# Temporal variations in fast shear-wave polarisation direction observed during and after the 2011-2012 El Hierro eruption from local shear-wave splitting

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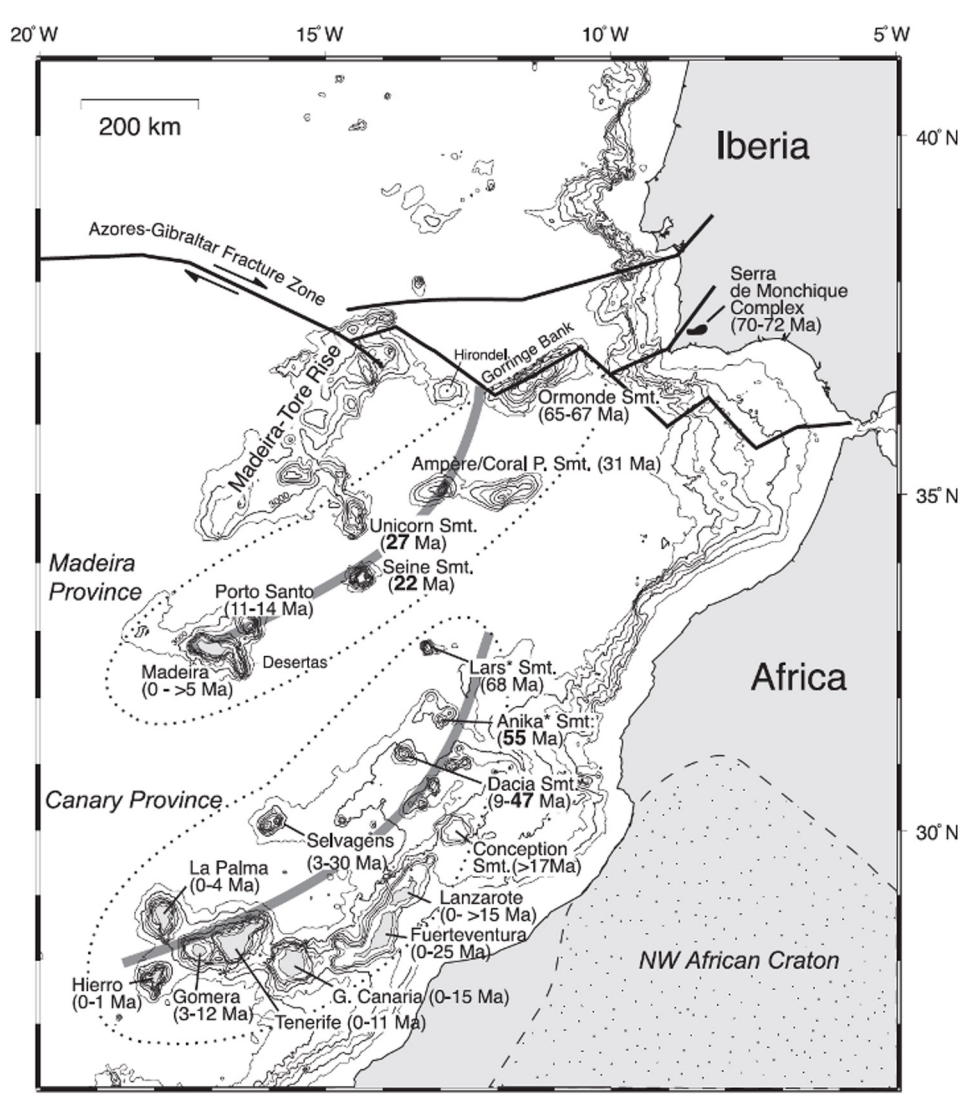
Pablo J. González, and Resurrección Antón

# Introduction and Motivation




*(Geldmacher et al., 2005, EPSL)*

- El Hierro: westernmost island of the Canaries.
- Due to westward migration of underlying mantle upwelling also the youngest island.
- Together with La Palma the sites of the most recent eruptions.

- Island experienced substantial uplift from 2011 to 2014 (~23 cm).

- Subsurface structure and dynamics has influence on stress field.
  - Can be investigated studying seismic anisotropy patterns of the region.
  - In crust: orientation in the direction of maximum stress is observed → parallel to alignment of fractures or cracks. Melt and fluids can enhance strength.

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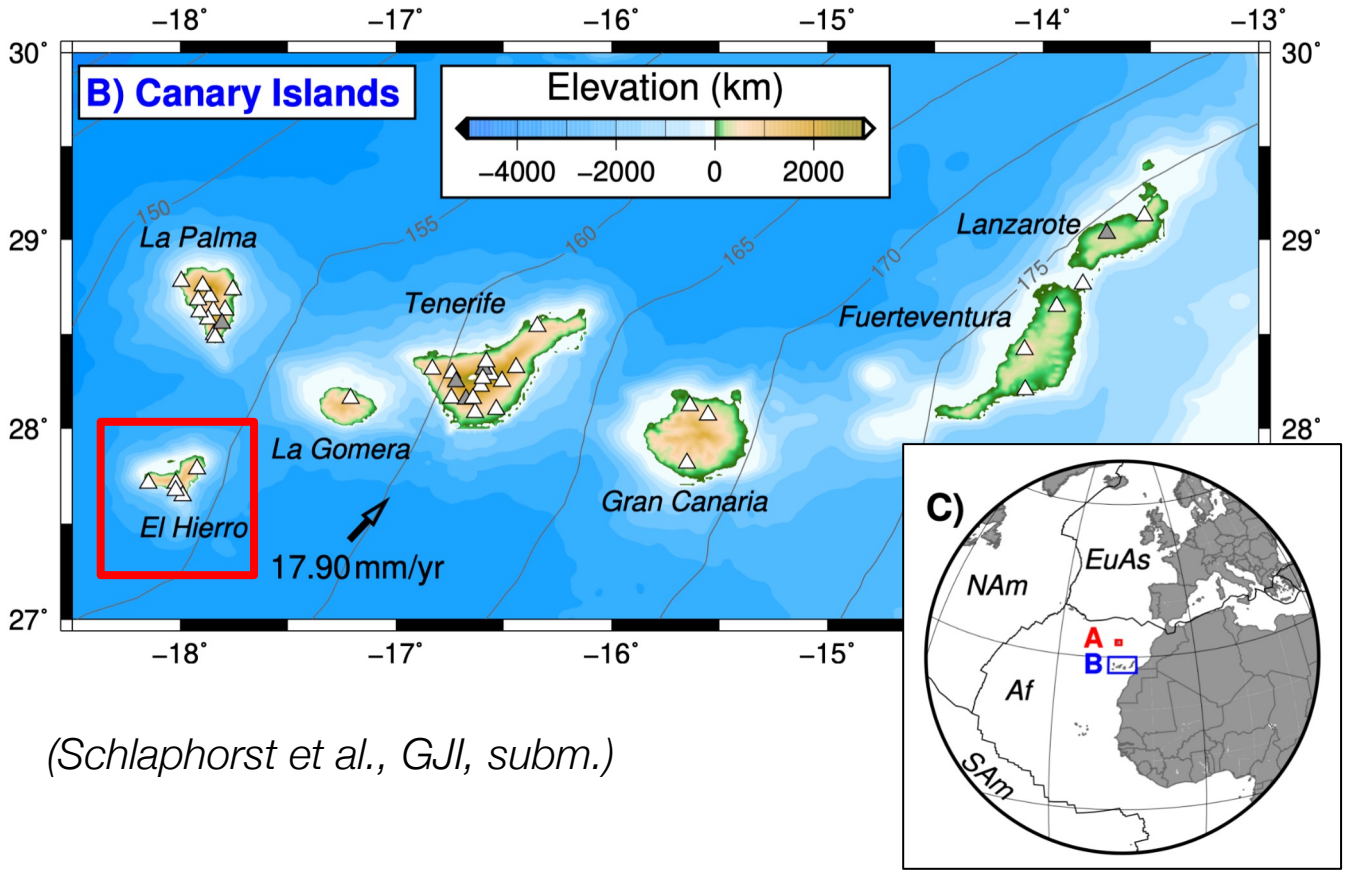
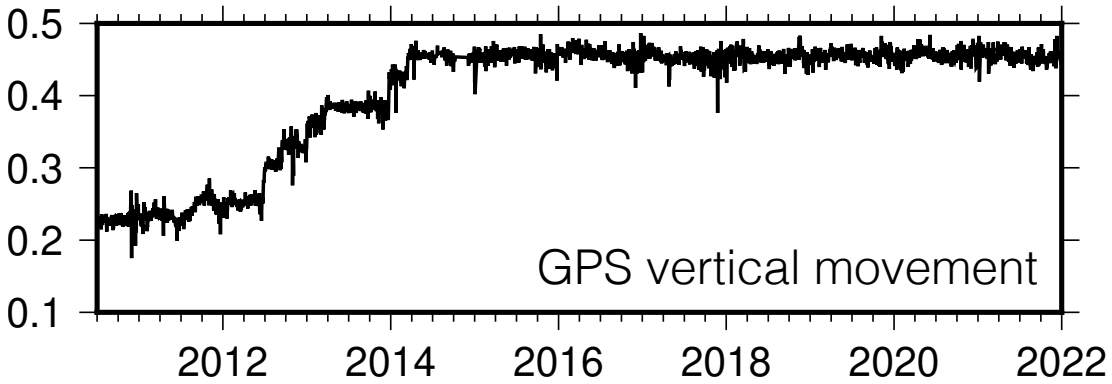



*(Schlaphorst et al., GJI, subm.)*

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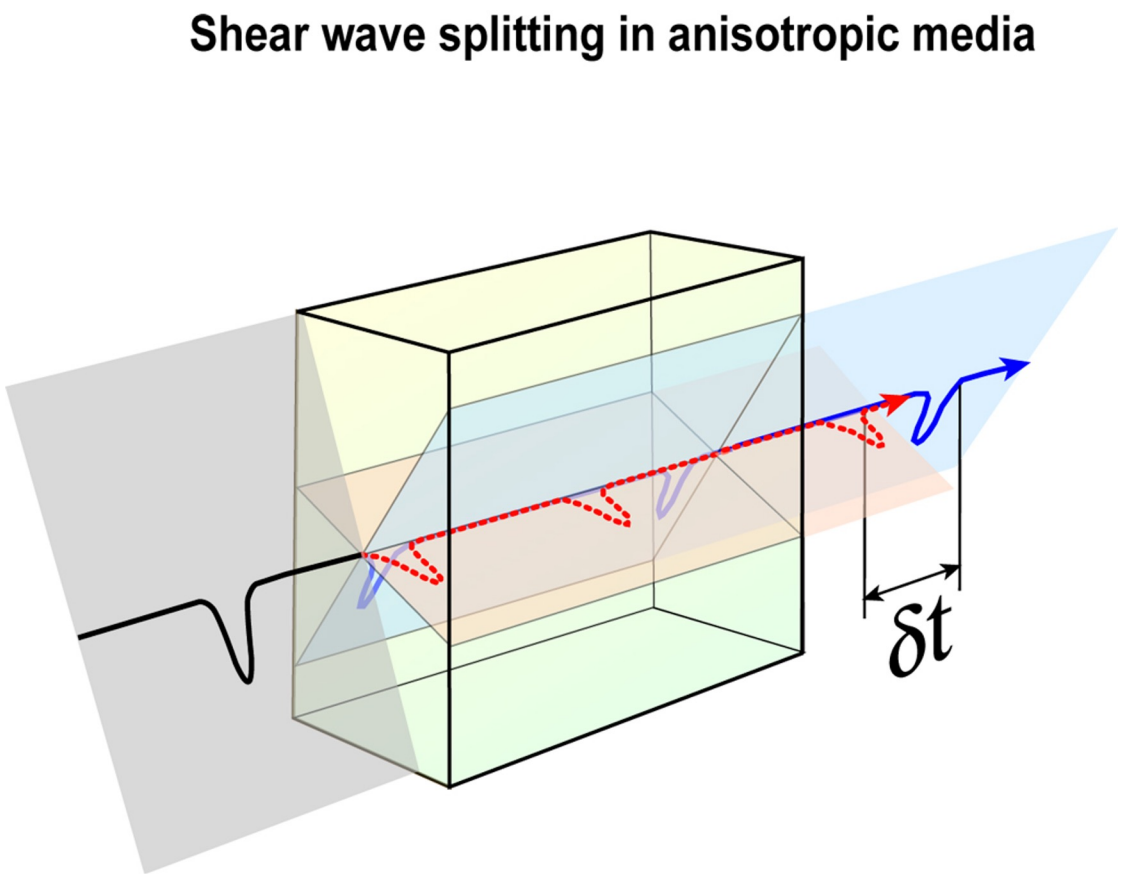
# Method: shear wave splitting

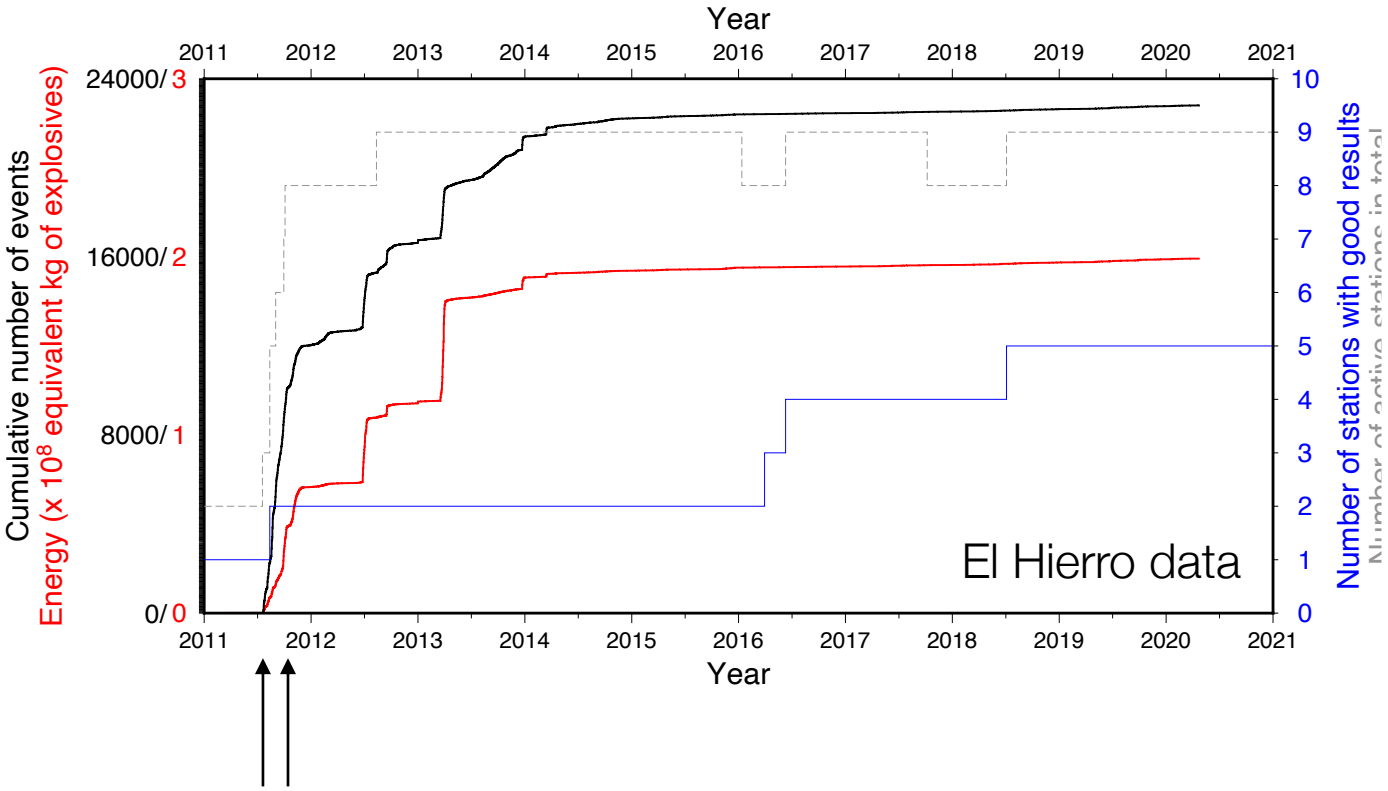



*(Ed Garnero, downloaded 22/05/2022: http://garnero.asu.edu/research_images/anis/garnero15ani_crampin3.jpg)*

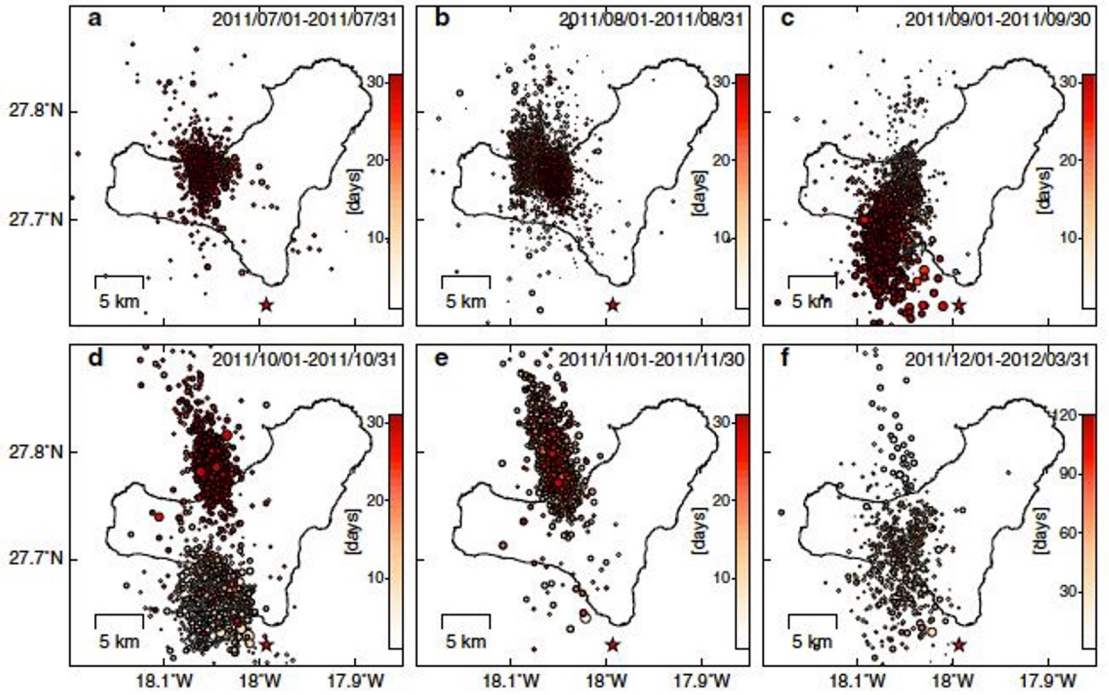
- Shear-wave has certain incoming polarisation.
- In anisotropic medium splits in two shear-waves with orthogonal polarisation (can be different to initial polarisation).
- One wave travels faster than the other.
- After leaving the anisotropic region, waves retain polarisation and time difference.
- At the surface, using a broadband 3-component seismic station, splitting parameters can be measured (i.e. fast shear wave polarisation direction (FPD), $\phi$, and time delay, $\delta t$) – see Silver & Chan (1991, JGR).
- Select events: M > 2.5
  incidence angle > 35 deg (Evans, 1984, JGR)
- Results can be plotted on maps using bars with:
  - Position: halfway between event and station.
  - Length: time delay.
  - Angle: FPD.
  - Colour: depth of the event.

# Data

Data provider: Instituto Geográfico Nacional (ign.es)




Effect of missing stations and incidence angle selection.




*(González et al., 2013, JGR)*

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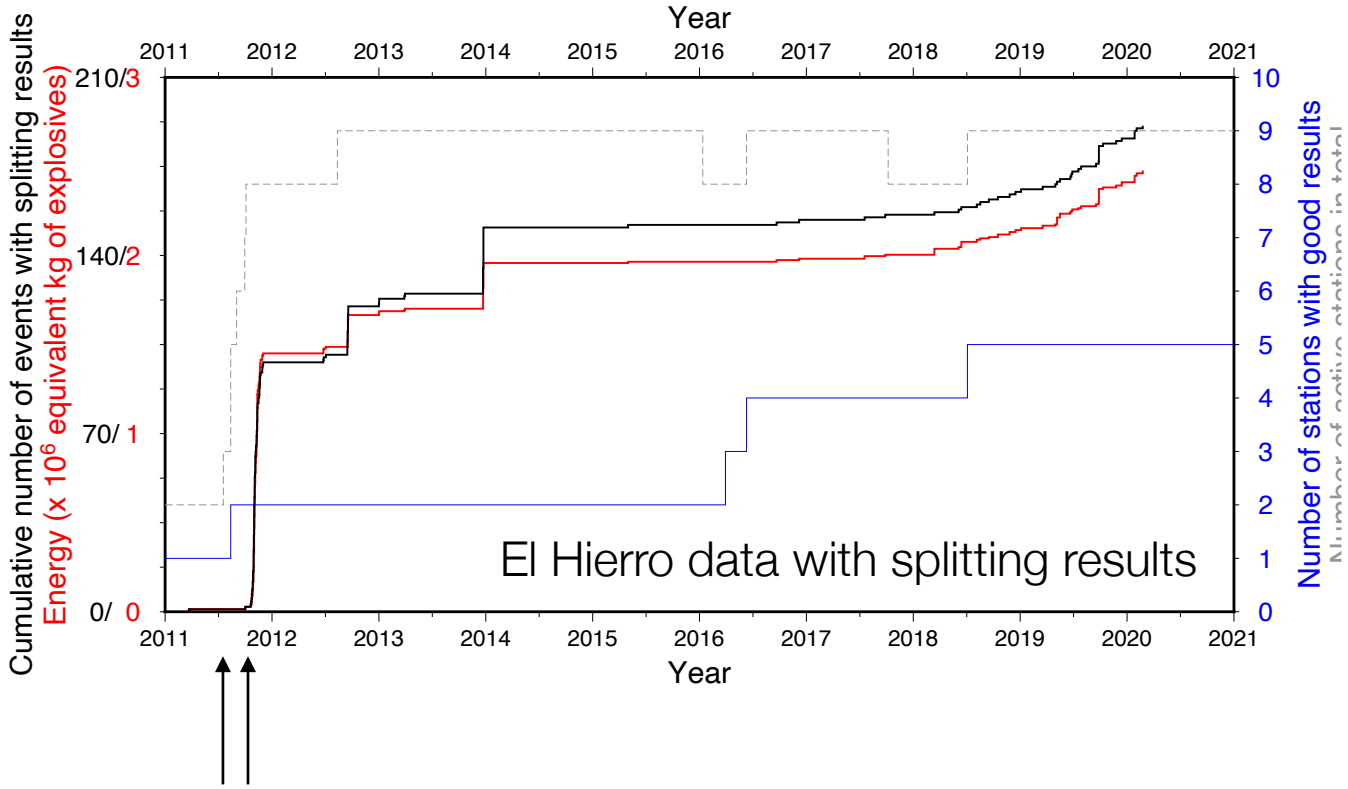


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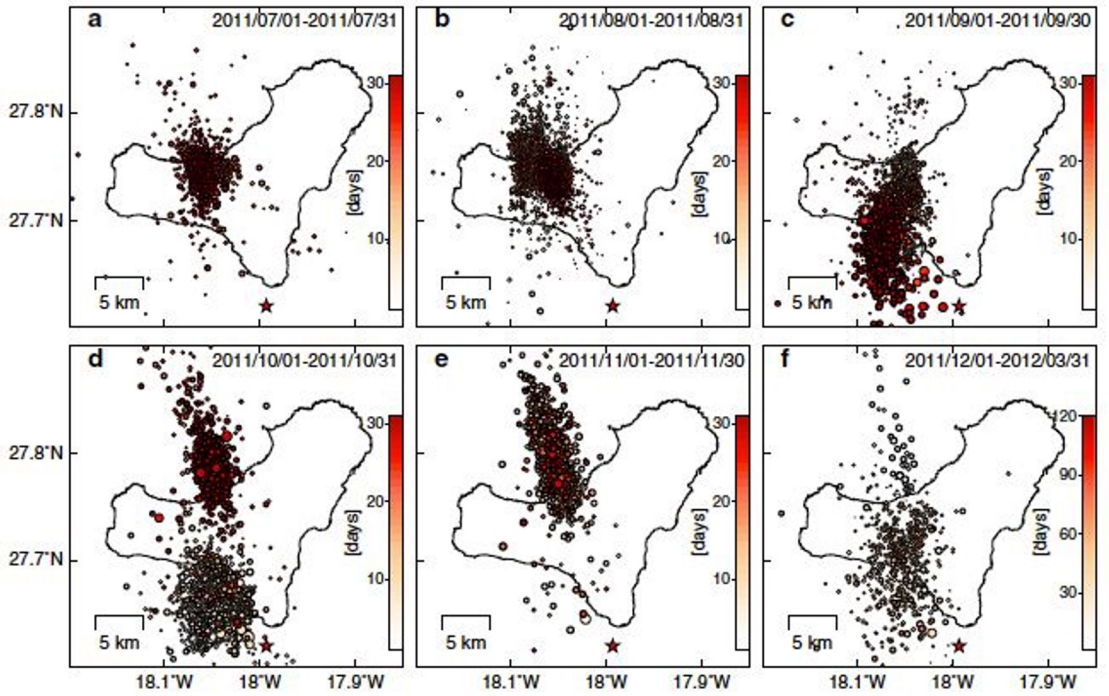


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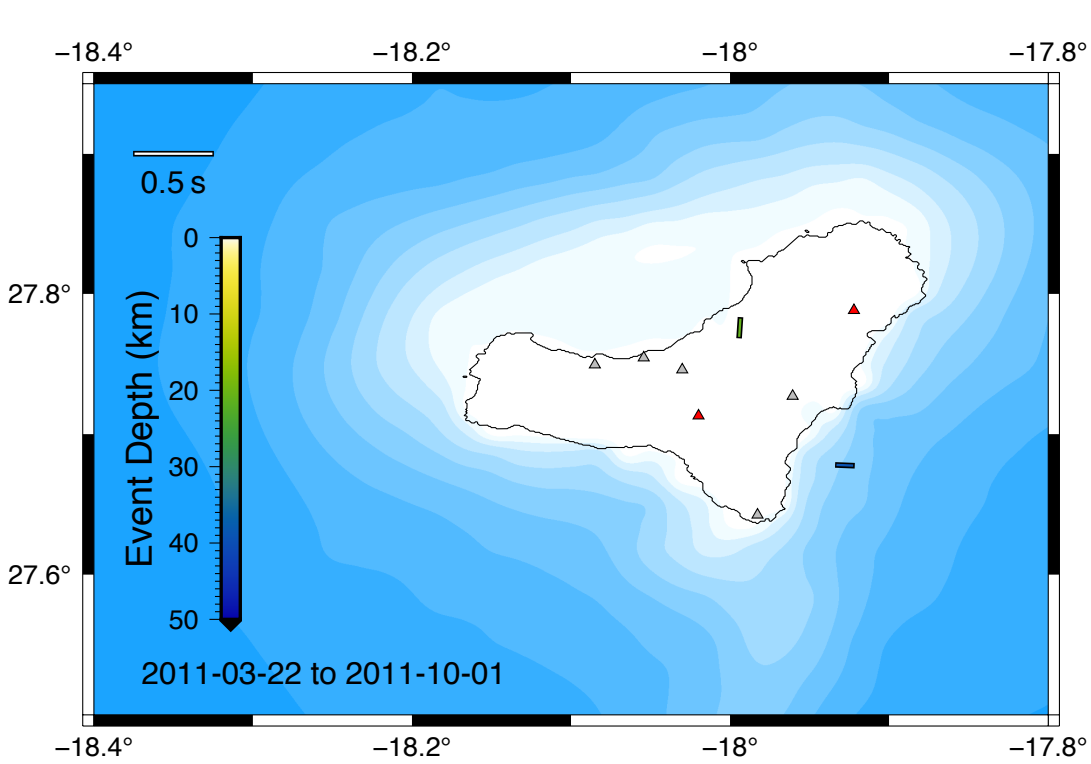


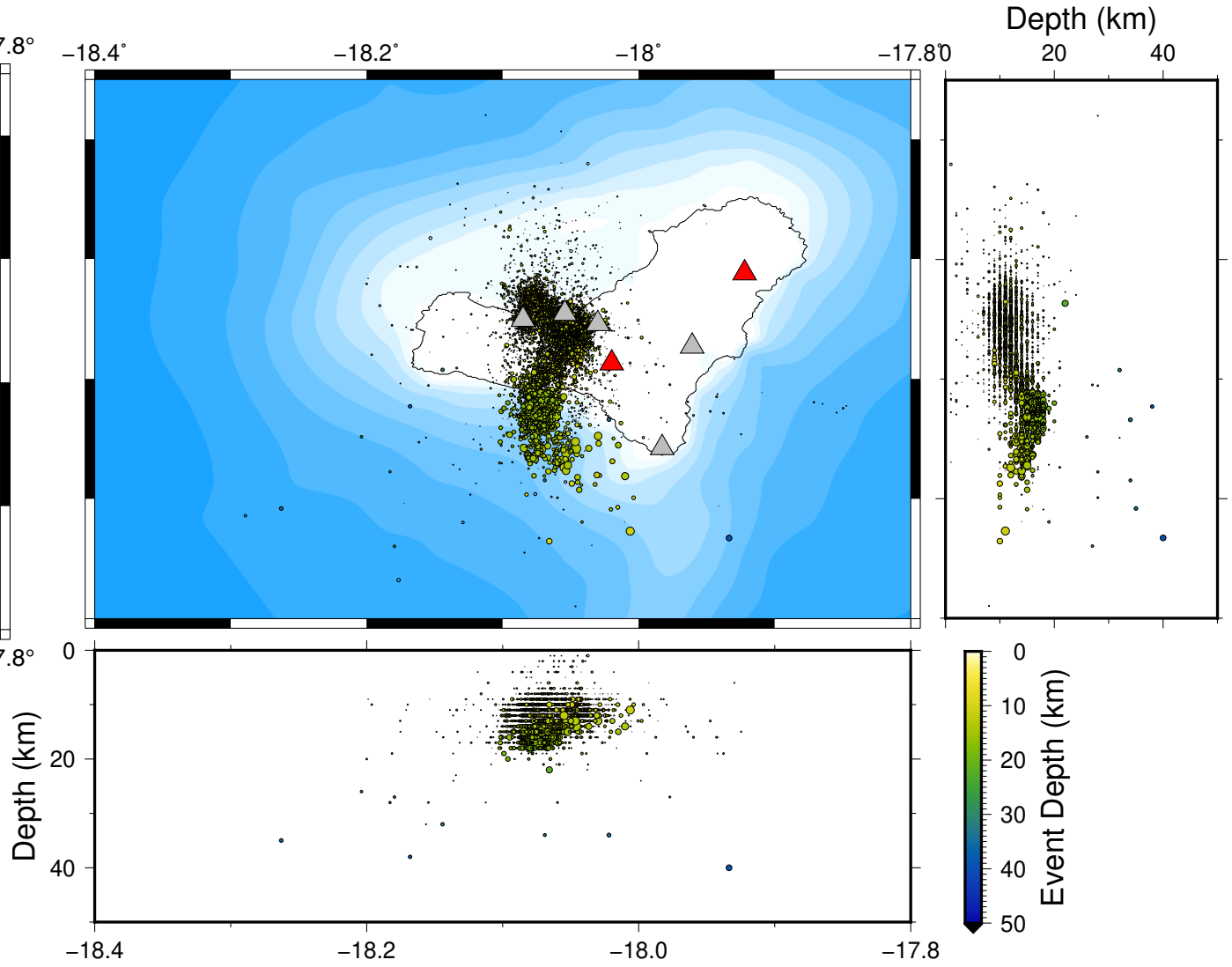


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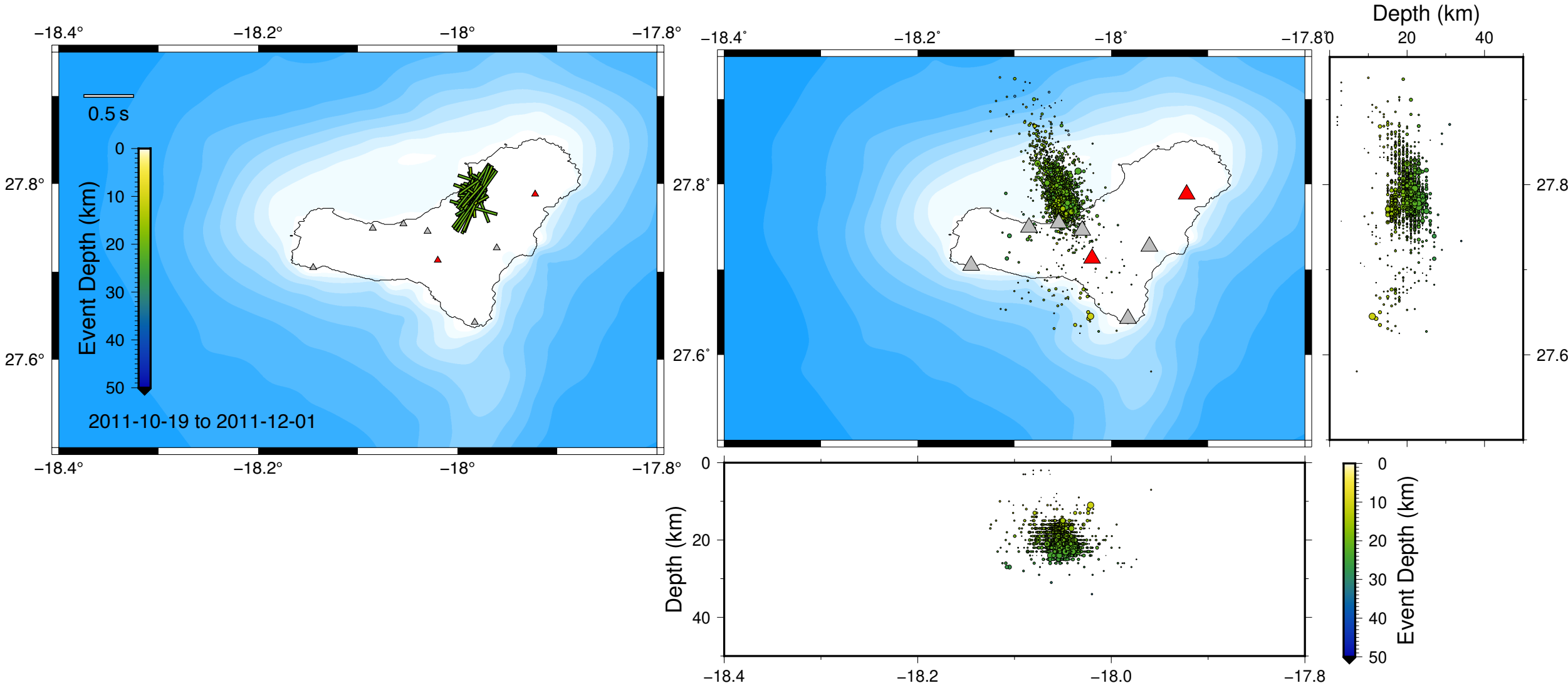
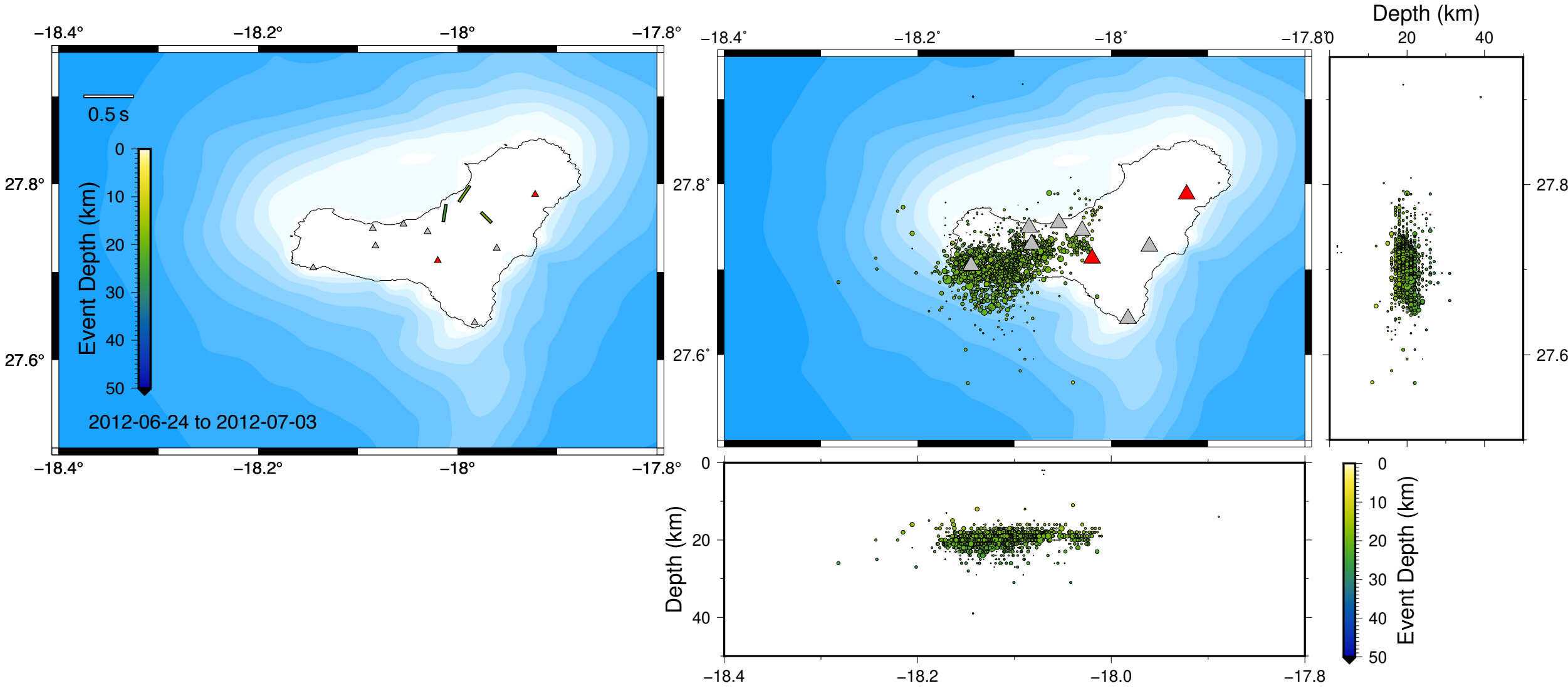
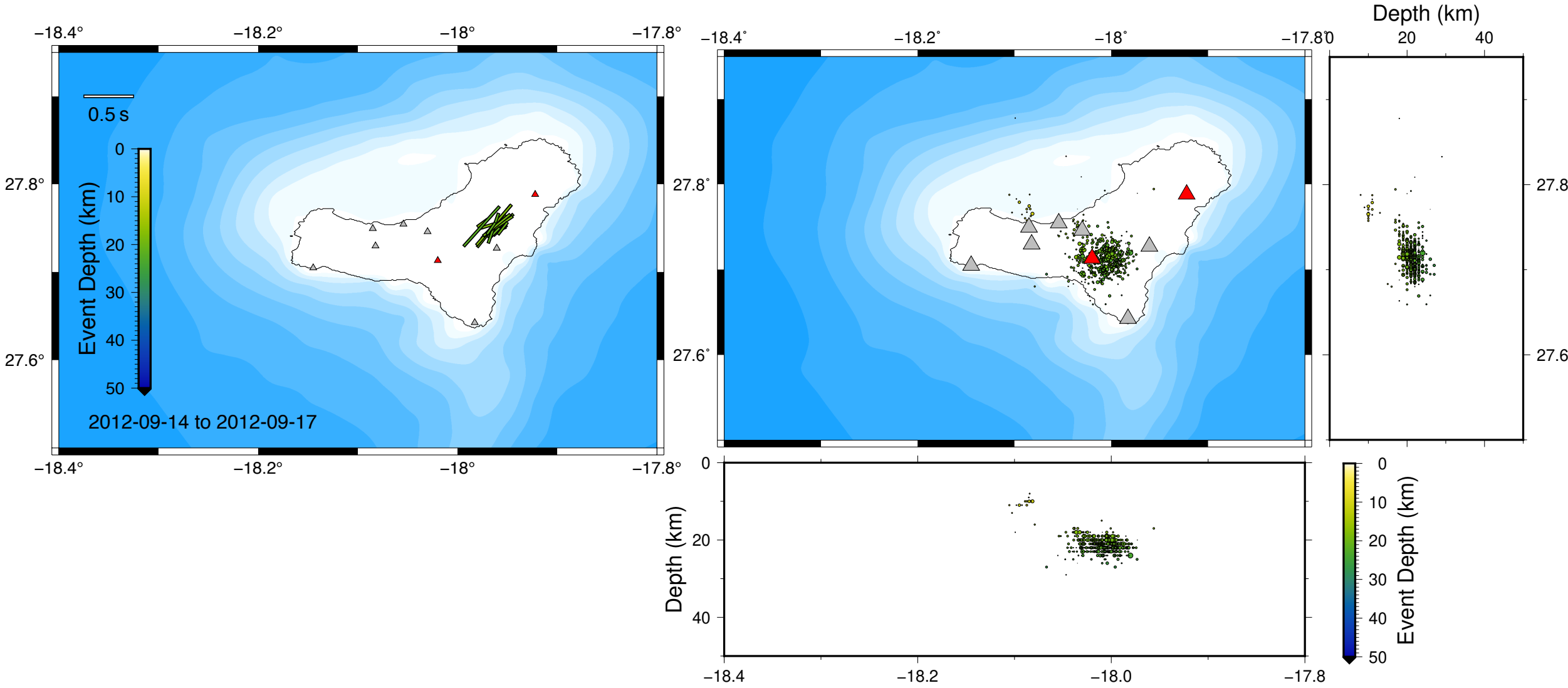
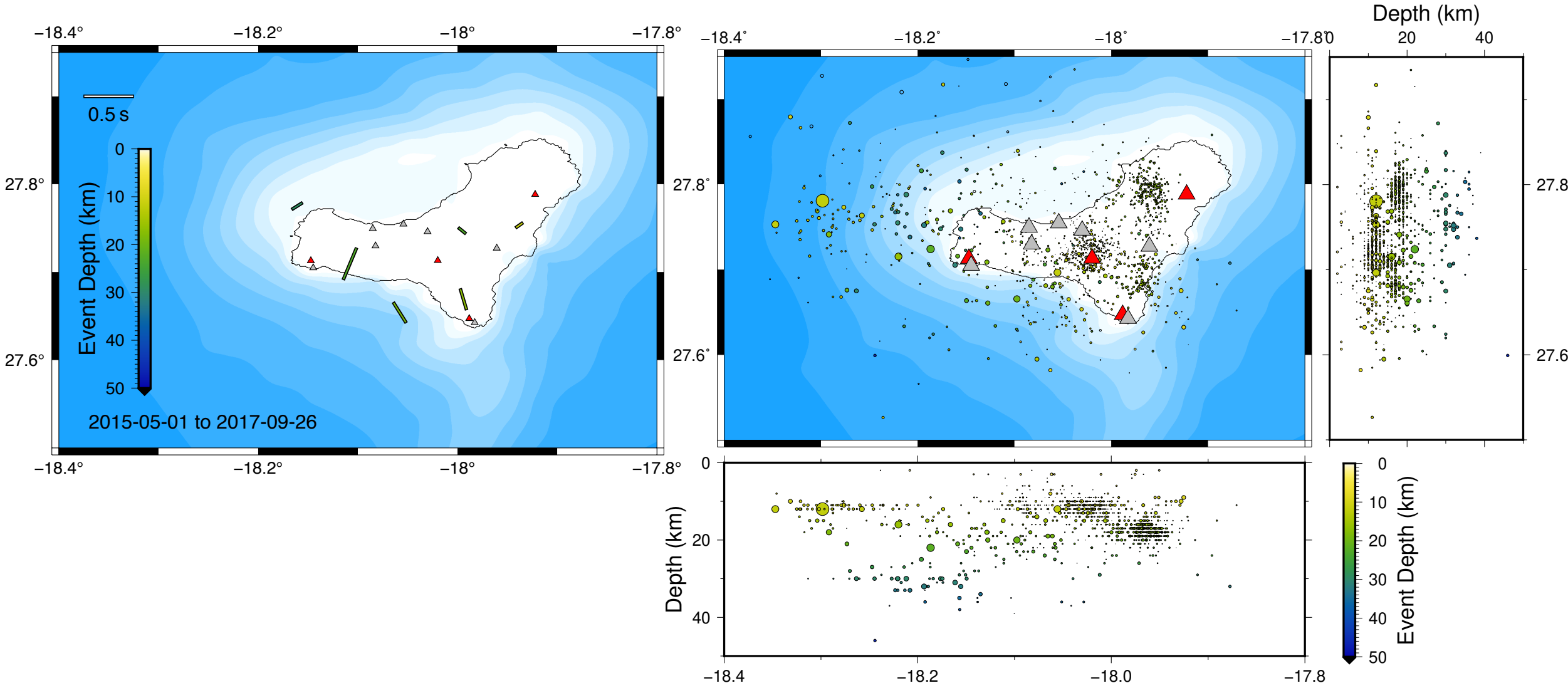
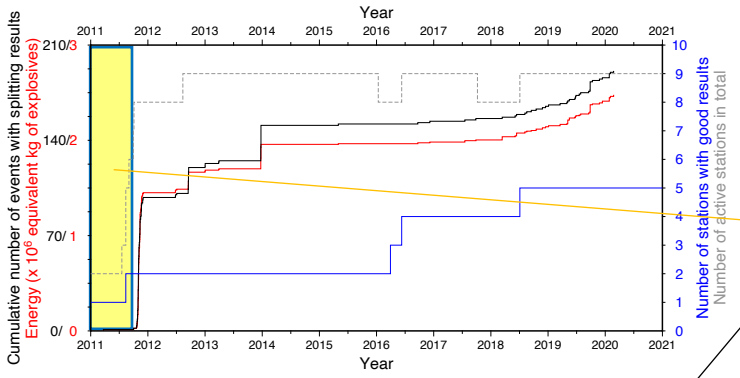

−18.4°
−18.2°
−18°
−17.8°
27.8°
27.6°
0.5 s
Event Depth (km)
0
10
20
30
40
50
2011-10-19 to 2011-12-01
−18.4˚
−18.2˚
−18˚
−17.8˚
27.8˚
27.6˚
Depth (km)
0
20
40
Depth (km)
0
20
40
−18.4
−18.2
−18.0
−17.8
Event Depth (km)
0
10
20
30
40
50


−18.4°
−18.2°
−18°
−17.8°
27.8°
27.6°
0.5 s
Event Depth (km)
0
10
20
30
40
50
2012-06-24 to 2012-07-03
−18.4˚
−18.2˚
−18˚
−17.8˚
27.8˚
27.6˚
Depth (km)
0
20
40
Depth (km)
−18.4
−18.2
−18.0
−17.8
Event Depth (km)


−18.4°
−18.2°
−18°
−17.8°
27.8°
27.6°
0.5 s
Event Depth (km)
0
10
20
30
40
50
2012-09-14 to 2012-09-17
−18.4˚
−18.2˚
−18˚
−17.8˚
27.8˚
27.6˚
Depth (km)
0
20
40
Depth (km)
0
20
40
−18.4
−18.2
−18.0
−17.8
Event Depth (km)
0
10
20
30
40
50


−18.4°
−18.2°
−18°
−17.8°
27.8°
27.6°
0.5 s
Event Depth (km)
0
10
20
30
40
50
2015-05-01 to 2017-09-26
−18.4˚
−18.2˚
−18˚
−17.8˚
27.8˚
27.6˚
Depth (km)
0
20
40
Depth (km)
−18.4
−18.2
−18.0
−17.8
Event Depth (km)

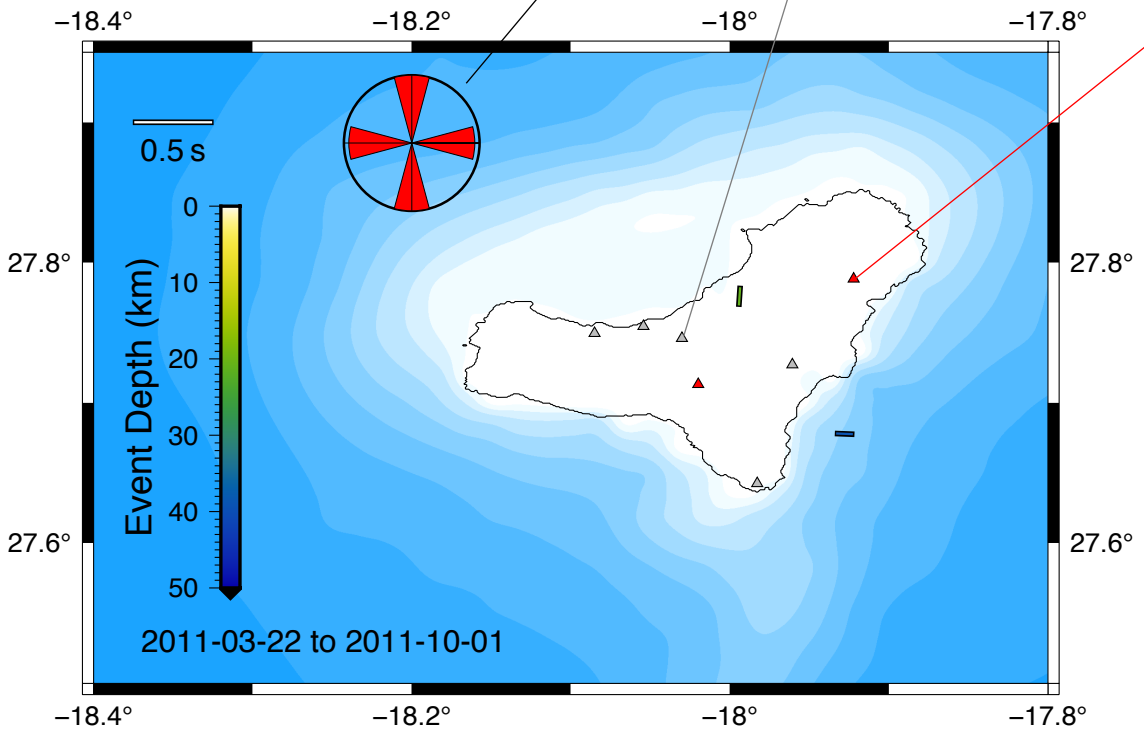


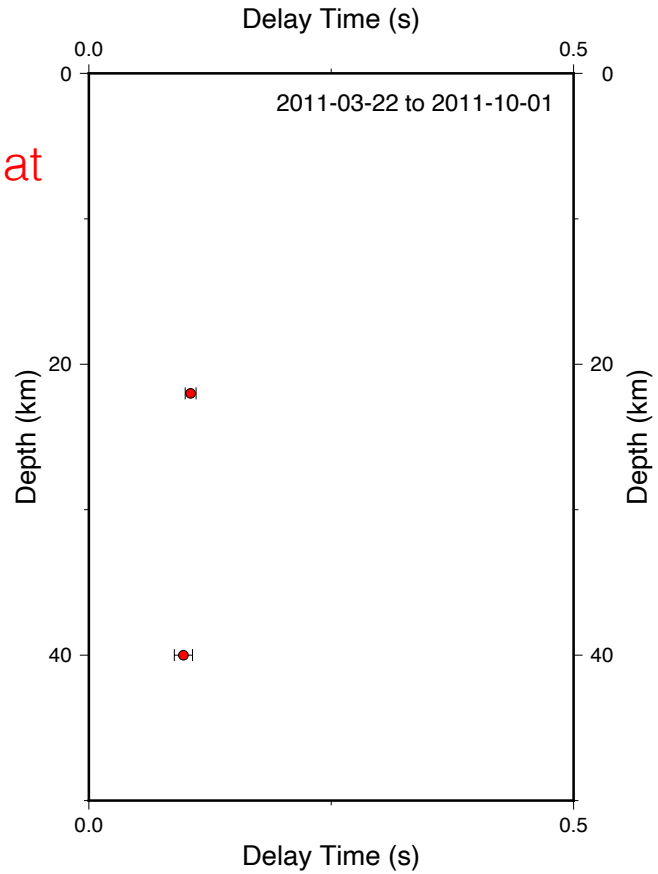

Yellow box: current time span.

Rose plot: histogram of all directions.

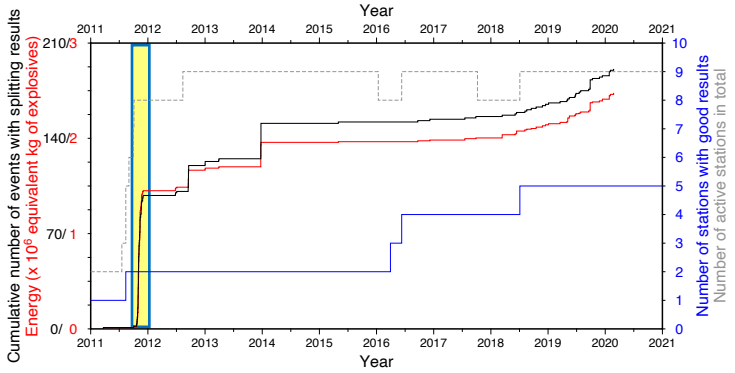
Grey triangles: active stations*.

Red triangles: active stations that provided good results.

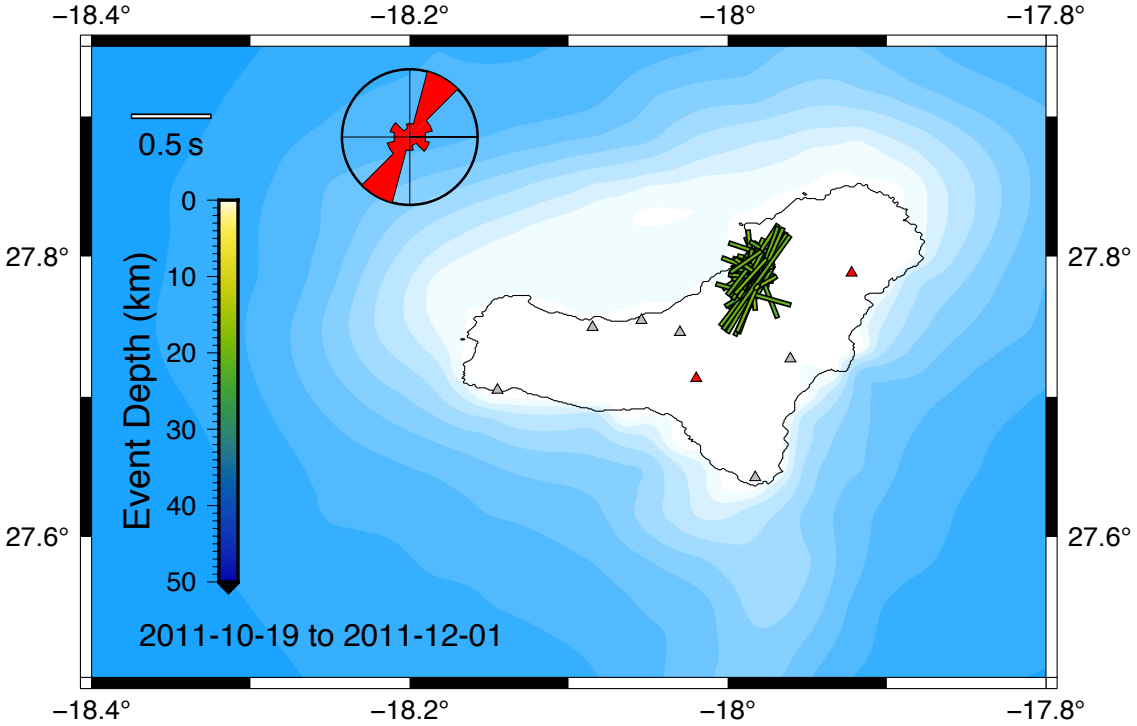


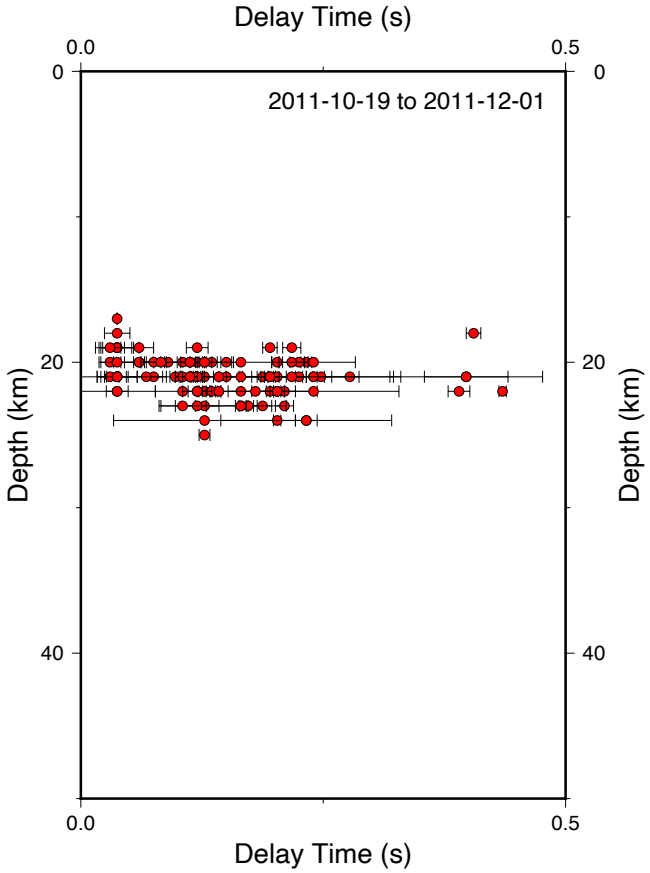



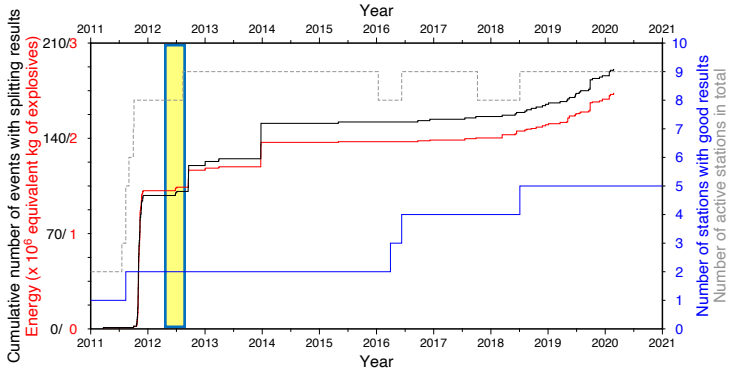

*(* Not all provided good data, also seen in teleseismic SKS splitting.)*



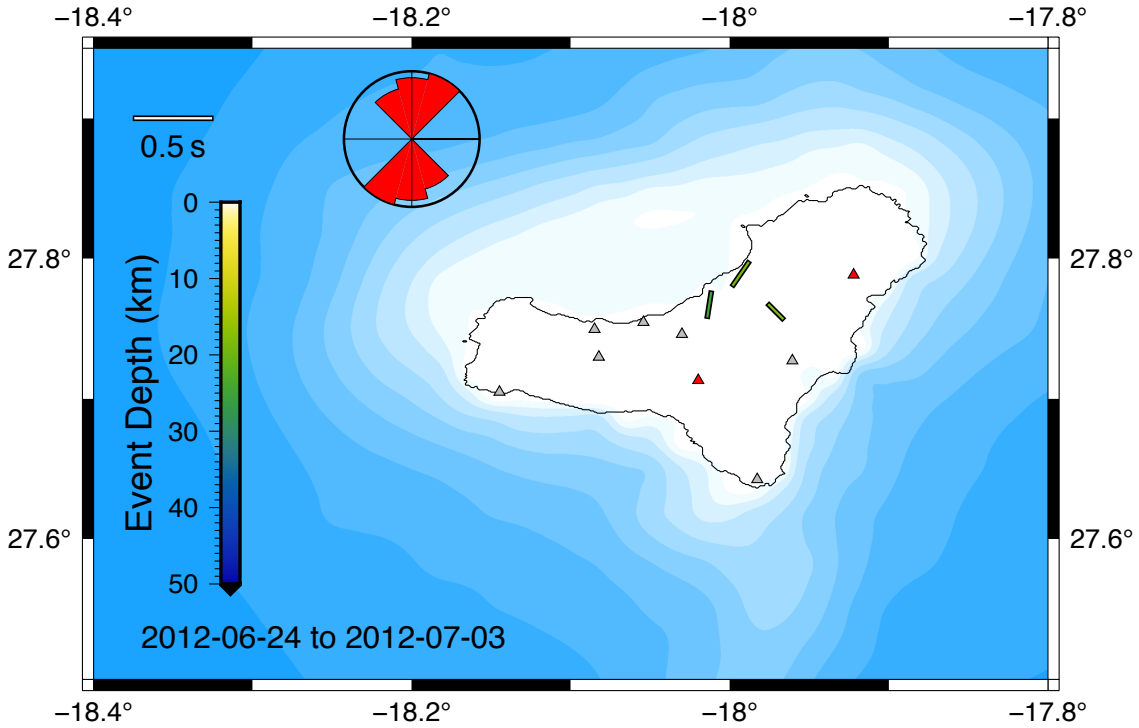

- Events in one cluster in NE part of the island.
- Depth constrained to 18 – 25 km.
- FPD almost uniform.

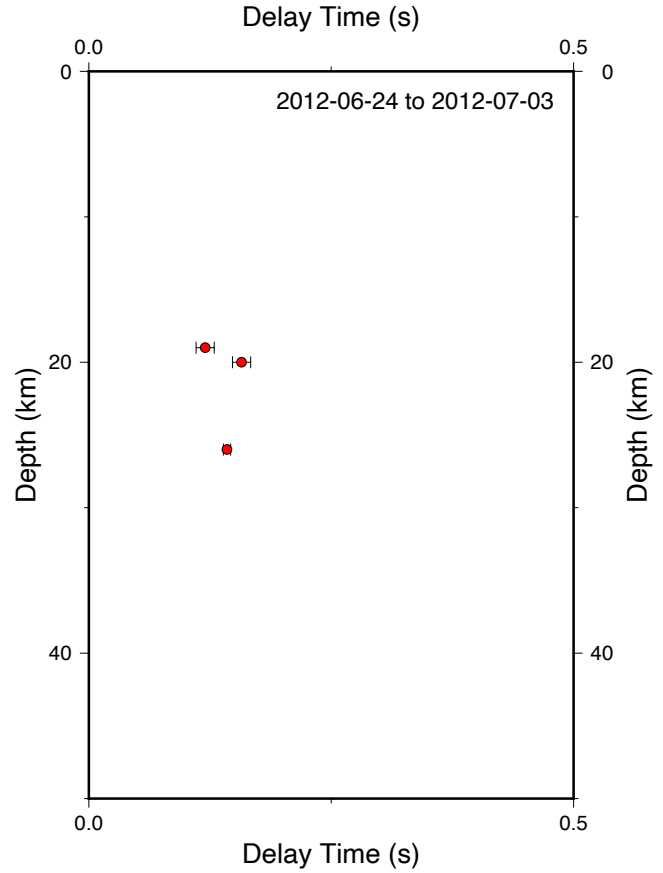


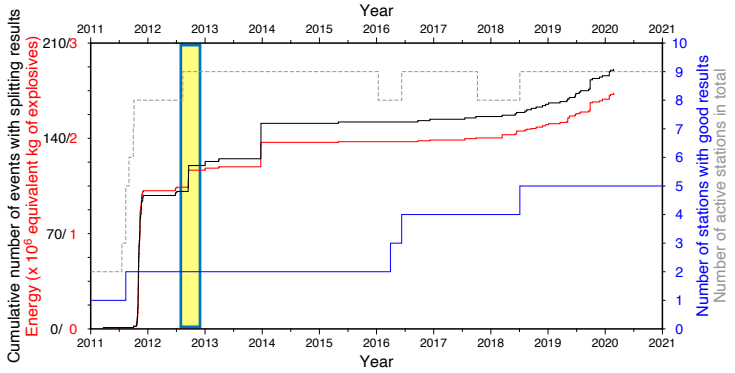





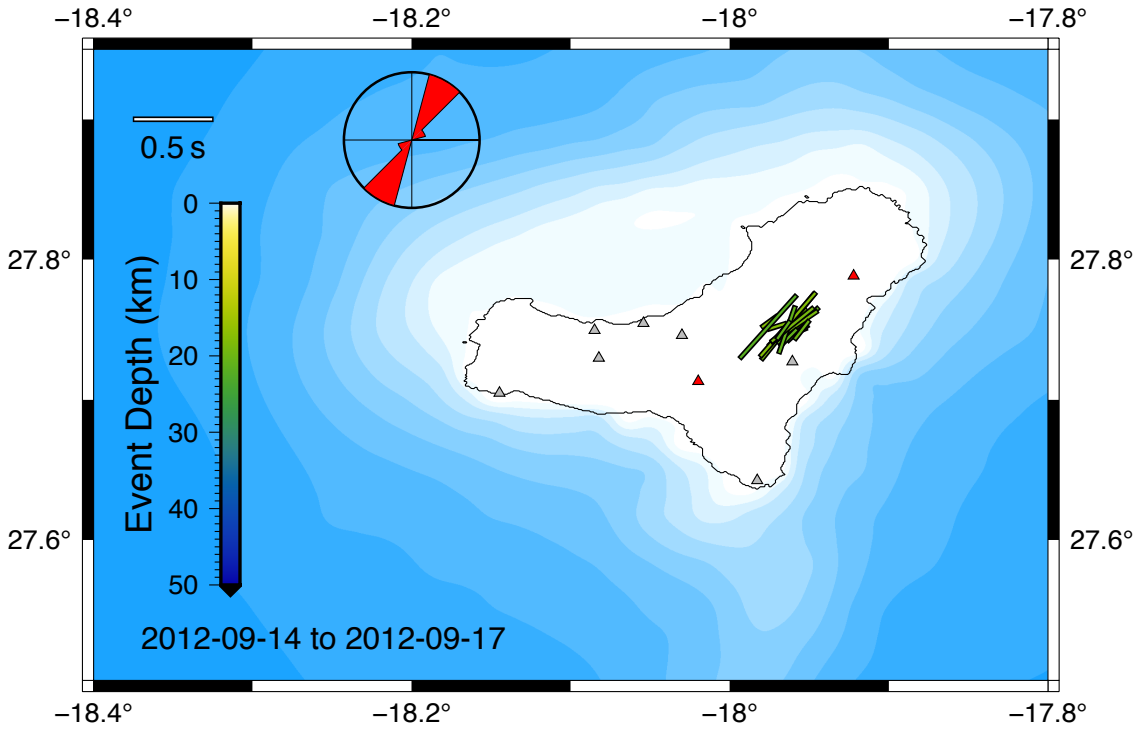

- Few more events in same area and depth, less well aligned.
- Station bias.

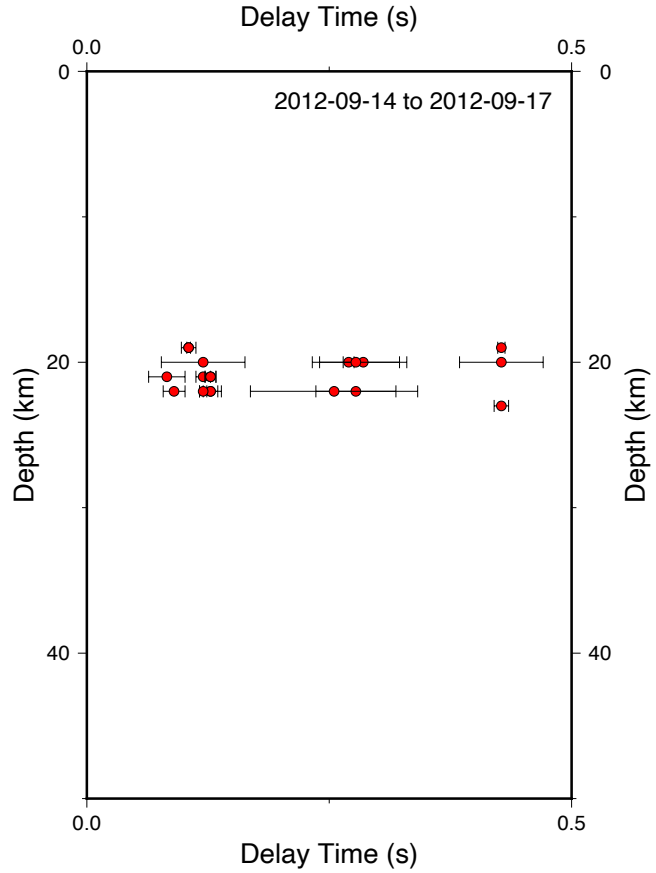


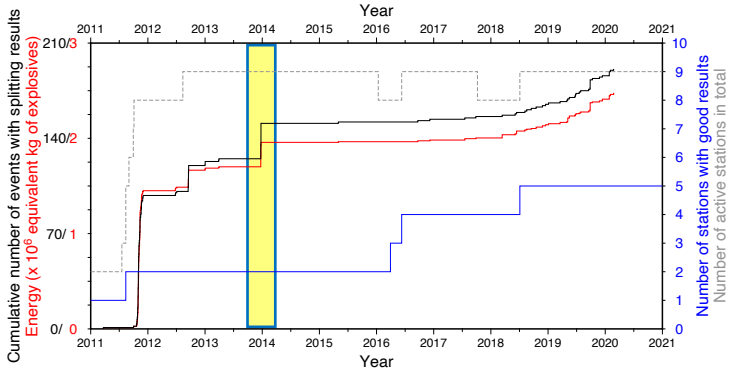





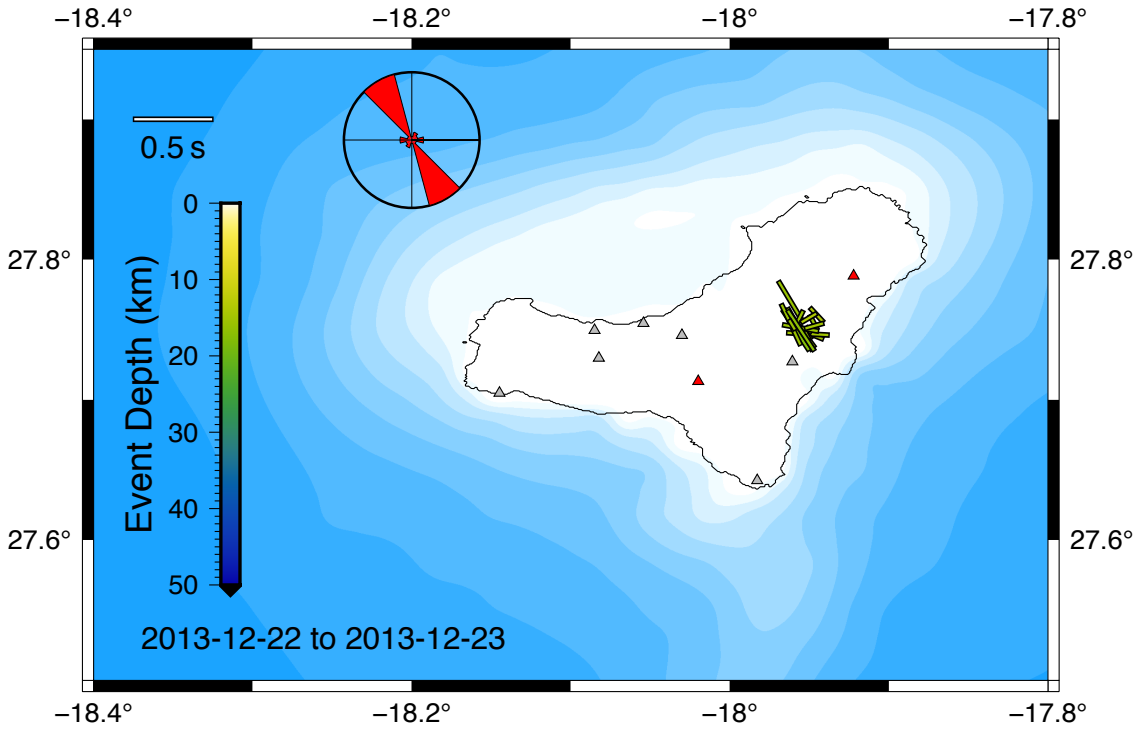

- Different cluster slightly further to SE, depth from 19 – 22 km.
- Strongly aligned FPD.

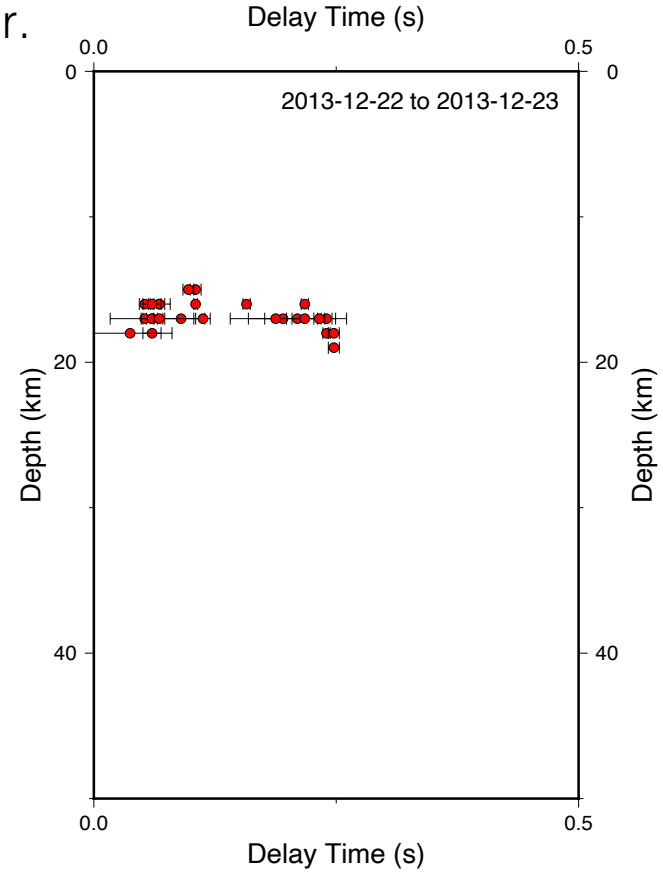


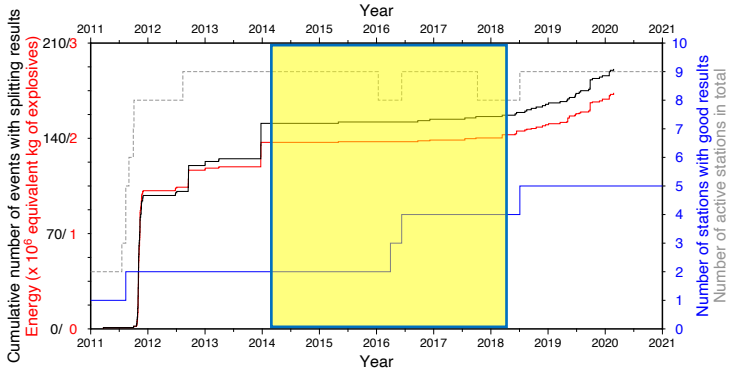





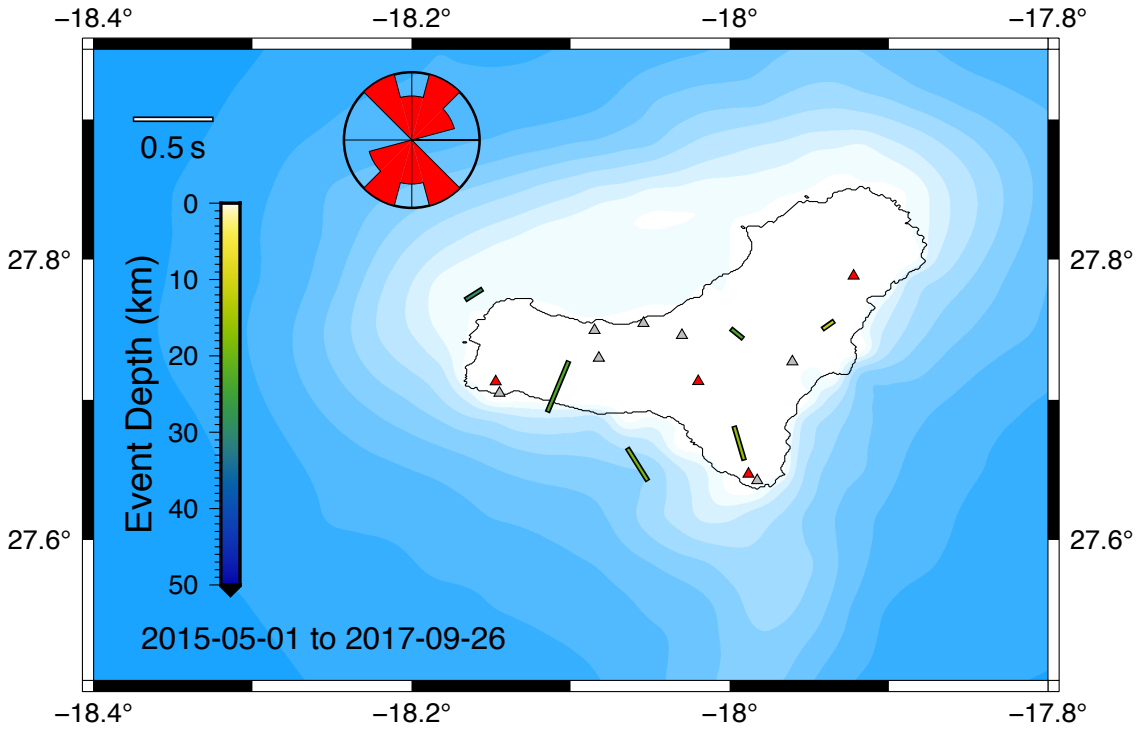

- Cluster in similar location as previous, but this time shallower at 15 – 19 km.
- FPD strongly uniform but almost perpendicularly to FPD previous cluster.

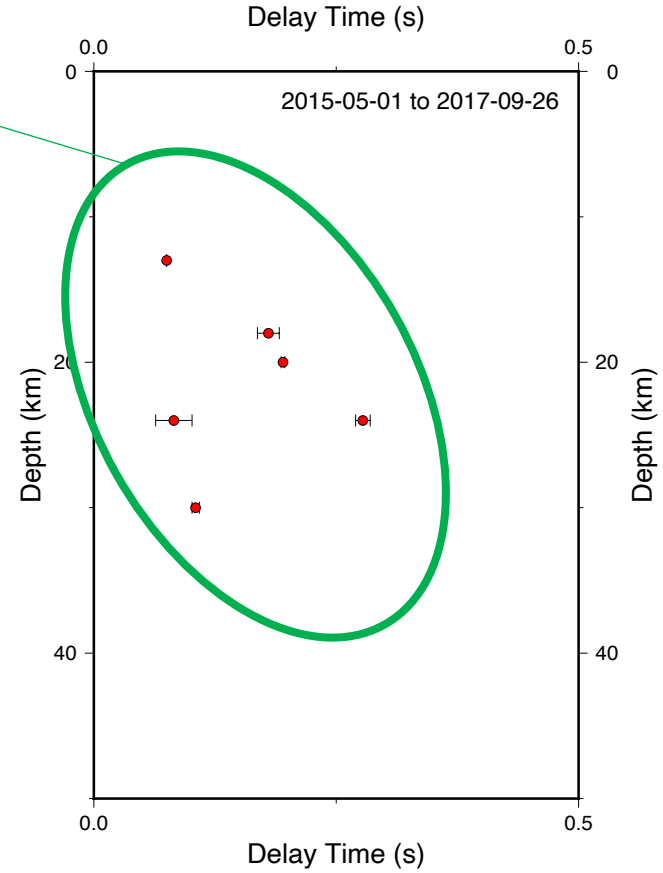


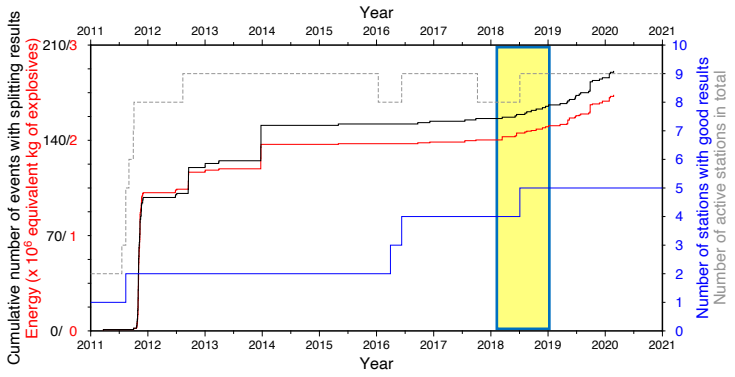





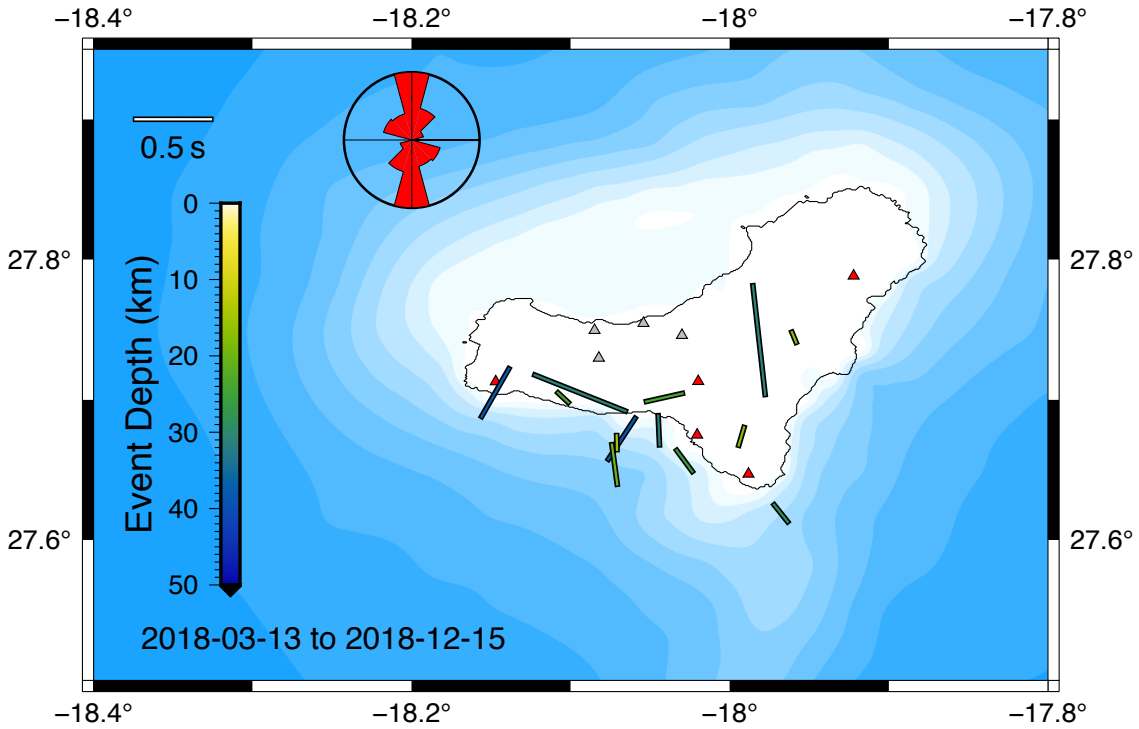

- No cluster, only occasional individual results in these four years.
- No dominant FPD either.
- Maybe relation between depth and delay time.
- Correlates with an end of GPS measured uplift.

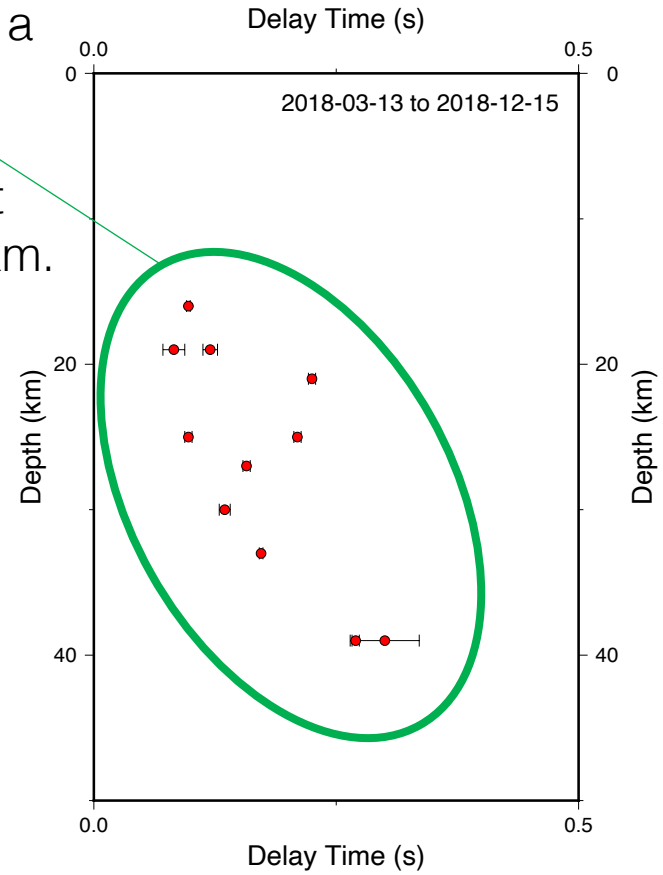


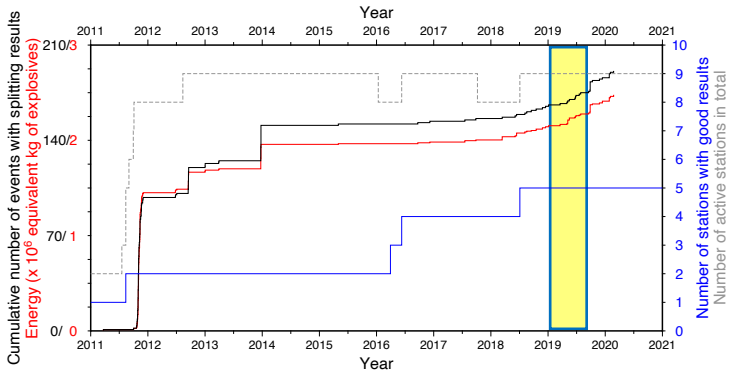





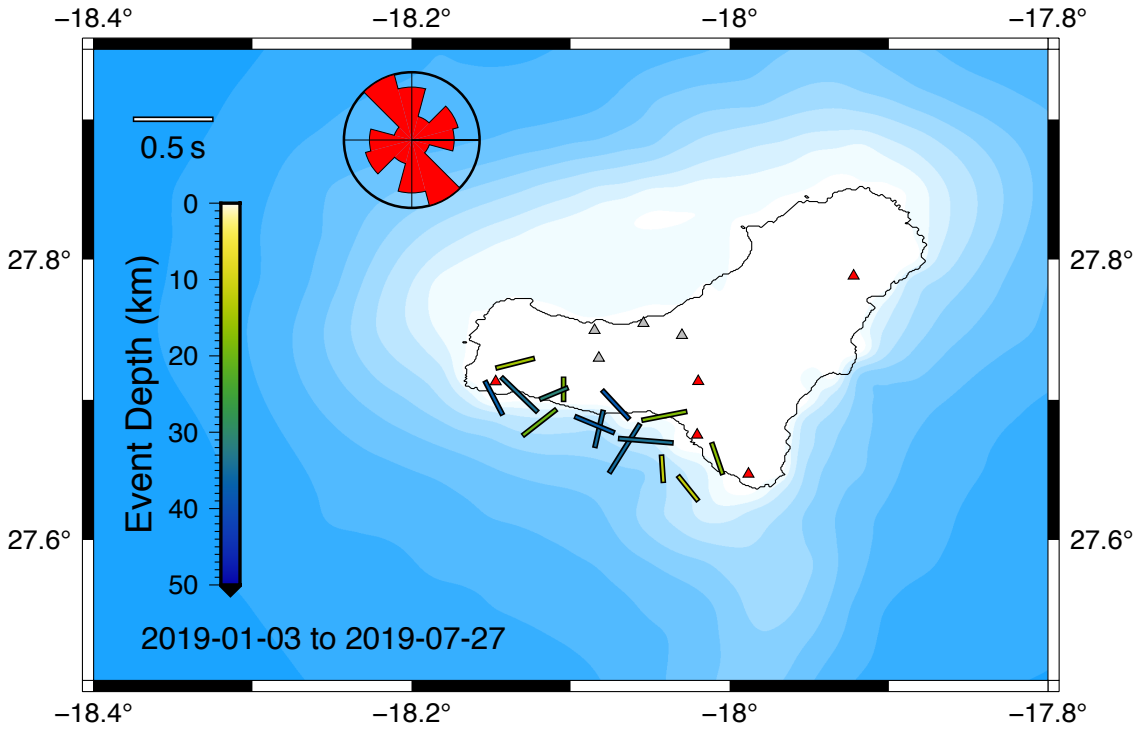

- Different spots, mostly N–S orientation but not as strongly aligned as previous clusters.
- Very likely due to the fact that it is over a broader time scale.
- But: interestingly, delay time strongly linked to depth here, so we can expect anisotropic layers throughout 20 – 40 km.

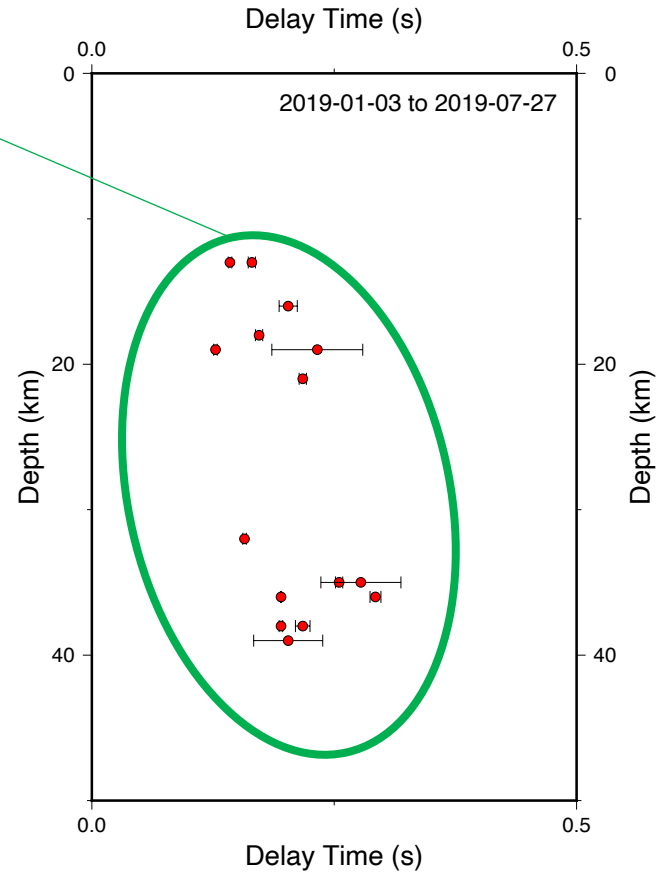


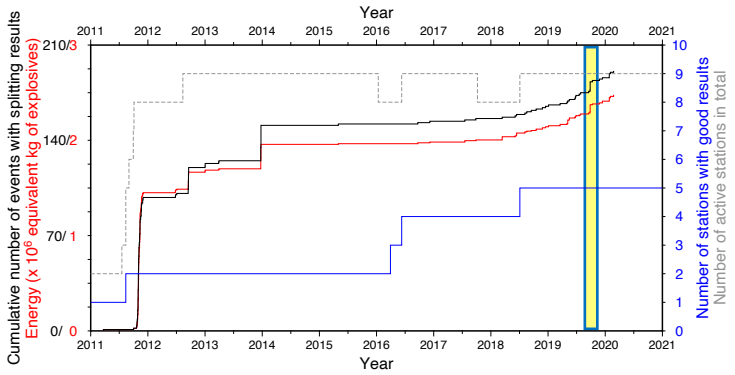





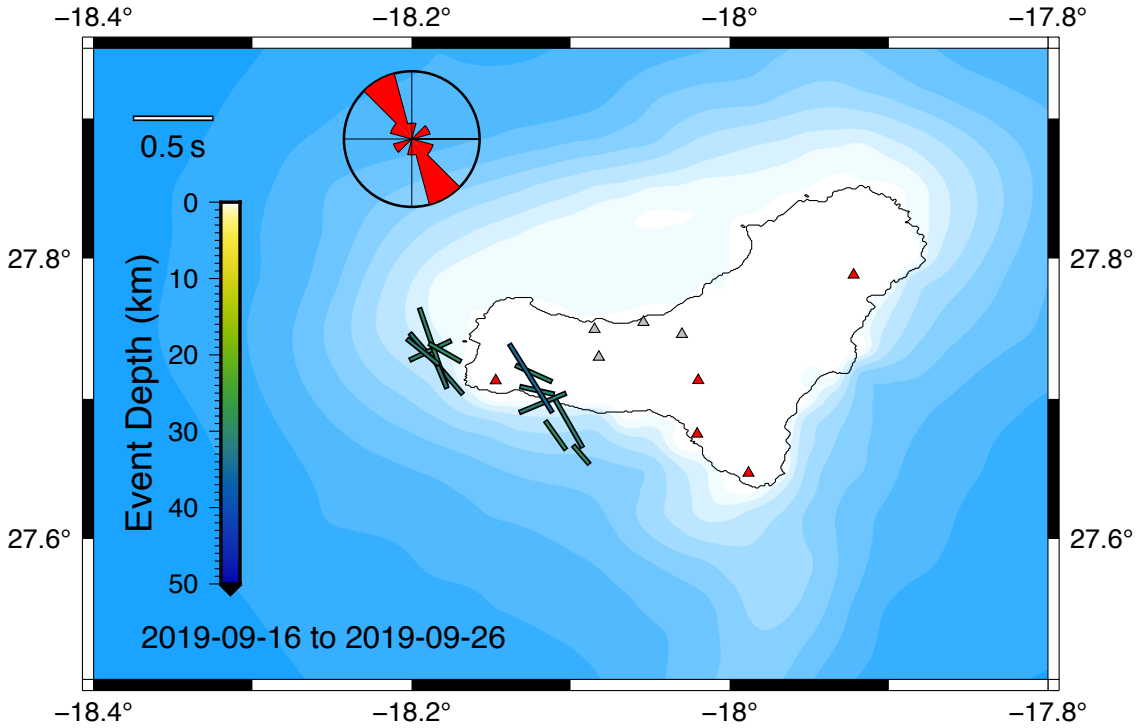

- Broad cluster along the southern coast (again, it is a longer time interval).
- Predominantly NW–SE FPD but not as strongly aligned as previous clusters.
- Again, delay time linked to depth here, so we can expect anisotropic layers throughout 15 – 40 km.
- BUT: increase not as strong, so anisotropy seems to be weaker.

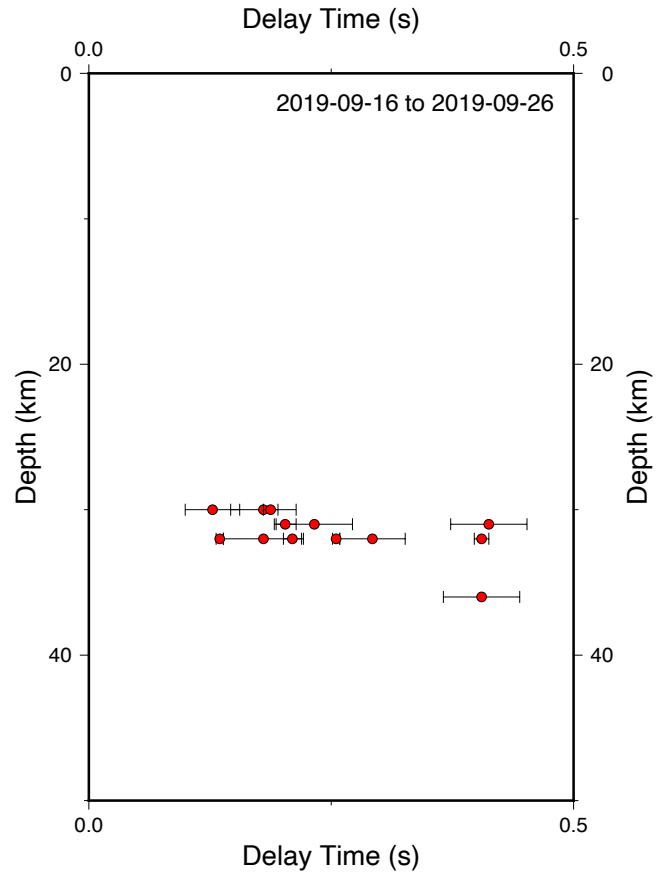


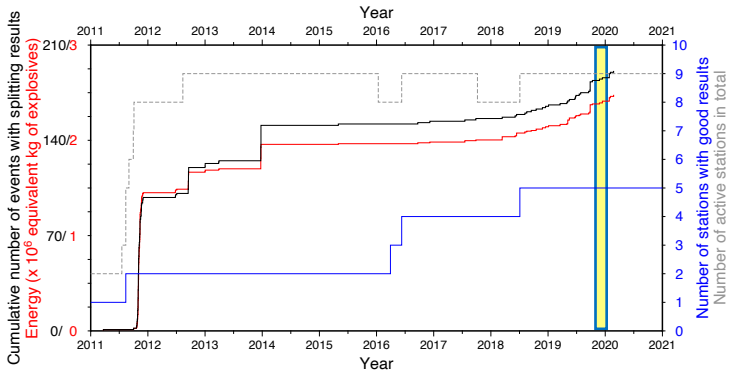





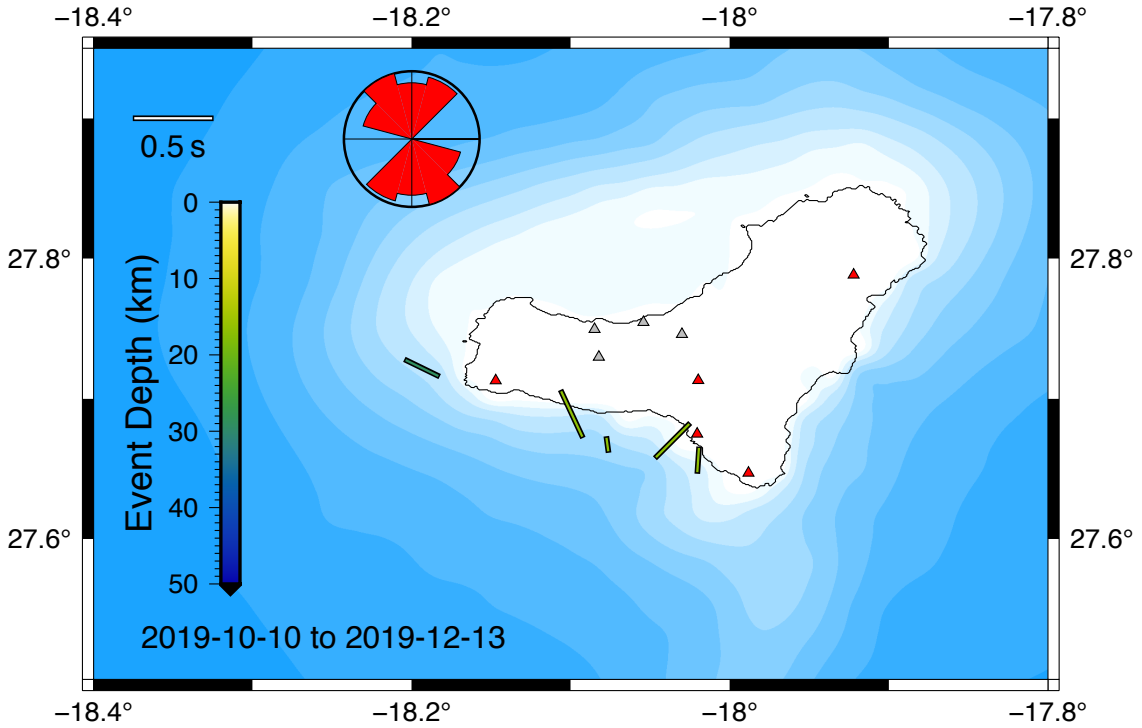

- Two parts of the cluster but all located quite deep compared to previous ones (30 – 36 km).
- Quite uniform FPD in NW–SE direction.

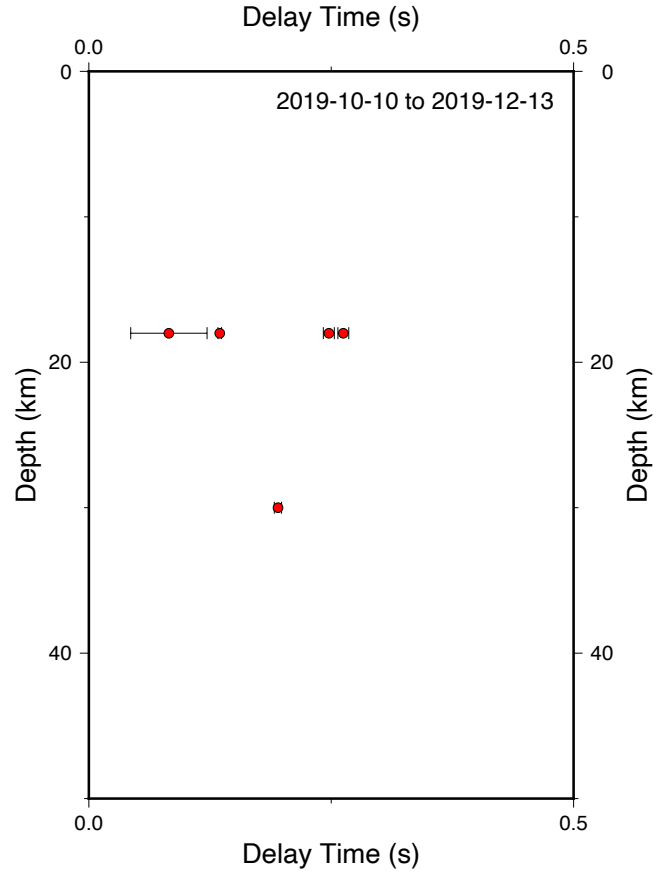


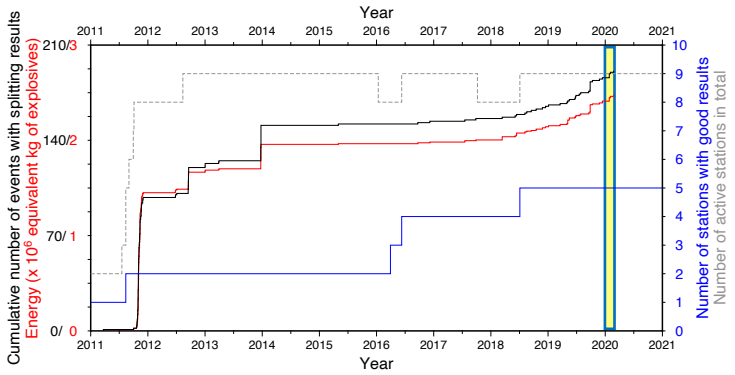





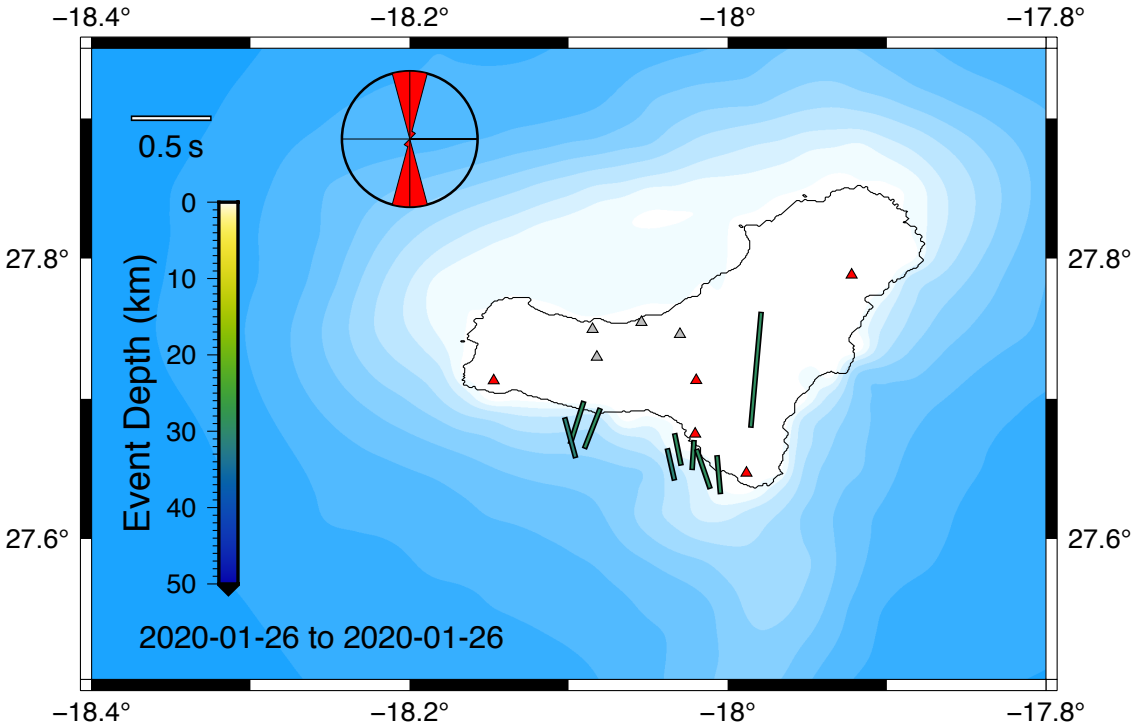

- Not a tight cluster (because it is a longer time interval again), therefore various locations, depths and FPD.
- All located along the southern coast.

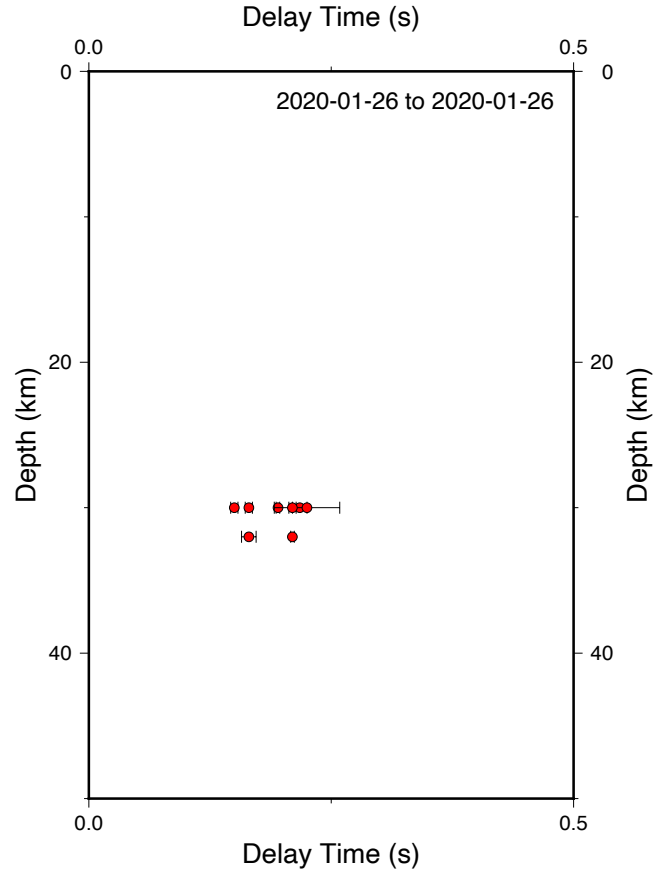


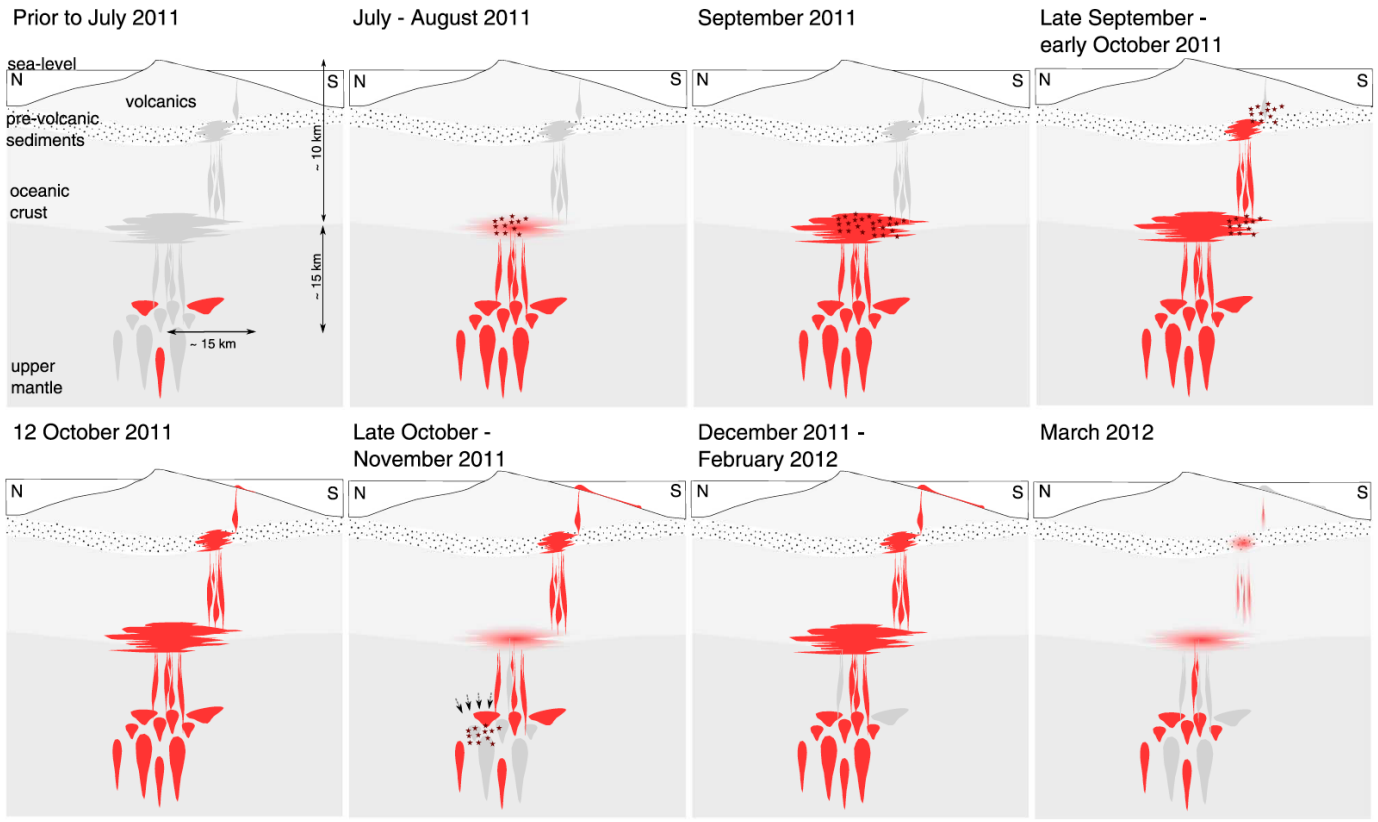



- Cluster spread laterally in comparison to previous clusters, but mostly off the southern coast.
- But, all events are very closely located in depth (30 – 33 km).
- Uniformly FPD in N–S direction.

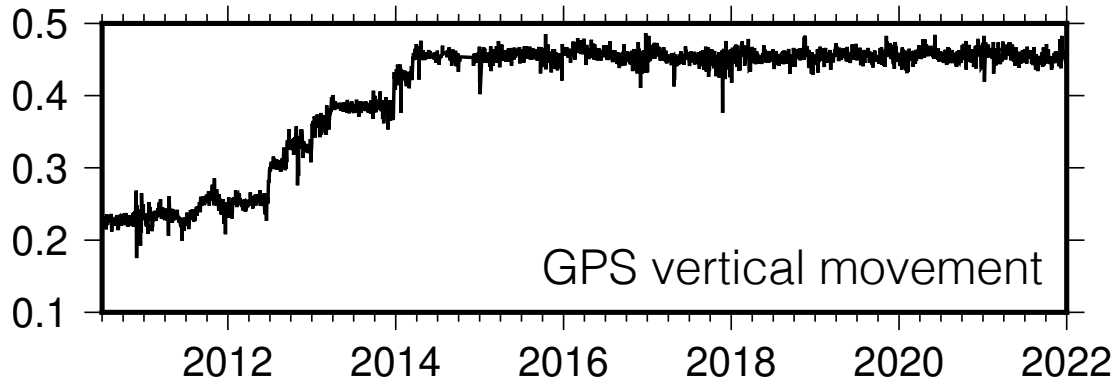


# Discussion

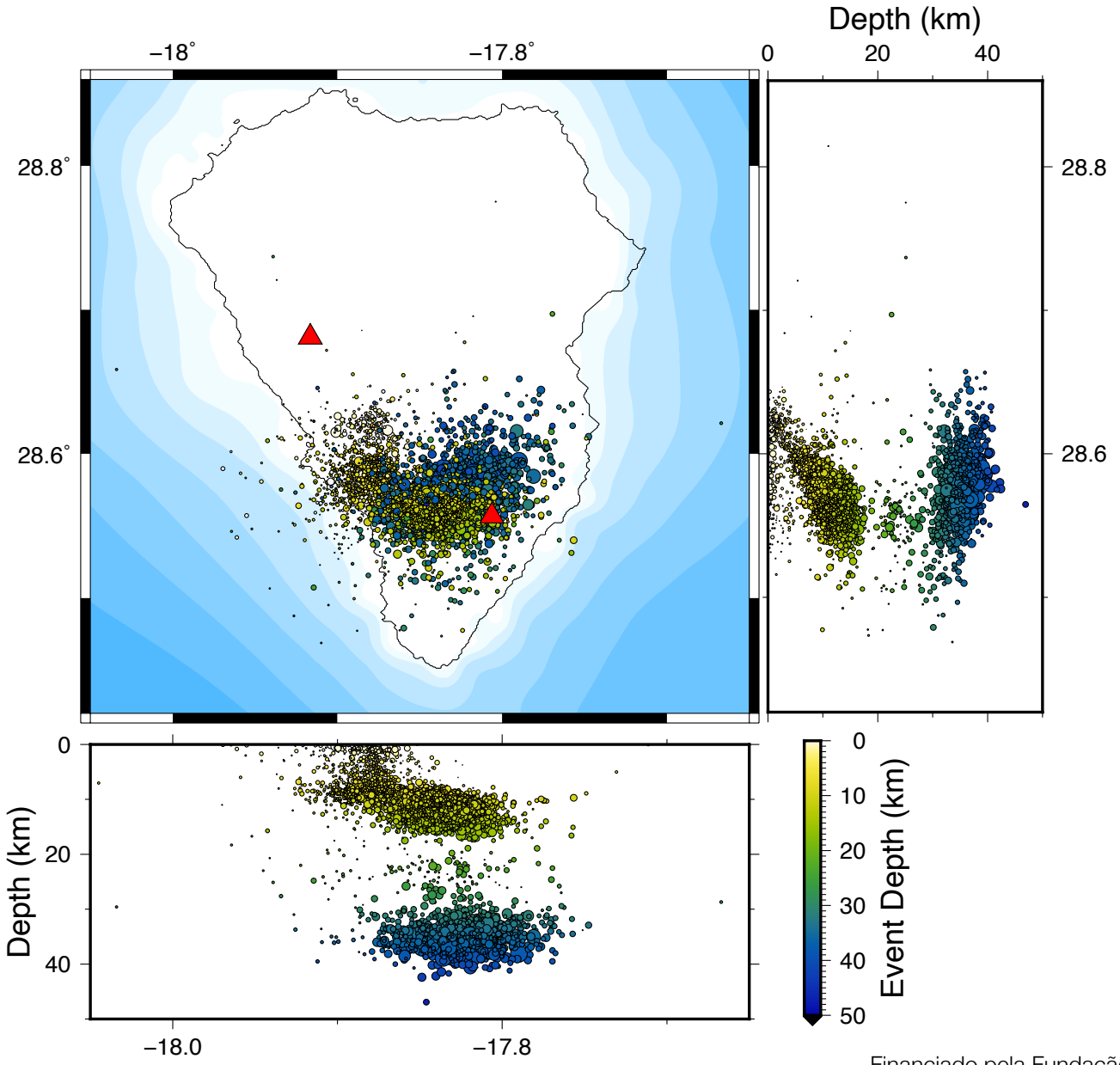



*(González et al., 2013, JGR)*




- Significant changes in depth, strength and FPD on short timescales.
- 2011 – 2014:
  - Uniform patterns of small-scale clusters with distinct FPD.
  - Stress changes due to magma influx. as it alters local stress in the crust, or a fabric induced by the lateral intrusion of sills at crustal level and/or beneath the island
- After 2014: stress changes not as big anymore, anisotropy found throughout the crust.
- After 2019: Concentration of results to the south of the island, more (deeper) FPD alignment again.
  → New deeper influx?
  → Does not show on the GPS data.

# Next steps: investigate La Palma 2021 eruption




- Like El Hierro located at western end of Canaries.
- Both islands are site of recent volcanic activity.
- BUT network of stations already operational before begin of eruption.
- Station location close to seismic activity (good incidence angle) → ~13500 evt-sta pairs, ~ half for each available station (cf. ~10000 evt-sta pairs in El Hierro).
- Longer period of splitting measurements before the eruption available.
- Observe patterns and compare to El Hierro.

Financiado pela Fundação para a Ciência e a Tecnologia, I.P./MCTES através de fundos nacionais (PIDDAC)" – UIDB/50019/2020