Noise-Based Seismic Measurements of Tidal- and Thermal-Induced Wave Speed Changes

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Massachusetts Institute of Technology

Earth Resources Laboratory

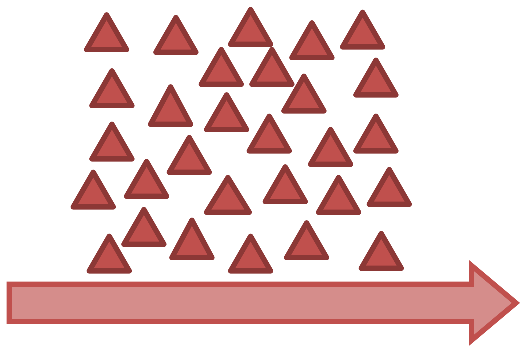
ISTerre
Institut des Sciences de la Terre

Motivation

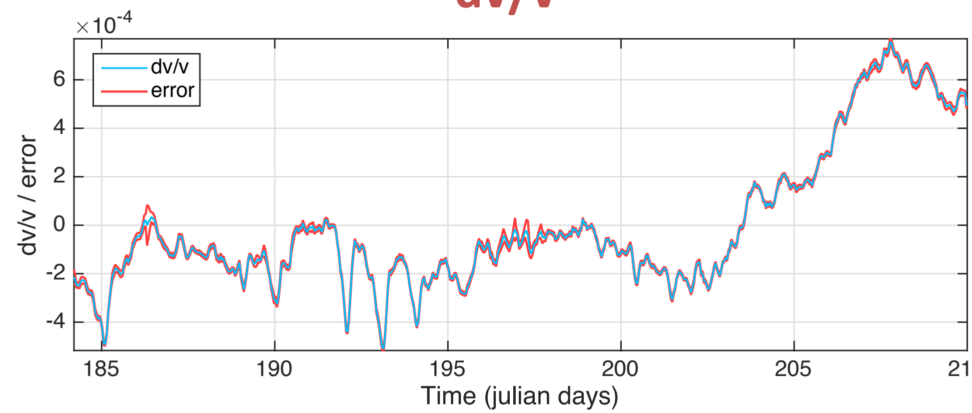
Real-time changes of relative seismic wave speed (dv/v)

Crustal stress variations

Seismic Array, Ambient Noise



dv/v



- **High temporal resolution (~ hourly)** for noised based monitoring.
- To better understand the response of dv/v to stress changes.

Outline

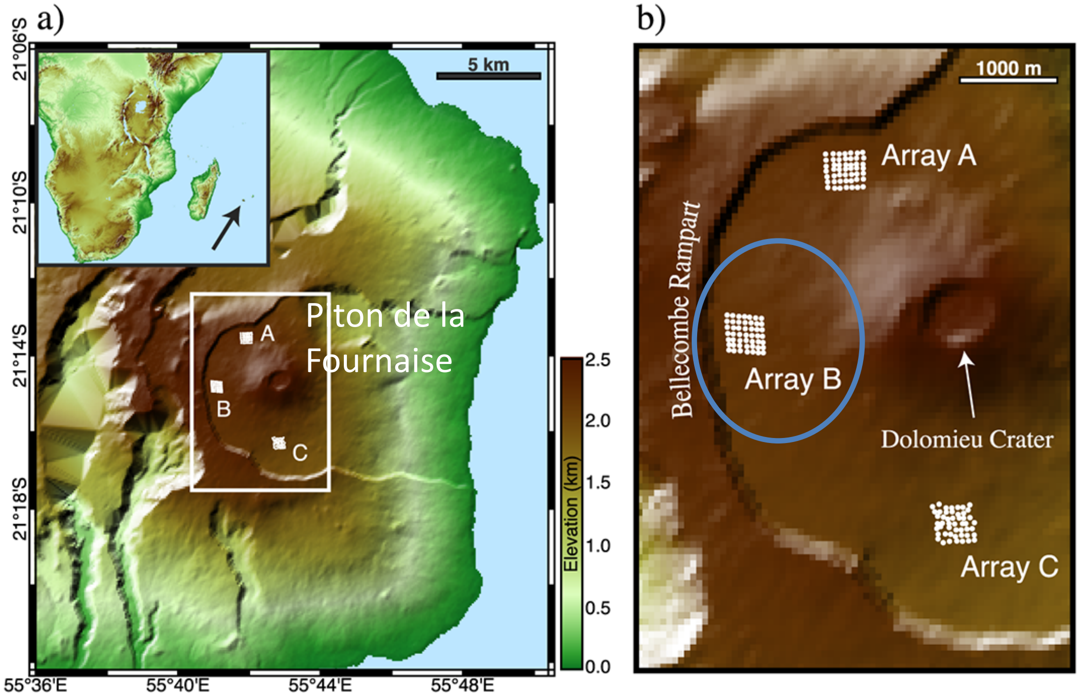
1. Data & Method

- The VolcArray Experiment
- Noise-based coda wave interferometry

2. Results & Discussion

- dv/v as a function of time
- Long period dv/v changes
- Short period dv/v changes

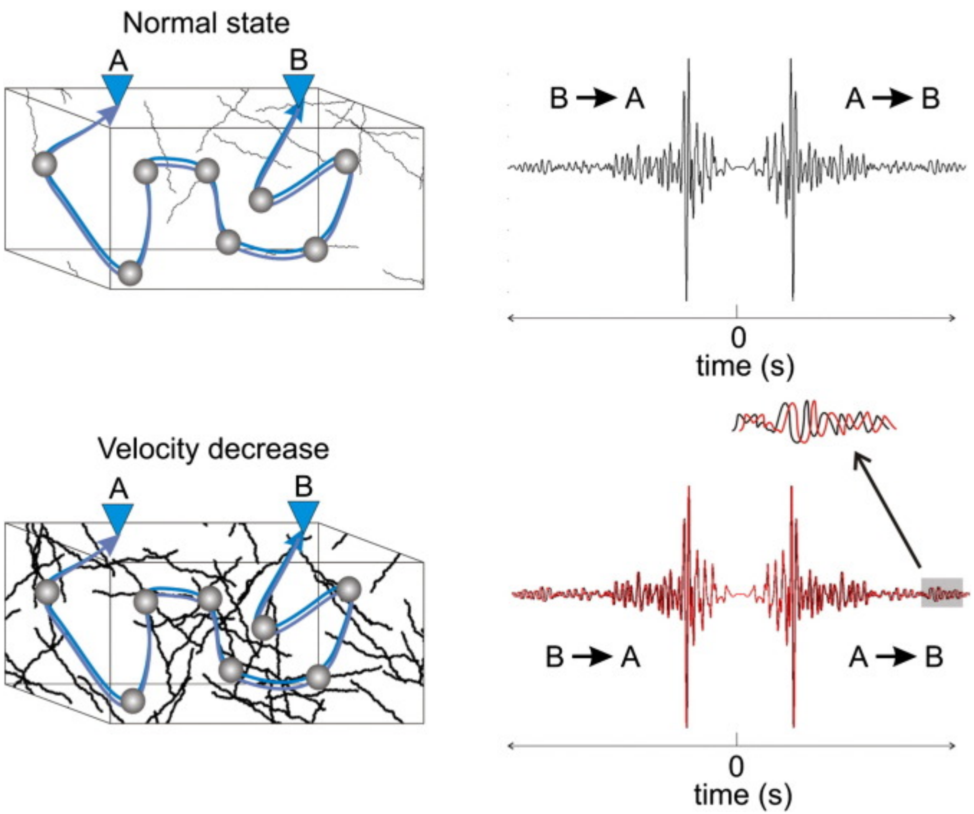
The VolcArray Experiment



- 26 days in July, 2014
- Vertical component geophones
- 3 Arrays, each has 7*7 receivers
- Spacing ~ 80m

- The locations of receivers in the VolcArray experiment. (Nakata el al, 2016)

Noise-based coda wave interferometry



Brenguier et al, 2016

i. Continuous Green's Functions: cross-correlations with **hourly** noise data (within each array)

ii. Coda ---- sensitive to multiple scattering

i. dv/v = -dt/t (1-5 Hz, within 100m depth)

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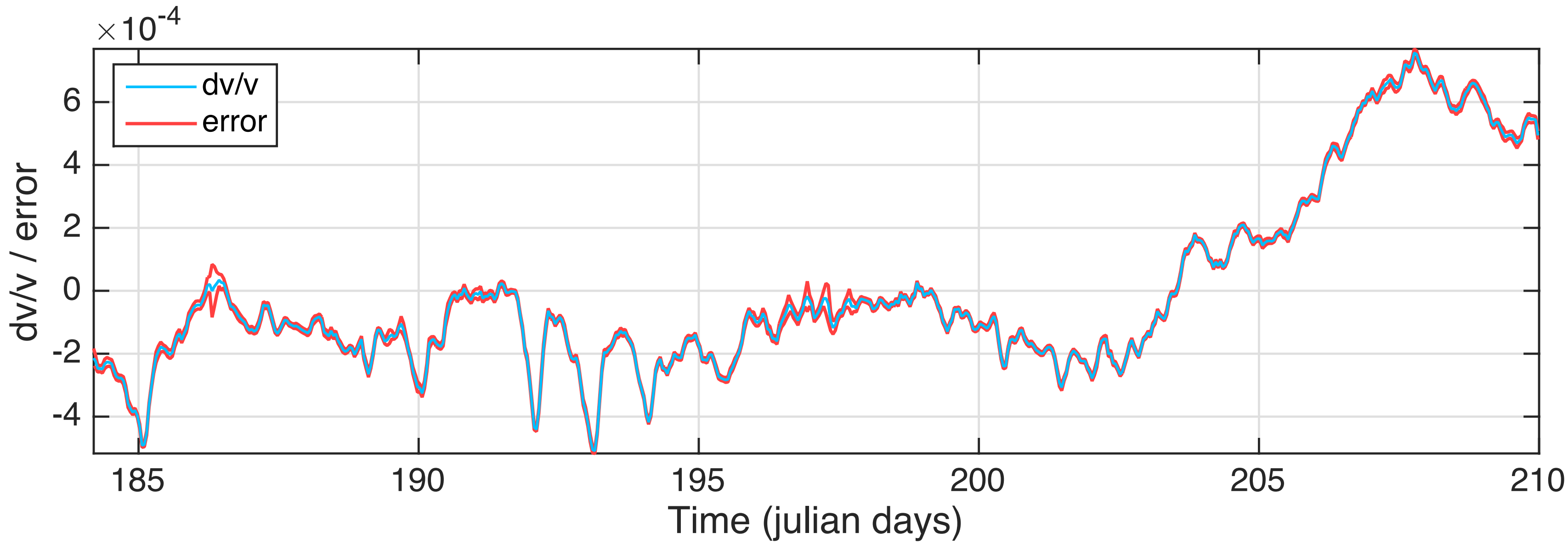
dv/v time series

Relative wave speed changes (1-5 Hz, within 100m depth)

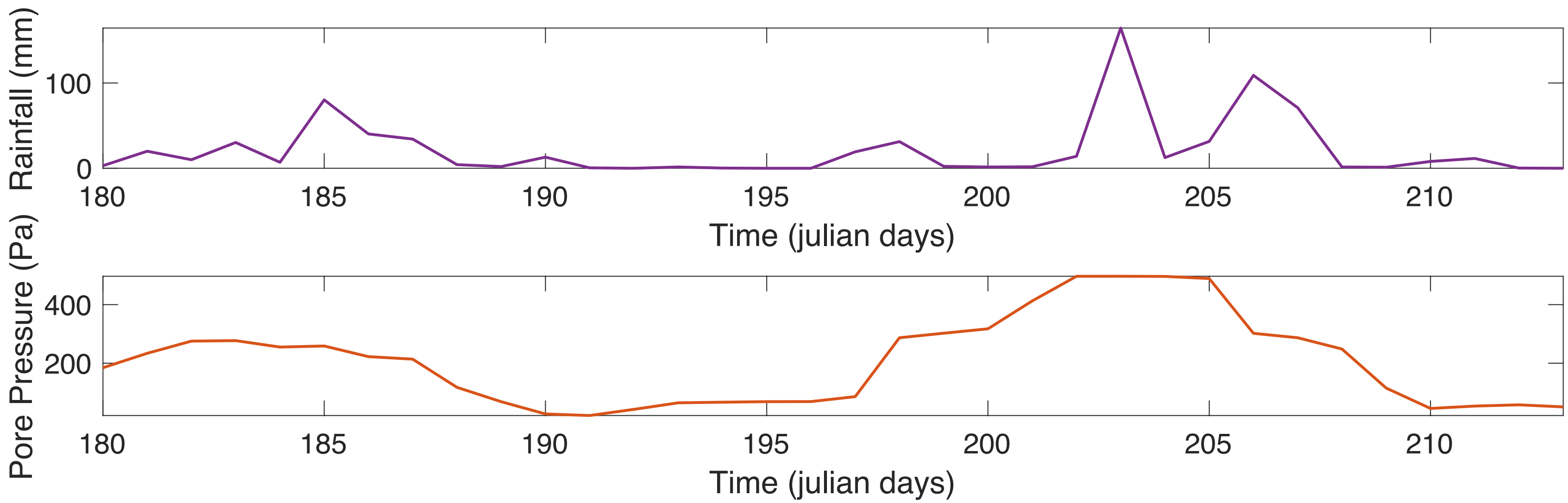
dv/v of average of 1225 station pairs in array B

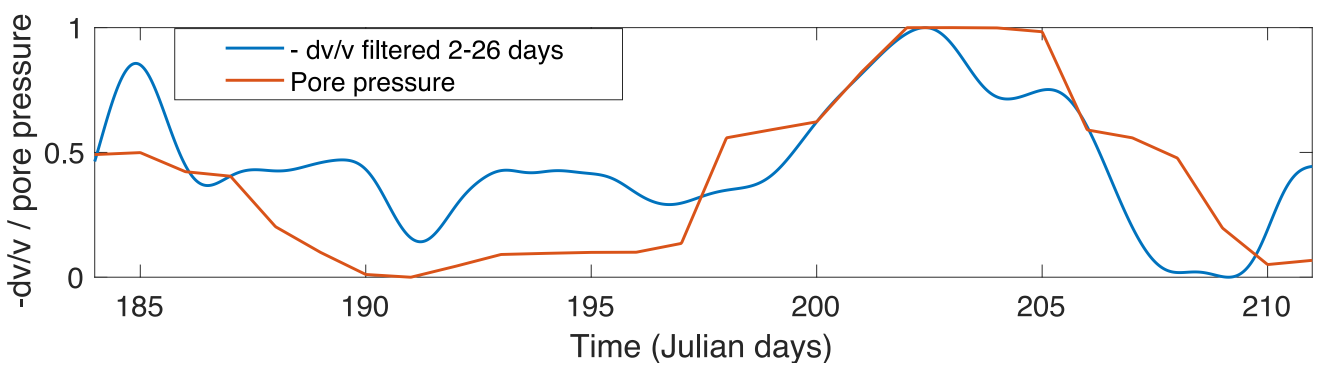


- **Long period variations (~days, 0.05%)**
- **Short period variations (~hours, 0.01%)**

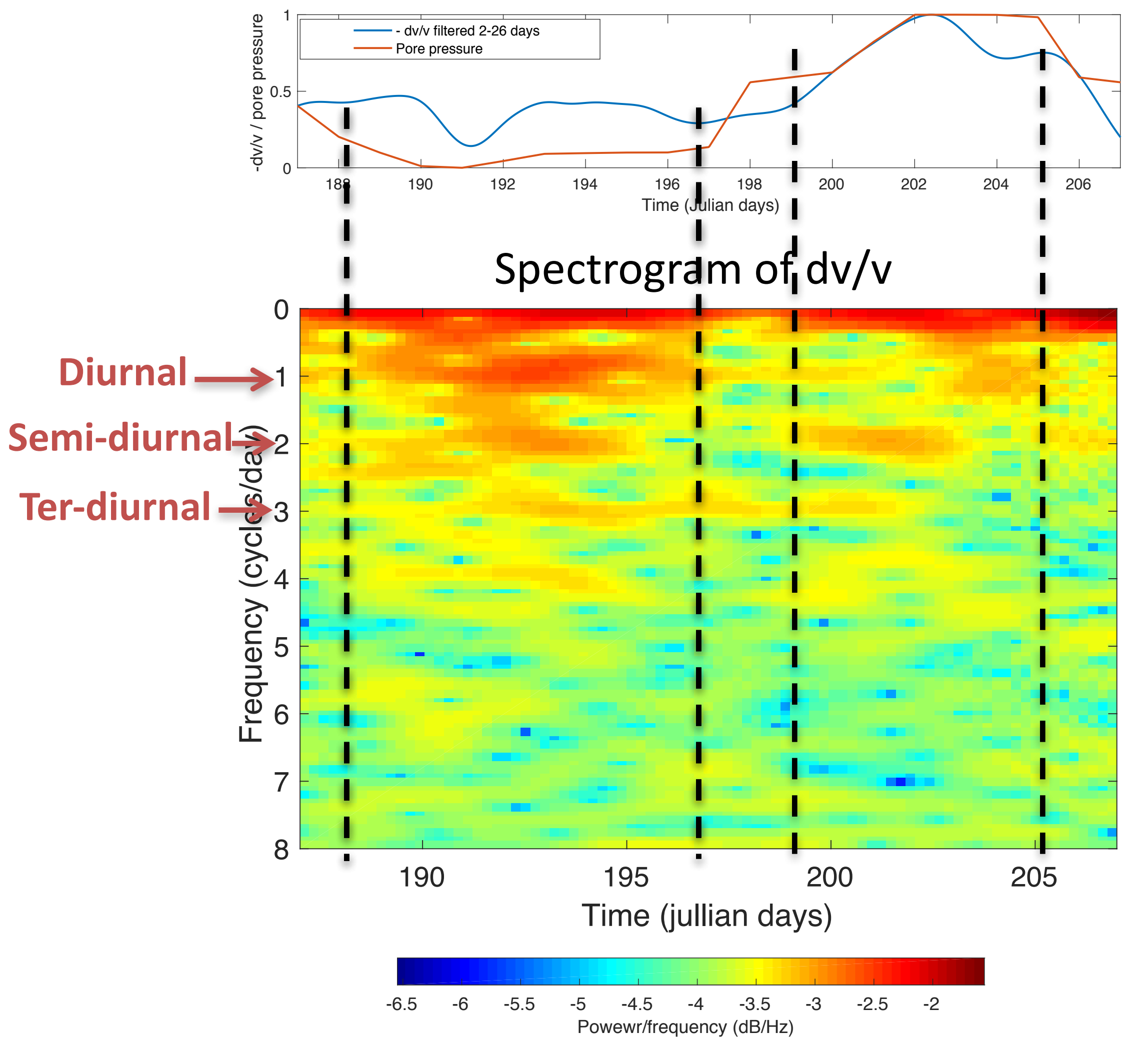
Long period dv/v changes

- Pore pressure changes due to precipitation: *(Talwani et al., 2007)*

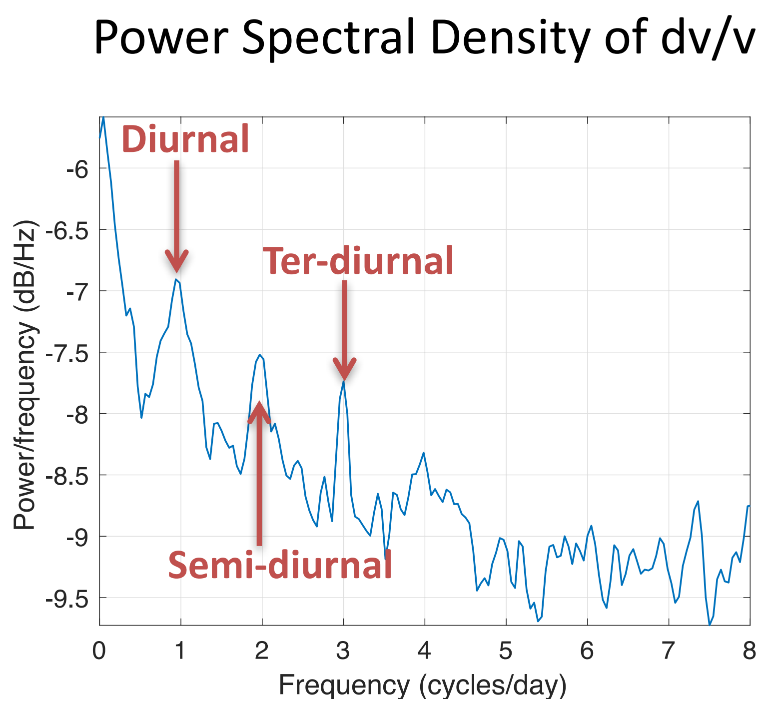




Long period signals to short period signals



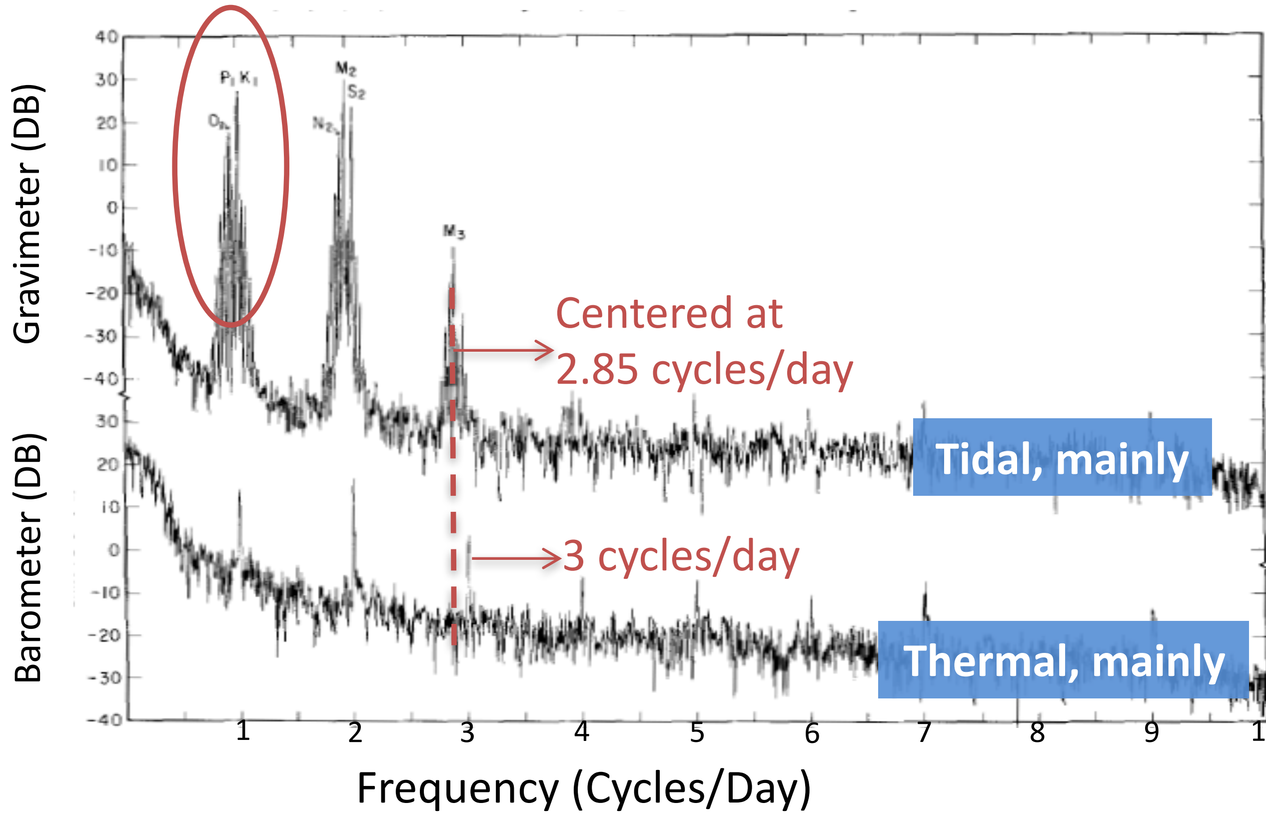
Short period signals



Short period dv/v changes

Earth's daily deformations

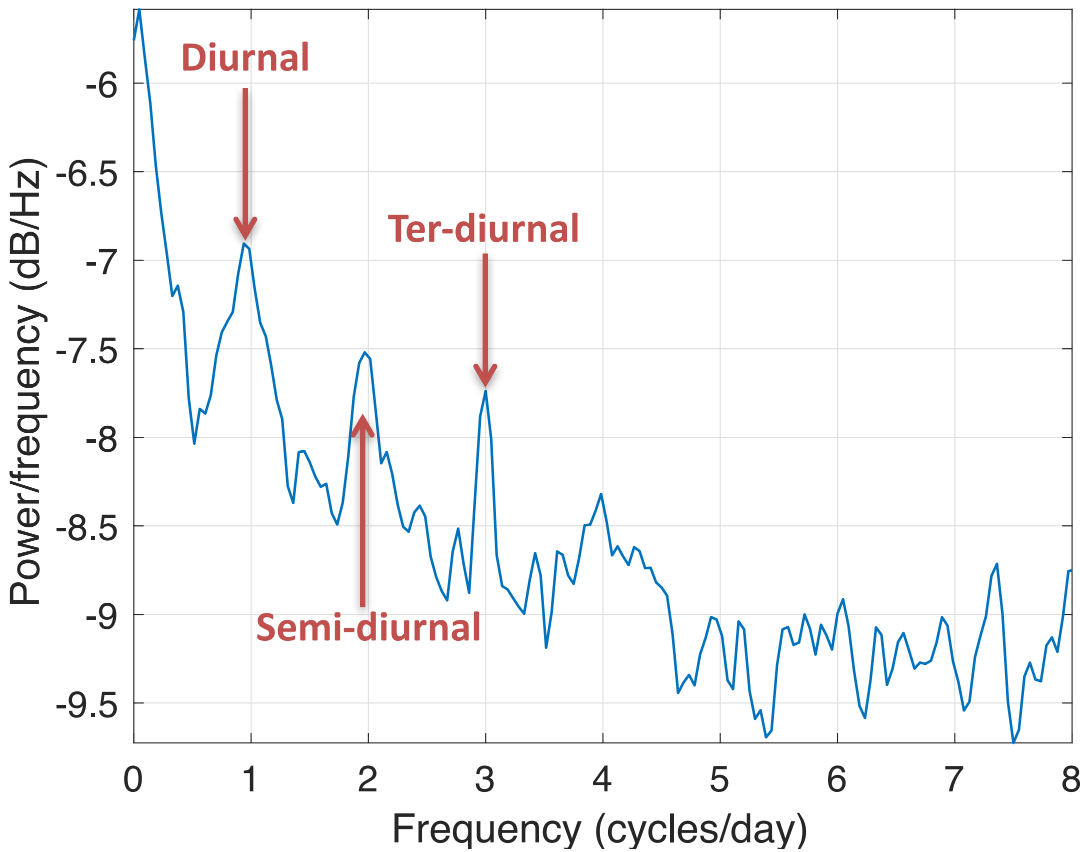
- **Tidal effects**
- **Thermal effects**



Warburton et al., 1977

Short period dv/v changes

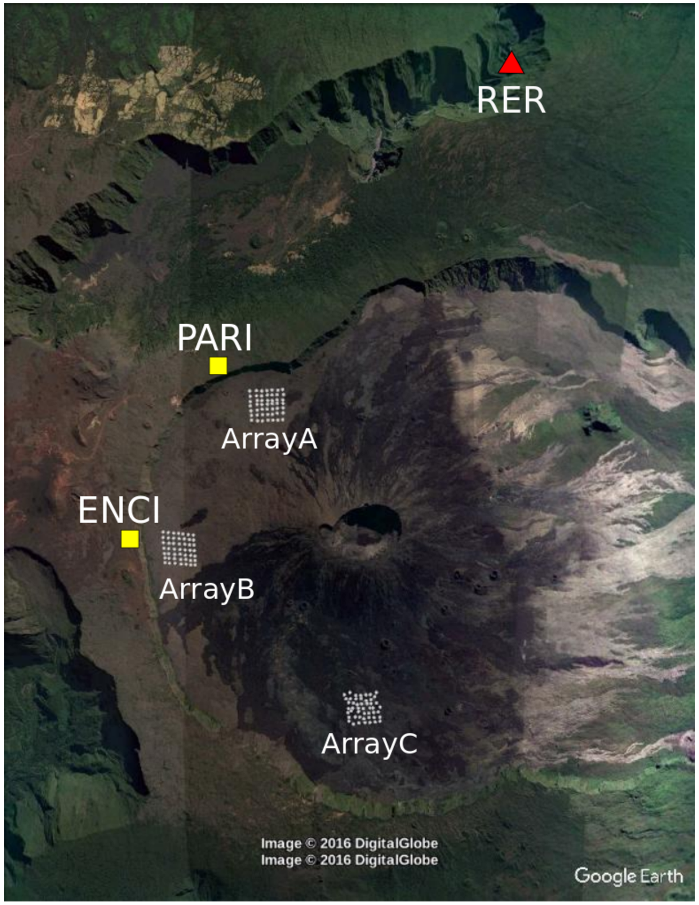
Power Spectral Density of dv/v



Short period dv/v changes

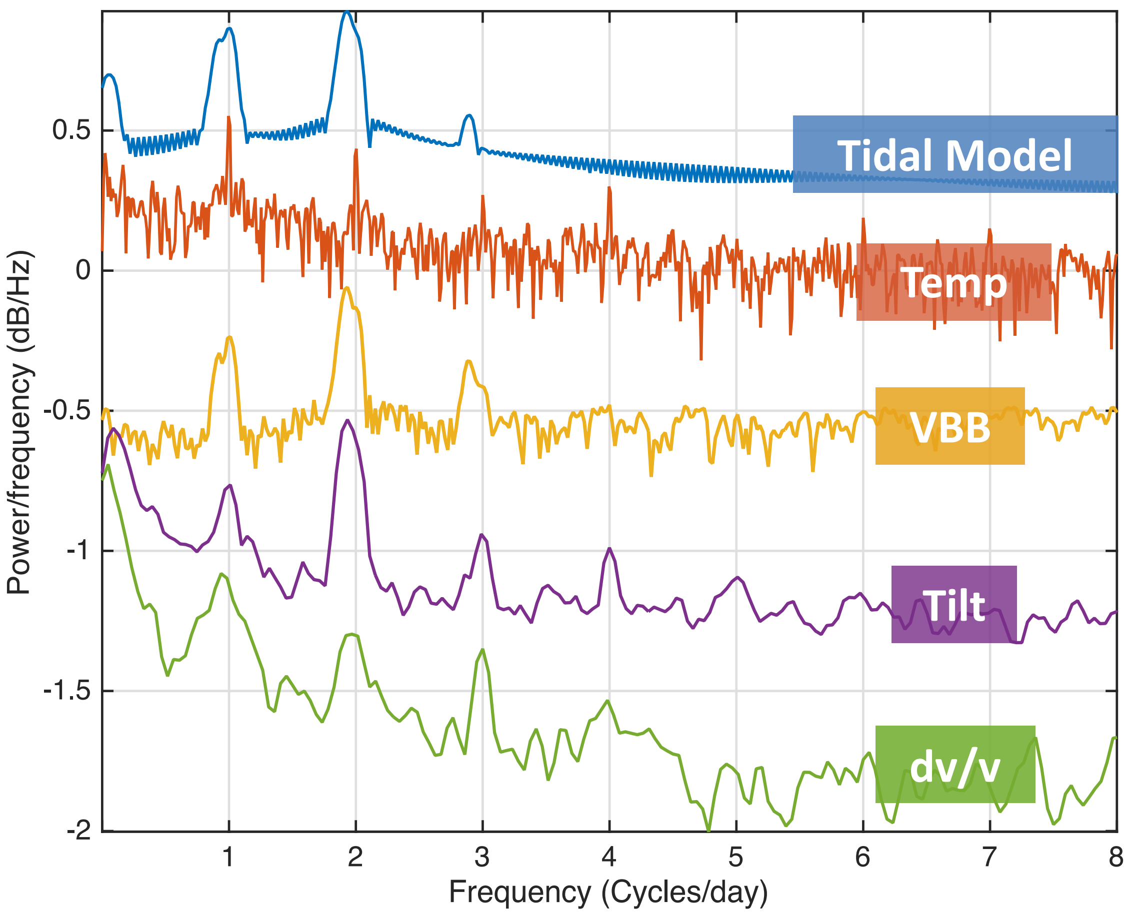
Comparisons with different types of data:

- **Tidal model:** simulations of tidal-induced volumetric strain by SPOTL (Agnew, 2012)
- **Temp:** temperature records at a meteorological station
- **VBB:** vertical records of a **very broad band** seismic station (*STRECKEISEN STS1*)
- **Tilt:** 2 borehole tilt meters



Short period dv/v changes

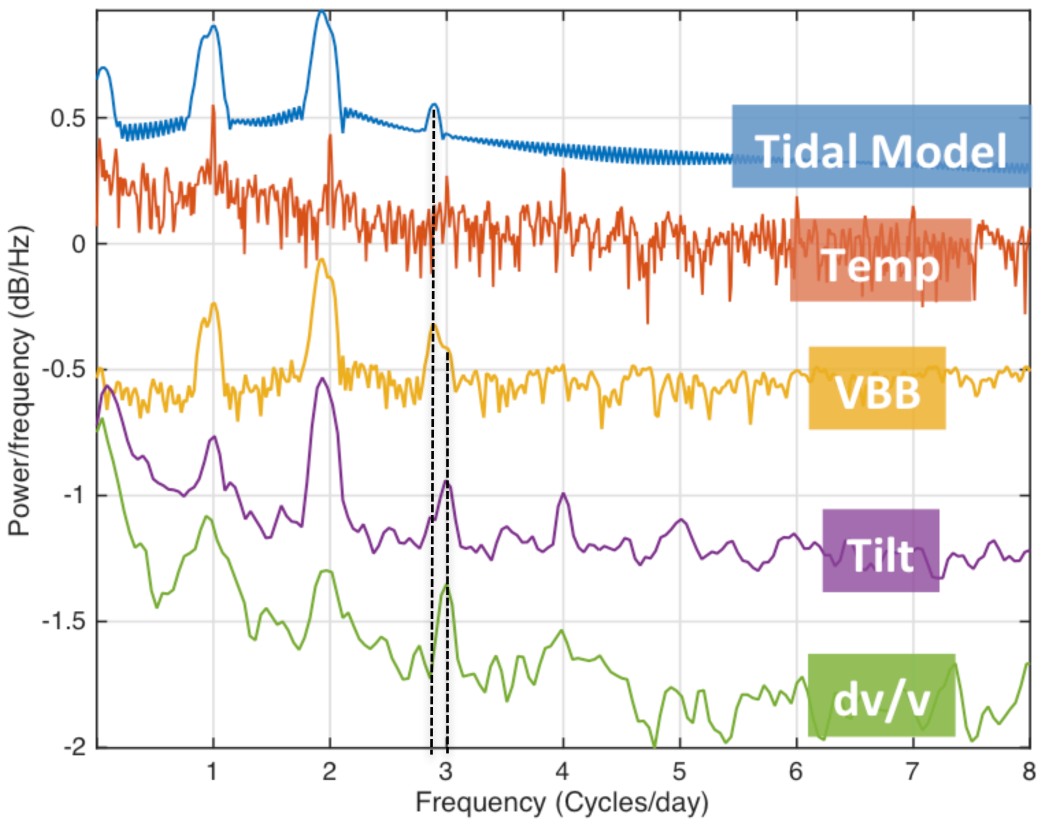
Spectra of Different Types of Data



Short period dv/v changes

- **Ter-diurnal**

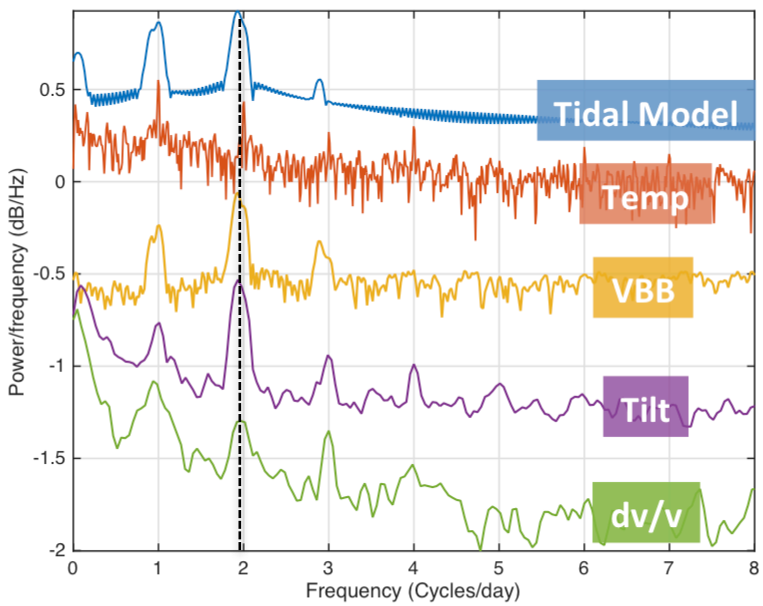
<u>Thermal dominant</u>



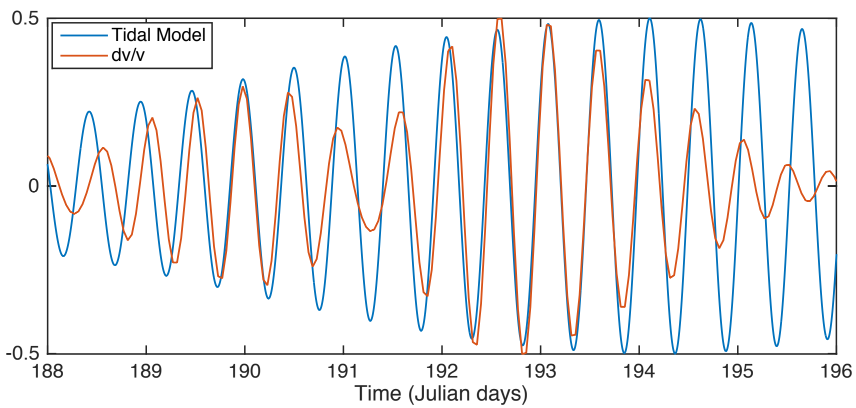
Short period dv/v changes

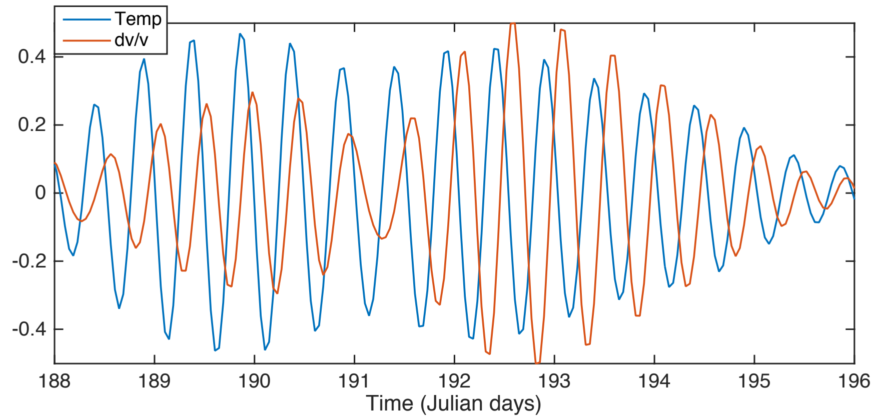
- **Semi-diurnal**

<u>Tidal dominant</u>



(filtered between 10~14 hours)



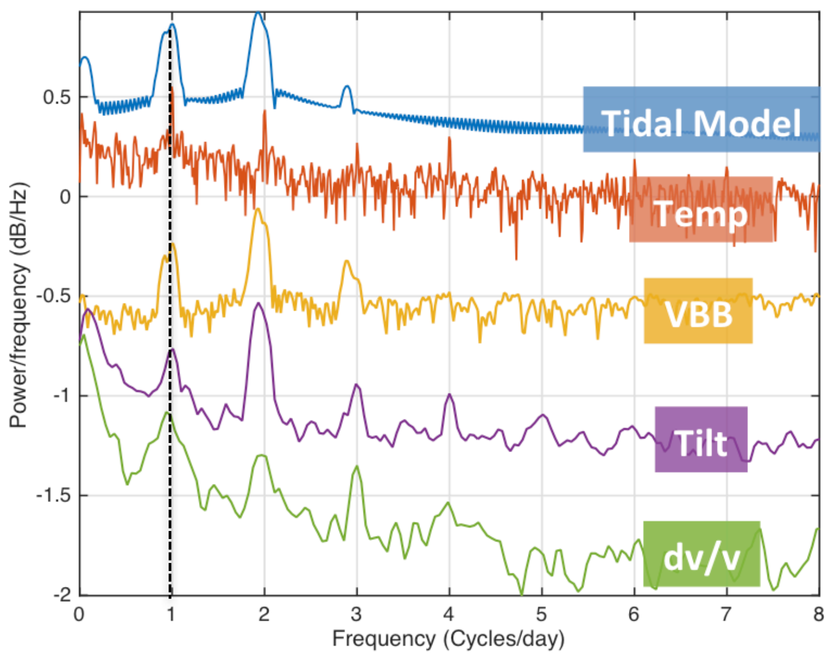


Short period dv/v changes

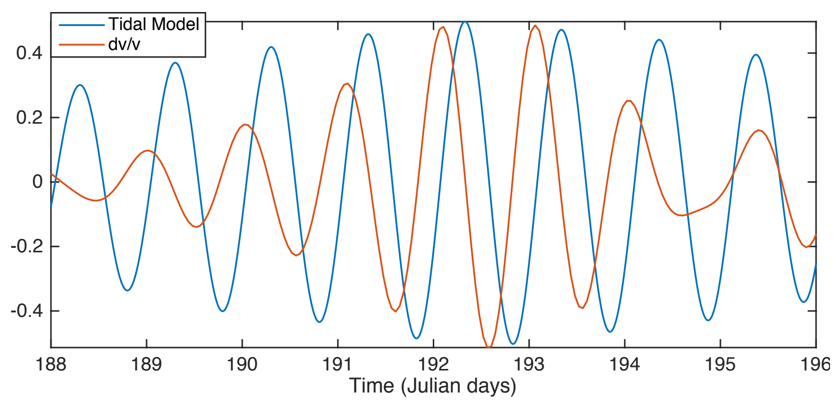
- **Diurnal**

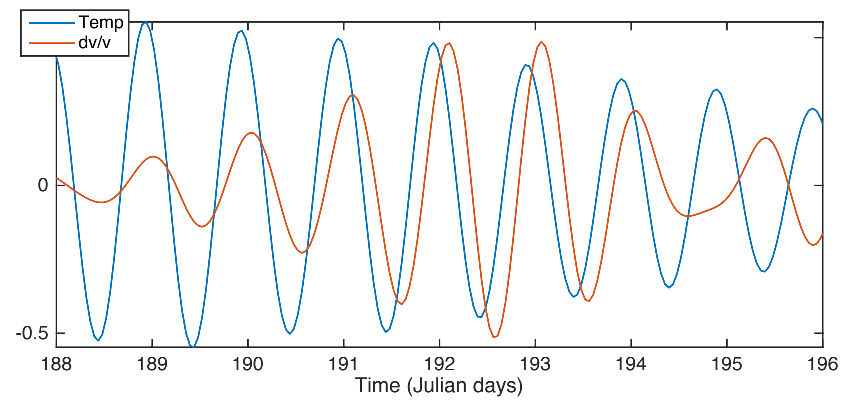
Tidal + Thermal

or Thermal ?



(filtered between 18~29 hours)





Conclusions

- It is feasible to apply noise-based dv/v measurements to monitor small changes of crustal strain with **high temporal resolution (~hourly)**.

- We retrieve dv/v variations related to precipitation (long periods, 0.05%) and tidal, thermal deformations (<u>short periods</u>, 0.01%). These dv/v can be corrected in further studies to better understand the changes induced by tectonic activities.

- The observations of dv/v suggest that tidal- and thermal-induced strain are approximately of similar order of magnitude, but differs in each frequency bands. This is consistent with predictions by theoretical modeling.

Acknowledgements

- Thanks Foudation Del Duca for founding the VolcArray Experiment.
- Thanks Observatoire Volcanologique du Piton de la Fournaise (OVPF) and Institute de Physique du Globe de Paris (IPGP) for seismic data, and thanks Christophe Brunet for tilt data.
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fondation Simone et Cino Del Duca INSTITUT DE FRANCE

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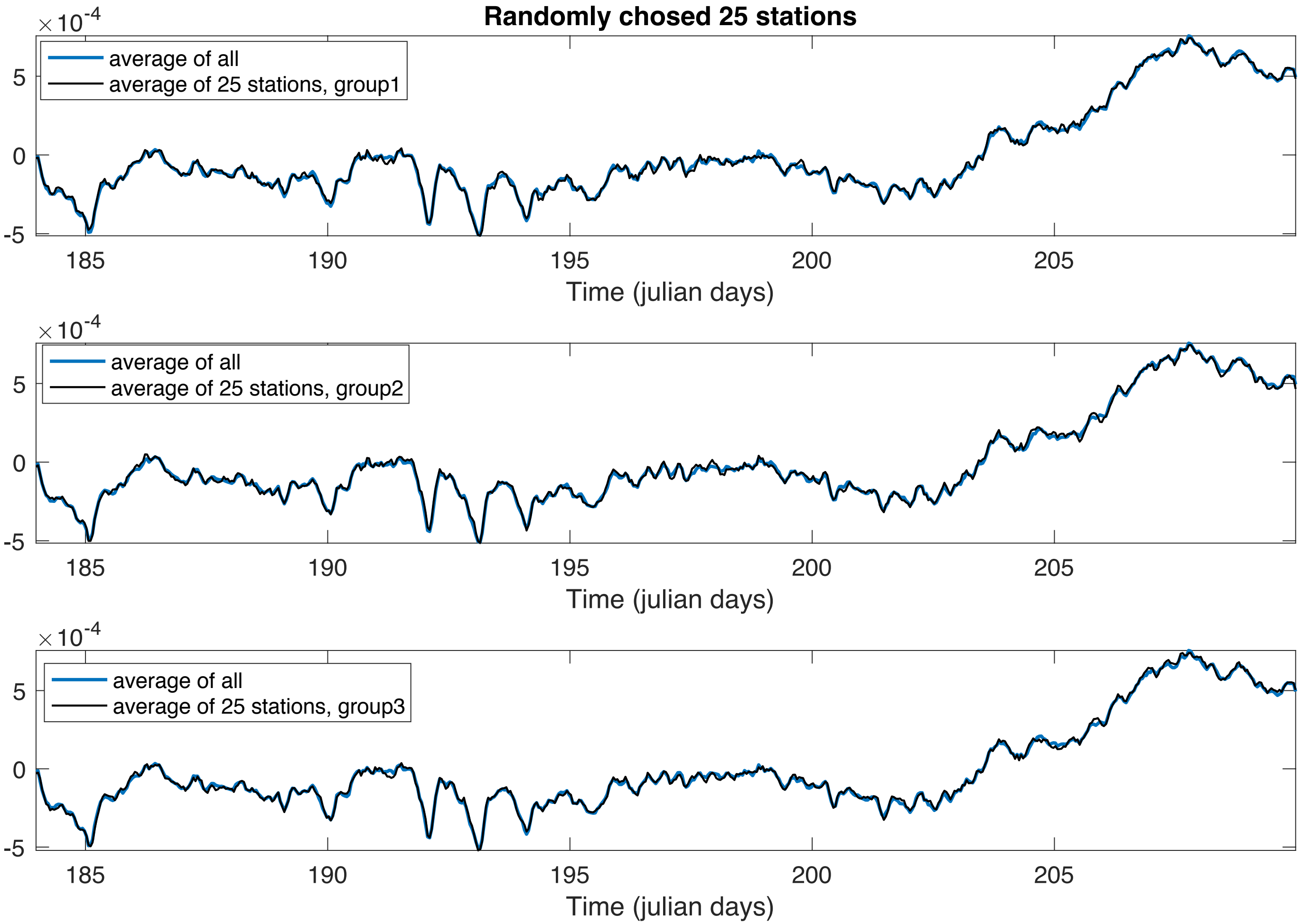
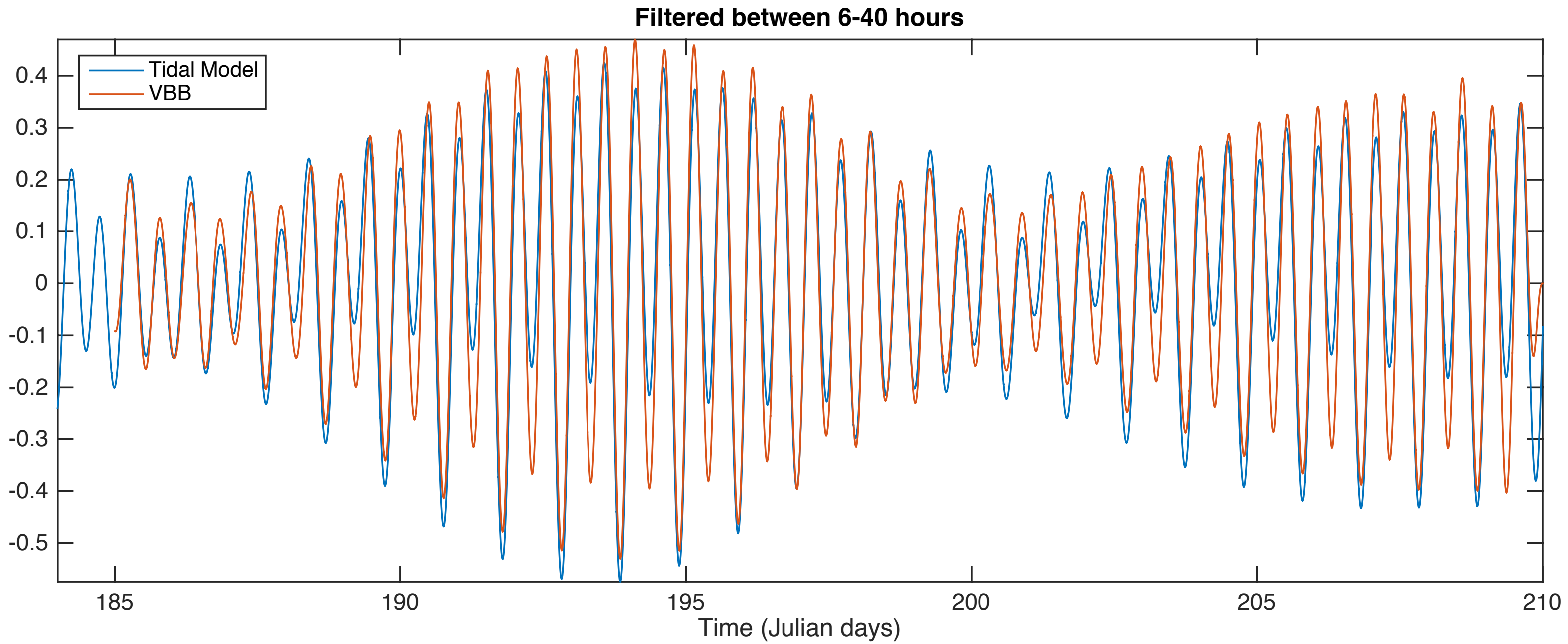
IPGP INSTITUT DE PHYSIQUE DU GLOBE DE PARIS

Thank you!


Randomly chosed 25 stations
×10-4
5
0
-5
average of all
average of 25 stations, group1
185
190
195
200
205
Time (julian days)
×10-4
5
0
-5
average of all
average of 25 stations, group2
185
190
195
200
205
Time (julian days)
×10-4
5
0
-5
average of all
average of 25 stations, group3
185
190
195
200
205
Time (julian days)


Filtered between 6-40 hours
Tidal Model
VBB
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
185
190
195
200
205
210
Time (Julian days)

$$\mu = \frac{1}{NM} \sum_{n_1, n_2 \in \eta} a(n_1, n_2)$$

and

$$\sigma^2 = \frac{1}{NM} \sum_{n_1, n_2 \in \eta} a^2(n_1, n_2) - \mu^2,$$

$$b(n_1, n_2) = \mu + \frac{\sigma^2 - \nu^2}{\sigma^2} (a(n_1, n_2) - \mu),$$

Long period signals

- Pore pressure changes due to precipitations:

(Talwani et al., 2007)

$$P_i(r,t) = \sum_{i=1}^{n} \alpha \delta p_i erf\left[\frac{r}{\left(4c(n-i)\delta t\right)^{1/2}}\right] + \sum_{i=1}^{n} \delta p_i erfc\left[\frac{r}{\left(4c(n-i)\delta t\right)^{1/2}}\right],$$

Undrained loading

Diffusio
n

Different Constituents of Tidal Effects

Major Tidal Constituents	Period (hours)	Origin	Group
Mf	327.85899	Moon	Fornightly
Q1	26.86836	Moon	Diurnal
O1	**25.81934**	**Moon**	
P1	24.06589	Sun	
K1	**23.93447**	**Moon and Sun**	
M2	**12.42060**	**Moon**	Semi-diurnal
S2	**12.00000**	**Sun**	
K2	11.96723	Moon and Sun	
M3	8.27985	Moon	Ter-diurnal
M4	6.21030	Moon	Quat-diurnal

Wilhelm et al, 1997