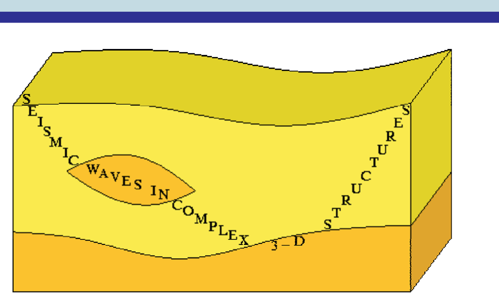

1-D versus 3-D Structural Model in Seismic Source Studies

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Motivation:

- earthquake mechanism retrieval affected by seismic noise, structural model applied, distribution of seismic stations around the focus
- unknown 3-D model of medium is often substituted by simplified 1-D model → importance to test possible distortion (orientation, DC/non-DC contents)

Inversion method:

- inversion of the P and S waves peak amplitudes of the ground displacement
- full moment tensor expression of the mechanism, i.e. M_{11}, M_{22}, M_{33}, M_{12}, M_{13} a M_{23} → linear inverse problem
- solution by the Singular Value Decomposition method
- decomposition of complete moment tensor into ISO, DC and CLVD parts

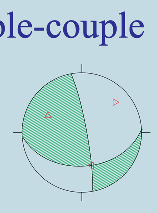
Test with synthetic data:

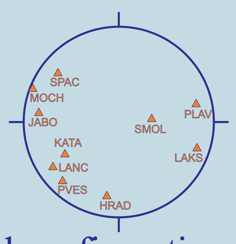
synthetic data computed for 3-D model and inverted for both 1-D and 3-D models

random noise up to 10% and 20% was added to the input data

source model of tectonic event, i.e. 100% double-couple

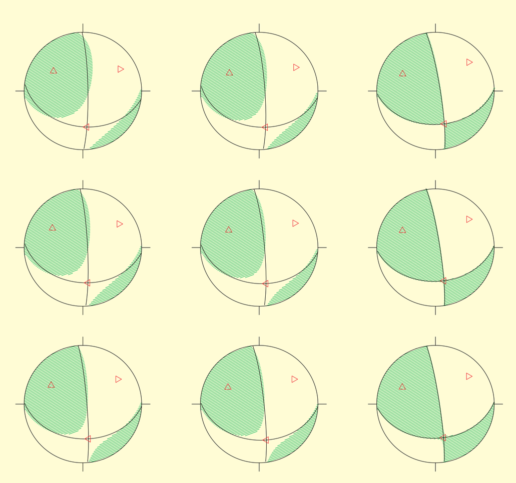
dip 43°
strike 80°
rake 10°





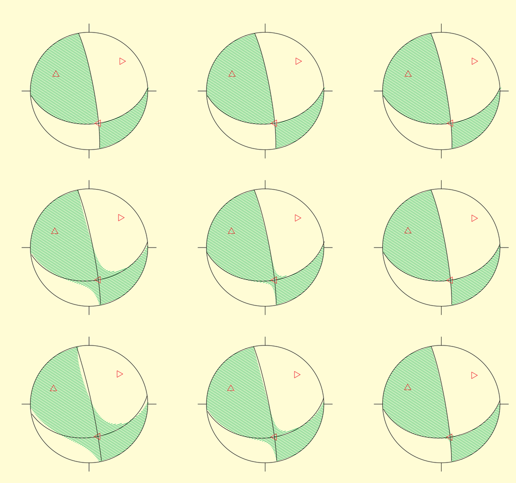
real configuration

1-D model :



	P wave vertical	P wave	P & S waves
noise free	NRMS 0.116 V (exp) 5.6% DC 34.6% CLVD (T) 59.8%	NRMS 0.189 V(exp) 4.4% DC 51.7% CLVD (T) 49.9%	NRMS 0.177 V (exp) 2.9% DC 91.4% CLVD (T) 5.7%
10 % noise	NRMS 0.100 V (exp) 4.8% DC 49.5% CLVD (T) 45.7%	NRMS 0.166 V (exp) 3.4% DC 61.3% CLVD (T) 35.3%	NRMS 0.188 V (exp) 2.2% DC 93.9% CLVD (T) 3.9%
20 % noise	NRMS 0.086 V (exp) 3.7% DC 68.4% CLVD (T) 27.9%	NRMS 0.151 V (exp) 2.4% DC 72.5% CLVD (T) 25.1%	NRMS 0.205 V (exp) 1.5% DC 96.5% CLVD (T) 1.9%

3-D model :



	P wave vertical	P wave	P & S waves
noise free	NRMS 0.0003 V (exp) 0.0% DC 99.4% CLVD (T) 0.6%	NRMS 0.0006 V(exp) 0.0% DC 99.7% CLVD (T) 0.3%	NRMS 0.0006 V 0.0% DC 100.0% CLVD 0.0%
10 % noise	NRMS 0.014 V (imp) 1.4% DC 77.5% CLVD (P) 21.1%	NRMS 0.034 V (imp) 1.3% DC 91.6% CLVD (P) 7.1%	NRMS 0.038 V (imp) 0.8% DC 97.2% CLVD (P) 2.0%
20 % noise	NRMS 0.026 V (imp) 2.8% DC 55.9% CLVD (P) 41.3%	NRMS 0.065 V (imp) 2.7% DC 82.8% CLVD (P) 14.5%	NRMS 0.077 V (imp) 1.6% DC 94.3% CLVD (P) 4.1%

results of synthetic tests:

orientation of double-couple part of the mechanism:

- in all cases (even for 1-D model, 20% noise and inversion of vertical component of P wave) almost OK

decomposition of complete moment tensor:

1-D structural model
- the decomposition is distorted unless both P & S waves are inverted
- the effect of incorrect velocity model bigger than the effect of noise

3-D structural model
- noise free - the effect of configuration → success even for vertical P wave inversion
- 10% noise - distortion only for vertical P wave
- 20% noise - distortion only for vertical P wave and P wave

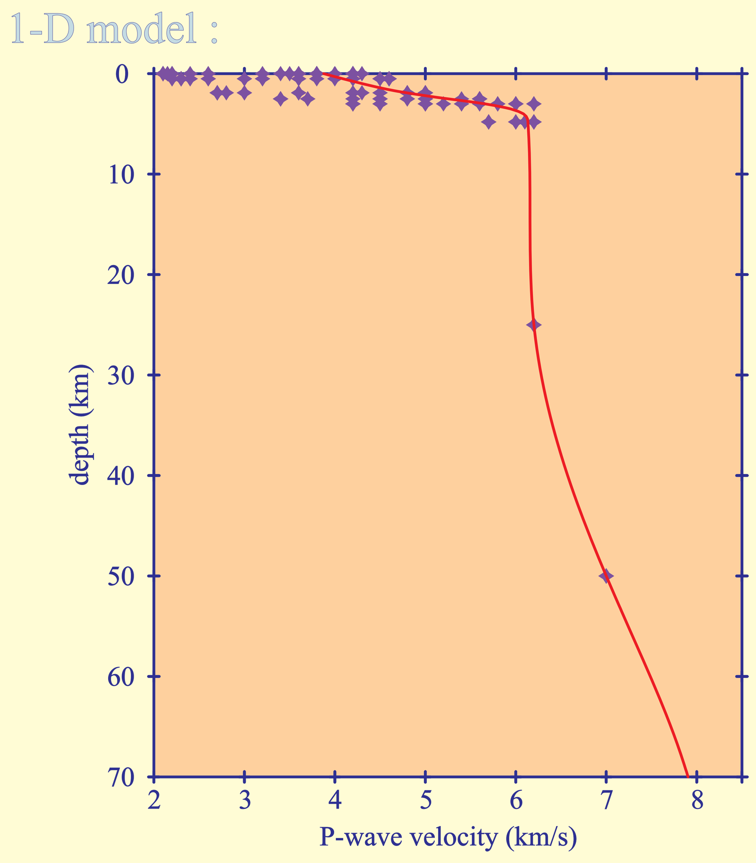
Structural models:

on the basis of 3-D model of Geofyzika Brno (1985)
- P and S-wave velocity data given on a very sparse, rectangular but irregular grid of 7x8x8 points

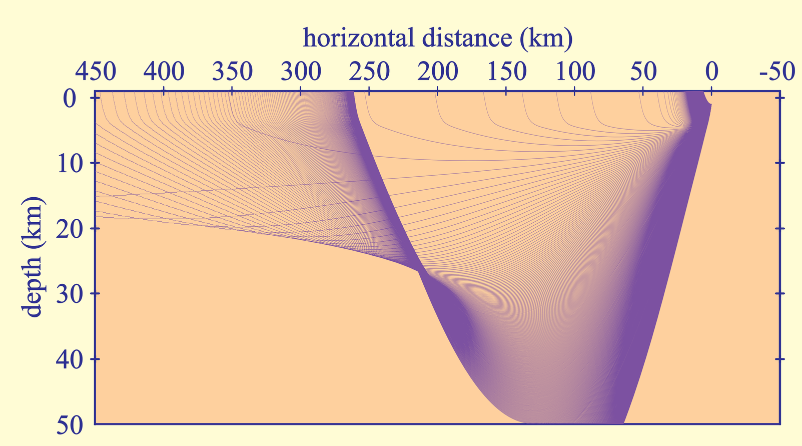
the construction of structural models
- the grided data used to construct two versions of a smooth continuous velocity models (1-D and 3-D)
- the method of the least-square inversion of discrete data with minimization of the Sobolev norm of the model composed of second velocity derivatives
- the models should be as close as possible to data, but smooth enough to be suitable for ray tracing

Green functions
- calculated by two-point ray tracing

1-D model :

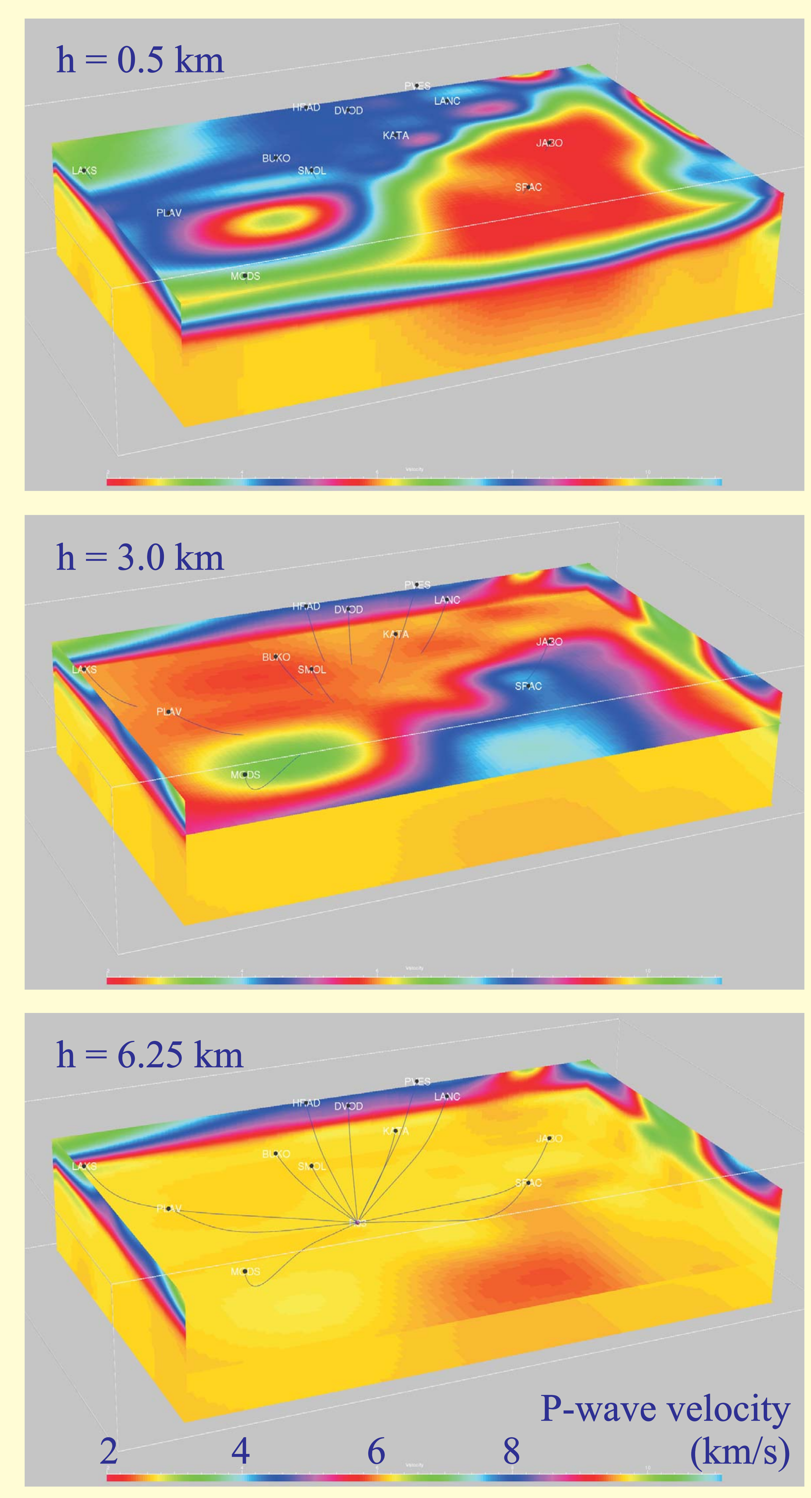


- P-wave velocity data (crosses)
- the resulting 1-D velocity model (red curve)



- initial-value rays traced with a constant step of 0.0005 rad in the vertical shooting angle

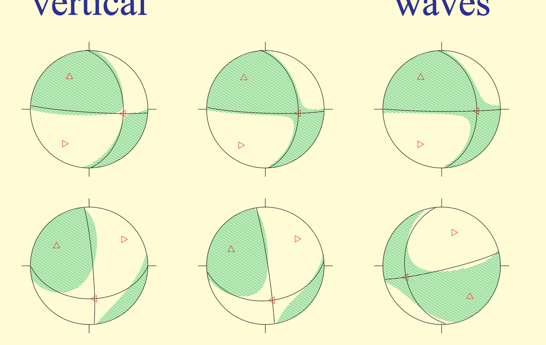
3-D model :



- P-wave velocity (horizontal sections in depths of 0.5, 3.0 and 6.25 km)
- two point rays calculated from a seismic hypocenter to the MKNET stations

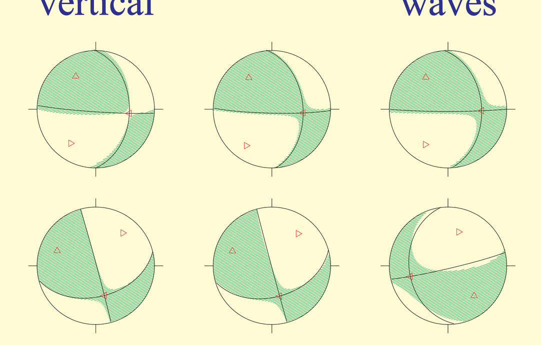
Events from Dobrá Voda zone:

1-D model :



	P wave vertical	P wave	P & S waves
06/03/14 11:42	NRMS 0.444 V (exp) 10.6% DC 66.2% CLVD (T) 23.2%	NRMS 0.559 V(exp) 6.8% DC 86.7% CLVD (T) 6.5%	NRMS 1.012 V (exp) 8.2% DC 85.8% CLVD (T) 6.1%
06/08/05 09:00	NRMS 0.325 V (exp) 7.5% DC 26.7% CLVD (T) 65.8%	NRMS 0.472 V (exp) 2.7% DC 58.5% CLVD (T) 38.8%	NRMS 0.373 V (imp) 5.7% DC 52.7% CLVD (P) 41.6%

3-D model :



	P wave vertical	P wave	P & S waves
06/03/14 11:42	NRMS 0.420 V (exp) 7.6% DC 73.2% CLVD (T) 19.2%	NRMS 0.510 V(exp) 5.3% DC 91.7% CLVD (T) 3.0%	NRMS 0.935 V(exp) 8.7% DC 88.9% CLVD(T) 2.4%
06/08/05 09:00	NRMS 0.167 V (exp) 1.2% DC 93.3% CLVD (P) 5.5%	NRMS 0.375 V (imp) 2.0% DC 83.9% CLVD (P) 14.1%	NRMS 0.381 V (imp) 7.1% DC 48.5% CLVD (P) 44.4%

results:

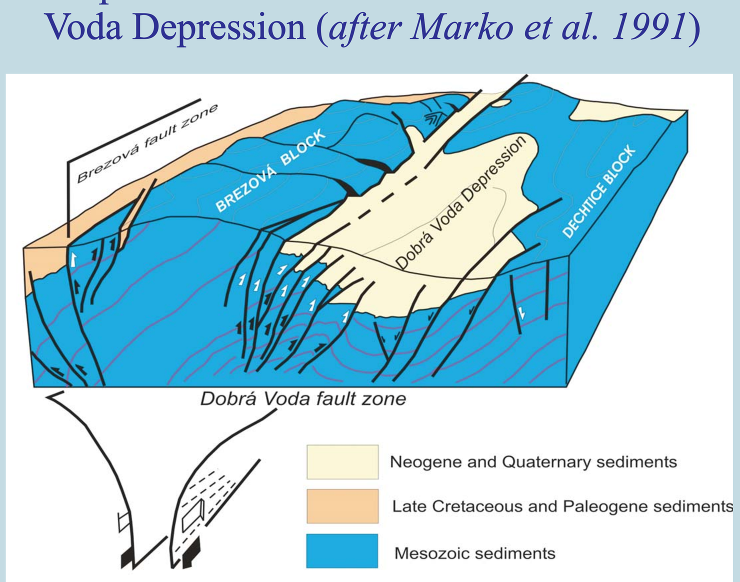
message from inversion of synthetic data:
- resulting moment tensors keep similar orientation of double-couple parts when we invert vertical P wave or P wave or P & S waves
- V / DC / CLVD contents is varying
- consistent DC orientations of event 06/03/14 → moment tensor is reliable
- inconsistent DC orientations of event 06/08/05 → obviously a problem in the data

Seismic zone Dobrá Voda:

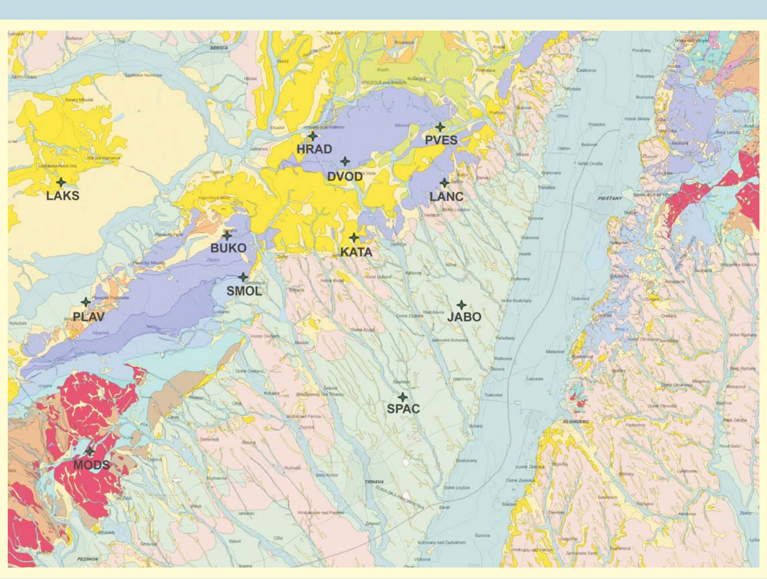
historic evidence of earthquake activity at mountain region of Malé Karpaty:
- event Dobrá Voda (1906) reached macroseismic intensity I = 8°
- events Júr (1880), Jablonica (1904) and Dobrá Voda (1930) with intensity I = 7°
- chronicles document earthquakes in the vicinity of Trnava next to Malé Karpaty: earthquakes in 1515 and 1586 with intensity 6°≈7°

the strongest earthquake in 20th century 06/01/09
- the first earthquake recorded by seismometers, M_w = 5.7, I = 8°
- ground cracks: 80-200cm deep, 33m long
- variations of groundwater level, discovery of new water sources

simplified tectonic situation of the Dobrá Voda Depression (*after Marko et al. 1991*)



last ten years
- moderate seismicity with earthquakes up to M~3.5



geological map of seismic zone Dobrá Voda (*after State Geological Institute of Dionýz Štúr*)

seismic stations of Malé Karpaty network - MKNET (*ProgSeis*)

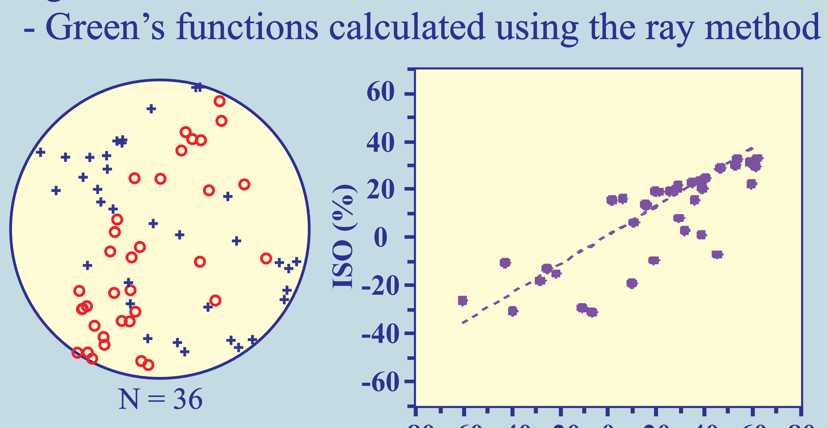
Conclusions:

- orientation of double-couple part of mechanism estimated properly even from noisy data and with a simple structural model
- availability of complete reading of P and S waves in a high quality → a coarse structural model (even 1-D) may be sufficient
- increasing the number of seismic stations → distorsion of non-double-couple parts is decreasing even if coverage of focal sphere remains sparse

DC and non-DC components of moment tensors using 1-D velocity model:

A) Full moment tensors from the P-wave amplitudes

(program AMT, Vavryčuk 2008)
- at least 8 local or regional stations
- P waves with predominant frequencies between 2 to 20 Hz
- gradient 1-D medium model
- Green's functions calculated using the ray method



P/T axes of moment tensors determined from P-wave amplitudes (A).

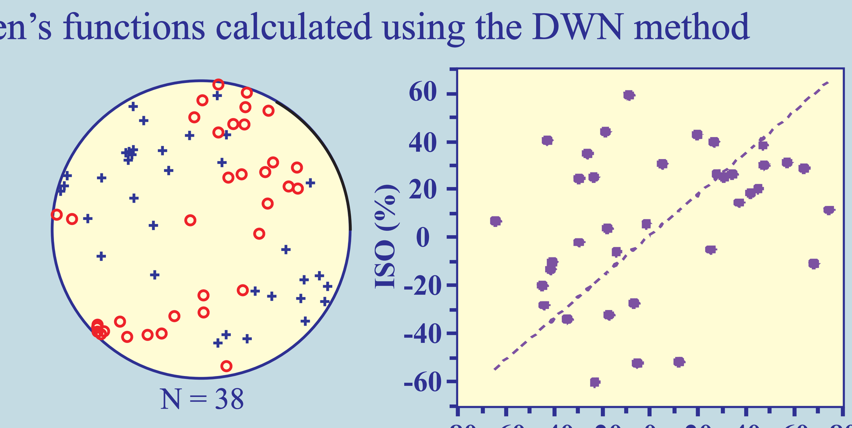
The ISO versus the CLVD component. Correlation: 0.81

○ P axes of moment tensors
+ T axes of moment tensors

The lower-hemisphere equal-area projection is used.

B) Full moment tensors from complete seismograms

(program ISOLA, Sokos & Zahradník 2009)
- waveforms from 3 to 5 nearest local seismic stations
- S waves and surface waves with frequencies less than 2 Hz
- layered 1-D medium model
- Green's functions calculated using the DWN method



P/T axes of moment tensors determined from complete waveforms (B).

The ISO versus the CLVD component. Correlation: 0.30

Conclusions

The DC components of moment tensors using 2 different methods are statistically similar.
The non-DC components can be numerical errors of the inversion, however the positive correlation between the ISO and CLVD can be an indicator of their physical origin.
The amplitude inversion seems to be more accurate than the waveform inversion, producing the non-DC components, which are probably more reliable and less affected by numerical errors.

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