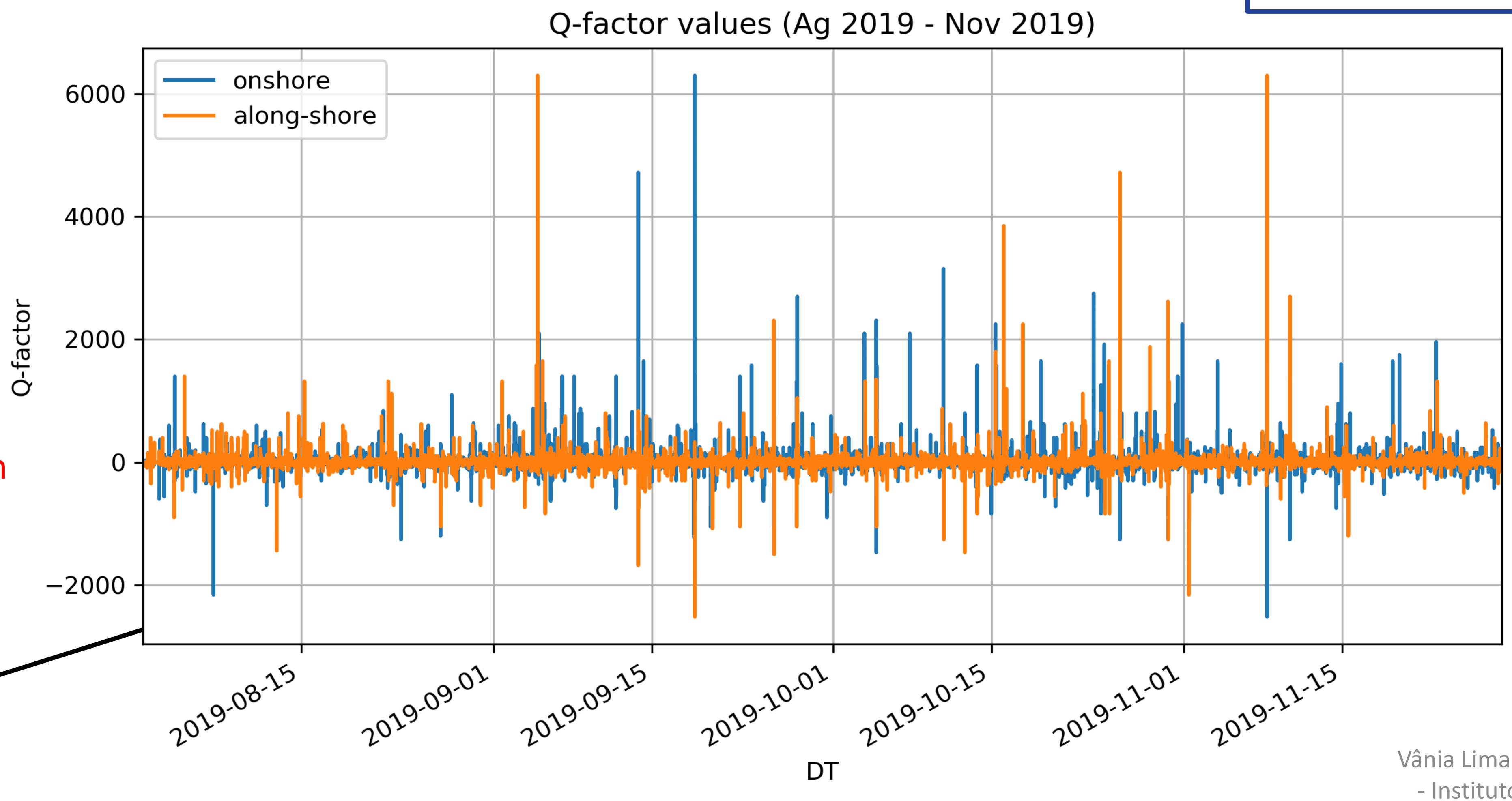




SGR HF radar / Q-factor Detection Data

2nd config

19 instances w/ Qfactor > 2000
5 instances w/ Qfactor > 4000



Novel configuration HF Radar SAGRES Tsunami Detection Module 1-Aug-2019

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HF radar Sagres

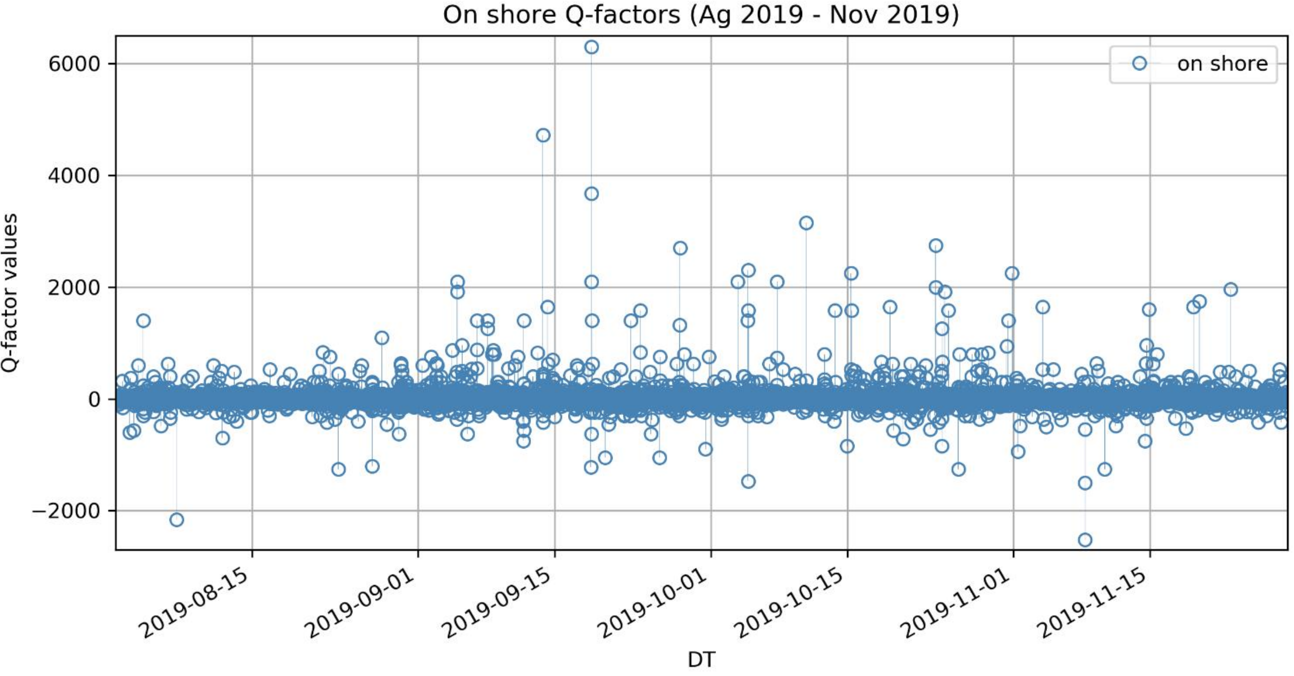
- Qfactor on shore and along shore values (Ag 2019 – Nov 2019)

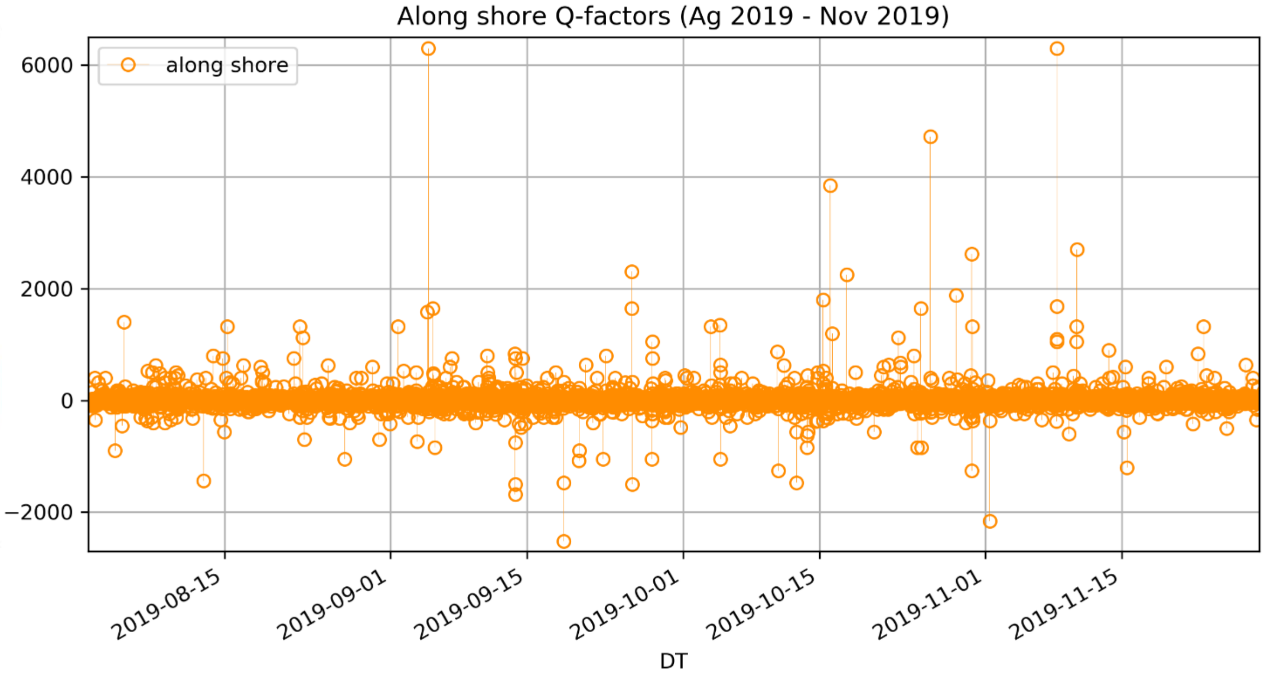
Qfactor		Value	No Ocurrances
On shore	Maximum	**6300**	1
	Minimum	**-2520**	1
Along shore	Maximum	**6300**	2
	Minimum	**-2520**	1

n = 60925

$\sigma_{onshore} = 66.5$

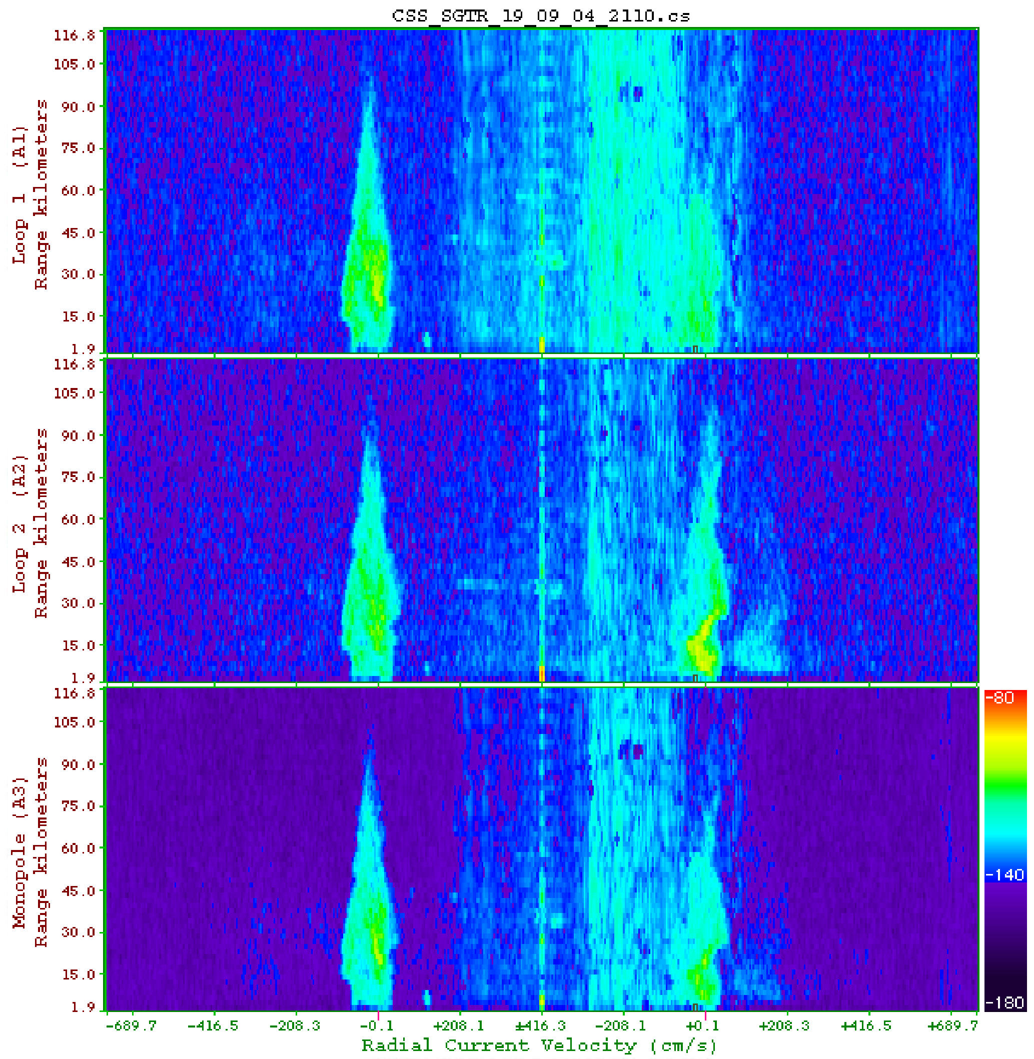
$\sigma_{alongshore} = 59.6$





SGR HF radar / Q-factor Detection Data

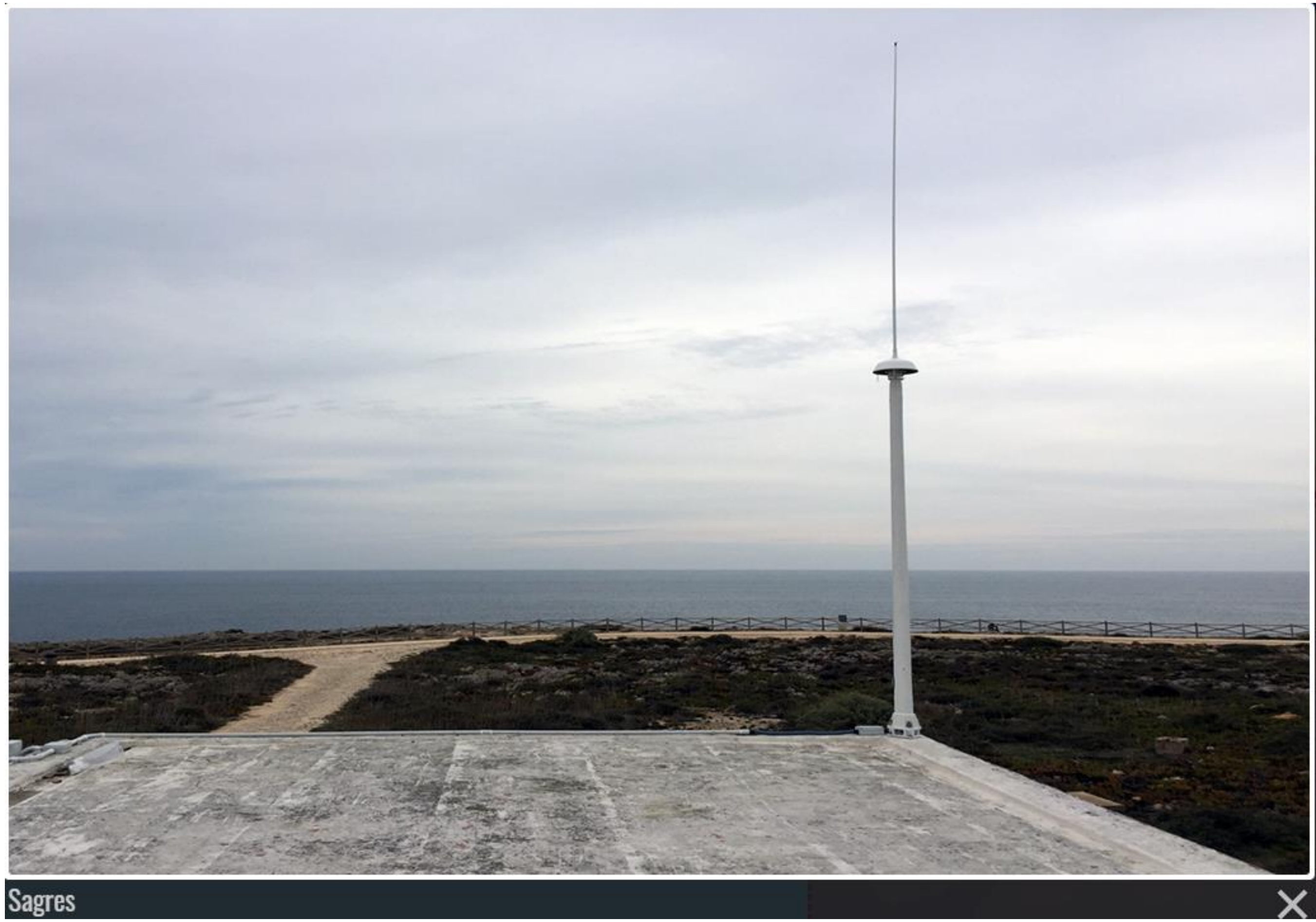
Noise Level at SGTR During Qfactor spike events



SAGRES HF radar

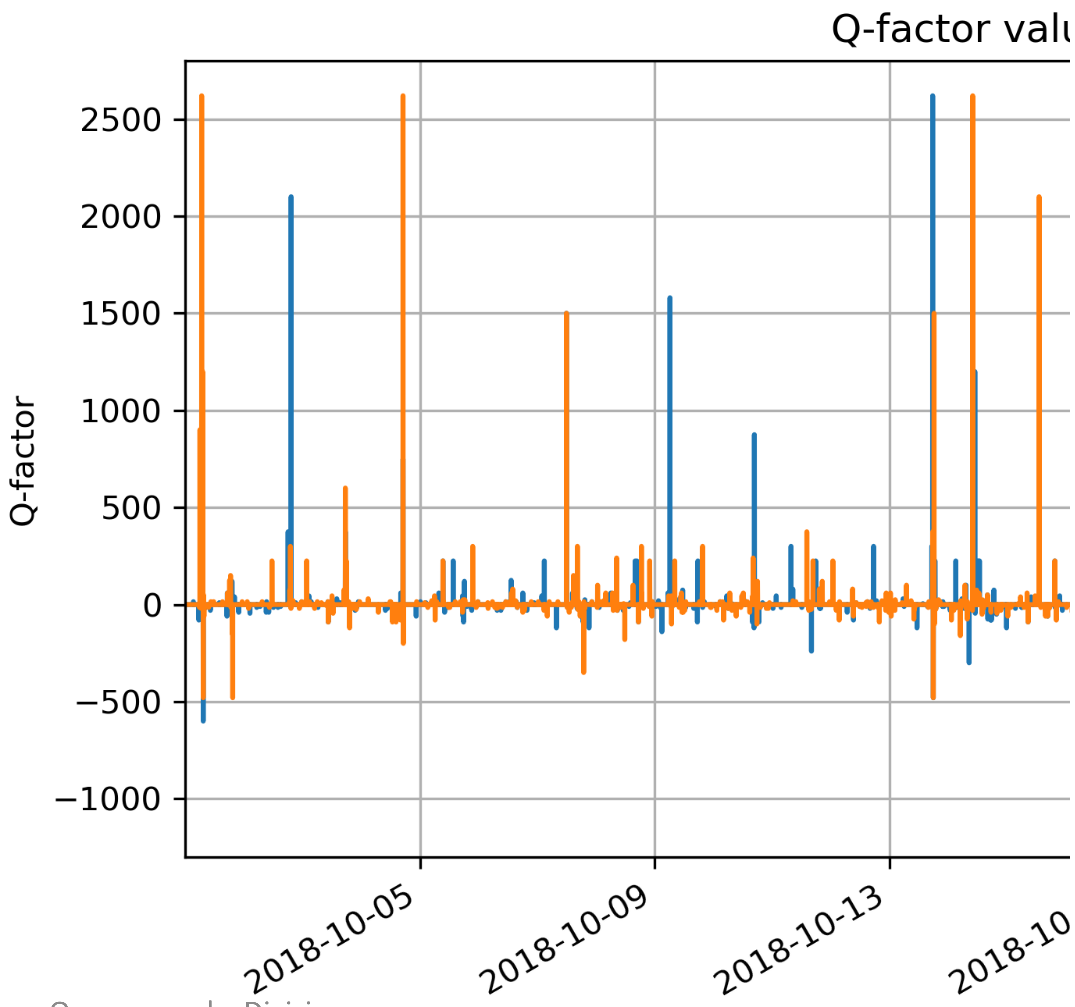
Tsunami detection module

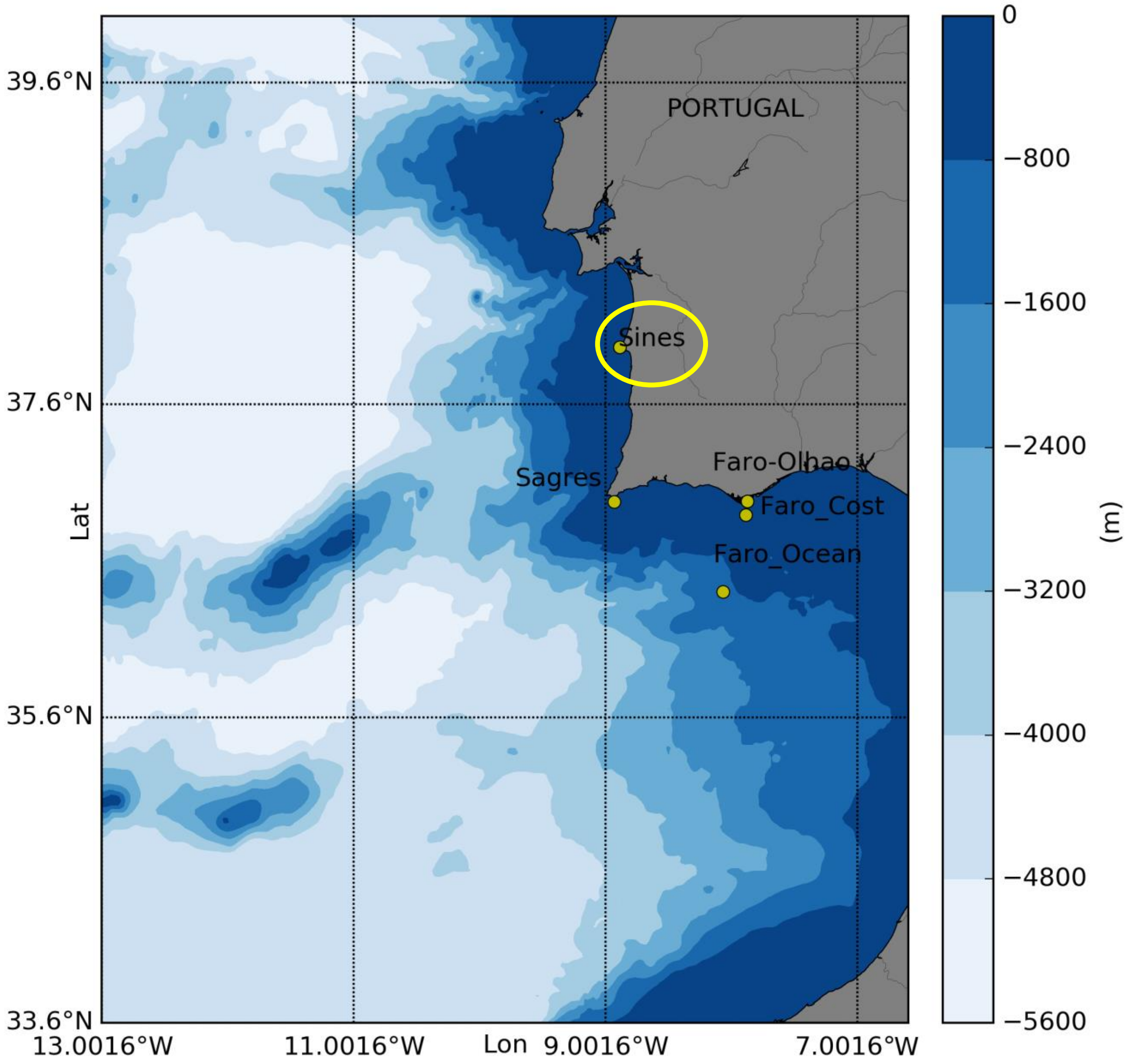
EVENT ANALYSIS



October 2018 Event

1st config





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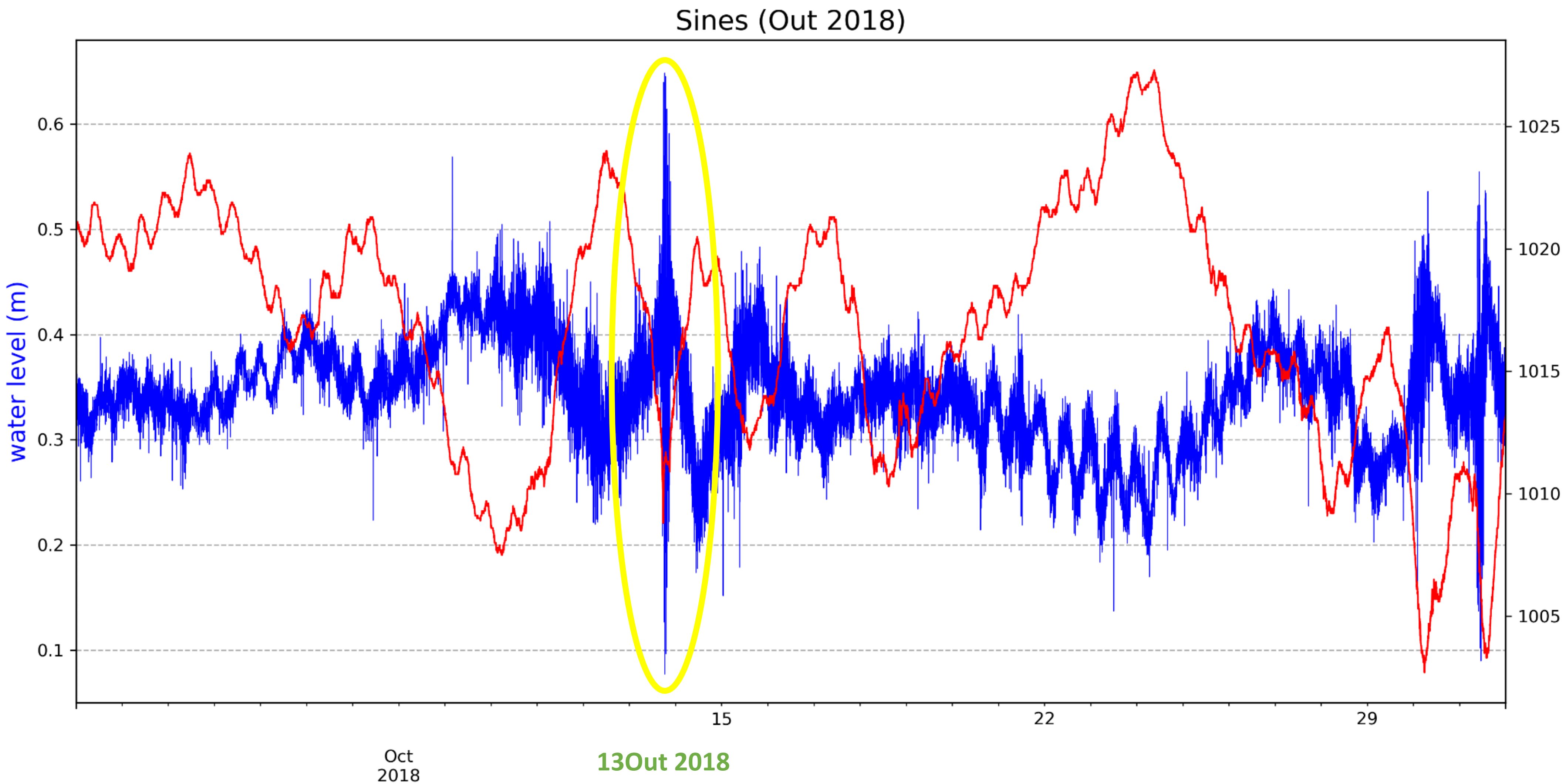
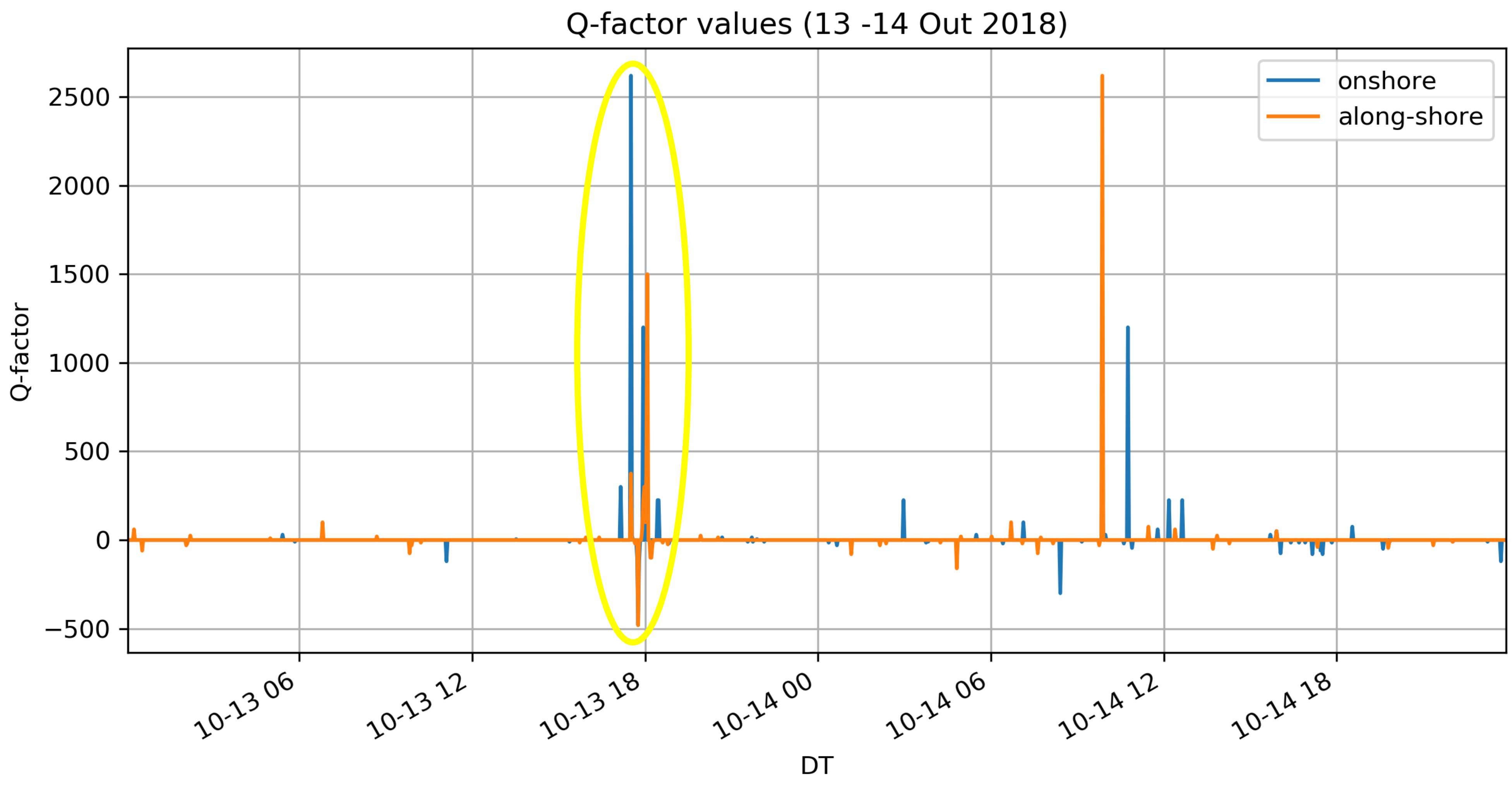
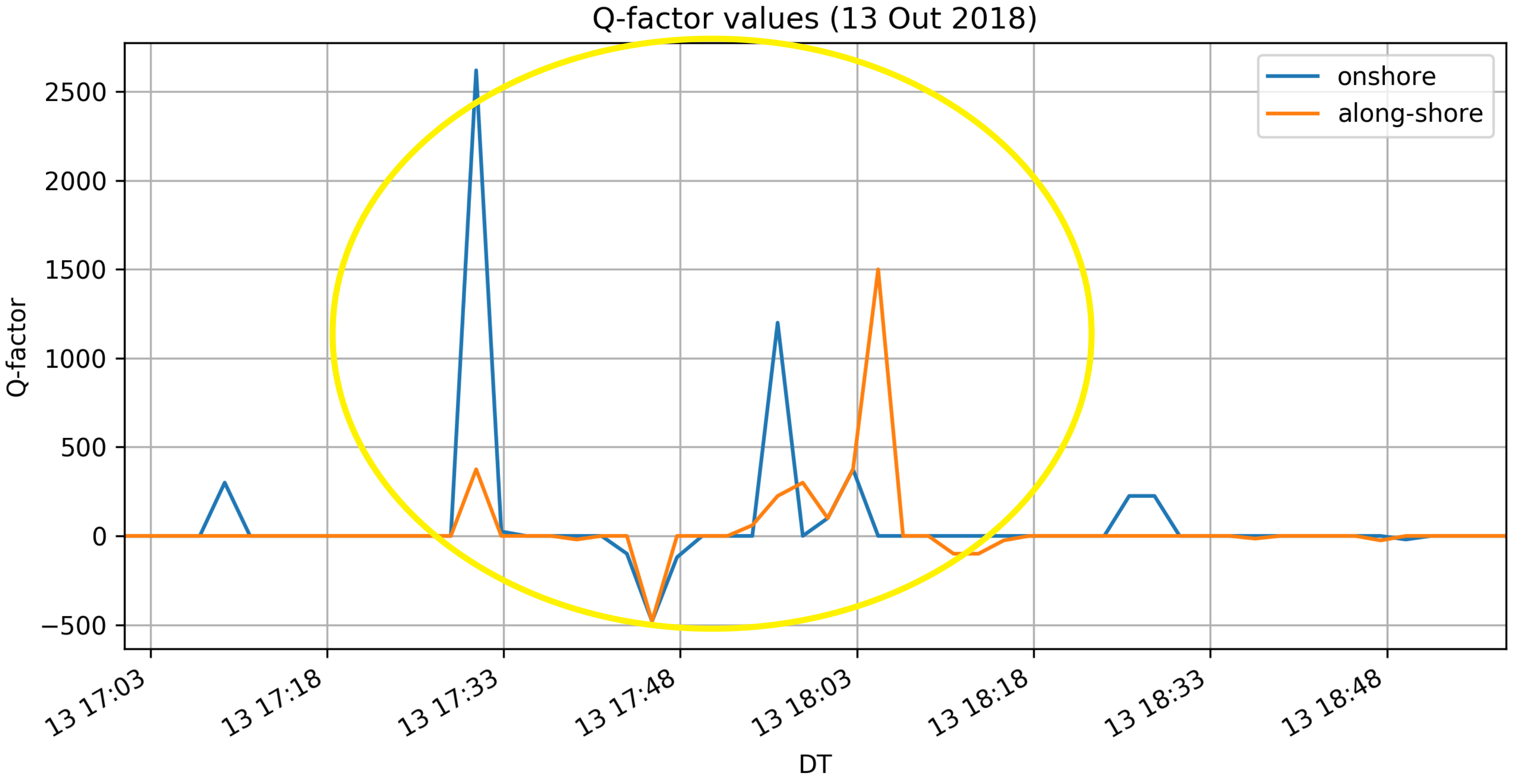
October 2018 Event



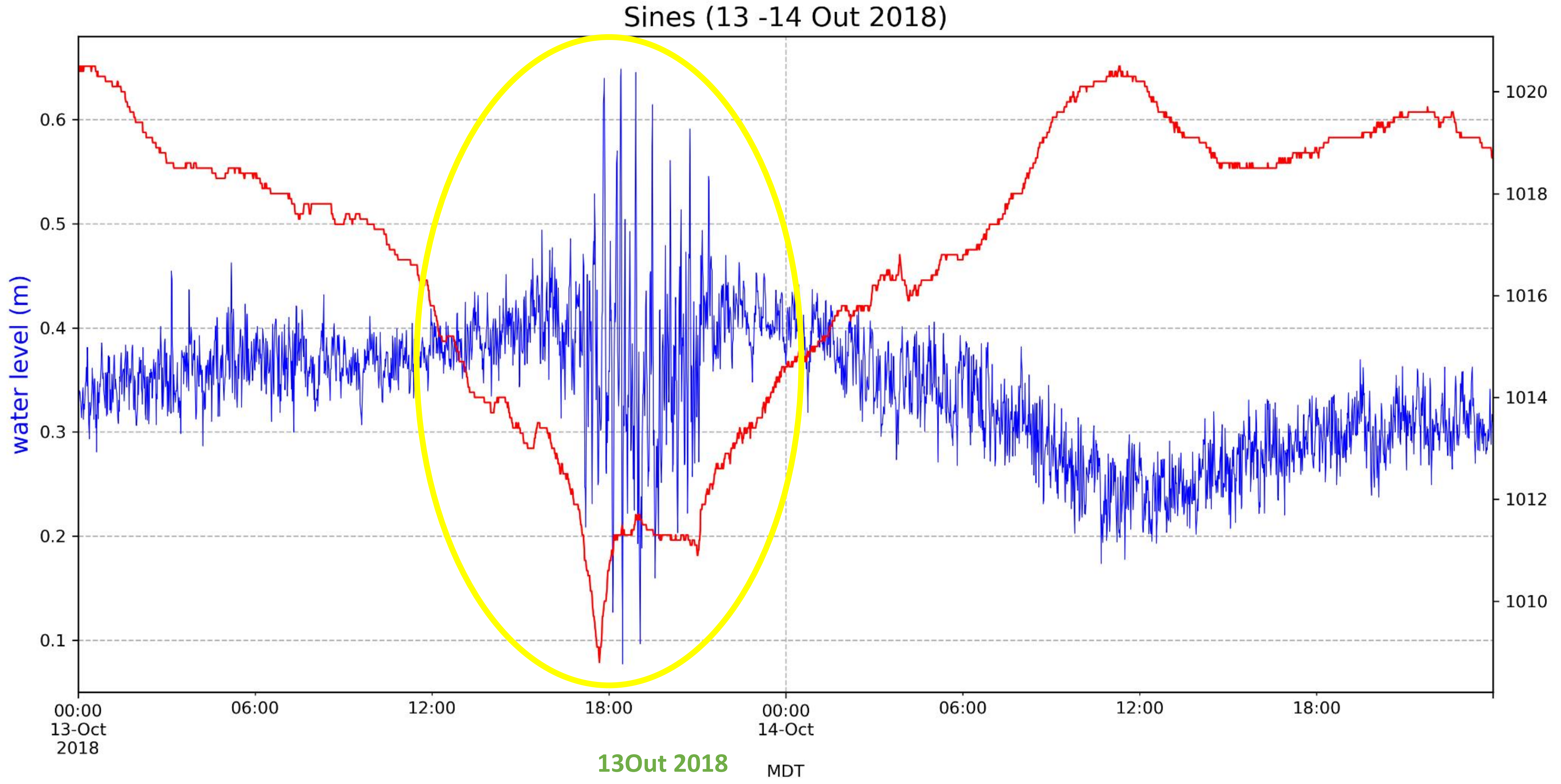
October 2018 Event



October 2018 Event

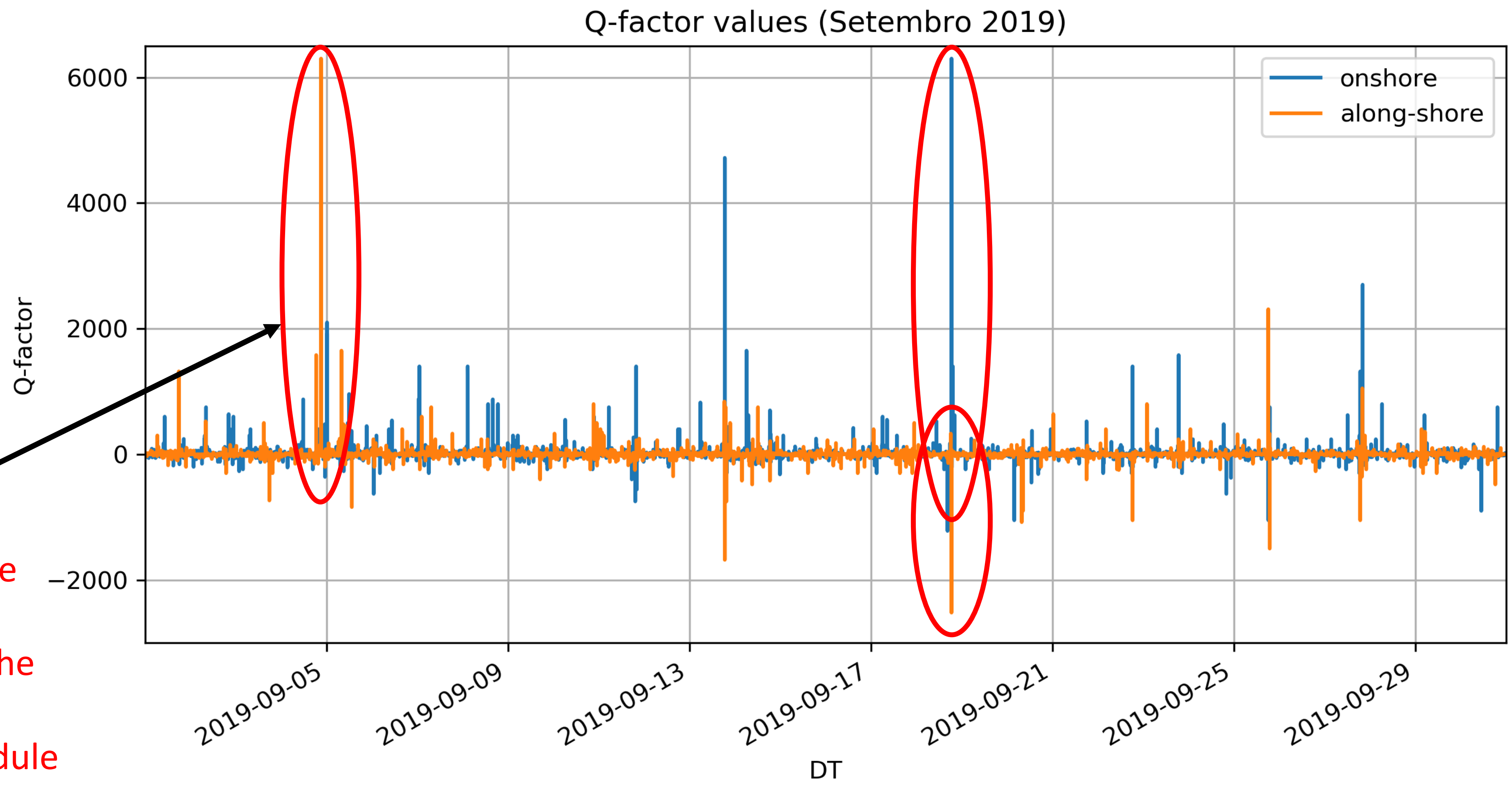


October 2018 Event



Qfactor spikes (September 2019)

2nd config

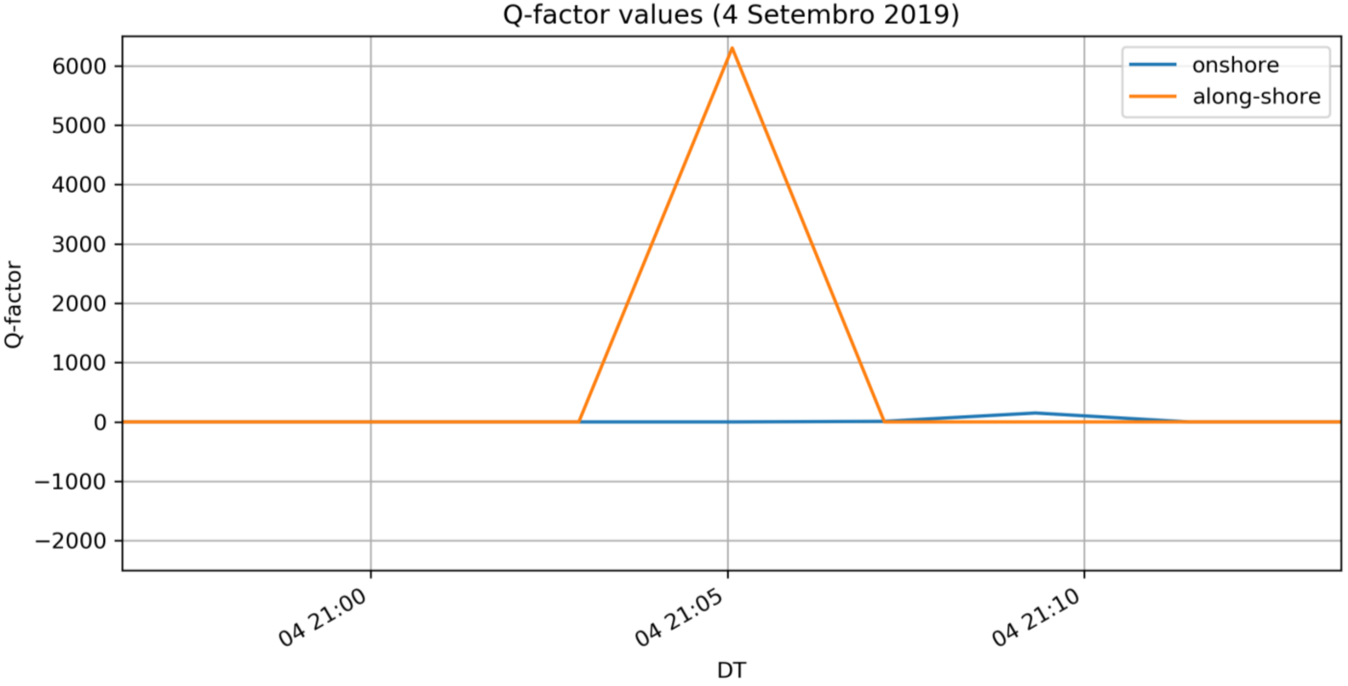


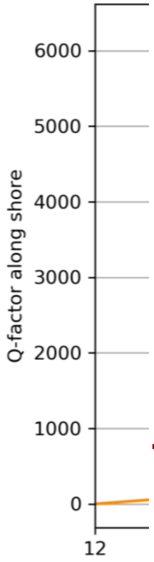
New highest maximum registered 6300, since the beggining of operation of the tsunami detection module

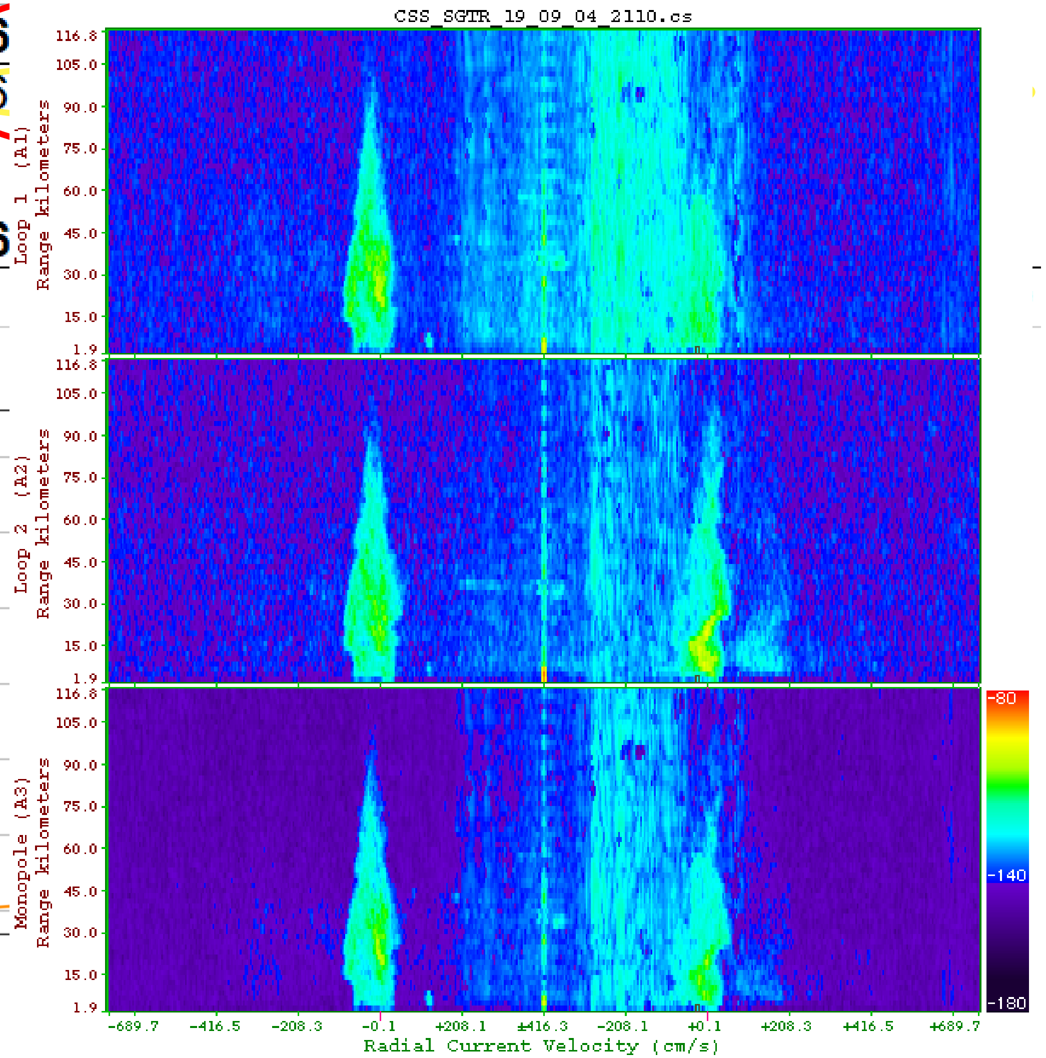
Qfactor spikes (4th September 2019)

Data - Hora	Qf along	0 km	2 km	4 km	6
2019-09-04 21:05:04	6300	0	150	0	6

Data - Hora	Qf on	0 km	2 km	4 km	6
2019-09-04 21:05:04	0	0	0	0	



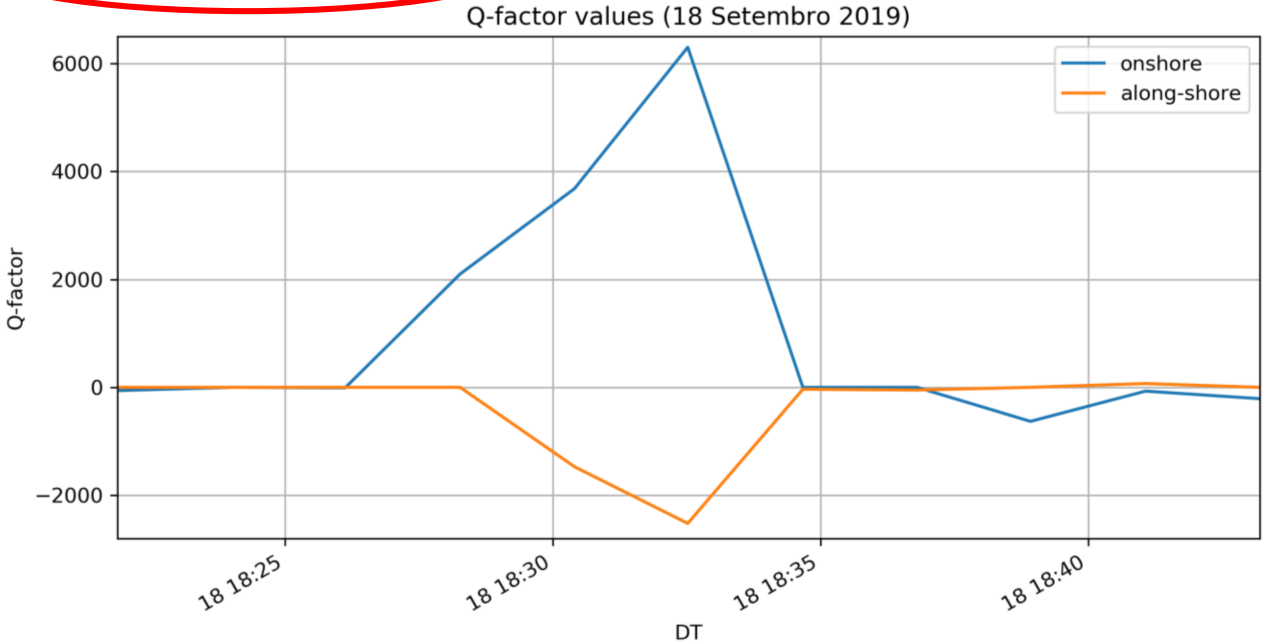


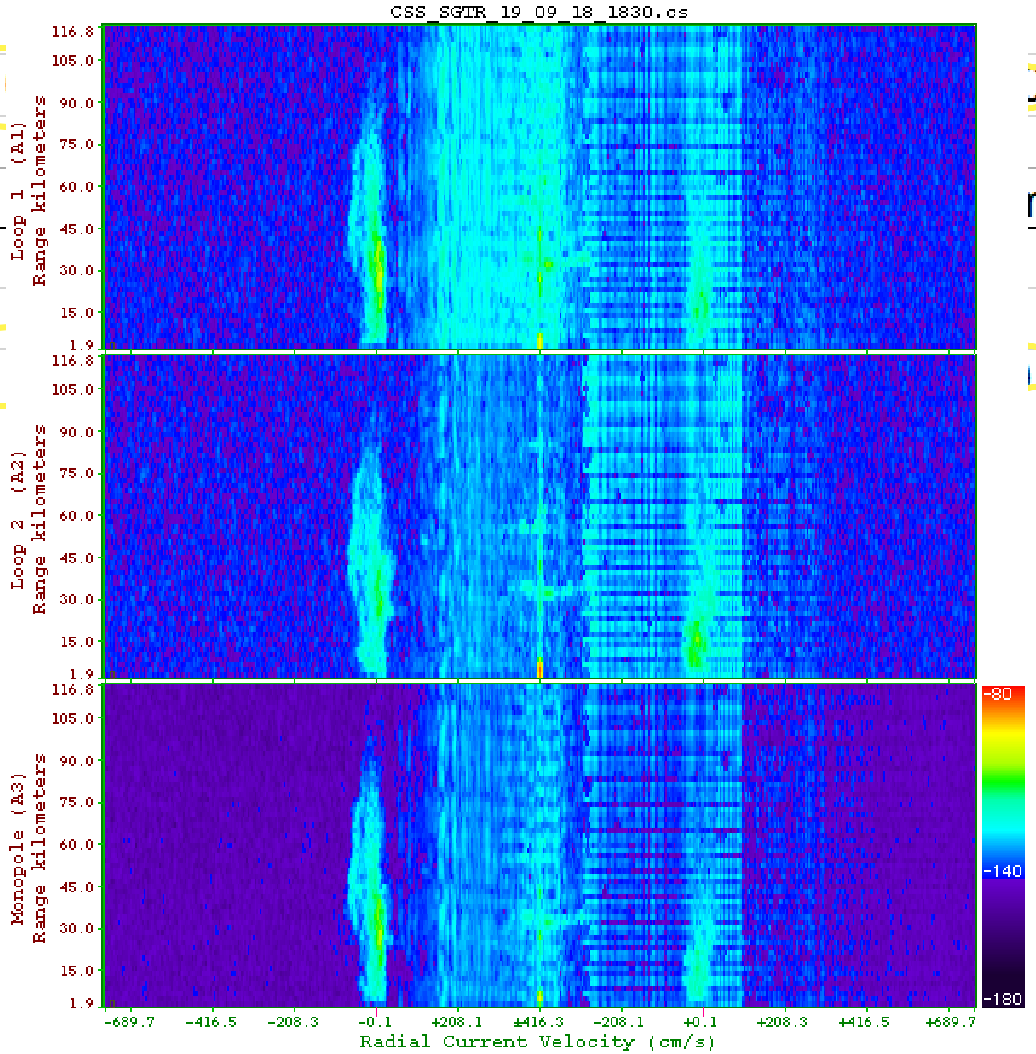


Qfactor spikes (18th September 2019)

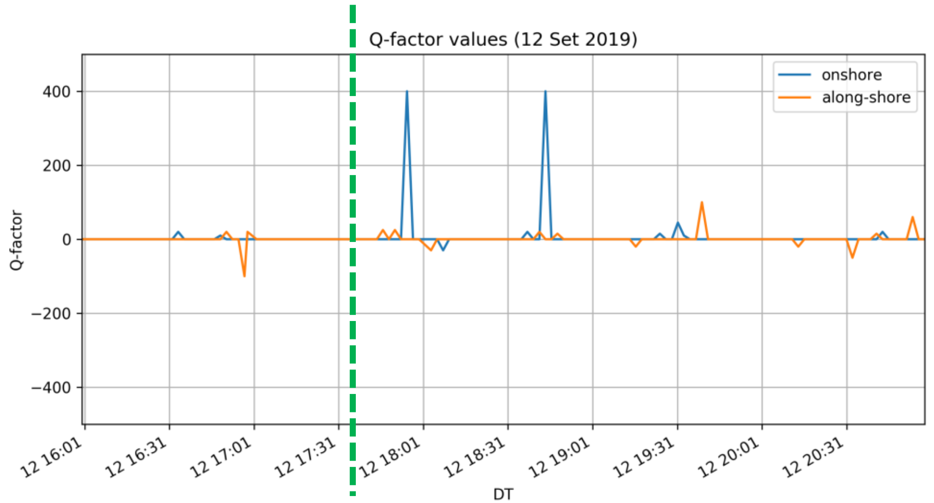
Data-Hora	Qf on	0 km	2 km	4 km	6 km	8 km	10 km	12 km	14 km
2019-09-18 18:28:16	2100	2100	2620	2620	1050	525	0	0	0
2019-09-18 18:30:24	3680	3680	3680	2100					
2019-09-18 18:32:31	6300	210	0	6300					

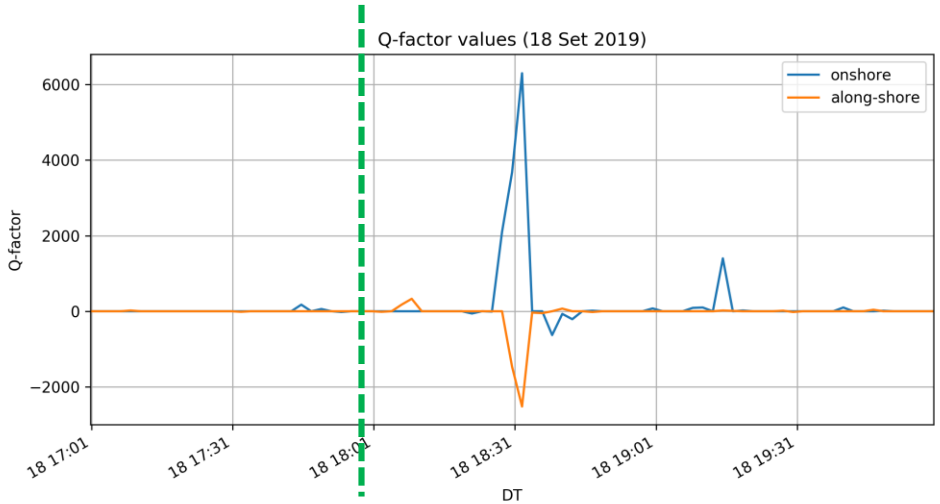
Data-Hora	Qf along	0 km	2 km	4 km
2019-09-18 18:28:16	0	0	-210	-210
2019-09-18 18:30:24	-1470	-1470	-1470	-840
2019-09-18 18:32:31	-2520	-210	0	-2520

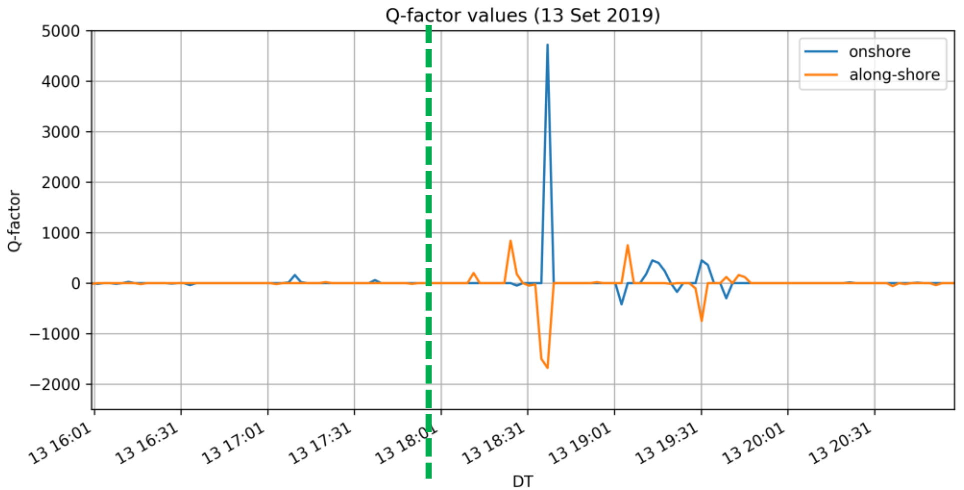


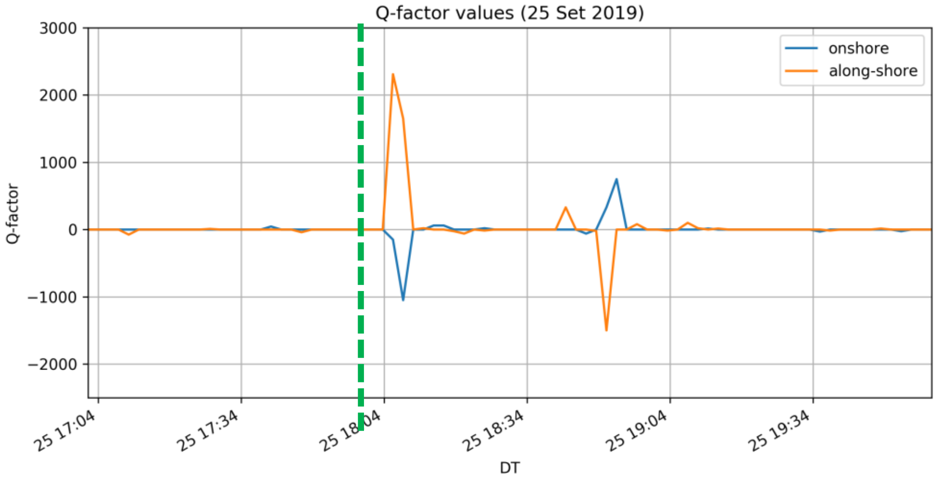


Qfactor vs sistematic occurrences (Set 2019)

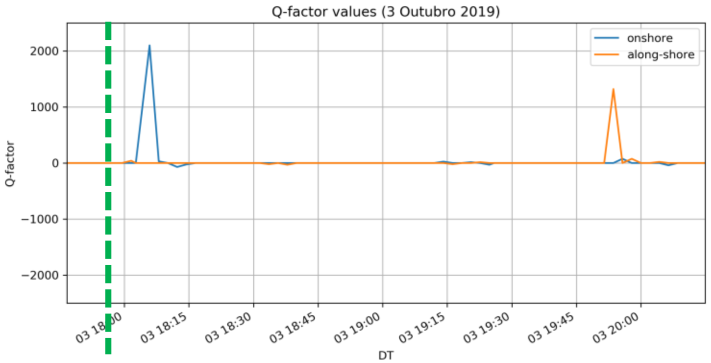


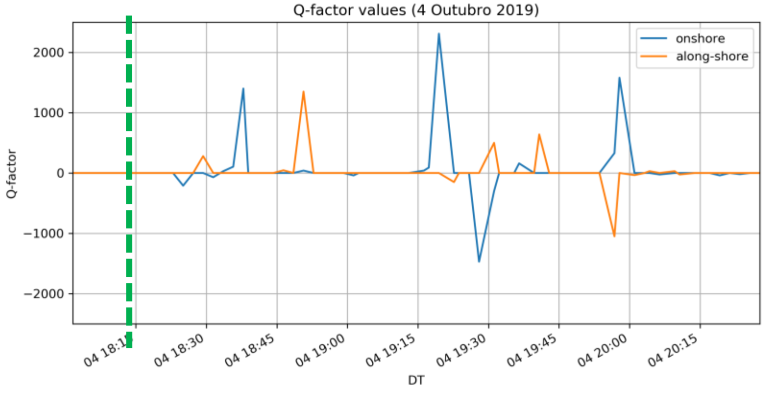


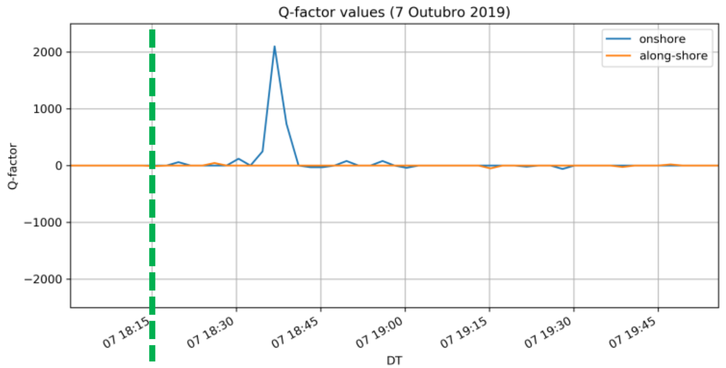


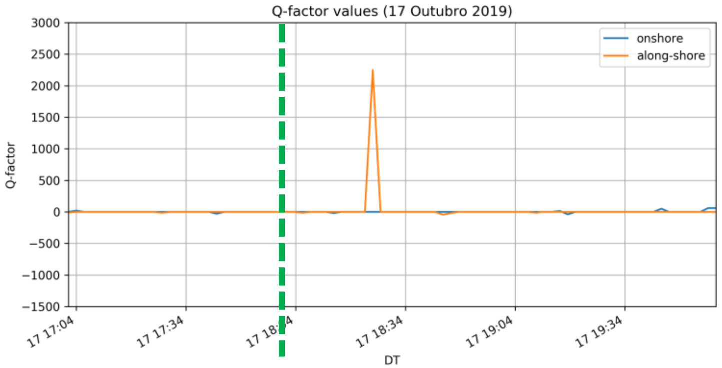


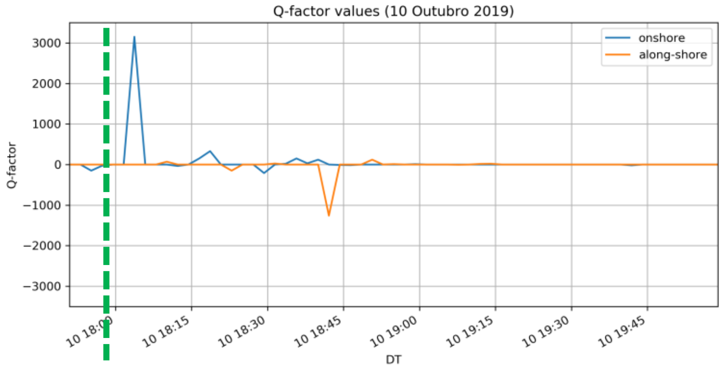
Qfactor vs sistematic occurrences (Out 2019)











High Qfactor events associated w/ Medium to high HF noise

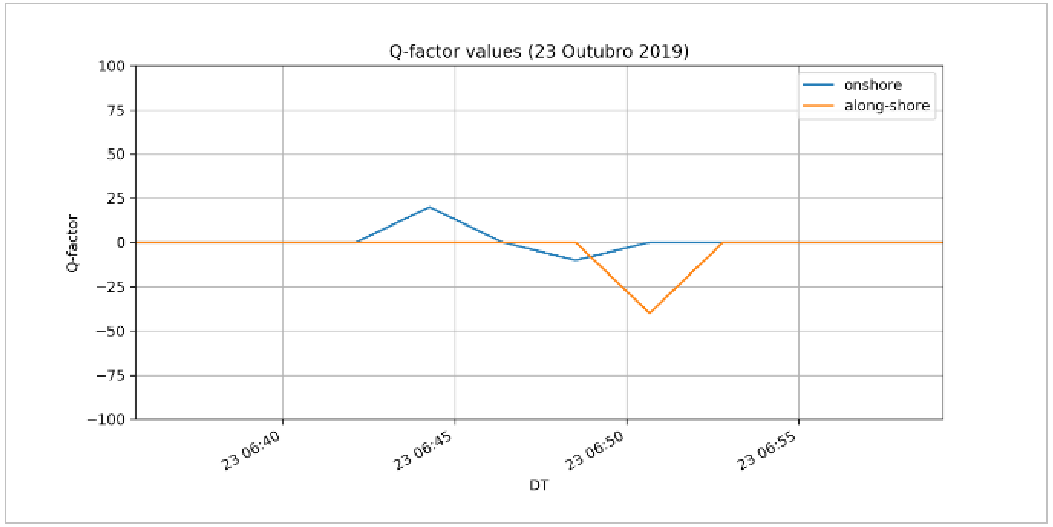
2019-10-23 06:43:33	36.56	-9.71	16	1.5	SW Cabo S.Vicente	IPMA

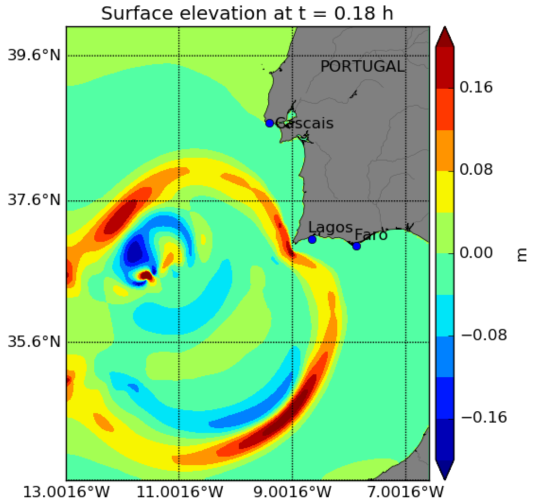
Distância (radar - epicentro) = 83.27 km

Tempo chegada máximo estimado = 10.65 minutos

Qfactor vs seismic events

- **Seismic event / Ref location:**
  - 1) location (Lat, Lon)
  - 2) depth
  - 3) Mw
- **Δx** (Radar, Event location)
- Estimate **TTT** at radar's near field according to SW relation **c** = √gh
- Qfactor comprised in **Δt**





V. Lima "CM1 / GeoClaw-FUNWAVE-TVD" (2017)

Qfactor vs seismic events

For Mw > 3 :

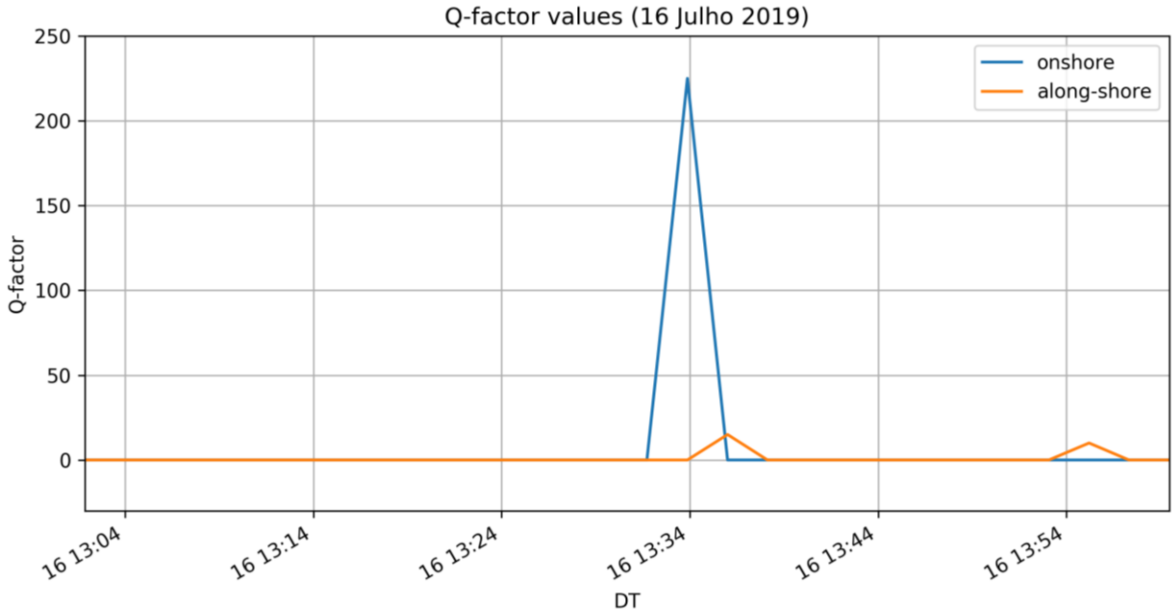
Evento sísmico 16 Julho 2019 13:31 UTC:

Data e hora	Lat	Lon	depth	Mag	Ref	Fonte
16/07/2019 13:31	36.37	-8.01	34	3.9	S Faro	IPMA

Registo HF radar:

Data e hora	Qf onshore	Qf alongshore
2019-07-16 13:33:52	225	0

- Dist Radar/Epic ~ 110 km



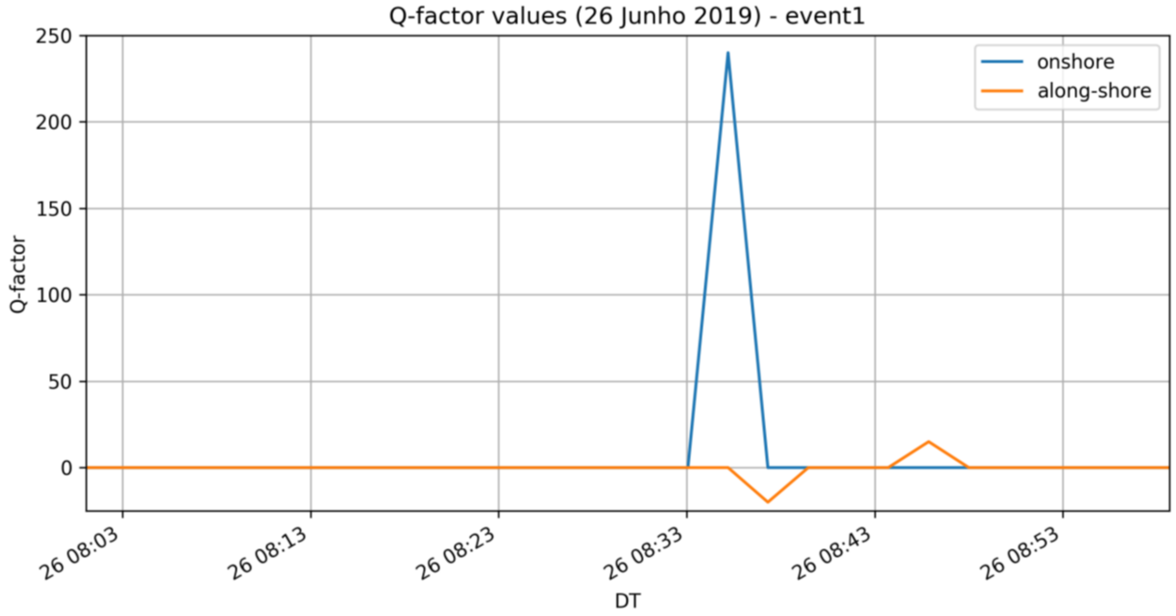
Evento sísmico em 26 Junho 2019 08:33 UTC:

Data e hora	Lat	Lon	depth	Mag	Ref	Fonte
26/06/2019 08:33	36.16	-8.48	32	3.1	SW Albufeira	IPMA

Registo HF radar:

Data e hora	Qf onshore	Qf alongshore
2019-06-26 08:35:12	240	0

- Dist Radar/Epic ~ 95 km



Summary

- CODAR Tsunami detection software functioning at Sagres HF radar station since Set 2018

- Outputs Qfactor spikes which indicate potential tsunami wave (Lipa et al 2016)

- Shallow continental shelf means greater software detection distance and warning time

Summary

- Main Goal: Establish threshold Qfactor value for tsunami alert

- Qfactor 2000 averaged 1 per/week

- 2nd config (Ag 2019 – Nov 2019):
    - 19 instances of Qfactor > 2000
    - 5 instances of Qfactor > 4000

Summary

- Noise presence probable contributor false alarms
- Analyze and minimize external noise sources at HF radar Sagres
- To be considered: Several Qfactor thresholds providing alerts for given levels of confidence
- Real time crossing of Qfactor, meteo and seismic events data

OCASO Project

Tsunami Arrival Detection with High Frequency (HF) Radar Technology

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5th December 2019

Sagres