Analysis of Environmental and Loading Effects in Tilt and SG Gravity Observations at Conrad (Austria) and Peters Seismological (Australia) Observatories

Papp, G., Ruotsalainen, H., Meurers, B., Leonhardt, R., Benedek, J., Hutchinson, P. and Szántó, M.

Our investigations are supported by NKFIH-OTKA K128527 project

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General research aims:

Monitoring of surface deformation for

1) the investigation of ***local*** tectonic processes,

2) the investigation of ***global*** phenomena related to the time variations of the Earth's gravity field.

Infrastructure:

Conrad Observatory (Austria):

- a superconducting gravity meter (GWR SG025),
- tilt sensors

The Peters Seismological Observatory (Australia)

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All instruments have ***nano-range*** or better resolution (nm/s^2, nm,nrad).

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resulting

- pre- (?) and post-seismic deformations
- orogenic deformations
- sediment compaction
- basin sinking
- etc…

2) the investigation of … variations of the Earth's gravity f…

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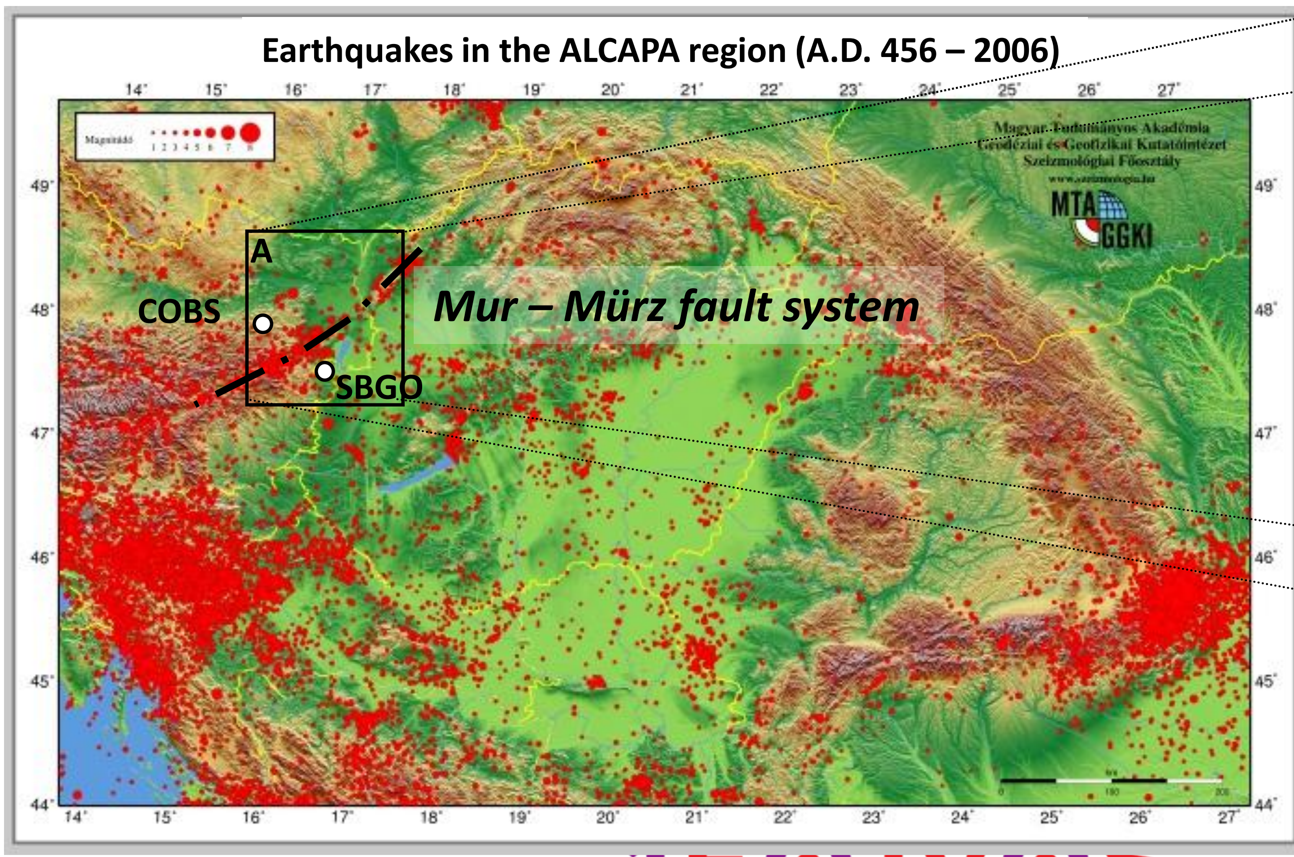

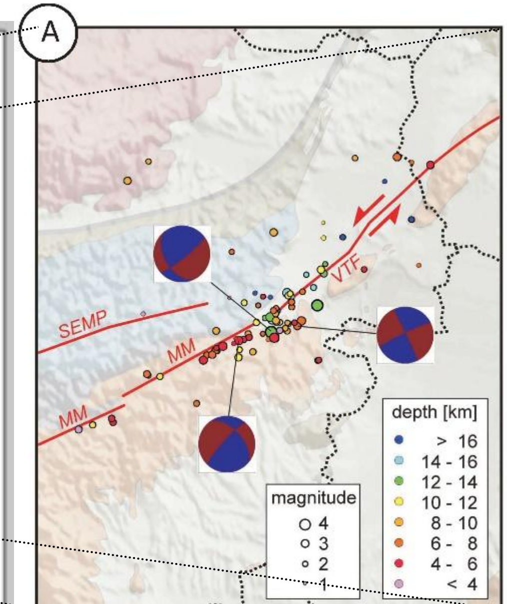

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- ocean loading effects
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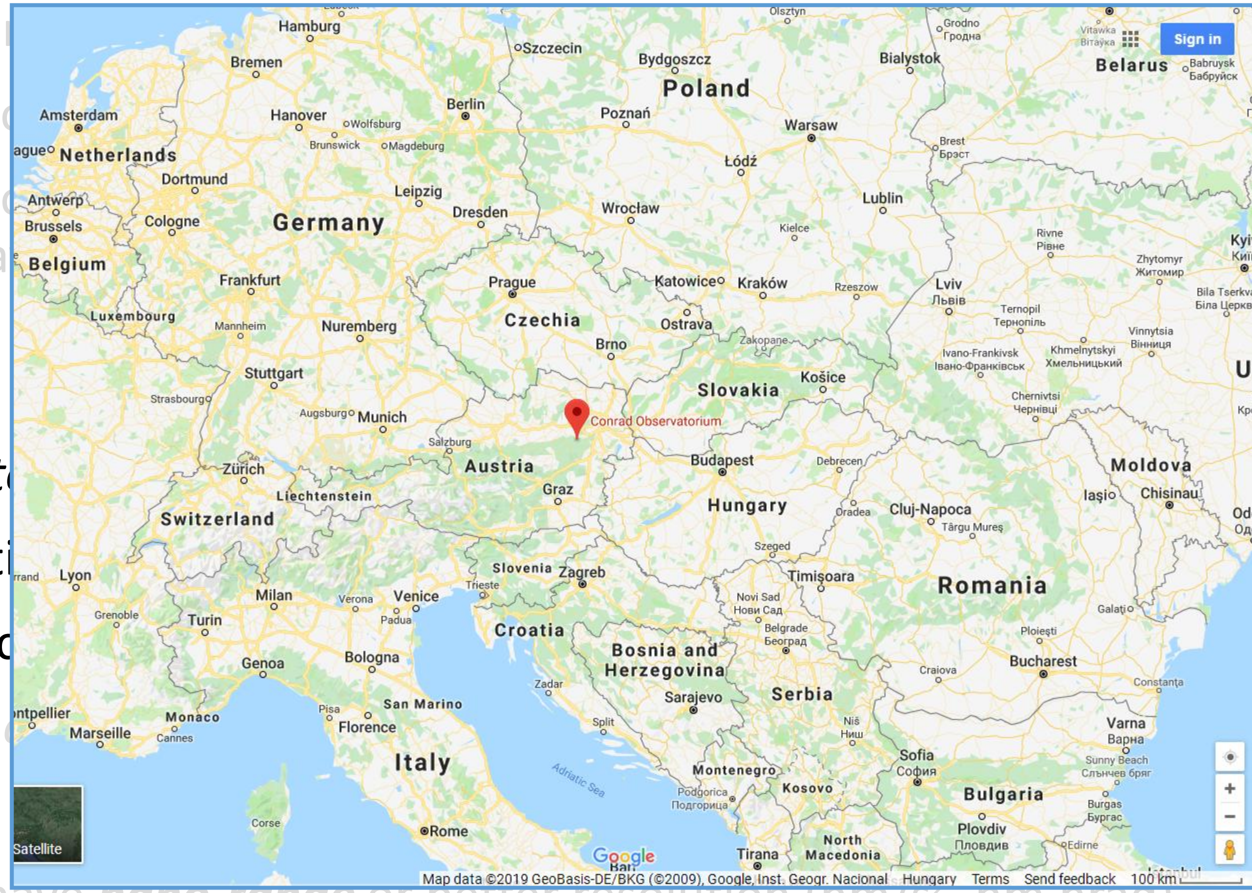

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General

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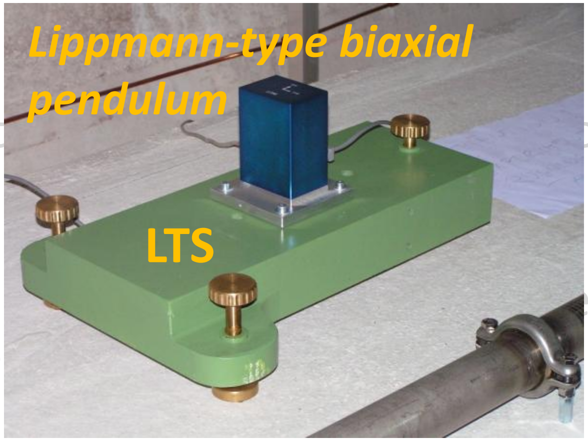

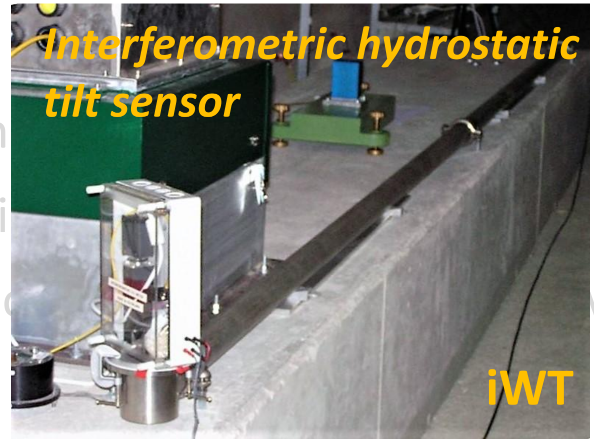

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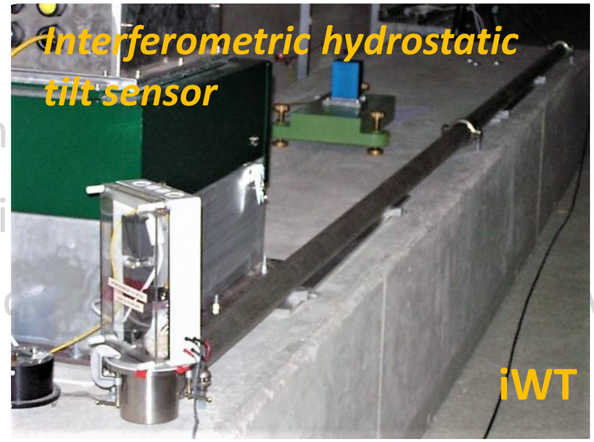

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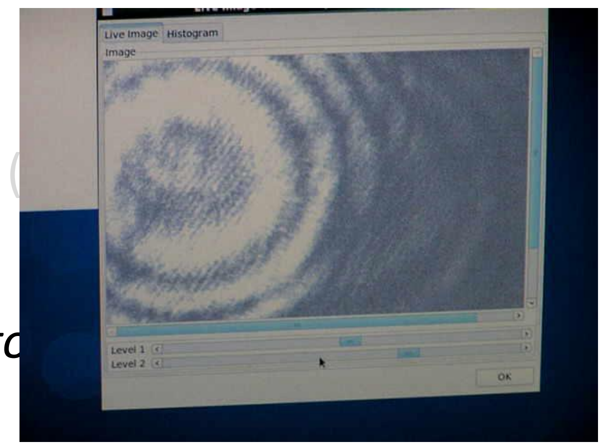

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Observation of tidal effects at COBS: gravity and deformation

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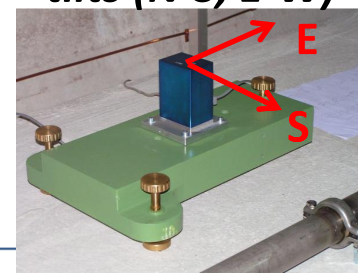
Observation of tidal effects at COBS: gravity and deformation

GWR SG05

gravity

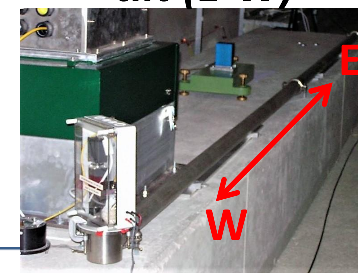
LTS

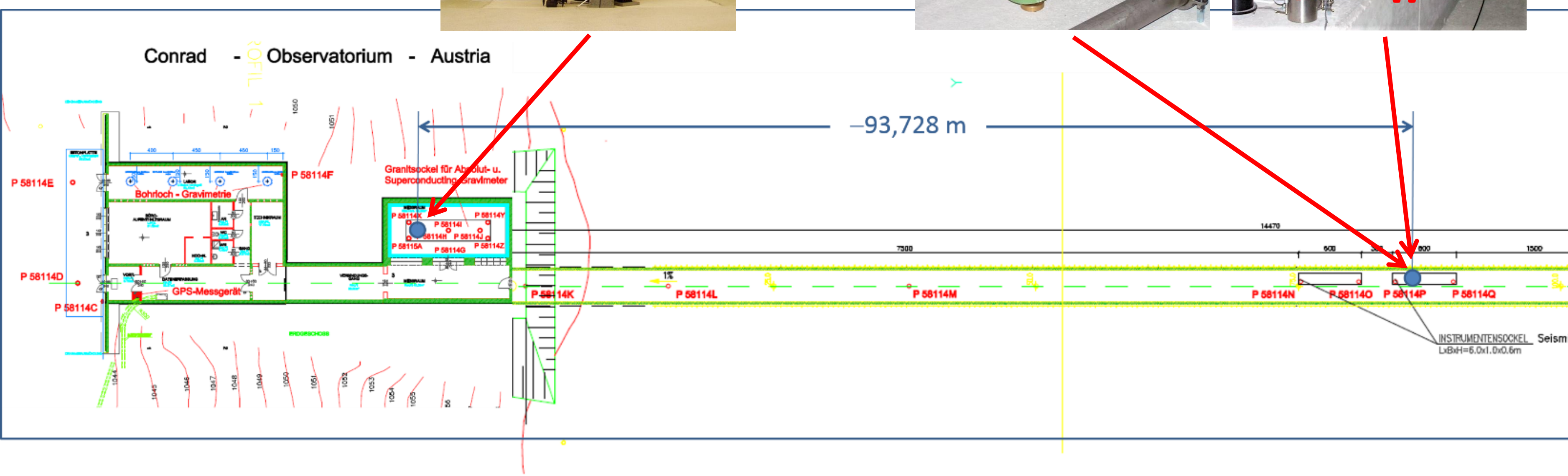
tilts (N-S, E-W)



iWT

tilt (E-W)





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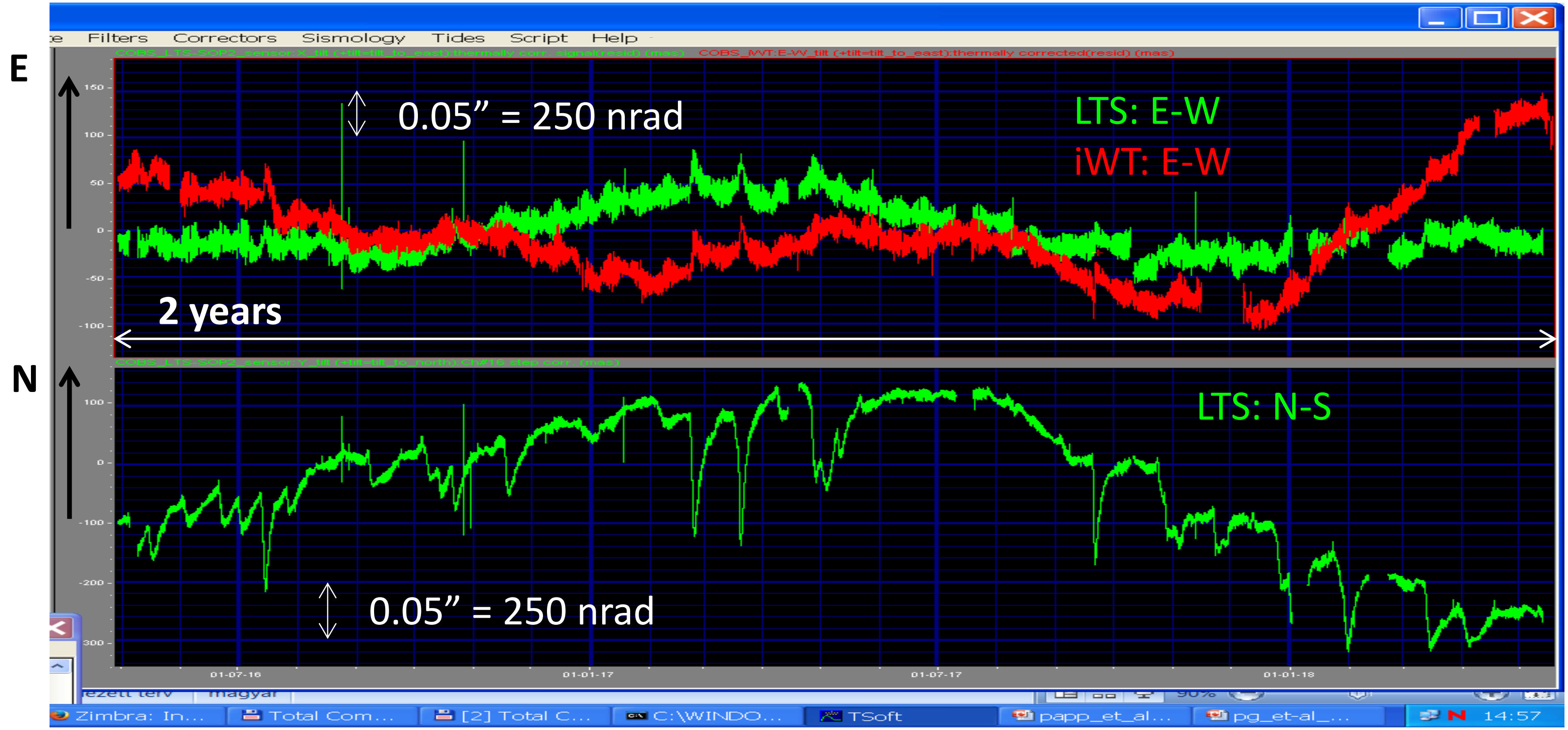
Observation of tidal effects at COBS: gravity and deformation

Tilts related to Earth tides and many other phenomena: nonlinear components (n>2)

29-04-2016 – 13-05.2018



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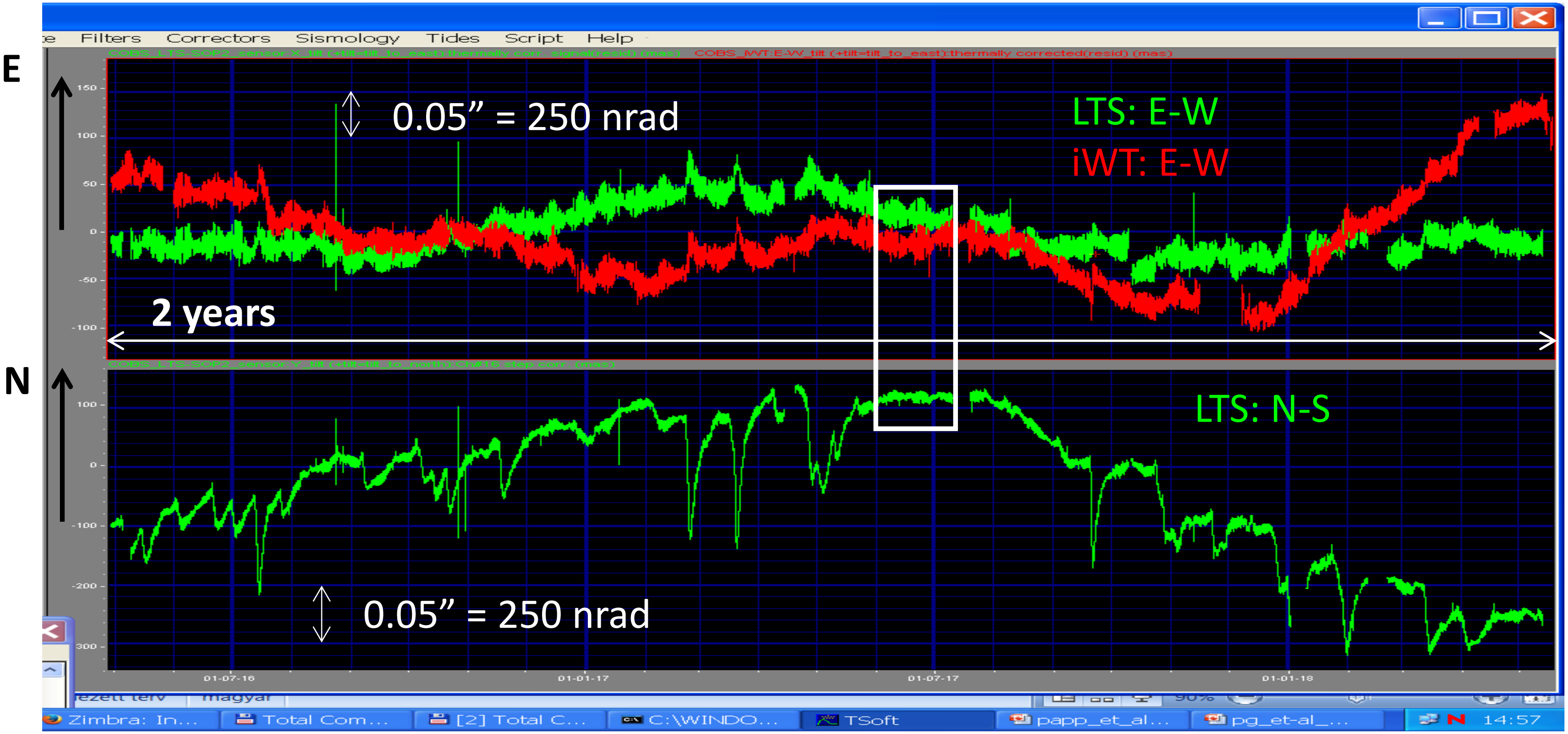

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Harmonic analysis of tilt time series recorded at COBS*: standard procedure using ETERNA package*

		N-S			E-W					
		LTS-Y			LTS-X			iwt-X		LTS/iwt
Darwin	γ (WD)	amp [mas]	γ σ(γ)	ϕ σ(ϕ)	amp [mas]	γ σ(γ)	ϕ σ(ϕ)	γ σ(γ)	ϕ σ(ϕ)	
Q1	0.6940	0.1235	2.9289 1.3921	-17.218 12.022	0.9257	0.6976 0.0490	1.776 4.042	0.6937 0.0851	-13.136 7.011	1.0056
O1	0.6944	0.6449	**1.2940** 0.1533	12.022 9.648	4.8347	**0.7105** 0.0104	-7.020 0.838	**0.6783** 0.0170	-12.356 1.434	1.0475
K1	0.7362	0.9070	**1.2184** 0.1536	10.551 7.200	6.7995	**0.7808** 0.0073	-8.045 0.462	**0.7346** 0.0108	-11.556 0.839	1.0629
N2	0.6911	1.5053	**0.6744** 0.0306	-4.524 2.590	2.0279	**0.7516** 0.0889	-2.863 0.676	**0.7200** 0.0115	-4.697 0.918	1.0439
M2	**0.6911**	7.8622	**0.6574** 0.0060	-2.313 0.522	10.5916	**0.7404** 0.0019	-3.853 0.147	**0.6827** 0.0023	-5.559 0.192	1.0845
S2	0.6911	3.6579	**0.6599** 0.0128	-1.436 1.128	4.9278	**0.6865** 0.0044	-1.609 0.363	**0.6306** 0.0519	-5.493 0.460	1.0886

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$$\gamma_n = \frac{b_{\beta,n}}{b^{th}_{\beta,n}} = 1 + k_n - h_n$$

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promising agreement

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Scale problem?

$\gamma_{LTS}/\gamma_{iWT}>1$

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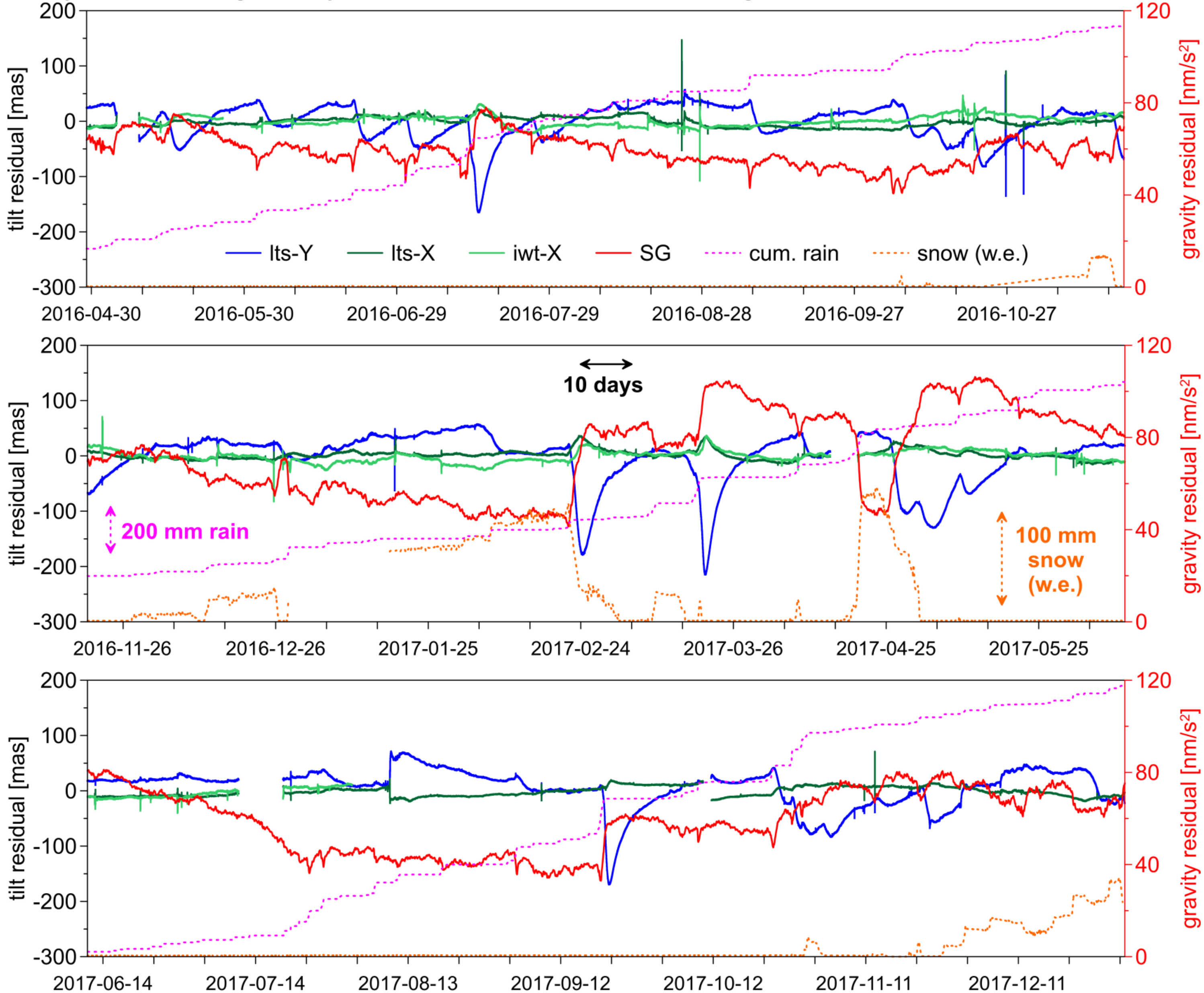
Comparison of gravity and tilt residuals: investigation of local effects at COBS



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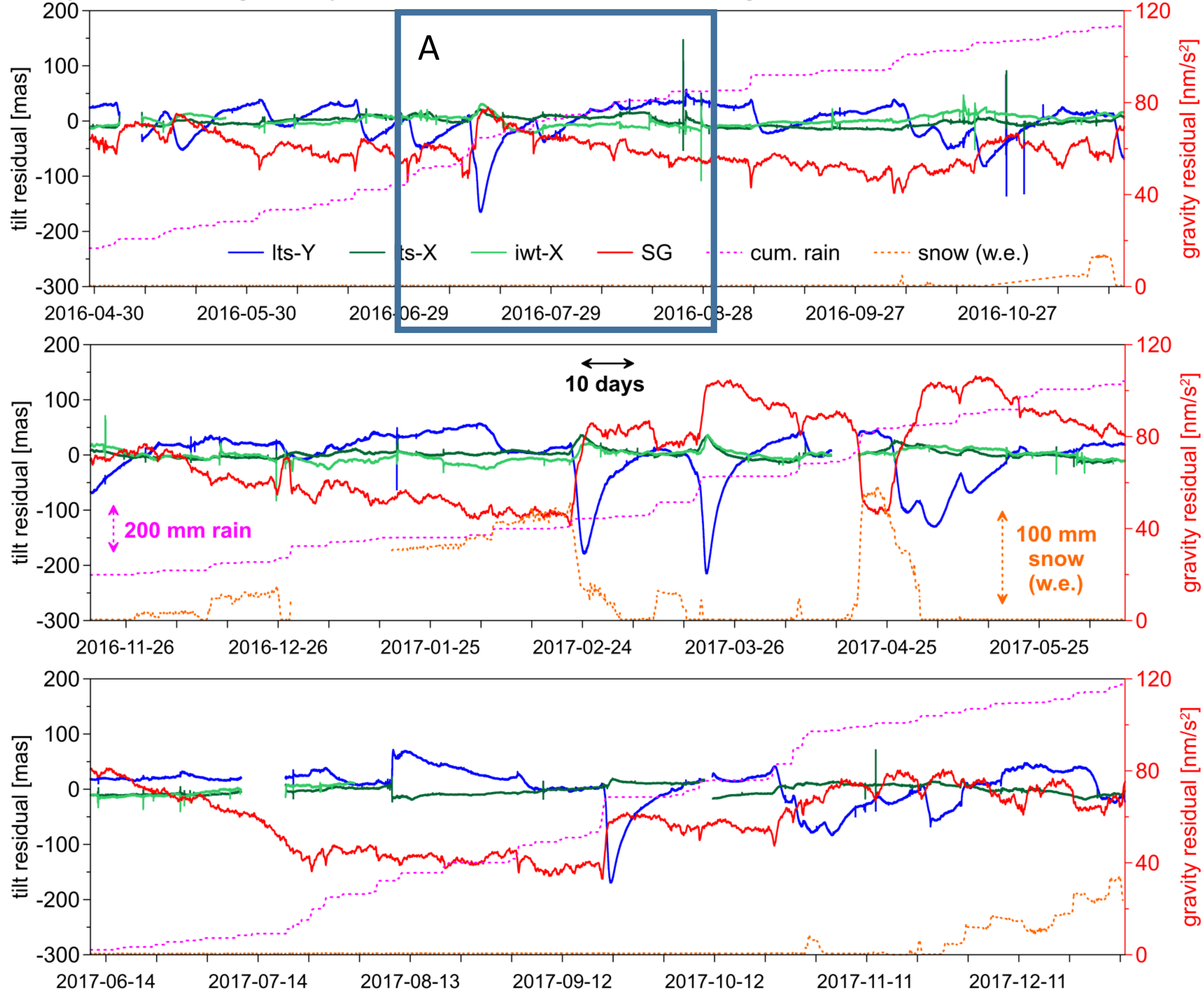
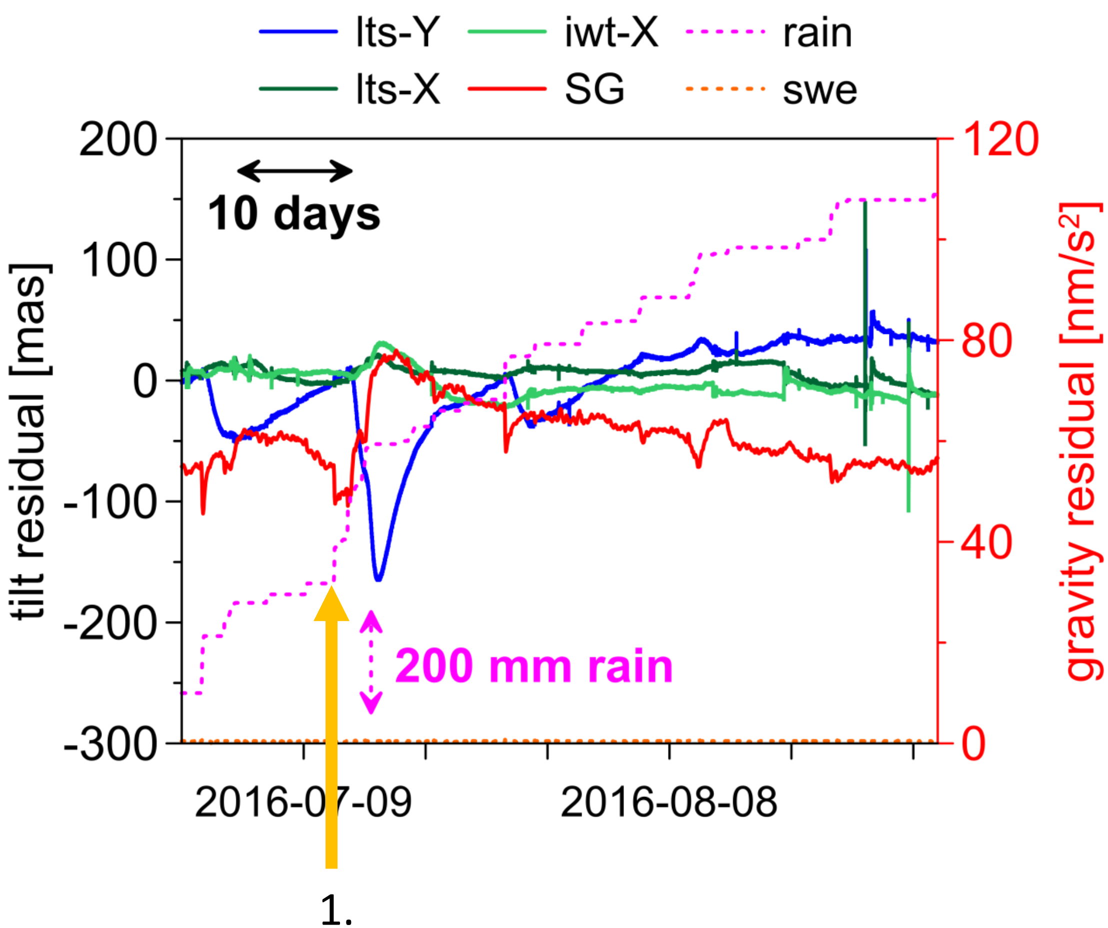
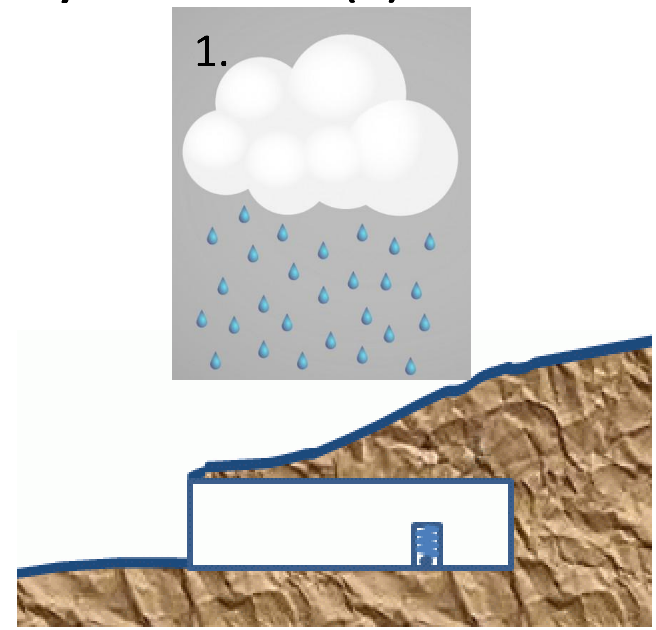


The effect of precipitation on the residual gravity and tilt data (A)





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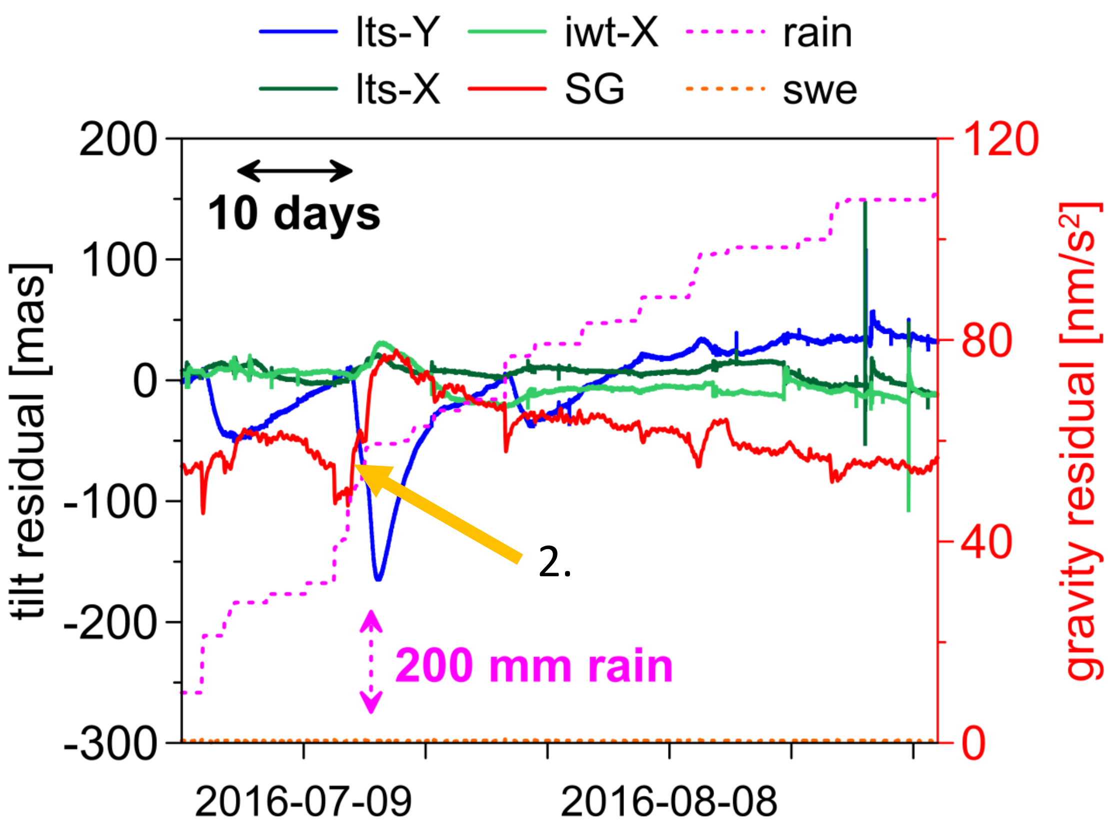

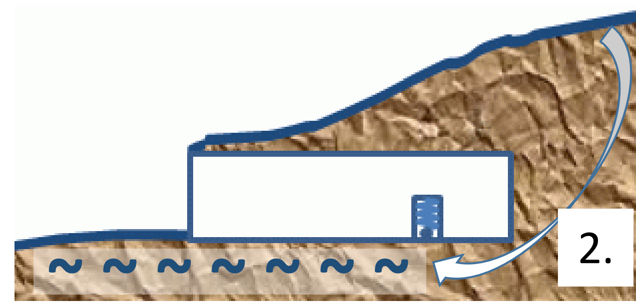

N-S tilt decrease delayed by 2 – 5 hr w.r.t. gravity increase
→
residual anomalies:
caused by different sources, but triggered by the same hydrological process

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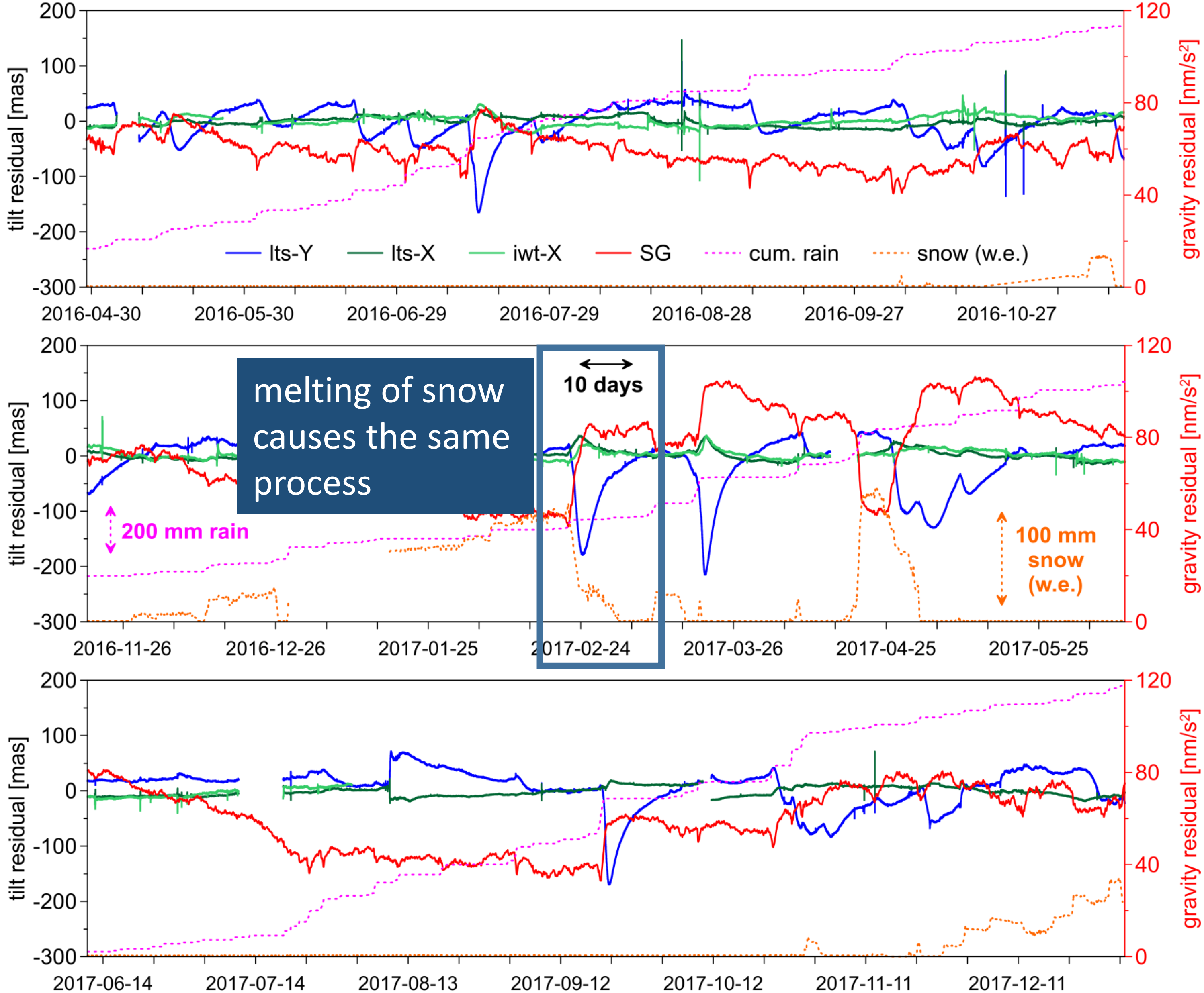

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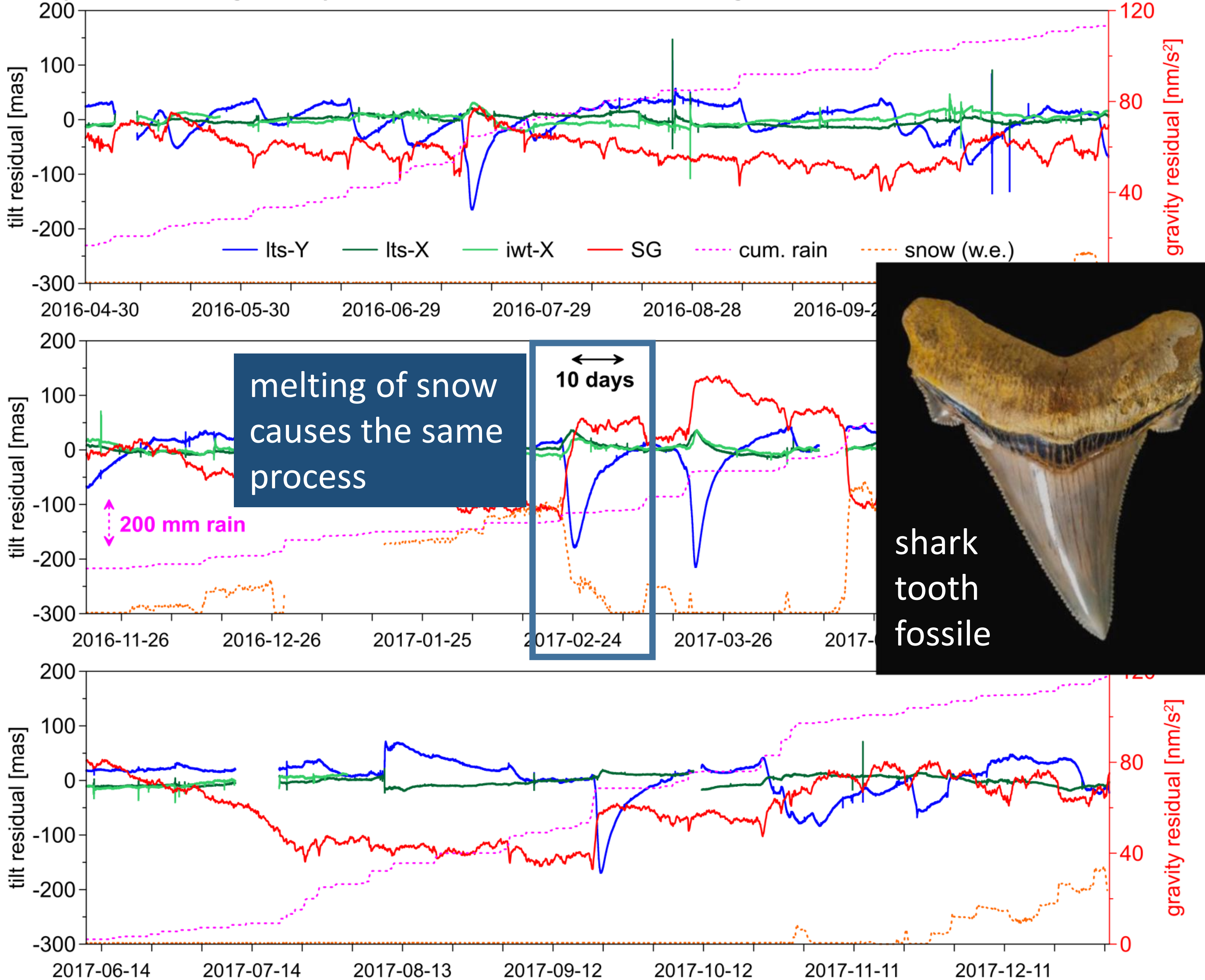


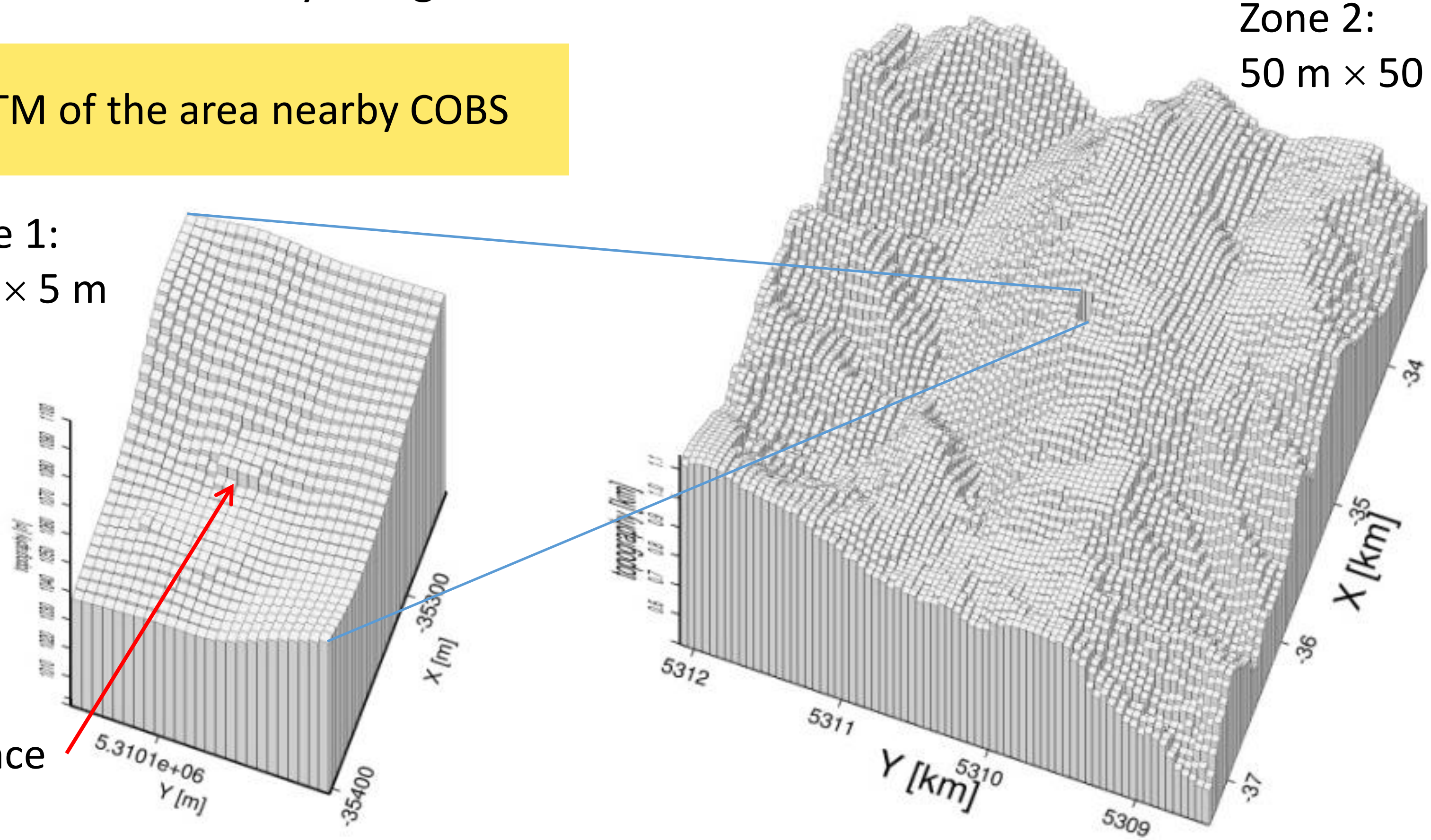
Modeling of „shark tooth” tilt anomalies

Can it be caused by the gravitation of rainwater masses?

DTM of the area nearby COBS

Zone 1:
5 m × 5 m

Zone 2:
50 m × 50 m



entrance

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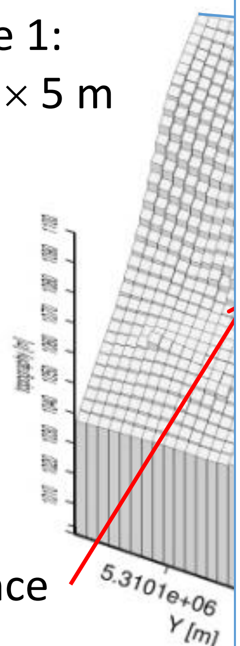
Zone 2:

DTM of the ar

Zone 1:
5 m × 5 m



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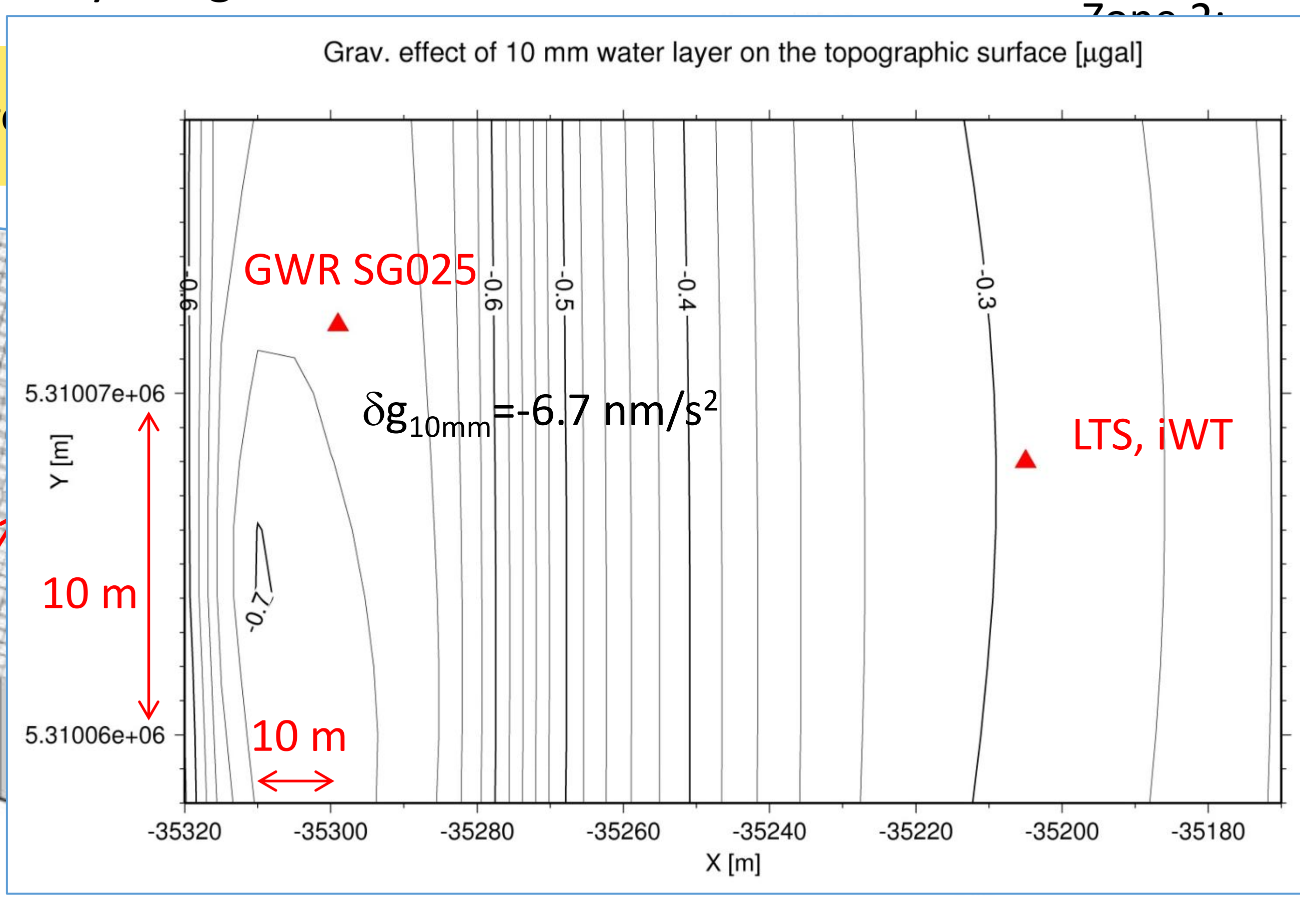

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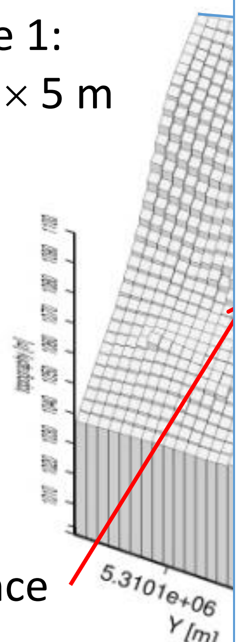
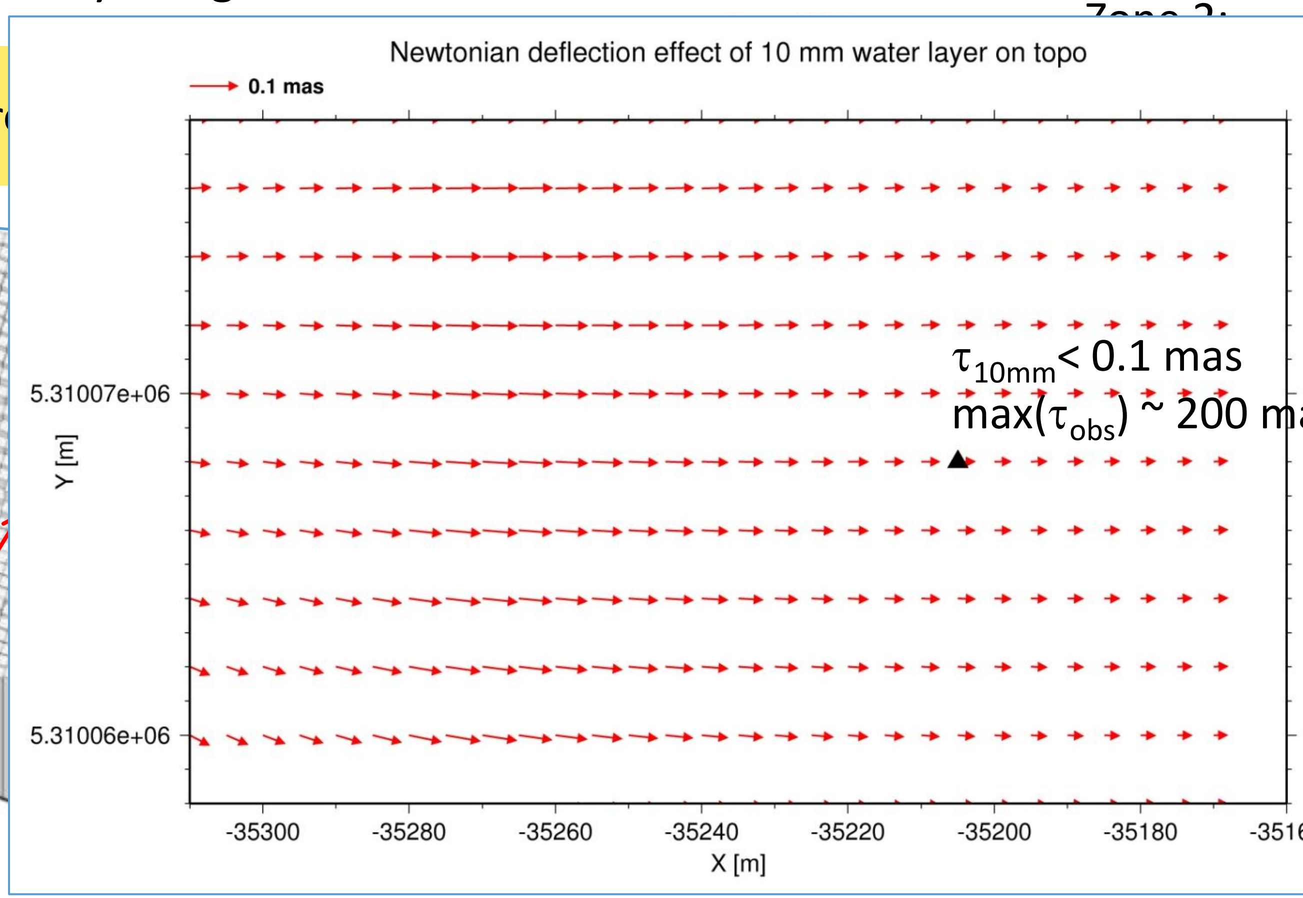


entrance



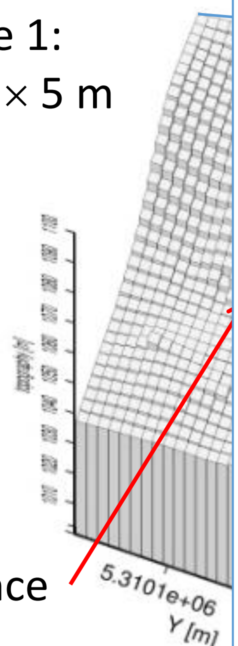
Modeling of „shark tooth” tilt anomalies

Can it be caused by the gravitation of rainwater masses?

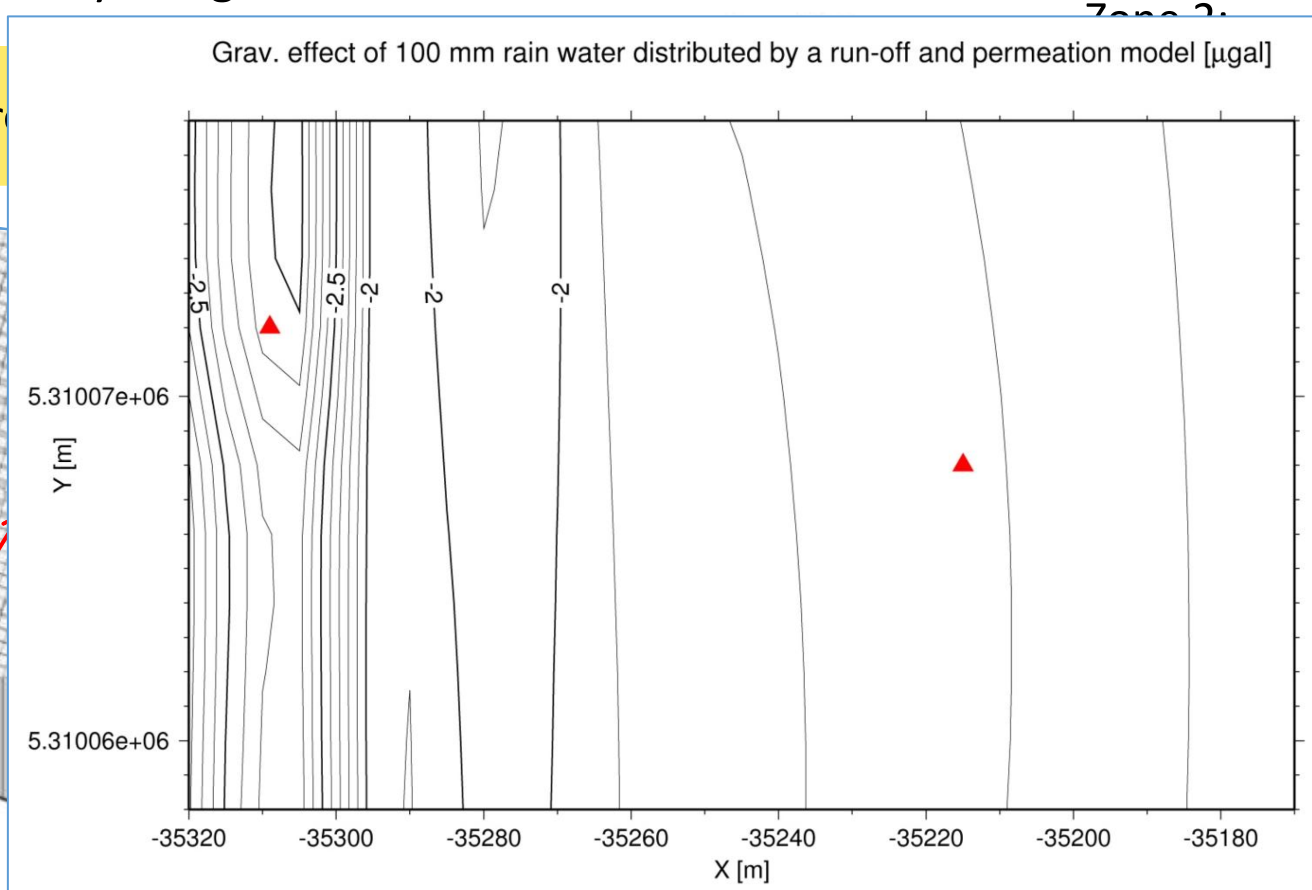
Zone 2:

DTM of the ar

Zone 1:
5 m × 5 m



entrance



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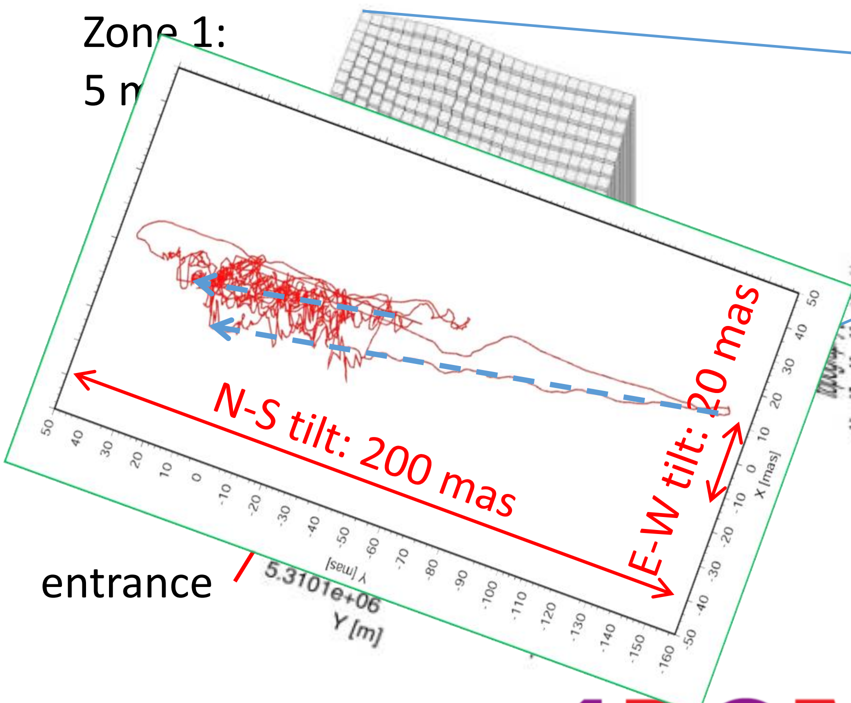
Modeling of „shark tooth" tilt anomalies

Can it be caused by the gravitation of rainwater masses?

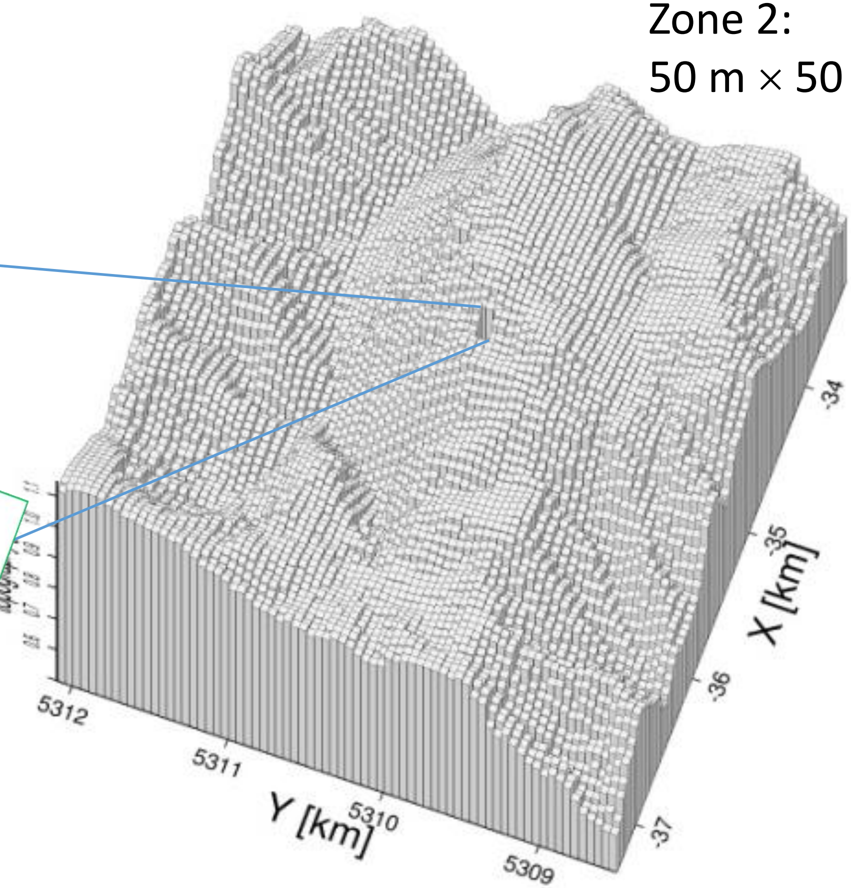
DTM of the area nearby COBS

Zone 2:
50 m × 50 m

Zone 1:
5 m



entrance



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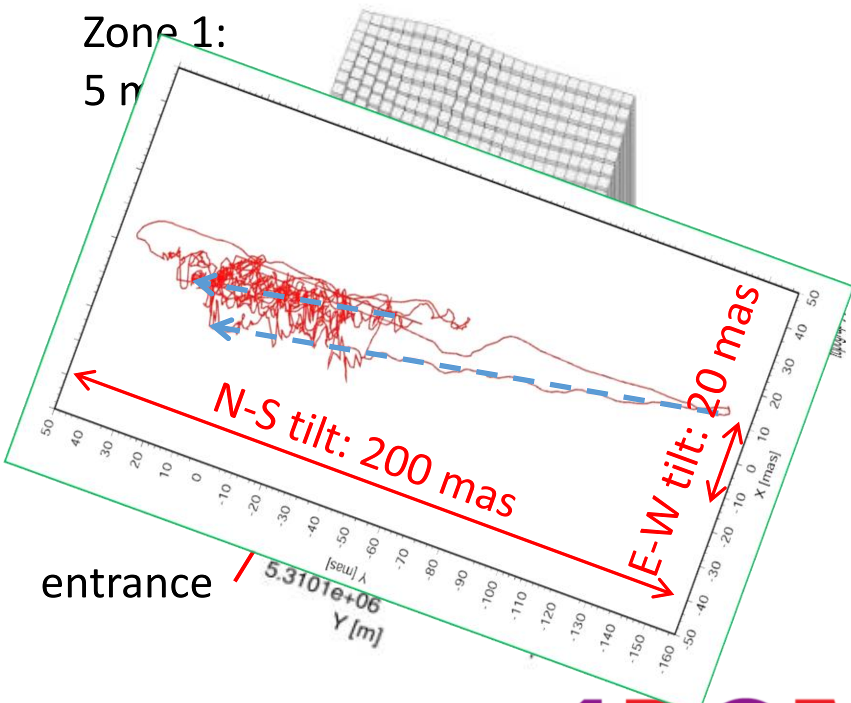
Modeling of „shark tooth" tilt anomalies

Can it be caused by the gravitation of rainwater masses?

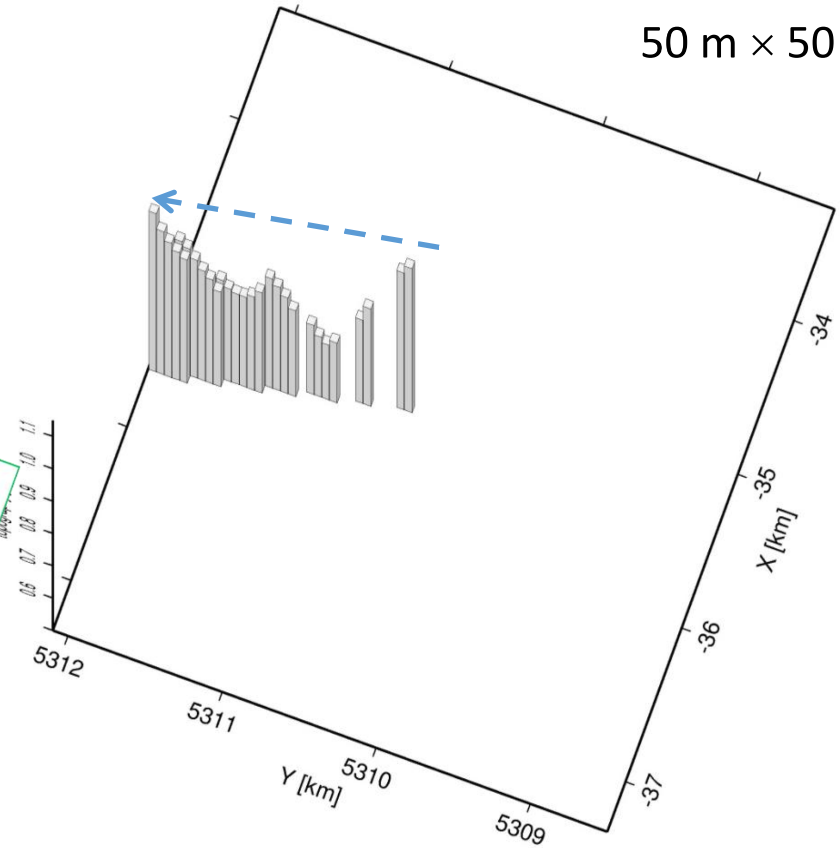
DTM of the area nearby COBS

Zone 1:
5 m



entrance

Zone 2:
50 m × 50 m



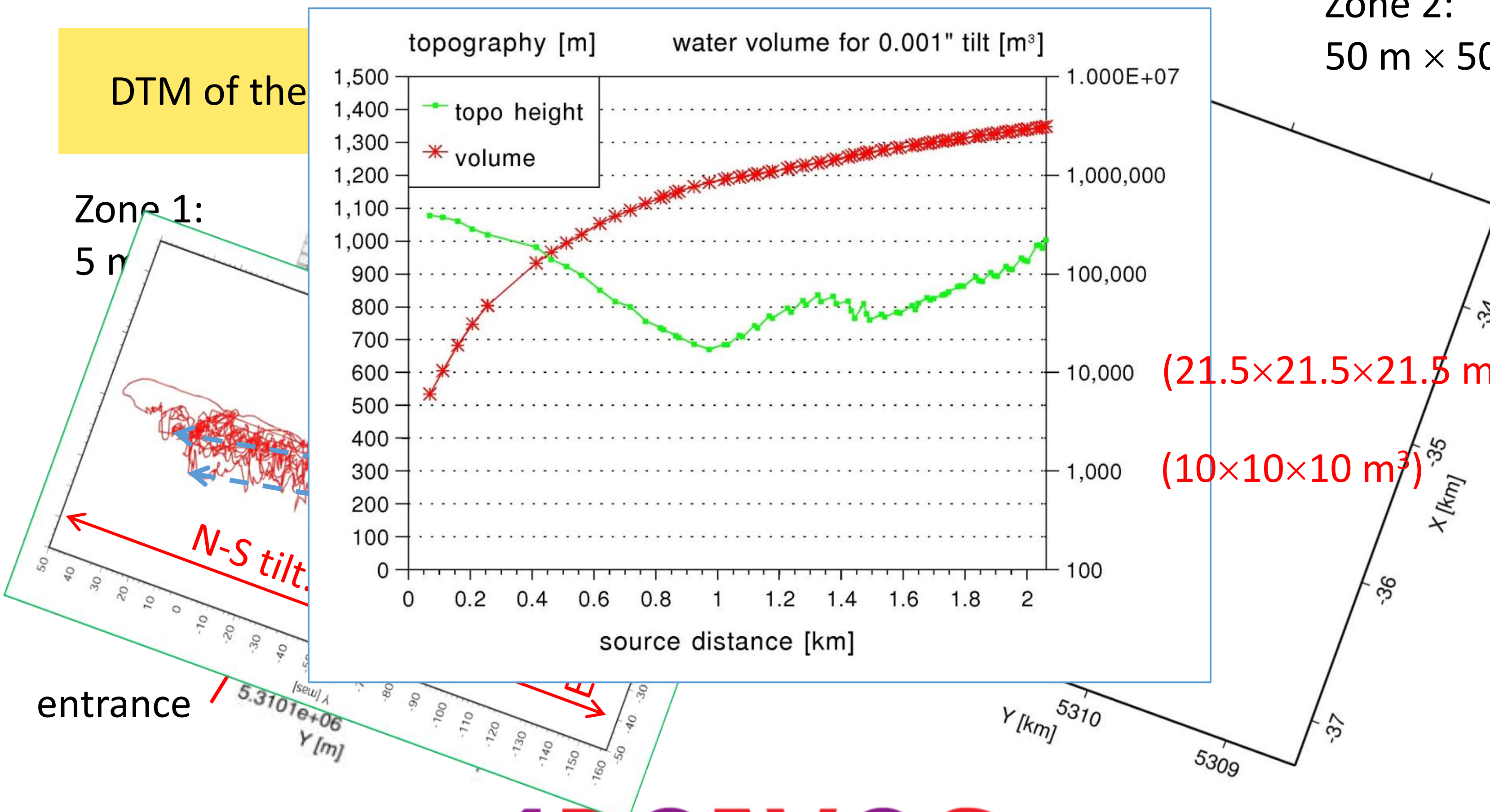
Modeling of „shark tooth" tilt anomalies

Can it be caused by the gravitation of rainwater masses?

Zone 2:
50 m × 50 m

DTM of the

Zone 1:
5 m



entrance

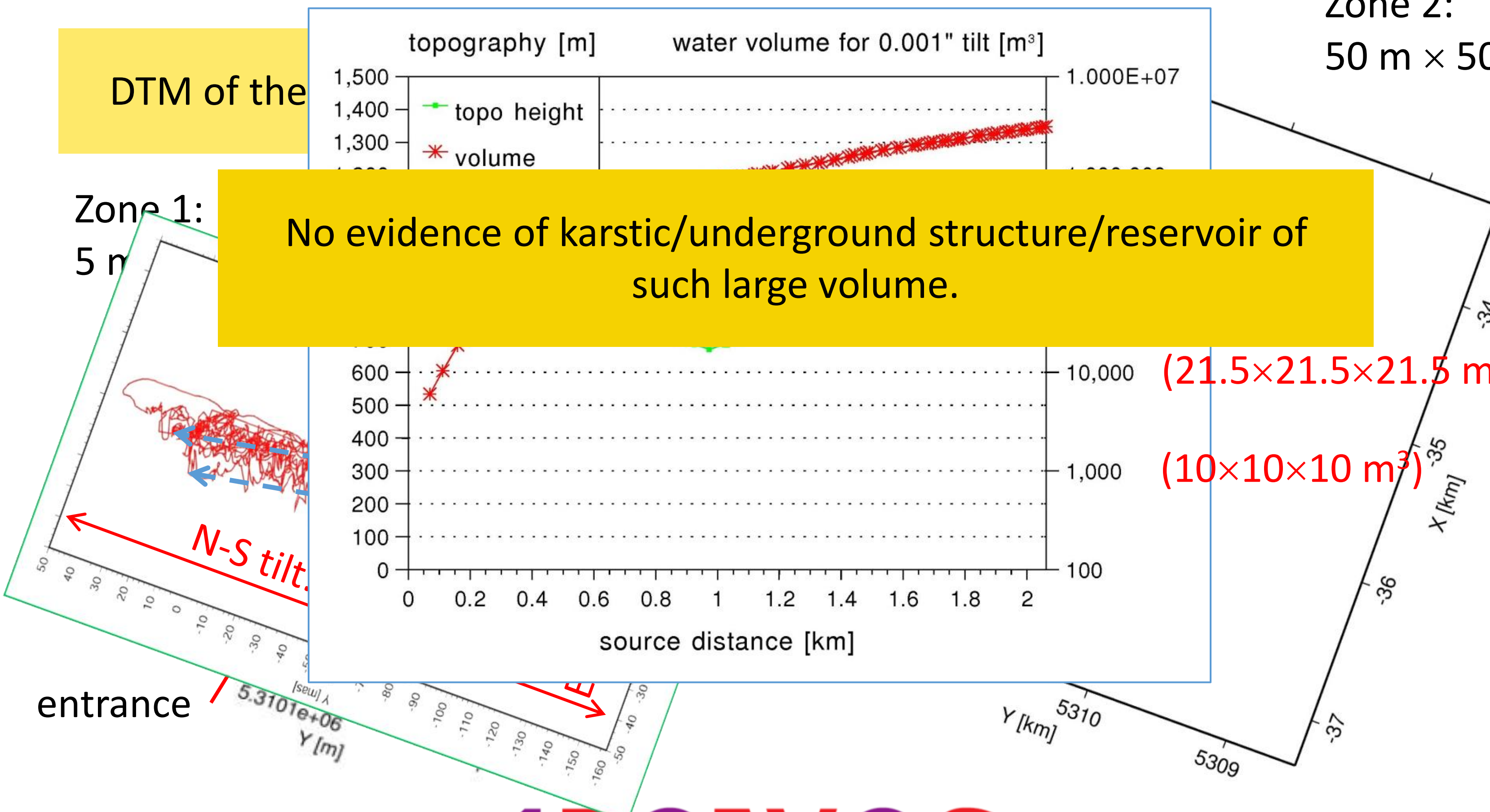
Modeling of „shark tooth” tilt anomalies

Can it be caused by the gravitation of rainwater masses?

Zone 2:
50 m × 50 m

DTM of the

Zone 1:
5 m



No evidence of karstic/underground structure/reservoir of such large volume.

(21.5×21.5×21.5 m³)

(10×10×10 m³)

entrance

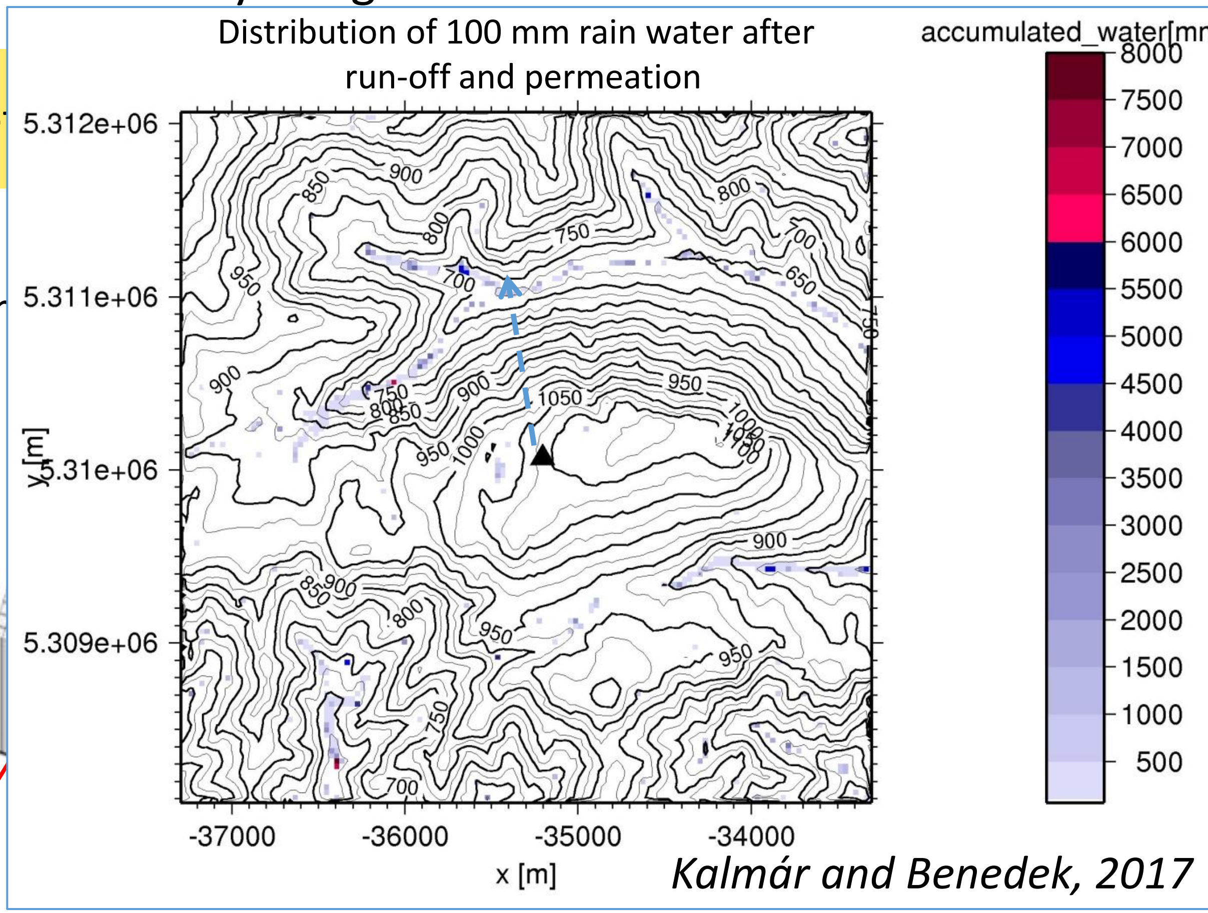
Modeling of „shark tooth" tilt anomalies

Can it be caused by the gravitation of rainwater masses?

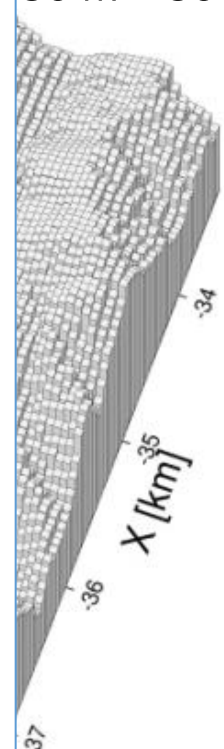
DTM o

Zone 1:
5 m × 5 r

entrance



Zone 2:
50 m × 50 m



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Tilt time series recorded at TPSO, Victor Harbor, Australia

04-09-2018 – 19-02-2019

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Tilt time series recorded at TPSO, Victor Harbor, Australia

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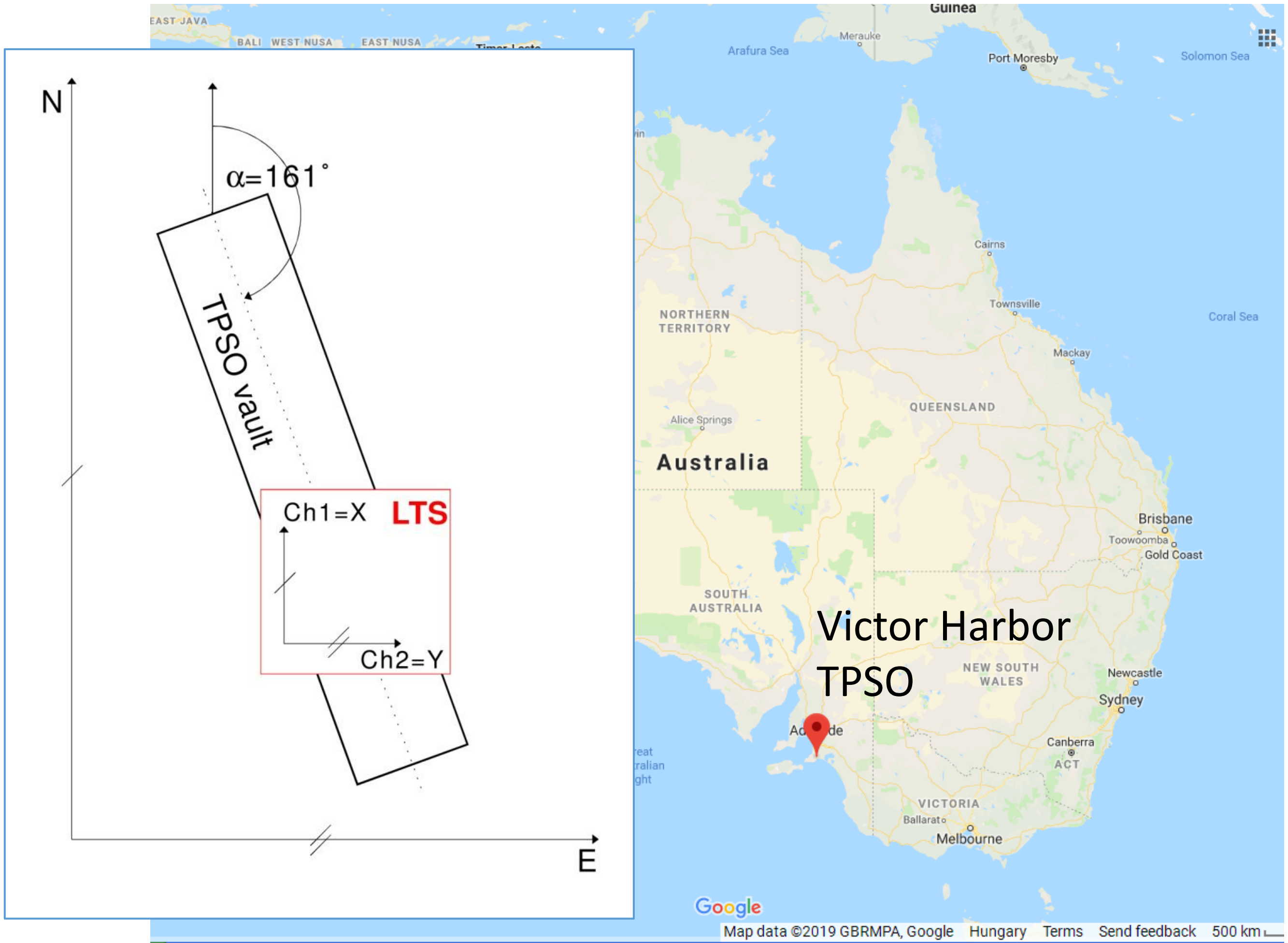

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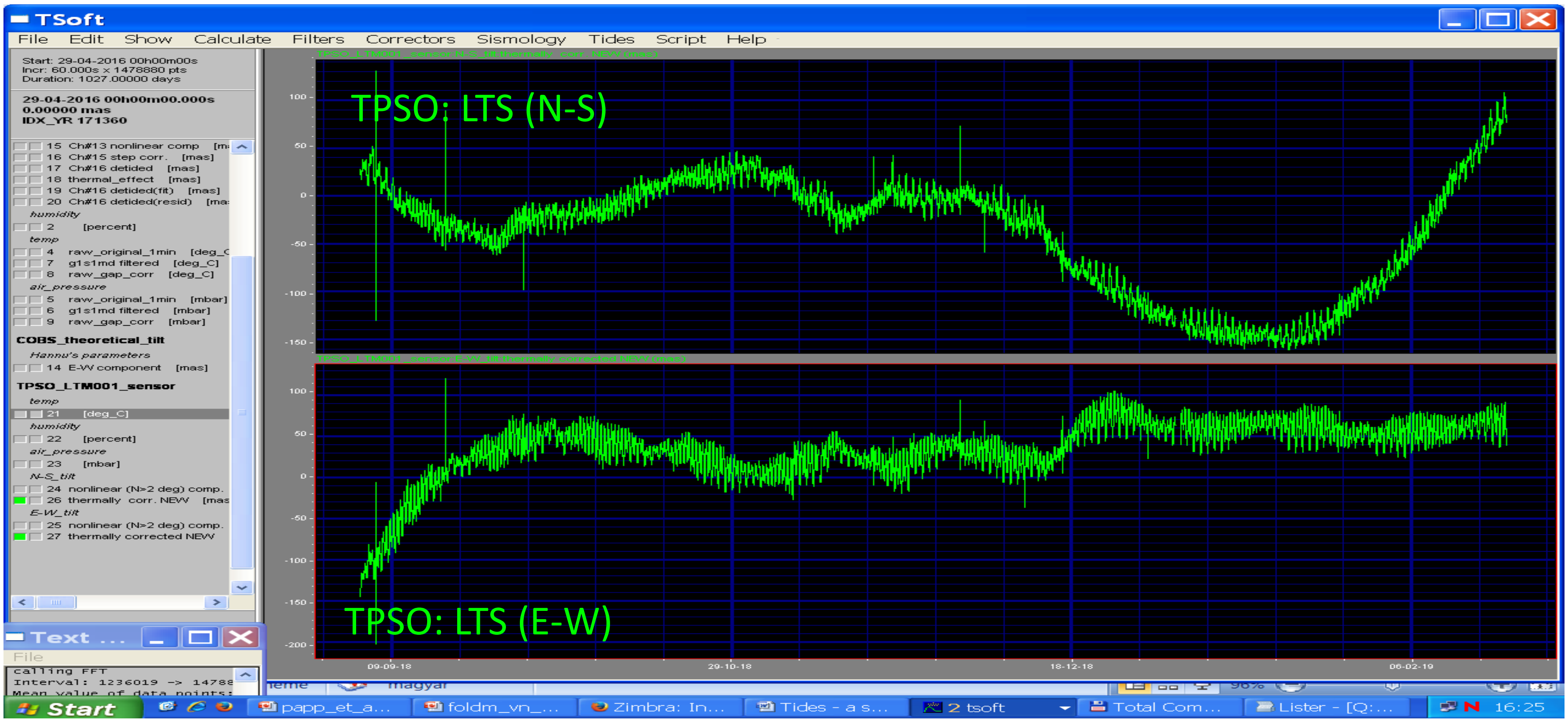
Tilt time series recorded at TPSO, Victor Harbor, Australia

04-09-2018 – 19-02-2019

Investigation of ocean loading effects ⇒ validation of models (TOPEX, FES2014,…)



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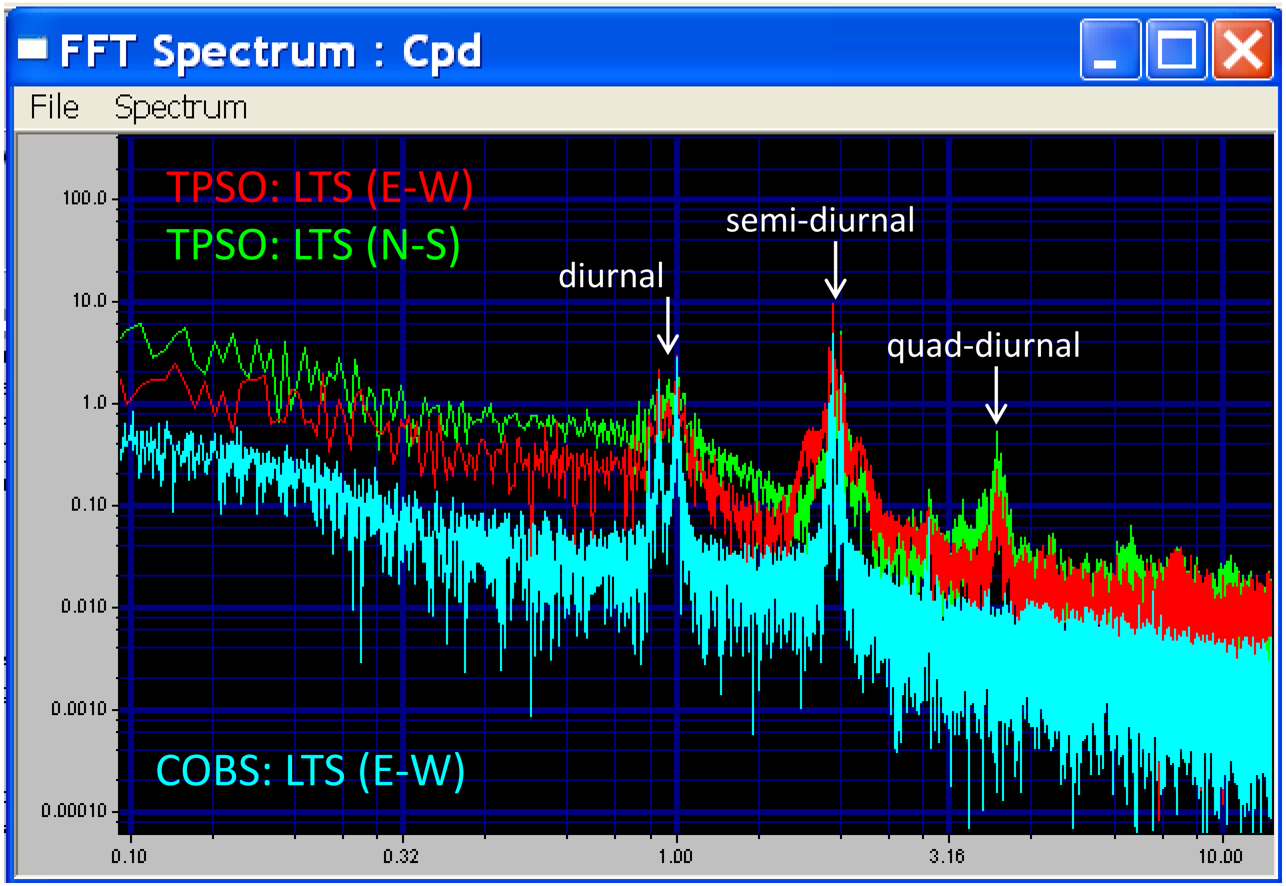
Comparison of FFT spectra of tilt time series recorded at COBS and TPSO



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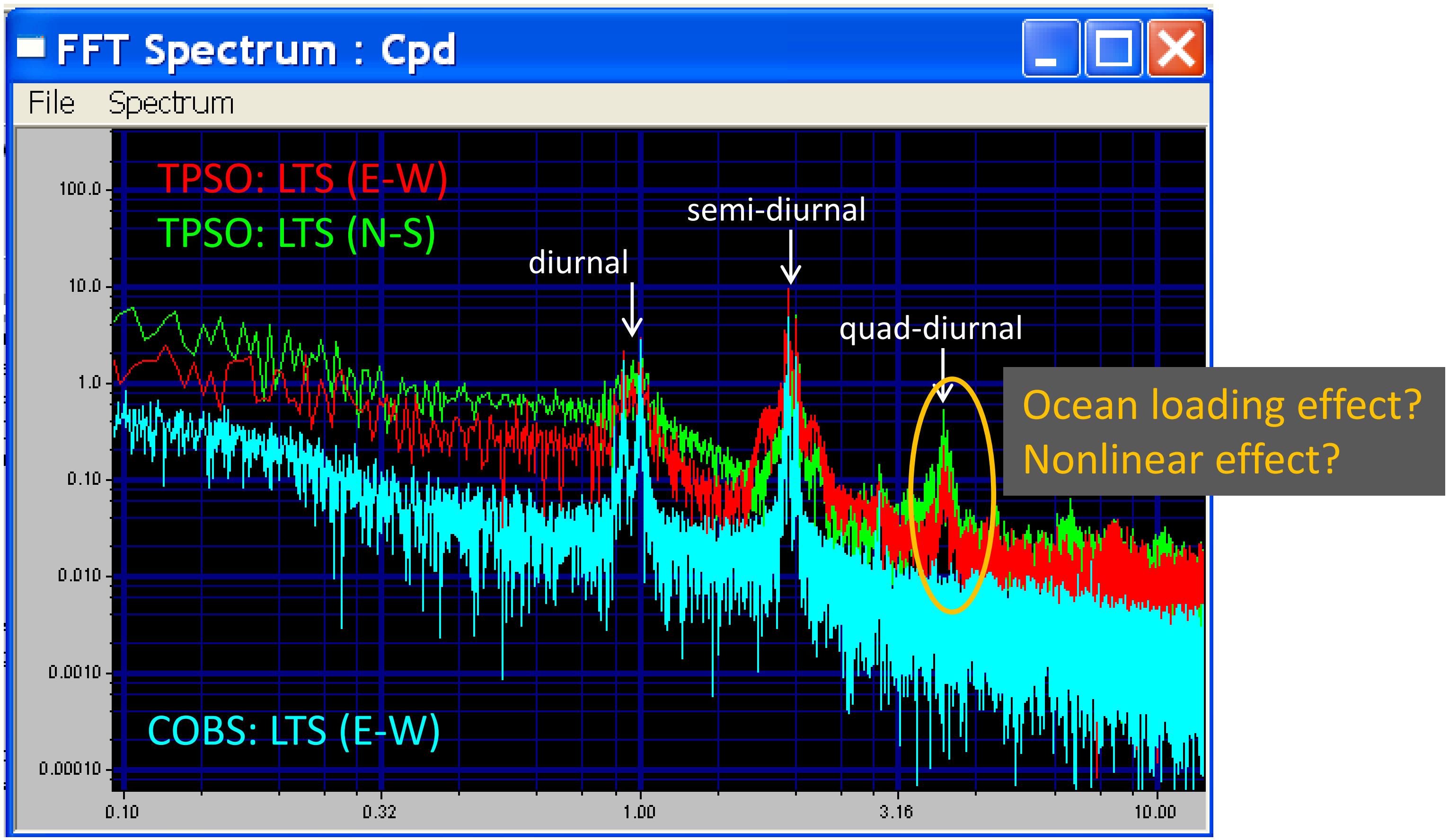
Comparison of FFT spectra of tilt time series recorded at COBS and TPSO



***Harmonic analysis of tilt time series recorded at TPSO**: standard procedure using ETERNA package (preliminary results)*

		LTS-X (N-S) Q1 ⇒ M3 m_0= 1.47 mas		
Darwin	**γ (WD)**	**amp [mas]**	**γ σ(γ)**	**ϕ σ(ϕ)**
Q1	0.6940	1.0471	**2.5405** **0.3079**	6.128 6.936
O1	0.6944	4.2407	**1.9701** **0.0538**	-4.275 1.569
K1	0.7362	5.2998	**1.7513** **0.0351**	-23.645 1.148
N2	0.6911	0.9089	**0.6350** **0.0405**	-154.872 3.650
M2	0.6911	2.7278	**0.3649** **0.0077**	44.742 1.212
S2	0.6911	6.9356	**1.9944** **0.0164**	-38.440 0.470
M3		0.1468	**1.2272** **0.3545**	-163.683 16.544

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Harmonic analysis of tilt time series recorded at TPSO*: standard procedure using ETERNA package (preliminary results)*

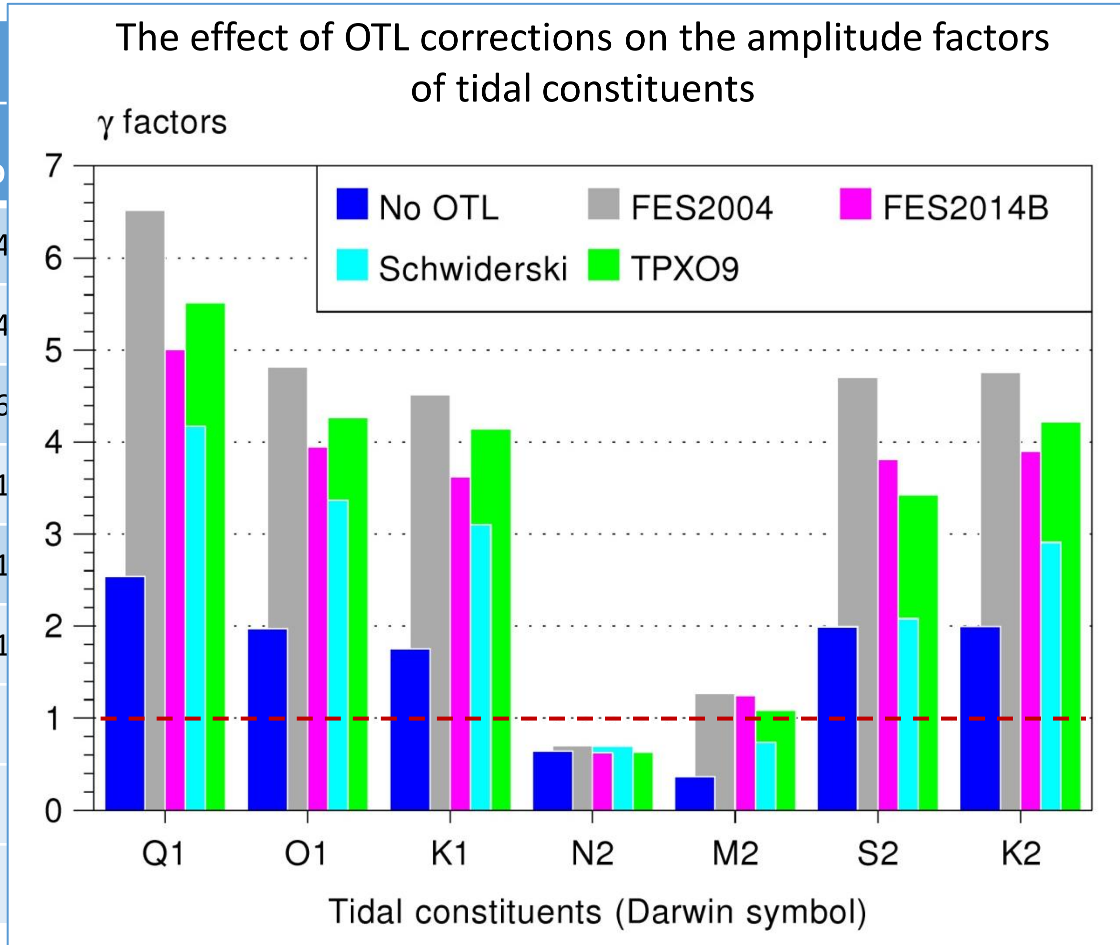
		LTS-X (N-S) Q1 ⇒ M3 m_0= 1.47 mas			LTS-X (N-S) Q1 ⇒ M4 m_0= 1.28 mas		
Darwin	**γ (WD)**	**amp [mas]**	**γ σ(γ)**	**ϕ σ(ϕ)**	**amp [mas]**	**γ σ(γ)**	**ϕ σ(ϕ)**
Q1	0.6940	1.0471	**2.5405 0.3079**	6.128 6.936	1.0475	2.5417 0.3070	6.187 6.913
O1	0.6944	4.2407	**1.9701 0.0538**	-4.275 1.569	4.2420	1.9707 0.0537	-4.269 1.564
K1	0.7362	5.2998	**1.7513 0.0351**	-23.645 1.148	5.2998	1.7513 0.0350	-23.661 1.145
N2	0.6911	0.9089	**0.6350 0.0405**	-154.872 3.650	0.90669	0.6335 0.0401	-154.949 3.621
M2	0.6911	2.7278	**0.3649 0.0077**	44.742 1.212	2.7288	0.3650 0.0076	44.745 1.199
S2	0.6911	6.9356	**1.9944 0.0164**	-38.440 0.470	6.9346	1.9941 0.0162	-38.437 0.465
M3		0.1468	**1.2272 0.3545**	-163.683 16.544	0.1575	1.3172 0.3392	-163.992 14.748
M4					0.9090	511.55 50.44	10.762 5.647

Harmonic analysis of tilt time series recorded at TPSO*: standard procedure using ETERNA package (preliminary results)*

		LTS-X (N-S) Q1 ⇒ M3 m_0= 1.47 mas			LTS-X (N-S) Q1 ⇒ M4 m_0= 1.28 mas			LTS-X (N-S) Q1 ⇒ M3 (& NL) m_0= 1.15 mas		
Darwin	**γ (WD)**	**amp [mas]**	**γ σ(γ)**	**ϕ σ(ϕ)**	**amp [mas]**	**γ σ(γ)**	**ϕ σ(ϕ)**	**amp [mas]**	**γ σ(γ)**	**ϕ σ(ϕ)**
Q1	0.6940	1.0471	**2.5405 0.3079**	6.128 6.936	1.0475	2.5417 0.3070	6.187 6.913	1.0464	2.5388 0.3071	6.160 6.923
O1	0.6944	4.2407	**1.9701 0.0538**	-4.275 1.569	4.2420	1.9707 0.0537	-4.269 1.564	4.2419	1.9706 0.0537	-4.270 1.565
K1	0.7362	5.2998	**1.7513 0.0351**	-23.645 1.148	5.2998	1.7513 0.0350	-23.661 1.145	5.3012	1.7518 0.0350	-23.660 1.145
N2	0.6911	0.9089	**0.6350 0.0405**	-154.872 3.650	0.90669	0.6335 0.0401	-154.949 3.621	0.9228	0.6448 0.0401	-154.439 3.562
M2	0.6911	2.7278	**0.3649 0.0077**	44.742 1.212	2.7288	0.3650 0.0076	44.745 1.199	2.7292	0.3651 0.0076	44.585 1.191
S2	0.6911	6.9356	**1.9944 0.0164**	-38.440 0.470	6.9346	1.9941 0.0162	-38.437 0.465	6.9263	1.9917 0.0161	-38.381 0.464
M3		0.1468	**1.2272 0.3545**	-163.683 16.544	0.1575	1.3172 0.3392	-163.992 14.748	0.1568	1.3109 0.3378	-162.659 14.757
M4					0.9090	511.55 50.44	10.762 5.647			
M4 X								0.9400	0.9400 0.0493	-133.571 3.001

***Harmonic analysis of tilt time series recorded at TPSO**: standard procedure using ETERNA package (preliminary results)*

		M3 (& NL) mas	
Darwin	γ (WD		φ σ(φ)
Q1	0.694	38 71	6.160 6.923
O1	0.694	06 37	-4.270 1.565
K1	0.736	18 50	-23.660 1.145
N2	0.691	48 01	-154.439 3.562
M2	0.691	51 76	44.585 1.191
S2	0.691	17 61	-38.381 0.464
M3		09 78	-162.659 14.757
M4			
M4 X		00 93	-133.571 3.001



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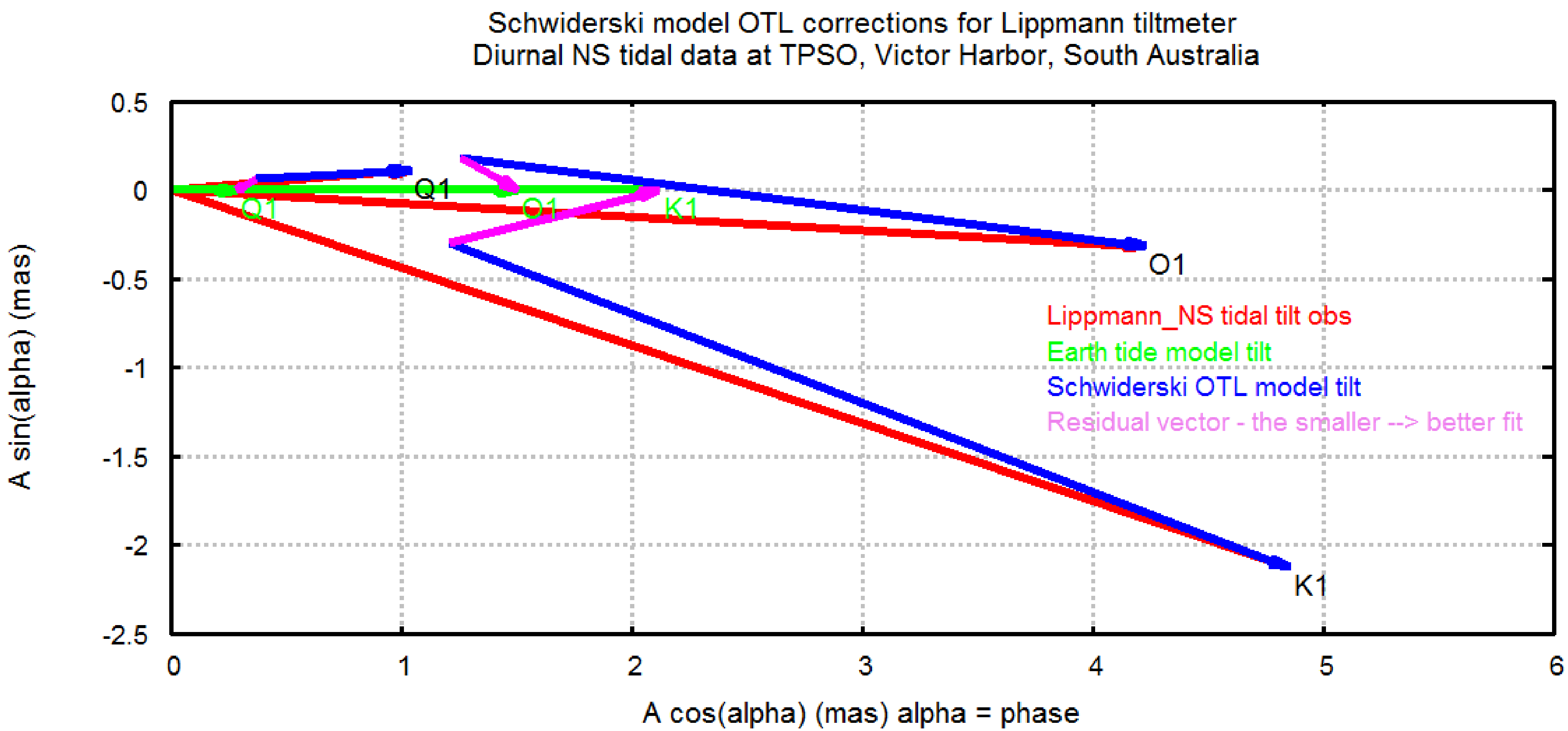
Harmonic analysis of tilt time series recorded at TPSO*: standard procedure using ETERNA package (preliminary results)*



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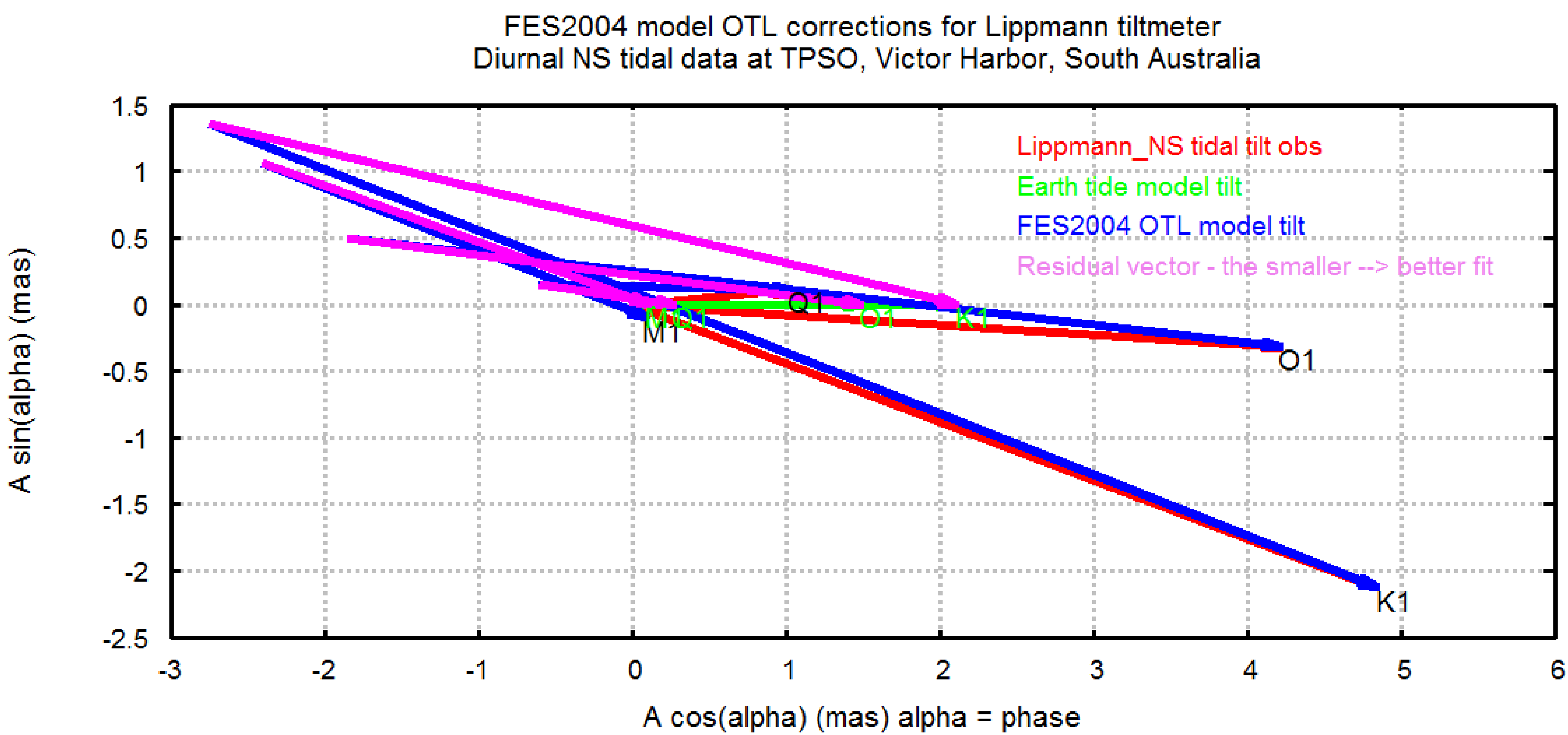
***Harmonic analysis of tilt time series recorded at TPSO**: standard procedure using ETERNA package (preliminary results)*



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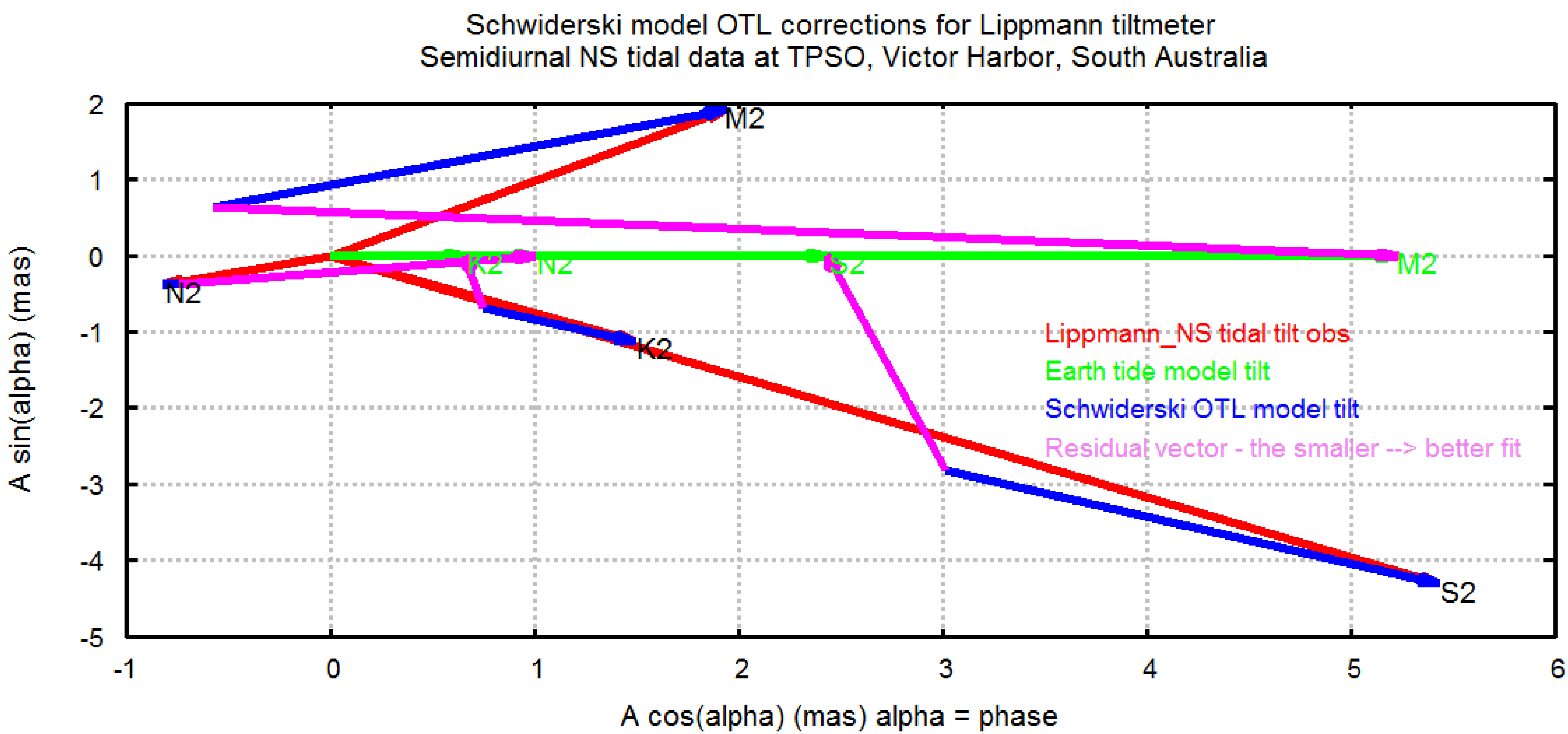
***Harmonic analysis of tilt time series recorded at TPSO**: standard procedure using ETERNA package (preliminary results)*



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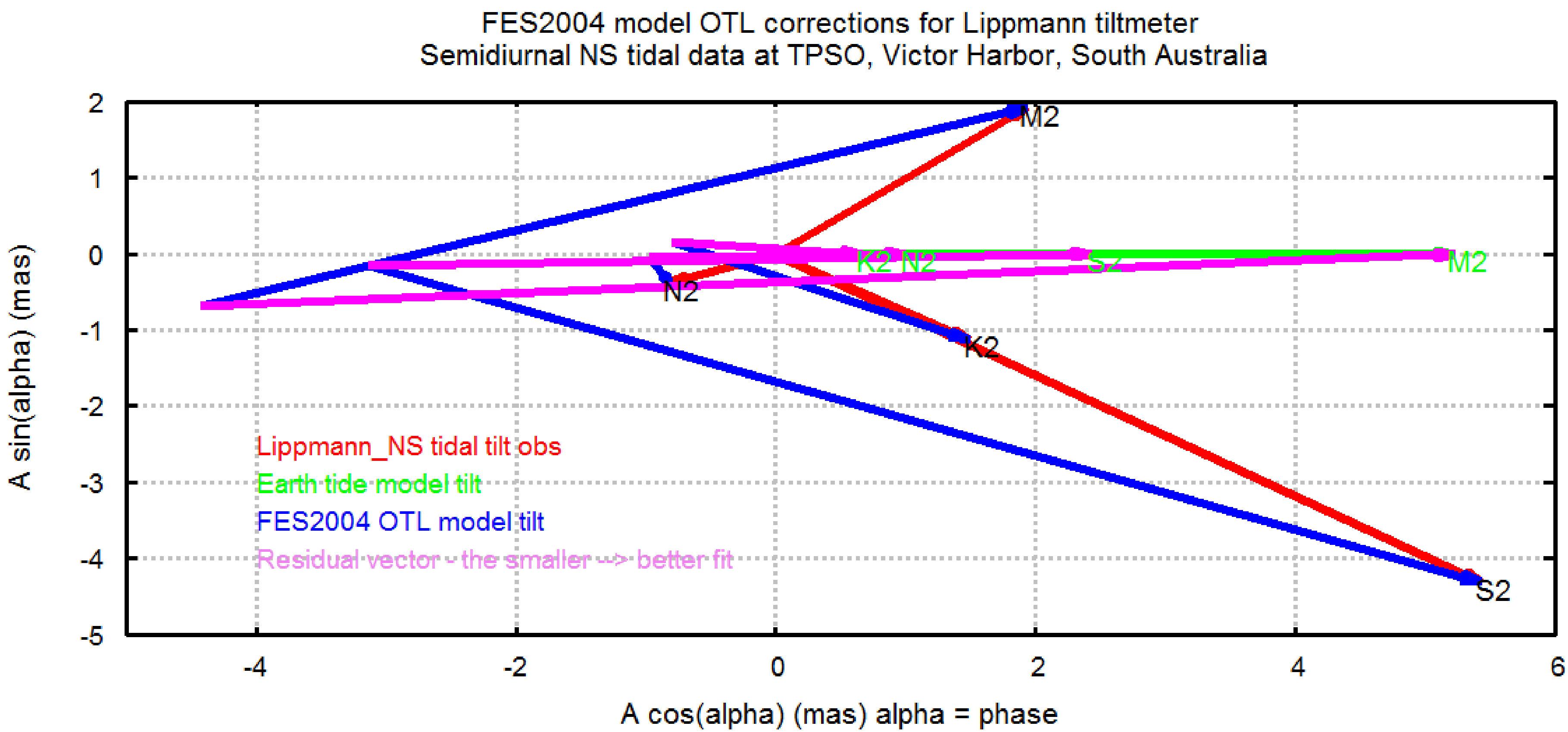
Harmonic analysis of tilt time series recorded at TPSO*: standard procedure using ETERNA package (preliminary results)*



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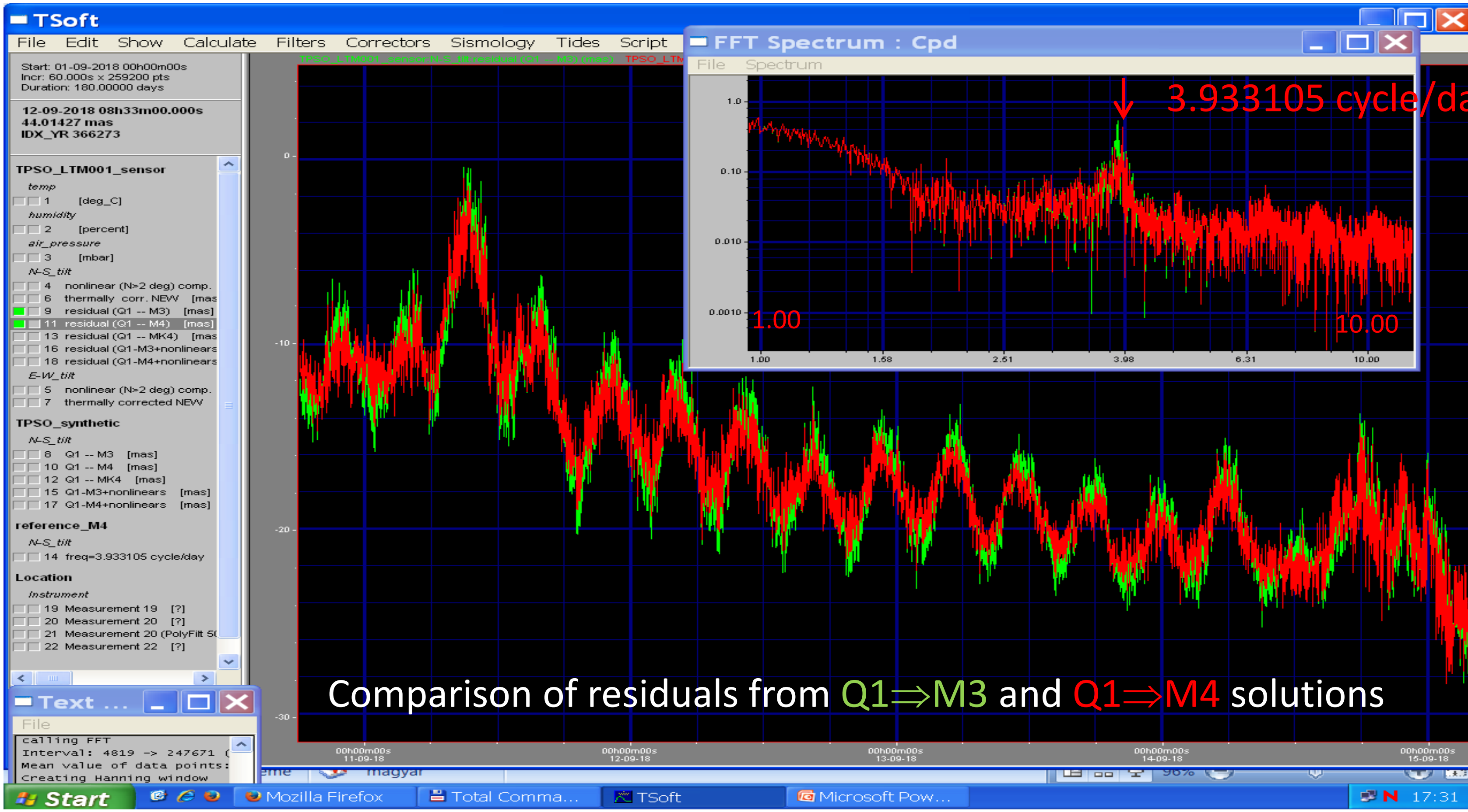
Harmonic analysis of tilt time series recorded at TPSO: standard procedure using ETERNA package (preliminary results)



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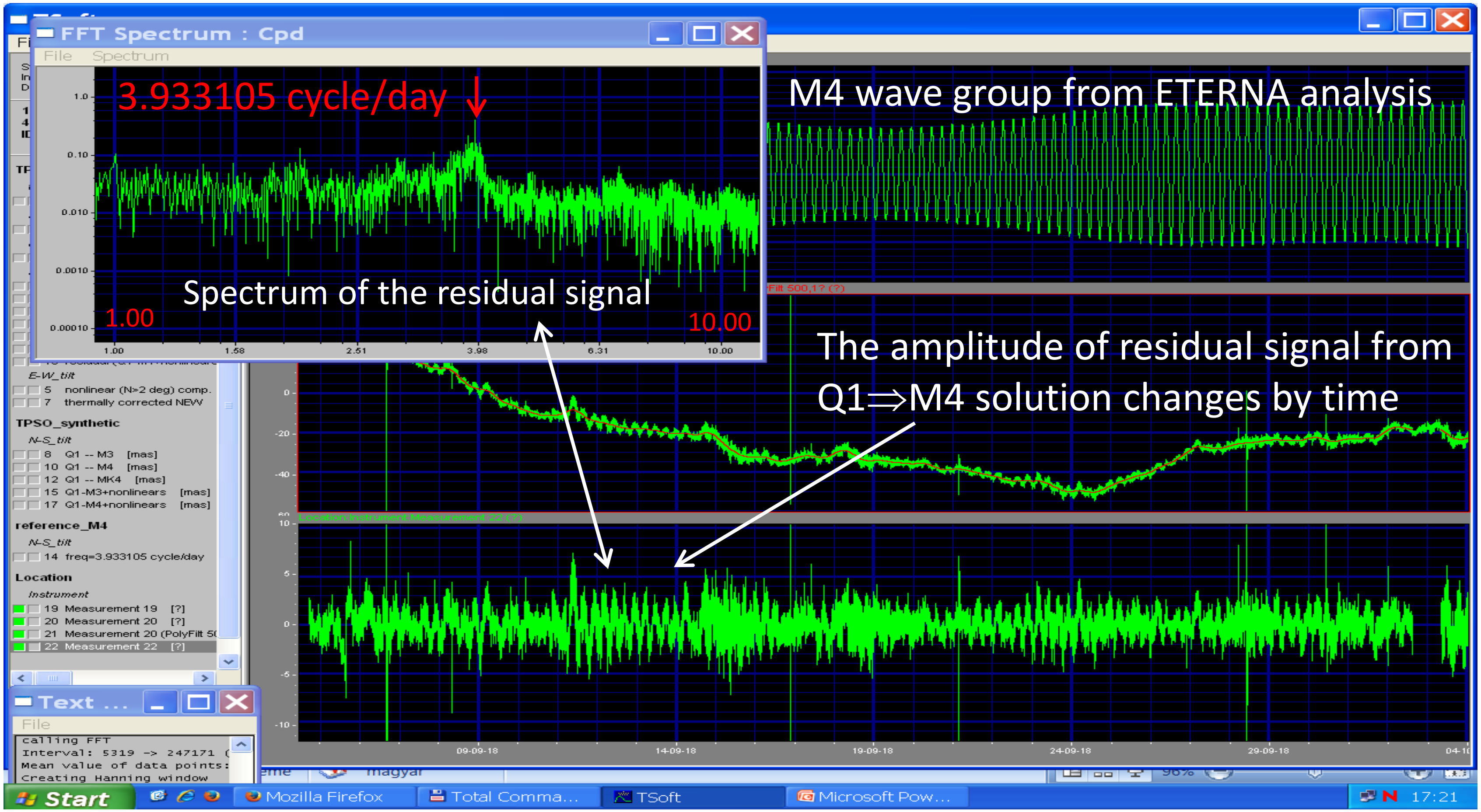
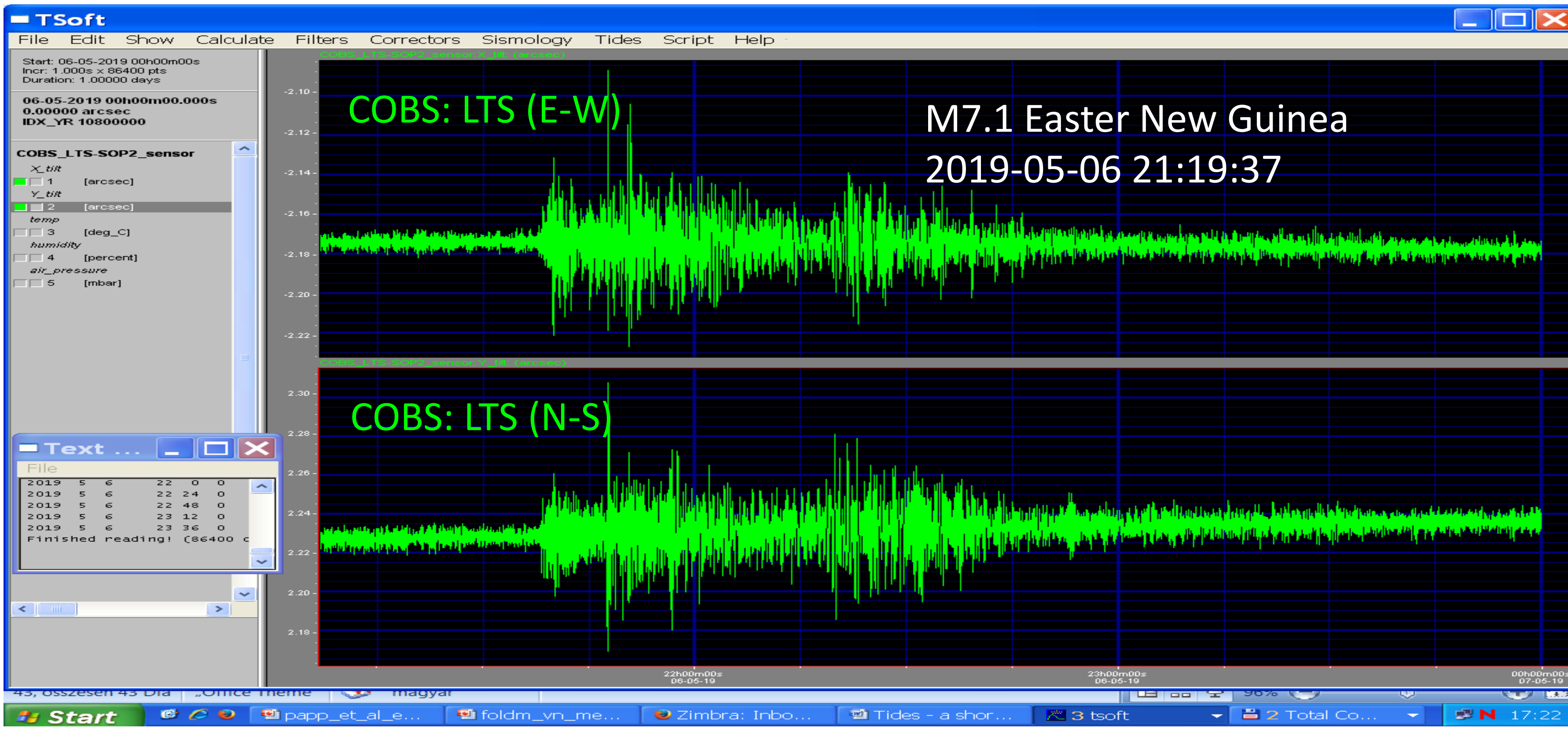
Harmonic analysis of tilt time series recorded at TPSO*: standard procedure using ETERNA package (preliminary results)*



Future perspectives of deformation measurements

- **Seismological applications?**



Future perspectives of deformation measurements

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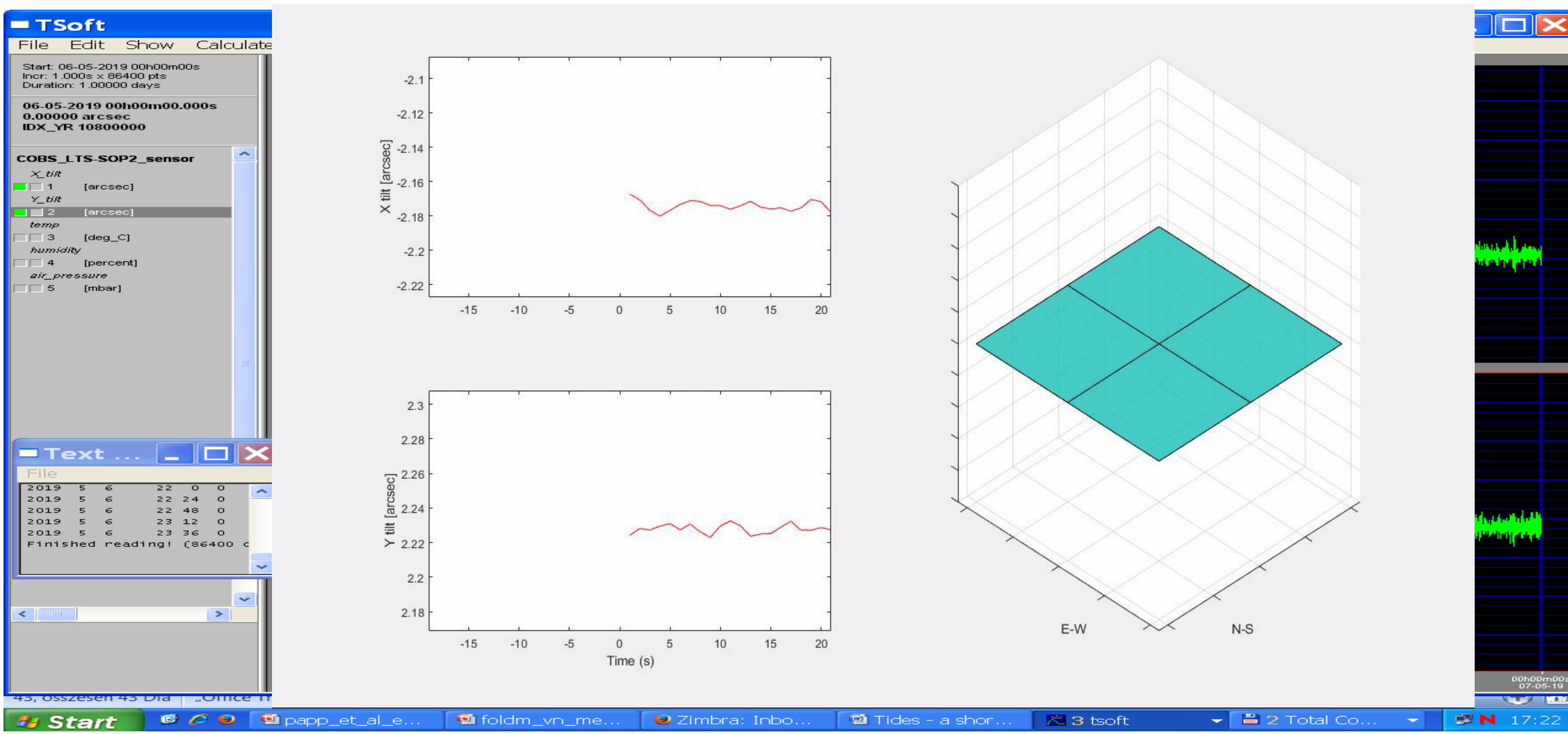

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Future perspectives of deformation measurements

- **Seismological applications?**
- **Monitoring of the change of the shape of the Earth?**

The happy Earth

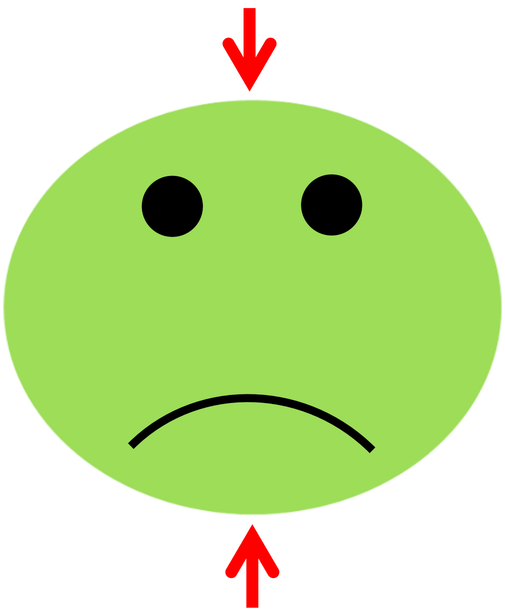
Future perspectives of deformation measurements

- Seismological applications?
- Monitoring of the change of the shape of the Earth?

Still happy…

Future perspectives of deformation measurements

- **Seismological applications?**
- **Monitoring of the change of the shape of the Earth?**



Not so happy and deformed…

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Future perspectives of deformation measurements

- **Seismological applications?**
- **Monitoring of the change of the shape of the Earth?**