Use of single station observations: data quality control and the noise field in Europe.

Helle Pedersen, Yang Lu, Laurent Stehly, Anne Paul, Nicolas Leroy, Dimitri Zigone, Martin Vallée, Adam Ringler, David Wilson & the AlpArray Working Group

Use of single station observations:
Part I: Quality control with component ratios : 20 years of GEOSCOPE data

Helle Pedersen, Nicolas Leroy, Dimitri Zigone, Martin Vallée,
Adam Ringler & David Wilson

Why we do this…

- Scientific users need to be able to evaluate data quality in spite of vast of data volumes – **automatic tools** for data rejection are needed
- Network operators need to be able to identify and correct instrument and metadata problems – **simple and/or automatic tools** are very valuable

But… it is not an easy task as there are many different instrument problems to handle

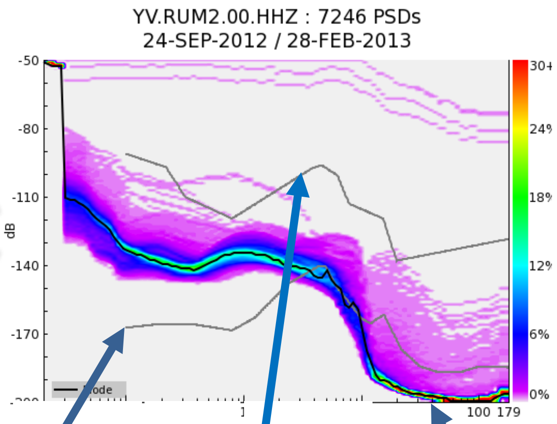
Here we focus on inconsistencies between different components of motion

Pedersen et al., SRL, in revision, codes available

Standard visualization: Power spectral density

Example RHUM-RUM temporary experiment, stat RUM2

Example of permanent permanent station Echéry (ECH), where reinstallation took place in 2015.



30dB

0.1 s 1 s 10 s

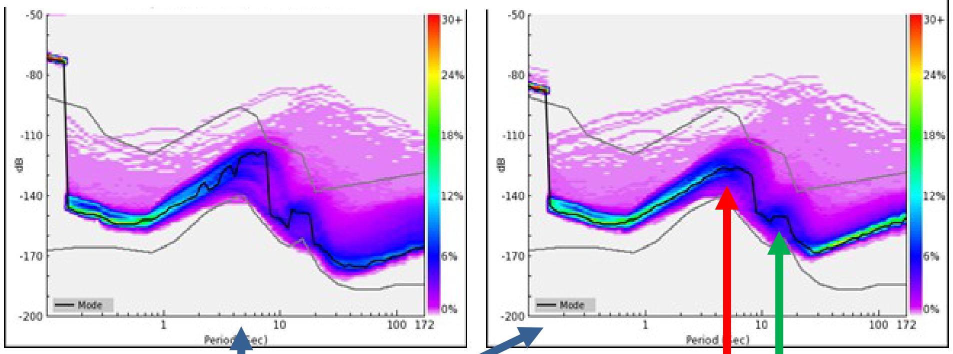
Low Noise Model

High Noise Model

Problem – noise below the low noise model

2014

2016



No obvious problems in either plot

2nd microseismic peak 3 s – 10 s

1st microseismic peak 10 s – 20 s

Method: use H/V ratios for fine characterization of incoherency between components

Method:
- Download daily files
- Dmean, detrend, prefilter, decimate, deconvolve with instrument respons
- Rotate to ZNE if necessary
- Cut into 5 min windows
- Calculate the average Energy of each component in each window, for 8 different frequency bands
- Calculate the ratio of Energy between the three components (E/Z,N/Z,E/N)
- Calculate the three **median** energy ratios over the 288 time windows of the day (reduce influence from earthquakes)

Data used:
- Network G: Institut de Physique du Globe de Paris and Ecole et Observatoire des Sciences de la Terre de Strasbourg (EOST), 1982.
- Network IU: Albuquerque Seismological Laboratory (ASL)/USGS, 1988.

How to cite seismic data

Citing is based on network code.
If the network has a DOI: Refer to the data as you would to a normal scientific manuscript, and include the reference in the normal list of references.

Network, citation and DOI information can be found at http://www.fdsn.org/networks/

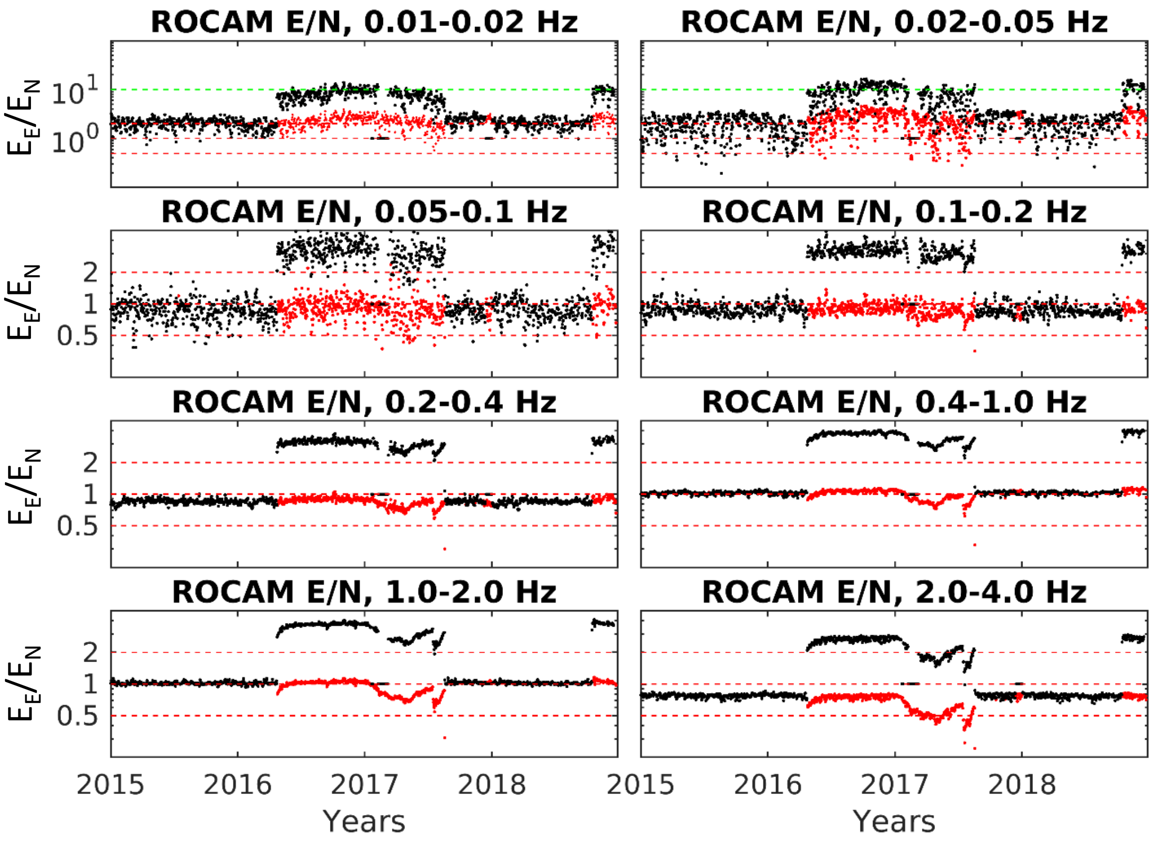
If many networks are used: most journals accept a ‘Data Section’

Example:
‘We used data from GEOSCOPE (Institut De Physique Du Globe De Paris (IPGP) and Ecole Et Observatoire Des Sciences De La Terre De Strasbourg (EOST), 1982) and GEOFON (Geofon Data Centre, 1993).’

References:
GEOFON Data Centre, 1993. GEOFON Seismic Network. Deutsches GeoForschungsZentrum GFZ. https://doi.org/10.14470/tr560404

Institut De Physique Du Globe De Paris (IPGP), & Ecole Et Observatoire Des Sciences De La Terre De Strasbourg (EOST), 1982. GEOSCOPE, French Global Network of broad band seismic stations. Institut de Physique du Globe de Paris (IPGP). https://doi.org/10.18715/geoscope.g

Example results: amplitude problem at station ROCAM



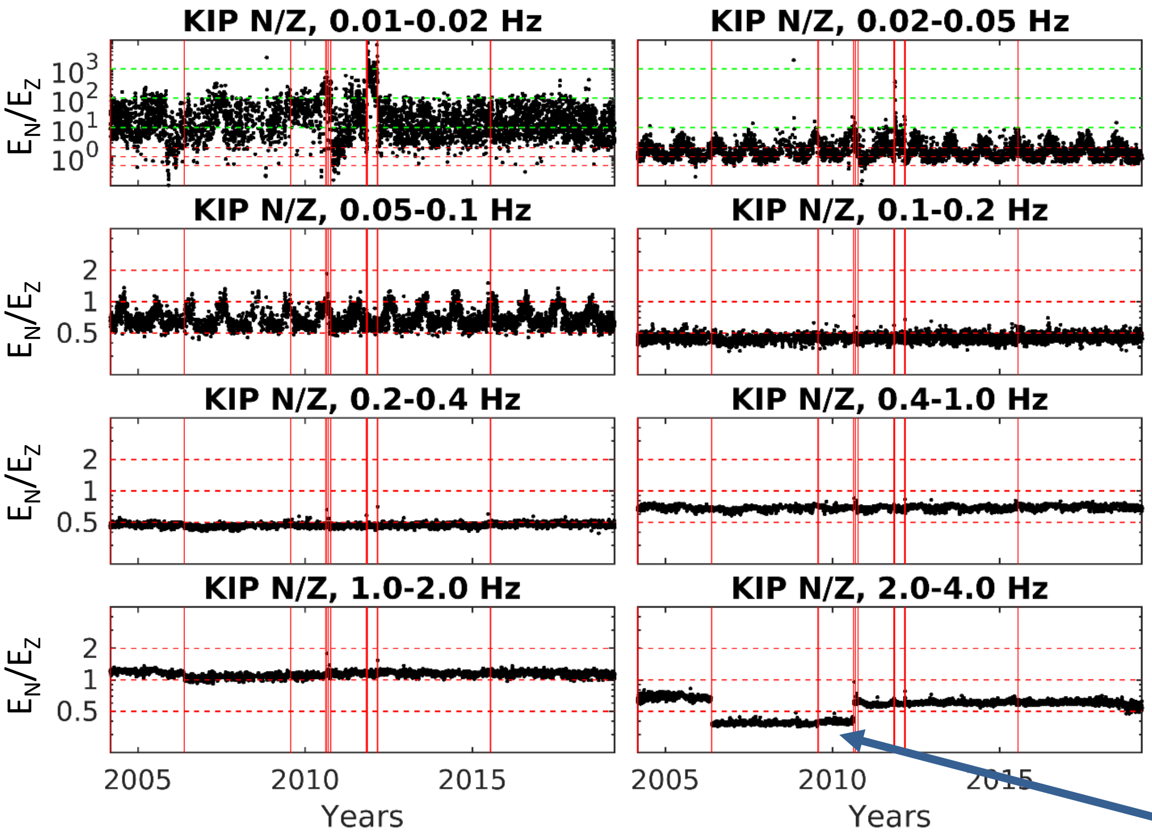
Gain problem between Q1 2016 and mid-2017

Corrected using this method

Black points: uncorrected

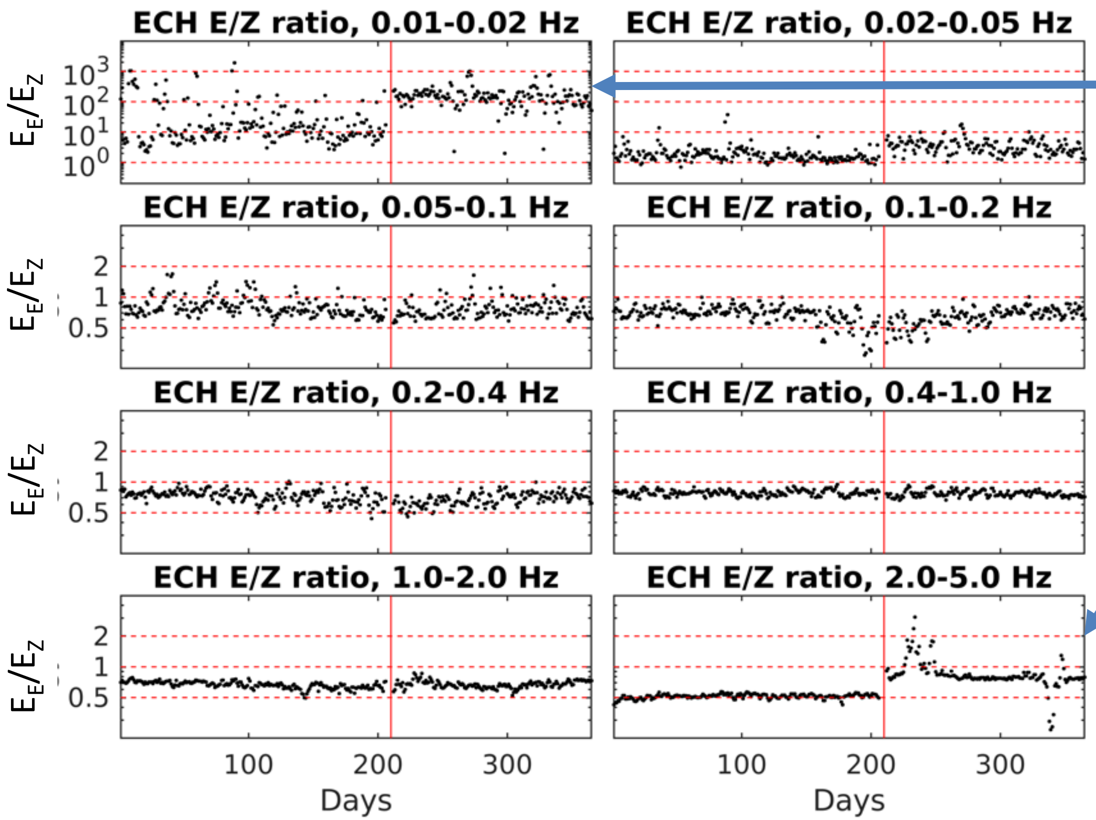
Red points: corrected

Example results: instrument response problem at station KIP (code share IU USGS)



Temporary problem with instrument response - probably erroneous at frequencies > 1Hz

Example results: 2 independent problems at station ECH



Low frequencies:
Abrupt change
Likely cause:
deterioriation of E component at reinstallation

High frequencies:
Abrupt change
Likely cause: error in instrument response for frequencies > 1Hz

Conclusions Part I

Don’t expect data to be perfect: visually check as much data as relevant or possible, and automatically apply relevant quality criteria - across all frequency bands that you use

Cite data correctly using DOIs when available

Use of single station observations:
Part II: Microseismic noise across Europe

Helle Pedersen, Yang Lu, Laurent Stehly, Anne Paul & the AlpArray Working Group

Why we do this…

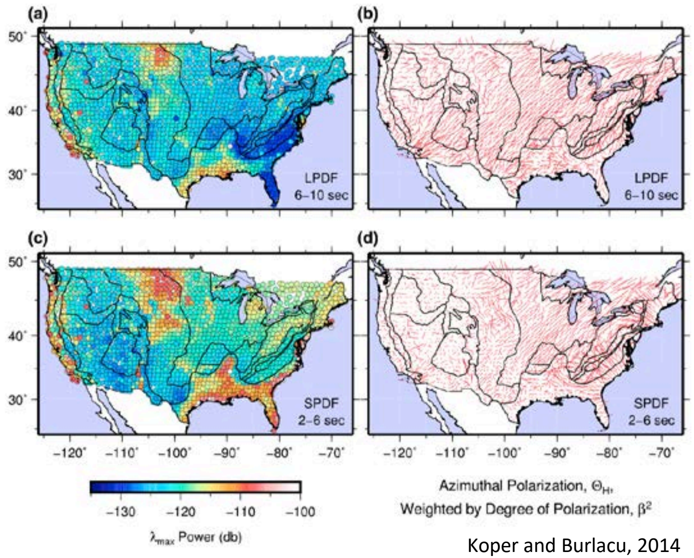
- Extracting the Green's function from seismic noise is based on an assumption of diffuse noise or well distributed noise sources – but this is not true
- Additional difficulty: the noise field varies in space and time
- The more we know about the noise field, the more intelligently we can use it for imaging in 2D, 3D and 4D

Here we focus on **spatial and temporal variations of the noise in Europe** – extracting some characteristics that we believe are informative

Using single stations: hugely underdetermined problem

Goal: characterize the microseismic noise across Europe, and its seasonal variations

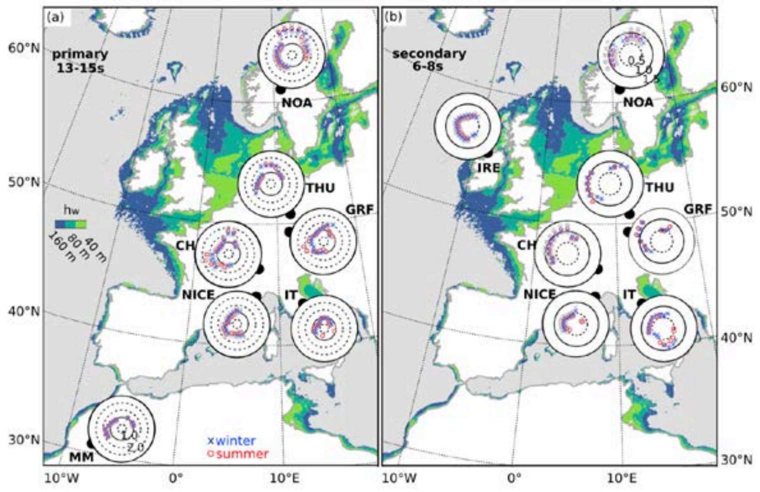
Single station observations in USA



Koper and Burlacu, 2014

1) Noise energy influenced by both structure and noise sources; Coherent azimuth patterns
2) Increased spatial complexity for higher frequencies

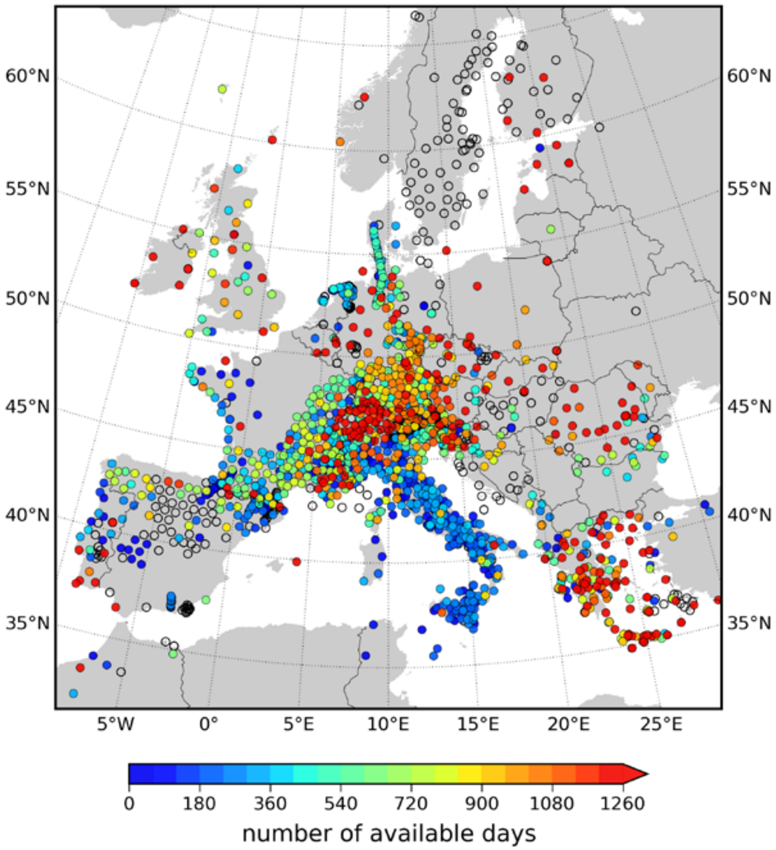
Array observations in Europe



Juretzek and Hadziioannou, 2016

1) Love waves dominate on average, especially in the primary microseismic peak
2) NW dominating source areas with spatial variability

Data : long time series and high station density in the wider Alpine area



2476 seismic stations (permanent and temporary) operated in the 7 years of 2011, 2012, 2013, 2014, 2016,2017,2018;

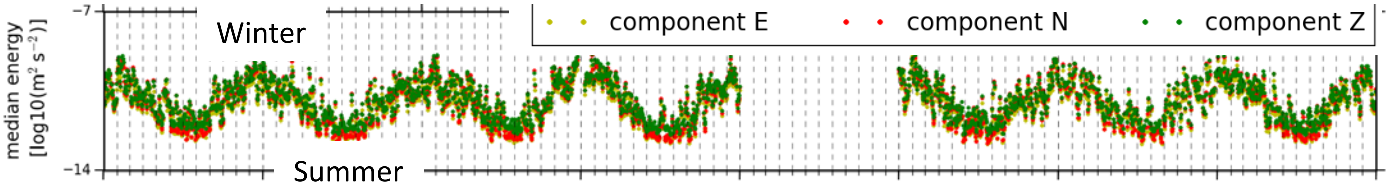
1648 seismic stations have available data;

222 seismic stations have >=3.5 years (1260 days) of data.

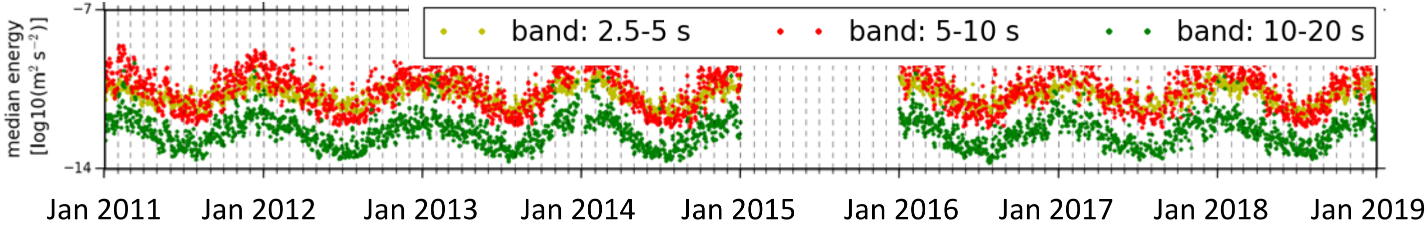
Standard preprocessing and downsampling to 1 Hz

Energy: example from the Alps

Daily energy **for three components** in period band **5-10 s**



Total daily energy **for three period bands**

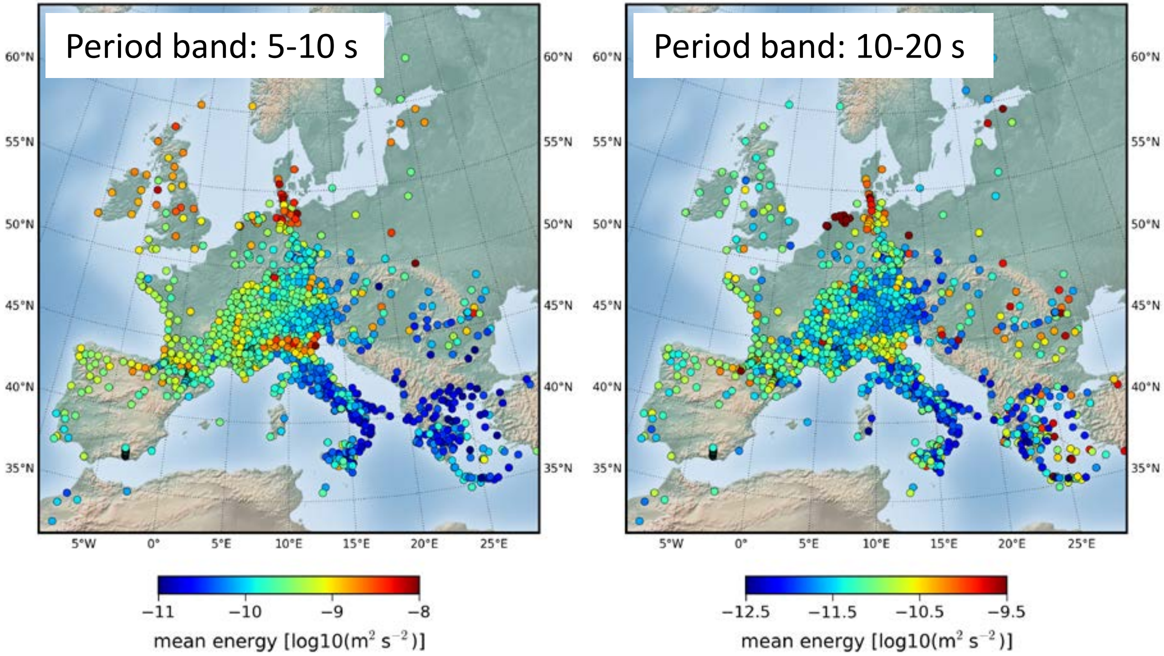


Daily measurements are calculated in each period band by the **median** value of measurements on up to 144 non overlapping windows (10 min windows)

In each 10 min window, energy for *i*th component is calculated as: $E_i = \frac{1}{N}\sum_{j=1}^{N}(u_{i,j})^2$ *u*: velocity; *N*: number of samples in the window .

Total energy for each period band is calculated as the sum of energy for three components: $E = \sum_{i=1}^{3} E_i$

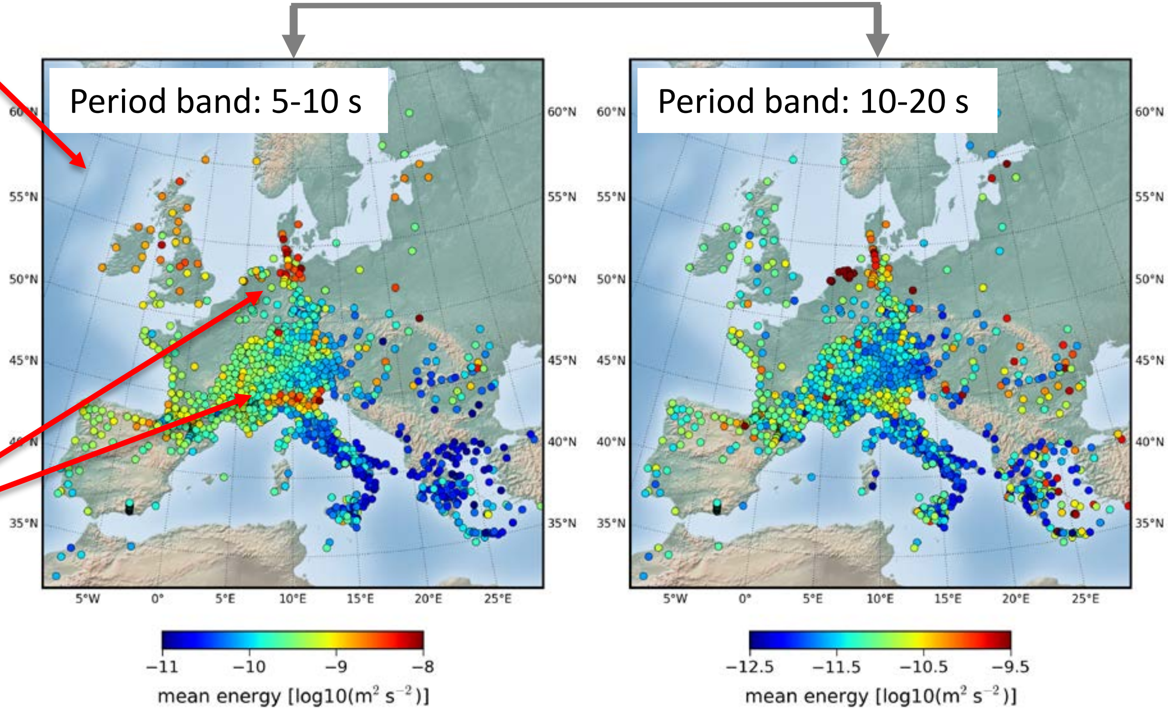
Spatial distribution of energy (mean over daily measurements 2011-2018)



Spatial distribution of energy (mean over daily measurements 2011-2018)

Energy gradient from source direction

Variations are dominated by distance to source; some effect of structure

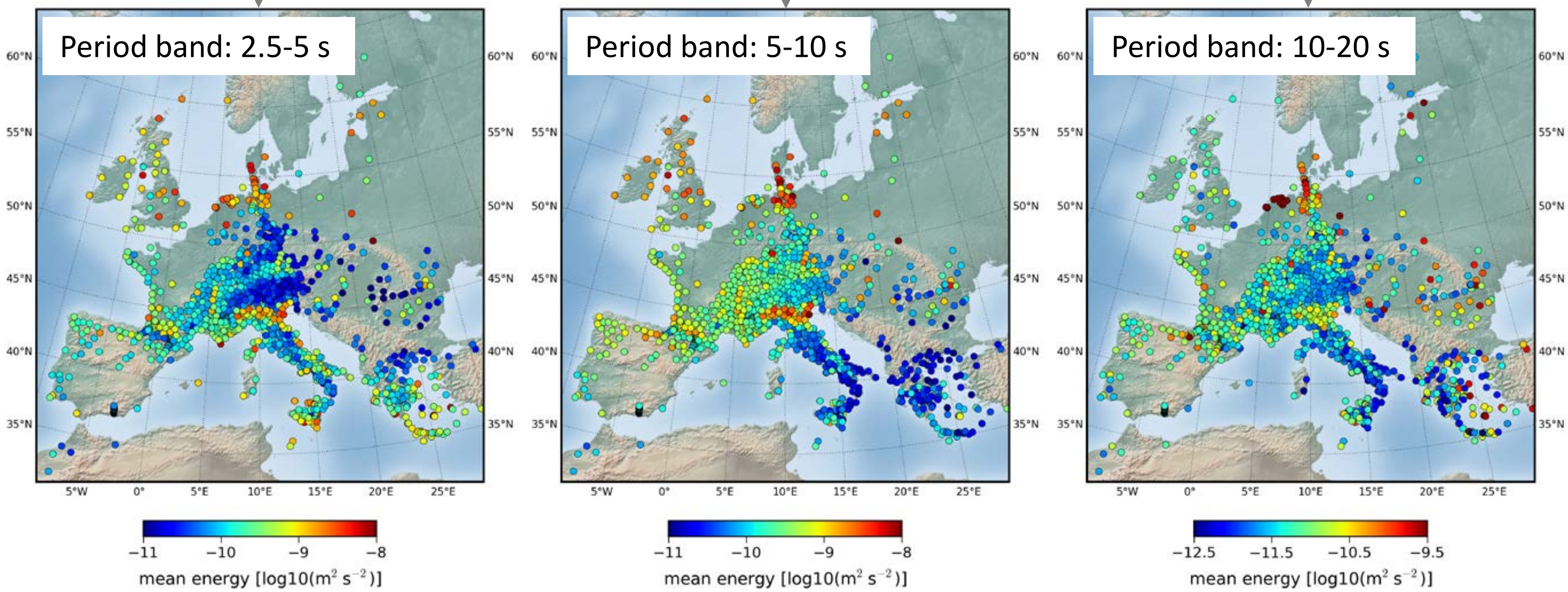


Effect of deep basins

Spatial distribution of energy (mean over daily measurements 2011-2018)

Variations are strongly influenced by structure

Variations are dominated by distance to source; some effect of structure



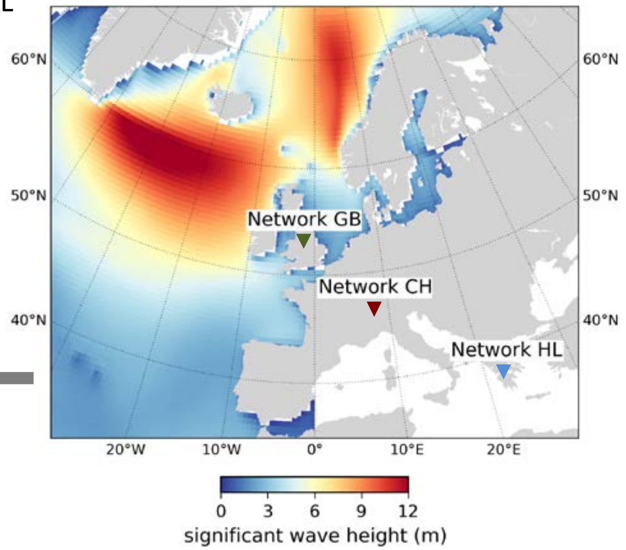
Temporal variation of energy for 3 networks (2018) at 5 s -10 s period

Peaks are strongly related to ocean activity in the North Atlantic

Date: 2018-01-15 (winter)

Network GB Network CH Network HL

Mean wave height in the North Atlantic



GB: Great Britain Seismograph Network.

CH: Swiss Seismological Service (SED) at ETH Zurich (1983).

HL: National Observatory of Athens Seismic Network (1997).

Wave height data are from *NOAA WAVEWATCH III*.

Temporal variation of energy for 3 networks (2018)

Peaks are strongly related to ocean activity in the North Atlantic

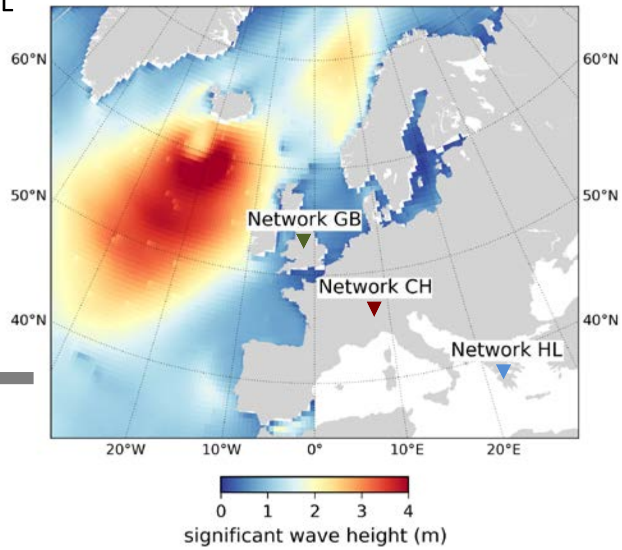
Date: 2018-07-15 (summer)

Network GB

Network CH

Network HL

Mean wave height in the North Atlantic



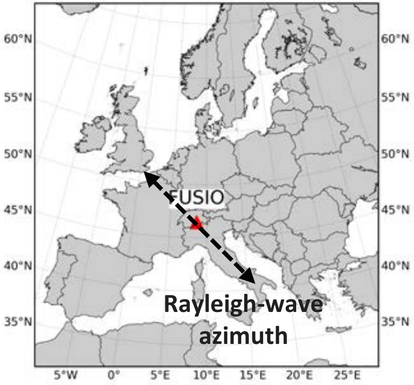
GB: Great Britain Seismograph Network.

CH: Swiss Seismological Service (SED) at ETH Zurich (1983).

HL: . National Observatory of Athens, Institute of Geodynamics, Athens (1997)

Wave height data are from *NOAA WAVEWATCH III*.

Rayleigh and Love waves: example from the Alps

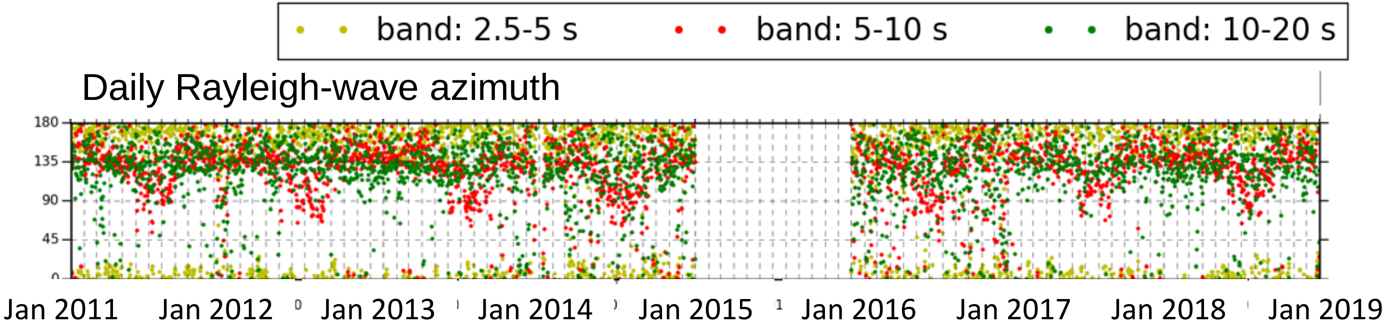


Rayleigh waves incident direction: Identifying the direction for which there is a 90° phase shift with the vertical component

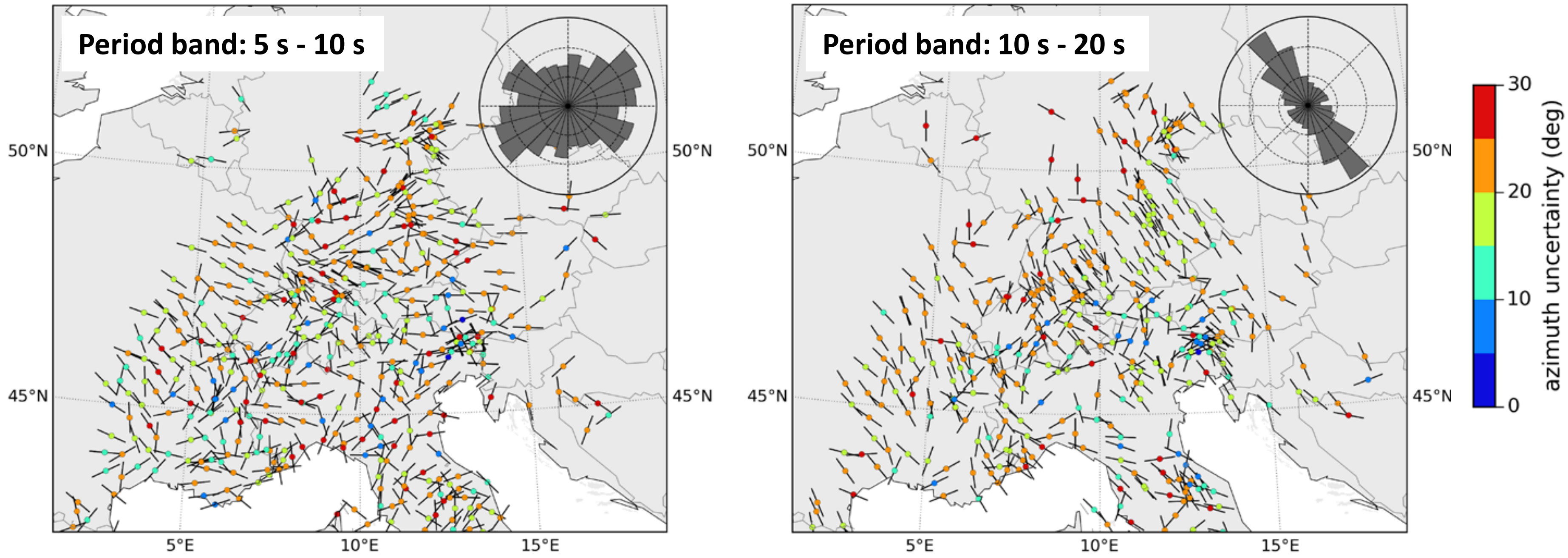
Rayleigh-wave azimuth is defined as:

$$\underset{\theta}{argmin}[|\varphi_{VR}(\theta) - 90°|]$$

where φ_{VR} is the vertical-radial phase difference in degree.

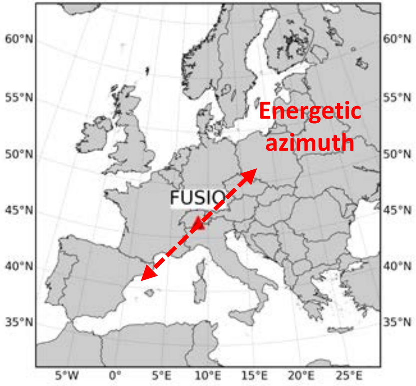


Azimuth of Rayleigh waves (mean over daily measurements 2011-2018)

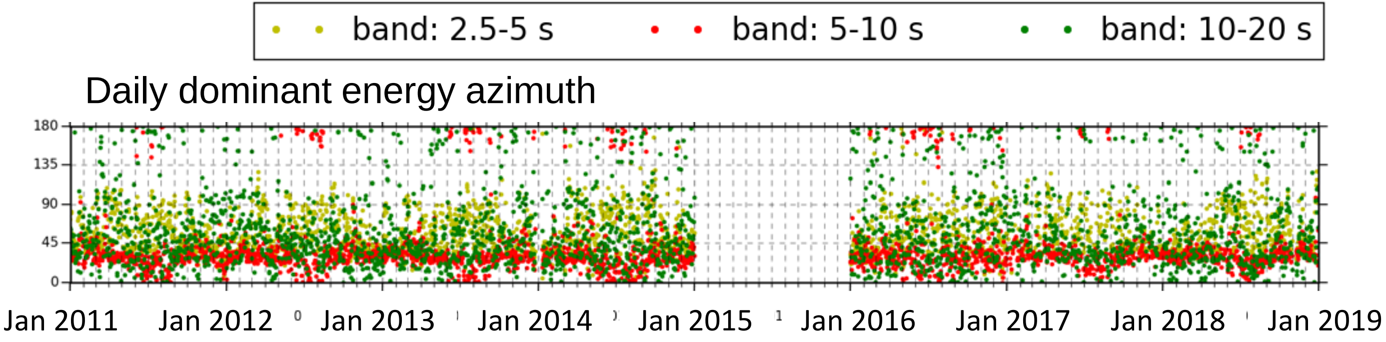


1) Clear source direction (NW) in first microseismic peak (10 s – 20 s)
2) Complex noise wavefield in secondary microseismic band (5 s - 10 s)
3) Azimuth uncertainties (one standard deviation) are mostly between 15°-20° → strong temporal variation.

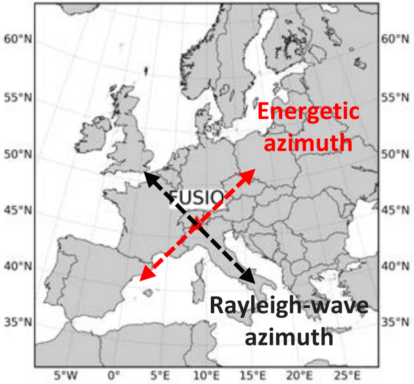
Rayleigh and Love waves: example from the Alps

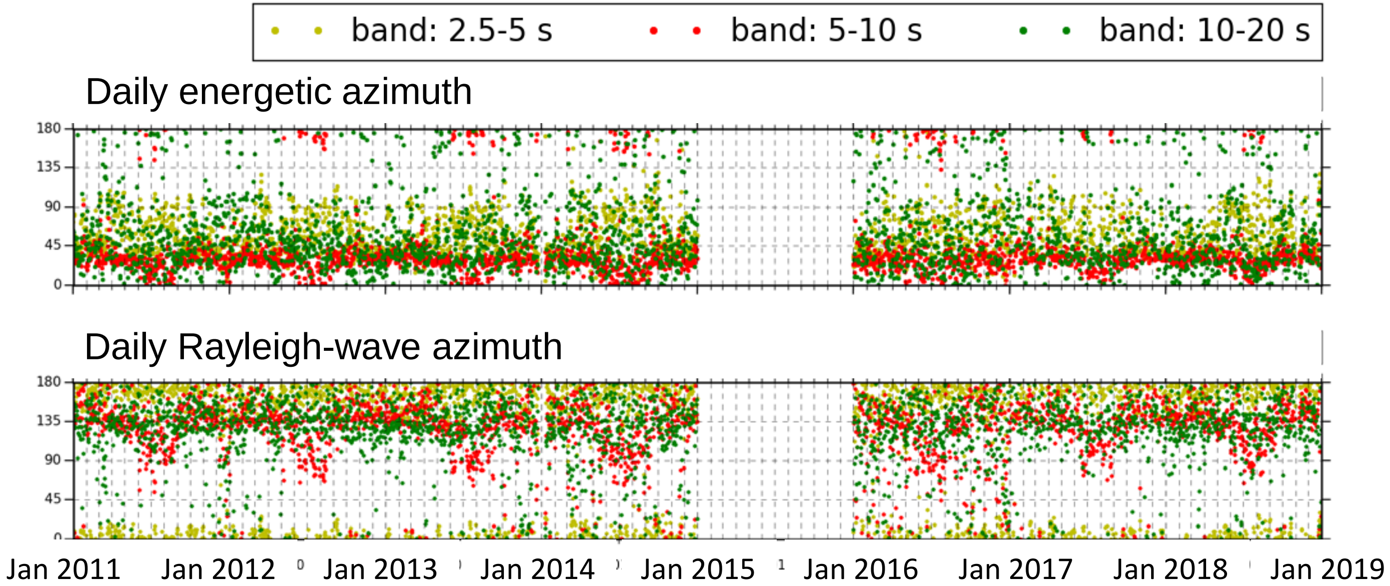


Energetic azimuth is calculated based on the eigenvalue decomposition of the covariance matrix of three components. Eigenvalues $(\lambda_1, \lambda_2, \lambda_3)$ and eigenvectors (v_1, v_2, v_3) are solutions of $(\mathrm{cov}[u_E, u_N, u_Z] - \lambda^2 I)v = 0$ and sorted so $\lambda_1 > \lambda_2 > \lambda_3$. The energetic azimuth (most important horizontal orientation of particle motion) is given by $\tan^{-1}(v_{21}/v_{11})$ (Flinn, 1965).

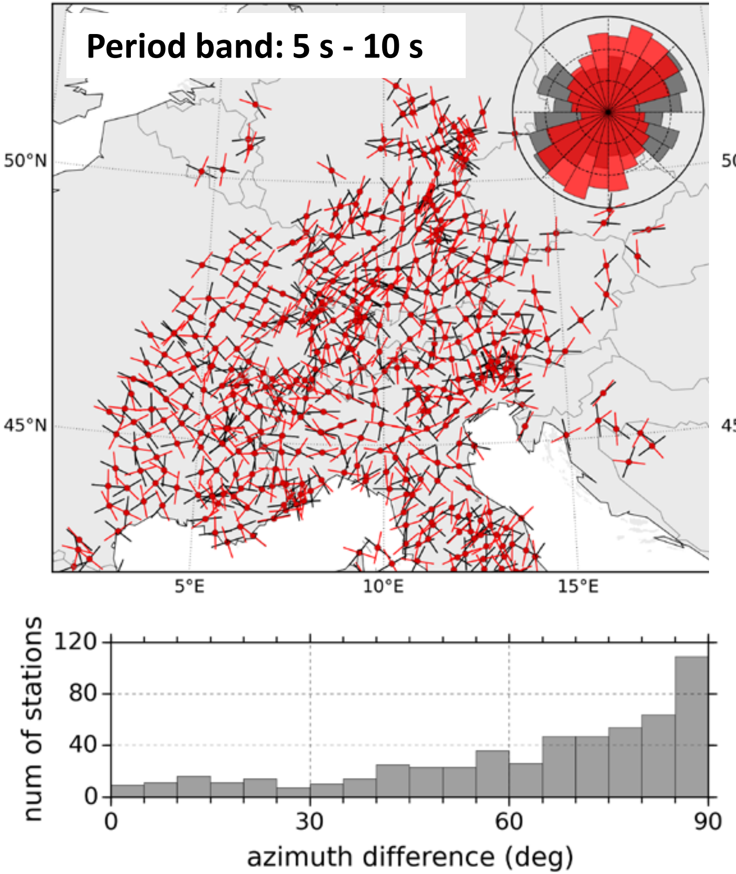


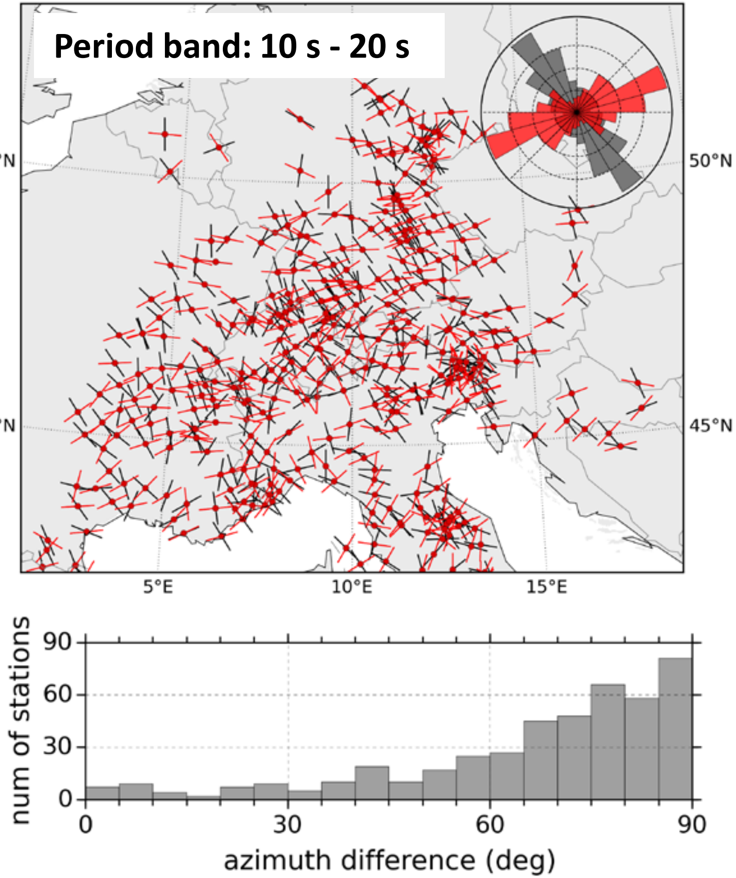
Rayleigh and Love waves: example from the Alps





Dominant energy azimuth (mean over daily measurements 2011-2018)





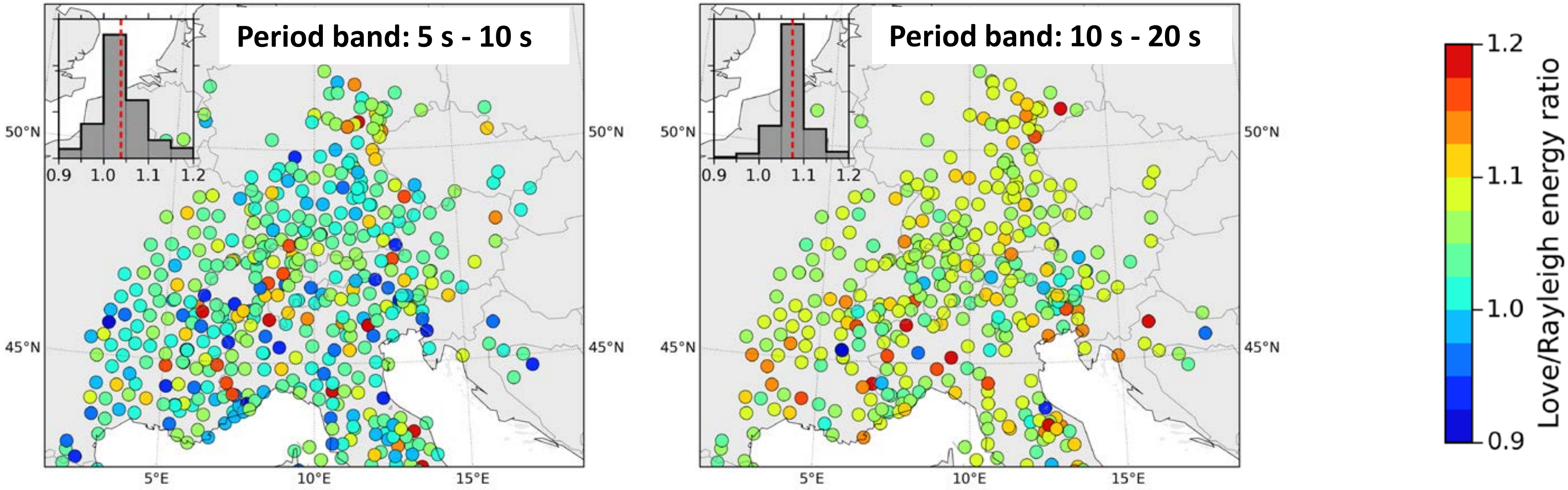
Dominant energy azimuths are ~perpendicular (60° -90°) to the Rayleigh wave azimuths.

↓

Love waves dominate in both period bands

We can calculate the approximate ratio Hor_L/Hor_R

Love / Rayleigh wave ratio of horizontal components based on single station observations



Love/Rayleigh wave ratio is defined as : $ratio = E_{\theta} / E_{\theta+90}$, where θ is Rayleigh-wave azimuth, and θ+90° is an estimate of Love-wave azimuth.

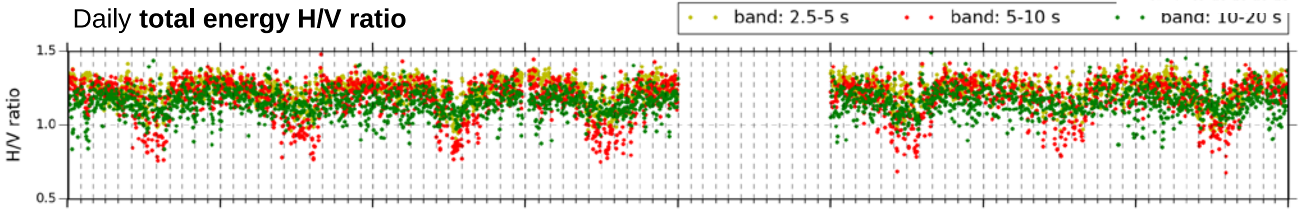
Love waves dominate on average with mean Love/Rayleigh wave ratio 1.04 in the secondary microseismic period band (5 s -10 s) and 1.07 in primary microseismic period band (10 s - 20 s).

No influence of distance to seismic noise source, no influence of structure

Body waves: indications of significant relative amplitudes in summer through H/V

Total energy H/V ratio is given by:

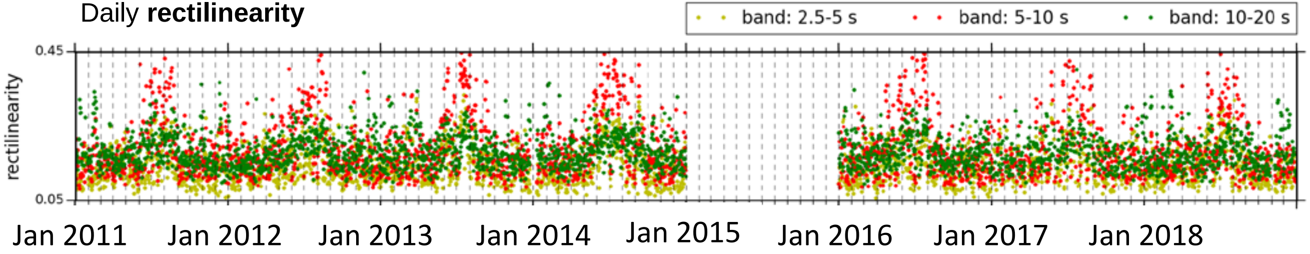
$$ratio = (E_E + E_N)/E_Z$$



Rectilinearity is given by:

$$rectilinearity = 1 - \sqrt{\lambda_2 / \lambda_1}$$

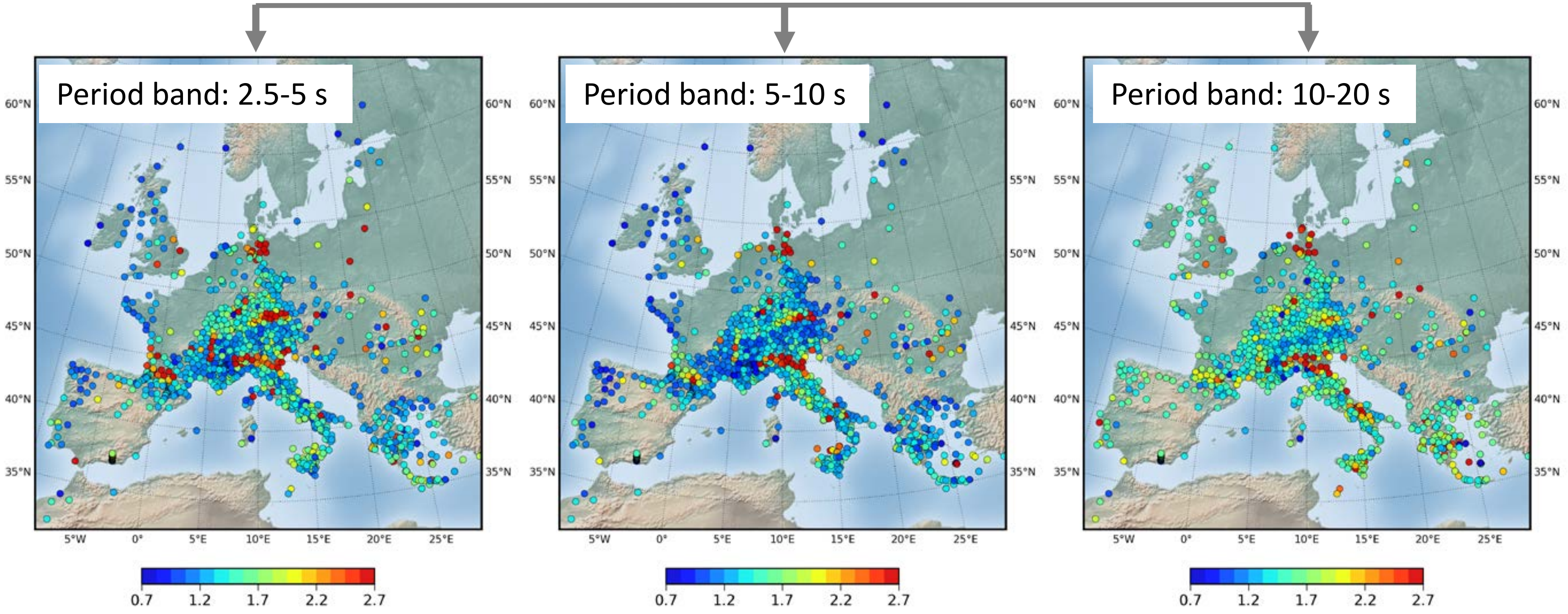
where λ_i $(\lambda_1 > \lambda_2 > \lambda_3)$ refers to the eigenvalues of the covariance matrix of the three components.



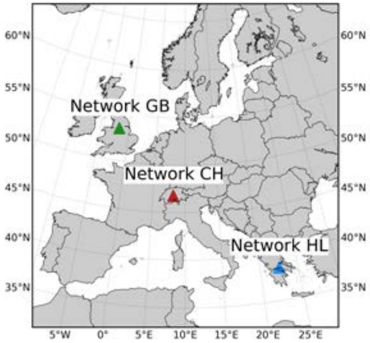
H/V decreases and rectilinearity increases in summer → higher influence of vertically propagating body waves?

Spatial distribution of total energy H/V ratio (mean over daily measurements 2011-2018)

Spatial variations are dominated by structure (but is the result of Rayleigh and Love waves)



Temporal variation of total energy H/V ratio (5 s - 10 s)



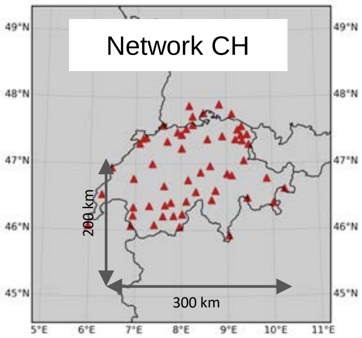
Daily energy d(H/V)

All years

Network GB

Network CH

Network HL

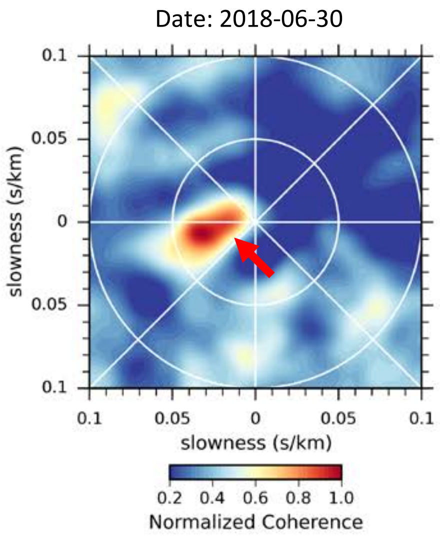


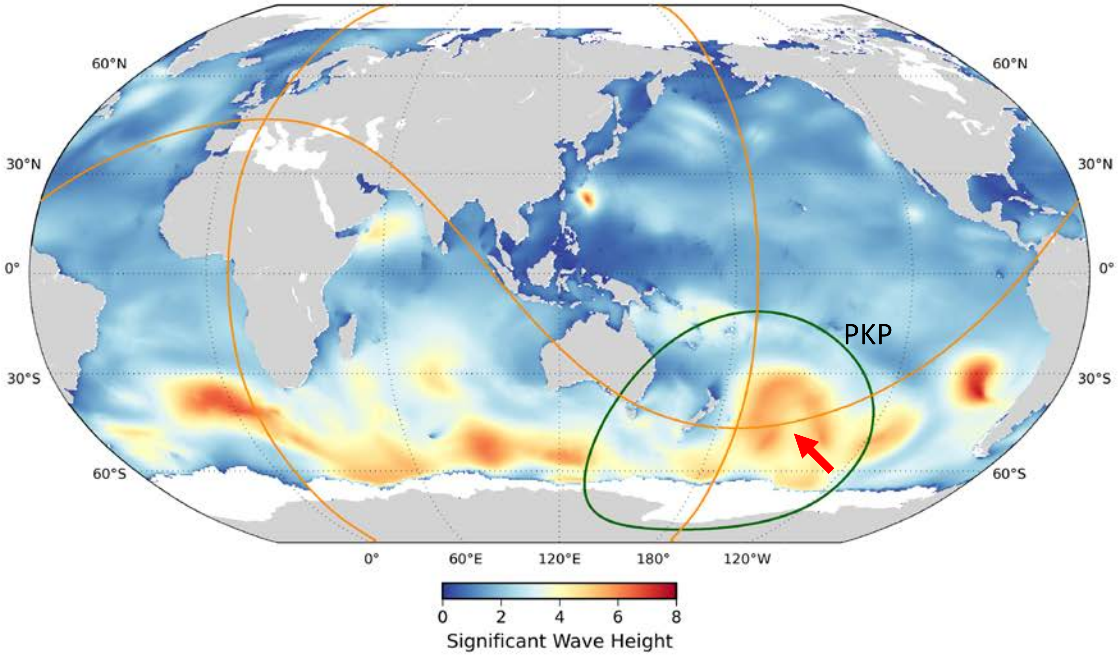
Daily energy d(H/V)

2018 for network CH

Significant decrease in H/V in summer for all networks – but large variations over time, and smaller effects for GB

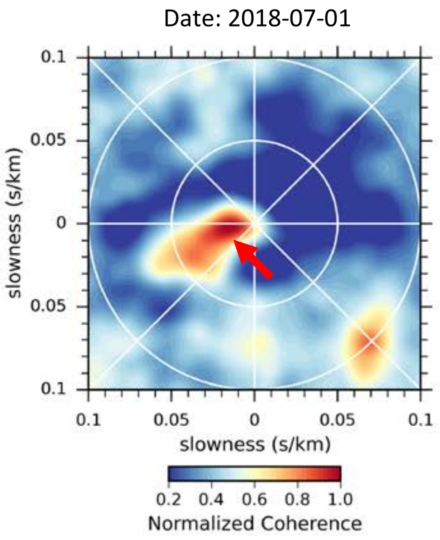
Beamforming: body waves detected by network CH

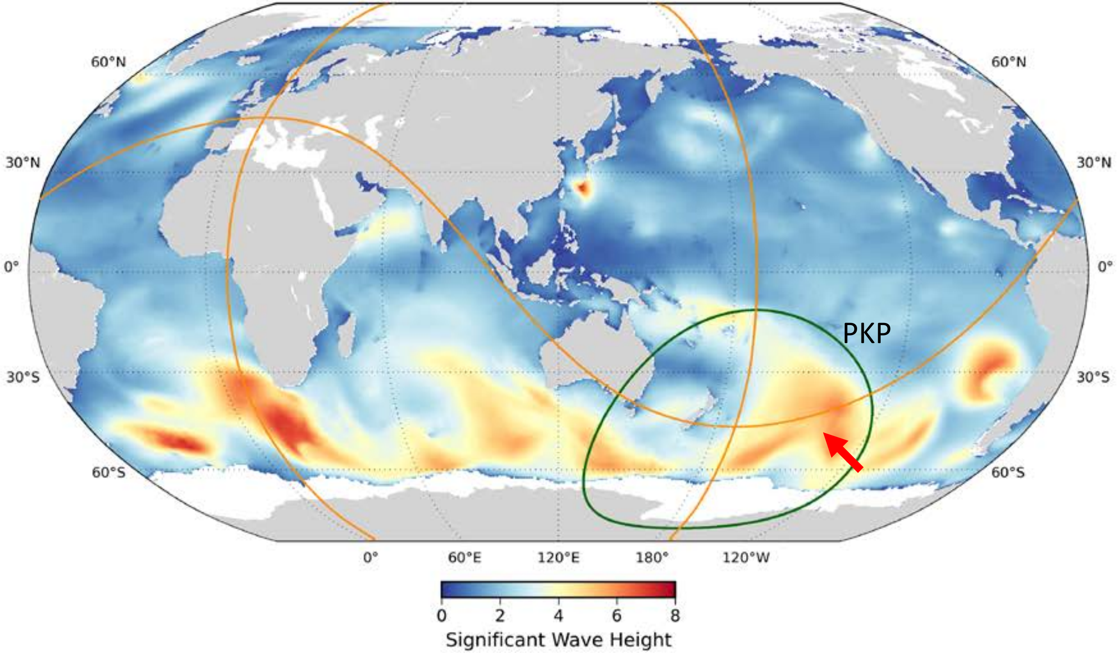




Clear observations of PKP wave from storm area in the south Pacific Ocean

Beamforming: body waves detected by network CH





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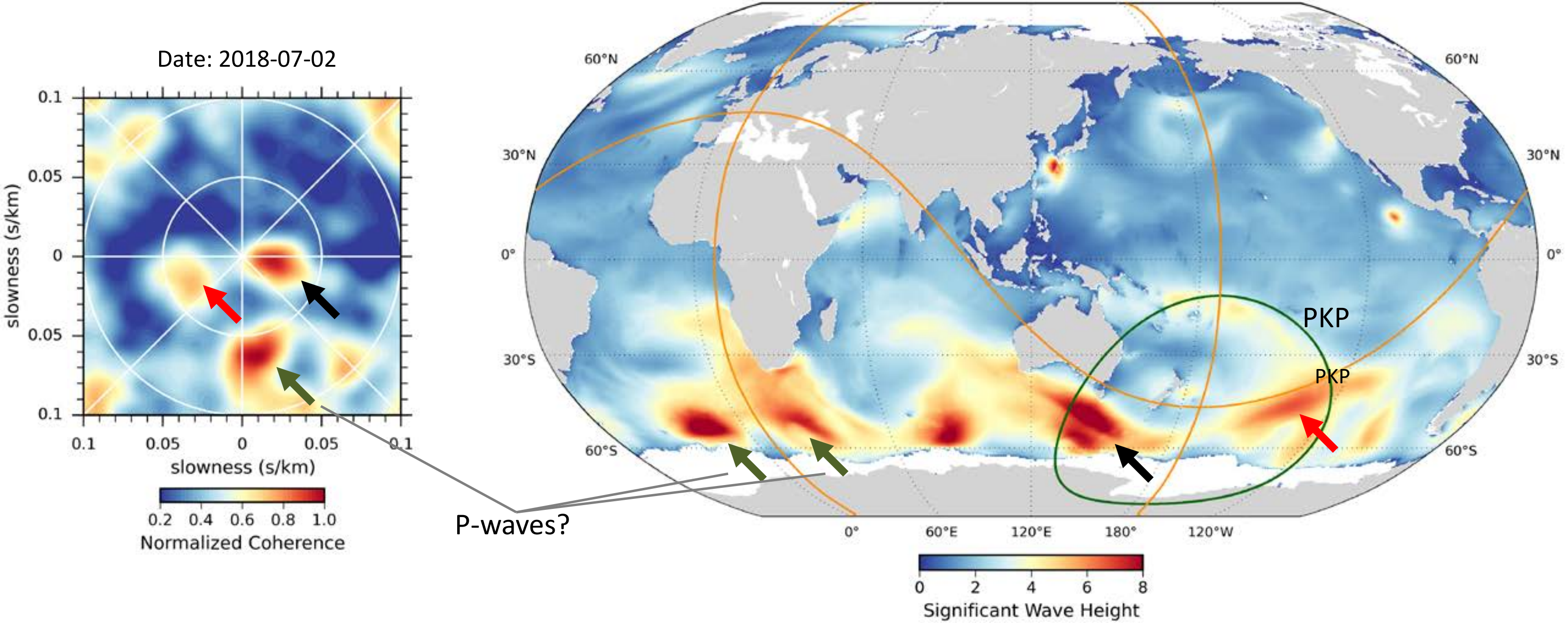
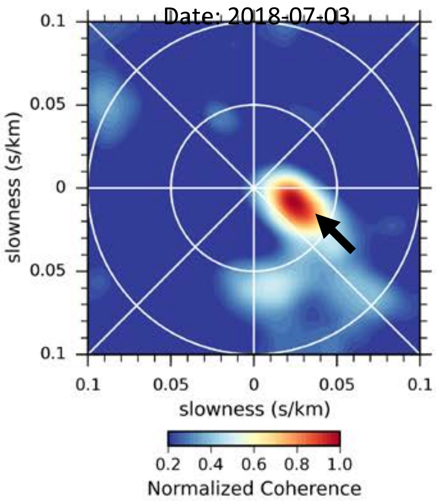
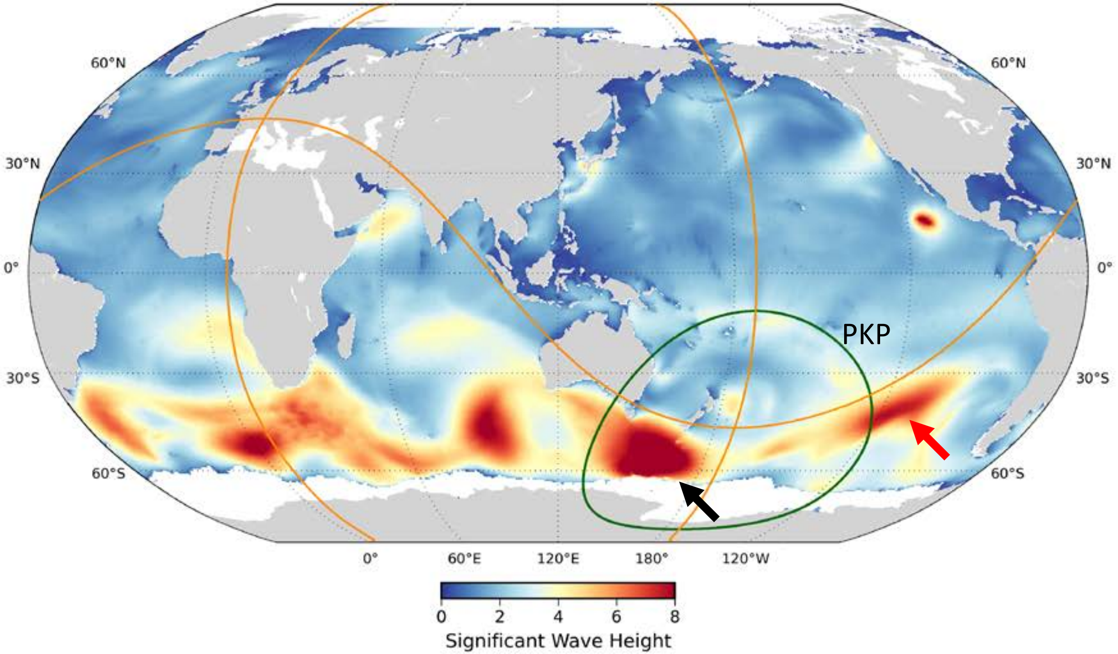


Clear observations of PKP waves from two storm areas in the south Pacific Ocean and from storm areas in South Atlantic

Beamforming: body waves detected by network CH





Clear observations of PKP wave from storm area in the south Pacific Ocean

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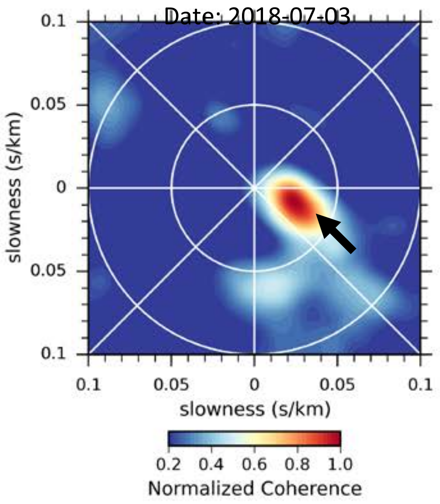
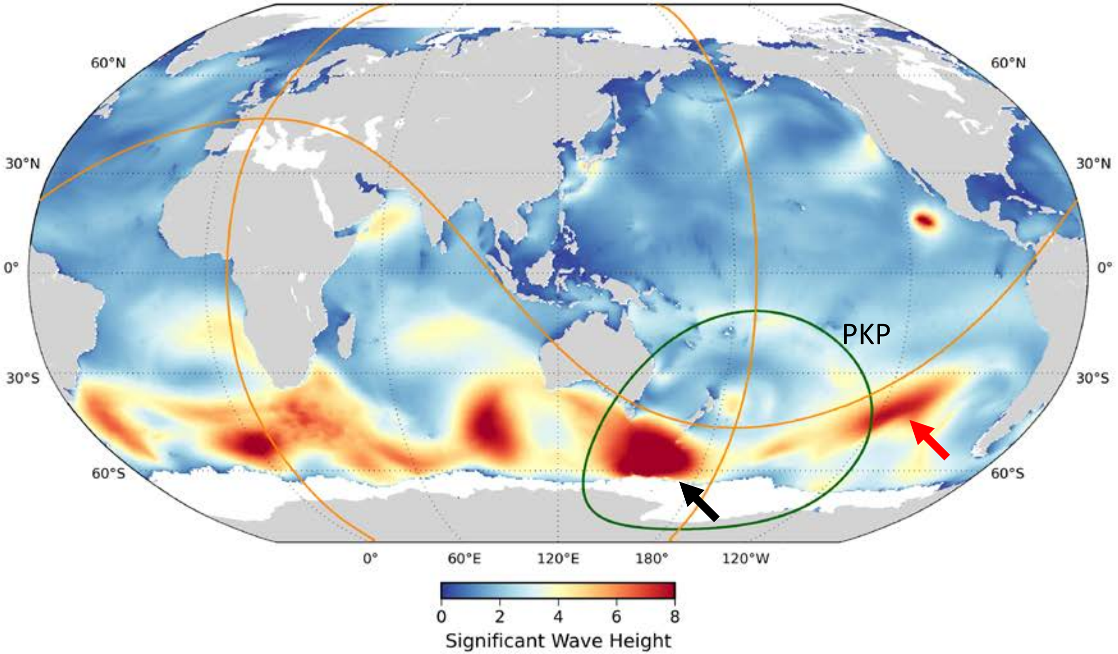
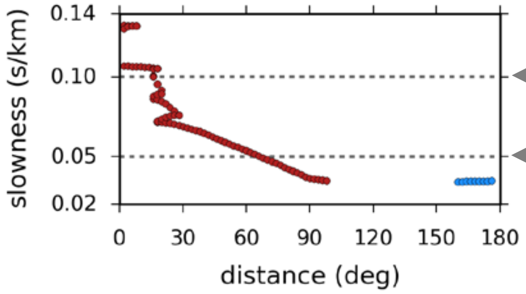






~40° incidence angle

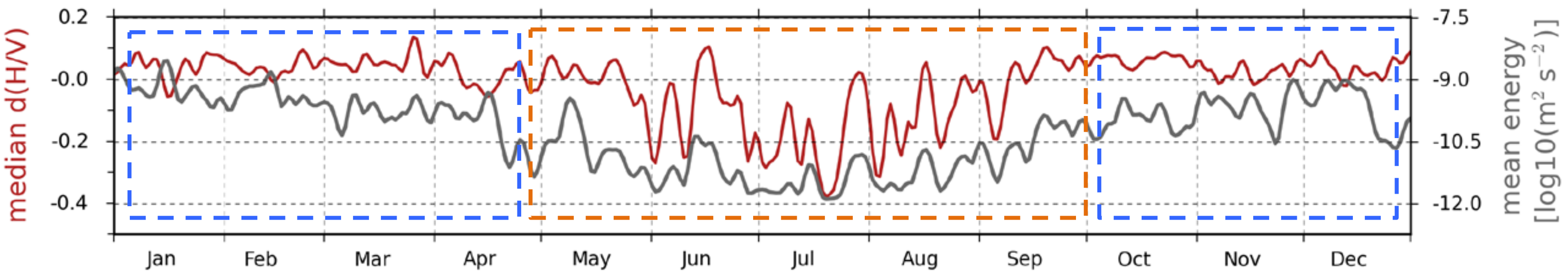
~20° incidence angle

PKP can be estimated from slowness p < 0.05 s/km

P can be estimated from 0.05 s/km < p < 0.1 s/km:

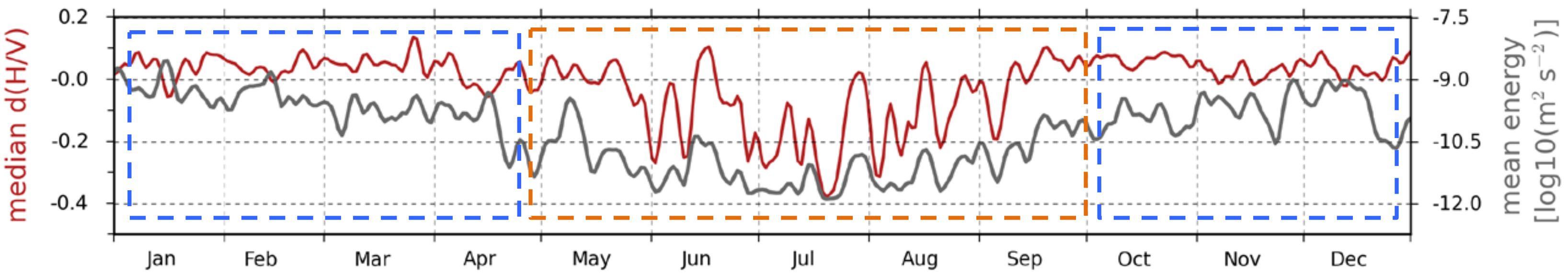
Proxy for Atlantic activity

Comparison of H/V and total Energy



Approximate expression of H/V ratio : $ratio_{HV} = \frac{S_H + P_H}{S_V + P_V + PKP}$, where S_H and S_V are surface waves, H and V are hor. and vert. energy.

Comparison of H/V and total Energy



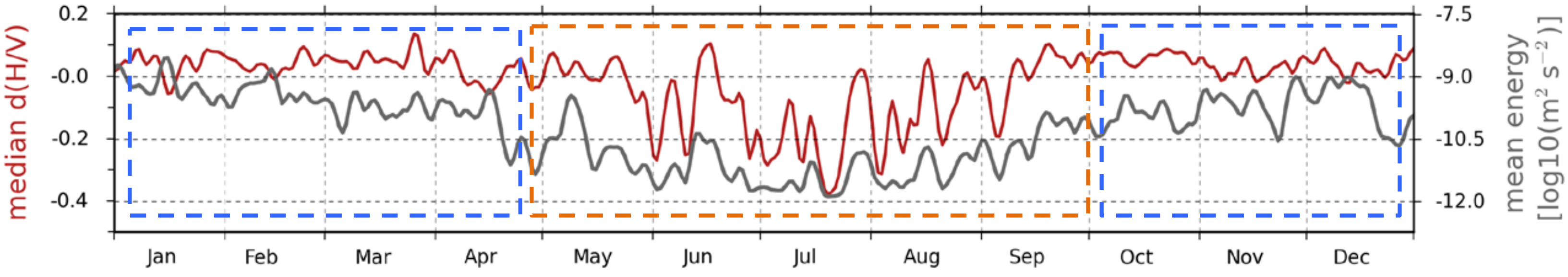
Approximate expression of H/V ratio : $ratio_{HV} = \frac{S_H + P_H}{S_V + P_V + PKP}$, where S_H and S_V are surface waves, H and V are hor. and vert. energy.

Small variations (and negative correlation?) **in winter**

Surface waves dominate the wavefield → $ratio_{HV} \approx \frac{S_H}{S_V} \approx \frac{R_H + L}{R_V} = \frac{R_H + a * R_H}{b * R_H}$

Love/Rayleigh ratio ***a*** dependent on total energy??

Comparison of H/V and total Energy



Approximate expression of H/V ratio : $ratio_{HV} = \frac{S_H + P_H}{S_V + P_V + PKP}$, where SH and SV are surface waves, H and V are hor. and vert. energy.

Small variations (and negative correlation?) **in winter**

Surface waves dominate the wavefield ➡ $ratio_{HV} \approx \frac{S_H}{S_V} \approx \frac{R_H + L}{R_V} = \frac{R_H + a * R_H}{b * R_H}$

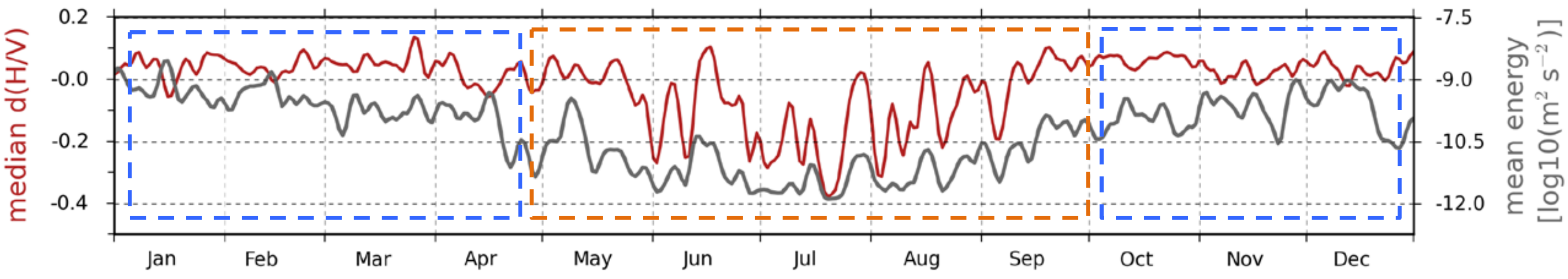
Love/Rayleigh ratio ***a*** dependent on total energy??

Strong variations and **positive correlation** in summer

Low Energy: Significant PKP waves ➡ $ratio_{HV} = \frac{S_H + P_H}{S_V + P_V + PKP}$

Increase of energy leads to increase of HV ratio, towards $\frac{S_H}{S_V}$

Comparison of H/V and total Energy



Approximate expression of H/V ratio : $ratio_{HV} = \frac{S_H + P_H}{S_V + P_V + PKP}$, where S_H and S_V are surface waves, H and V are hor. and vert. energy.

Small variations (and negative correlation?) **in winter**

Surface waves dominate the wavefield → $ratio_{HV} \approx \frac{S_H}{S_V} \approx \frac{R_H + L}{R_V} = \frac{R_H + a * R_H}{b * R_H}$

Love/Rayleigh ratio ***a*** dependent on total energy??

Strong variations and **positive correlation** in summer

Low Energy: Significant PKP waves → $ratio_{HV} = \frac{S_H + \cancel{P_H}}{S_V + \cancel{P_V} + PKP}$

Increase of energy leads to increase of HV ratio, towards $\frac{S_H}{S_V}$

Interpretation of H/V ratio temporal variation (comparison with beampower ratio)

Working hypothesis: In summer H/V ratio is the combined result of surface waves in the Atlantic and PKP waves in the south Pacific:

- H/V increases if there are storms in the (north) Atlantic
- H/V decreases if there are storms in the south Pacific

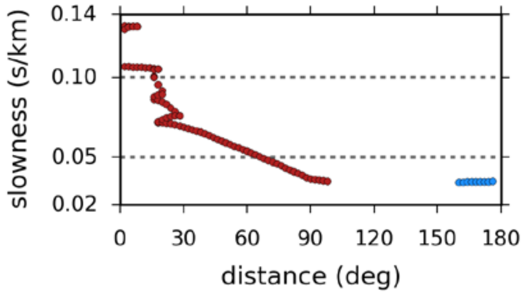
PkP P

Assumption: Energy (P)/Energy(PKP) is a proxy for the combined effect of North Atlantic and south Pacific

- P can be estimated from sum of beam power of slowness p: 0.05 s/km < p < 0.1 s/km
- PKP can be estimated from beam power of slowness p < 0.05 s/km

On all days we calculate

$$ratio_{beampower} = \frac{Energy\ of\ beam\ (0.05 < p < 0.1)}{Energy\ of\ beam\ (p < 0.05)}$$



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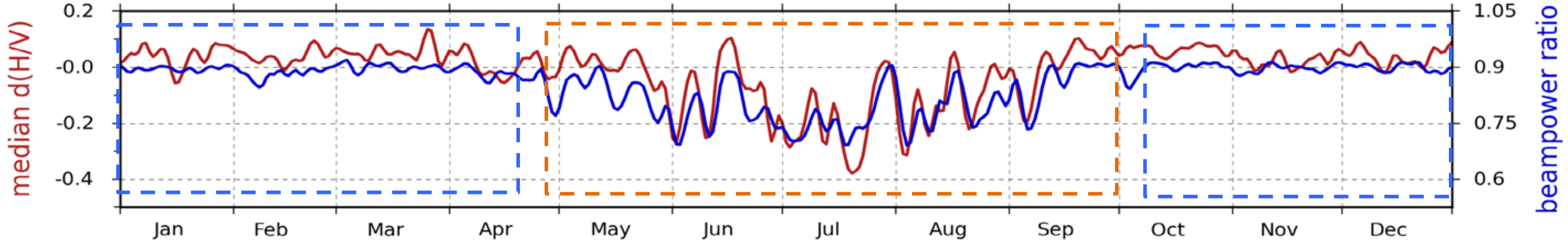


Beampower ratio explains the temporal variation of H/V ratio in summer (! ?)

Investigations to be continued…

PkP P

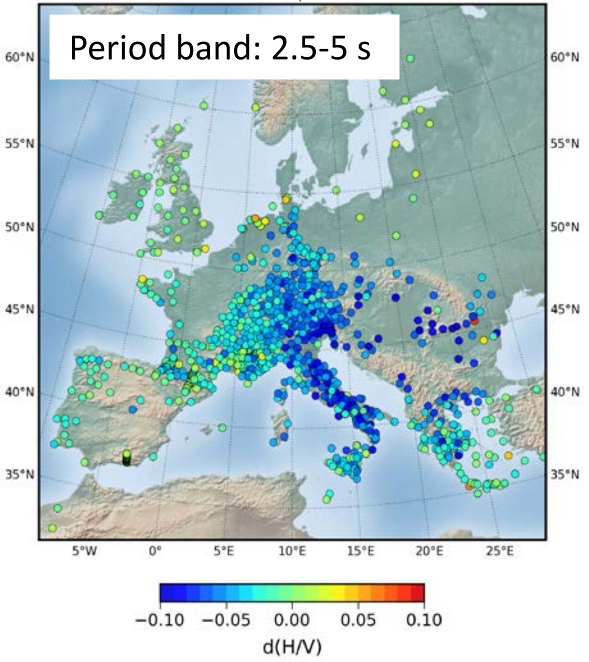
But *d(H/V)= Summer H/V – average H/V* gives some insight into relative strength between PKP and surface waves

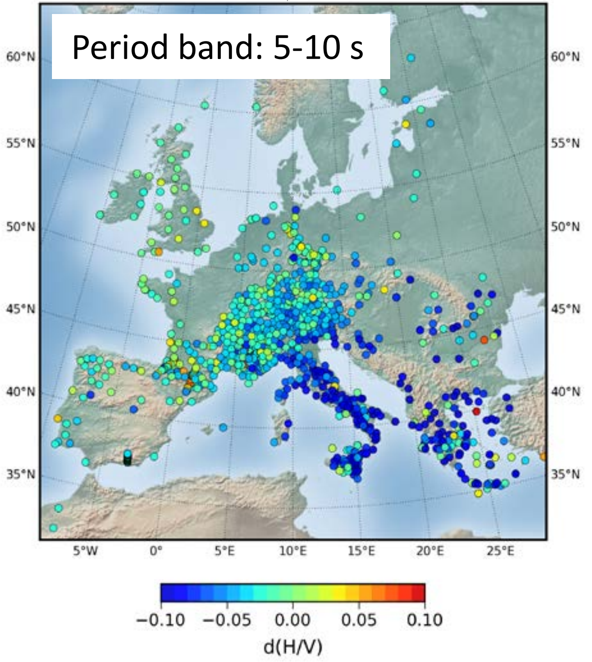
How does *d(H/V)* vary spatially?

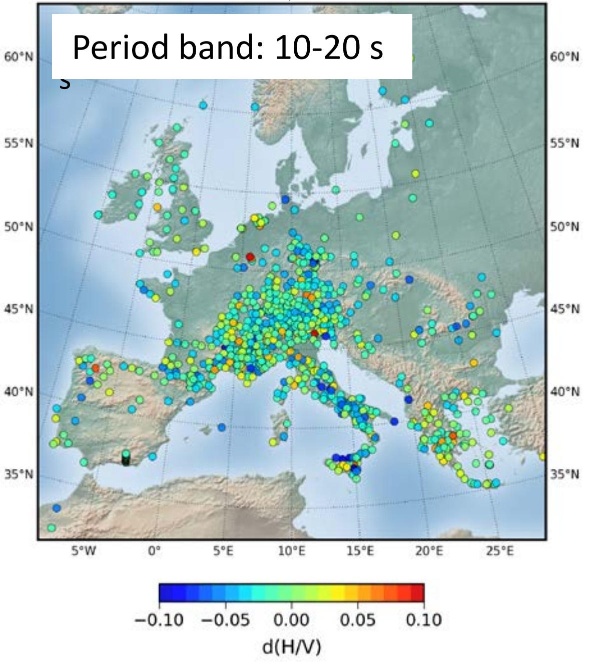
Mean d(H/V) over daily measurements in summers (2011-2018)

d(H/V) : effect dominated by the relative strength of local surface and teleseismic PKP waves.

d(H/V) is insignificant; two options: no significant PKP waves or surface waves still dominant in summer







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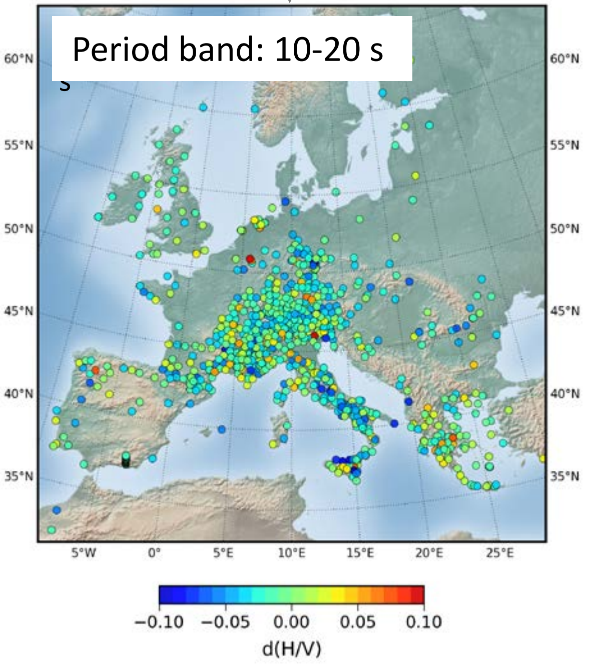

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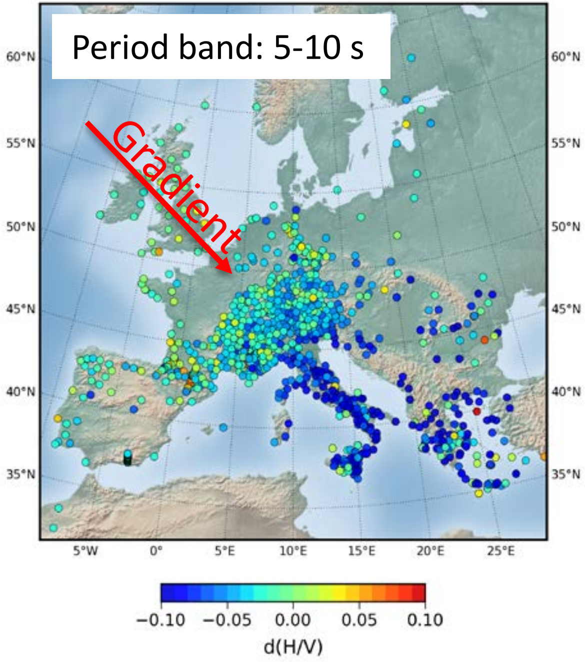

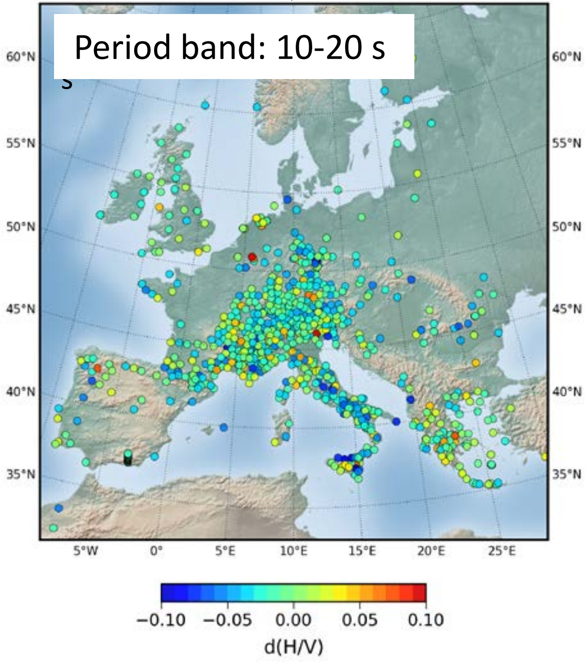

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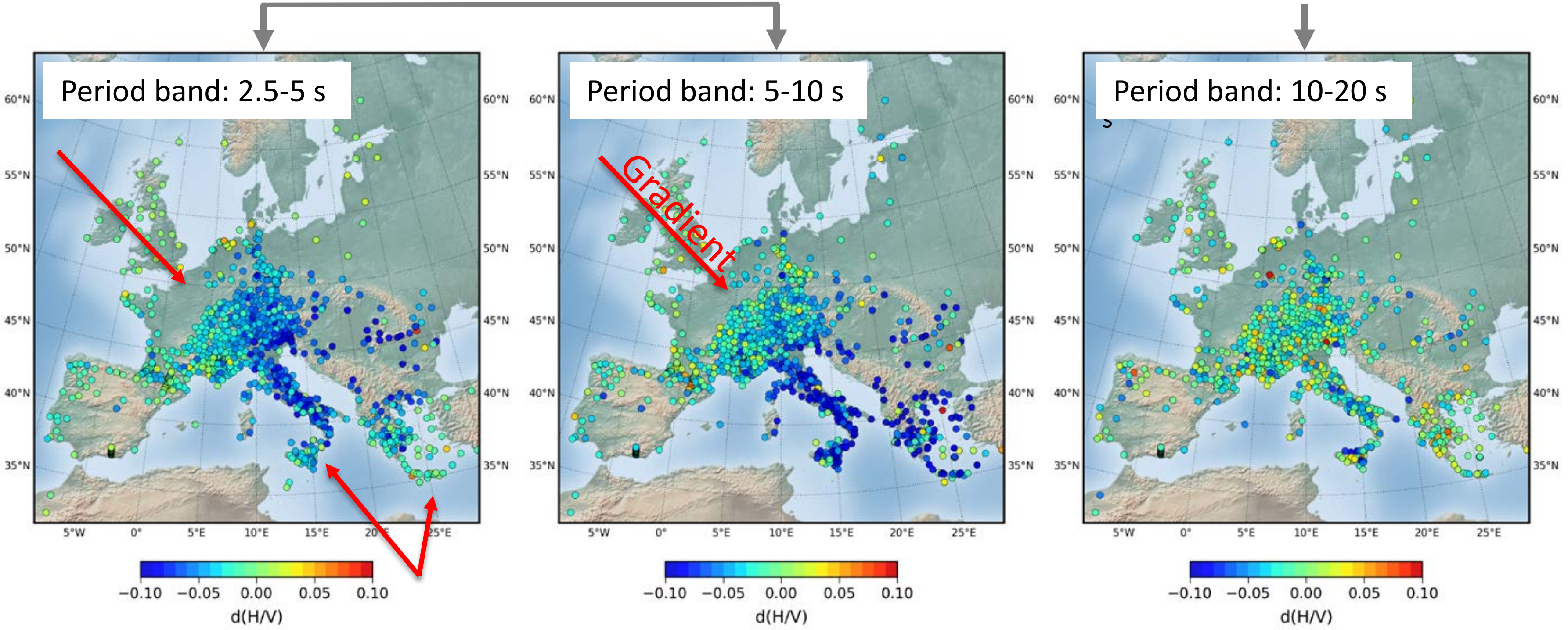

Conclusions

Mapping the noise field across Europe requires some use of single station measurements. In the framework of an underdetermined problem, we conclude that:

Using H/V in the first microseismic peak to invert for structure is a hazardous affair:

- Love waves are significant (and probably of higher amplitude on horizontal components than Rayleigh waves)
- Body waves are significant in summer even though surface waves dominate the wavefield coastal areas

3 component stations can give some insight as to the relative amplitudes of Rayleigh and Love waves

Variations of H/V can give some insight as to the relative strength of surface waves and body waves. We observe that:

- in the first microseismic peak, no such effects are visible: H/V does in general not have seasonal variations.
- in the second microseismic peak, PKP waves are sufficiently strong (as compared to the surface waves) in summer to modify H/V across most of Europe
- In the 5 s – 10 s period range, only the distance from the Atlantic Ocean is of relevance
- In the 2.5 s – 5 s period range, the distance to the Mediterranean coast is also of relevance