Noise correlations amplitude kernels

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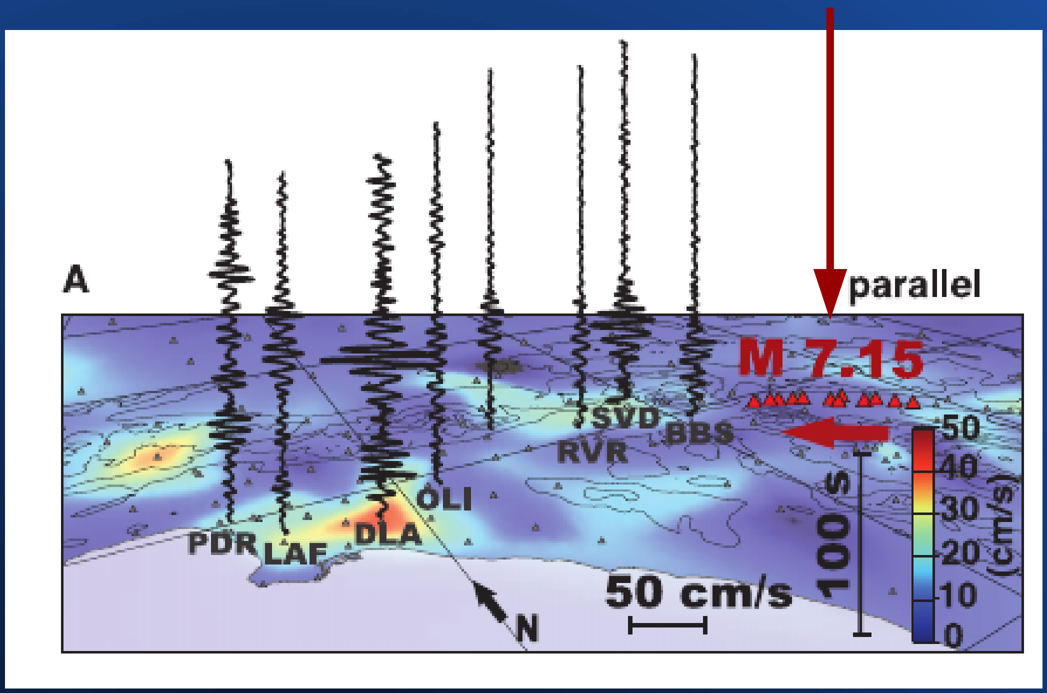
Why measuring the amplitude of the GF using noise correlations matters ?

- Measuring the amplitude of the Green's function using noise correlations
- 1) determine the attenuation of surface waves between any pair of receivers
- 2) image the medium
- 3) predict in advance what would be the ground motion associated with an earthquake

Using noise correlations to evaluate the ground motion produced by earthquakes ?

Stations deployed along the San Andreas Fault

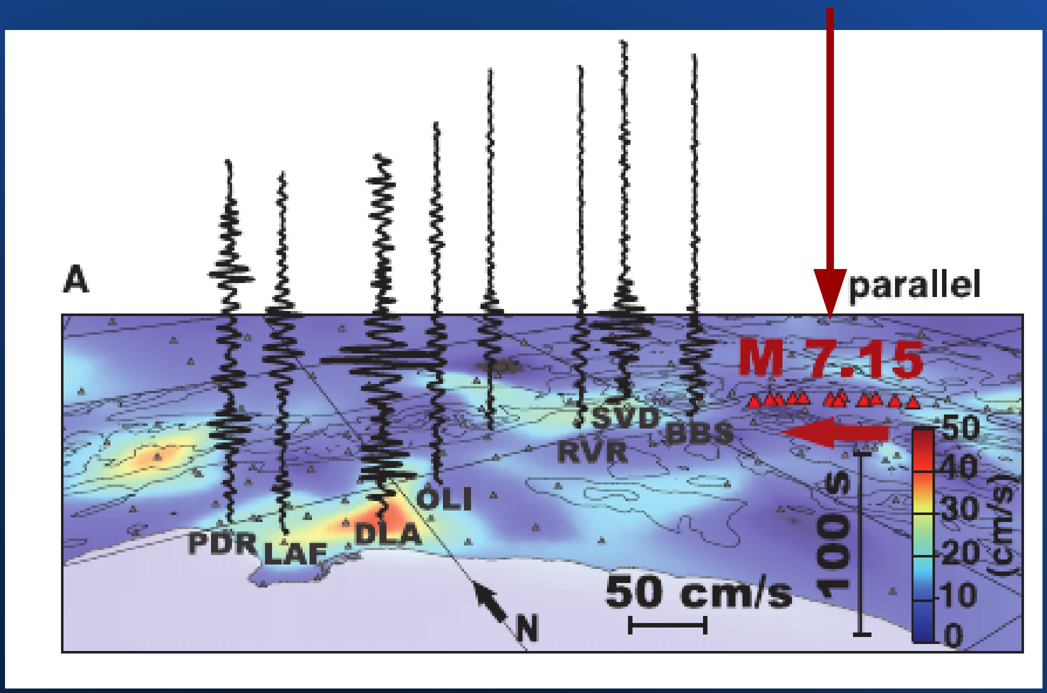


From Denolle et al., science, 2014

- 1) cross-correlate seismic noise between receivers located on a fault zone and in areas where people live
- relative amplitude of the correlations = relative amplitude of the ground motion ?

Using noise correlation to evaluate the ground motion produced by earthquakes ?

Stations deployed along the San Andreas Fault

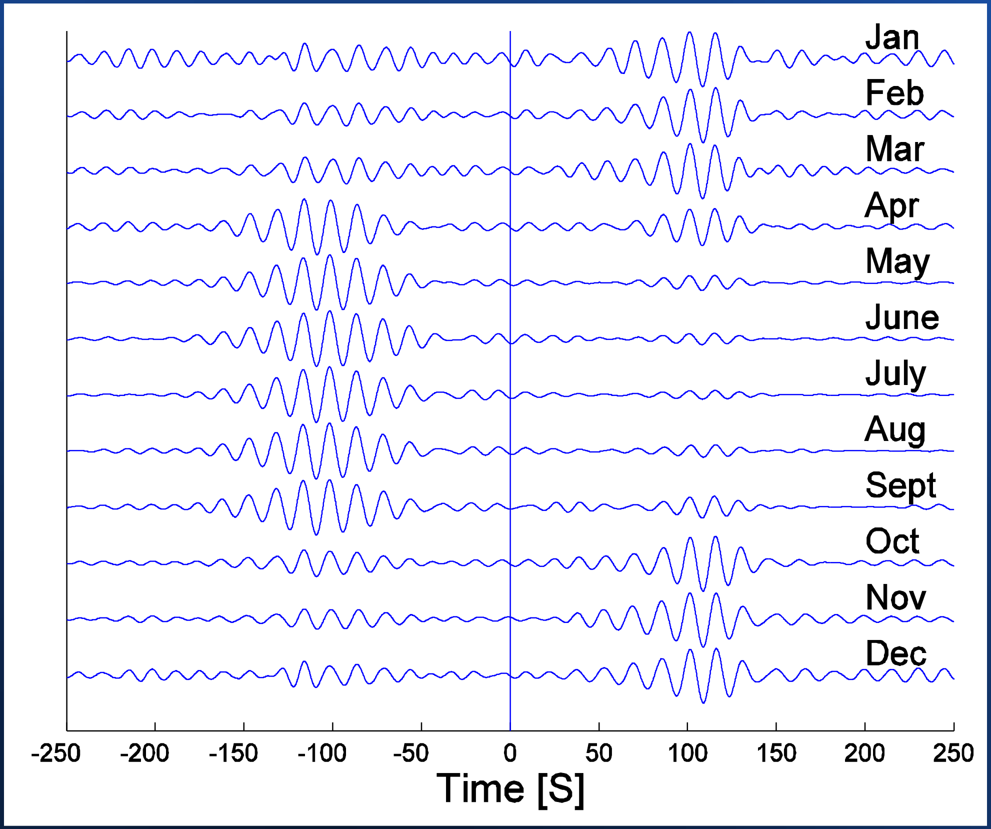


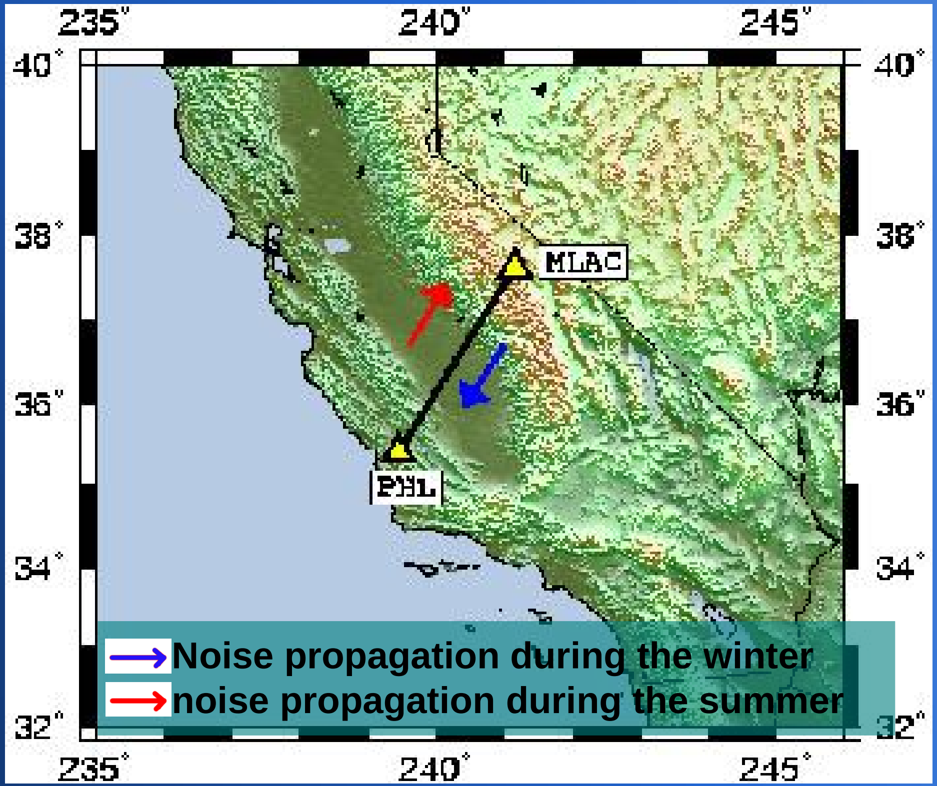
From Denolle et al., science, 2014

- Noise correlations amplitude depends on the :
- 1) attenuation of the medium
- 2) distribution of noise sources
- 3) way noise records have been processed before computing the correlations

Noise source distribution & correlations amplitude

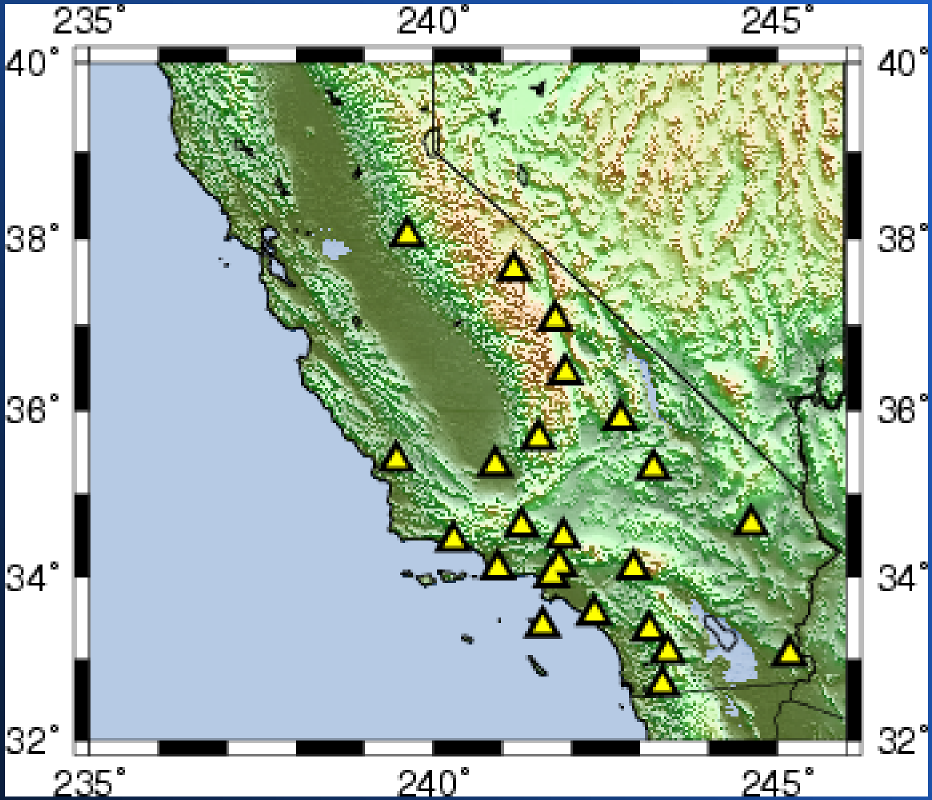
Monthly correlations between MLAC & PHL in the 10-20s period band





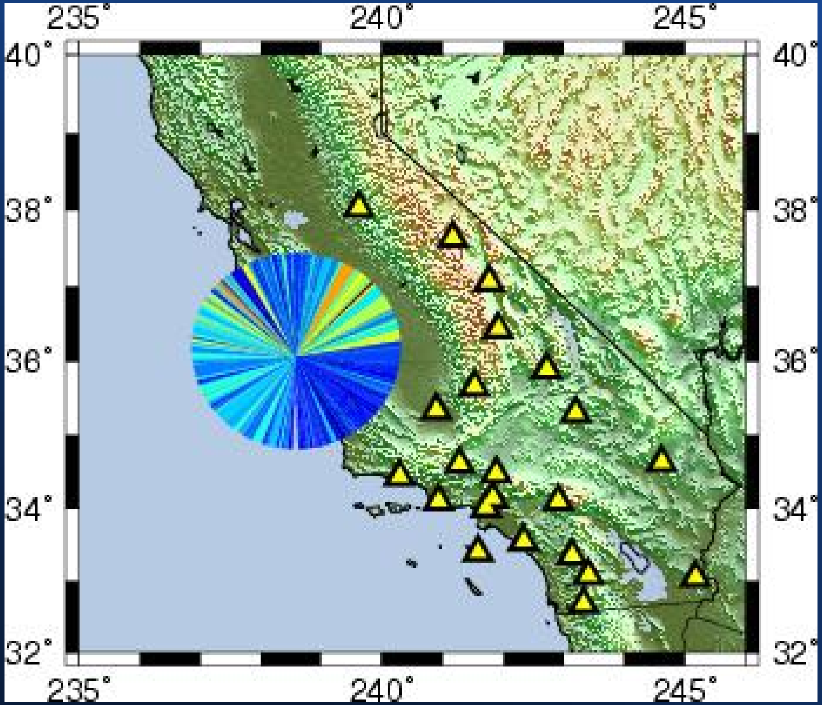
- **winter** : noise propagates mainly from MLAC to PHL
- **summer** : noise propagates mainly from PHL to MLAC

Noise correlations amplitude vs azimuth in the 10-20s period band

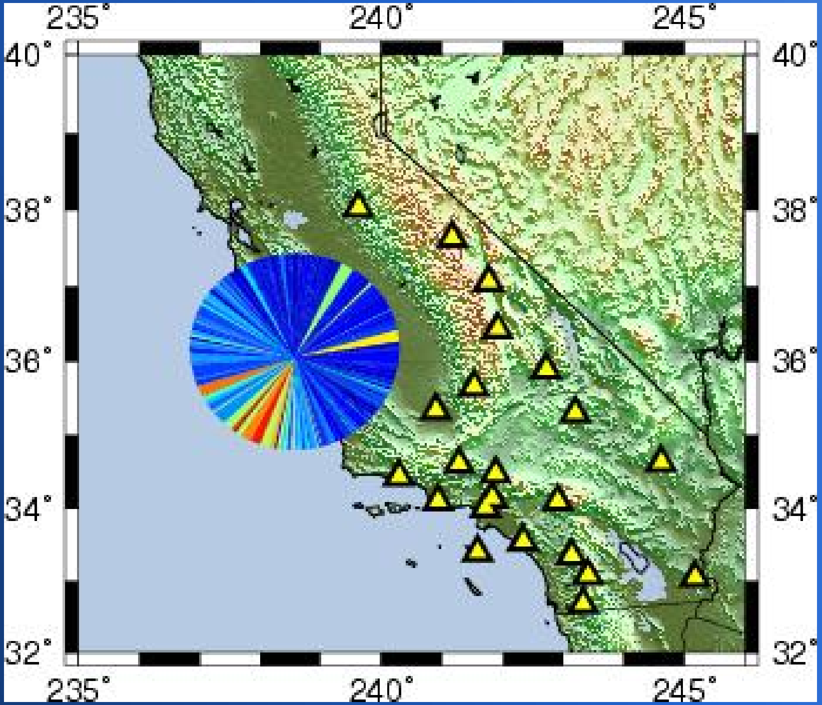


Network of 30 stations in southern California

Noise correlations amplitude vs azimuth in the 10-20s period band



winter



summer

Stehly et al, 2006

Partial conclusion

- noise correlations amplitudes depend on the distribution of the noise sources.
- noise correlations amplitude vs azimuth can be used to image the sources.
- Is it possible to use stations deployed along a line to measure the attenuation of surface waves ?

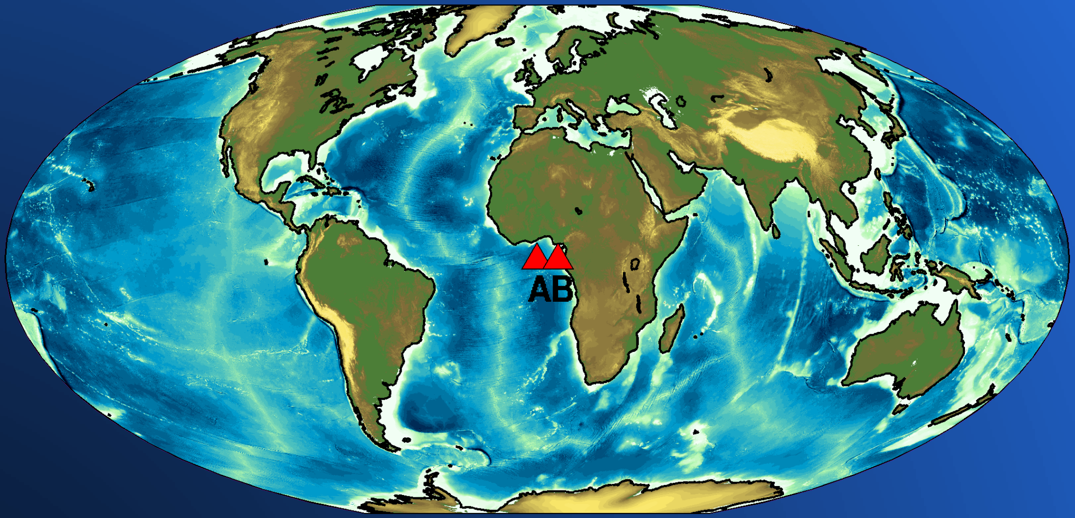
  => all correlations sensitive *more or less* to the same sources region ?

  => CC's amplitude depends only on the medium ?

noise correlations sensitivity kernels

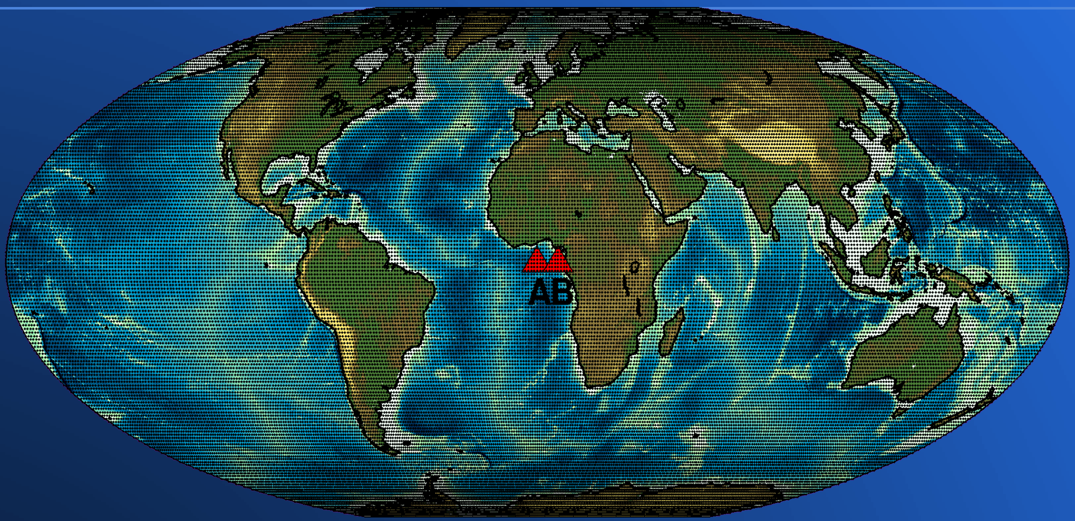
computed in PREM (still no scattering)

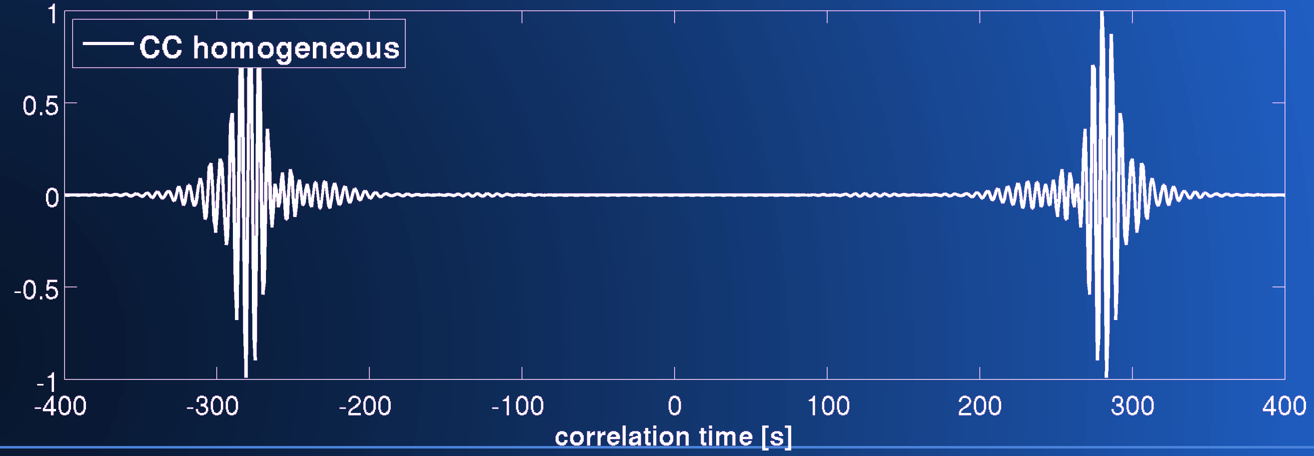
noise source kernels in PREM



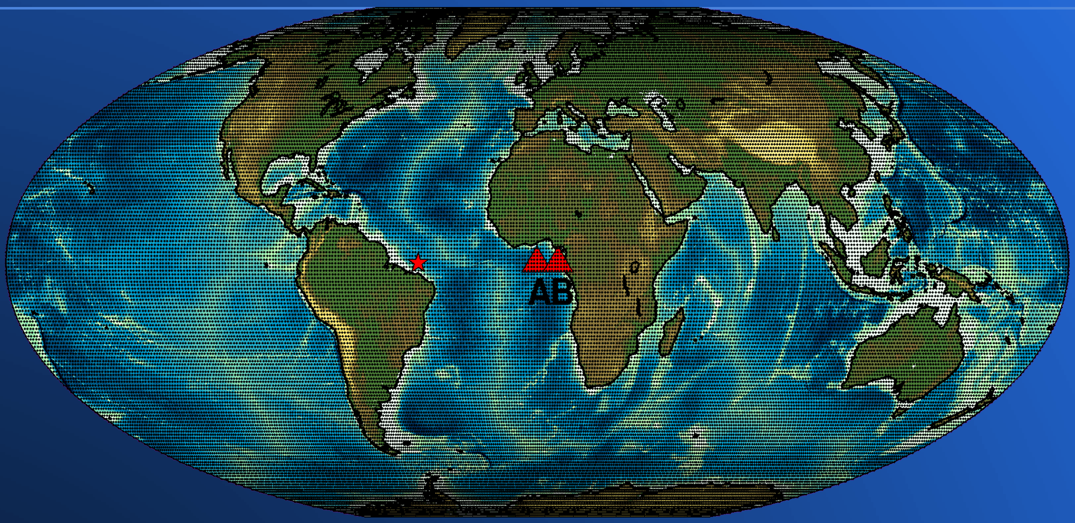
A and B are two receivers separated by 800 km

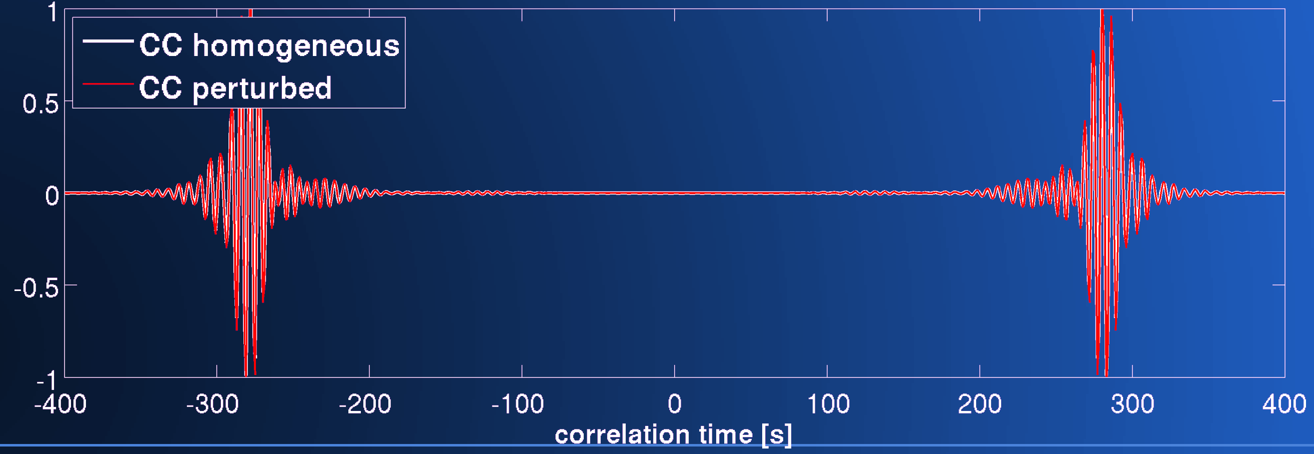
1) compute a reference correlation corresponding to a homogeneous distribution of noise soures



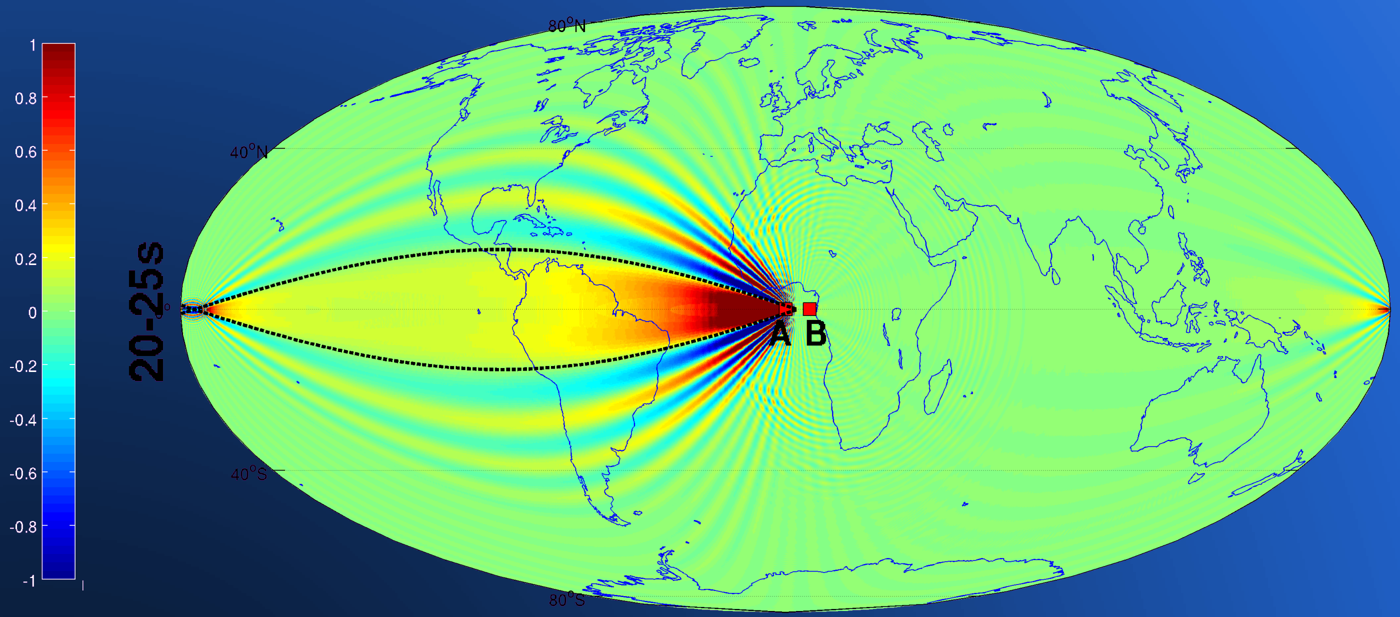


2) each source is perturbed one by one
3) for each perturbation we compare the amplitude of the reference and perturbed correlation at the arrival time of the surface waves



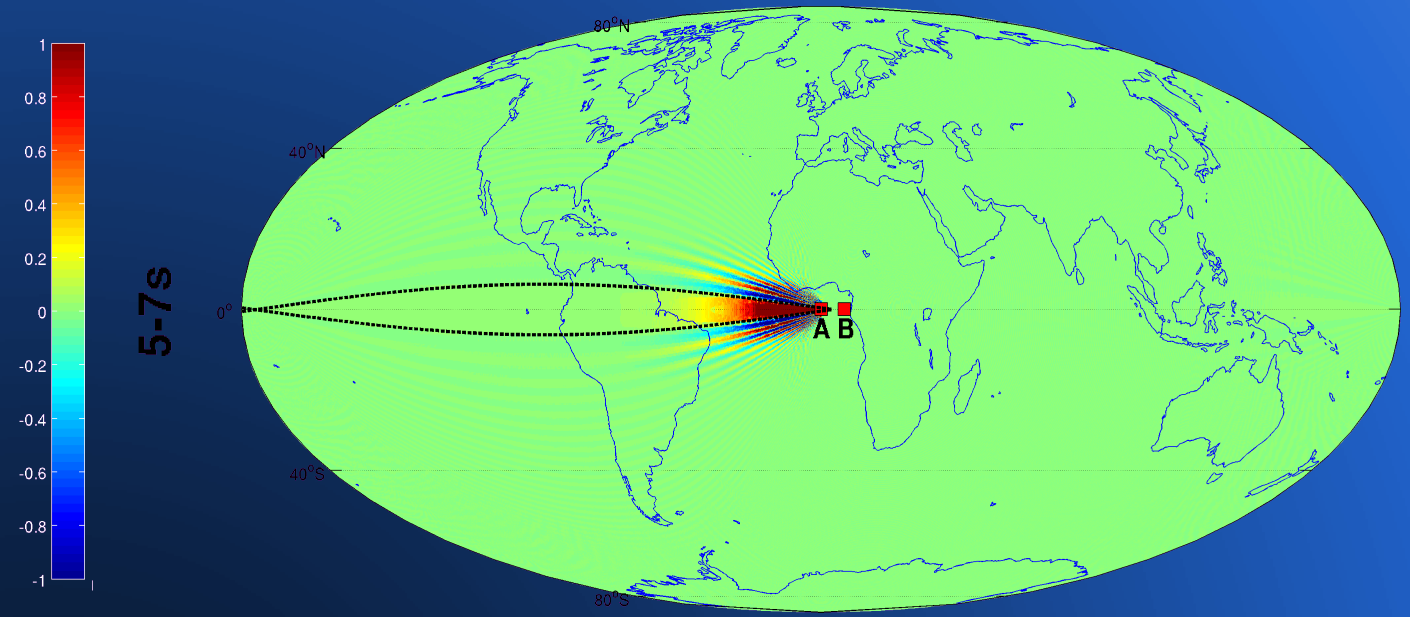


Noise source kernel in the 20-25 period band for surface waves propagating from A to B



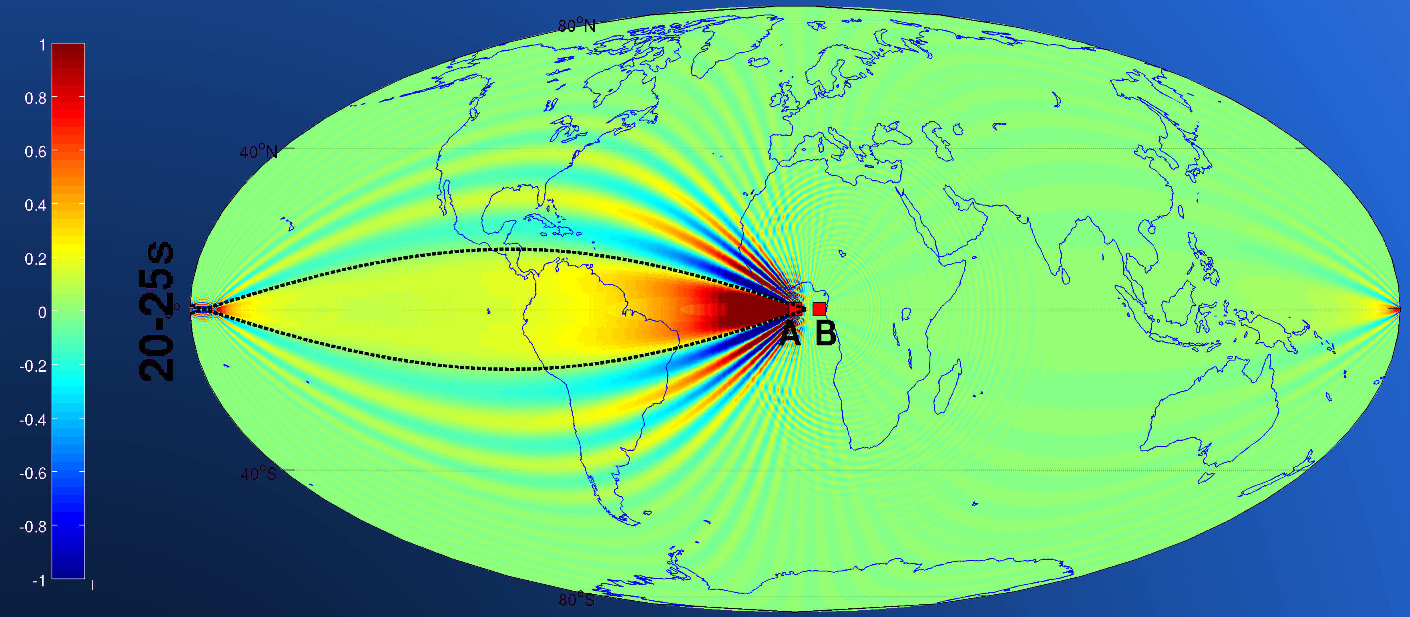
- no sensitivity between the receivers
- high sensitivity in the coherent area (dashed line)
- oscillations outside the cohrent area
- no sensitivity elsewhere

Noise source kernels vs frequency : 5-7s



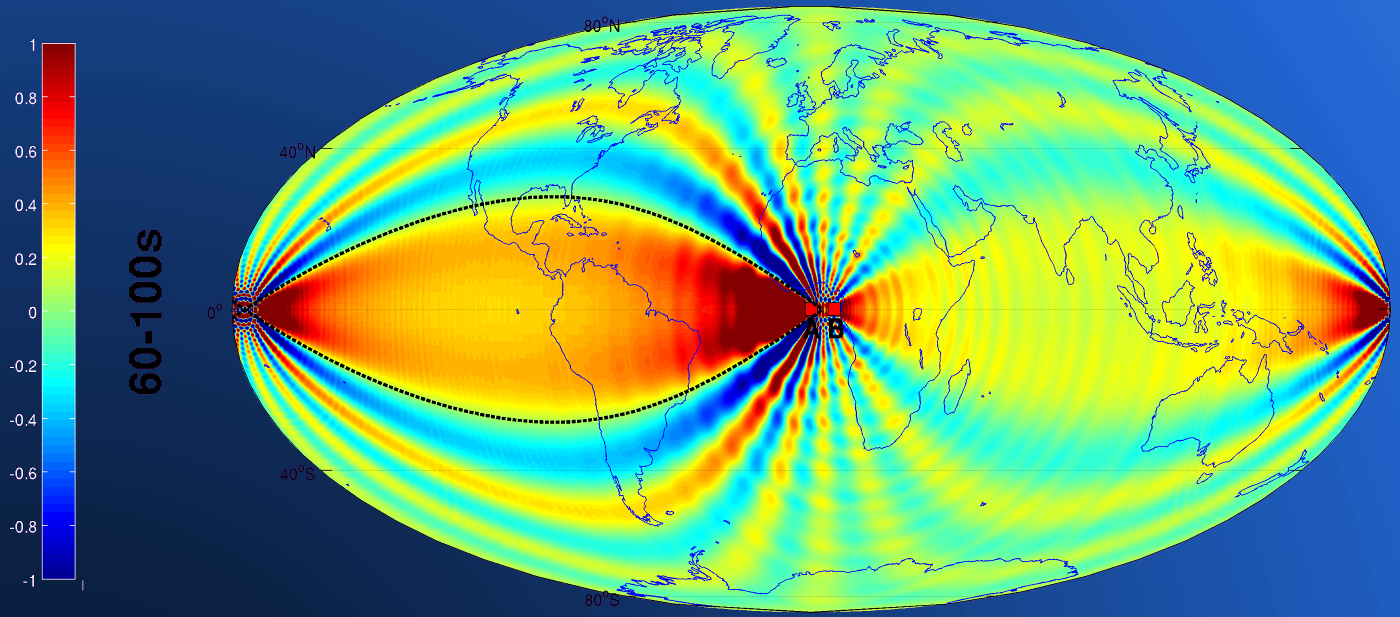
- **5-7s :** correlation amplitude mostly sensitive sources located close to the receivers

Noise source kernel in the 20-25 period band



- **5-7s :** correlation amplitude mostly sensitive to sources located close to the receivers
- **20-25s :** correlation amplitude sensitive to local sources + antipodal region

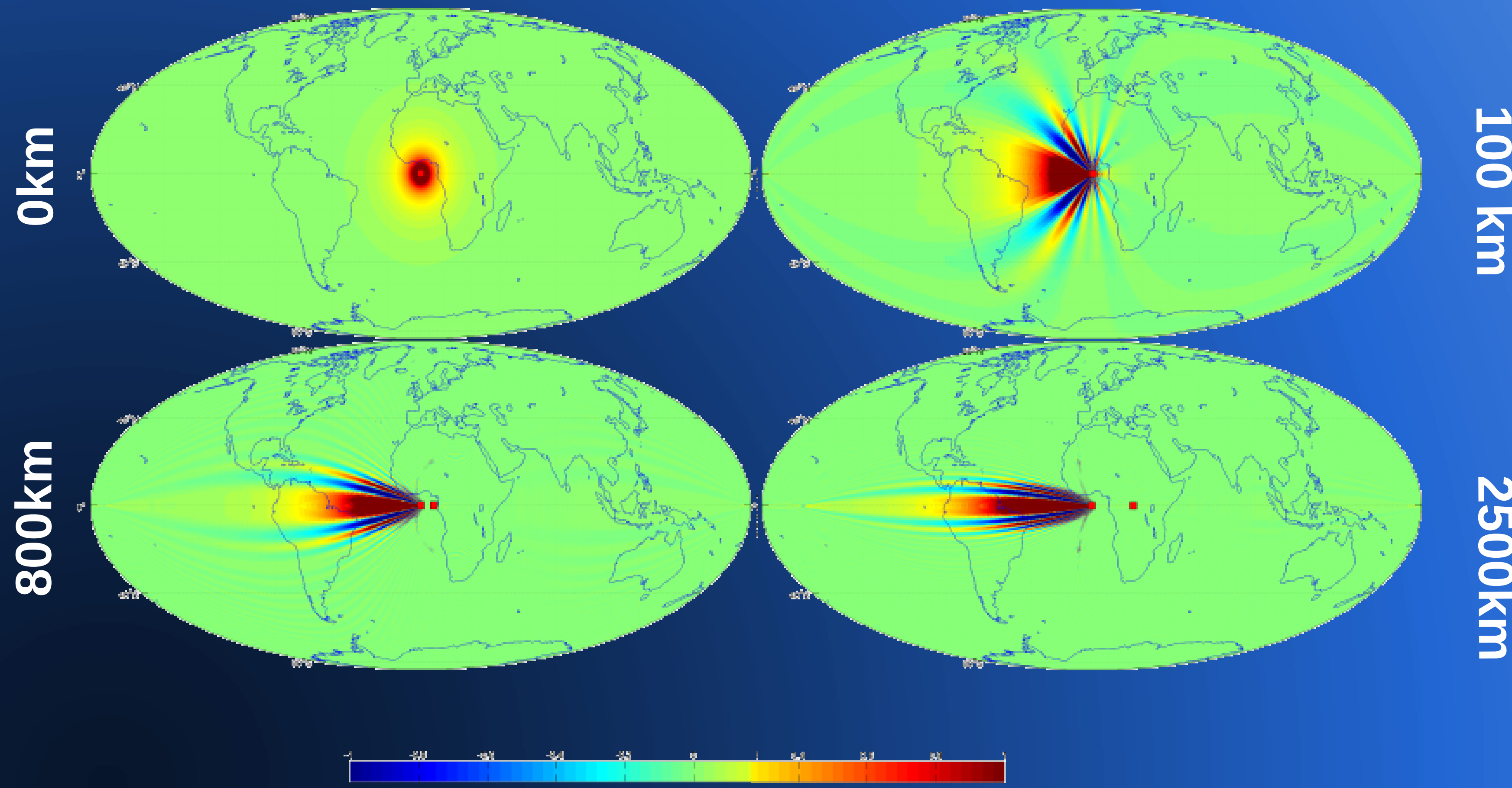
Noise source kernels vs frequency : 60-100s



- **5-7s :** correlation amplitude mostly sensitive sources located close to the receivers
- **20-25s :** correlation amplitude sensitive to local sources + antipodal region
- **60-100s :** correlation sensitive even to sources located beyond the antipodal point

are noise correlations computed along a line of receivers sensitive to the same source region ?

Noise source kernels vs inter station distance
(in the 15-25s period band)

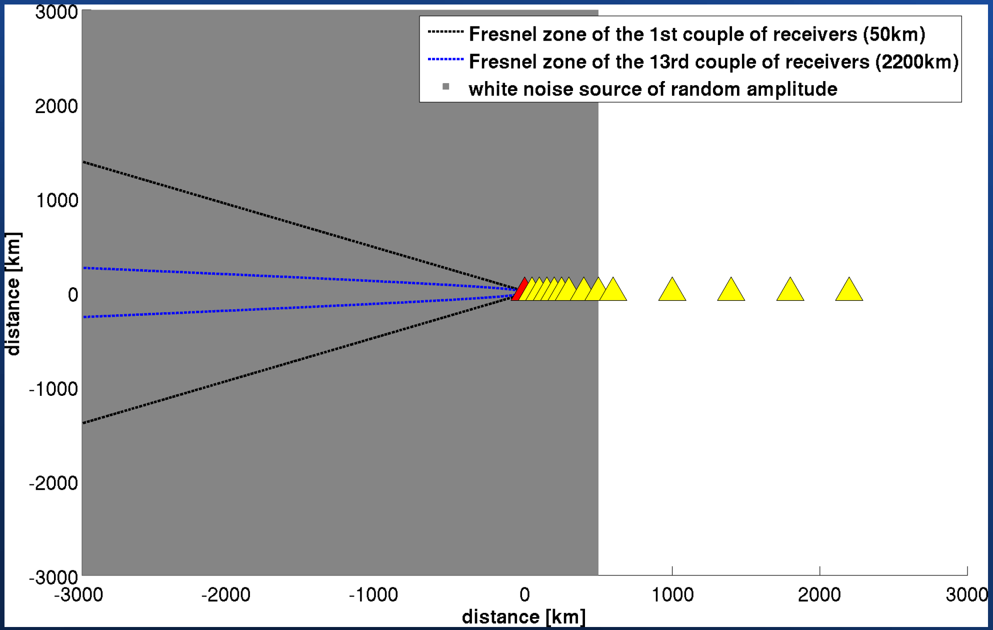


Partial conclusion

- Correlations computed along a line of receivers are sensitive to different source regions
- => uneven distribution of noise sources will affect noise correlations amplitude decay
- Is it nevertheless possible to extract attenuation coefficients ?

2D Numerical simulations
in a homogeneous medium

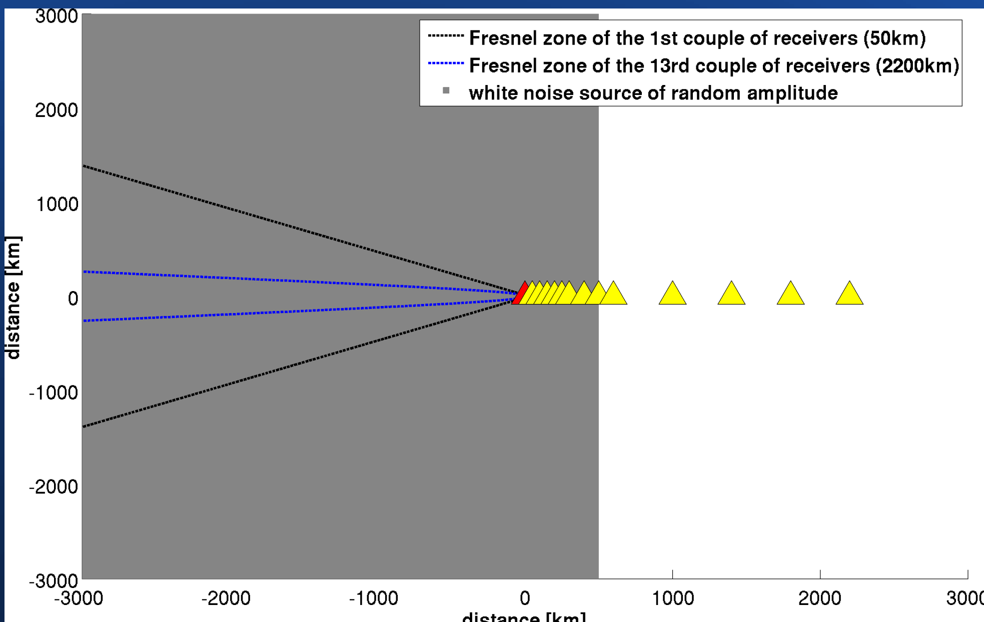
Numerical simulation : homogeneous distribution of noise sources

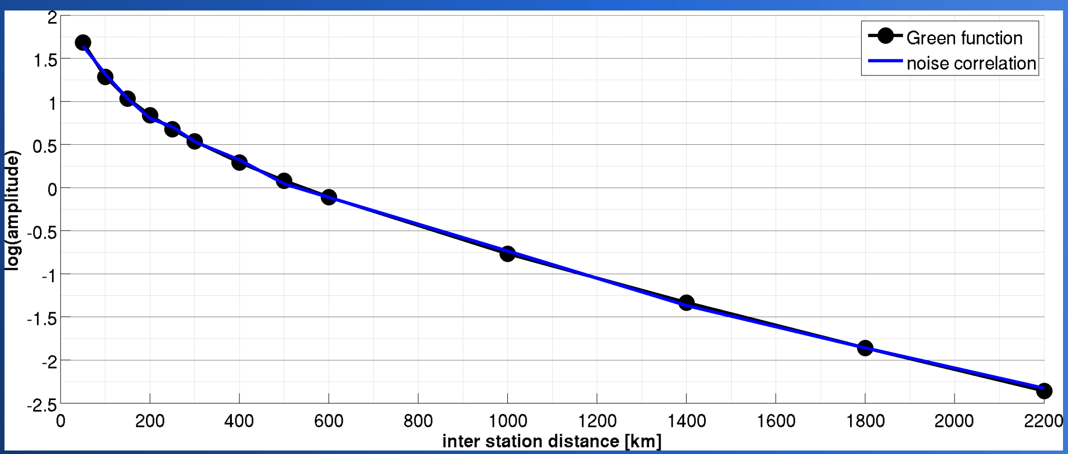


-We cross correlate the noise recorded by the 1st receiver (red) with the noise recorded by others receivers (yellow)

- The inter-receiver distance is between 50 and 2000 km

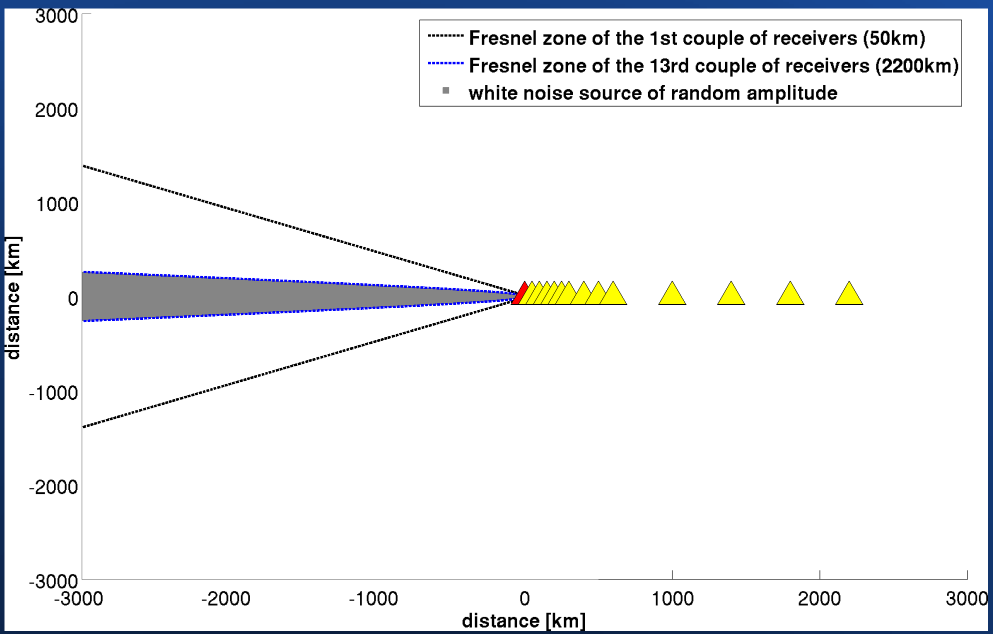
homogeneous distribution of noise sources

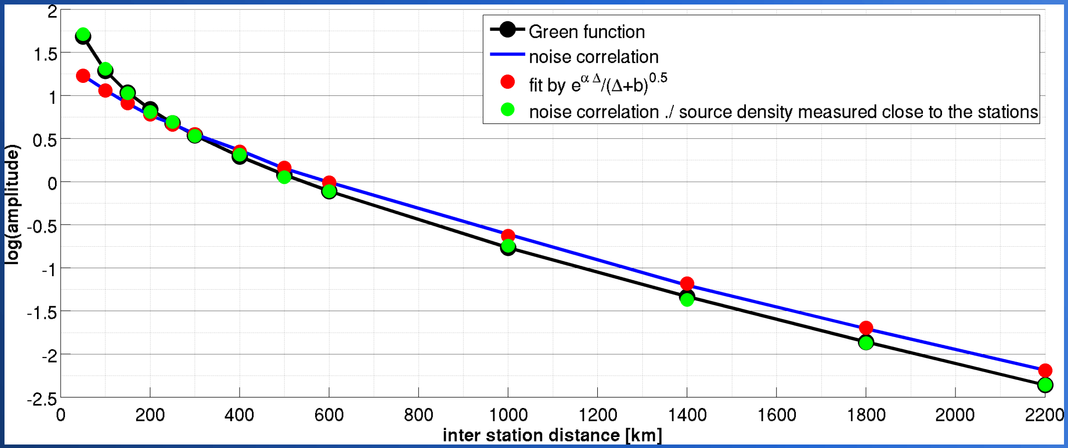




Correlations & Green functions have the same amplitude decay
=> possible to use correlations to measure attenuation

A simple case where noise correlations decays less than the GF

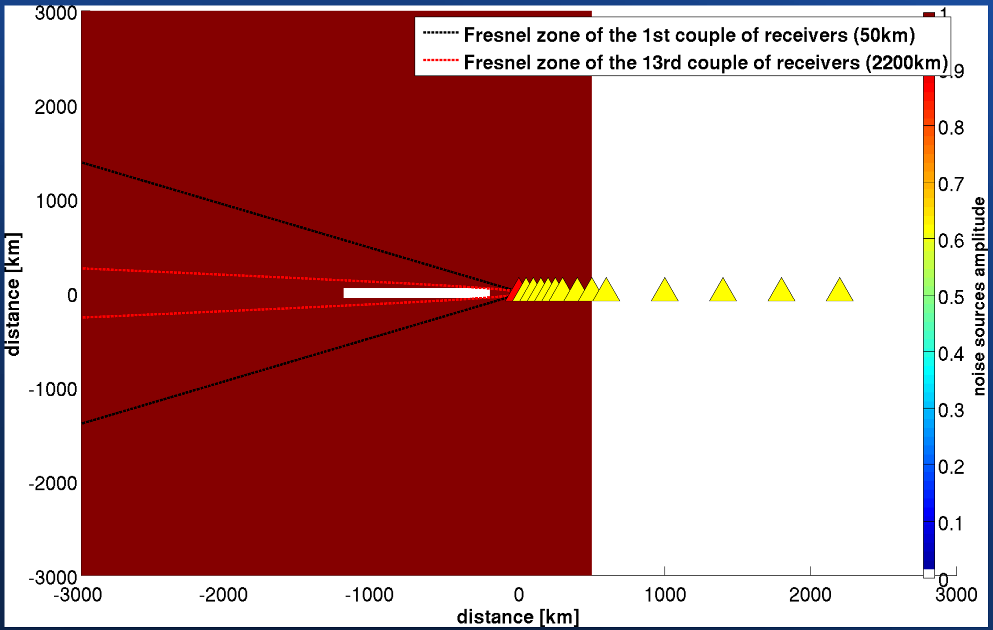


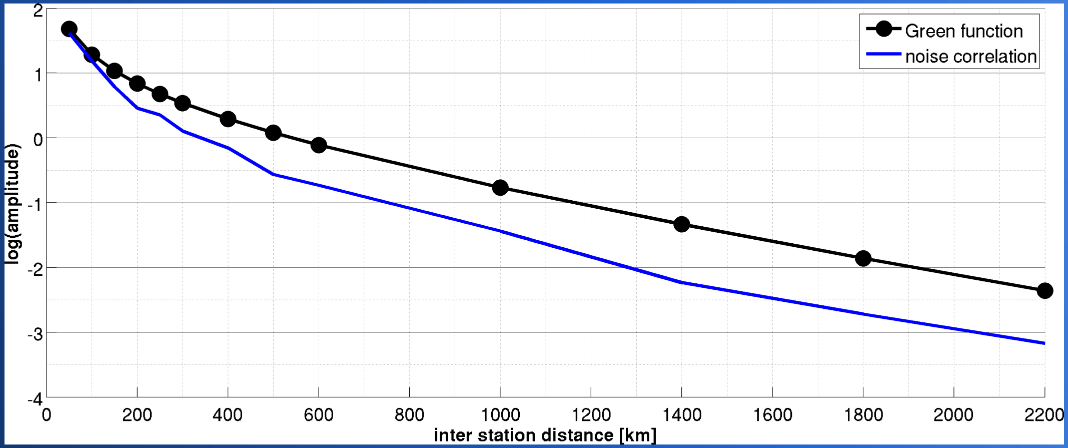


As the interstation distance increases :

- coherent area become narrower
- =>the density of sources within the coherent area increases
- => CCs have a weaker amplitude decay than the GF

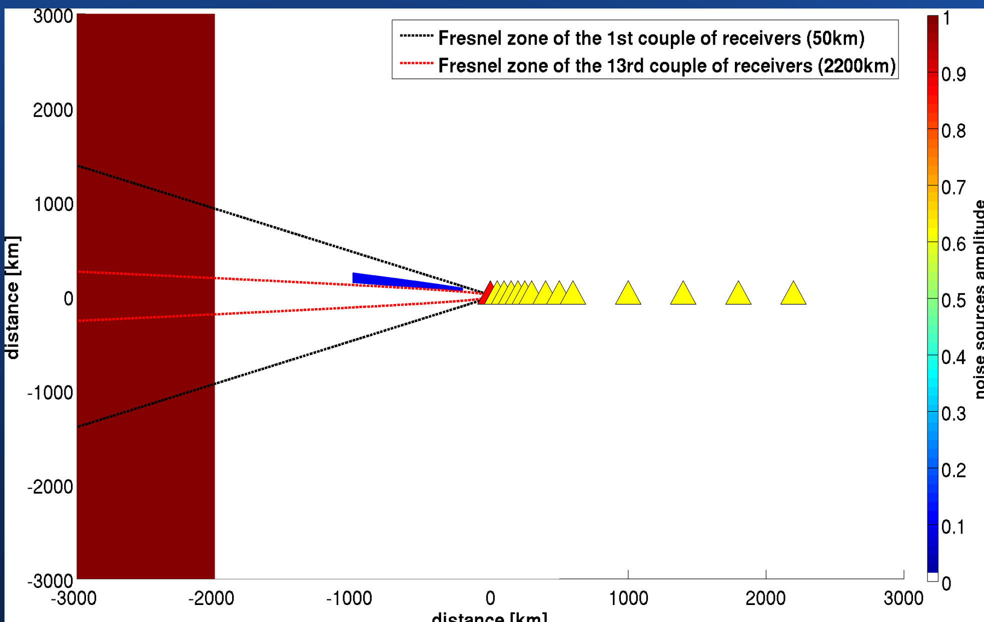
A simple case where noise correlations have a stronger amplitude decay than the GF

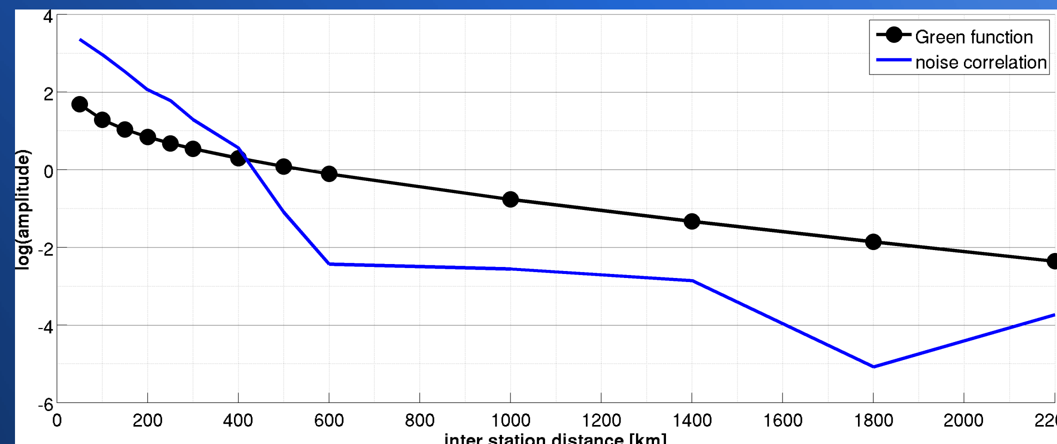




As the interstation distance increases :
- coherent area become narrower
- =>the density of sources within the coherent area decreases
- => CCs have a stonger amplitude decay than the GF

Effect of a small scale heterogeneity close to the receivers





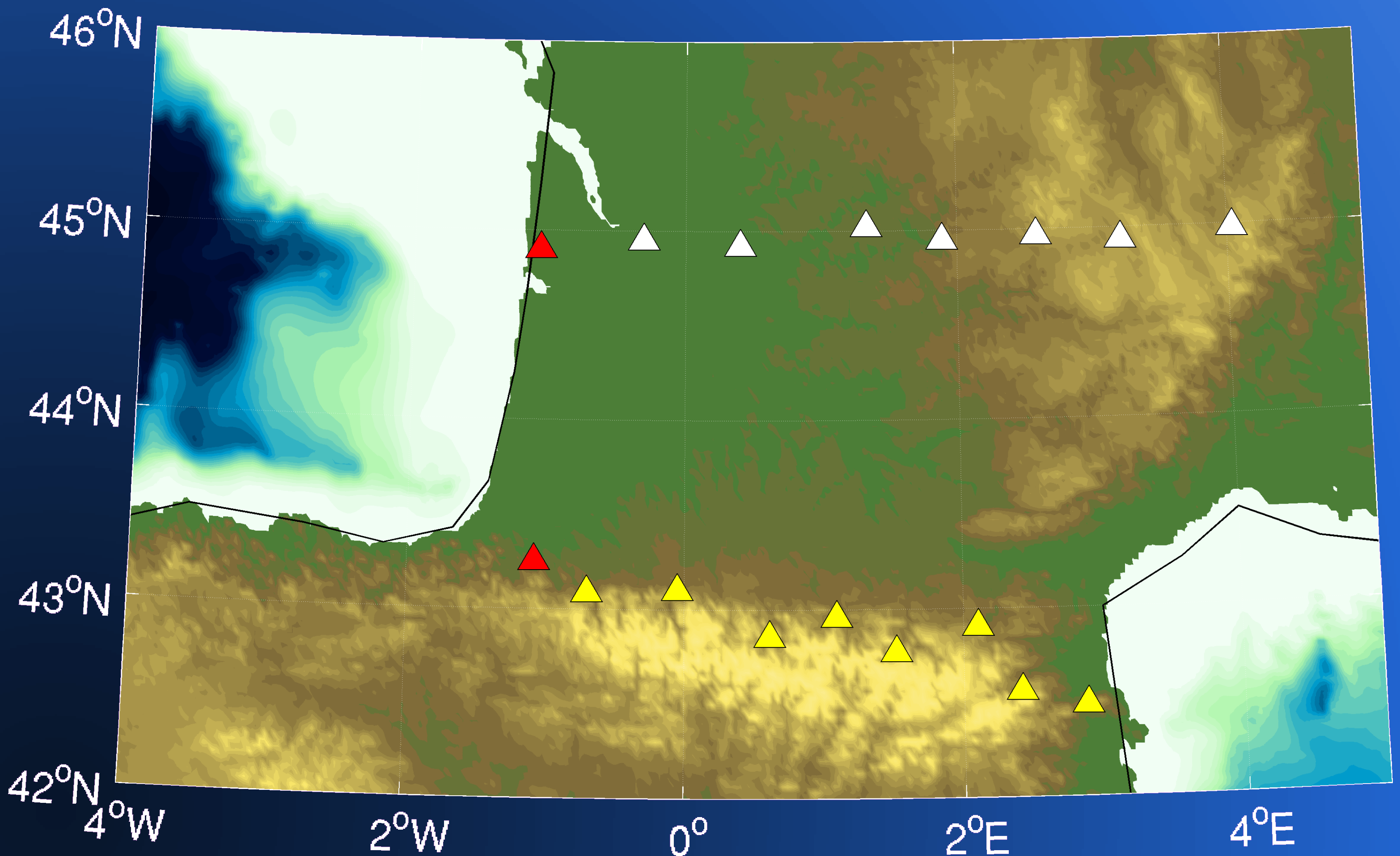
Depending on the inter-station distance :
- the heterogeneity can be on a positive or negative oscillation of the kernel
=> CCs have a stronger of weaker decay than the GF depending on the inter-station distance

Partial conclusion

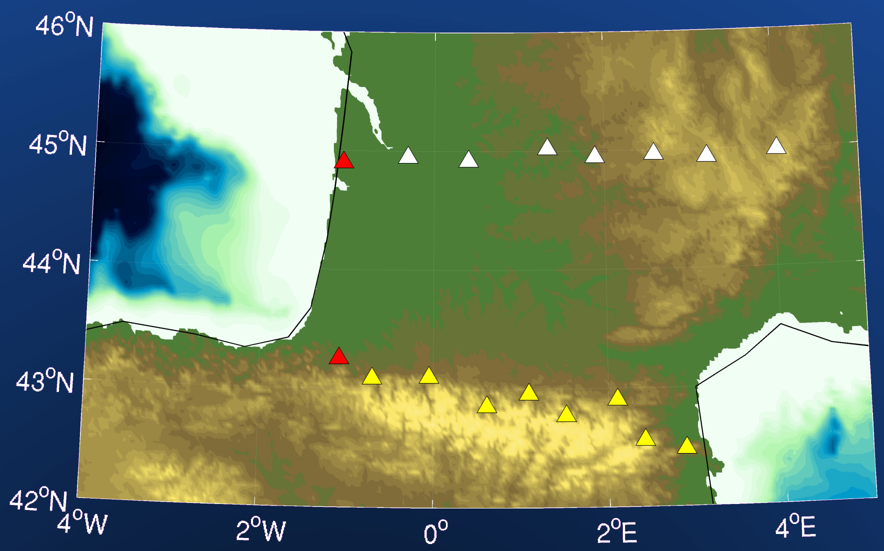
- Even when considering a line receivers, depending on the source distribution, the amplitude decay of the correlations can be similar, stronger or weaker than the amplitude decay of GF

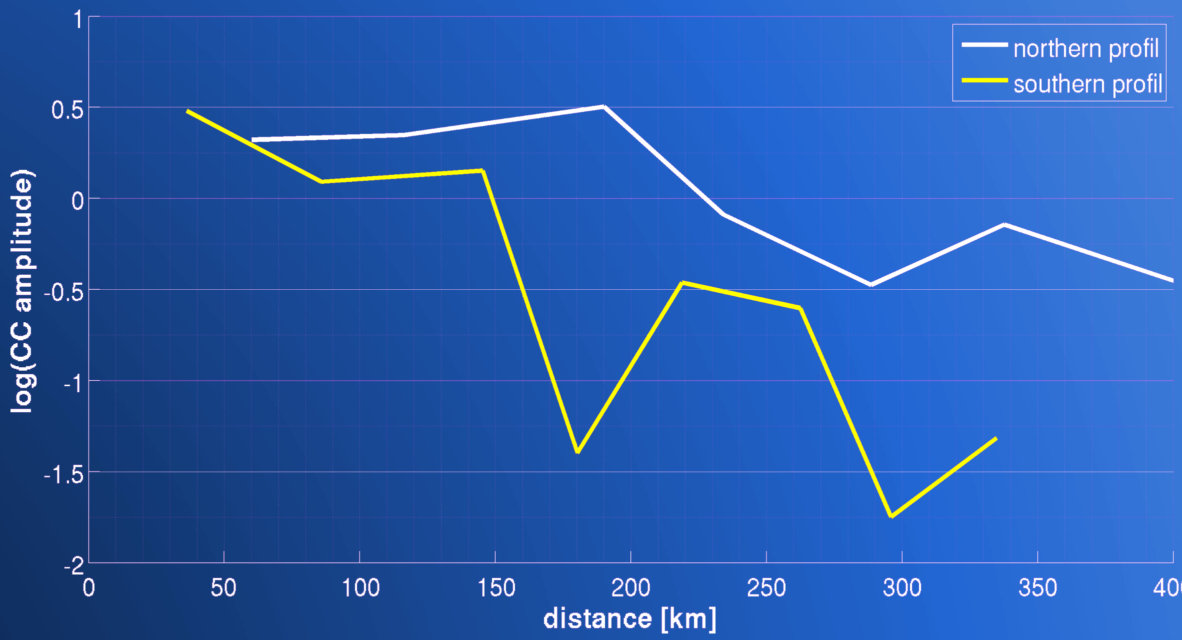
Application in the Pyrenees

Network used



noise correlations amplitude vs distance in the 5-10s period band

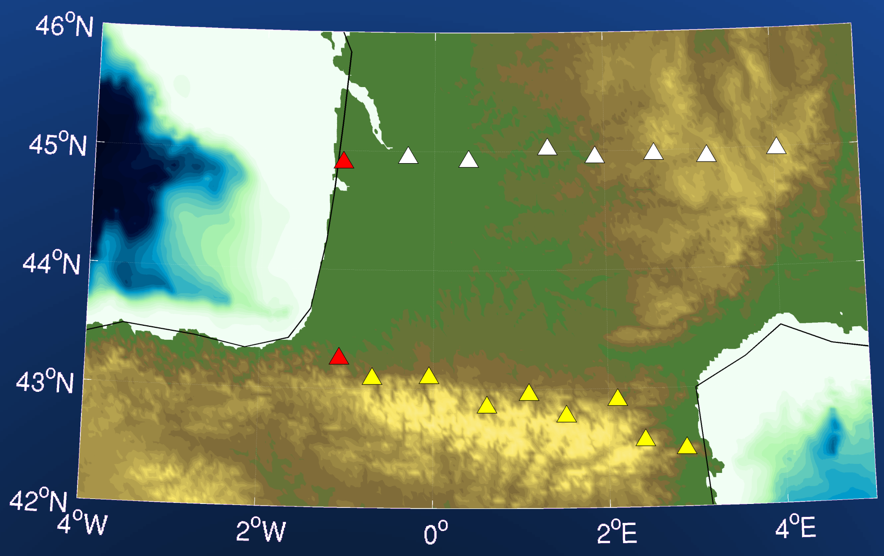


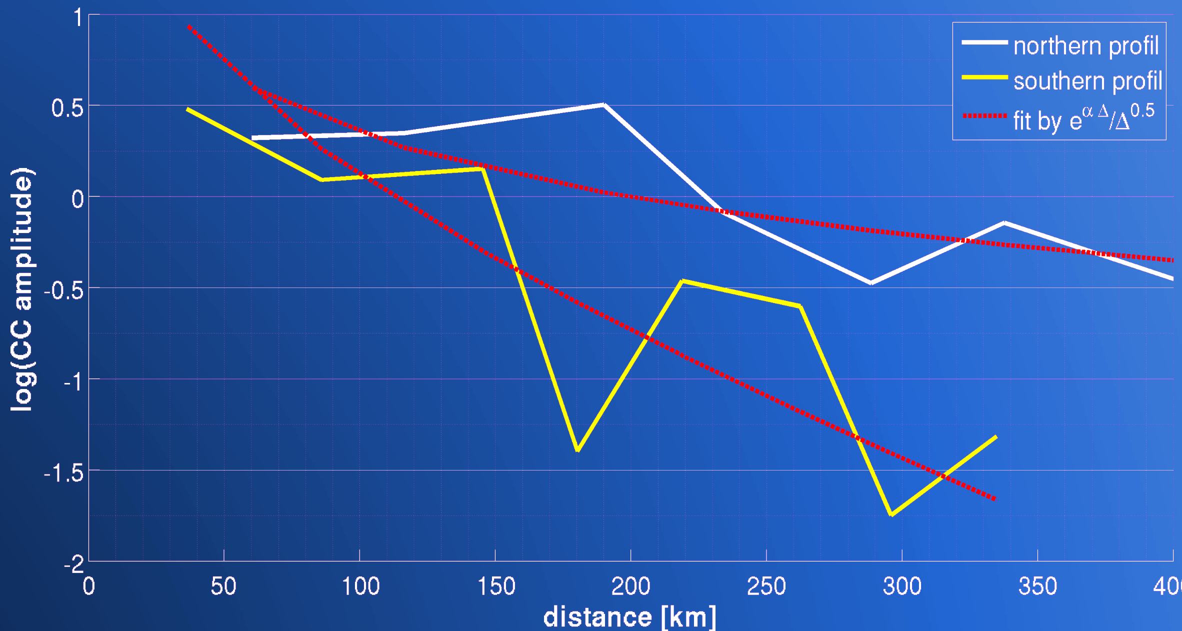


- Stronger amplitude decay for the southern profil

Interpretation 1 : assuming a homogenous distribution of noise sources so that CCs have the same amplitude decay than the GF

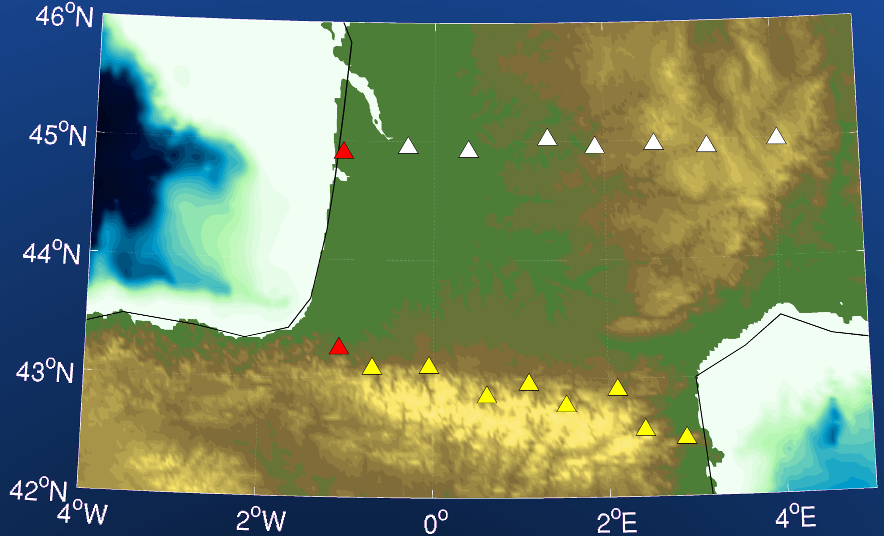
Fitting the amplitude by $\exp(-\alpha\Delta)/\sqrt{\Delta}$

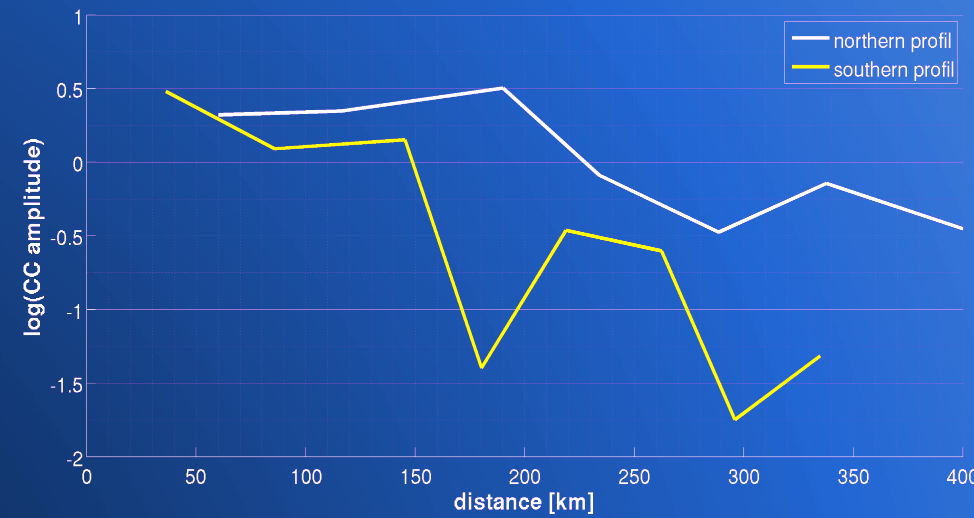




- northern profil : $\alpha = 0$
- southern profil : $\alpha = -5.10^{-3} \quad (Q_R \sim 40)$

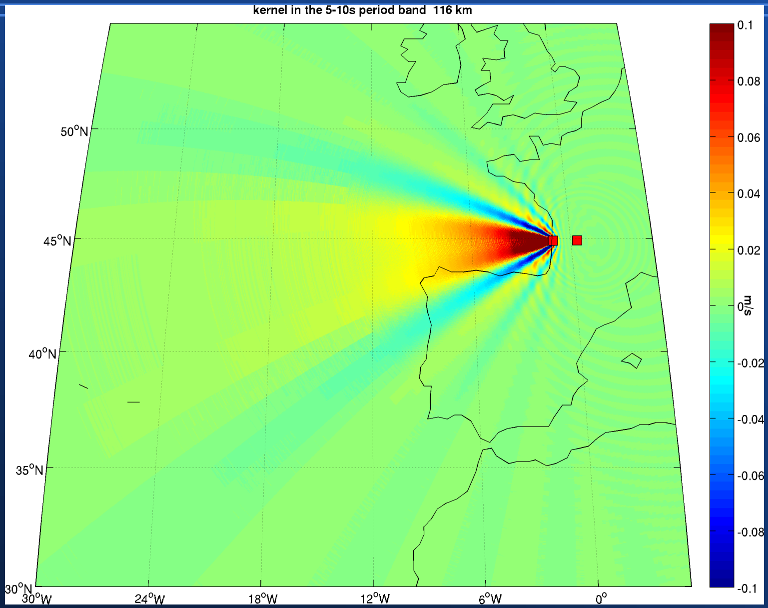
Interpretation 2 : we assume that the attenuation along both profils is the same.
=>is it possible to find a source distribution which explains our observations in a laterally homogeneous medium ?

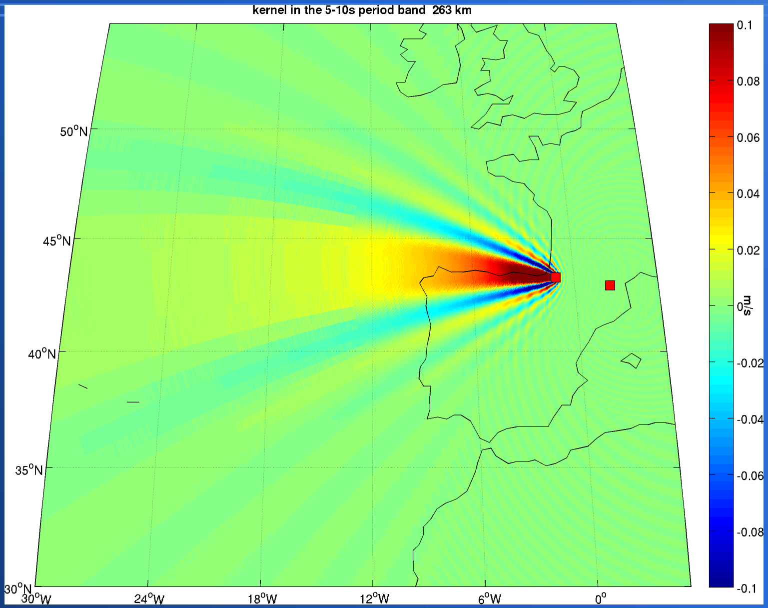




- We look for a source distribution for which synthetic correlations in PREM have the same amplitude decay that the observed CCs
- => We invert the amplitude of the CCs in PREM to find a source distribution
- We look specificaly for sources located close to the coastline

1st step of the inversion



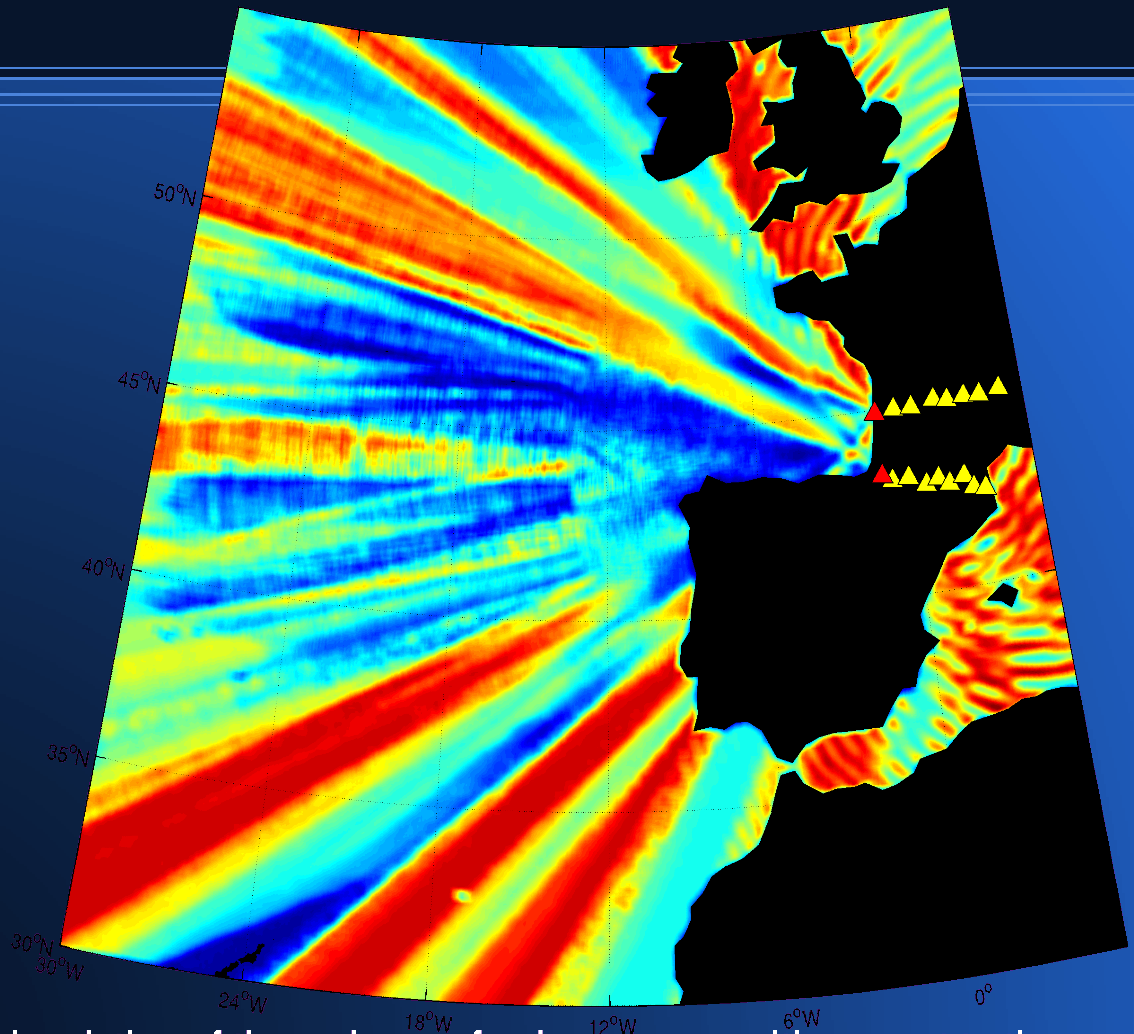


- Compute noise source kernels for each pair of receivers
- Amplitude of synthetic CCs = source * kernels
- => neglect the fact that the arrival time of surface waves can change when sources are perturbed
- Minimize misfit function : $$\chi = \sum_{i=1}^{n} \left[\log(A_i^0) - \log(A_i^s)\right]^2$$

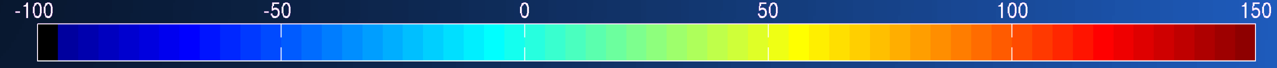
2nd step of the inversion

- Non linear : do not use the kernels anymore
- Perturb each source one by one
- Compute synthetic perturbed CCs and measure their amplitudes
- If the perturbation minimize the misfit we keep it.
- Reiterate several times ...

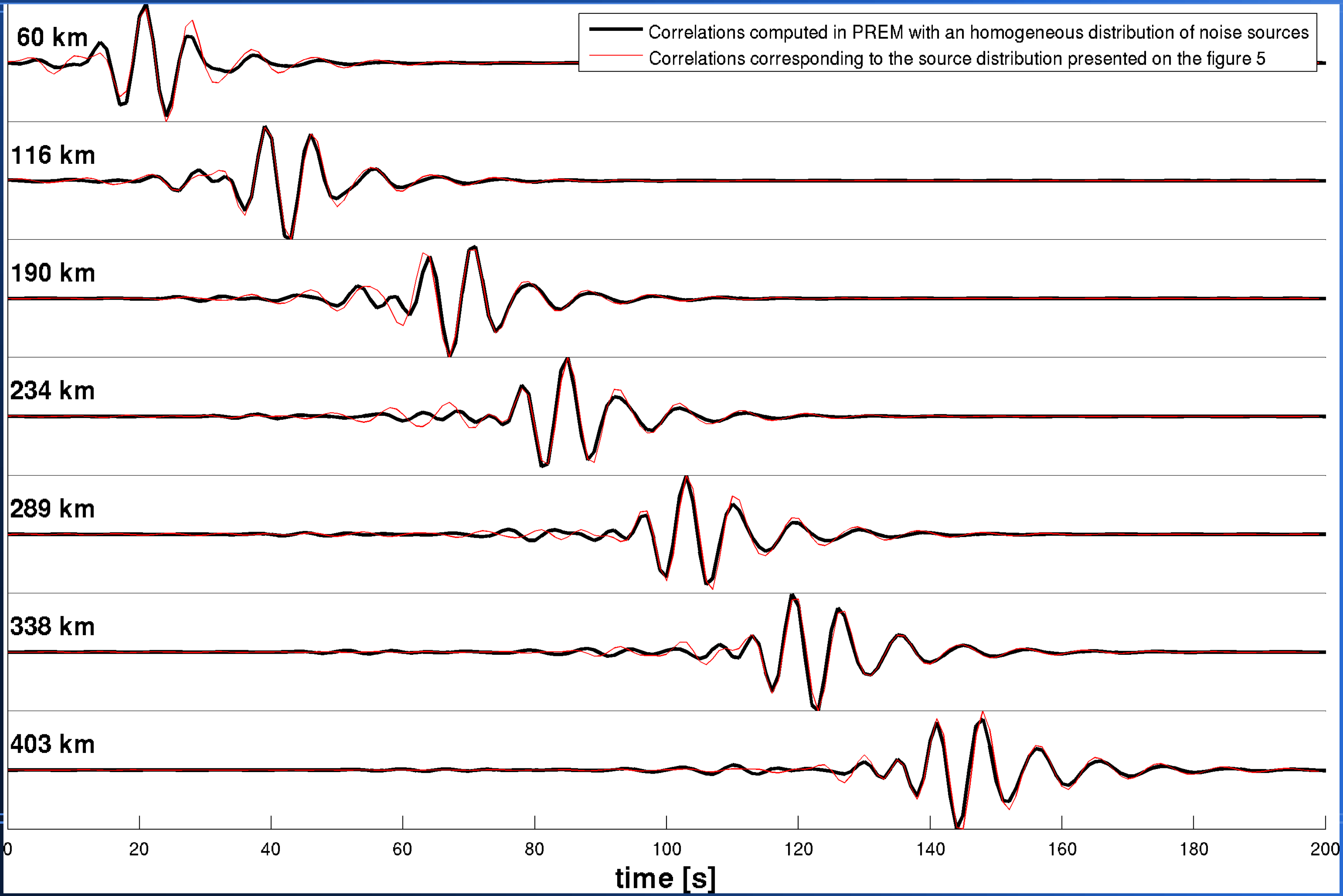
- We are NOT looking for a realistic source distribution
- 2 lines of receivers => poor azimuthal resolution
- Low spatial extent of the network => cannot get the distance of the sources
- Is it *theoretically* possible to find a distribution of source which explains our data ?



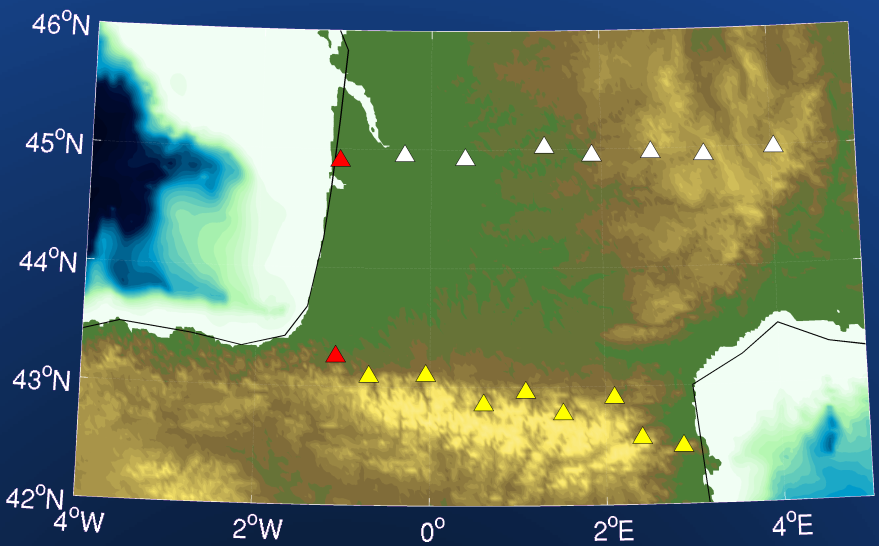
lateral variation of the variance of noise sources with respect to the mean in %

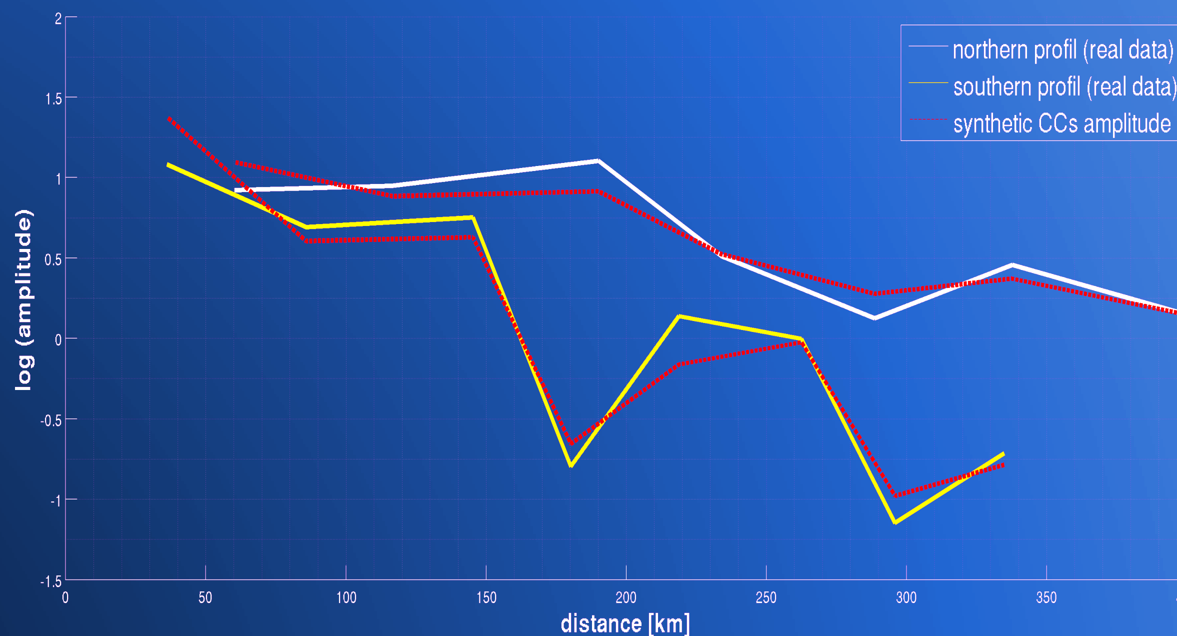


Synthetic correlations computed in PREM with a homogeneous (black) and heteogeneous (red) distribution of sources



Intepretation 2 : does this source distribution explains our observations ?





- Most of the observations can be explained by a heterogeneous source distribution and a homogeneous Earth model
- This does not imply that everything is **really** explained by the distribution of noise sources

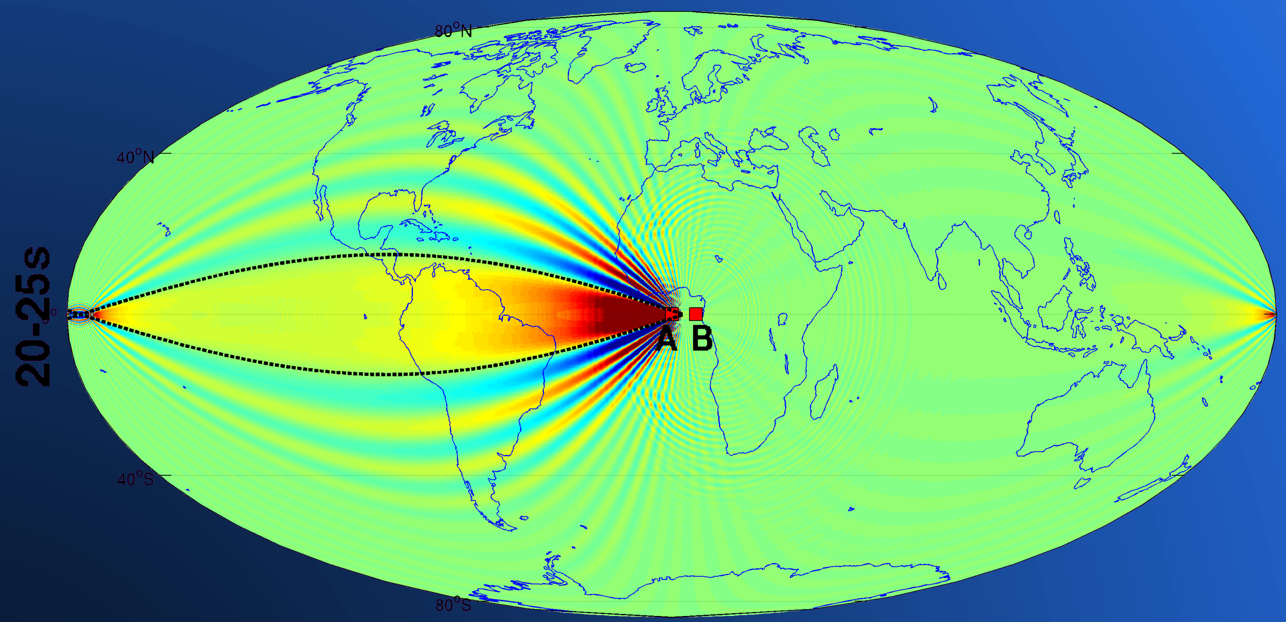
Partial conclusion

- There is no conclusion
- Even considering a line of receivers :
  - It is wrong to assume that the same source region contribute to all correlations
  - => CC can have a similar decay than the GF
  - => CC can have a stronger/lower amp. decay
- It is not safe to interpret the amplitude decay of noise correlations in term of attenuation, without making sure that the observations are not explained by the sources.
- **We assumed a non-scattering medium !**

related topics ...

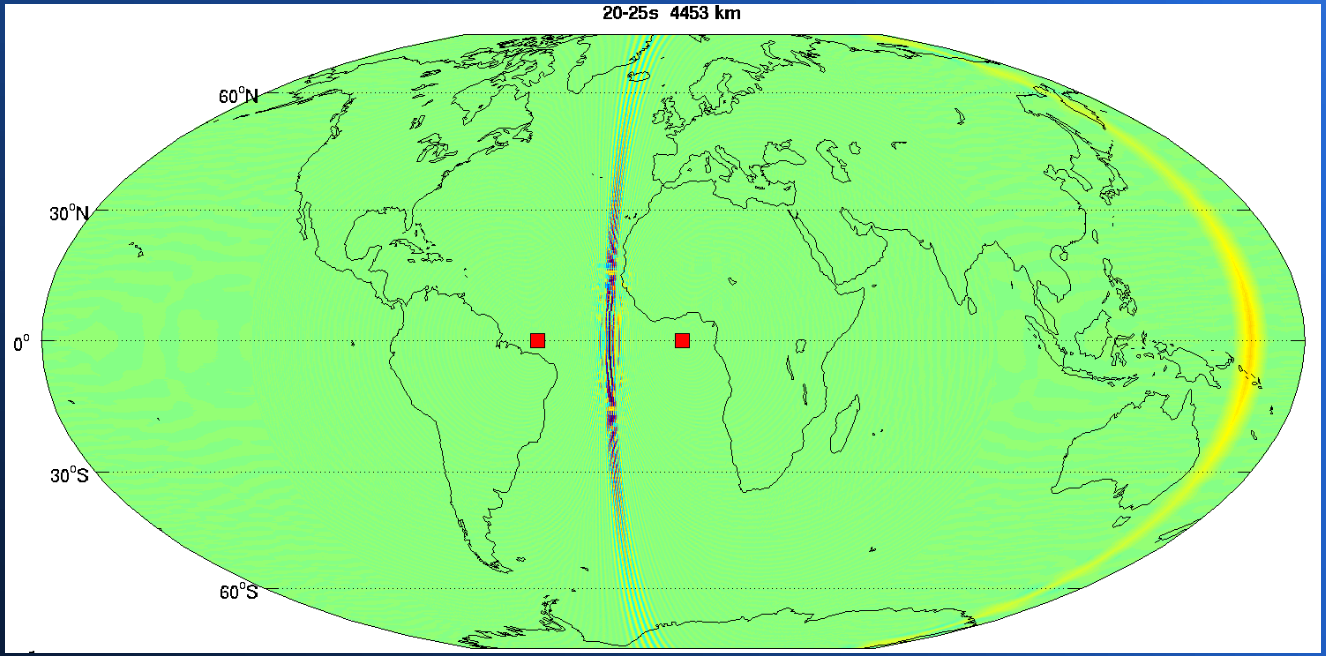
- Impact of pre-processing (1-bit normalization, ….) on the noise correlations amplitude
- Measuring amplitude kernels using correlation of noise correlations => Pierre Boué

Imaging the source using noise correlations



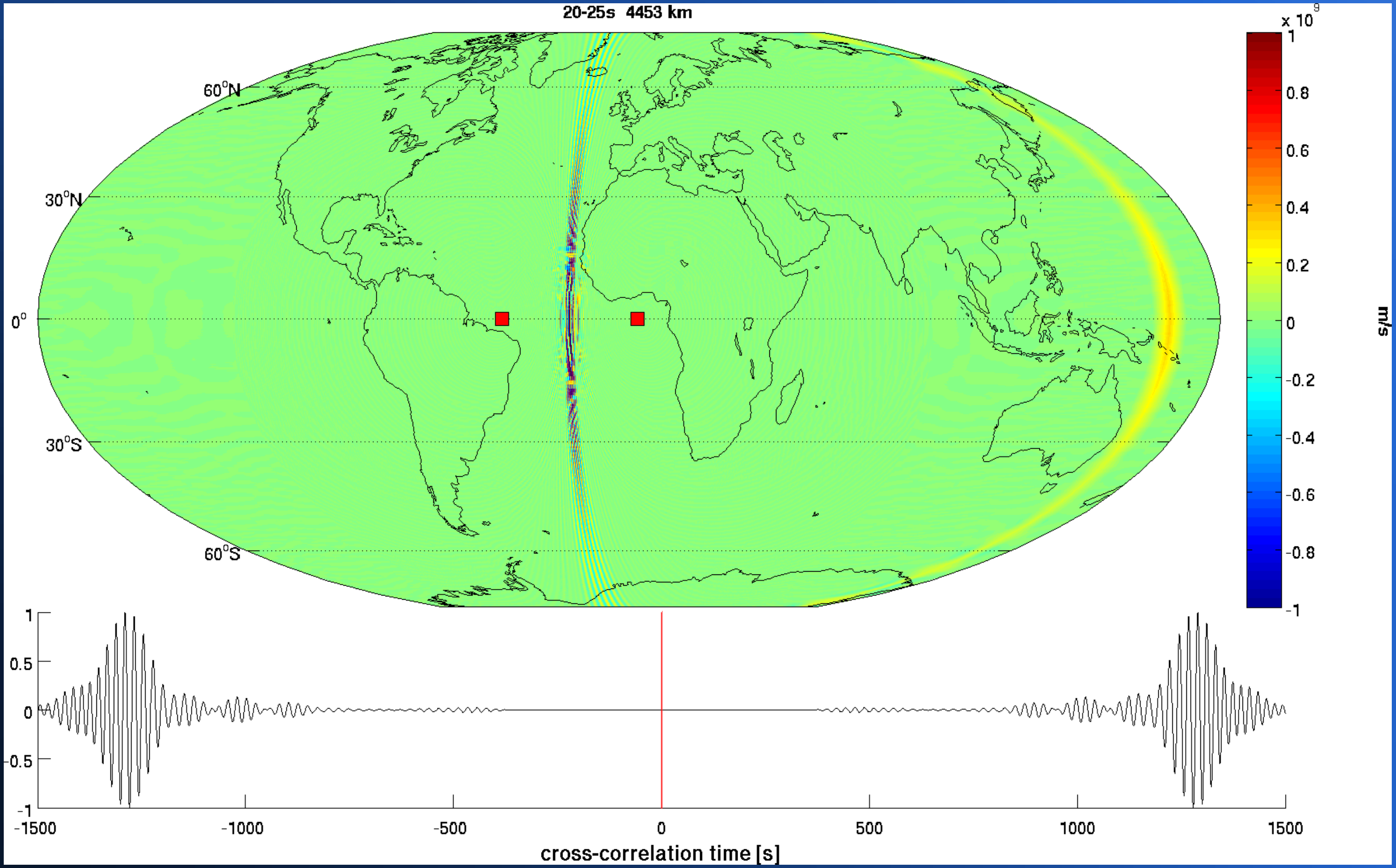
- Strategy 1 : using noise correlation surface waves amplitude

  Large kernel => limited resolution

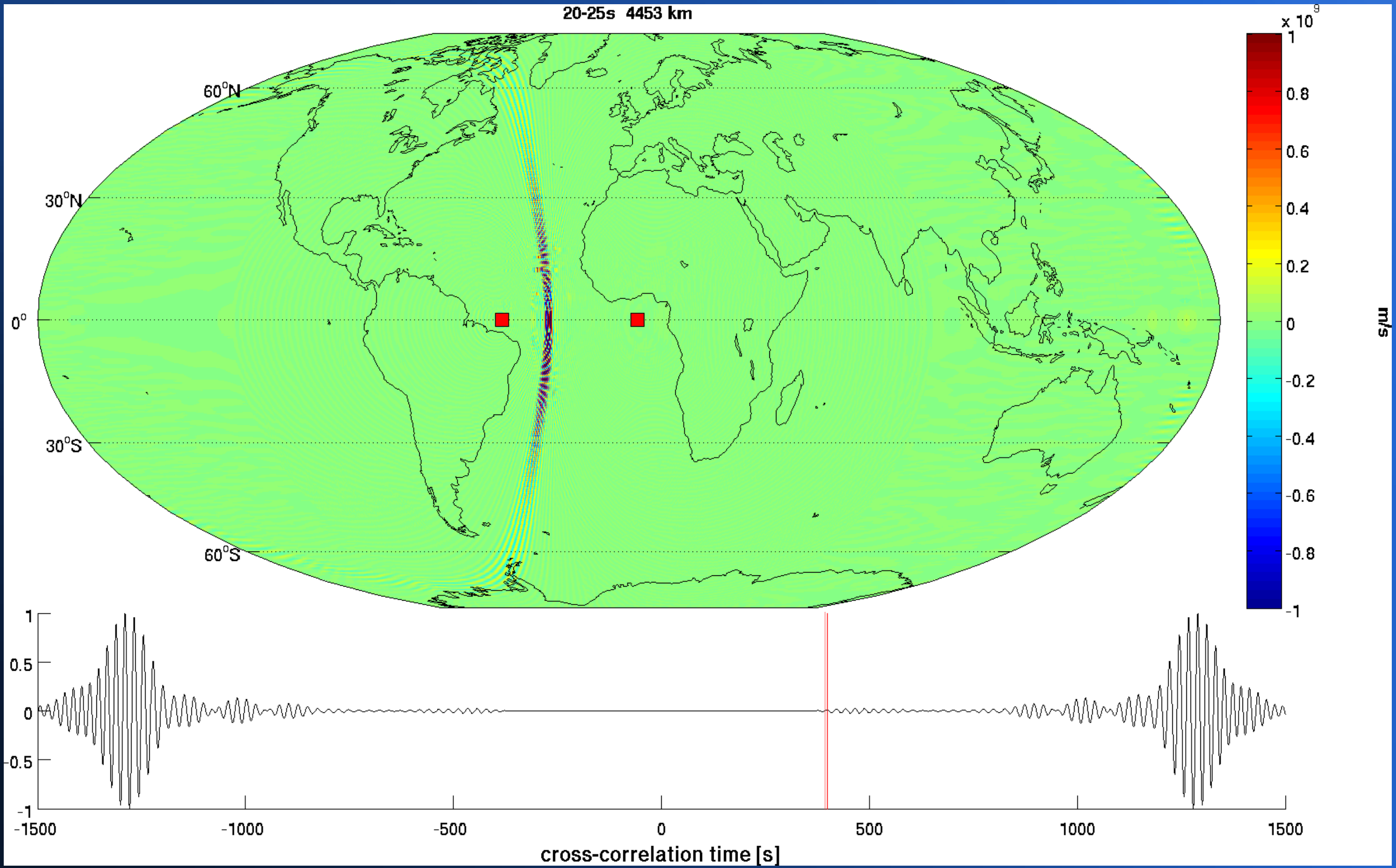


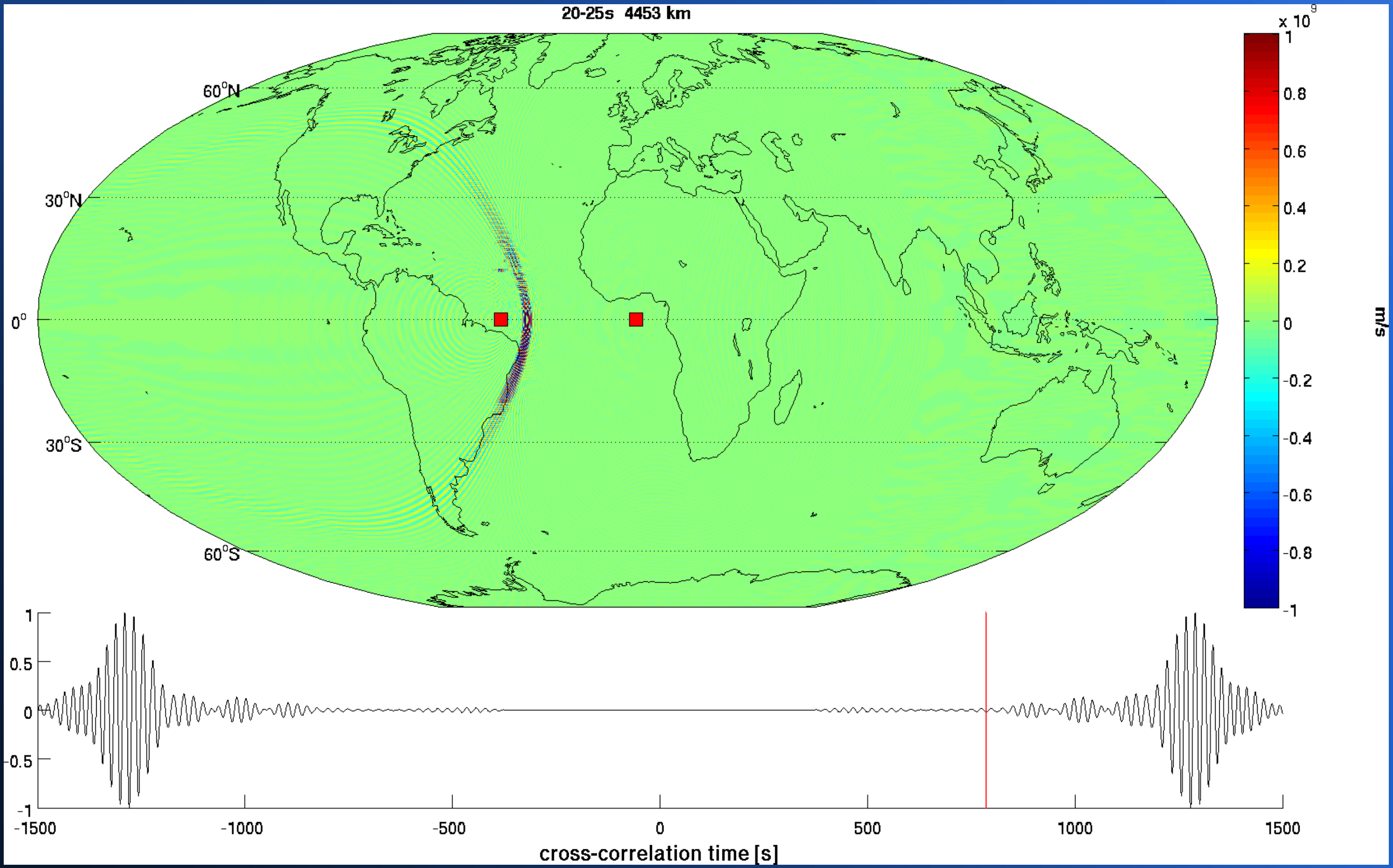
- Strategy 2 : using 2 stations on both side of the ocean
- Atlantic noise source => spurious arrival around the time 0

Noise source kernel computed at the time 0 of the correlation



Narrow kernel => greater resolution


20-25s 4453 km
60°N
30°N
0°
30°S
60°S
x 10^9
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
m/s
1
0.5
0
-0.5
-1
-1500
-1000
-500
0
500
1000
1500
cross-correlation time [s]



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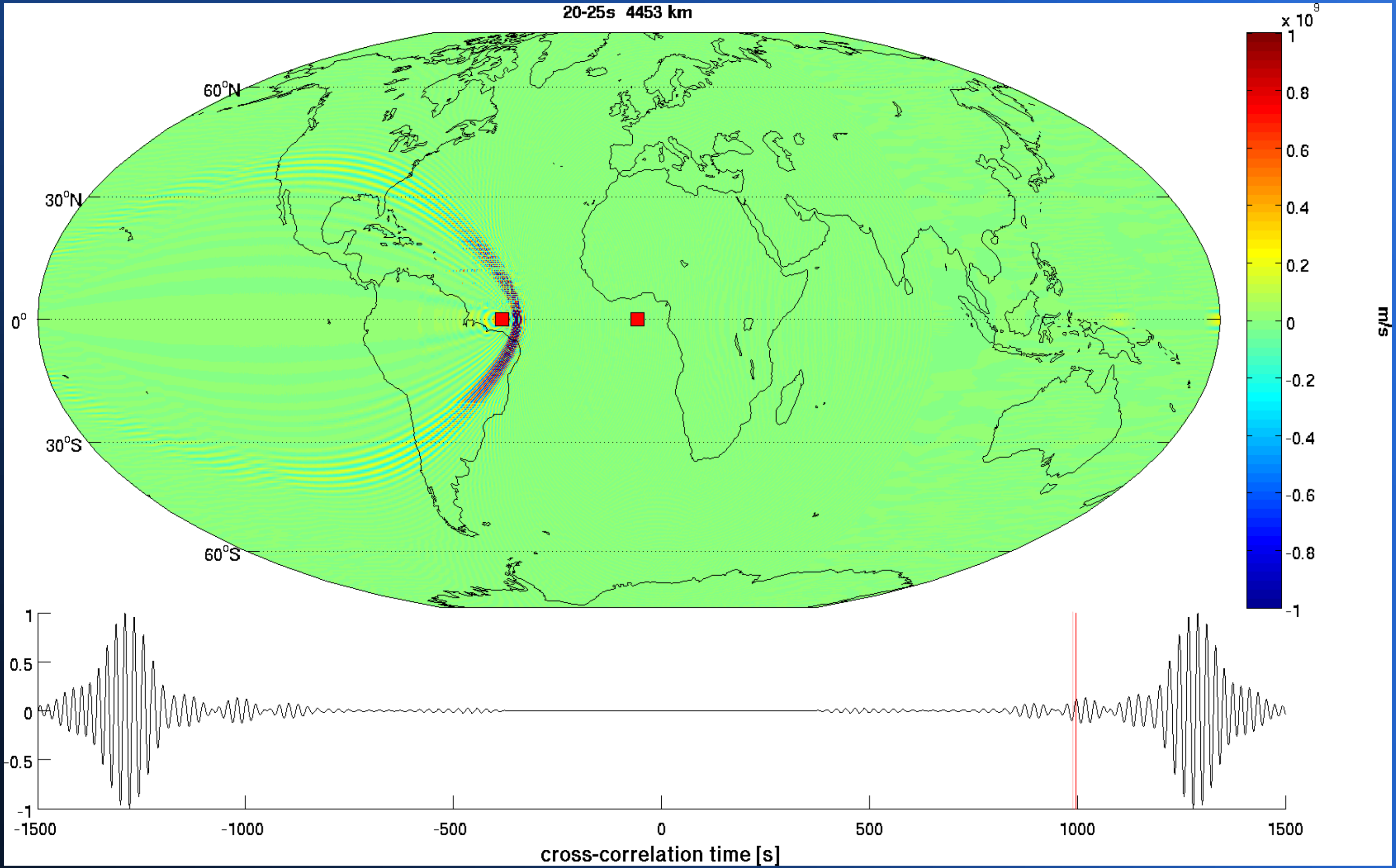

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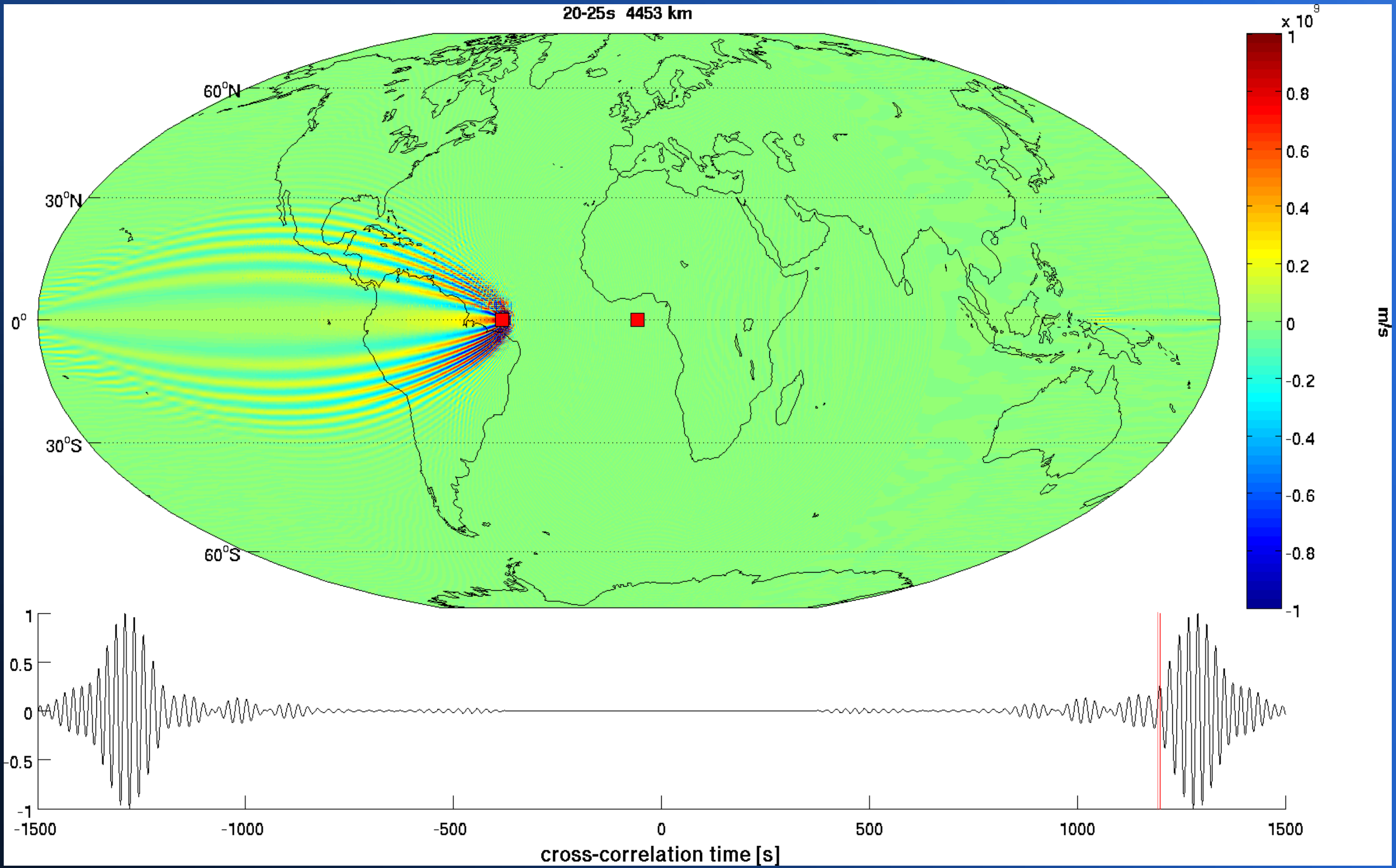
cross-correlation time [s]



20-25s 4453 km
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0°
30°S
60°S
x 10^9
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0.2
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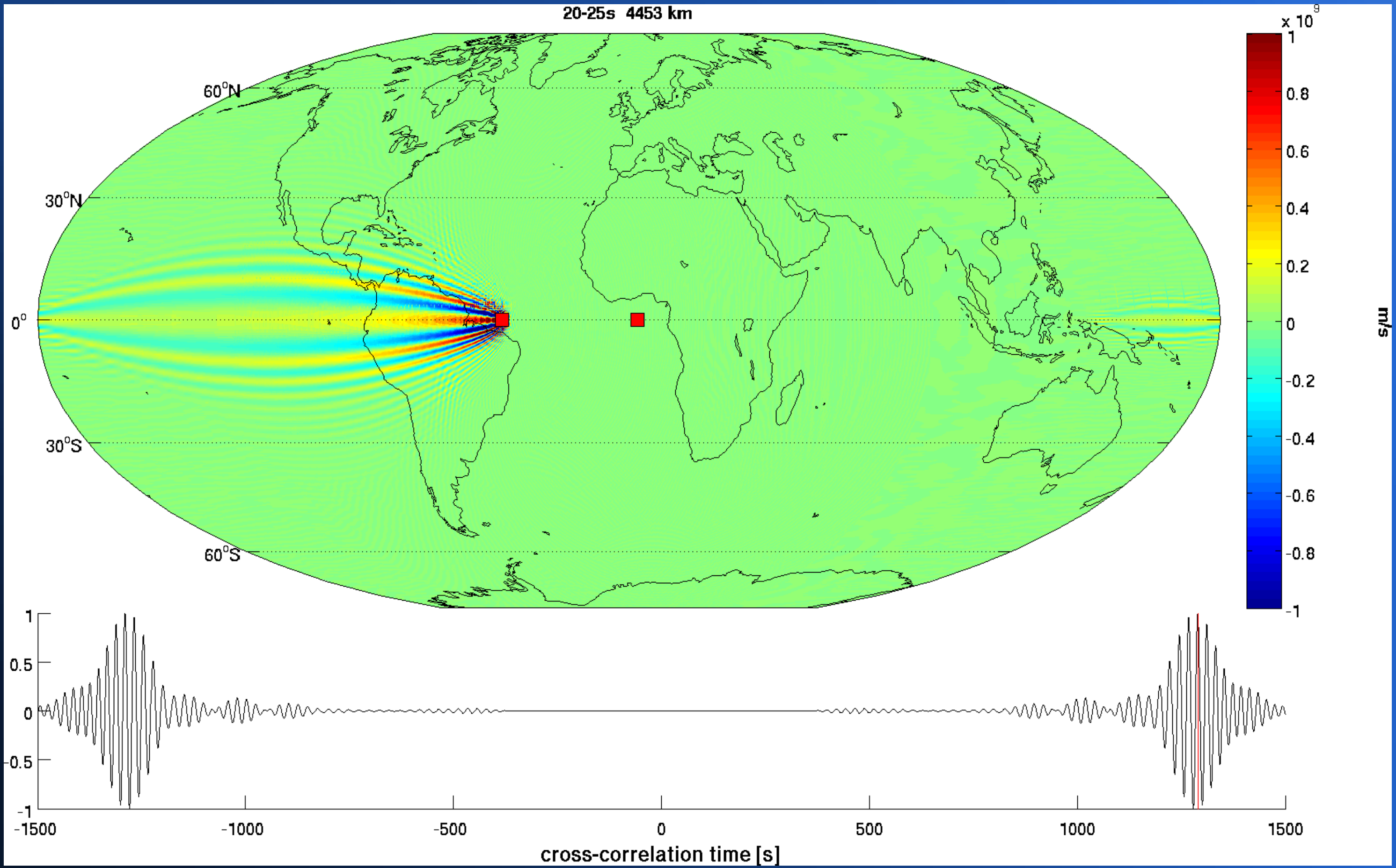
-0.2
-0.4
-0.6
-0.8
-1
0.5
-0.5
-1500
-1000
-500
500
1000
1500
cross-correlation time [s]



20-25s 4453 km
60°N
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60°S
x 10^9
1
0.8
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0.2
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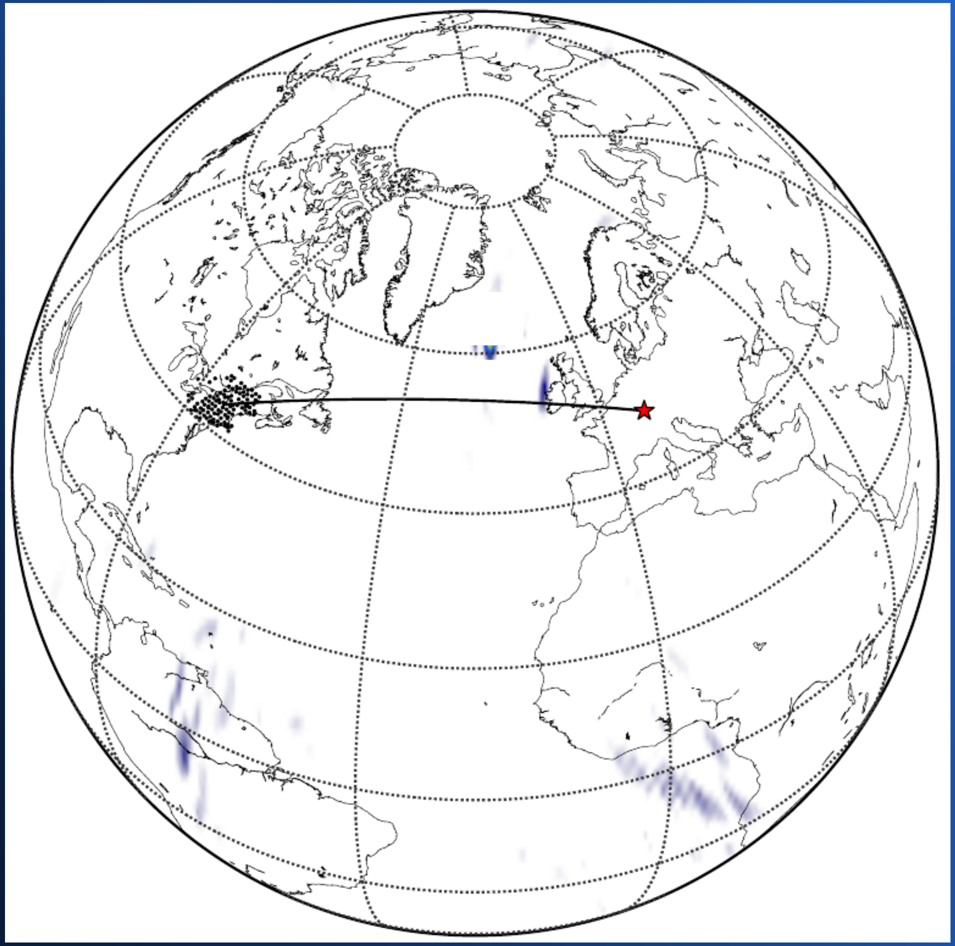
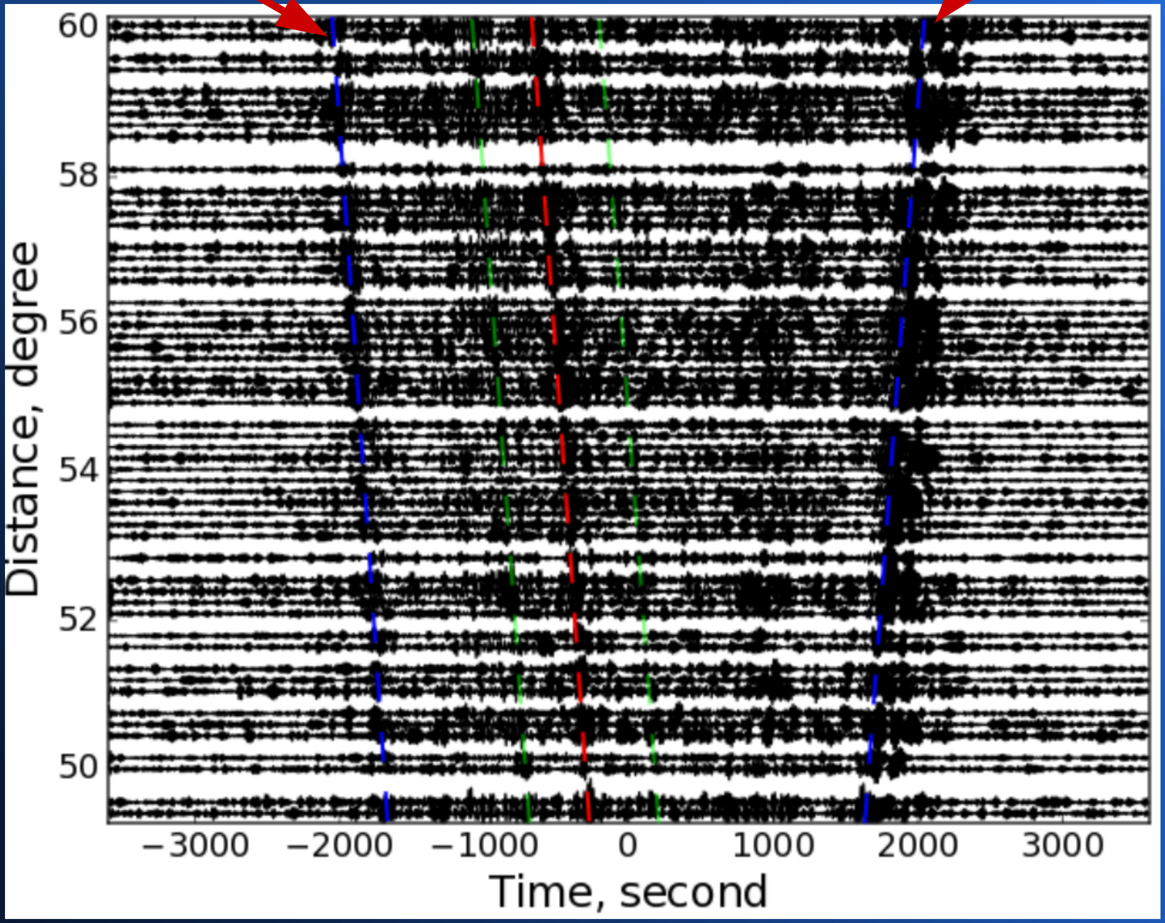
-0.2
-0.4
-0.6
-0.8
-1
m/s
1
0.5
0
-0.5
-1
-1500
-1000
-500
0
500
1000
1500
cross-correlation time [s]

Cross-correlations computed accross the Pacific ocean
(from Retailleau et al, submitted)

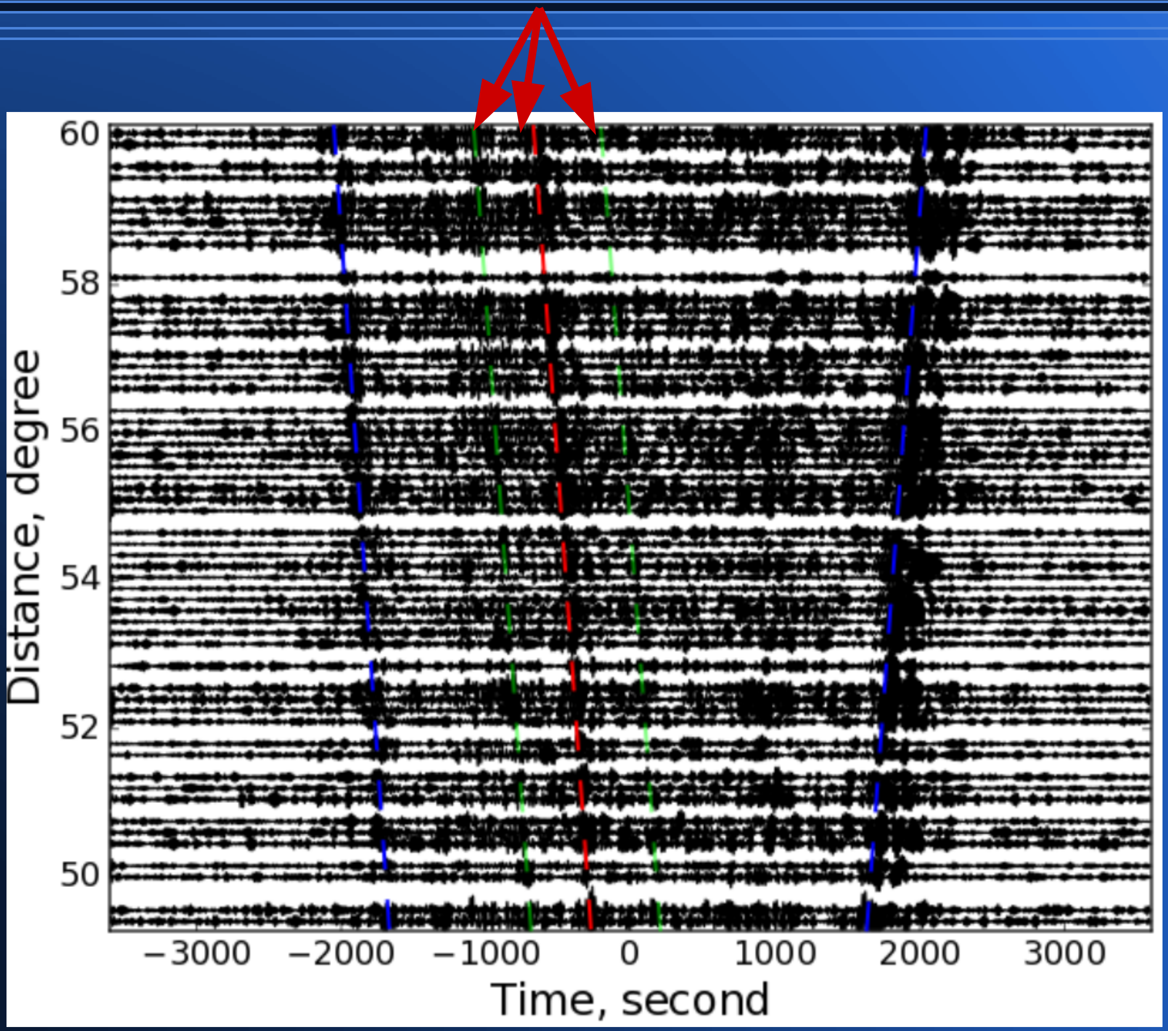


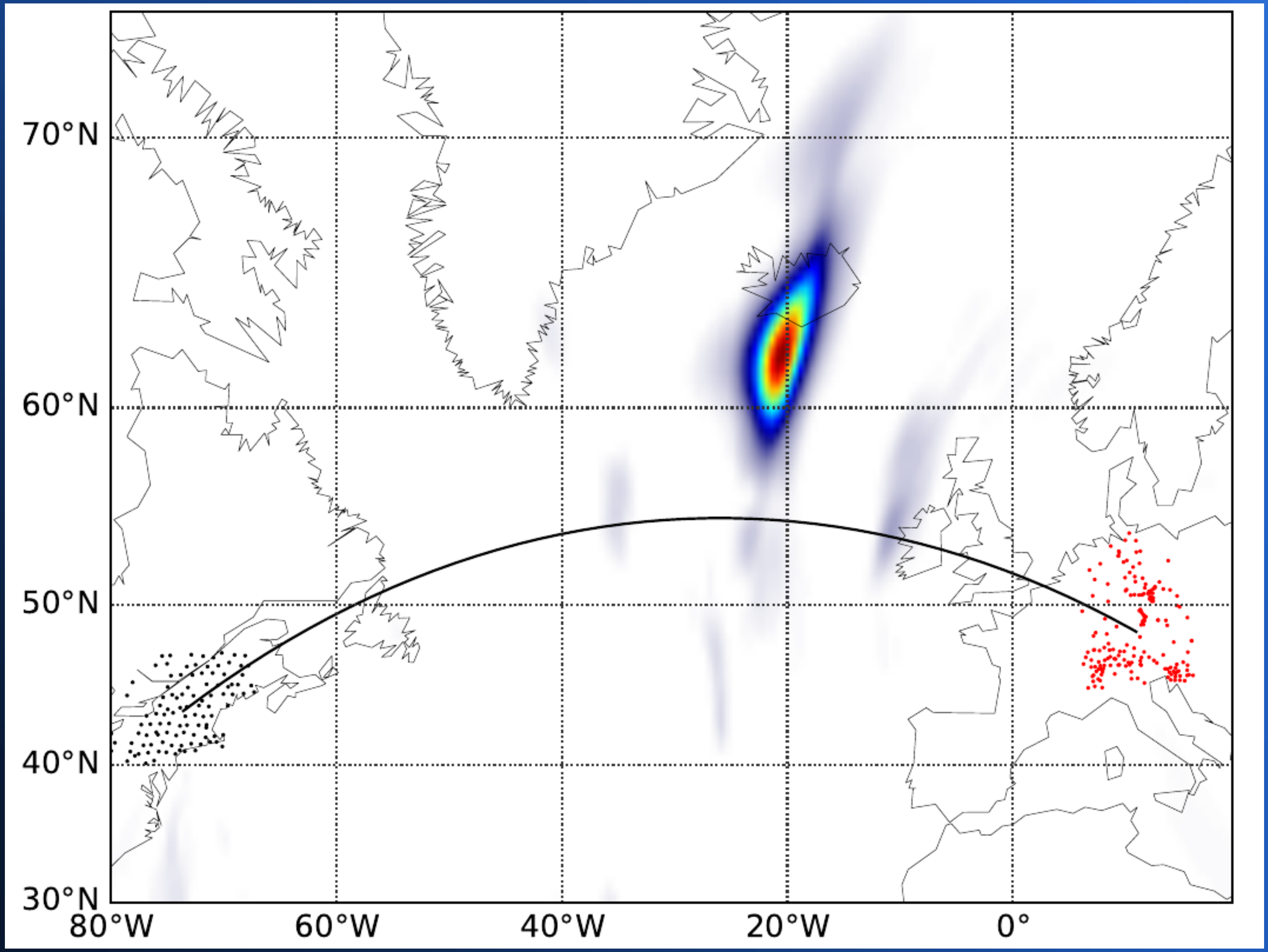
Rayleigh waves US=> Europe

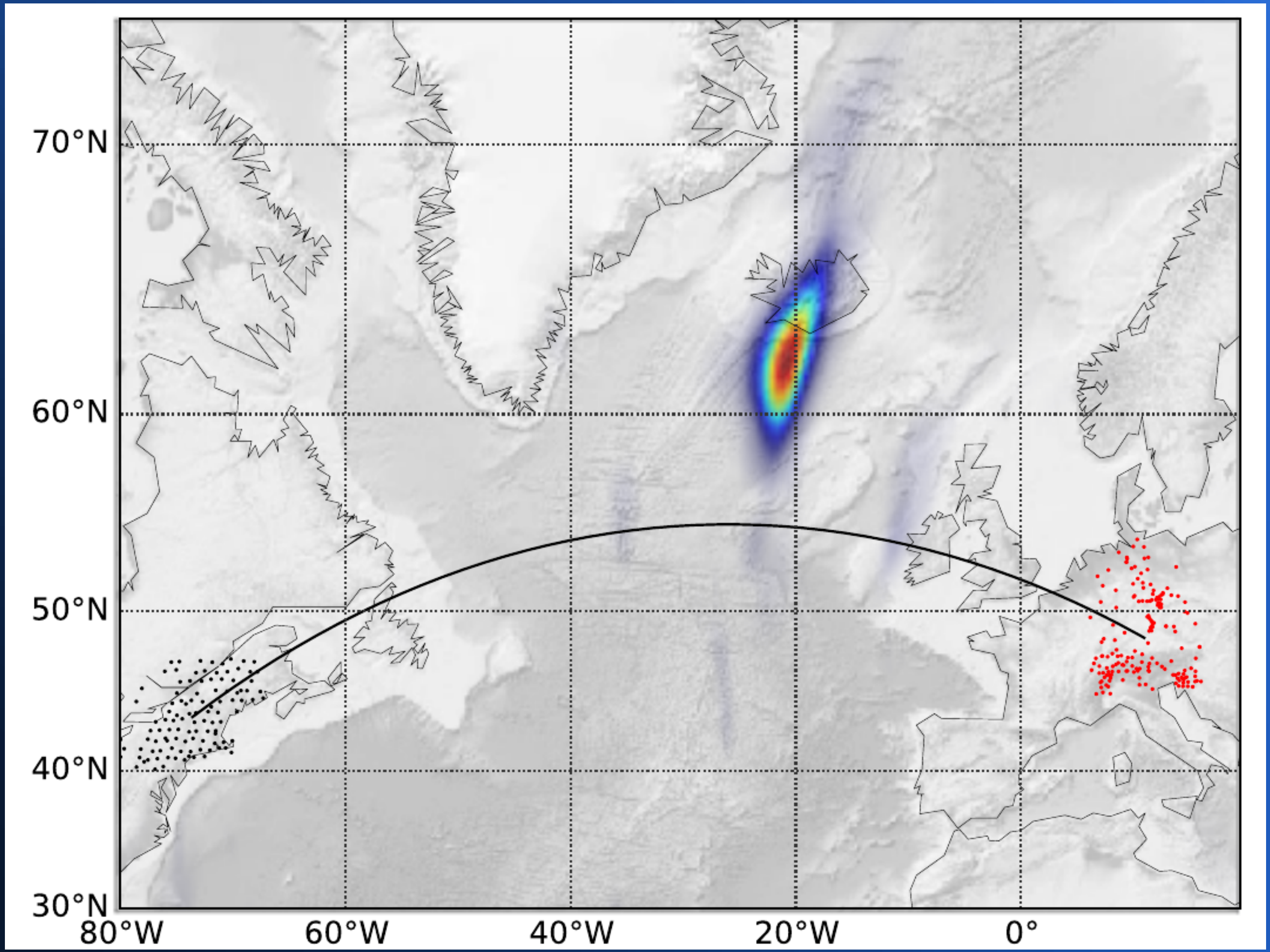
Rayleigh waves Europe => USA



Rayleigh waves from the Atlantic ocean to => BFO, USA
Which do not cancel in the correlations




70°N
60°N
50°N
40°N
30°N
80°W
60°W
40°W
20°W
0°



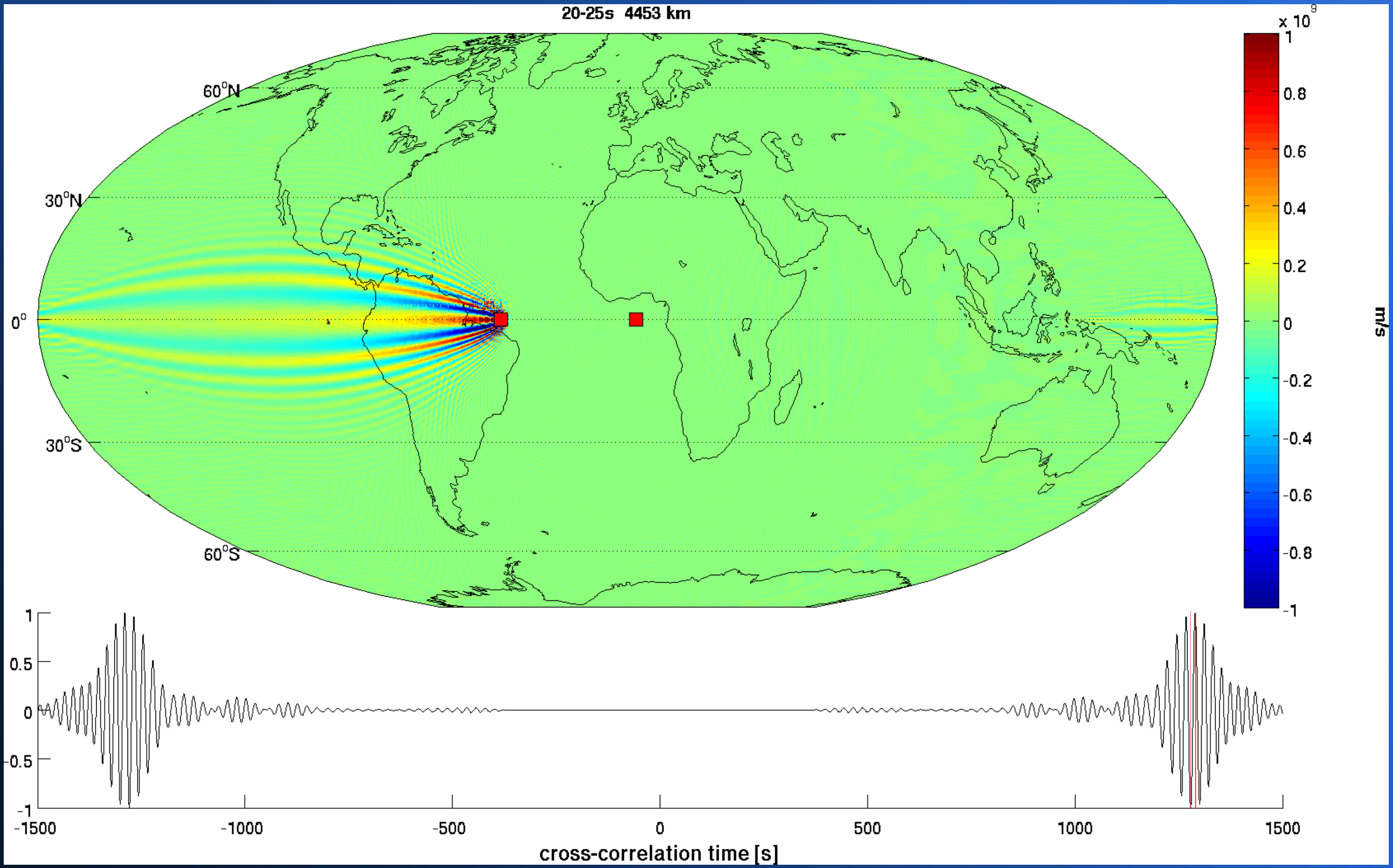
70°N
60°N
50°N
40°N
30°N
80°W
60°W
40°W
20°W
0°

Conclusion

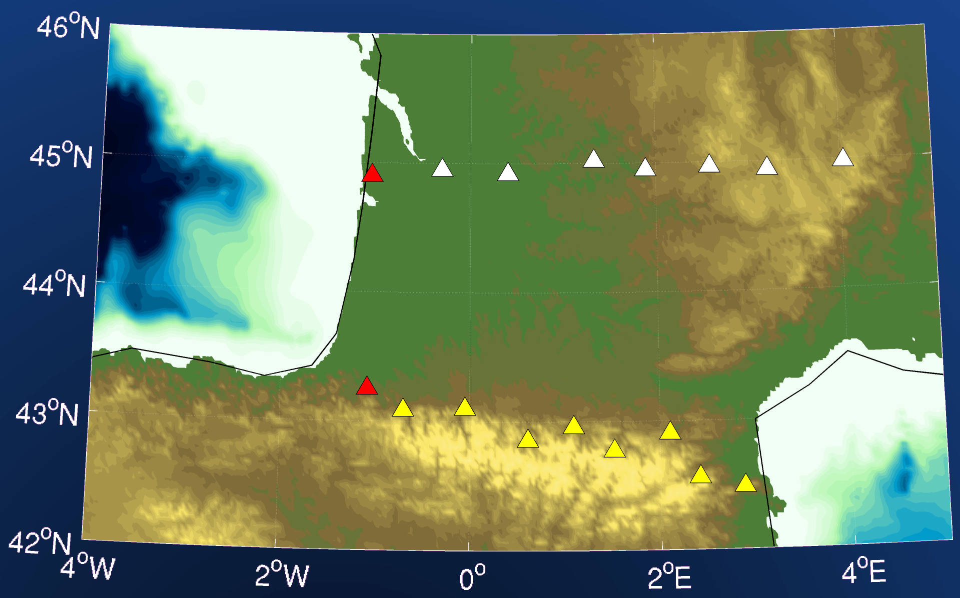
- Several strategies to image the source distribution :
  - Amplitude of the noise correlations surface waves vs azimuth
  - Spurious arrivals on transatlantic correlations
  - Beamforming

The end

Instead : consider two stations across the ocean => kernel become narrower, better azimuthal resolution when imaging sources



Partial conclusion 2/2



- Is it possible to use stations deployed along a line to measure the attenuation of surface waves ?

  => all correlations sensitive *more or less* to the same sources region ?

  => CC's amplitude depends only on the medium ?