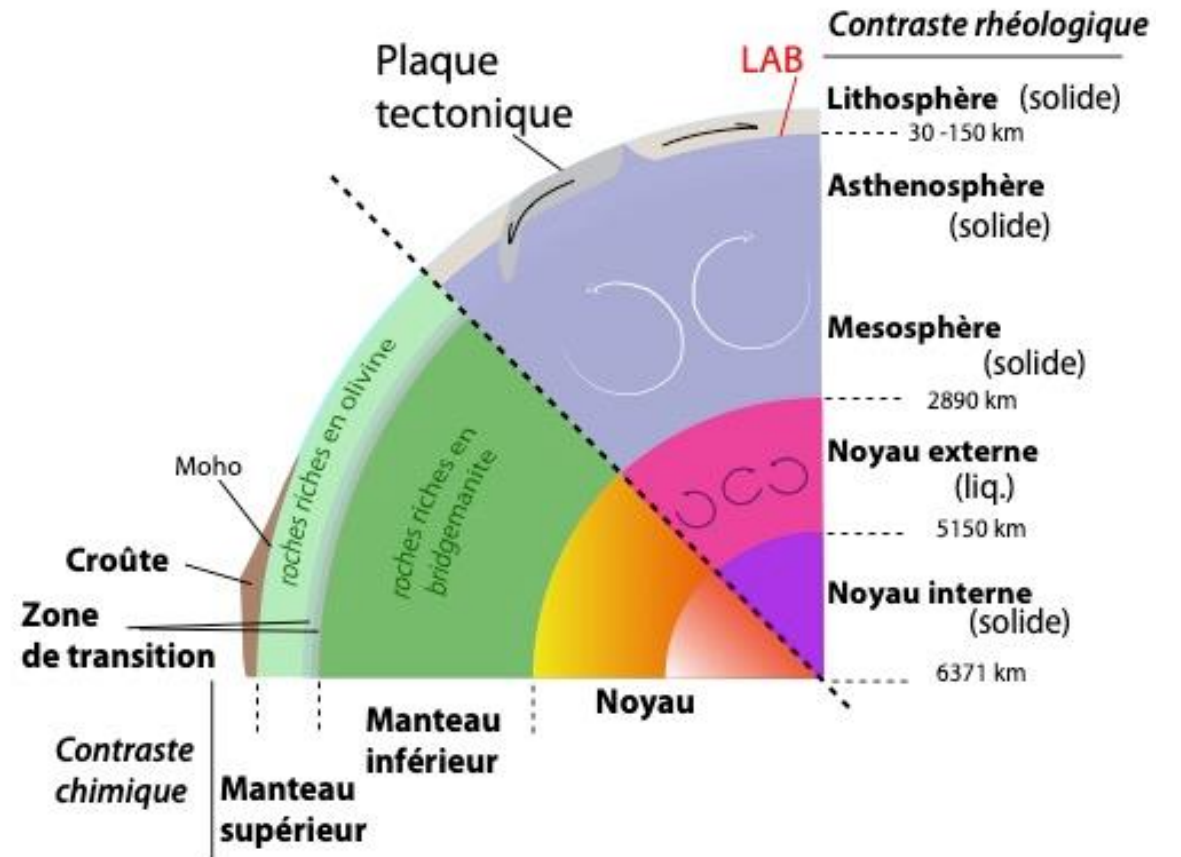
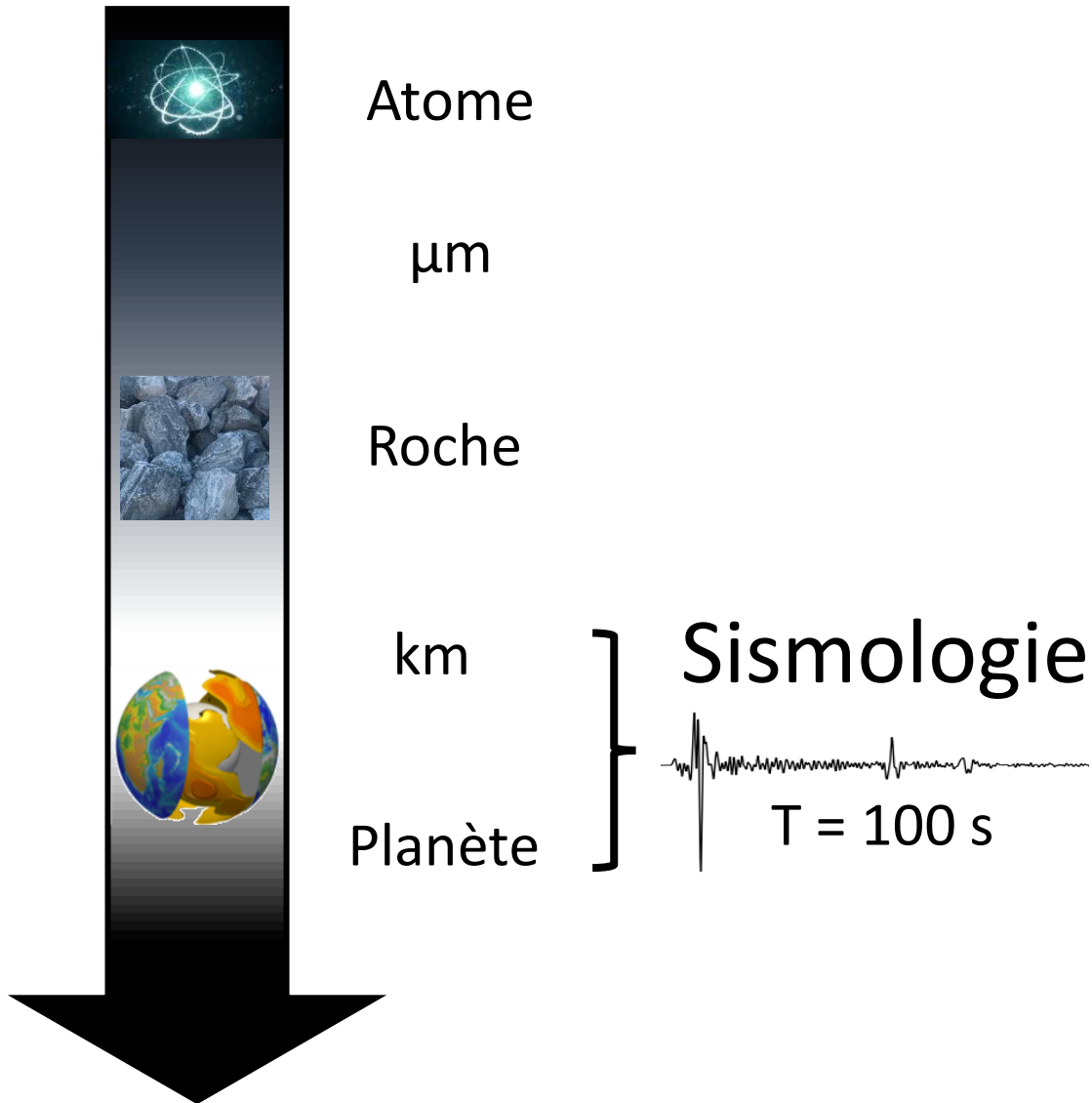
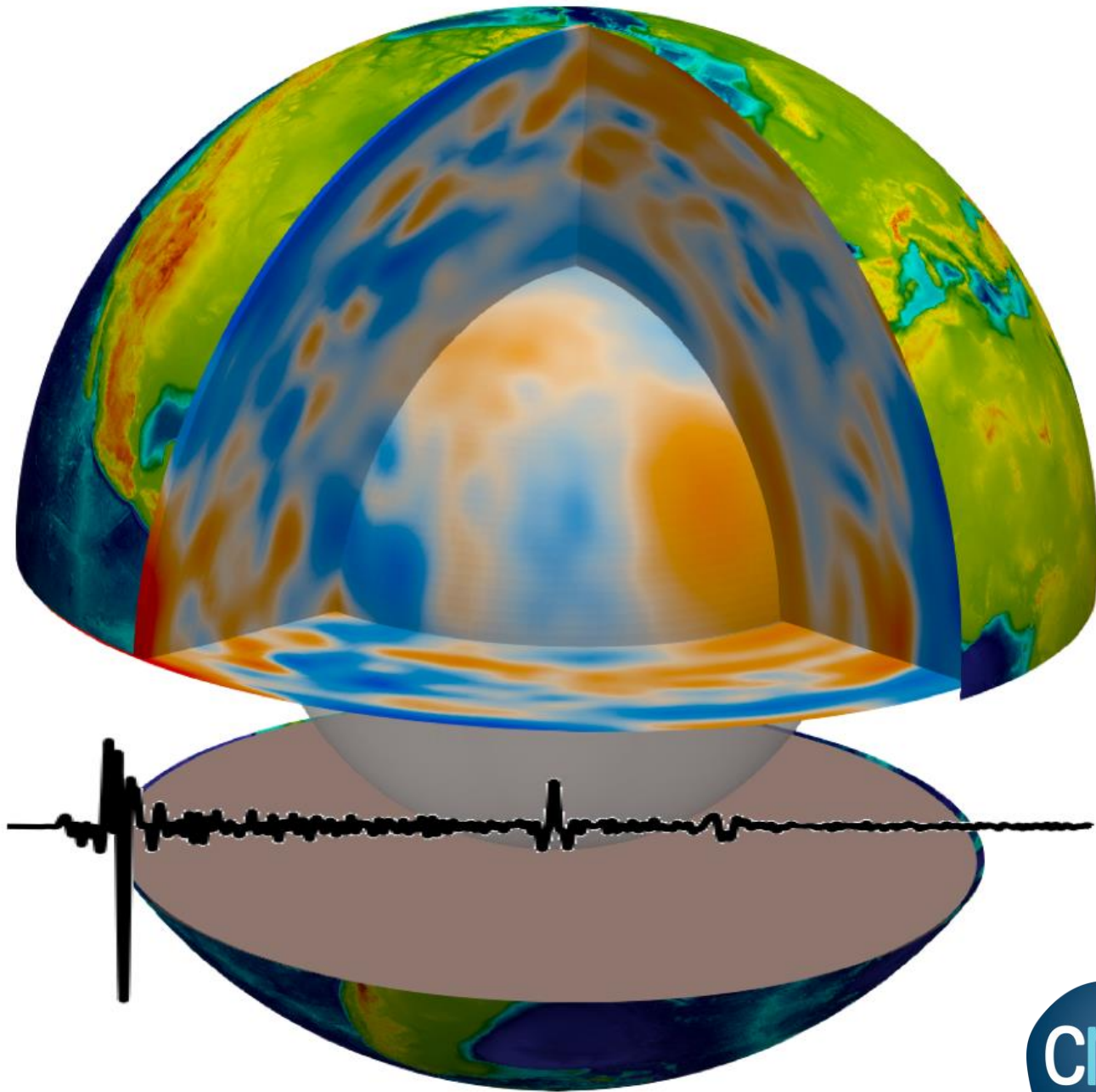


# L'impossible voyage au centre de la Terre



Courtesy of S. Demouchy





# Tomographie globale: Pourquoi ? Comment ? Quoi de neuf ?



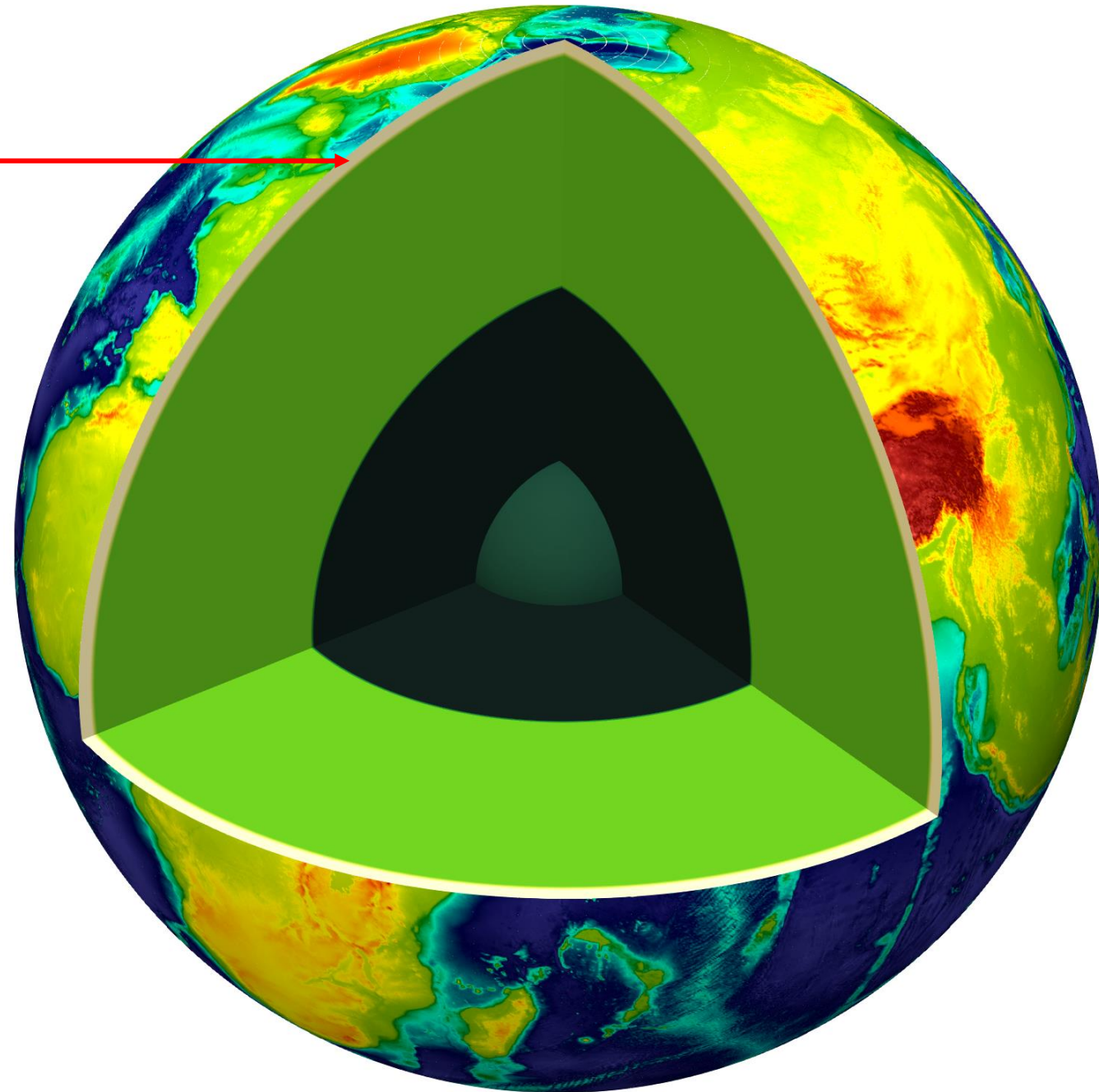
Stéphanie Durand  
Sismologue





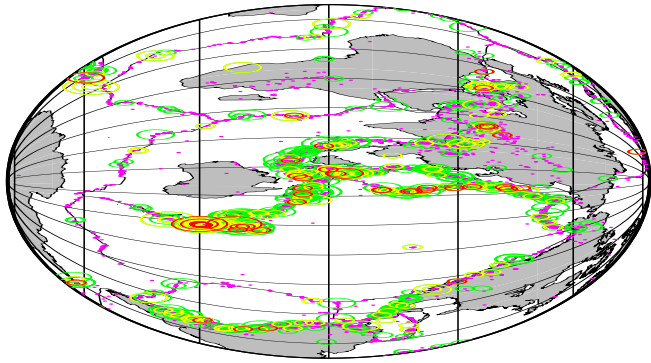
Forage Kola  
1970 - 1992  
Profondeur max 12,262 km

Croûte

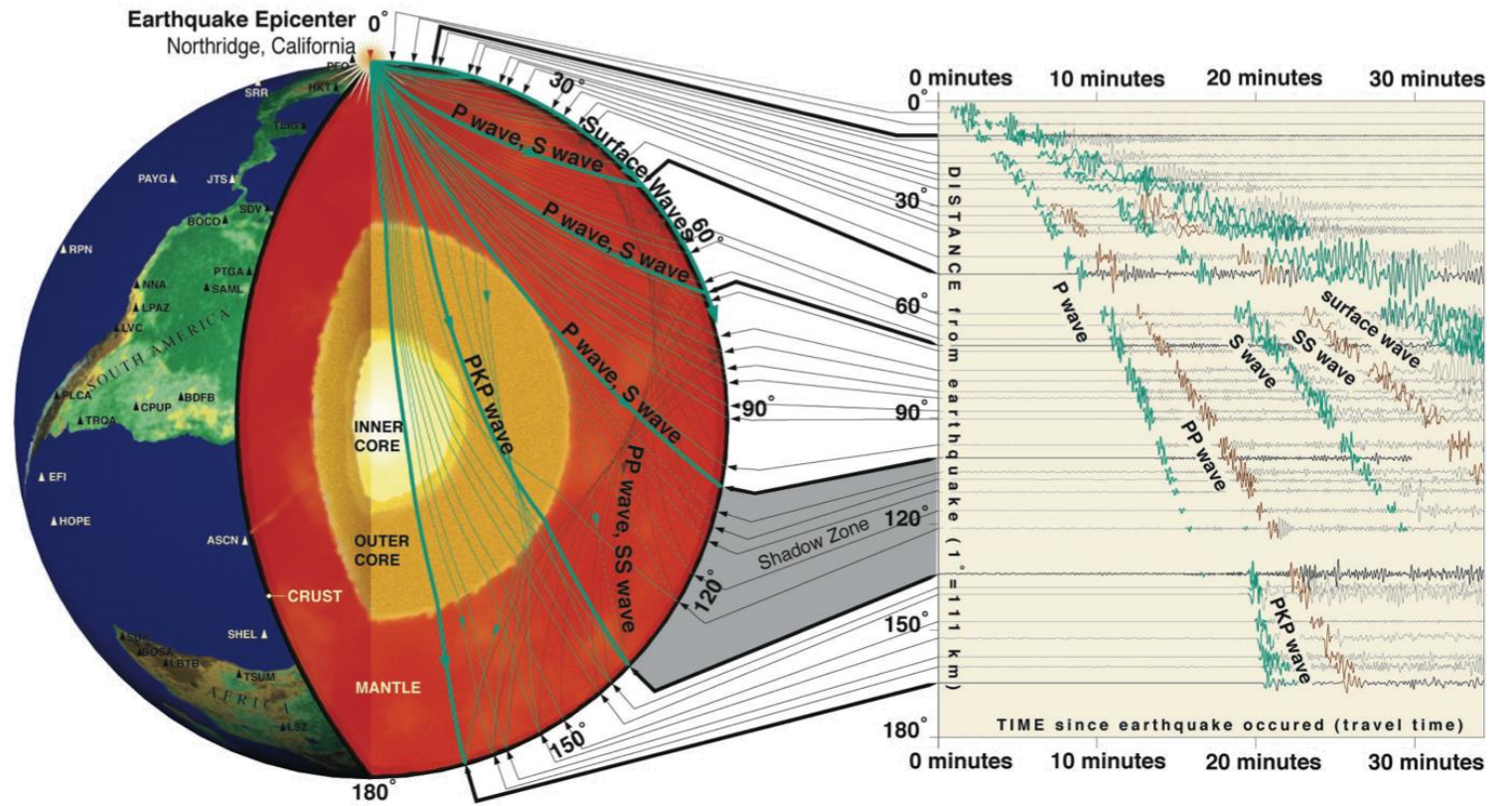
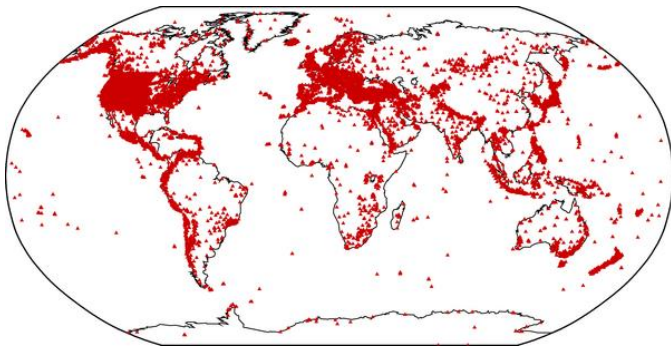




# Tremblements de terre

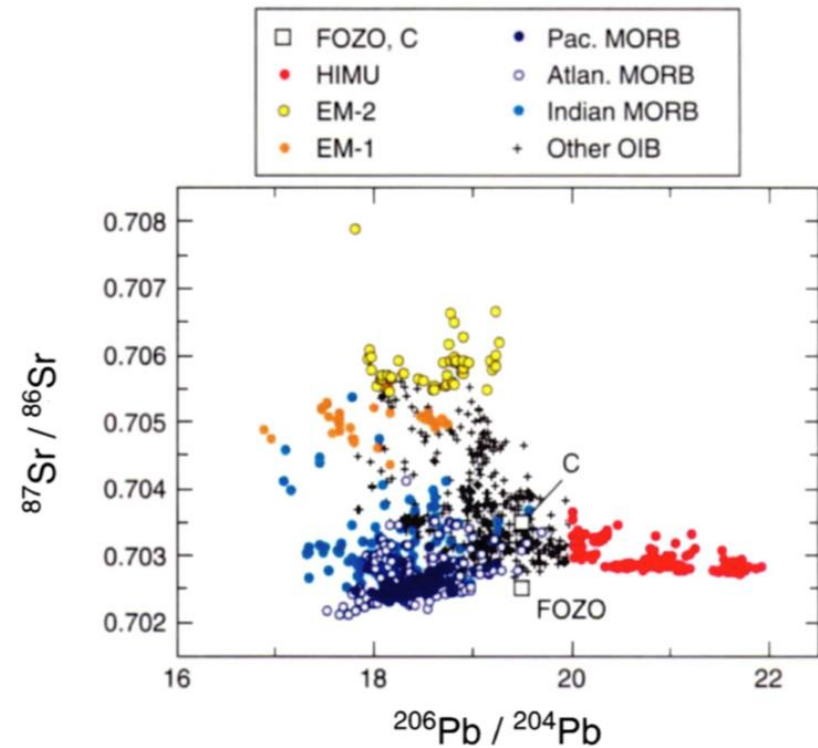
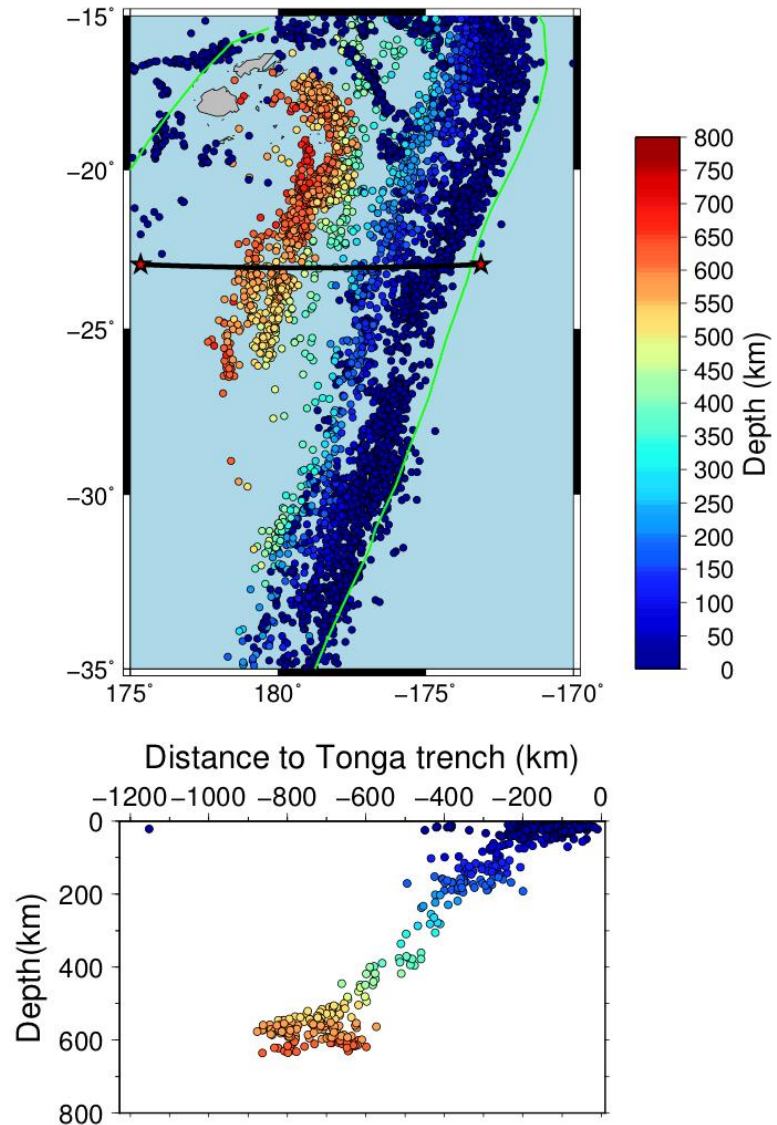


# Stations sismiques

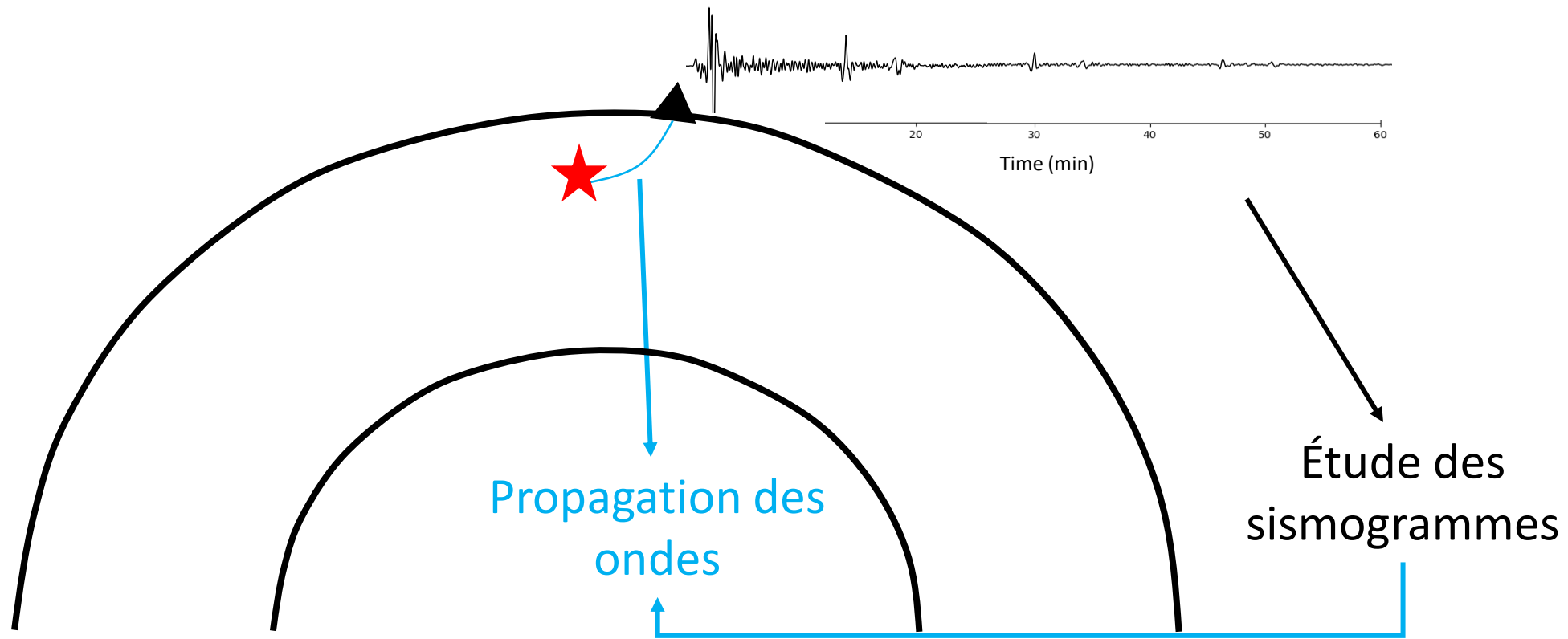




# Hétérogénéités latérales



Hofmann [1997]

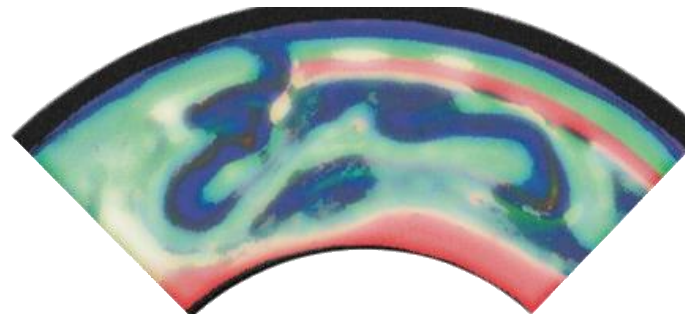
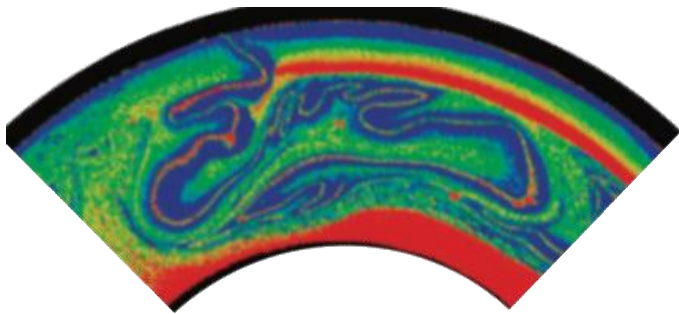






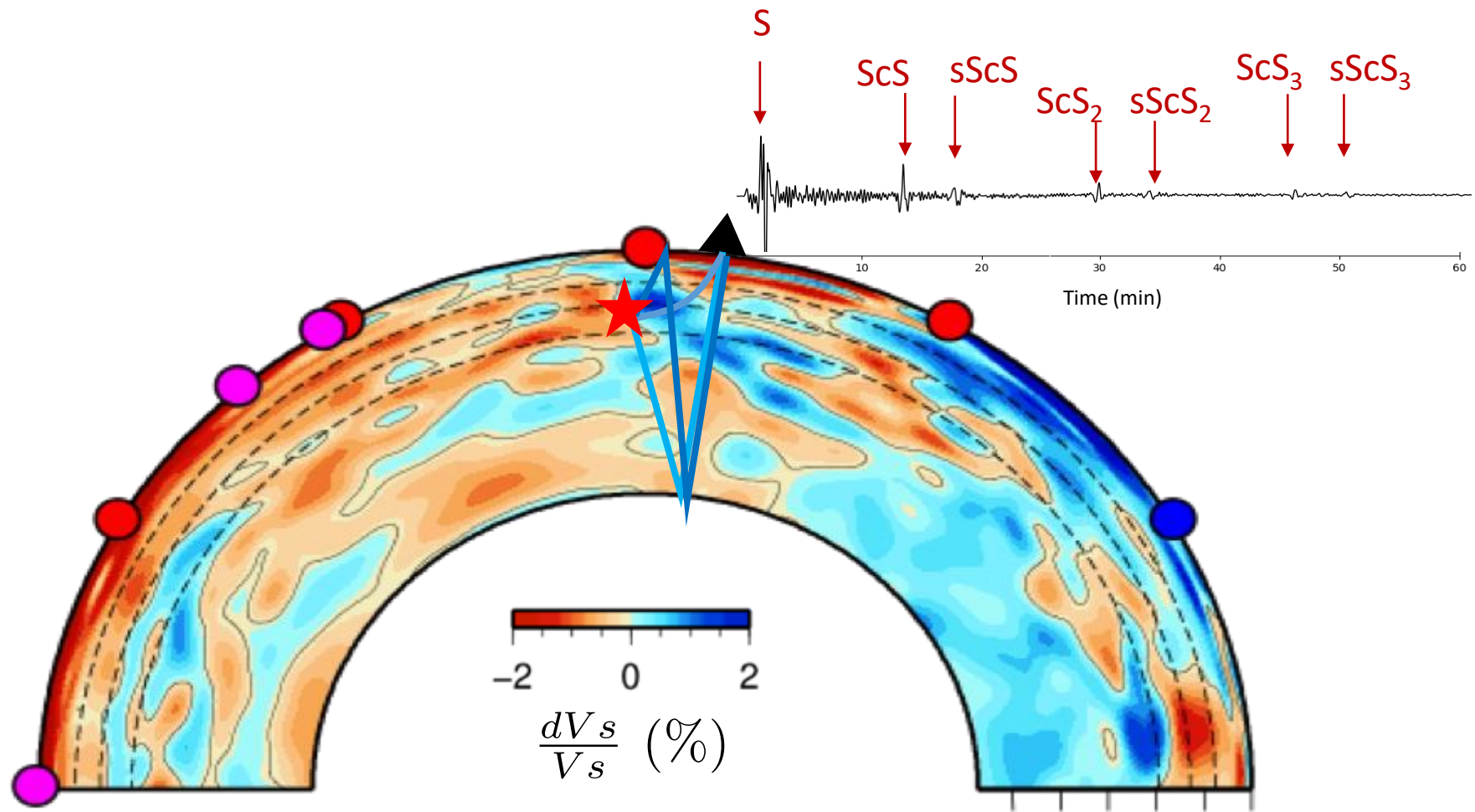
Michel-Ange [XVI]

Objectif : révéler par le dessin la complexité du drapé, les différentes échelles, amplitudes, les ombres et la texture. Quand c'est bien fait on arrive même à suggérer la structure qui est cachée !



Ballmer et al. [2015]

Même objectif en tomographie sismique.



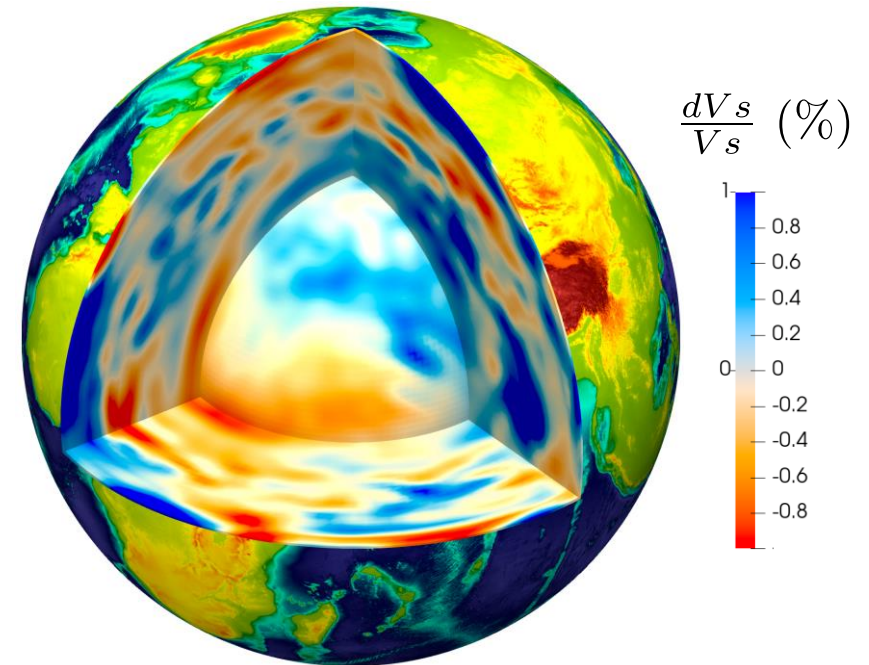


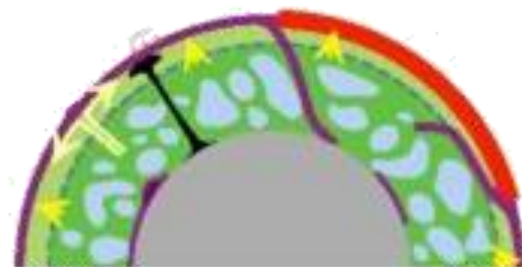
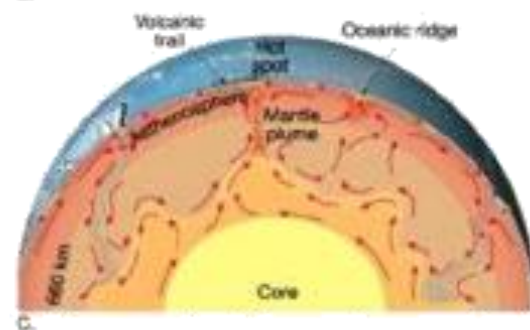
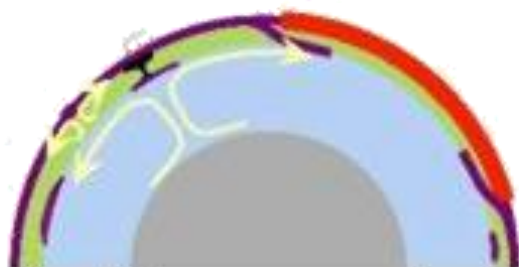
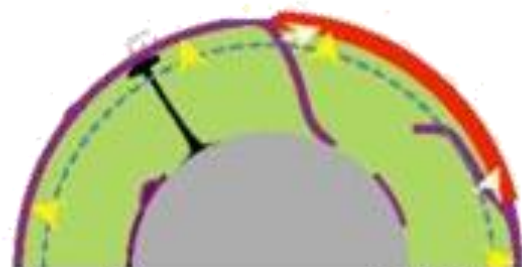
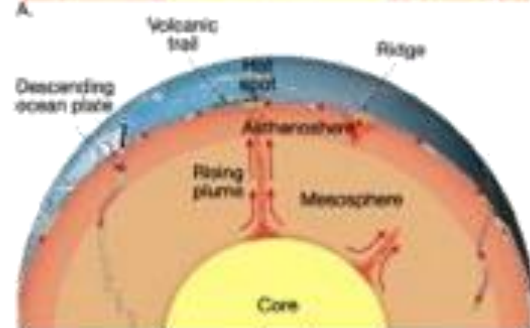
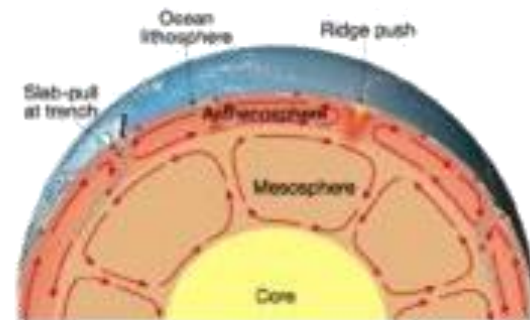
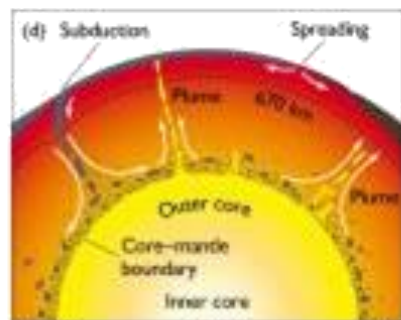
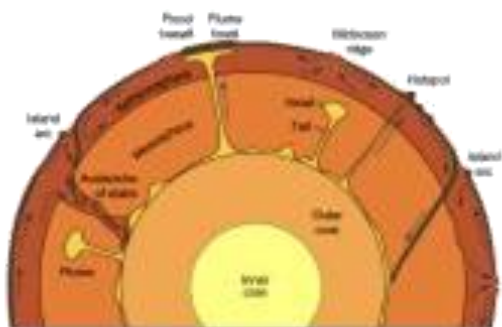
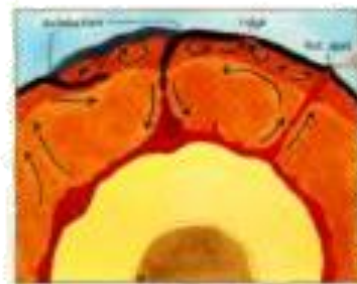
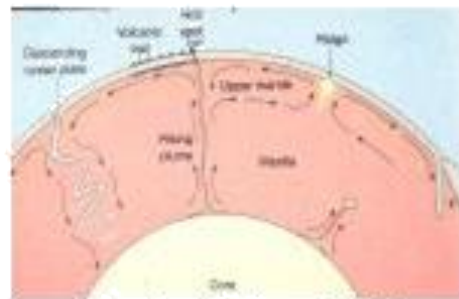
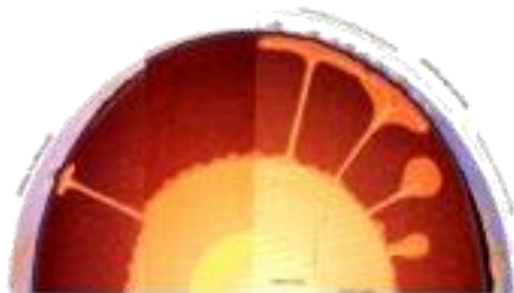
# Hétérogénéités latérales

$$V_p = \sqrt{\frac{\kappa + 4/3\mu}{\rho}} \quad V_s = \sqrt{\frac{\mu}{\rho}}$$

$$\left. \begin{aligned} \kappa &= f(T, P, \chi, \dots) \\ \mu &= f(T, P, \chi, \dots) \end{aligned} \right\}$$

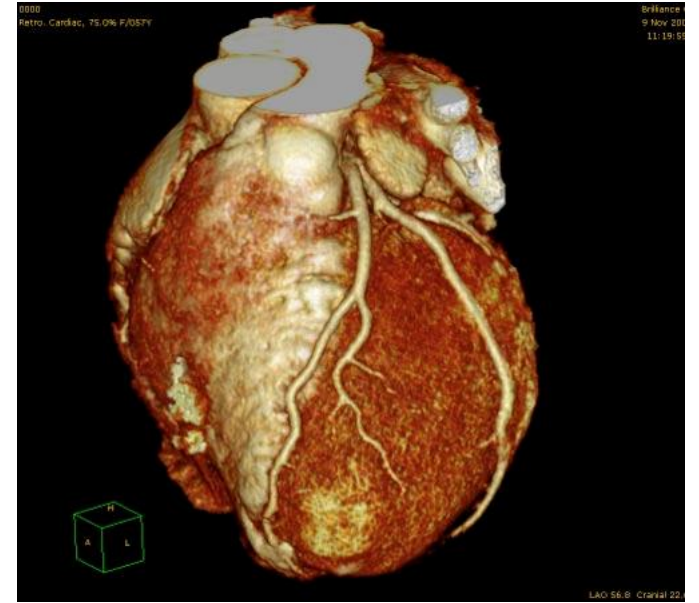
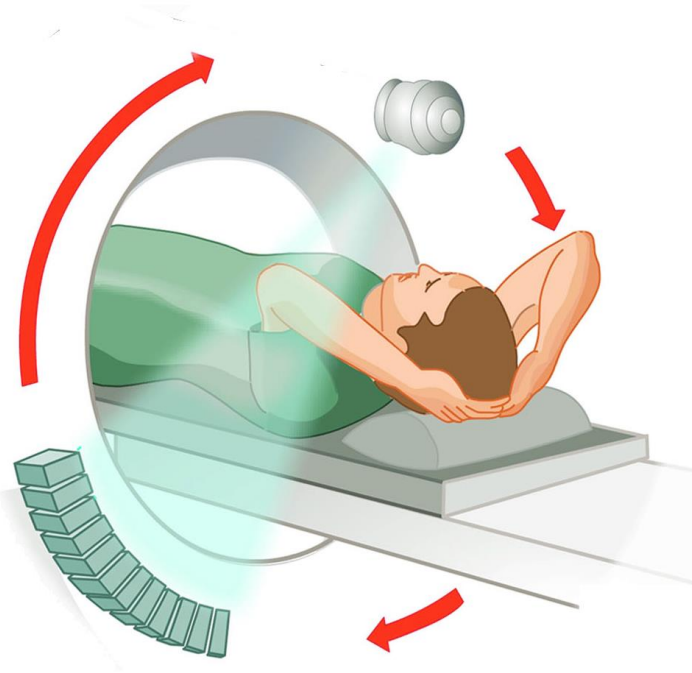
Interprétation en termes  
d'**hétérogénéités thermiques ou  
compositionnelles**

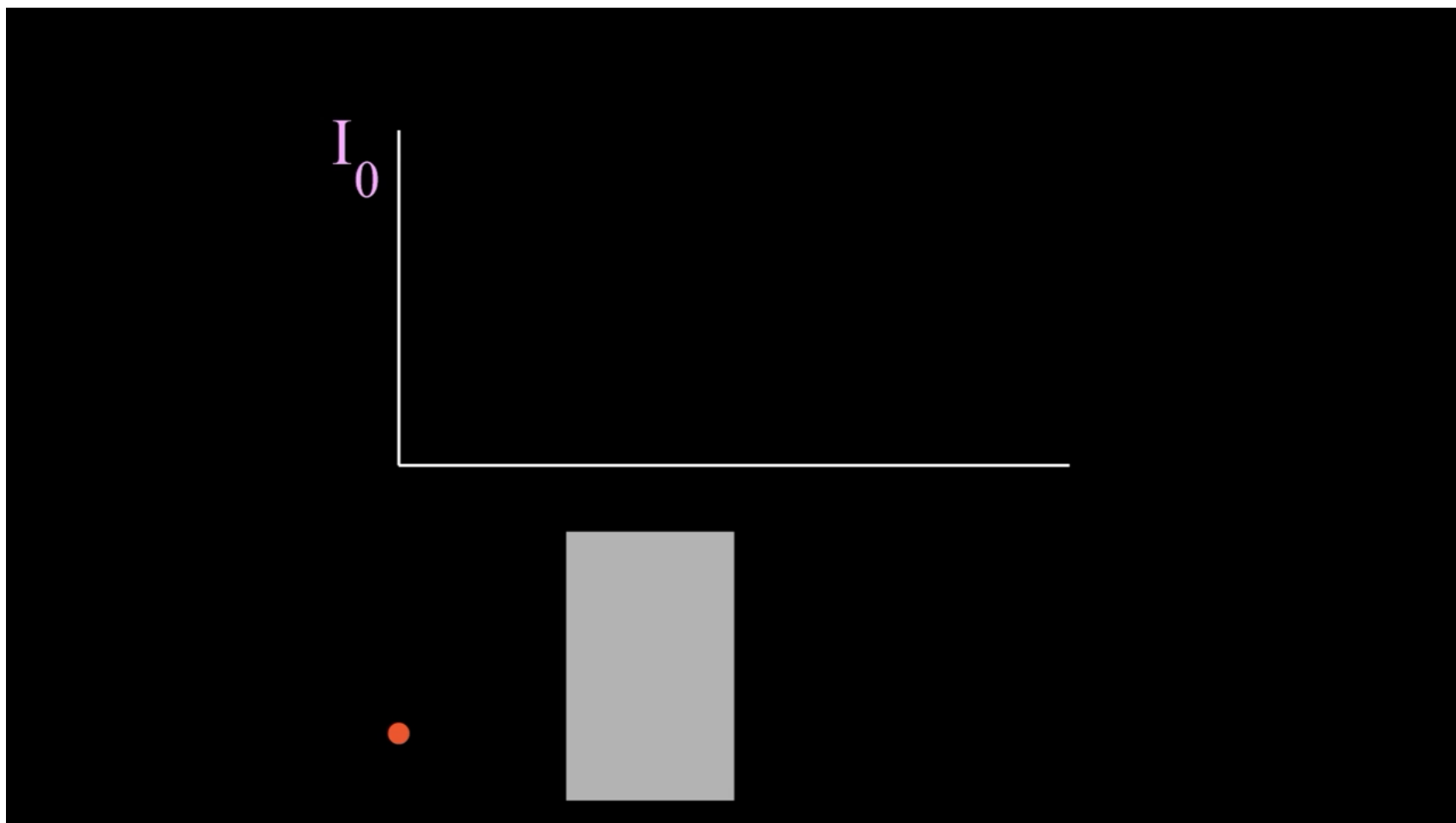




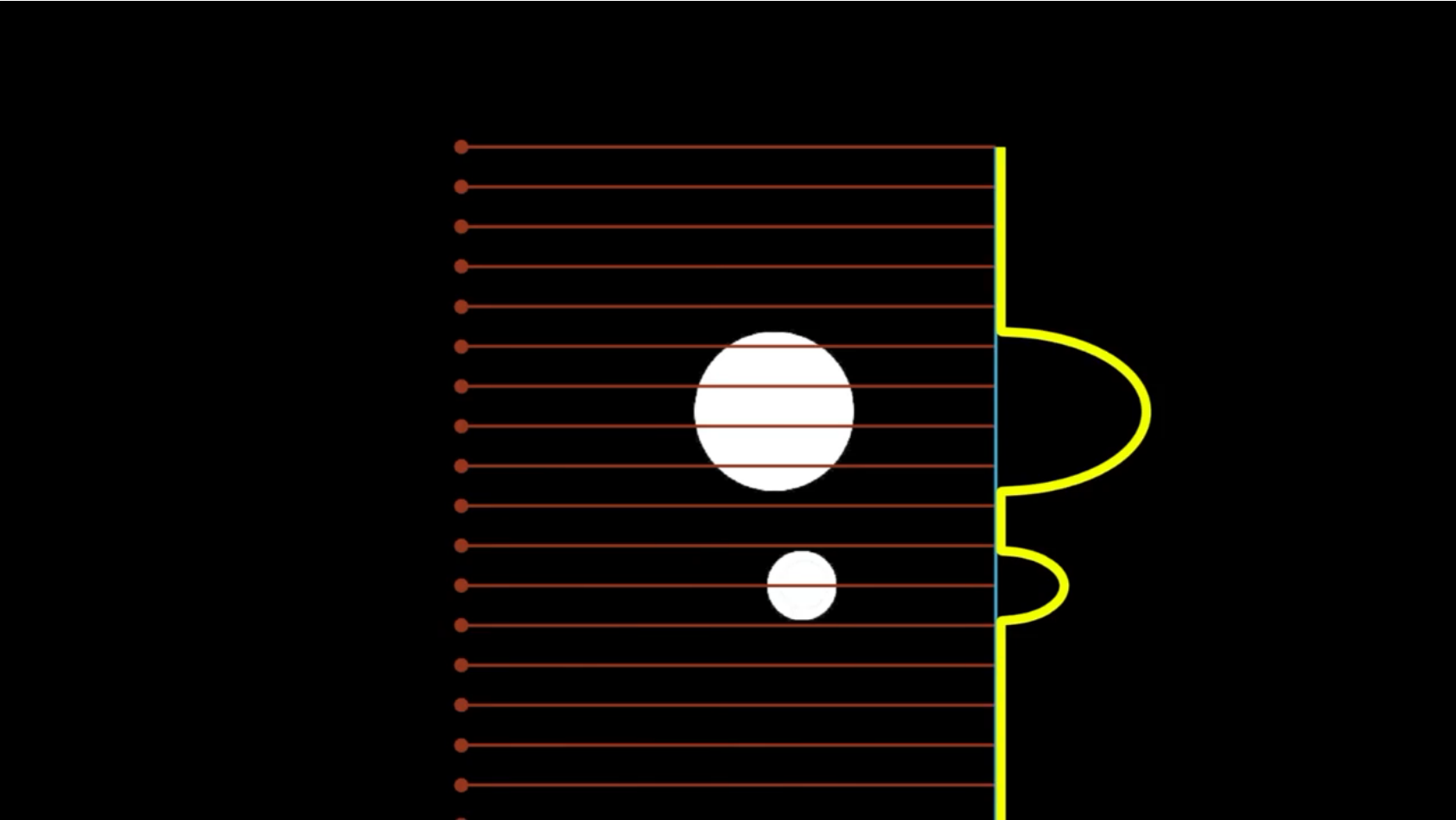


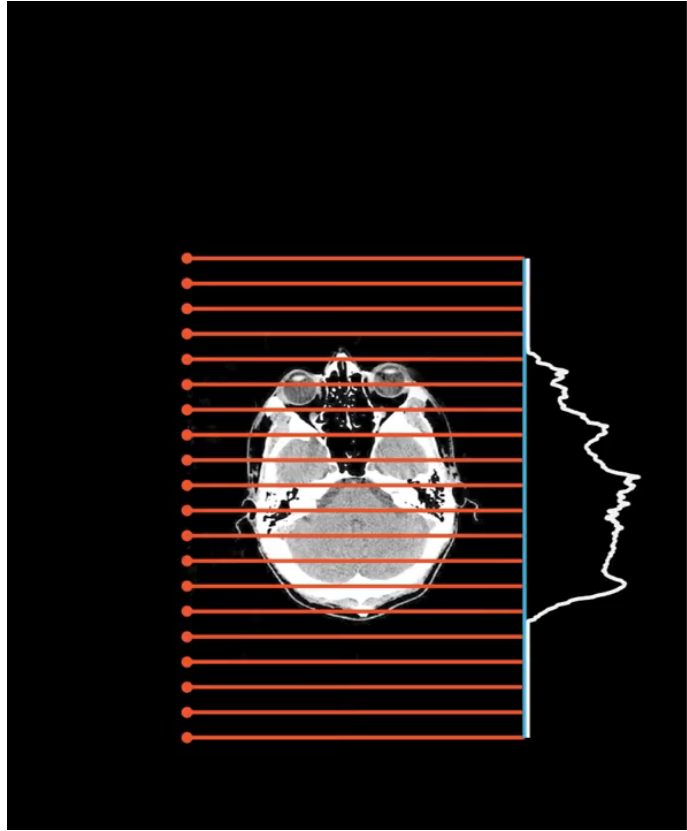


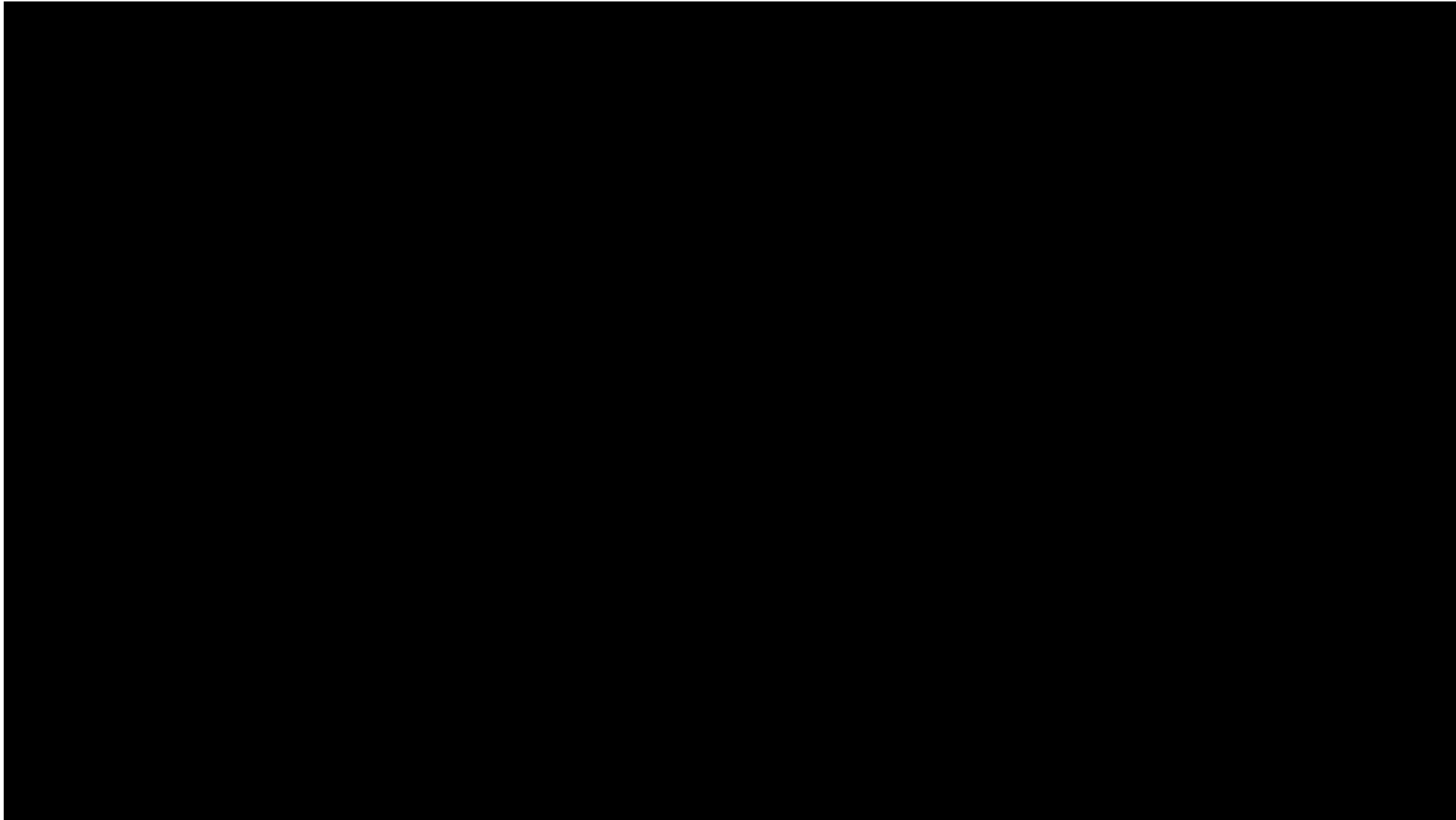




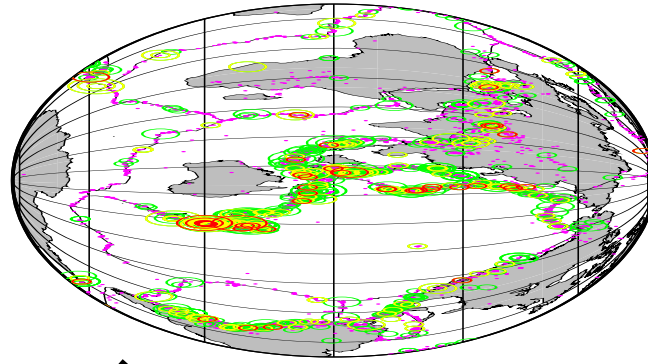
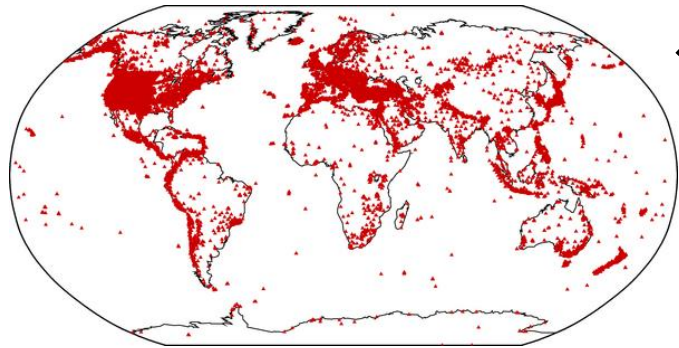
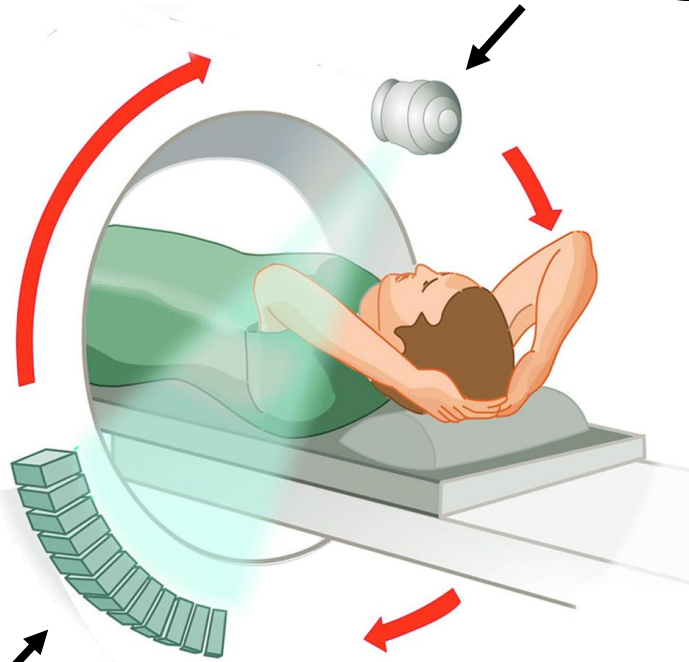


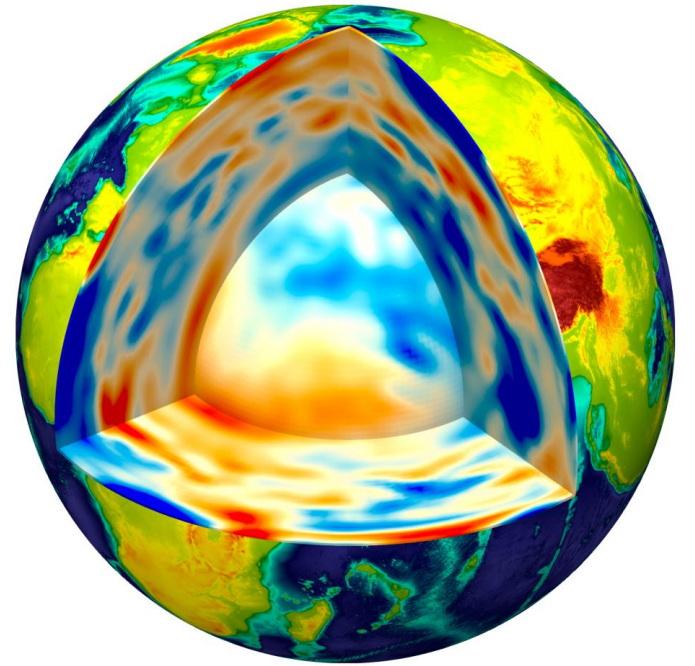
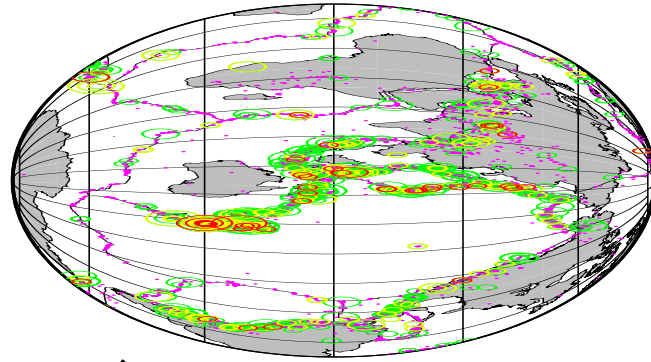
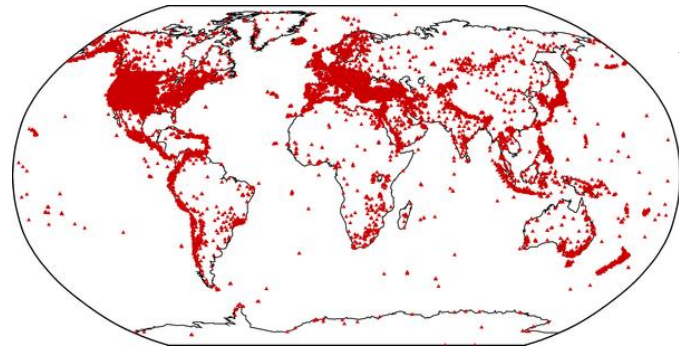
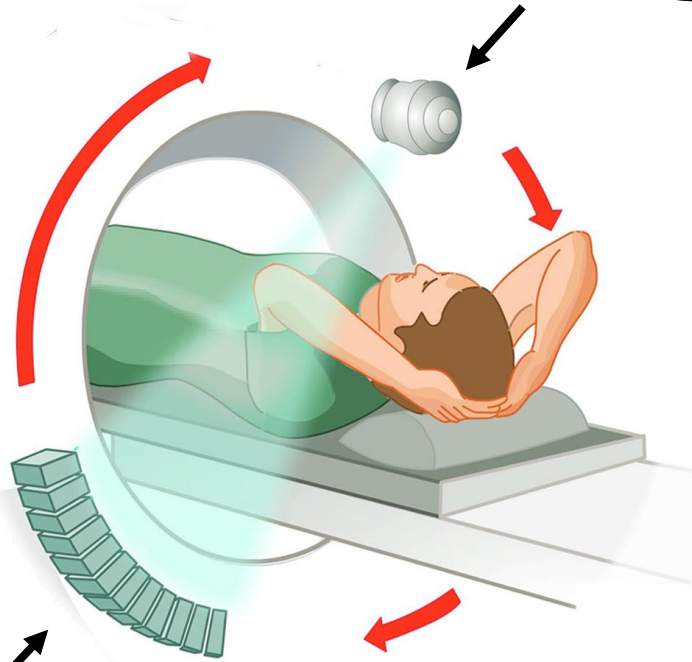






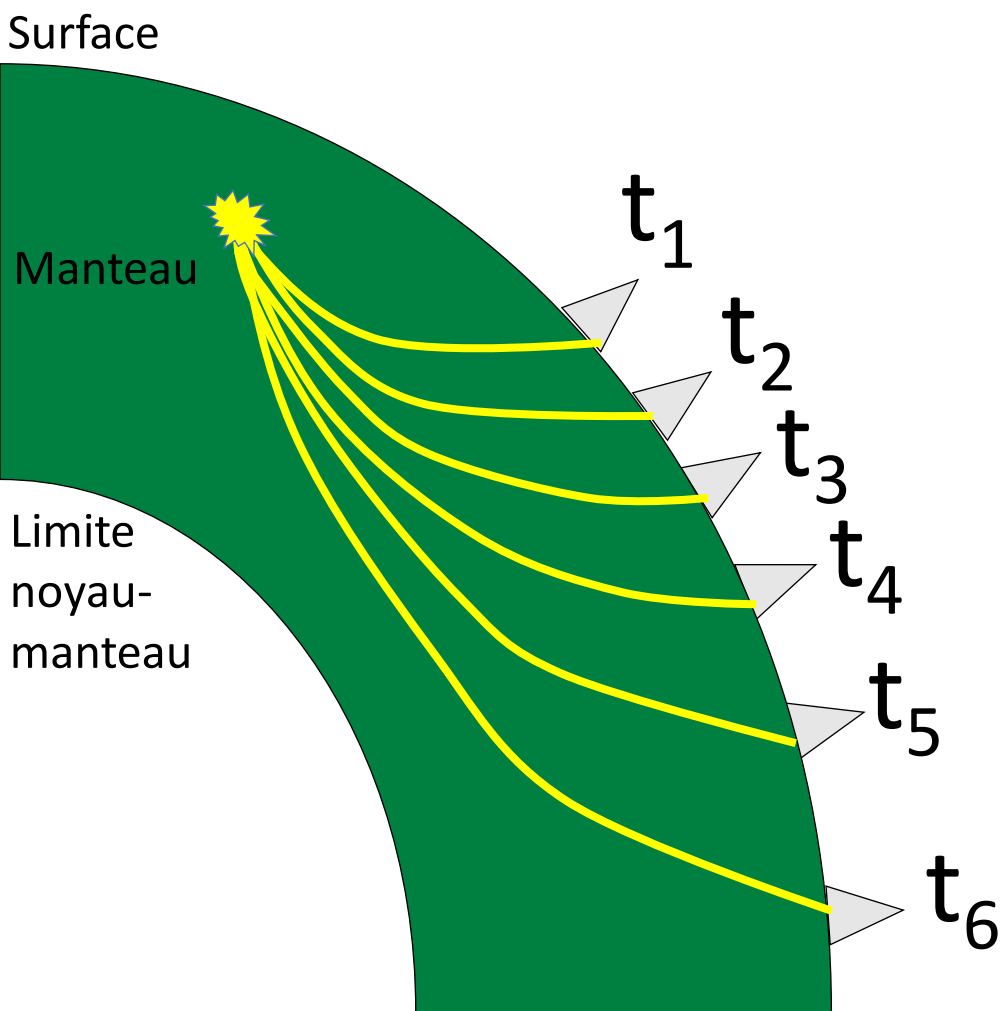






# Hypothèse

Manteau terrestres est homogène



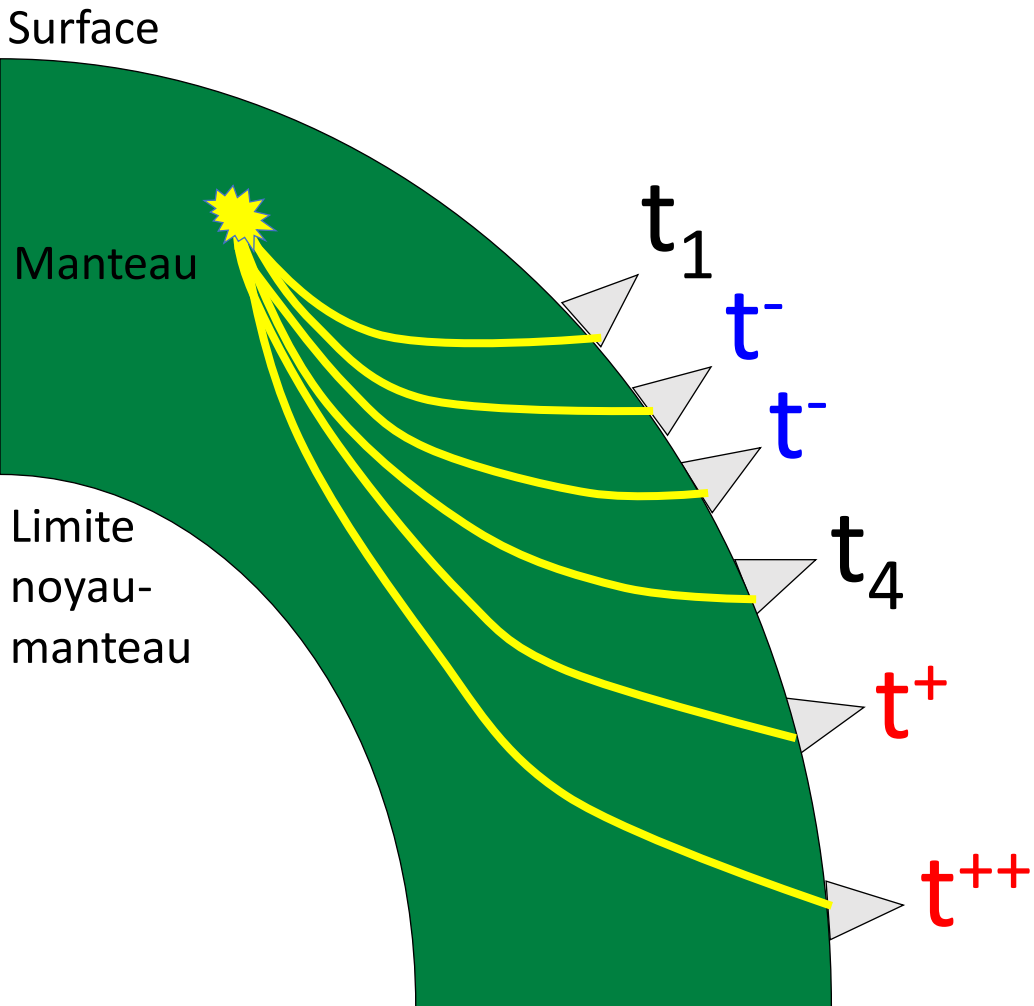


# Hypothèse

Manteau terrestres est homogène

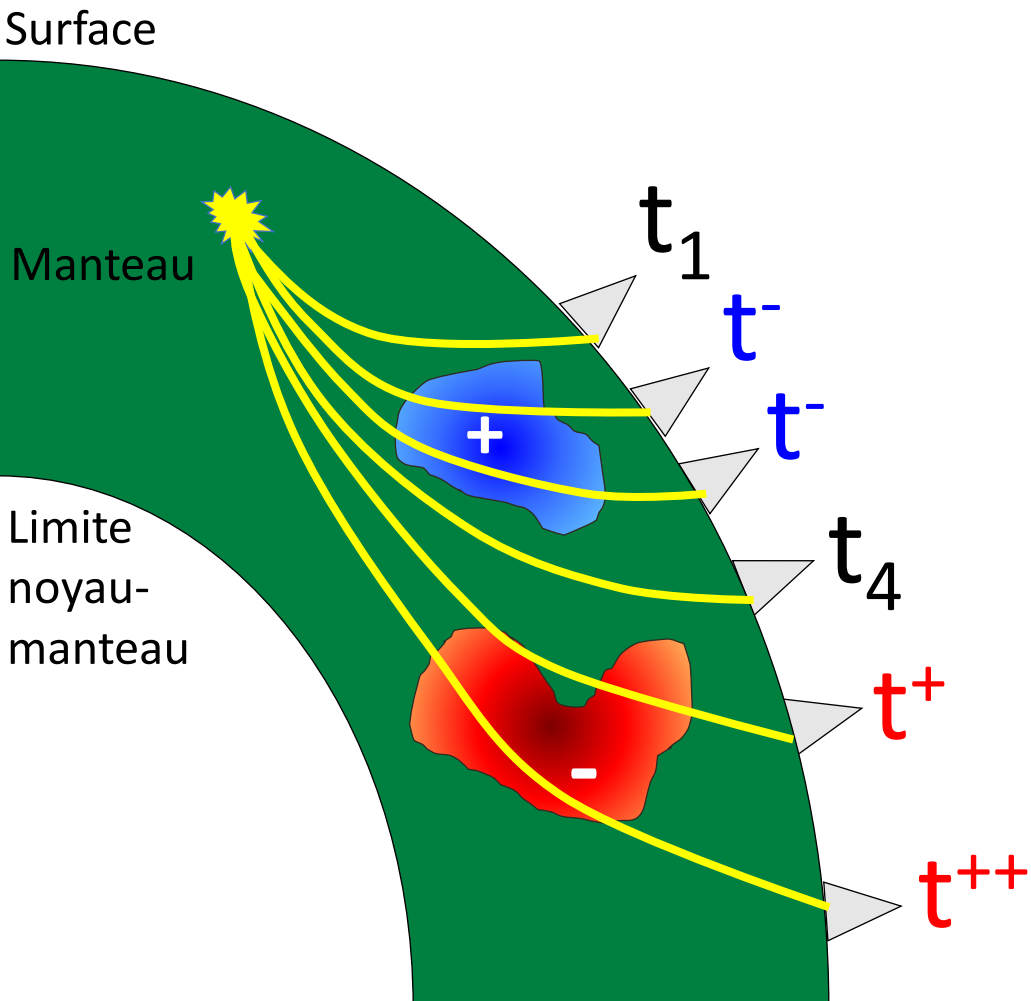
# Observations

Temps de trajet



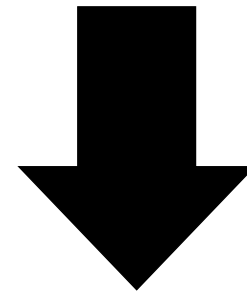
# Hypothèse

Manteau terrestres est homogène



# Observations

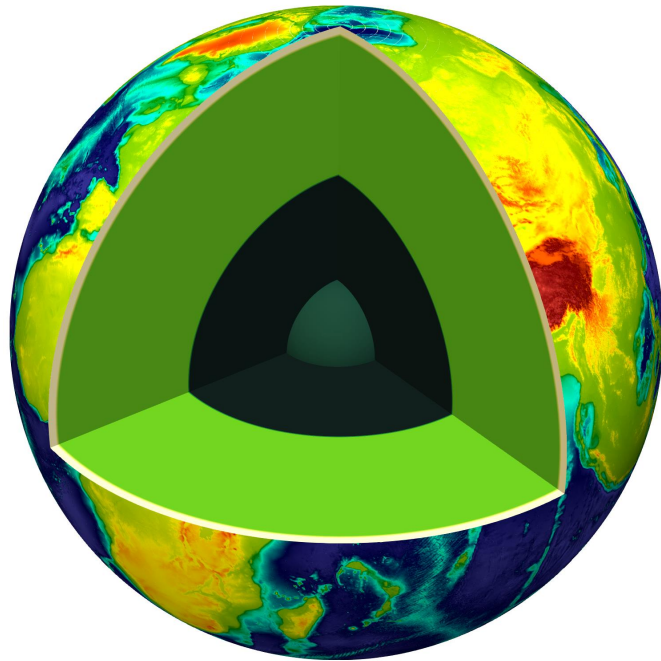
Temps de trajet



# Inversion tomographique

Modèles 3D de la vitesse des ondes dans le manteau terrestre

# Modèle (m)



Problème direct

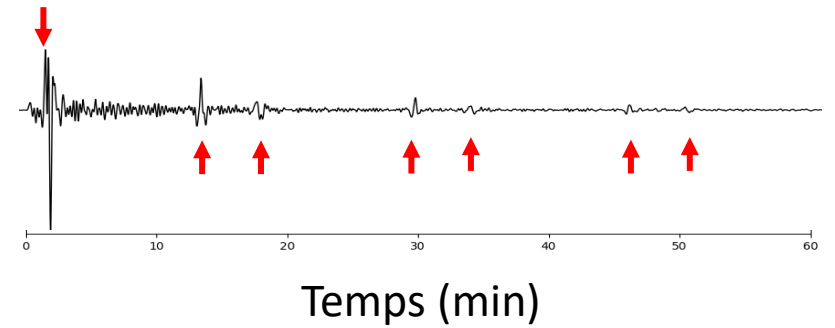
$$d = g(m) + \varepsilon$$

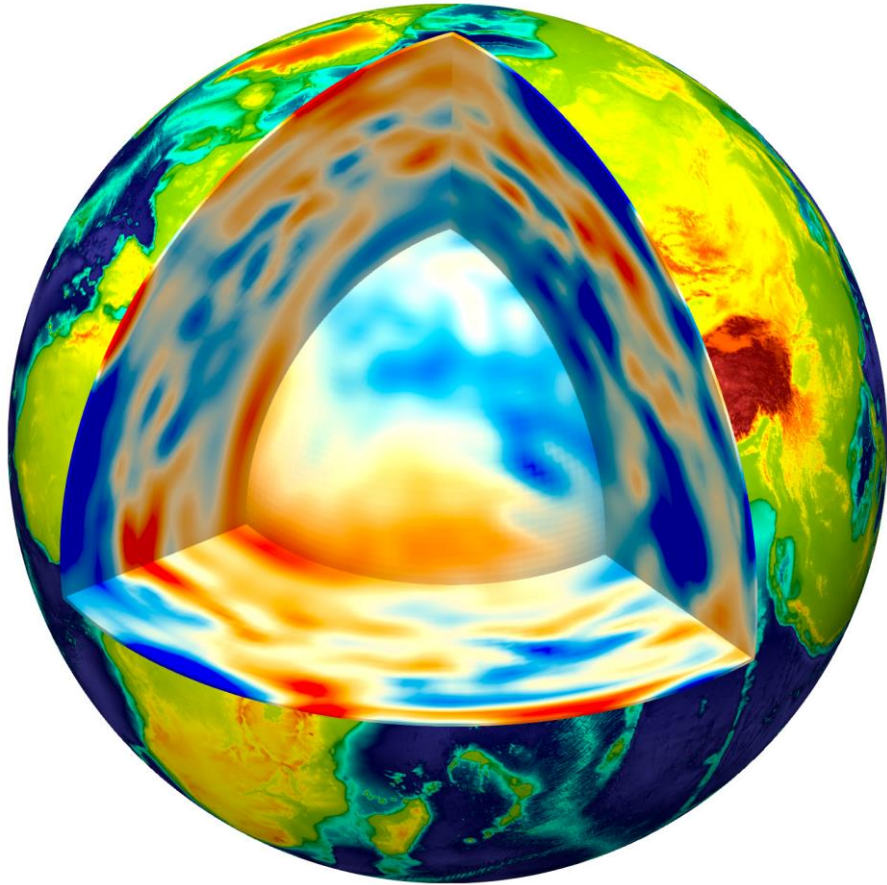


Problème inverse

$$m = \dots ?$$

# Données (d)





## DONNÉES SISMIQUES

- Modes propres, ondes de surface, ondes de volume
  - Mesures ou forme d'onde

## PARAMÉTRISATION

- Blocs ou fonctions continues
- Vitesse, anisotropie, atténuation

## THÉORIE

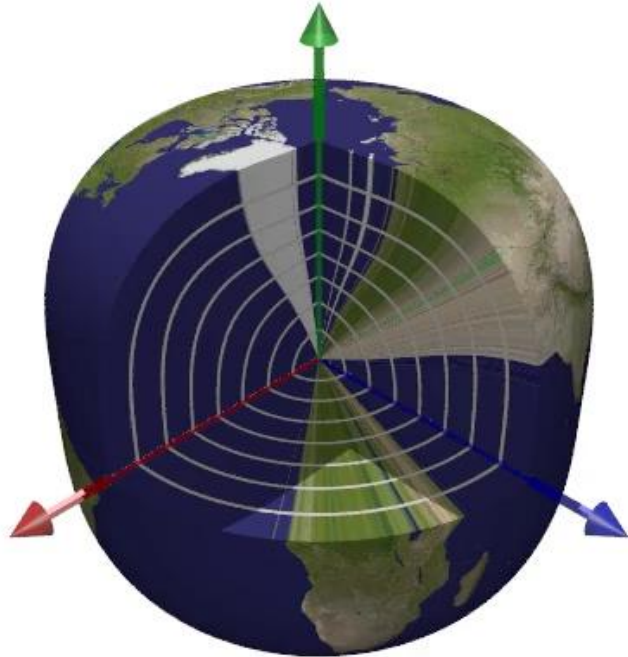
- Théorie des rais ou noyaux fréquence finie

## RÉGULARISATION

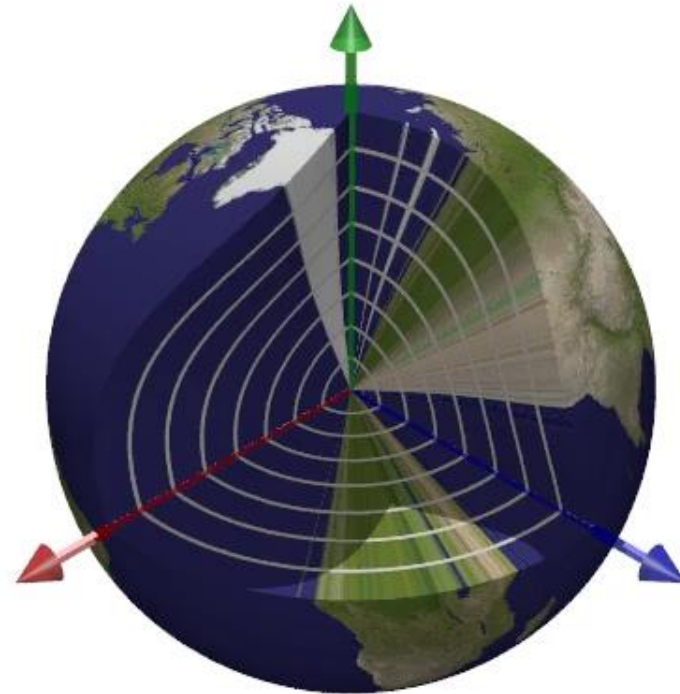
## DONNÉES SISMIQUES

- Modes propres, ondes de surface, ondes de volume
  - Mesures ou forme d'onde

${}_0S_4$  Period ~26 minutes



${}_0T_4$  Period ~22 minutes

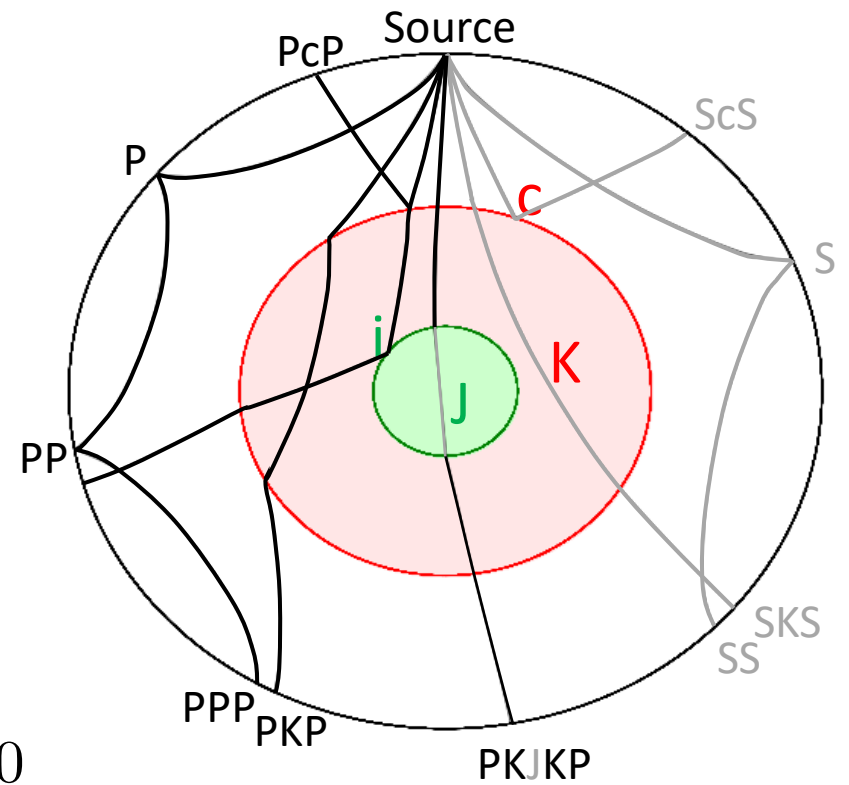
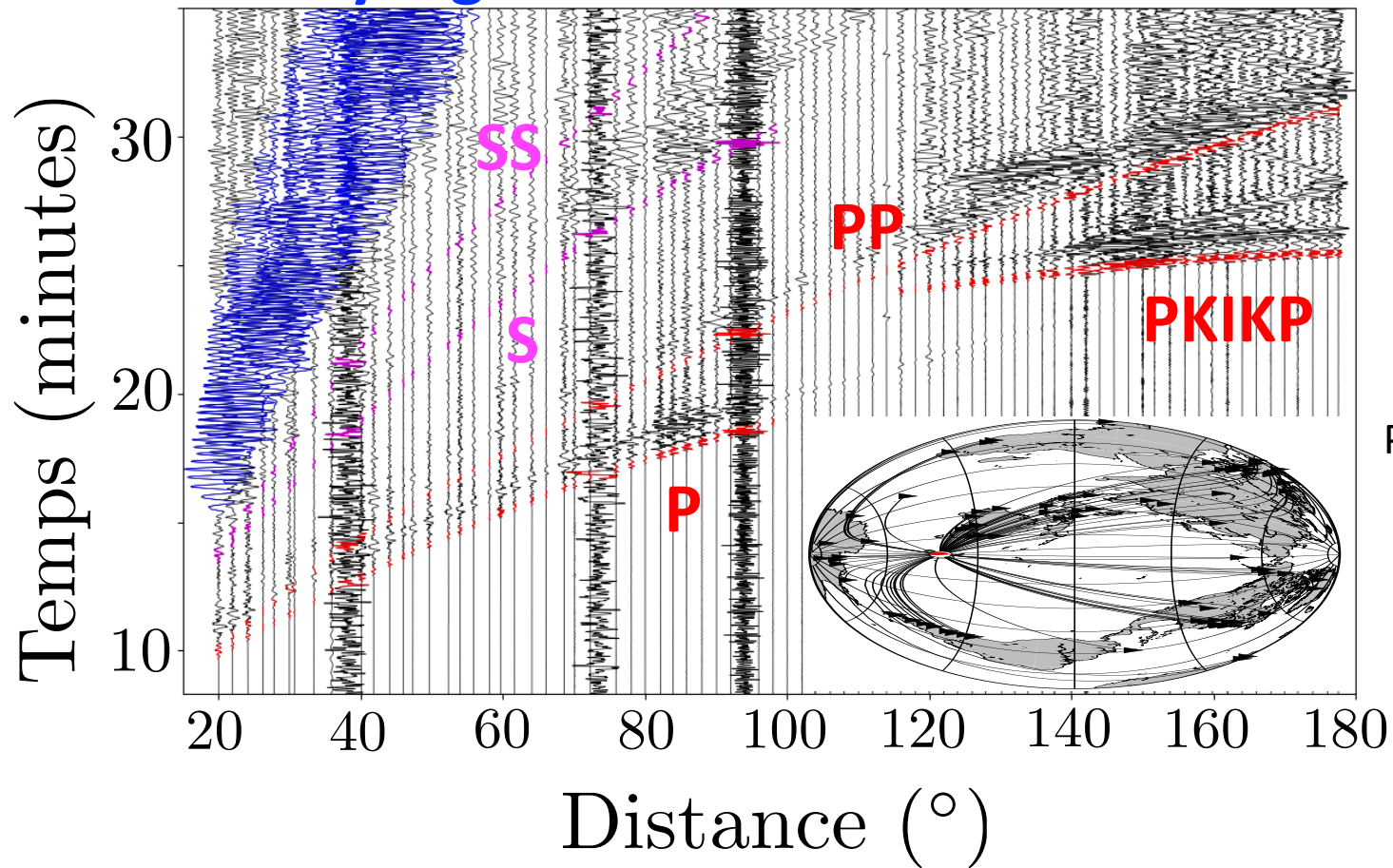




## DONNÉES SISMIQUES

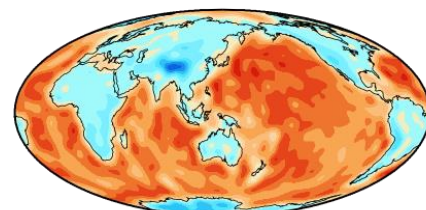
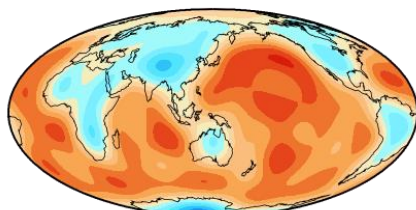
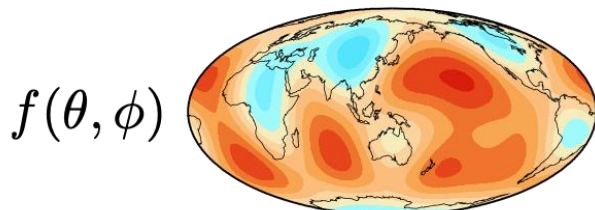
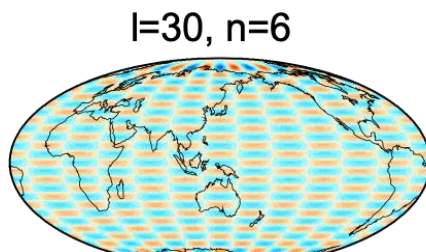
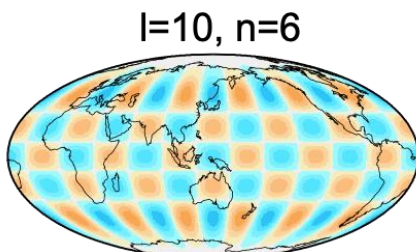
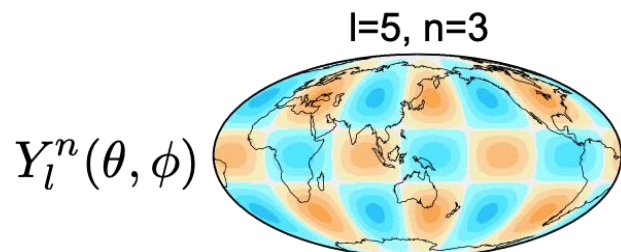
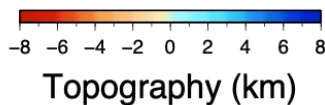
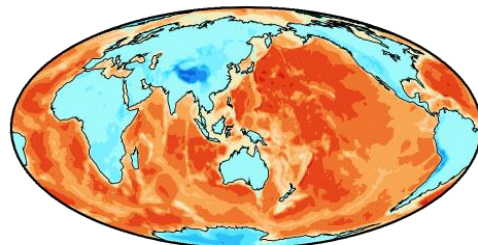
- Modes propres, ondes de surface, ondes de volume
- Mesures ou forme d'onde

### Rayleigh



## PARAMÉTRISATION

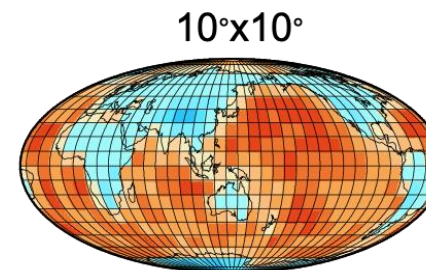
- Blocs ou fonctions continues
- Vitesse, anisotropie, atténuation



$l_{\max} = 5$   
 $\lambda \sim 8000 \text{ km}$   
 $N = 36$

$l_{\max} = 10$   
 $\lambda \sim 4000 \text{ km}$   
 $N = 110$

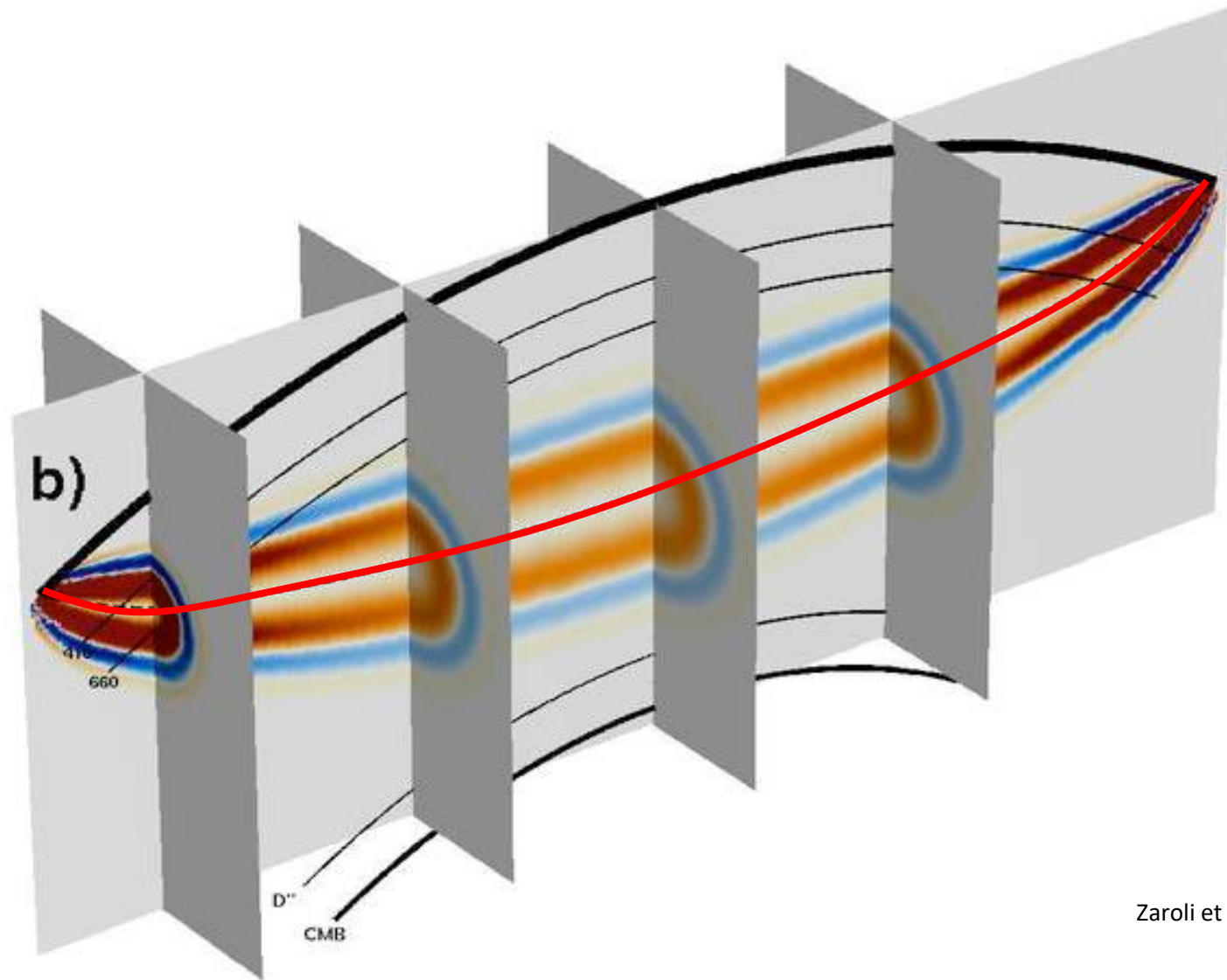
$l_{\max} = 30$   
 $\lambda \sim 1300 \text{ km}$   
 $N = 961$



$\lambda \sim 1100 \text{ km}$   
 $N = 648$

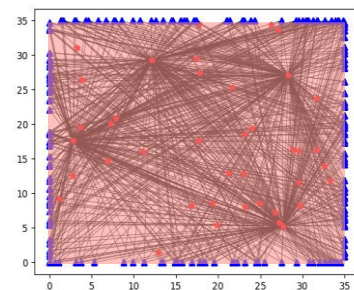
## THÉORIE

- Théorie des rais ou noyaux fréquence finie

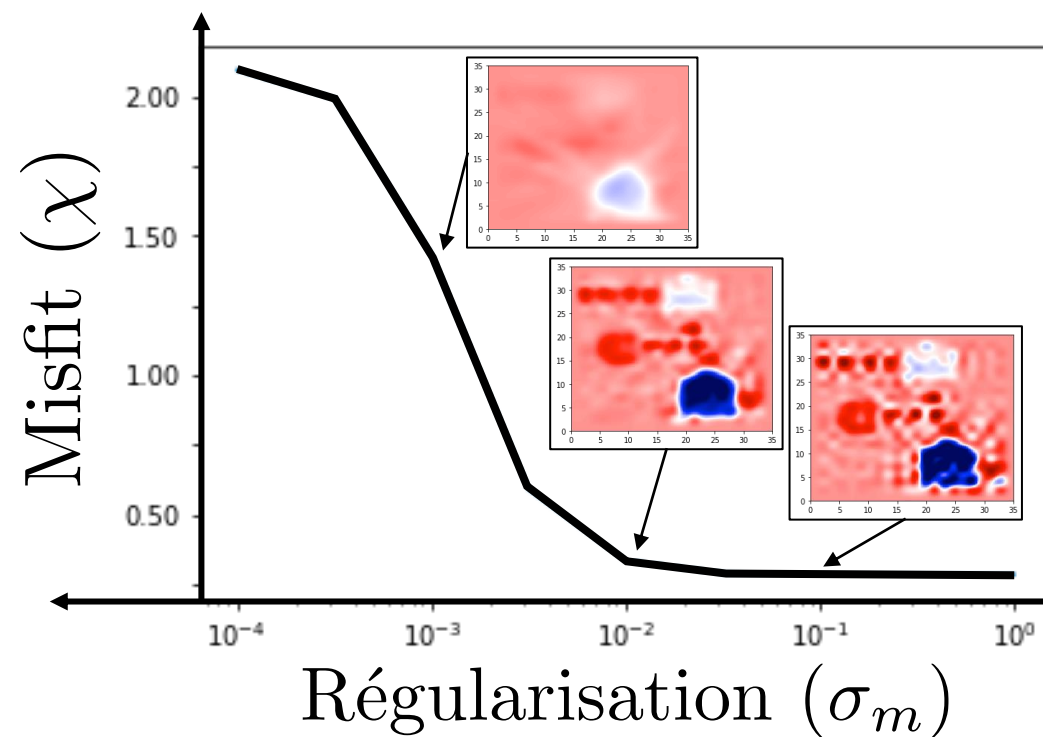
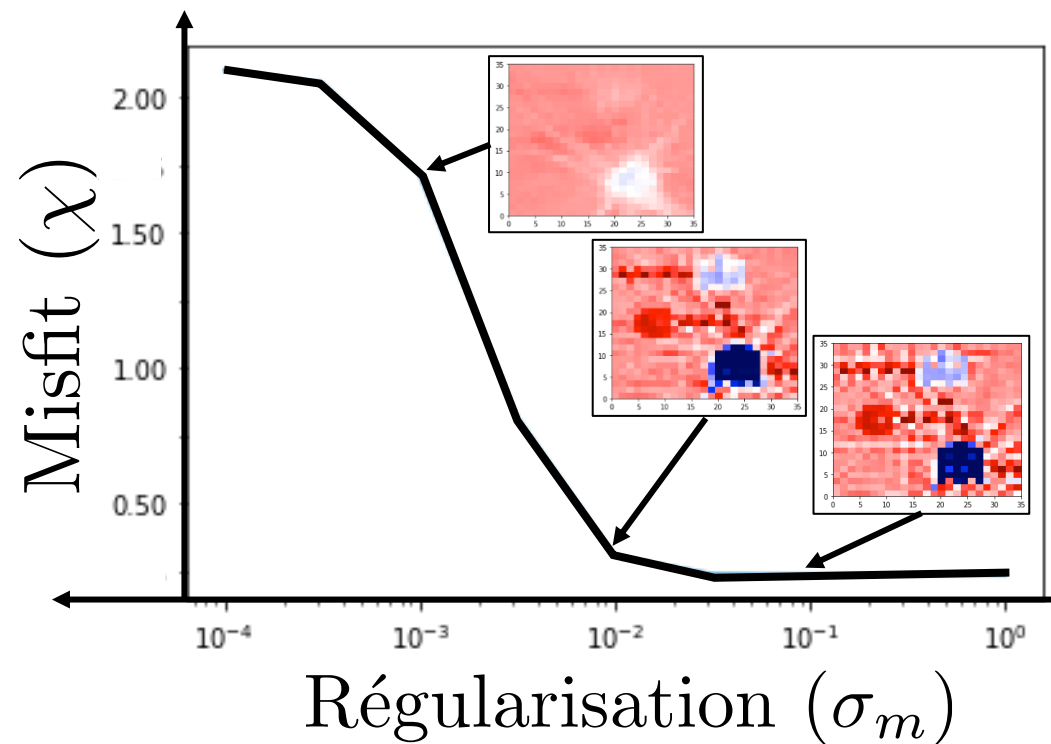
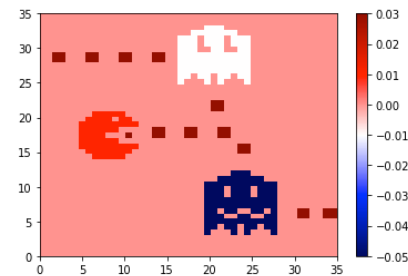


# RÉGULARISATION

## Modèle a priori

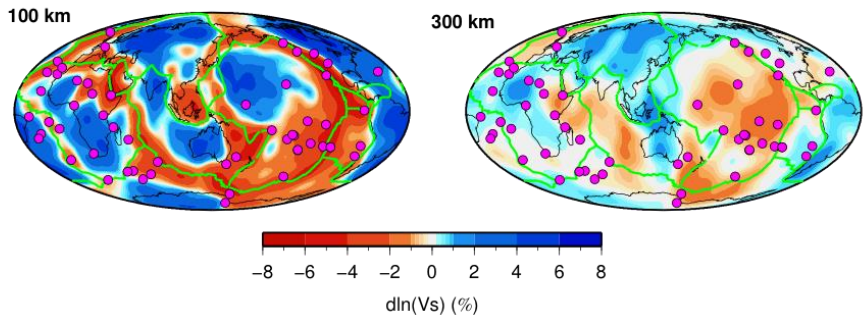


## Modèle vrai

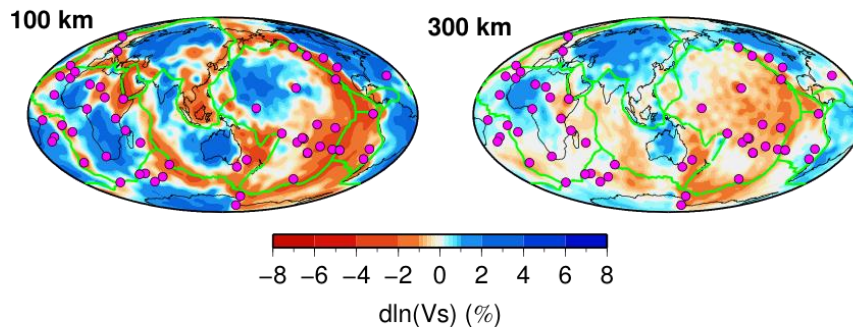




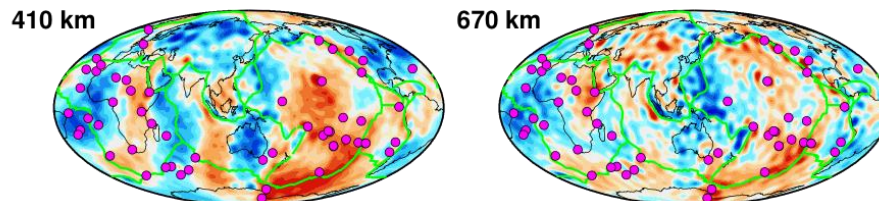
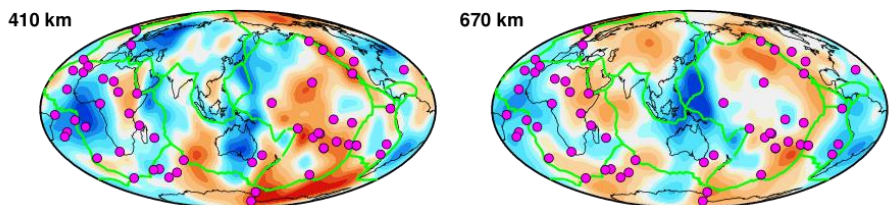
# SEISGLOB1



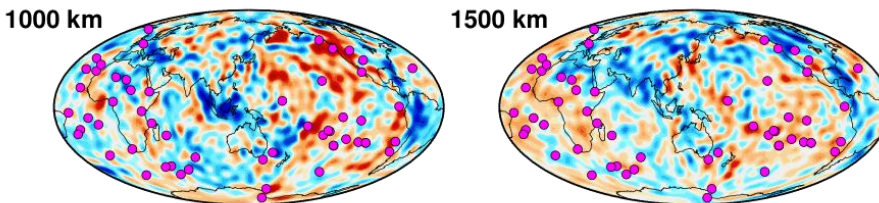
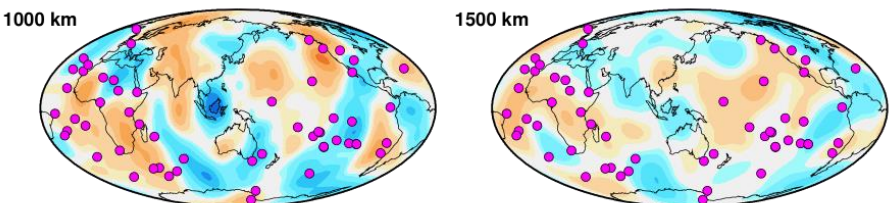
# SEISGLOB2



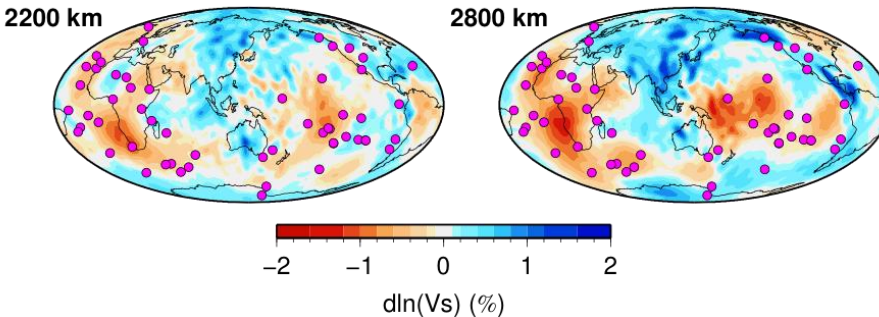
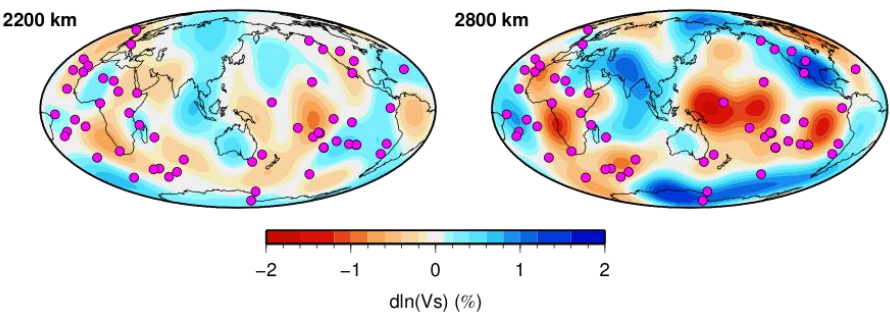
Tectonique  
de surface



Plaques en  
subduction

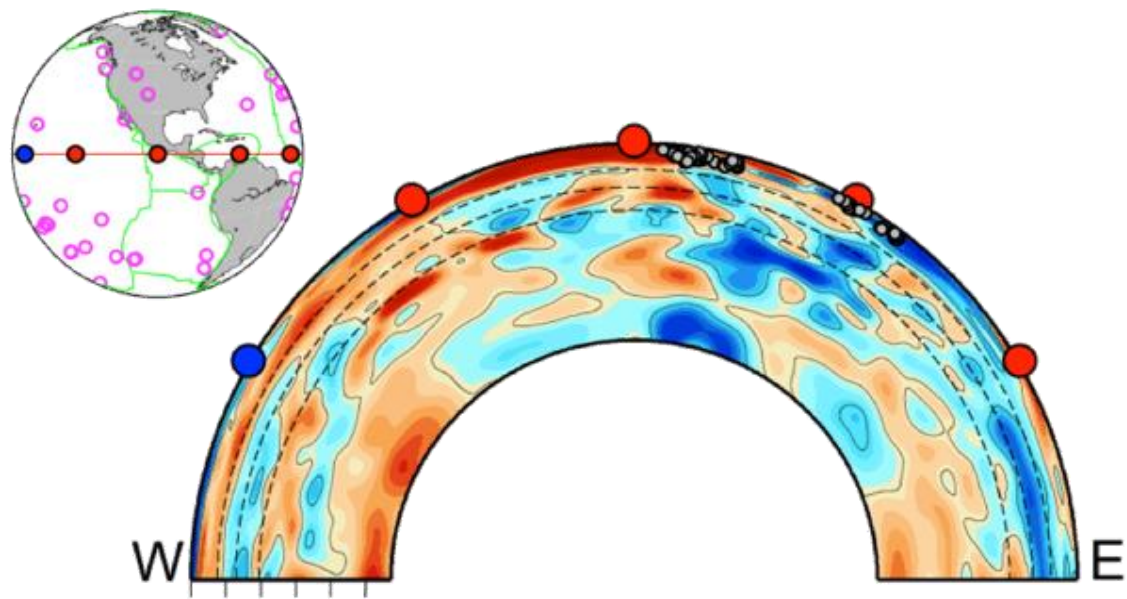


LLSVPs  
Large Low Shear  
Velocity Provinces

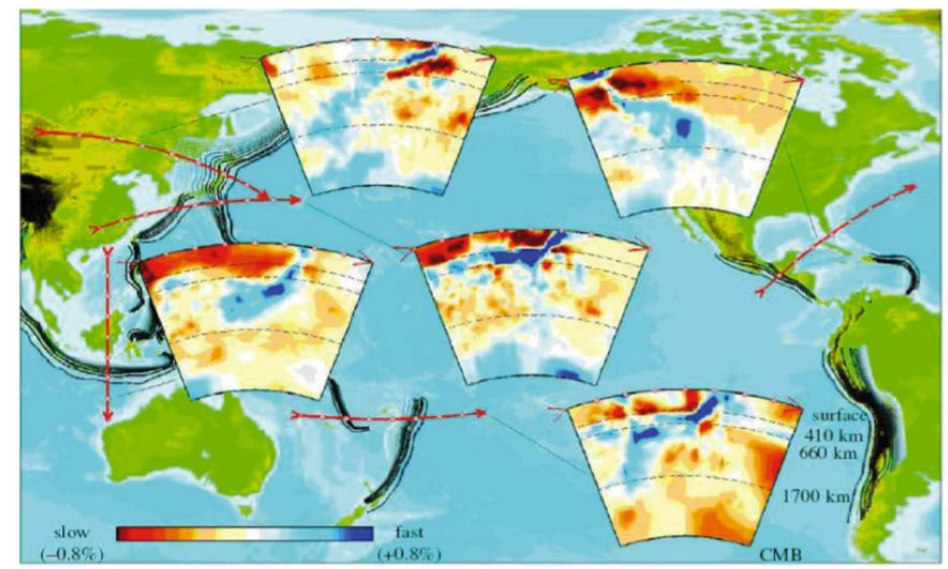




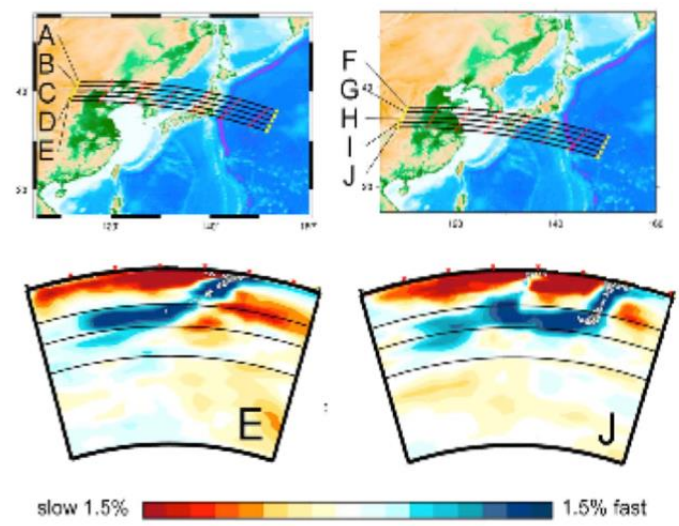
# Les plaques en subduction



Durand et al. [2017]

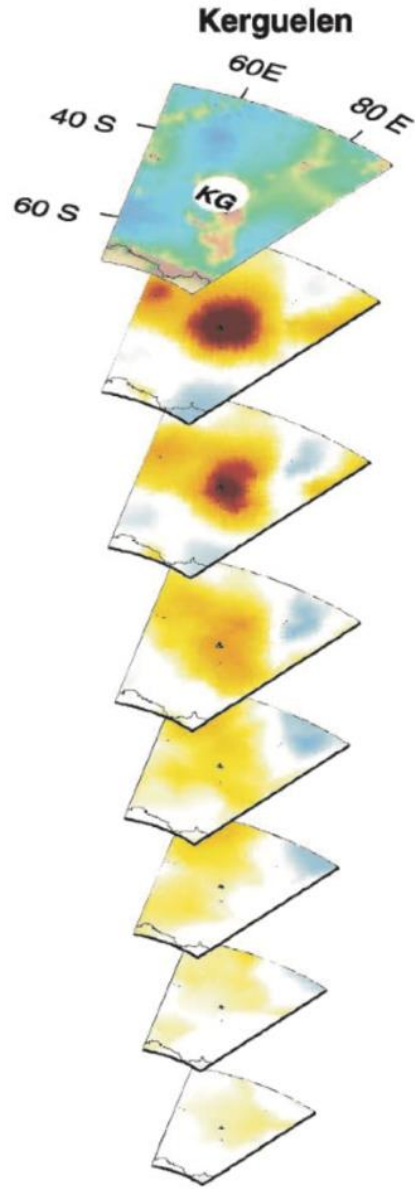


Karason & van der Hilst [2001]

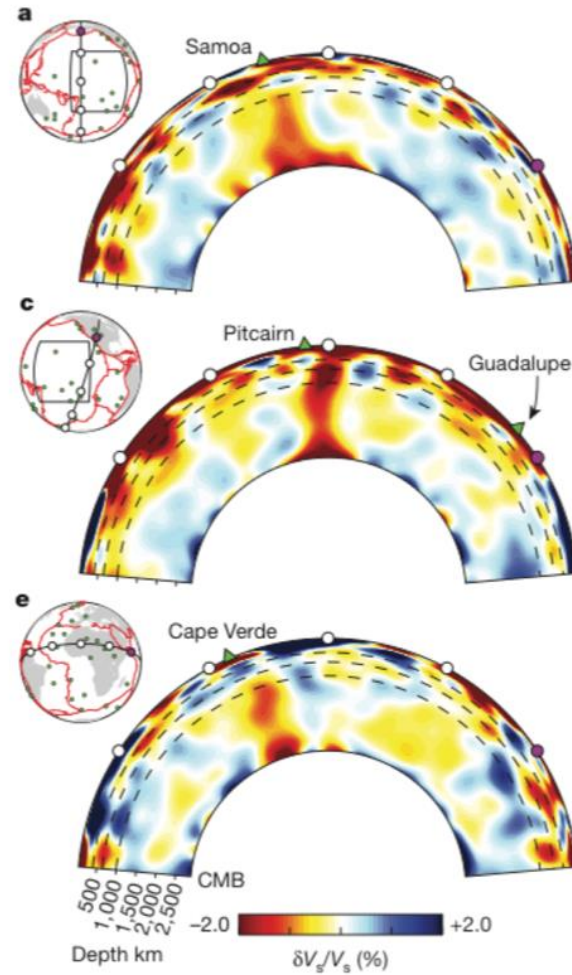


Fukao & Obayashi [2013]

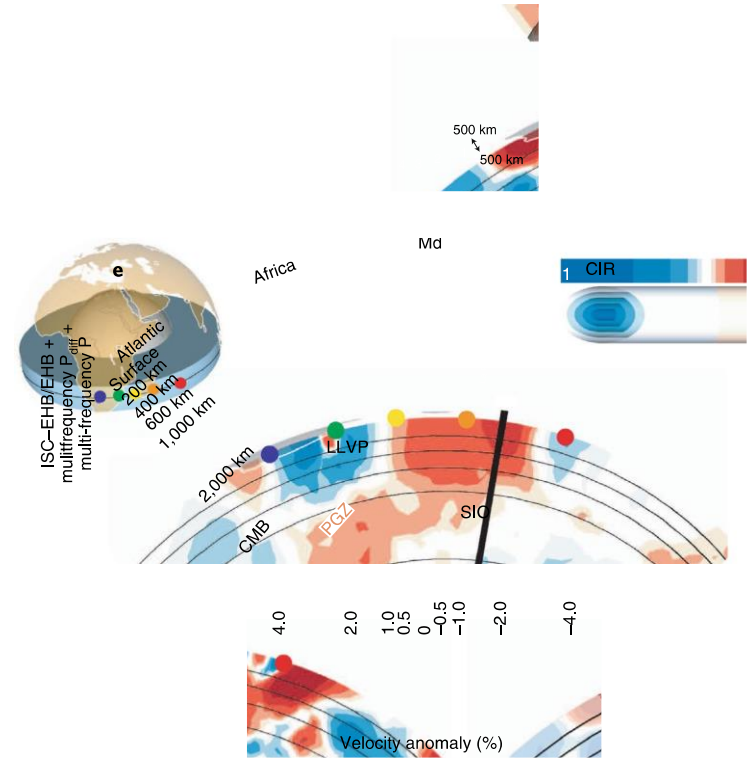
# Les panaches mantelliques



Montelli et al. [2004]

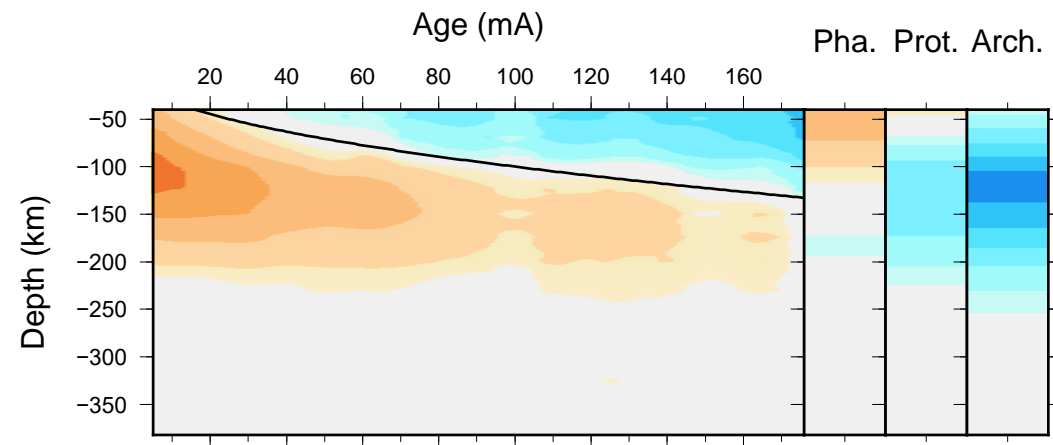
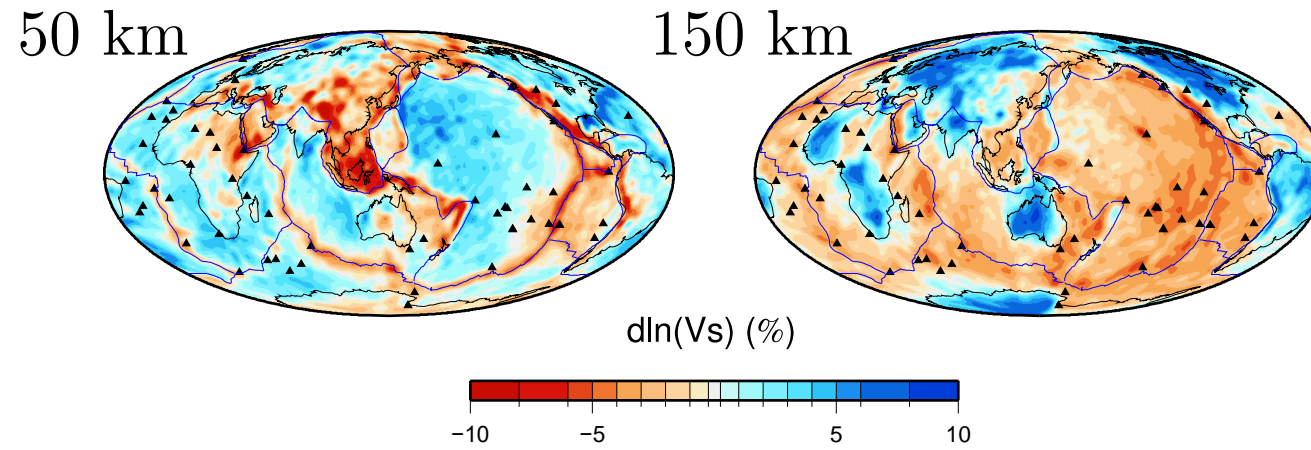


French & Romanowicz [2015]



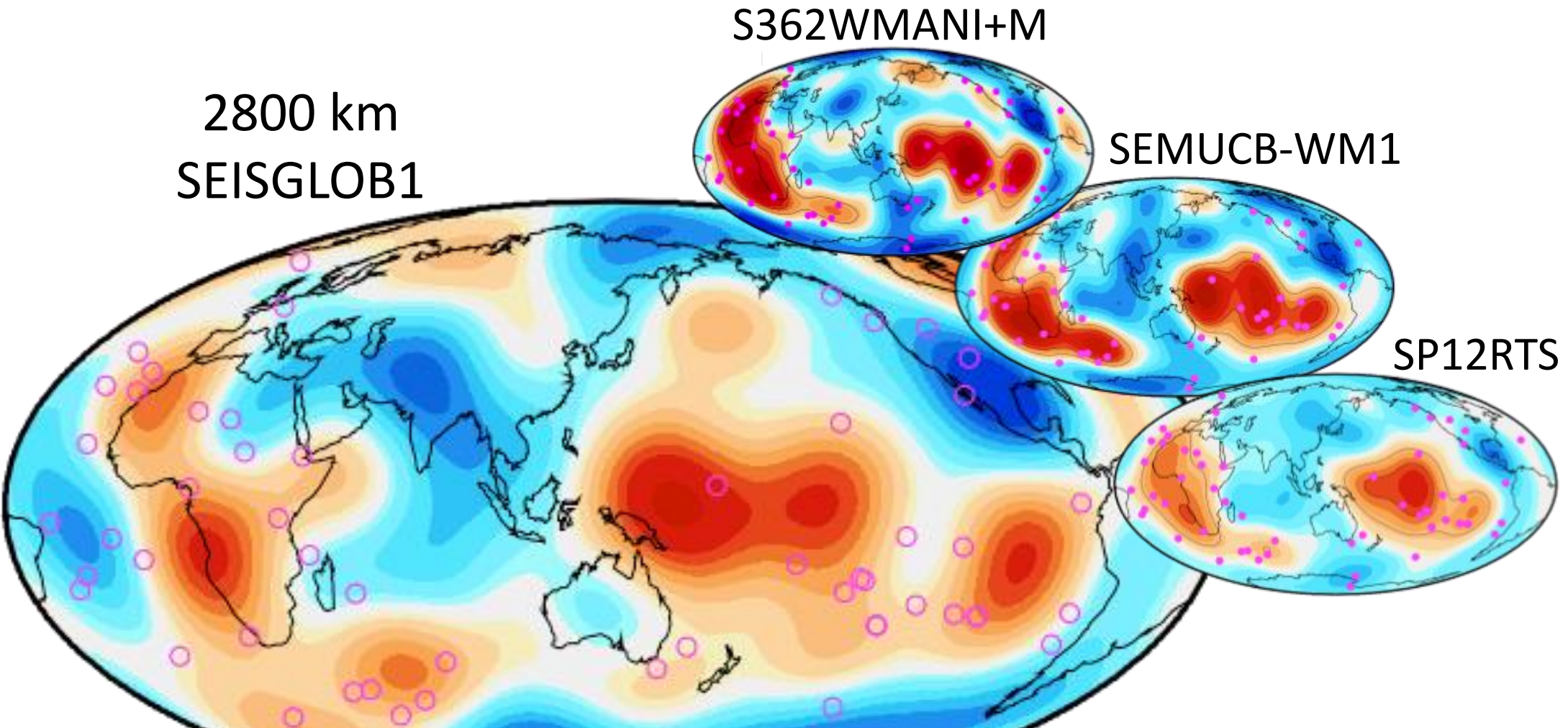
Tsekhmistrenko et al. [2021]

# La lithosphère océanique et cratons

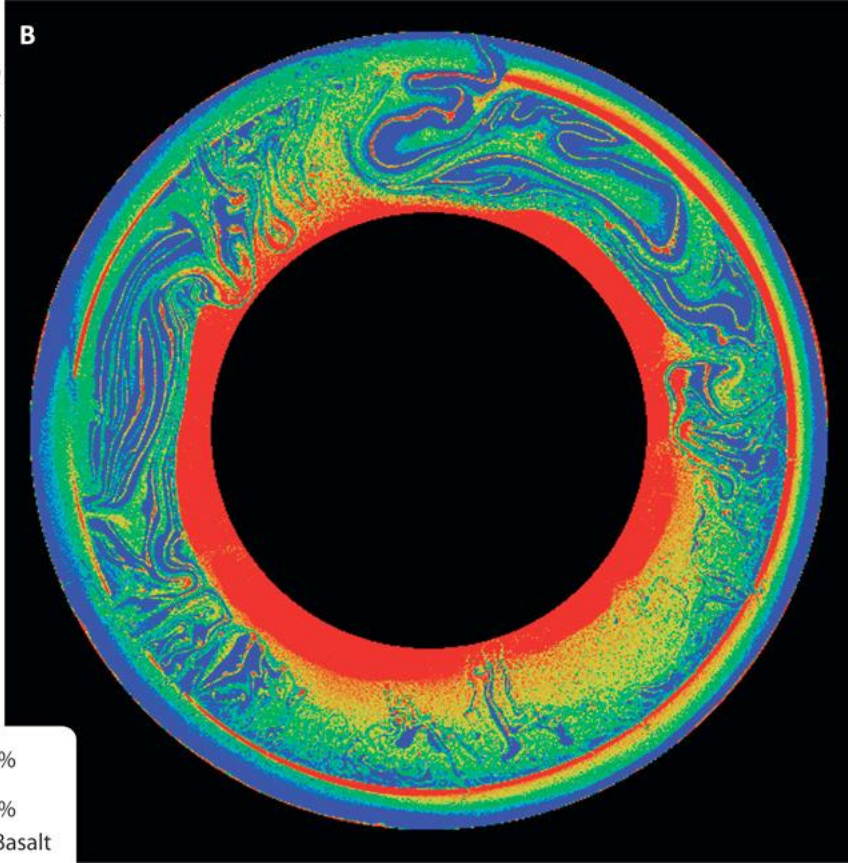
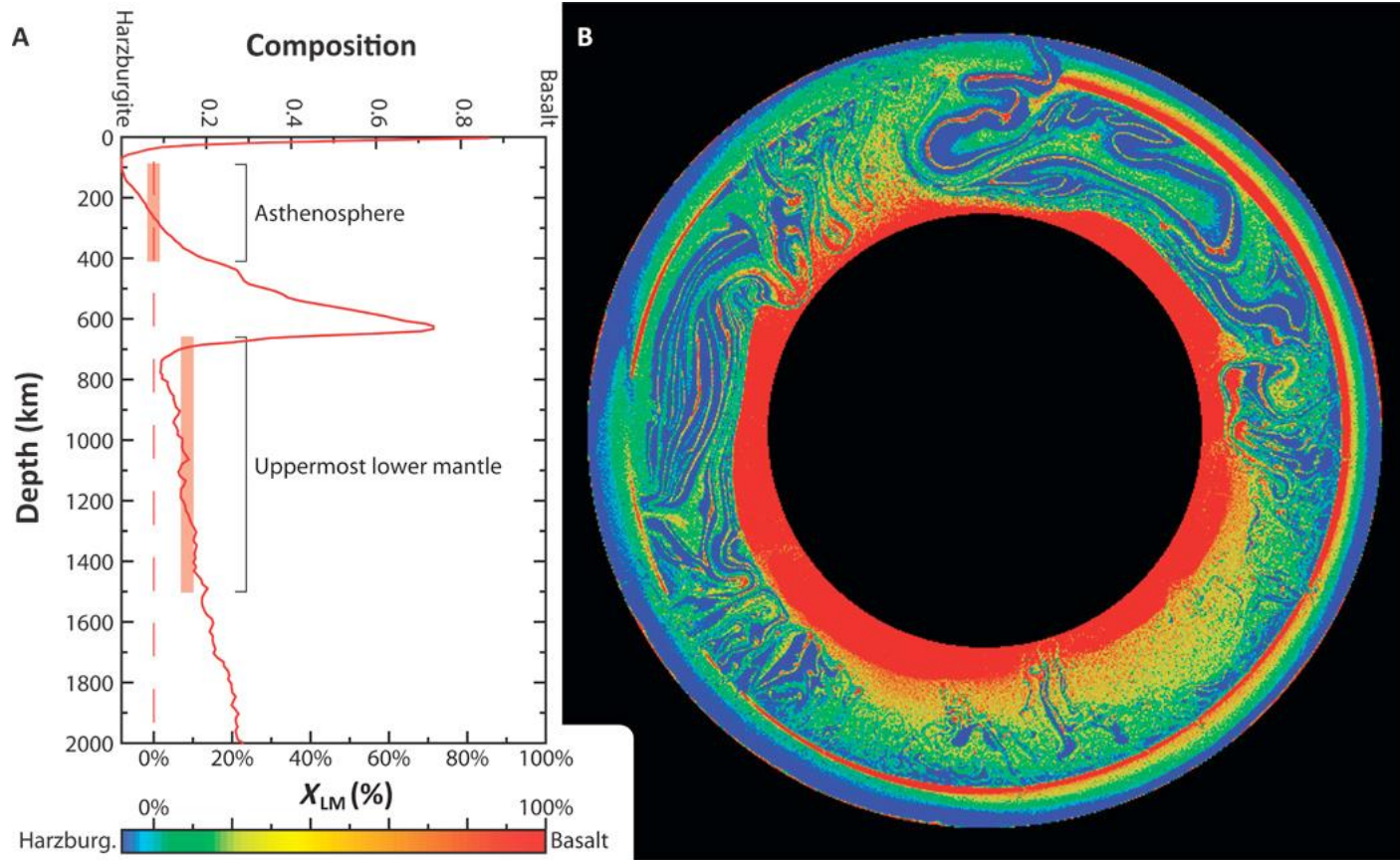




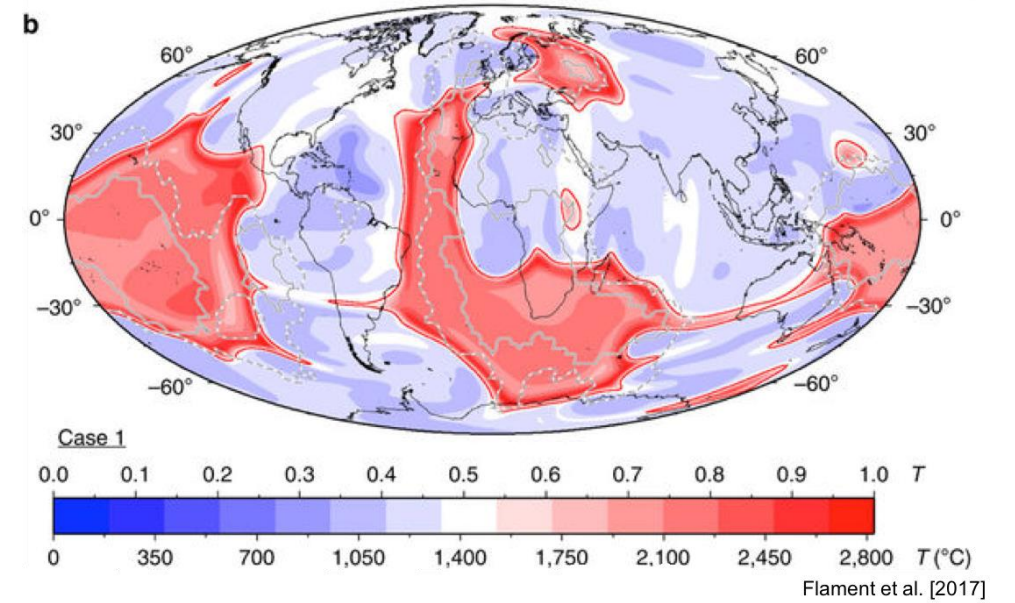
# Structure à la base du manteau



# Simulations numériques



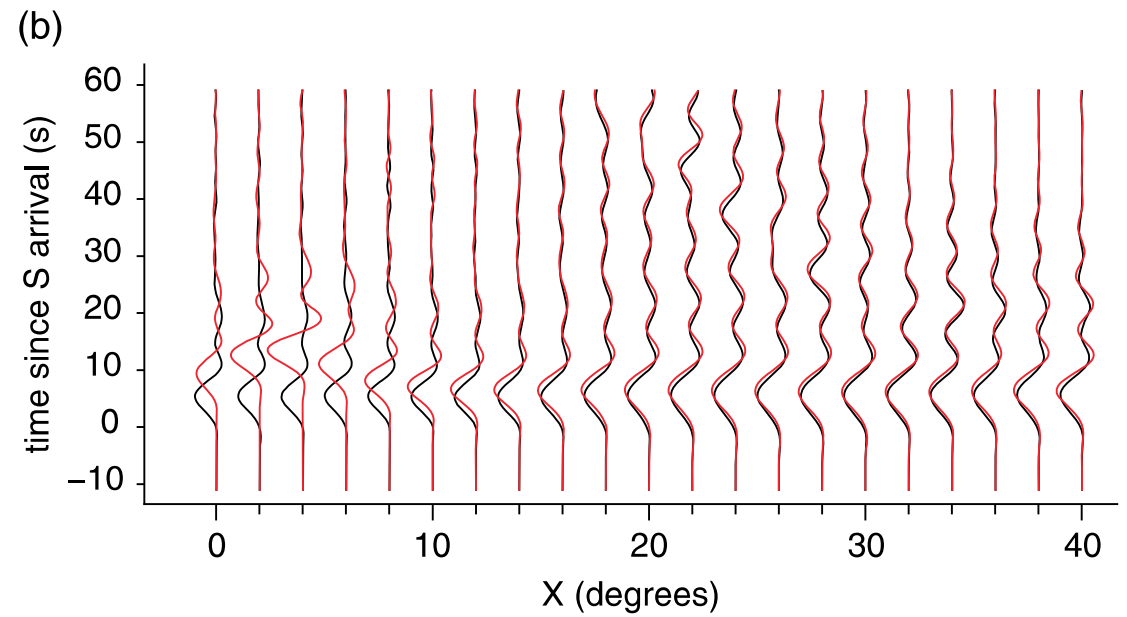
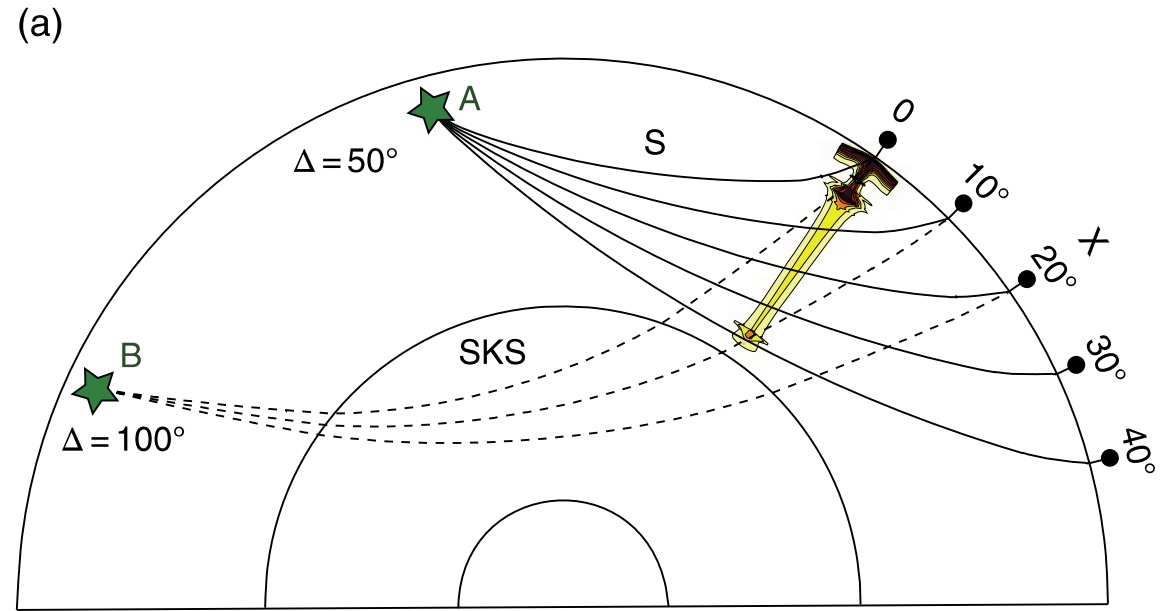
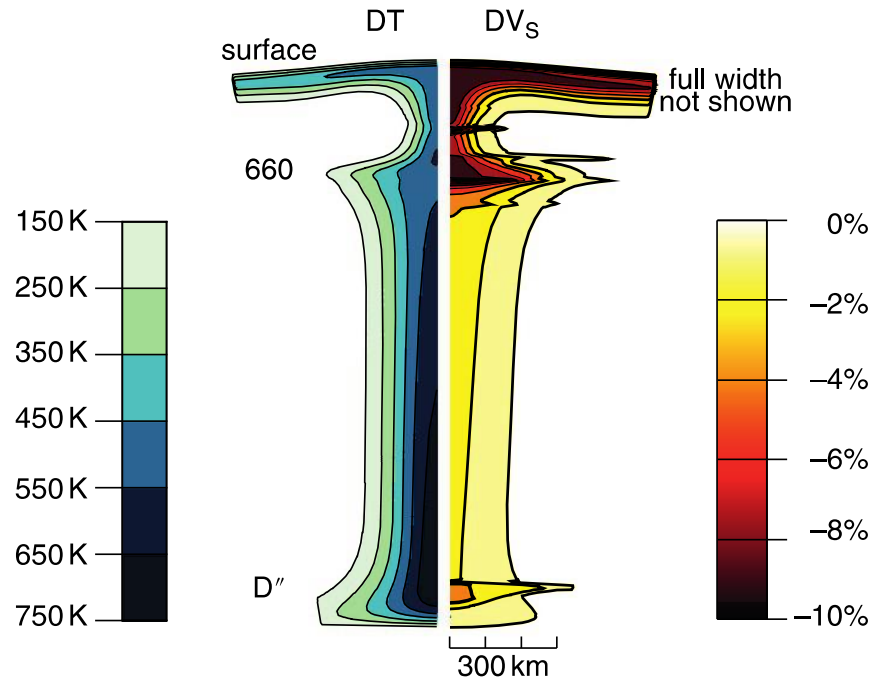
Ballmer et al. [2015]



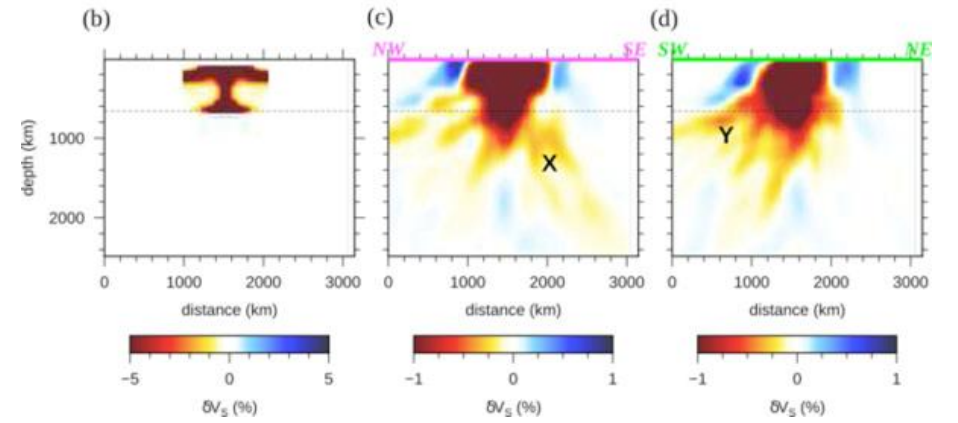
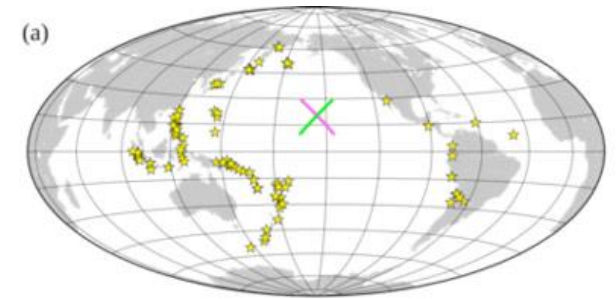
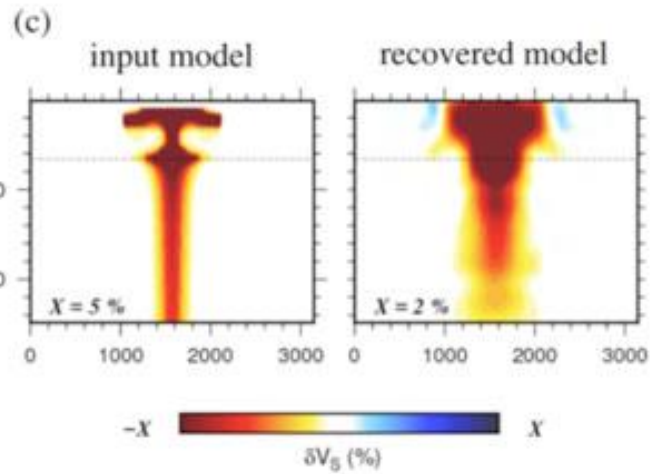
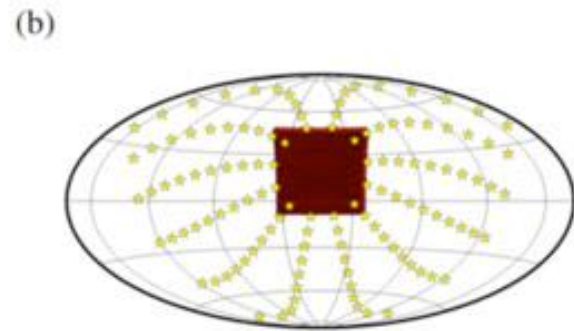
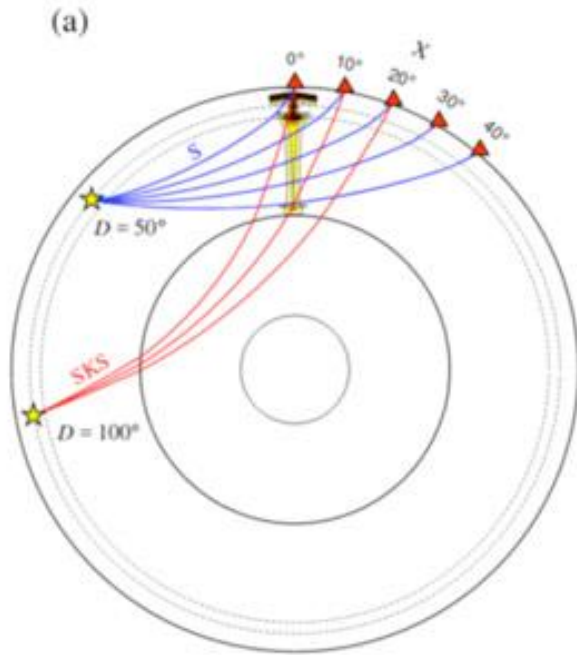




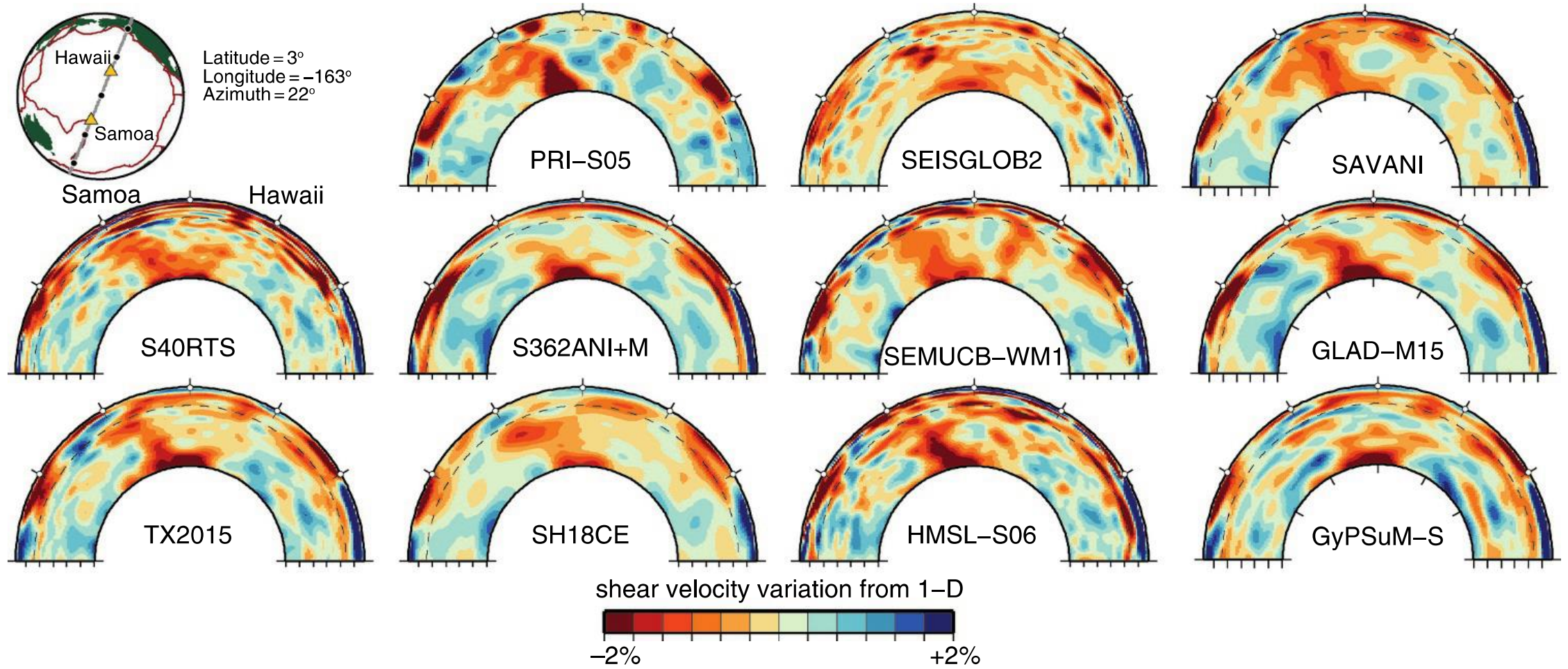
# À la recherche des panaches mantelliques



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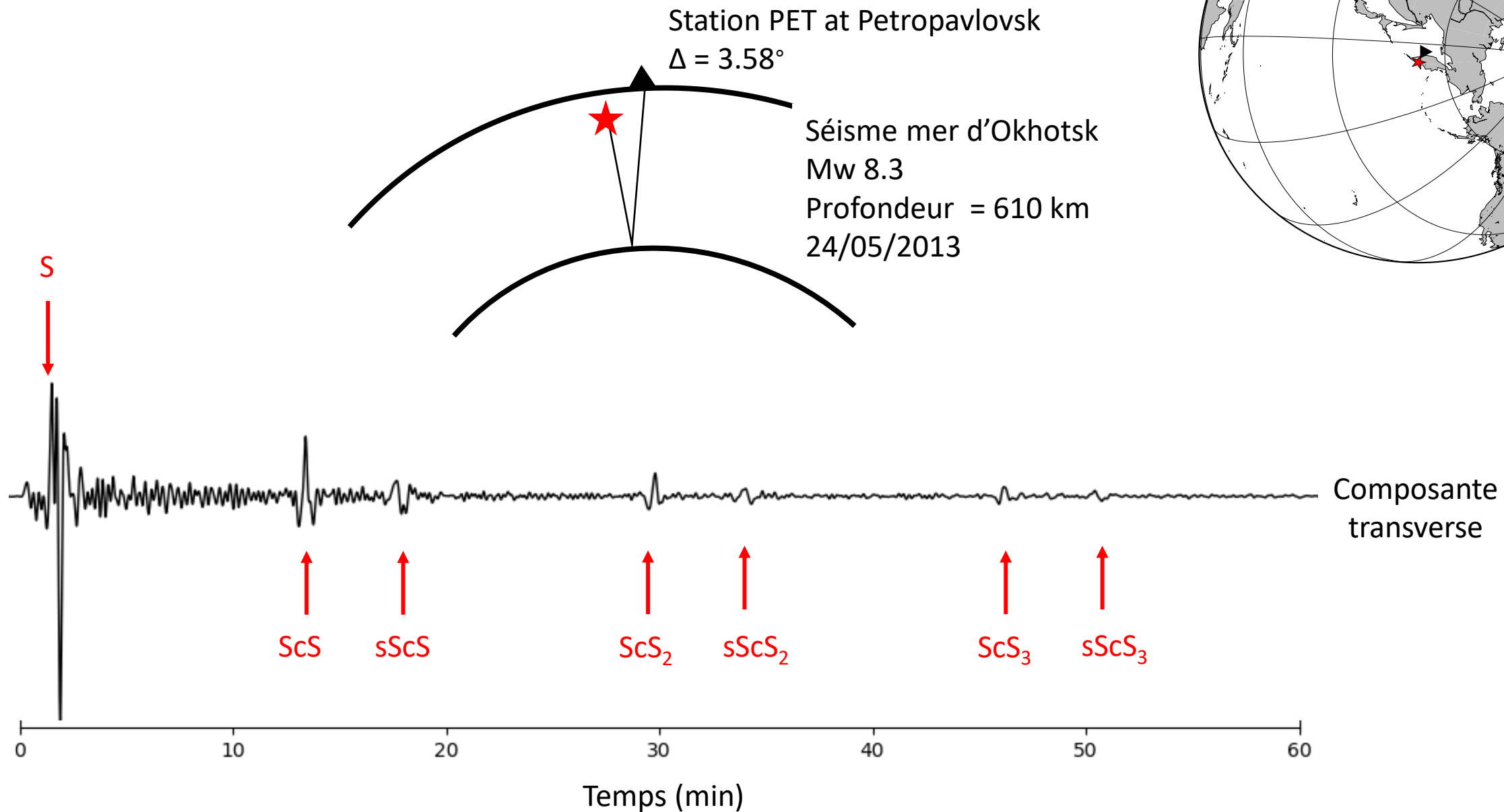
# À la recherche des panaches mantelliques







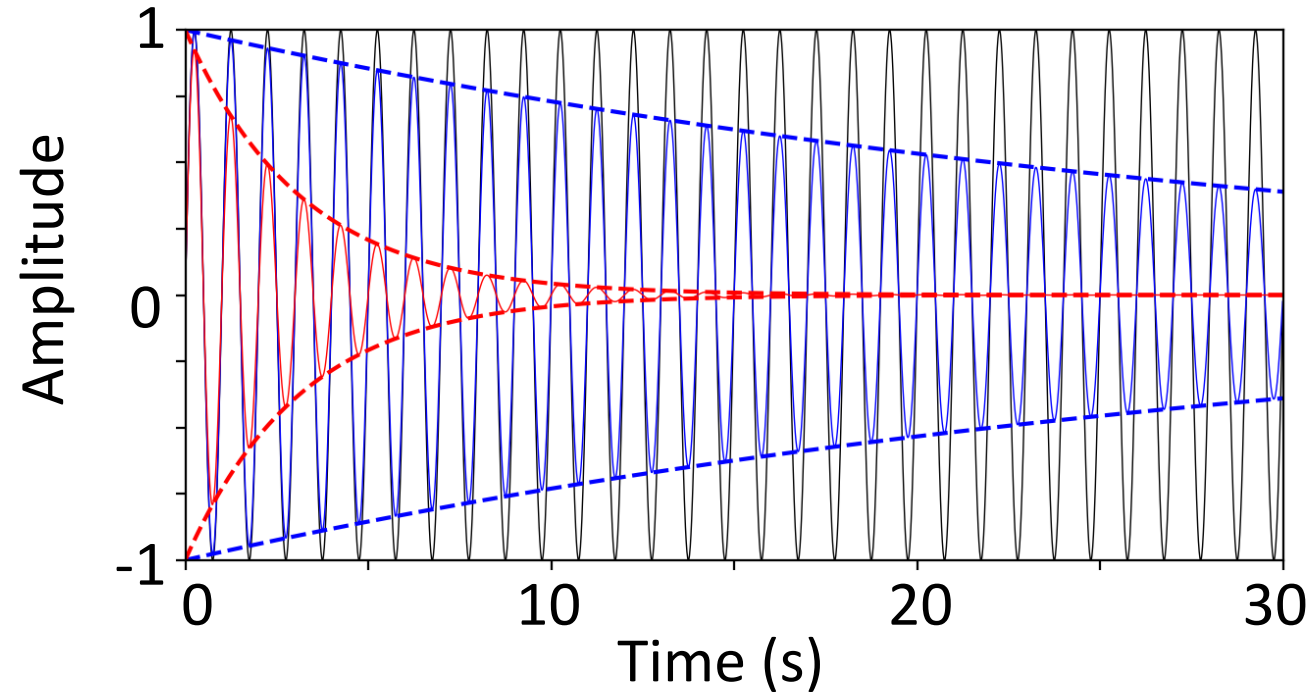
# Atténuation sismique $Q^{-1}$



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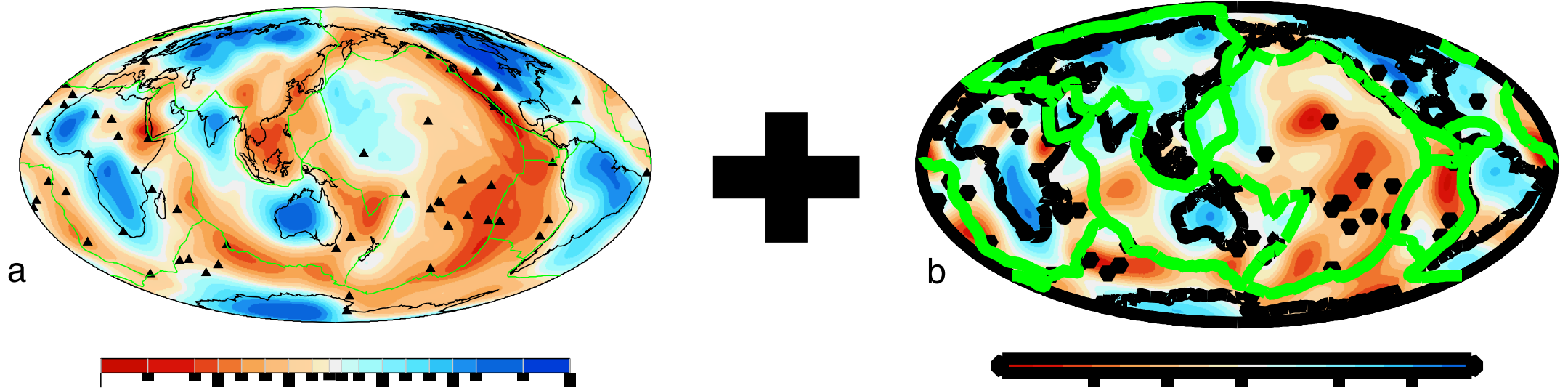
Facteur de qualité

$$Q_{\kappa}(\omega) \gg Q_{\mu}(\omega)$$



$Q = 10 \sim \Delta E/E = 66\%$   
 $Q = 100 \sim \Delta E/E = 6\%$   
 $Q = \infty$

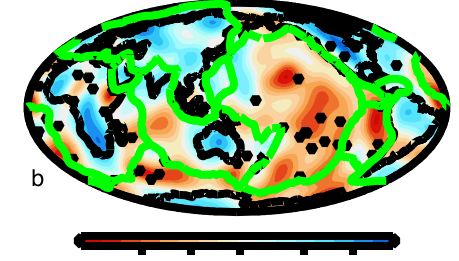
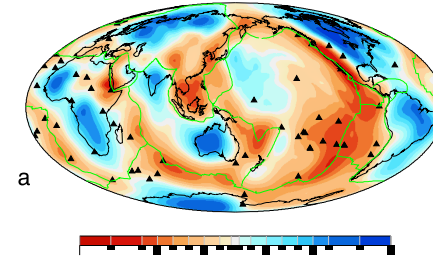
# Modèles globaux de vitesse et atténuation



Avec l'atténuation on a une information supplémentaire

Vs model –DR2020s  
(Debayle et al., 2020)

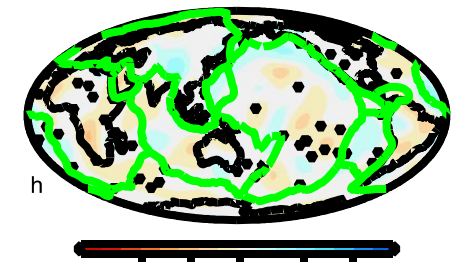
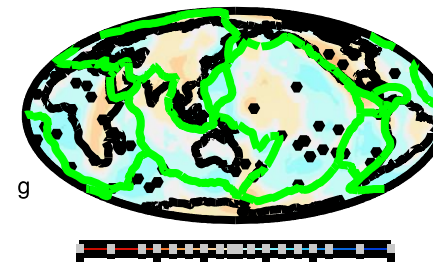
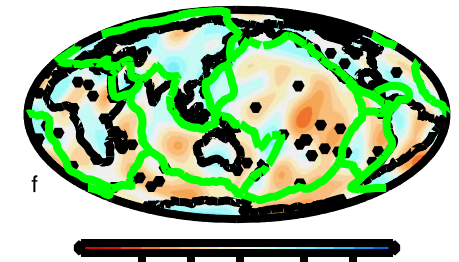
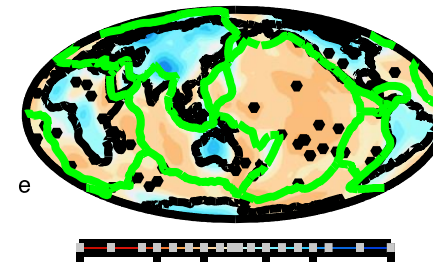
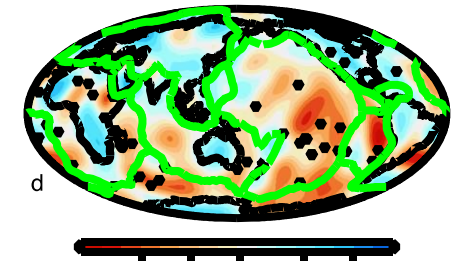
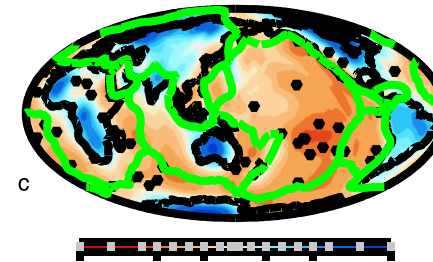
Qs model -QsADR17  
(Adenis et al., 2017)



$$V_s = f(T, \chi, \text{fusion}, \text{eau...})$$

$$Q_s = g(T, \chi, \text{fusion}, \text{eau...})$$

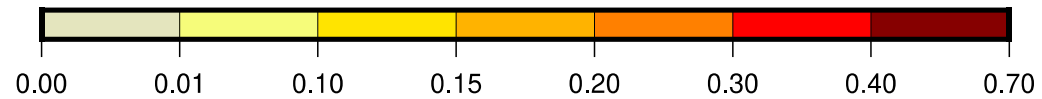
Opportunité de discriminer les effets





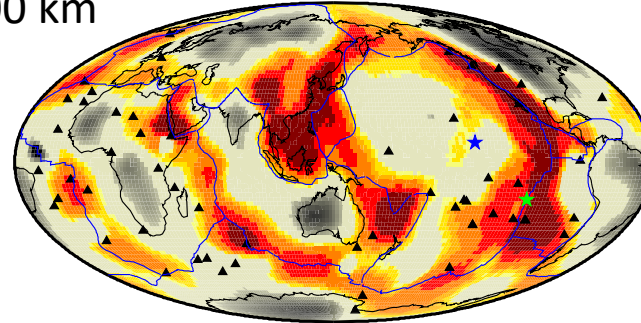
# Du manteau fondu à la base de la lithosphère

Melt fraction (%)

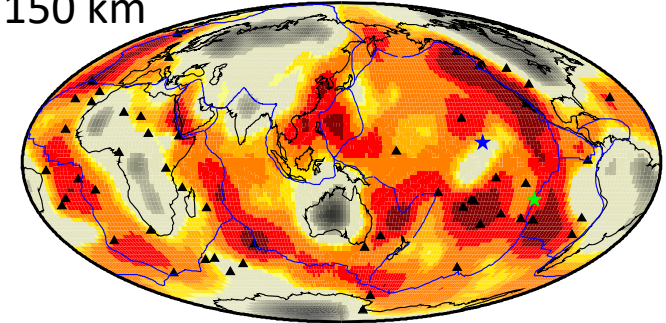


Misfit (%)

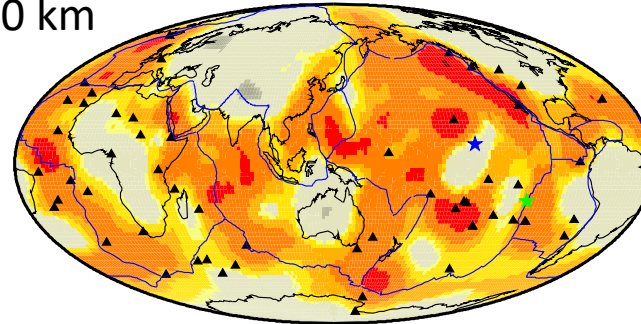
100 km



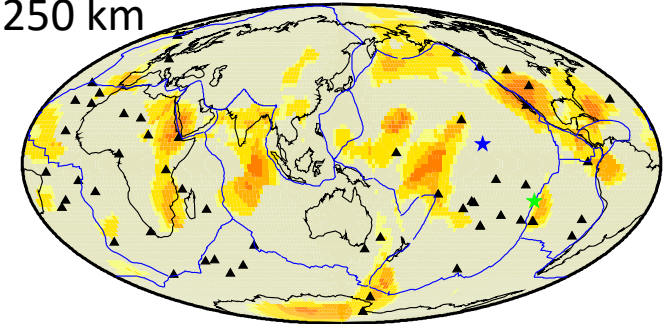
150 km



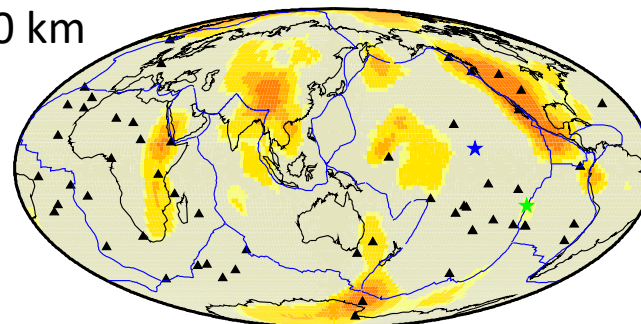
200 km



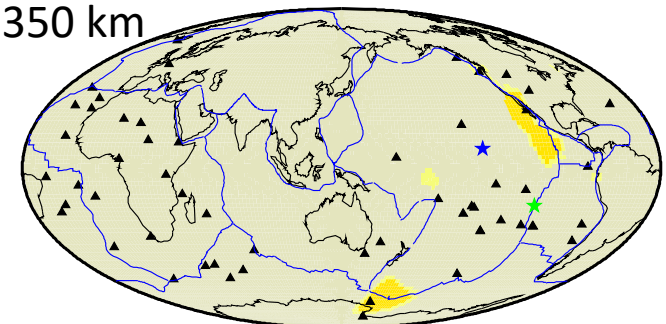
250 km



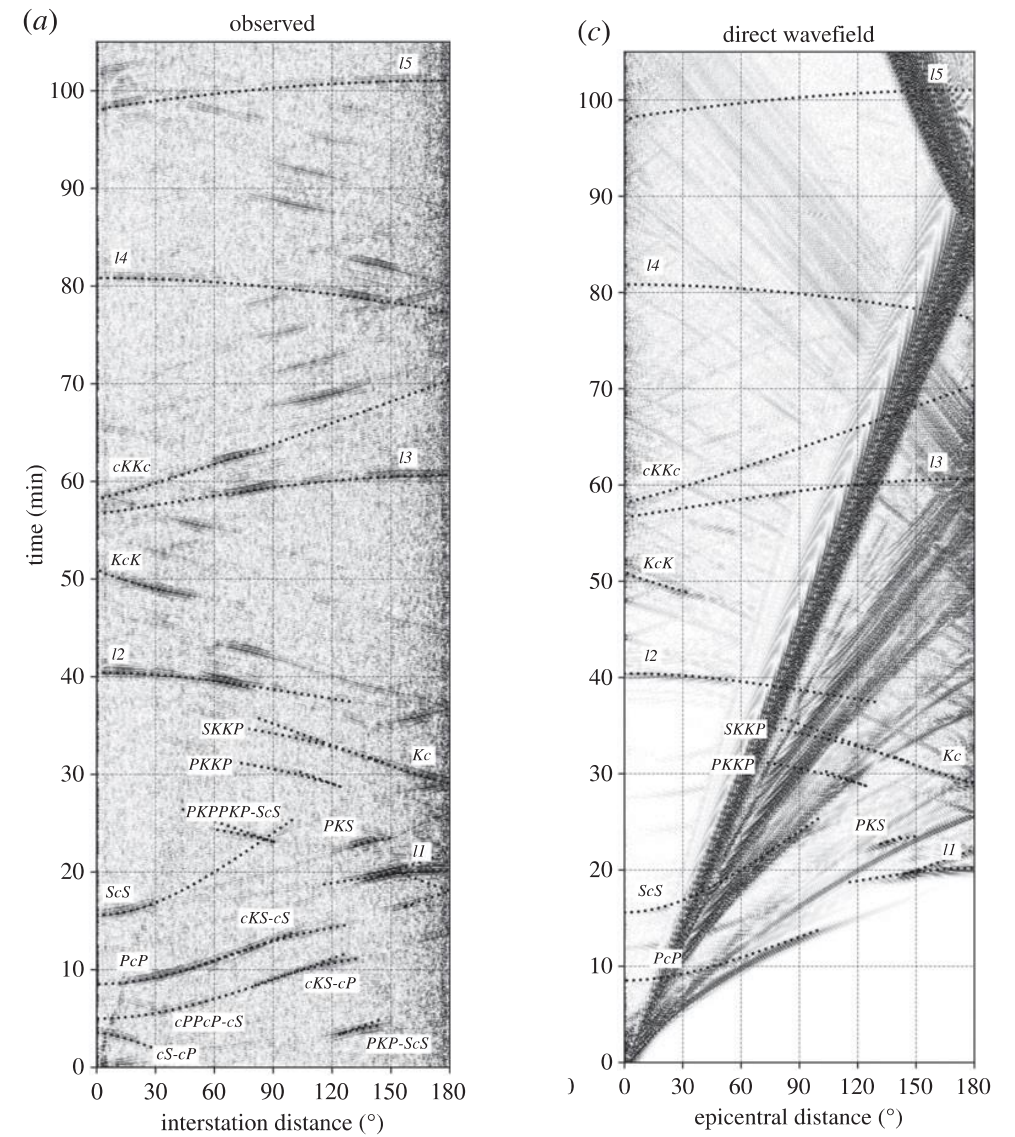
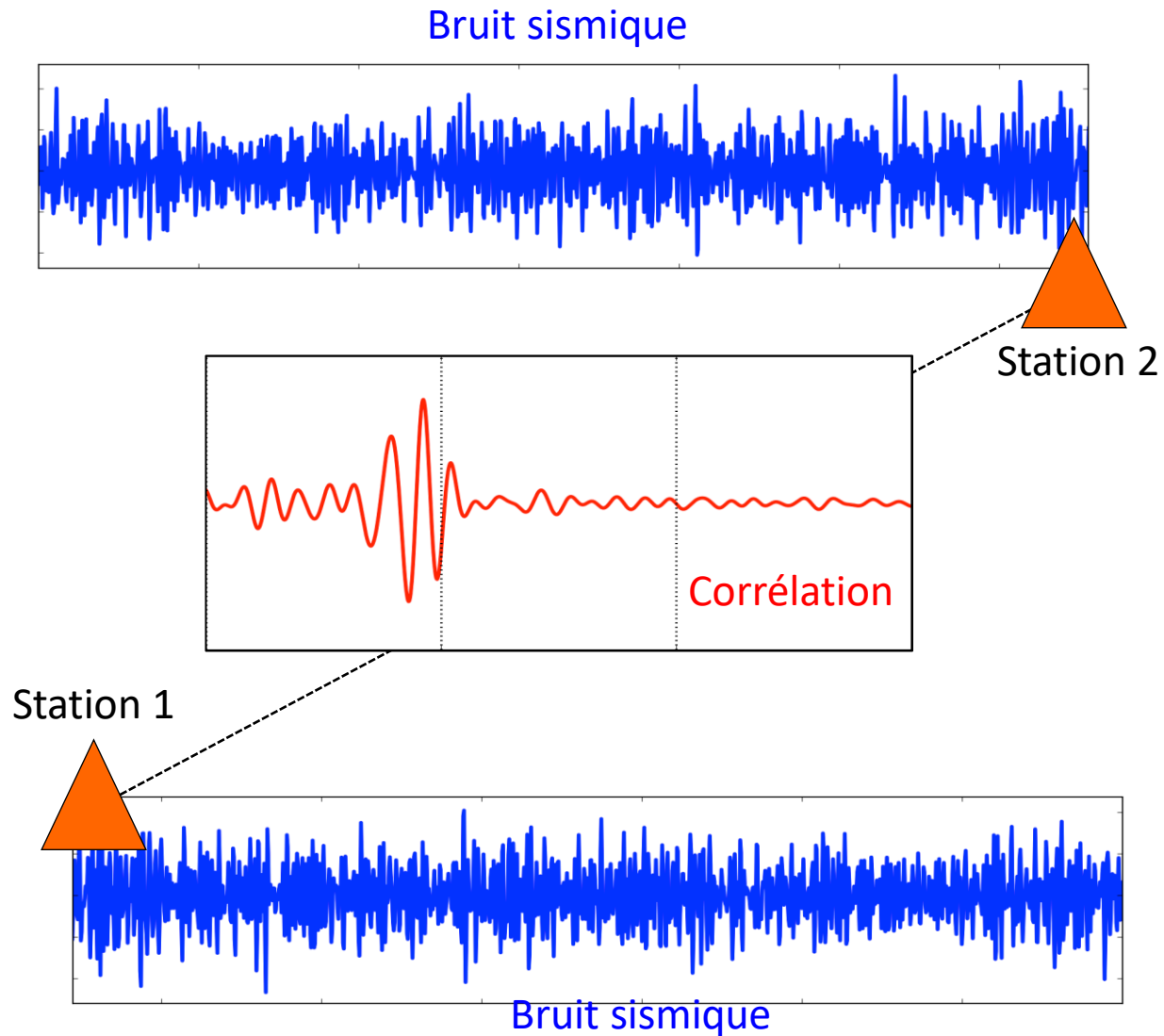
300 km



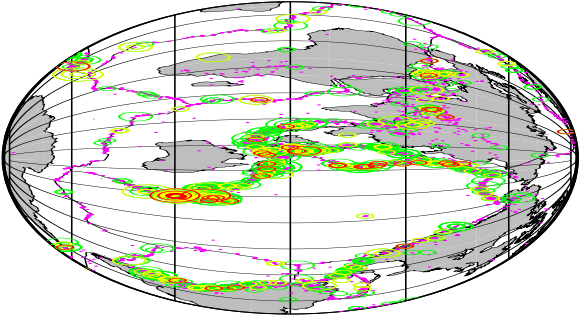
350 km



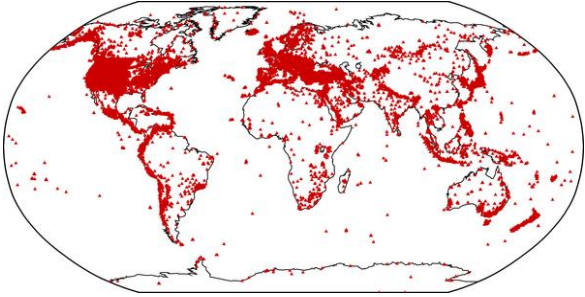
# De la sismologie sans séisme



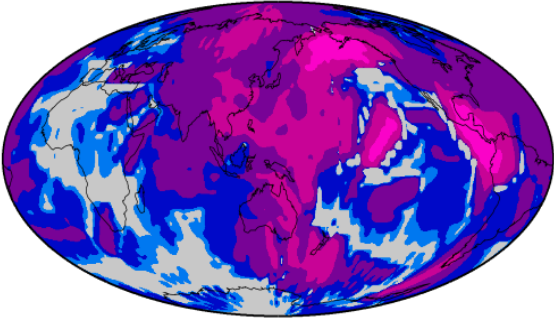
# De la sismologie sans séisme



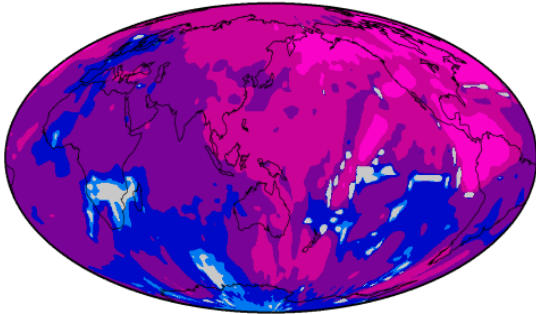
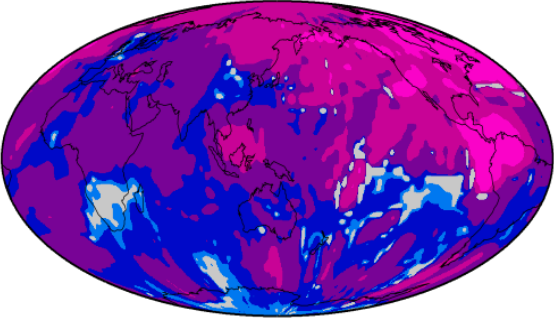
Earthquakes



Seismic noise



+



Ray density

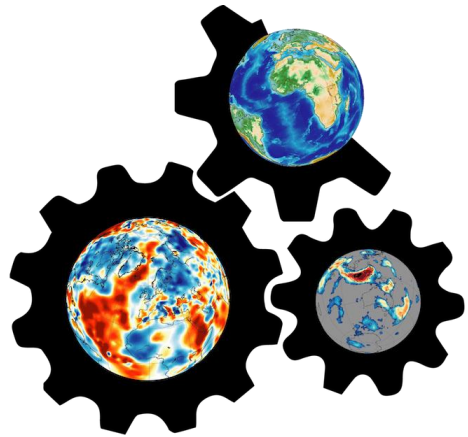


min

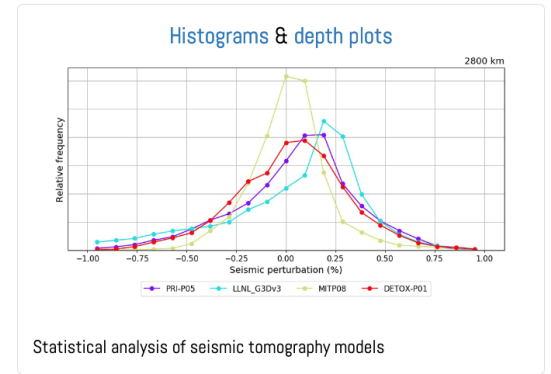
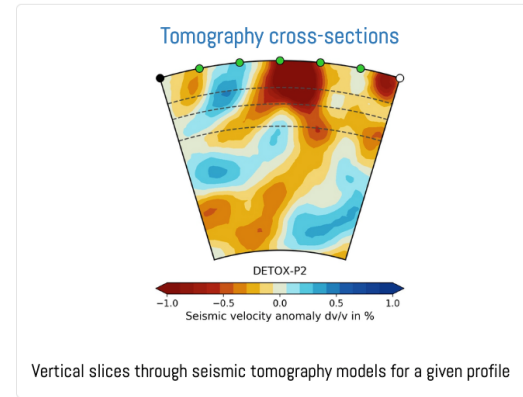
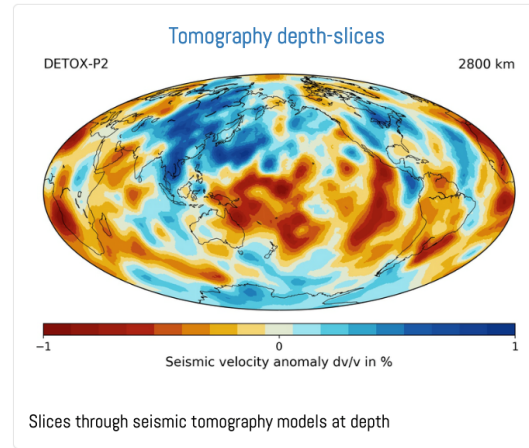
max





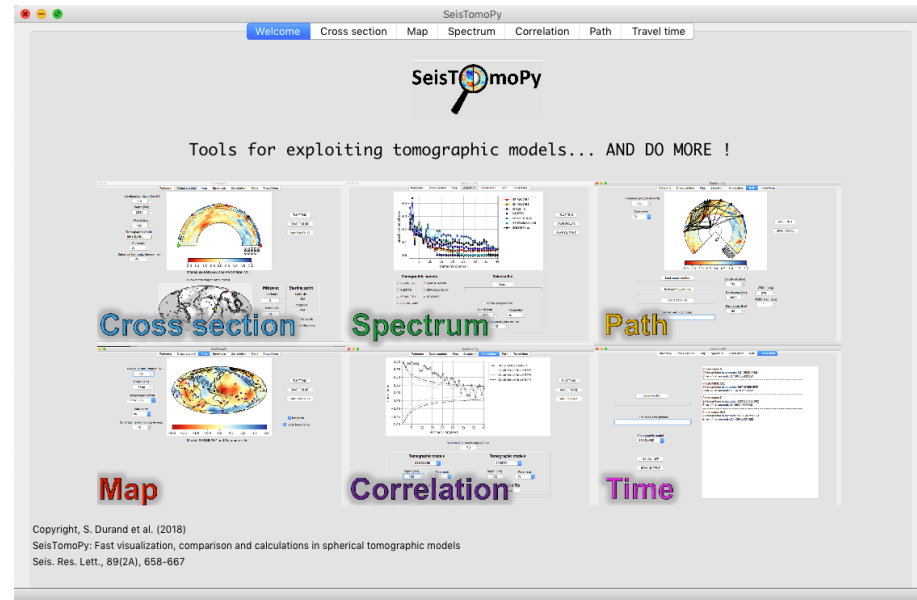


SubMachine



<https://www.earth.ox.ac.uk/~smachine/cgi/index.php>

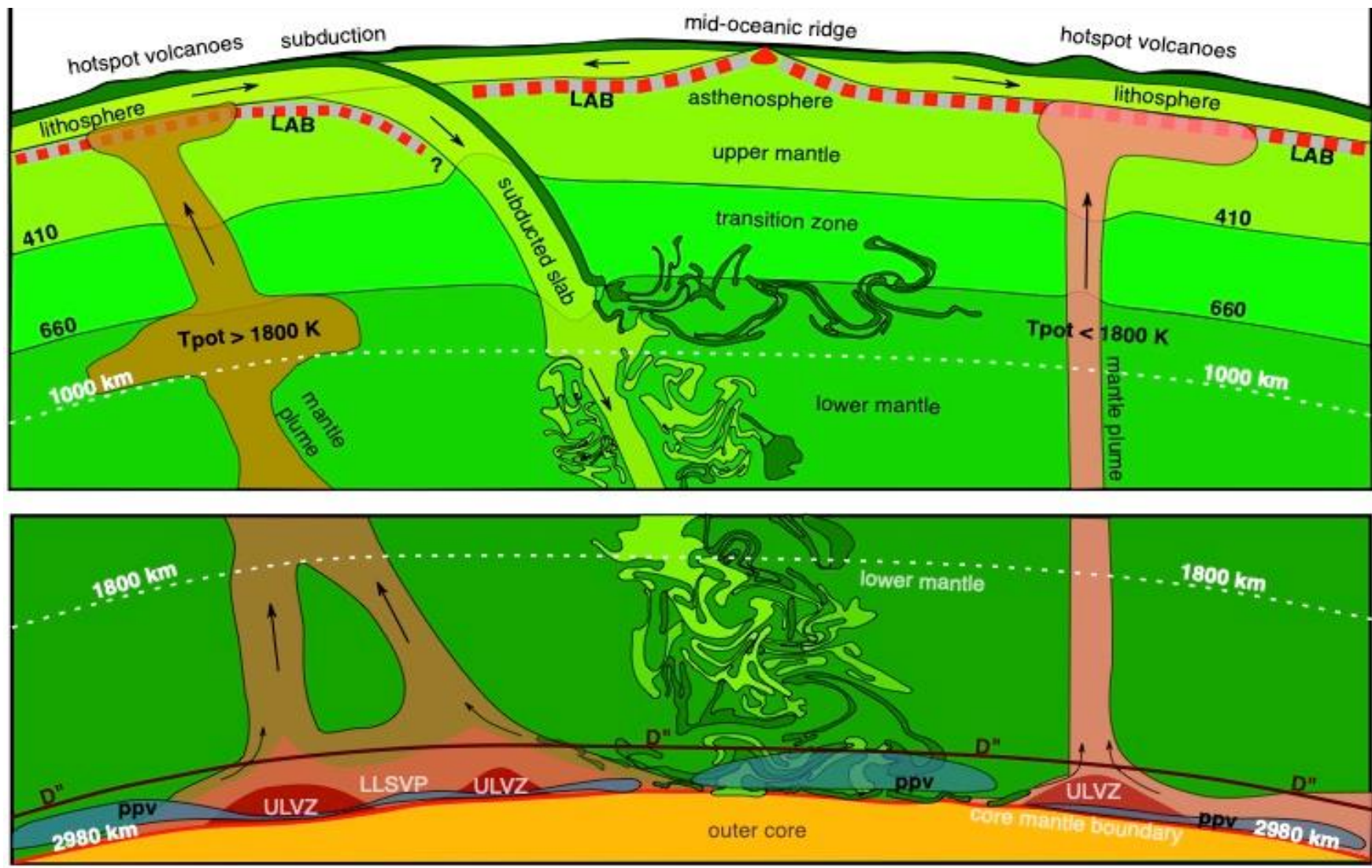
SeisTomoPy



[https://github.com/stephaniedurand/SeisTomoPy\\_V3](https://github.com/stephaniedurand/SeisTomoPy_V3)

[https://www.iris.edu/hq/inclass/search#type\[\]=7&language\[\]=1](https://www.iris.edu/hq/inclass/search#type[]=7&language[]=1)





S. Durand & B. Tauzin