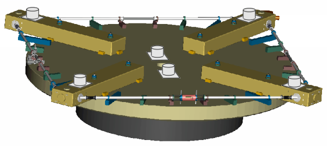
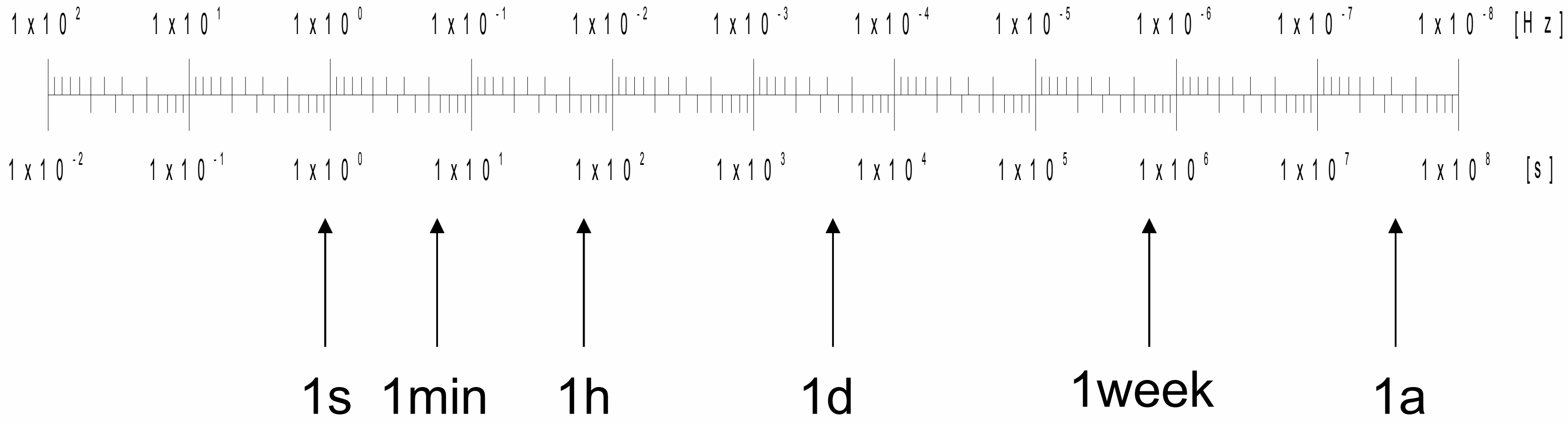
News from G-Wettzell

A. Gebauer, U. Schreiber, Th. Klügel

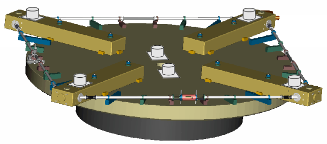
gebauer@fs.wettzell.de



10 decades of frequencies



- Signals
- Instrumental requests
- Solution / problems



$$f_{Sagnac} = \frac{4 \cdot L}{\lambda \cdot P} \cdot \vec{n} \cdot \vec{\Omega} + f_{Instrument}$$

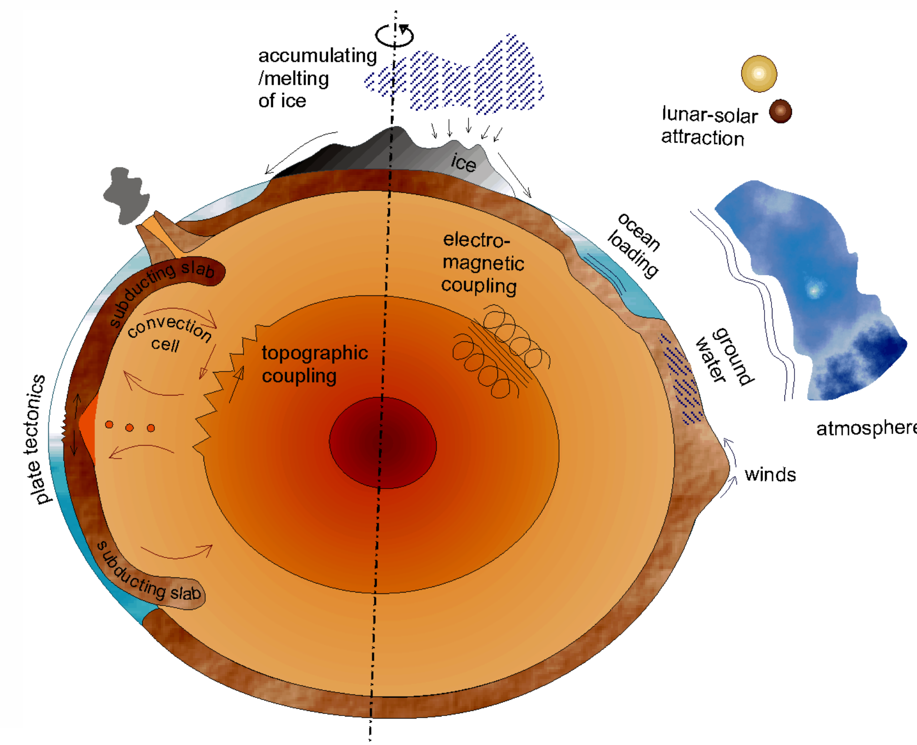
rotation / orientation | rotation / orientation

- tides
- hydrosphere
- atmosphere
- cryosphere
- mantle convection earthquakes …
- relativistic effects

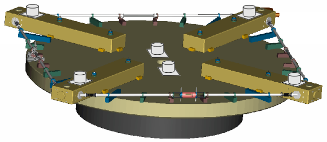
exogenous effects | endogenous effects

moment of inertia changes

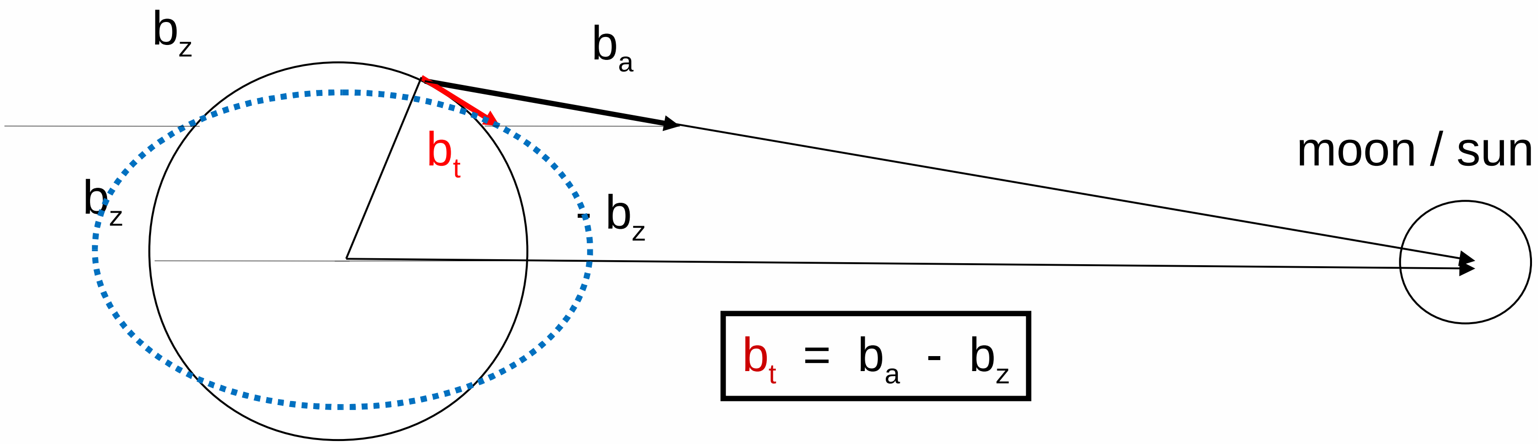
Earth rotation changes



global ←→ regional ←→ lokal   ms ←→ a



Tides

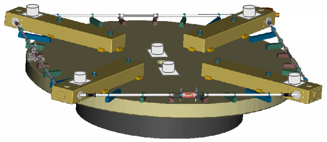


Attraction b_a: acts in direction to moon (sun) depending on the distance;

Centrifugal force b_z: acts in parallel to the connecting line between Earth and moon / sun, but in opposite direction; this force has the same value throughout the Earth, because we are still dealing with a rigid body which circulates around a center.

The difference of both forces (or accelerations) is the tidal force (acceleration) given in red. This vector is zero in the Earth‘s center, only. It points towards the tide generating body on the side facing it, and in the opposite direction on the other side. At the poles the tidal vectors point towards the Earth‘s center. The section of the Earth is changed from a circle to an ellipse.

The tidal forces of the sun and the moon are about 90% of the whole tidal force. Jentzsch (2009)



Rotation of the Earth

Celestial Pole

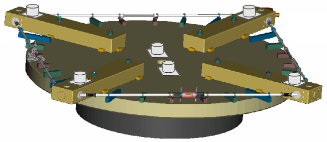
- Precession
  (18.6a, 9.3a, 1a, 0.5a, 13.7a)
- “Forced Nutation”
  seeming diurnal

Polar Motion

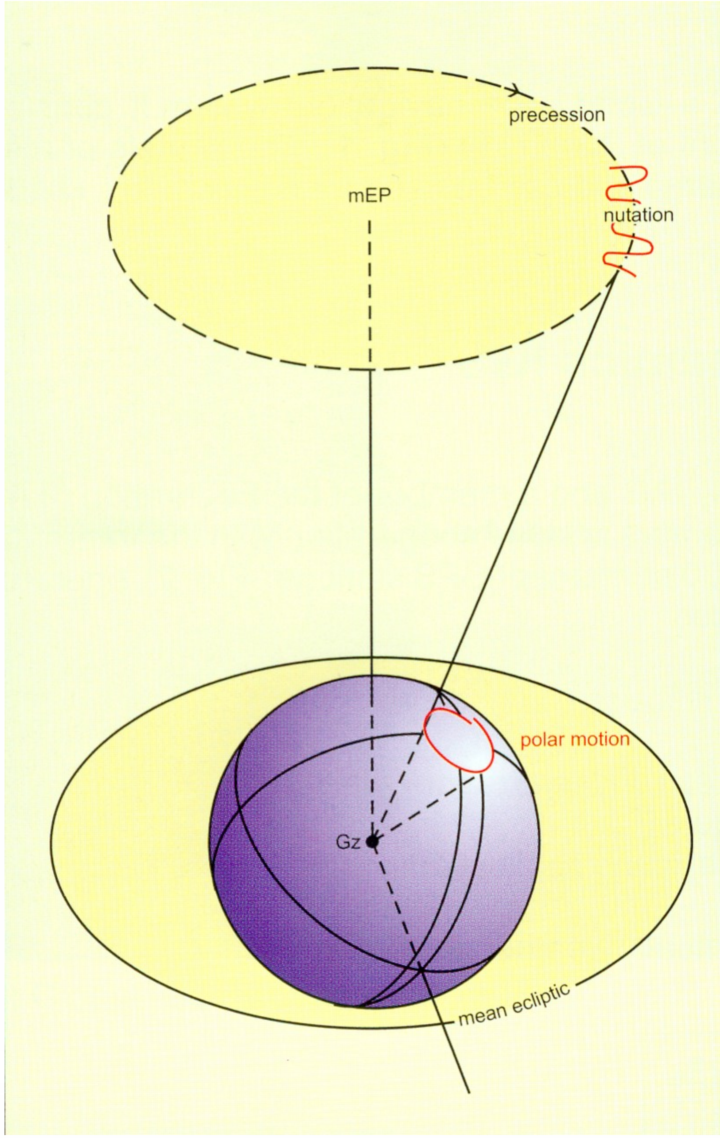
- x_p, y_p

Speed of Rotation

- LOD



Rotation of the Earth



Celestial Pole

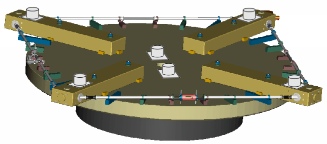
- Precession
  (18.6a, 9.3a, 1a, 0.5a, 13.7a)
- "Forced Nutation"
  seeming diurnal

Polar Motion

- x_p, y_p

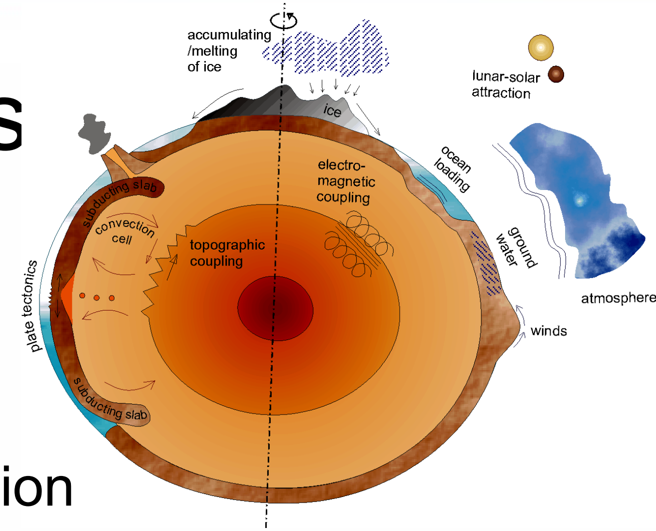
Speed of Rotation

- LOD



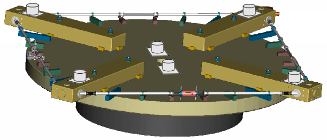
Introduction
Signals
Tides
Earth Rotation
Sagnac Signals
Hardware
Data
Stability
Meteorological effects
Seismology
Actual Stability
Conclusion
Outlook

Earth Rotation Changes



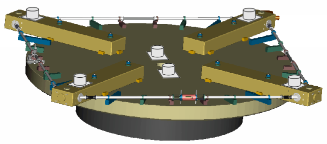
Mechanisms:

1. Angular momentum changes
   - Continuous decrease by tidal friction
   - External angular momentum ⇒ precession / forced nutation
   - Interaction between angular momentum and sub-systems
     - Rigid Earth ⇔ atmosphere, ocean, inner core
     - reversible
2. Moment of inertia changes
   - Relocation of masses (earth tides, barometric pressure, ocean, water, postglacial rebound, earthquakes)
3. Oscillation of rotation axis („free wobble“)
   - Figure axis und angular momentum axis not parallel
     ⇒ free nutation („Chandler wobble“, „free core nutation“)



Wherefore observations of Earth rotation?

- Generation and conservation of global reference frames for exact positioning on earth and in space
- Transformation between earth-fixed and space-fixed reference frames
- Astrometry, Astronomy
- Space travel, business of Satellites
- Navigation
- Understanding of global geophysical phenomena, model validation



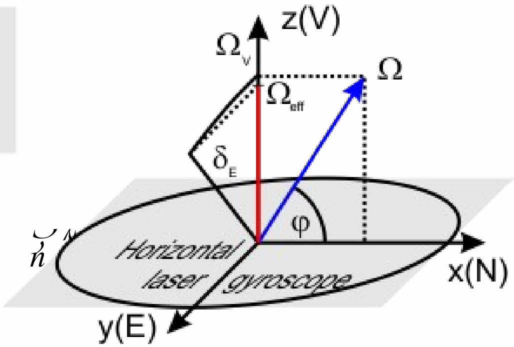
Sagnac Signal

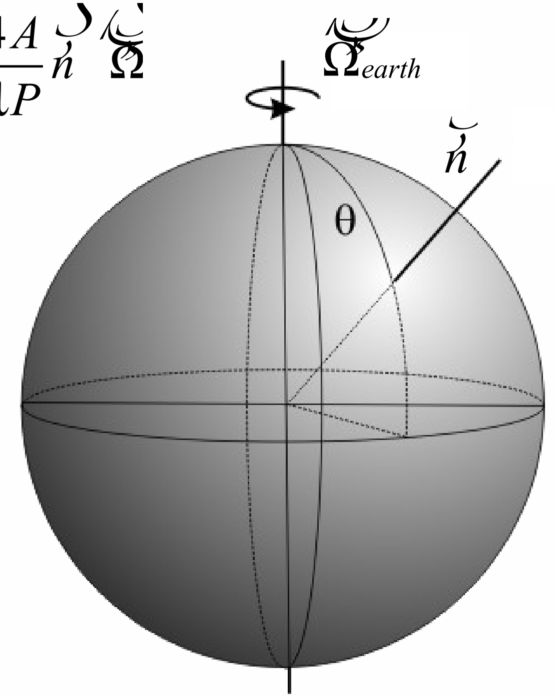
Introduction
Signals
Tides
Earth Rotation
Sagnac Signals
Hardware
Data
Stability
Meteorological effects
Seismology
Actual Stability
Conclusion
Outlook

Measurement $\Delta f = \frac{4A}{\lambda P}\vec{n}\cdot\vec{\Omega} + f_{nr}$

$$\vec{n}\cdot\vec{\Omega} = \Omega\cos(\varphi - \theta)$$

$$\delta f = \frac{4A}{\lambda P}\vec{n}\cdot\delta\vec{\Omega}$$

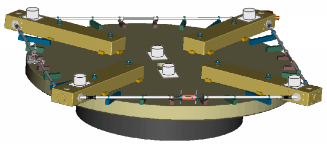




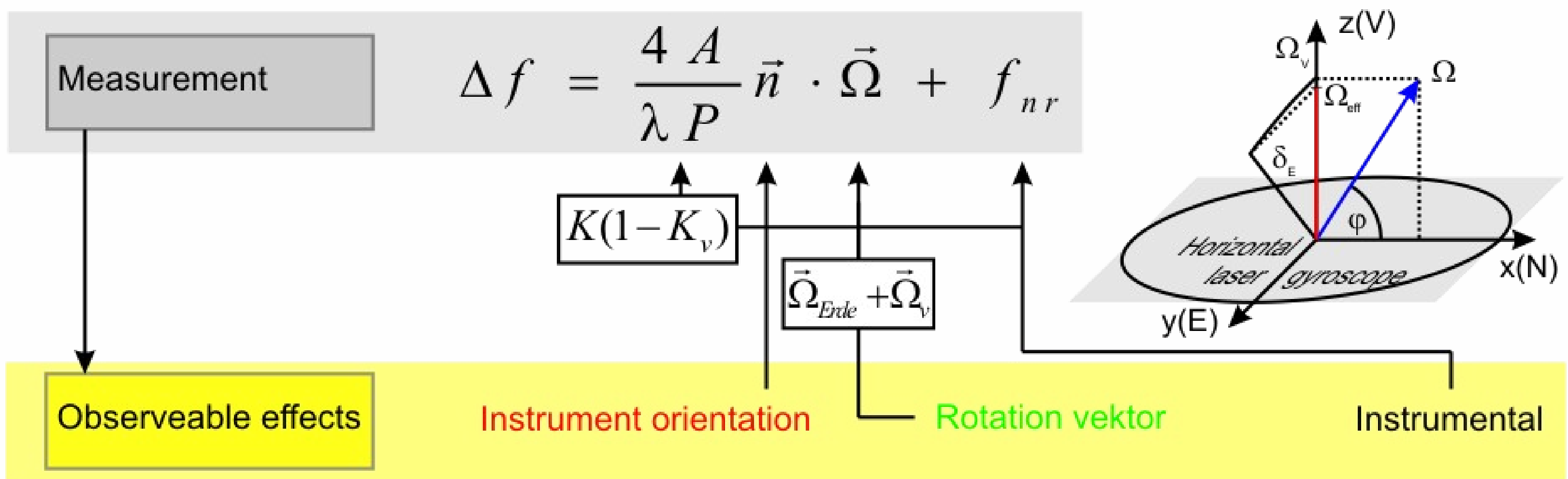
$$\vec{n}\cdot\vec{\Omega} = \Omega\cos(\varphi - 90 - 49.145)$$

$$\vec{\Omega} = \vec{\Omega}_{global} + \vec{\Omega}_{local}$$

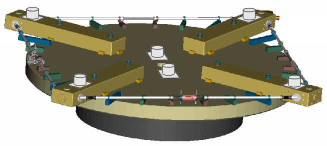
$$\vec{n}\cdot\vec{\Omega} = \Omega\cos(\varphi - 90) \quad \theta \quad \delta f$$



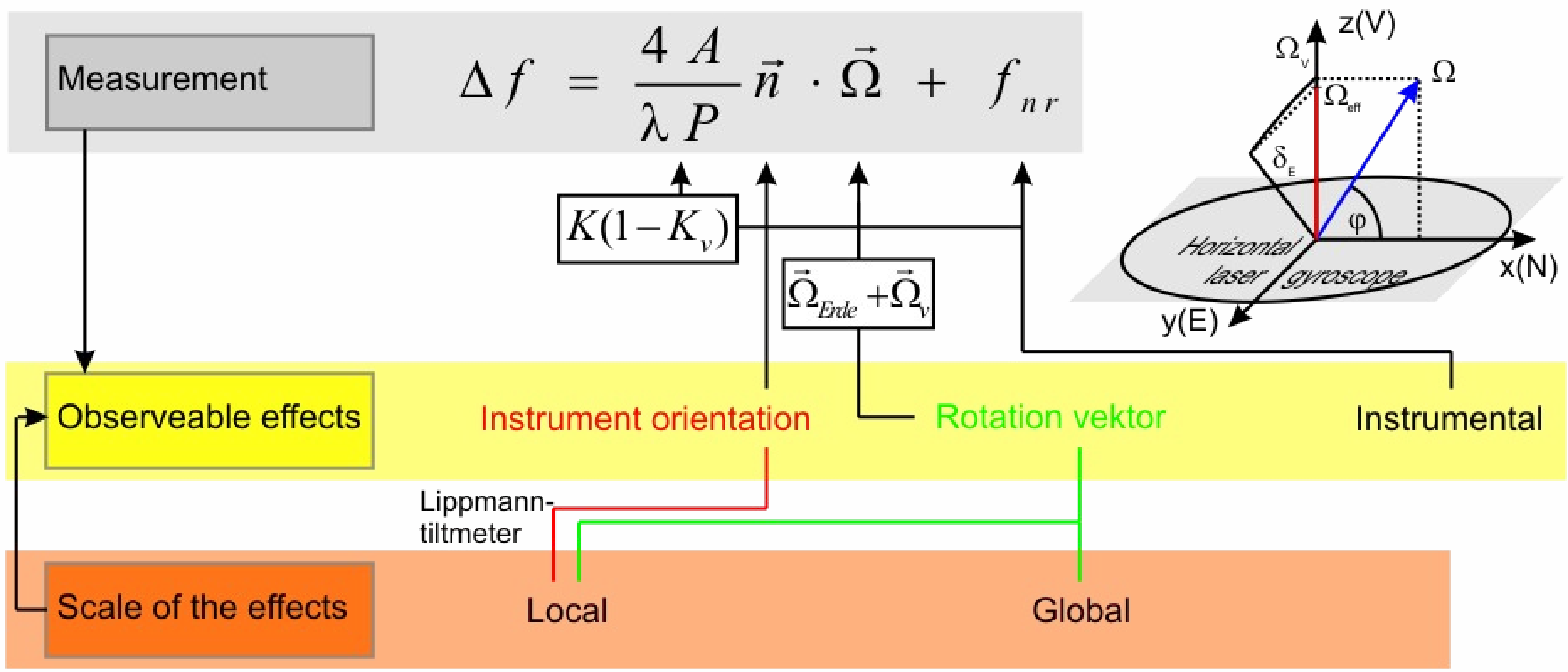
Sagnac Signal

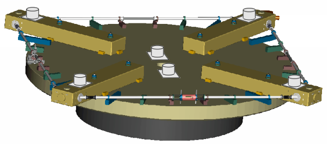


Introduction
Signals
Tides
Earth Rotation
Sagnac Signals
Hardware
Data
Stability
Meteorological effects
Seismology
Actual Stability
Conclusion
Outlook



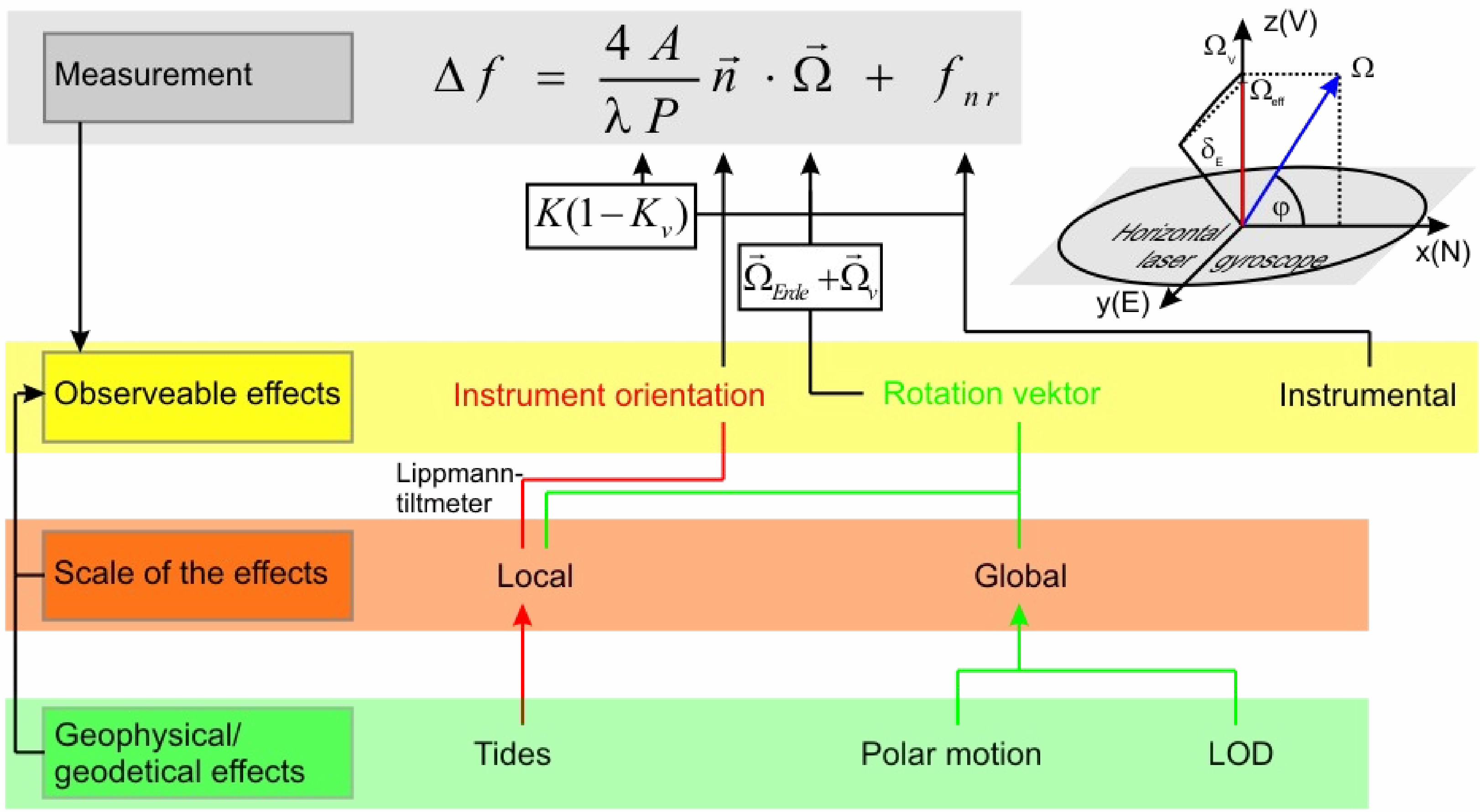
Sagnac Signal

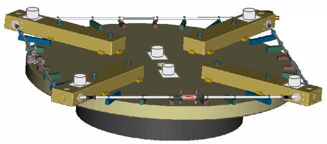




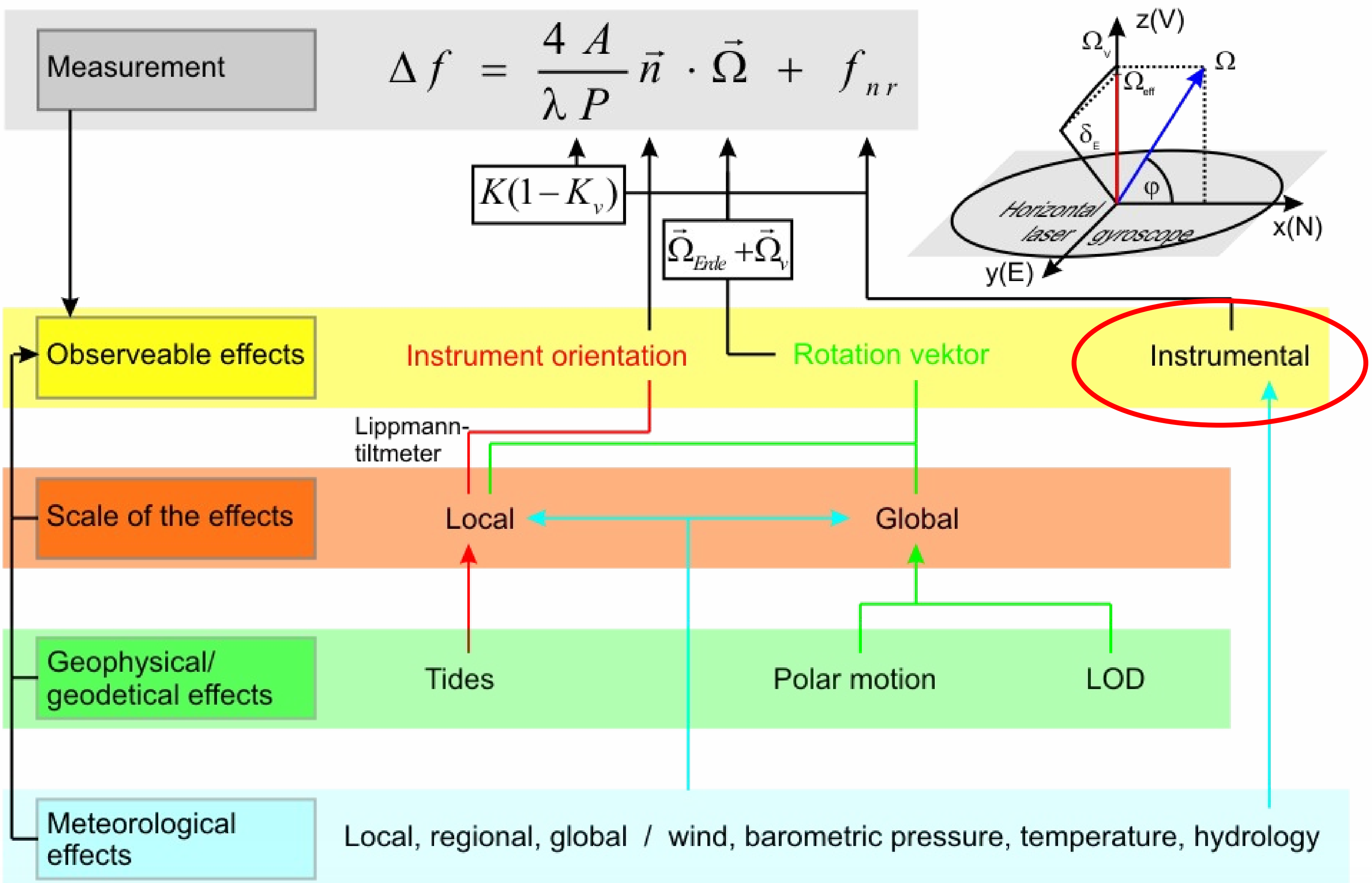
Sagnac Signal

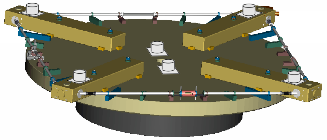
Introduction
Signals
Tides
Earth Rotation
Sagnac Signals
Hardware
Data
Stability
Meteorological effects
Seismology
Actual Stability
Conclusion
Outlook



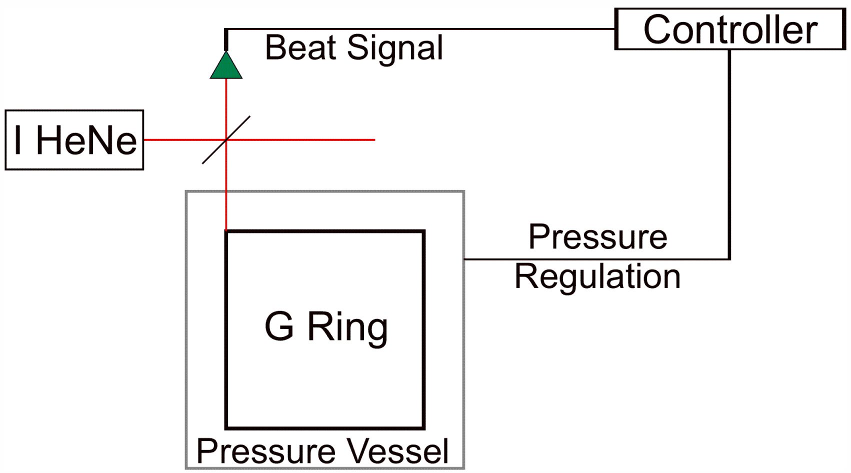


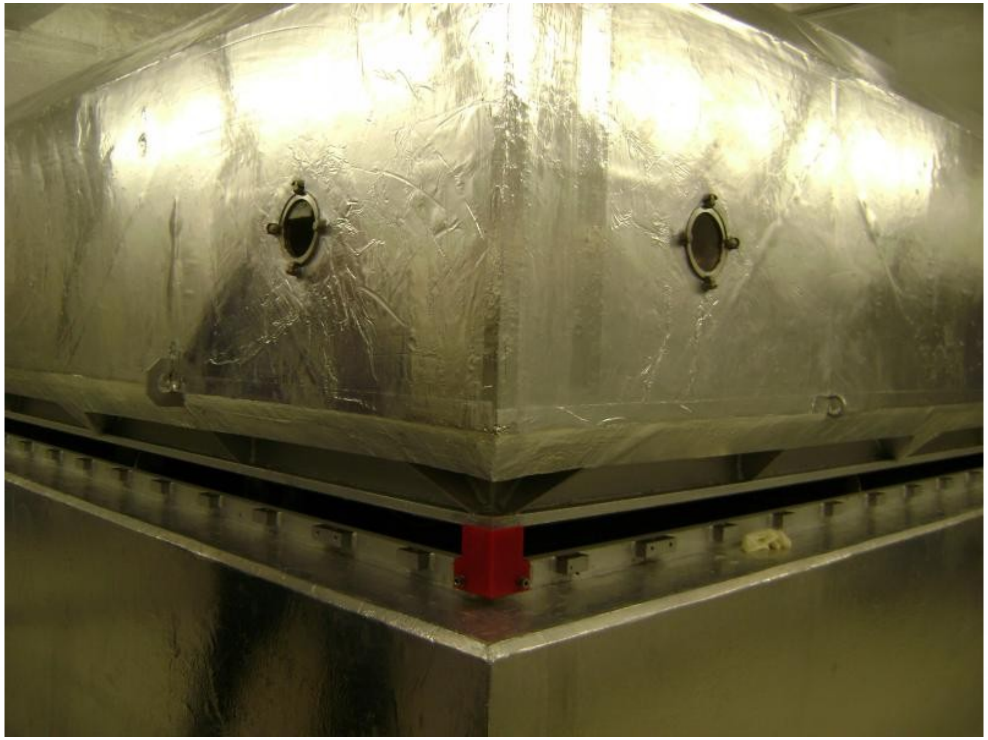
Sagnac Signal

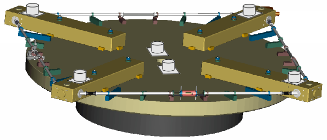




Hardware Update – pressure regulation



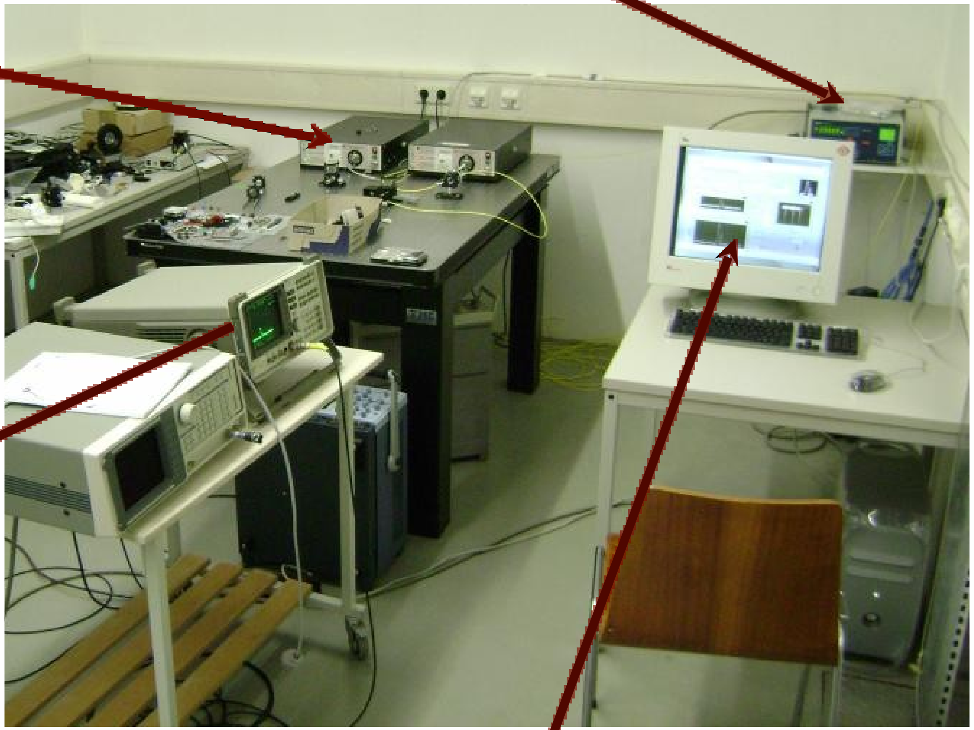


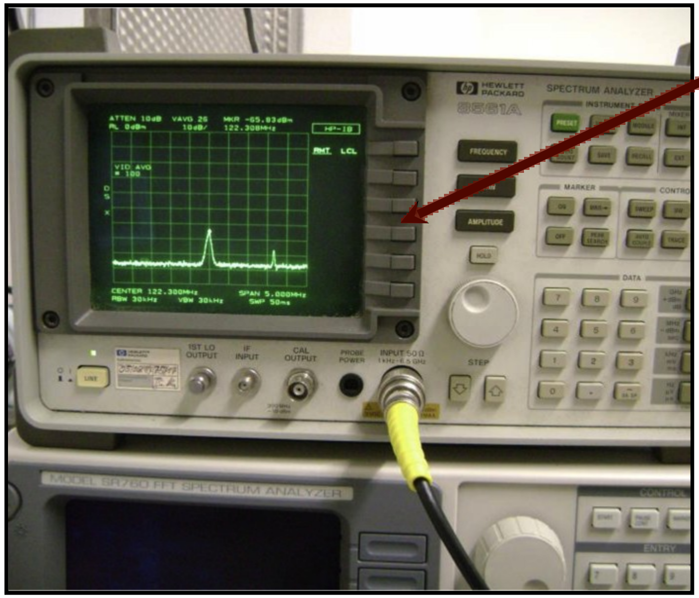


Hardware Update – pressure regulation

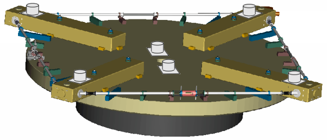
Pressure Regulator

Iodine stab. Laser





Feedback System



Introduction
Signals
Tides
Earth Rotation
Sagnac Signals
Hardware
Data
Stability
Meteorological effects
Seismology
Actual Stability
Conclusion
Outlook

Hardware Updates

$$\Delta f = \frac{4A}{\lambda P} n \cdot \Omega + f_{nr}$$

=const (4A=const)
Pressure regulation

f_{nr1} = const
Digital power control

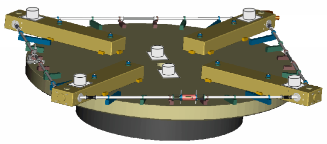
Avoid changes by barometric pressure and temperature.

Avoid drift of the Sagnac-Frequency

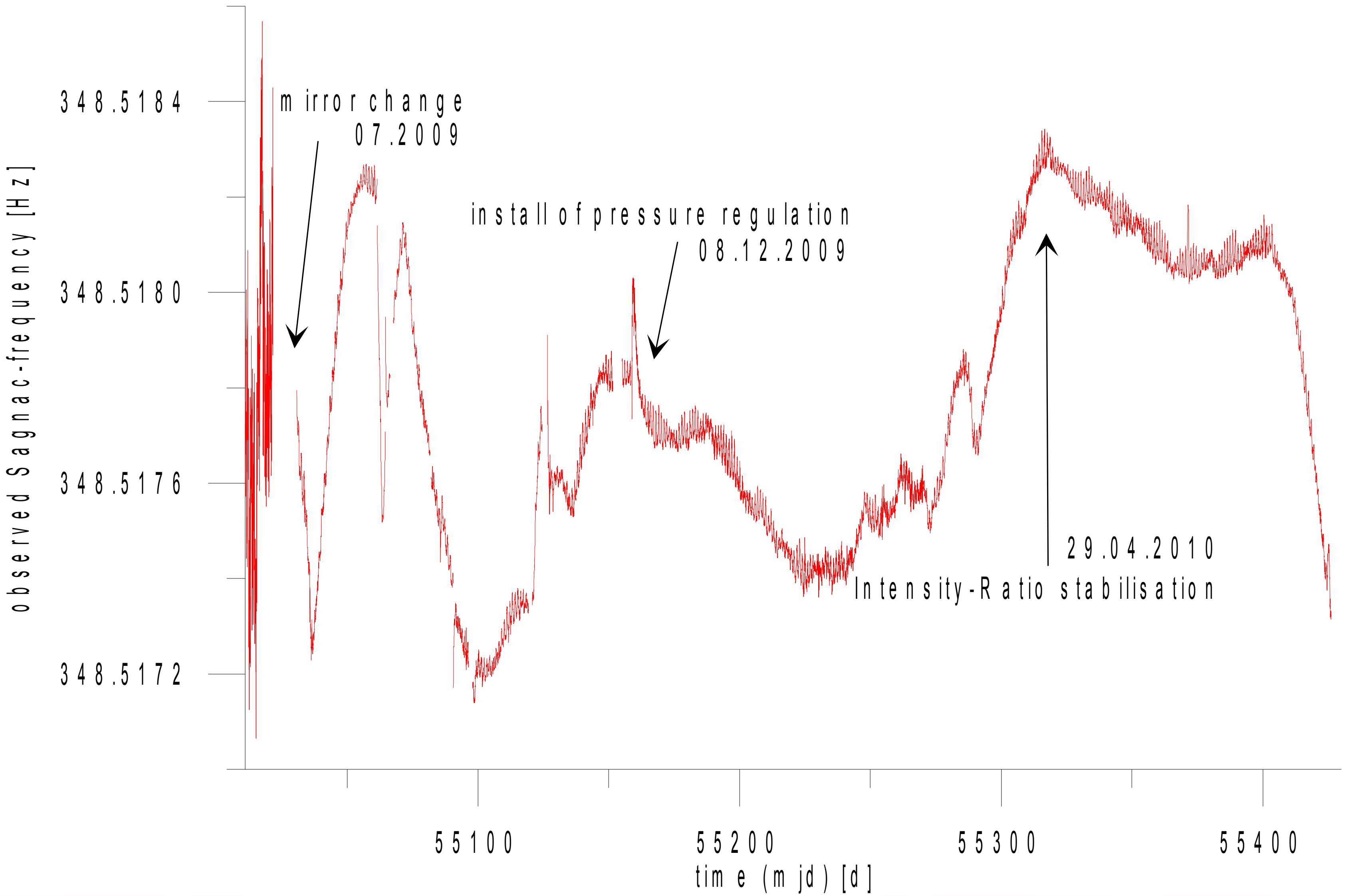
$f_{nr2} \neq$ const
Backscatter

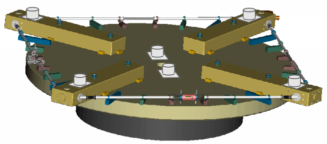
→ Actual stability ~ 10^{-8}–10^{-9}

→ Intended stability in scale factor 10^{-10}

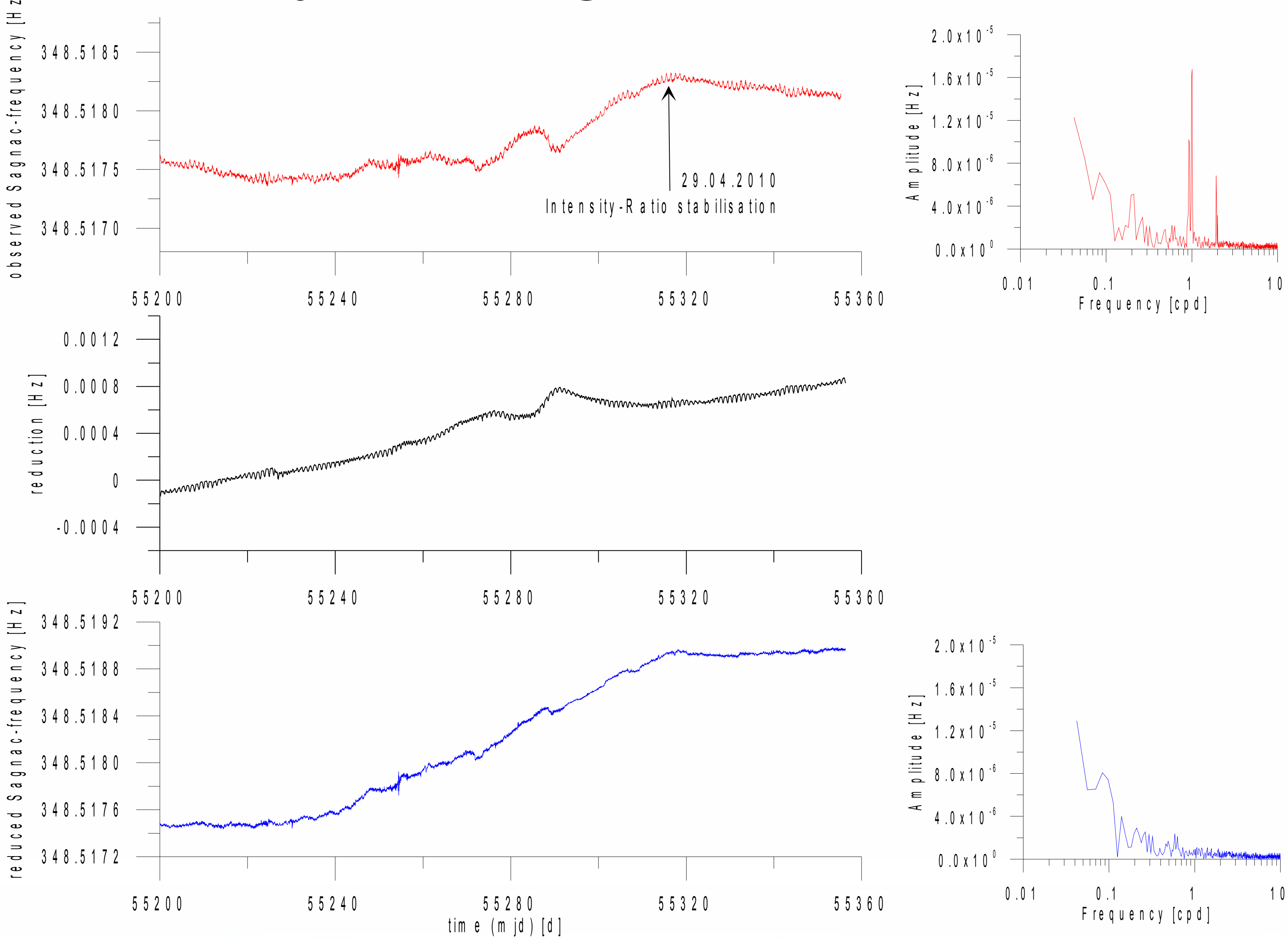


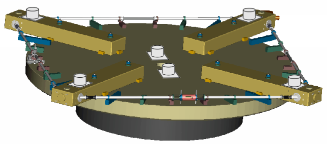
Sagnac Signal



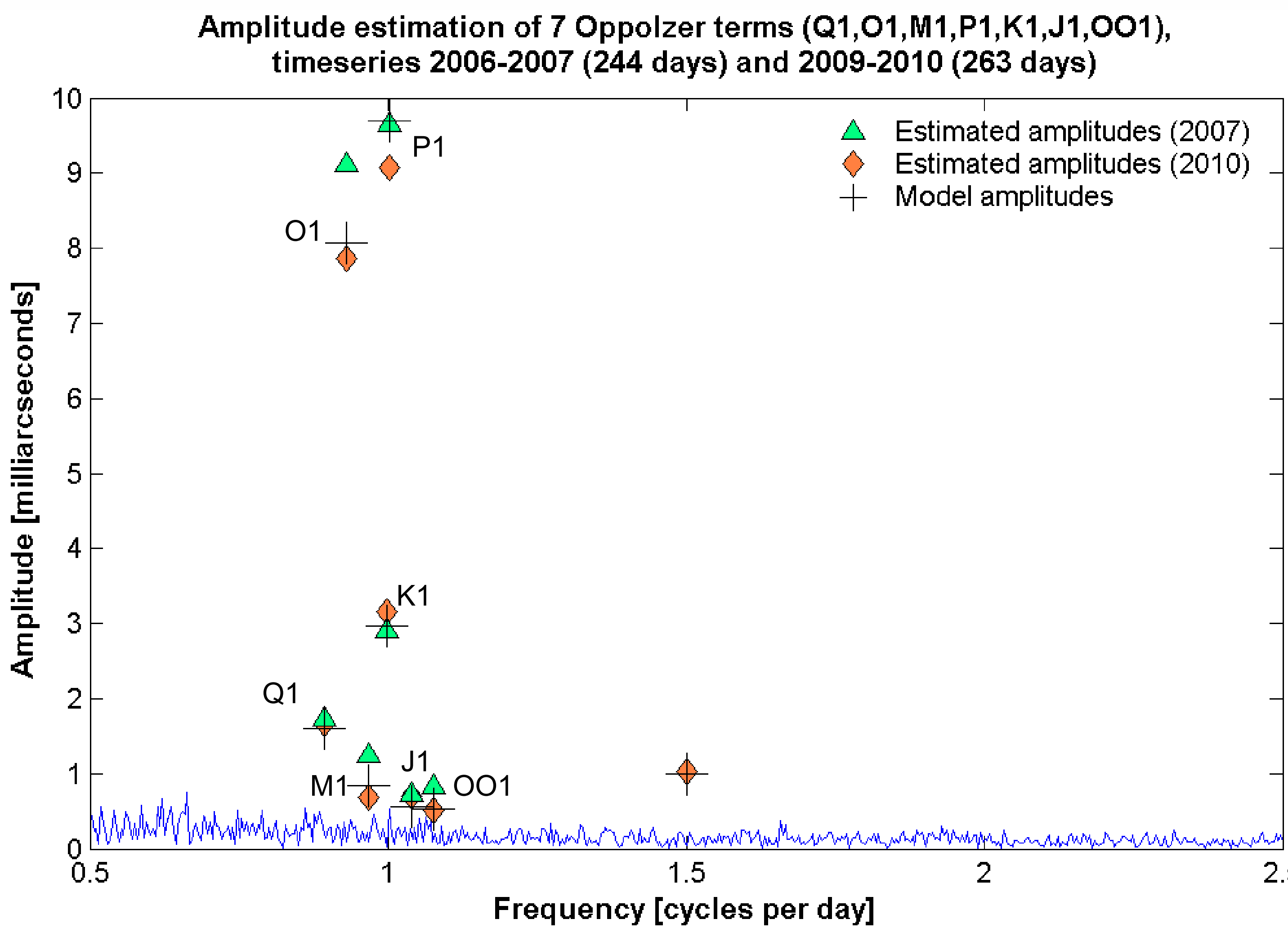


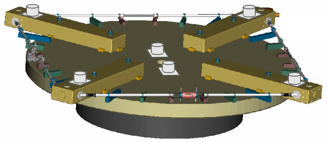
Geophysical Signals



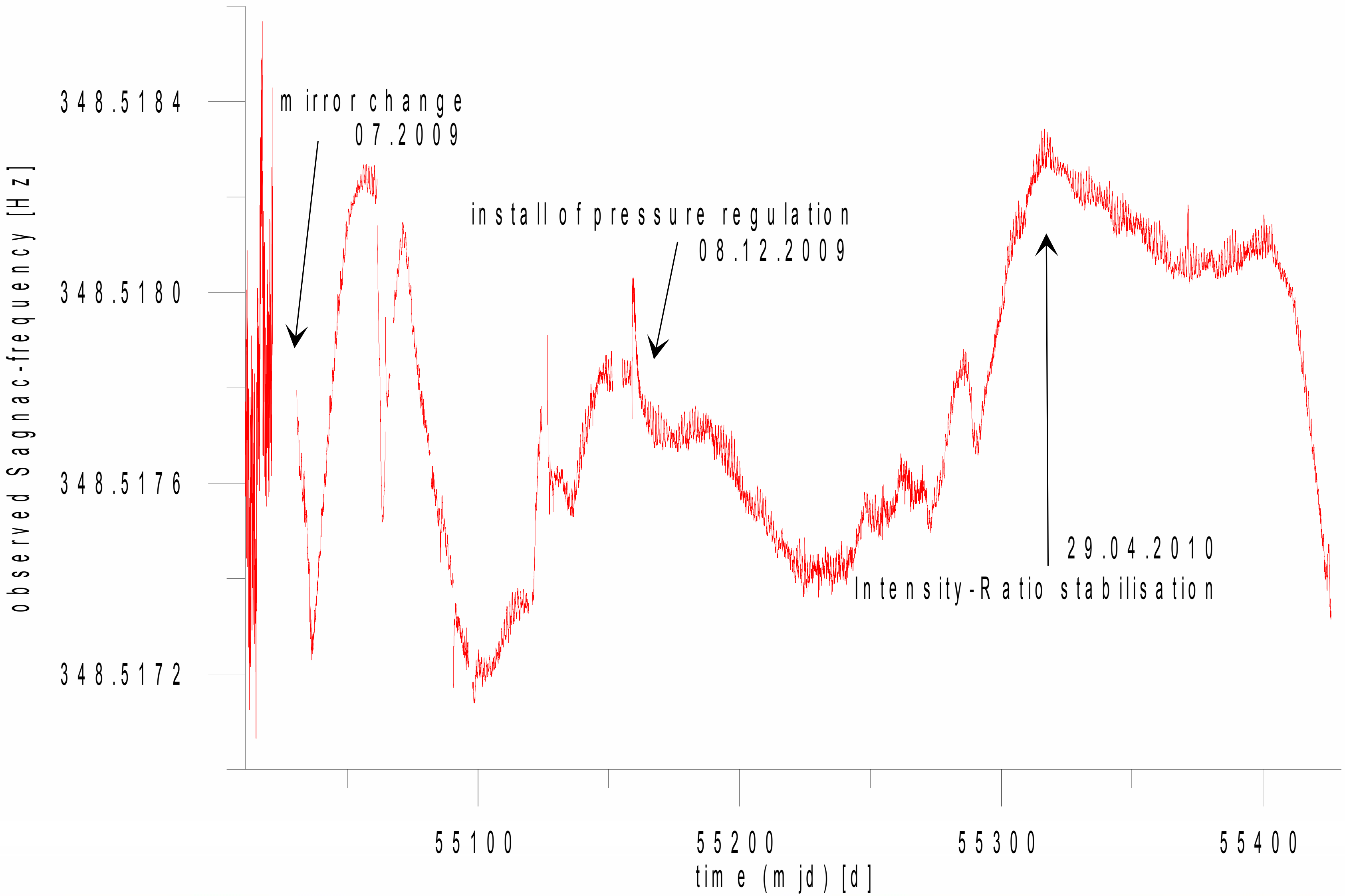


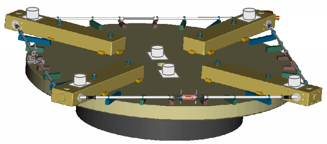
Polar Motion



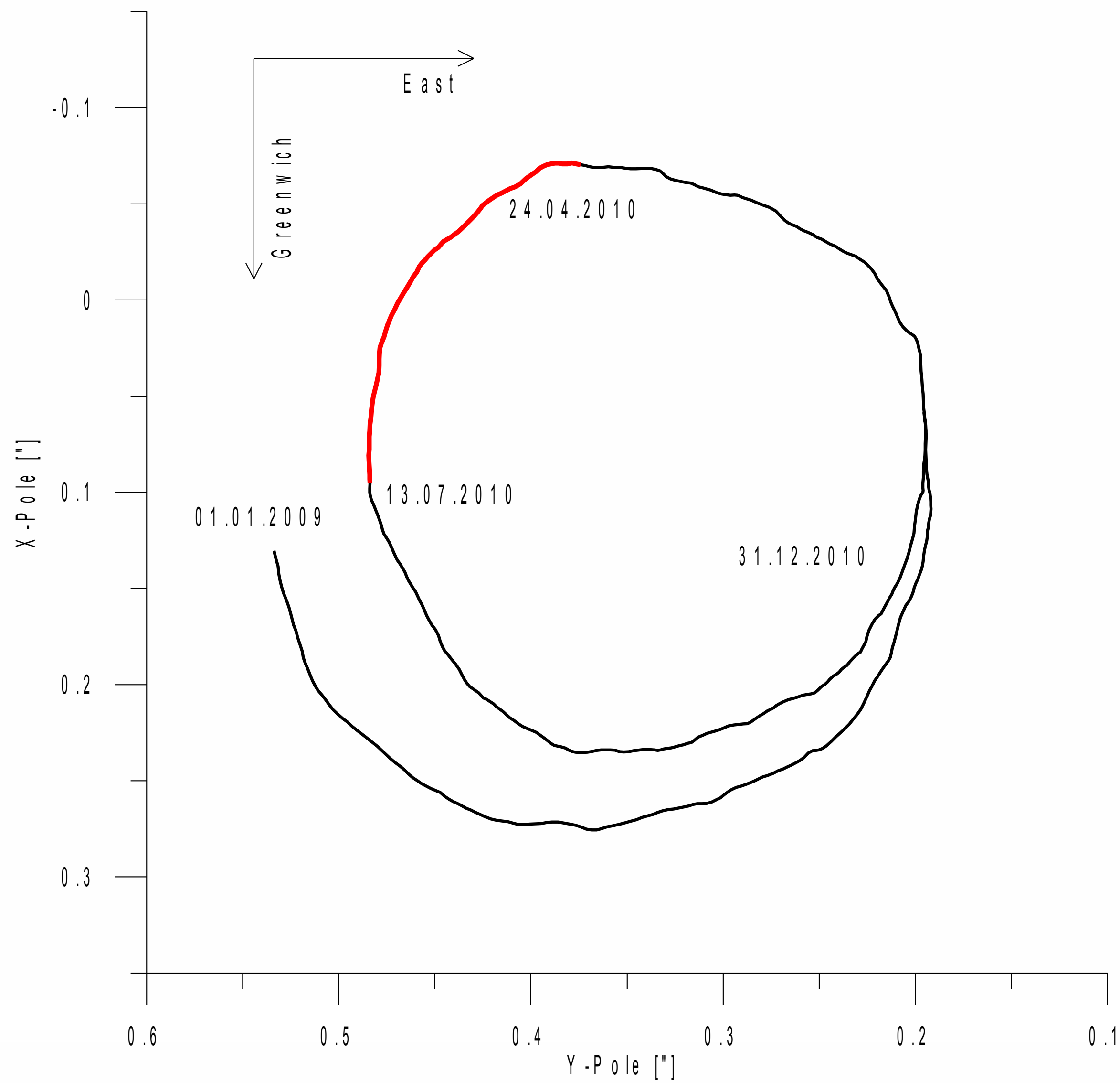


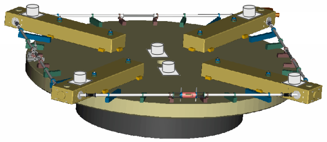
Sagnac Signal – Chandler/annual wooble



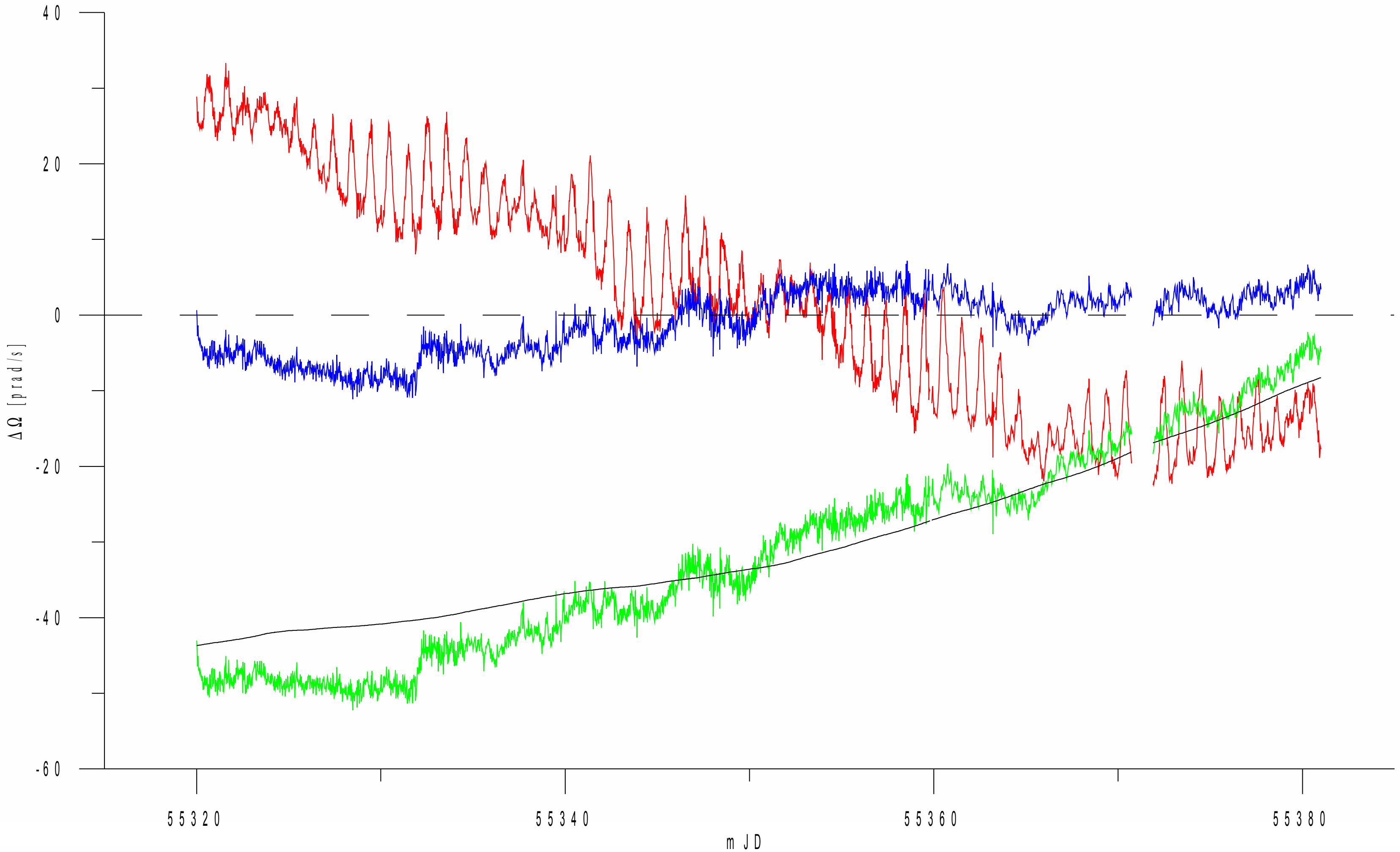


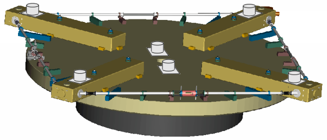
EOP (C04)


East
Greenwich
24.04.2010
13.07.2010
01.01.2009
31.12.2010
-0.1
0
0.1
0.2
0.3
X-Pole ["]
0.6
0.5
0.4
0.3
0.2
0.1
Y-Pole ["]



Chandler Wobble





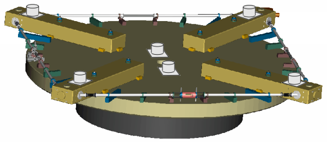
Long term Effects

- Periodic / Global effects well investigated:
  - Tidal tilt
  - Earth axis orientation changes (Oppolzer term)

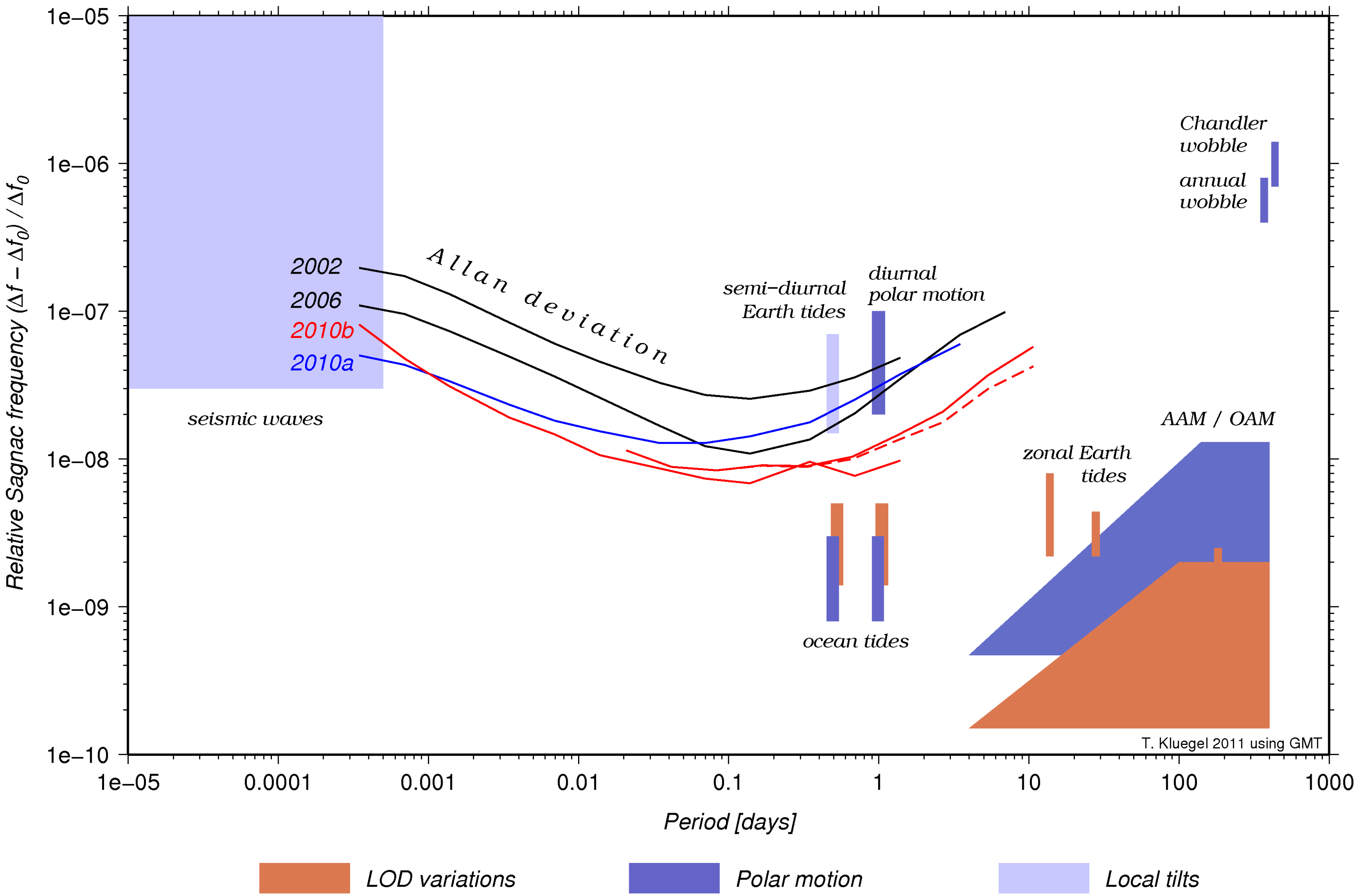
  → Models are working

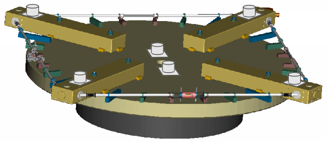
- Chandler Wooble is detected

- Several signatures in the data are still not understood

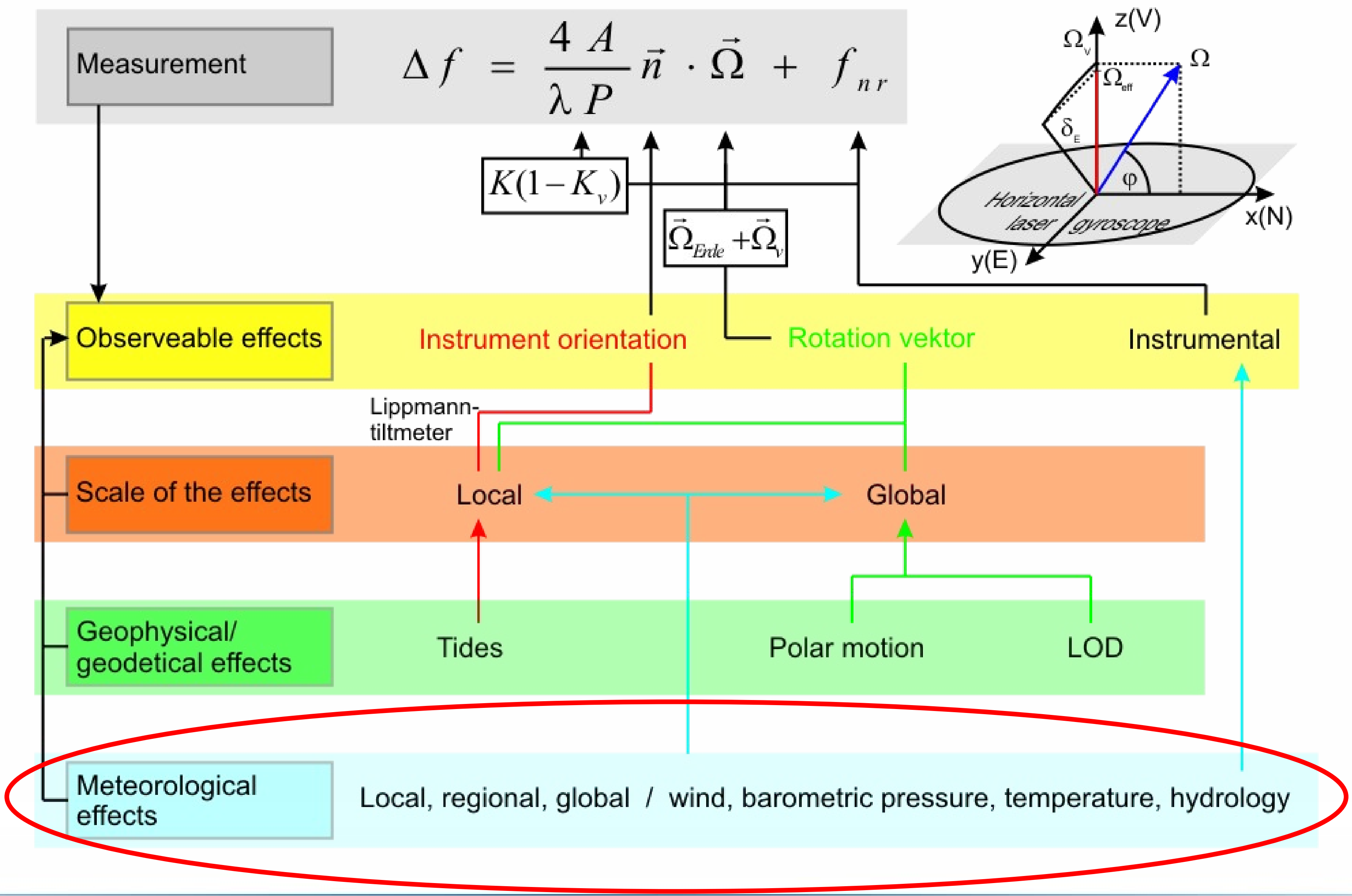


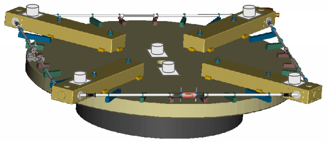
Ringlaser Stability





Meteorological effects

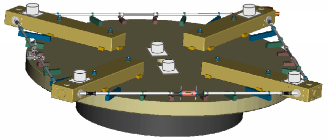




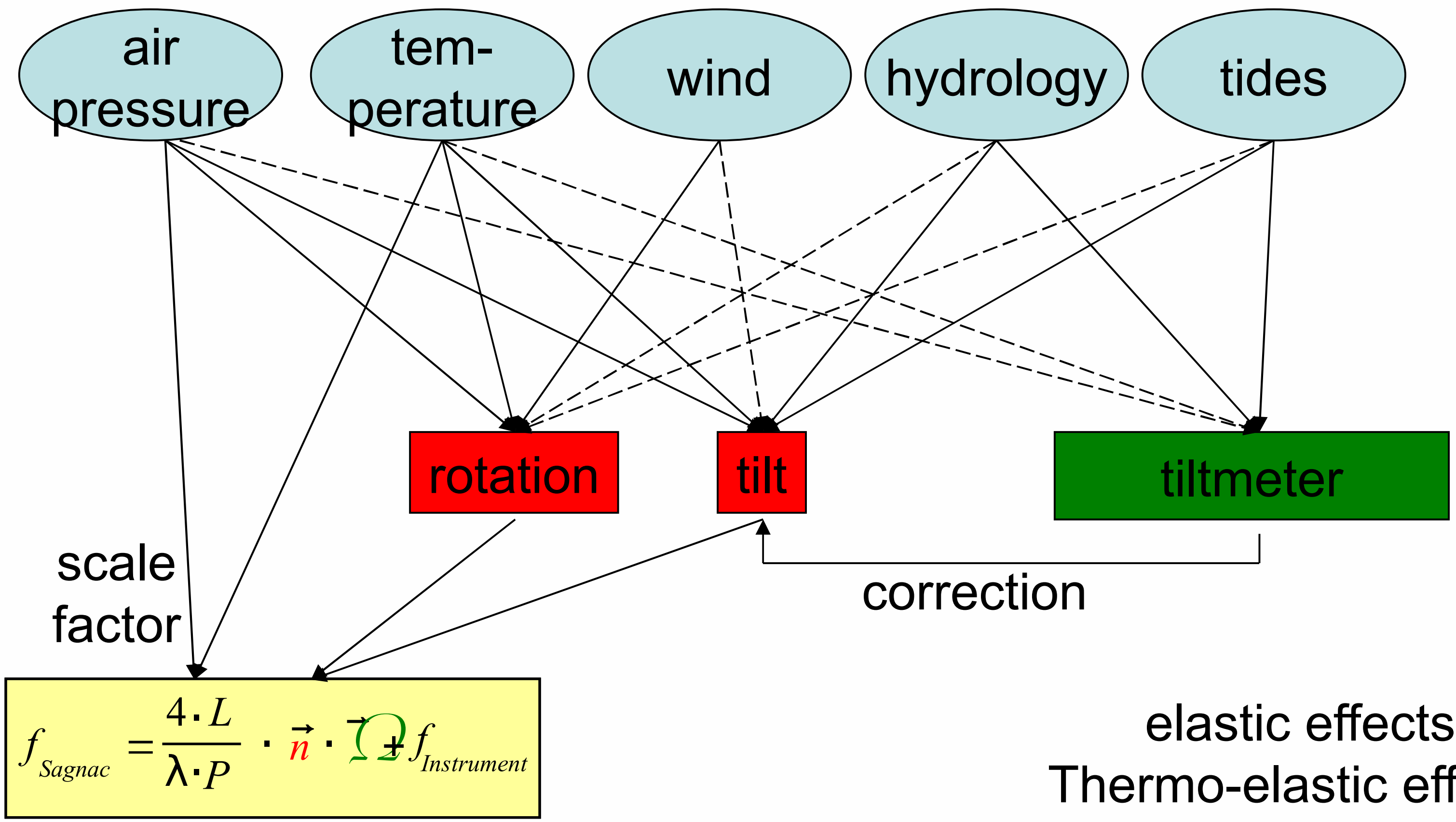
Meteorological effects

Possible forced by:

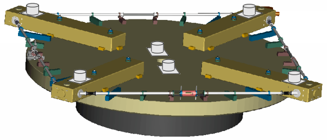
- Barometric pressure
- Temperature
- Hydrology
- Wind



Local (disturbing-) effects

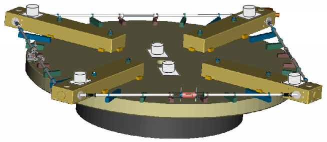


elastic effects
Thermo-elastic effects
Cavity effect
geological effects
Tilt-Strain-coupling



Local effects

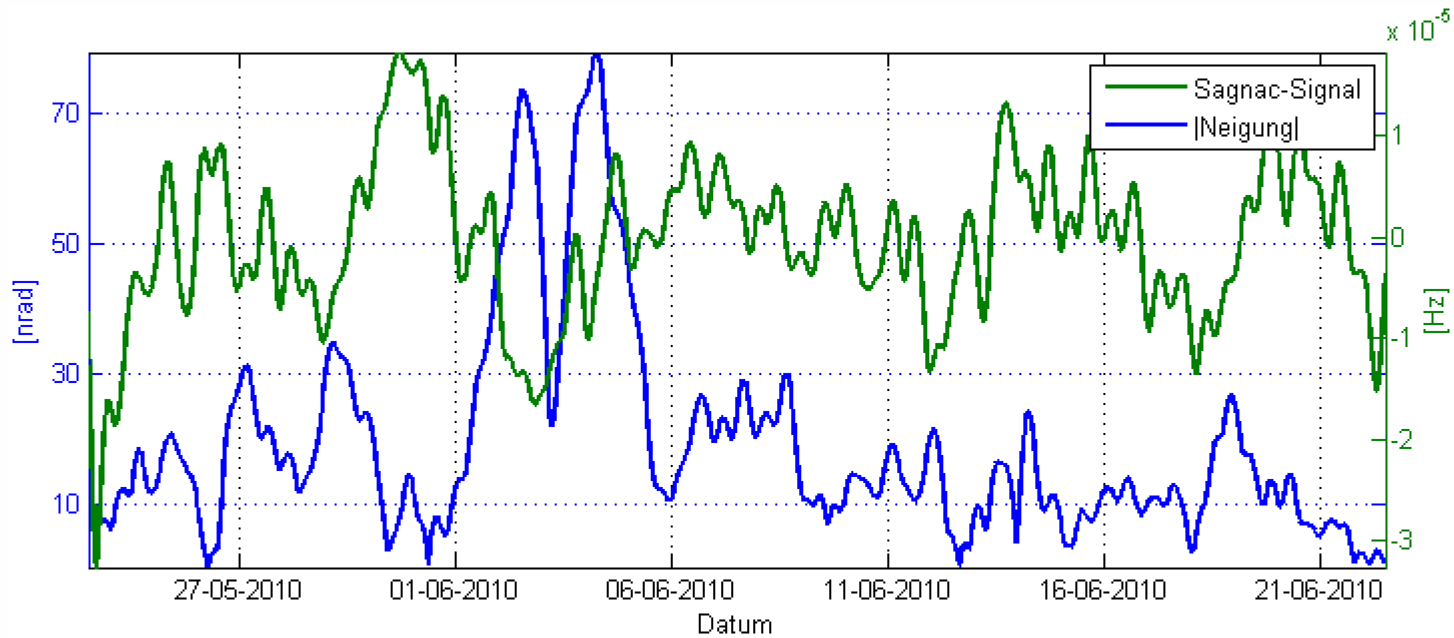
- Barometric pressure changes
- Temperature changes
- Ground water level changes
- Wind effects



Hydrological effects

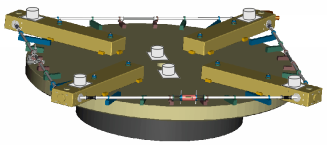
- Introduction
- Signals
- Tides
- Earth Rotation
- Sagnac Signals
- Hardware
- Data
- Stability
- **Meteorological effects**
- Seismology
- Actual Stability
- Conclusion
- Outlook

Can groundwater level changes cause rotations?



→ No

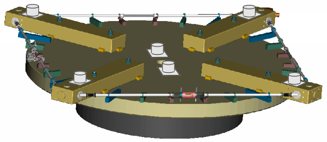
Stetter 2011



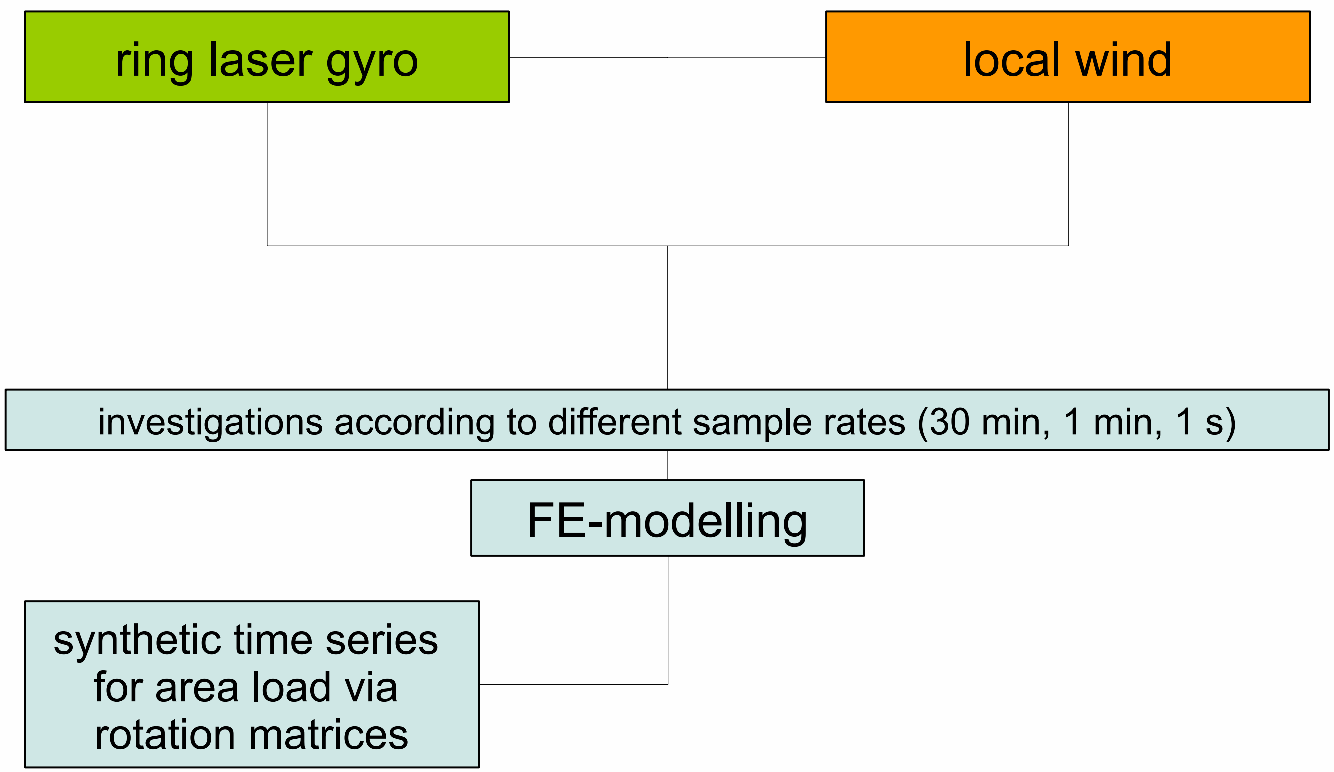
Local wind effects

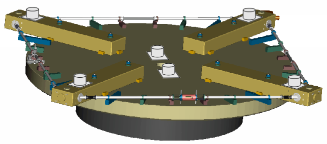
ring laser gyro — local wind

investigations according to different sample rates (30 min, 1 min, 1 s)

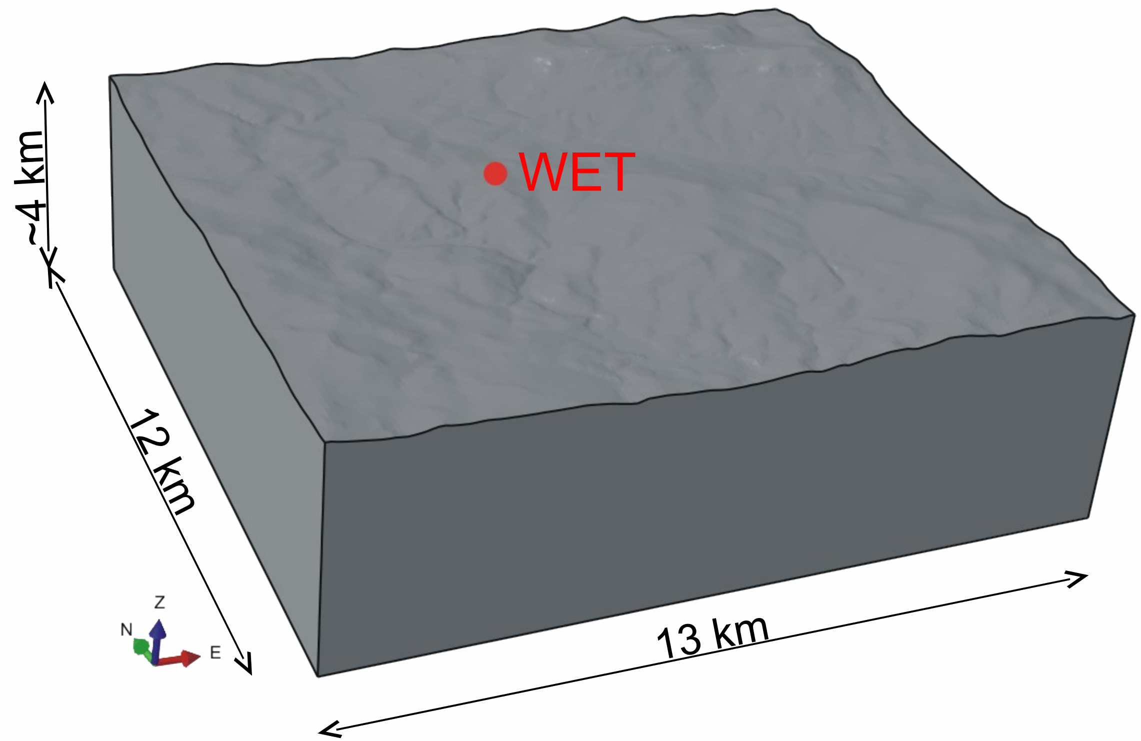


Local wind effects

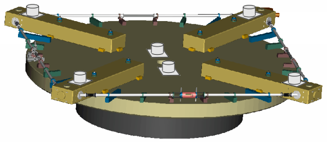




Local wind effects – FE-Model



Elastische Rheologie
2.7 mio. Tetraeder
Knoten basierende Last auf Oberfläche aus DGM und DLM

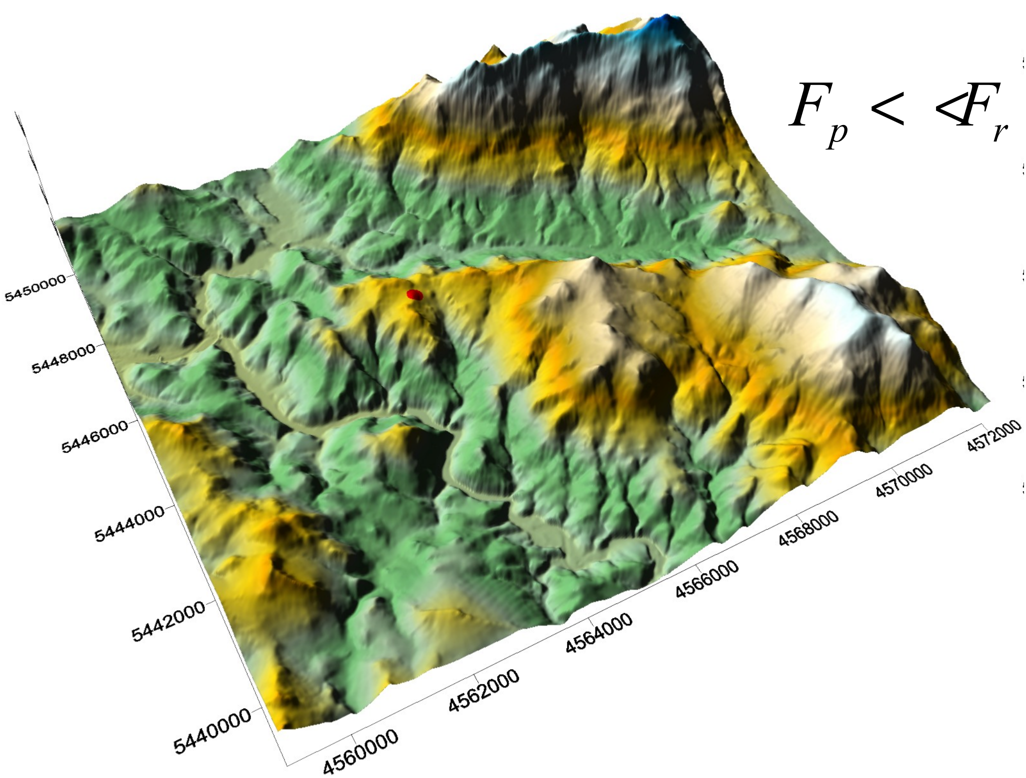


Local wind effects – FE-Model

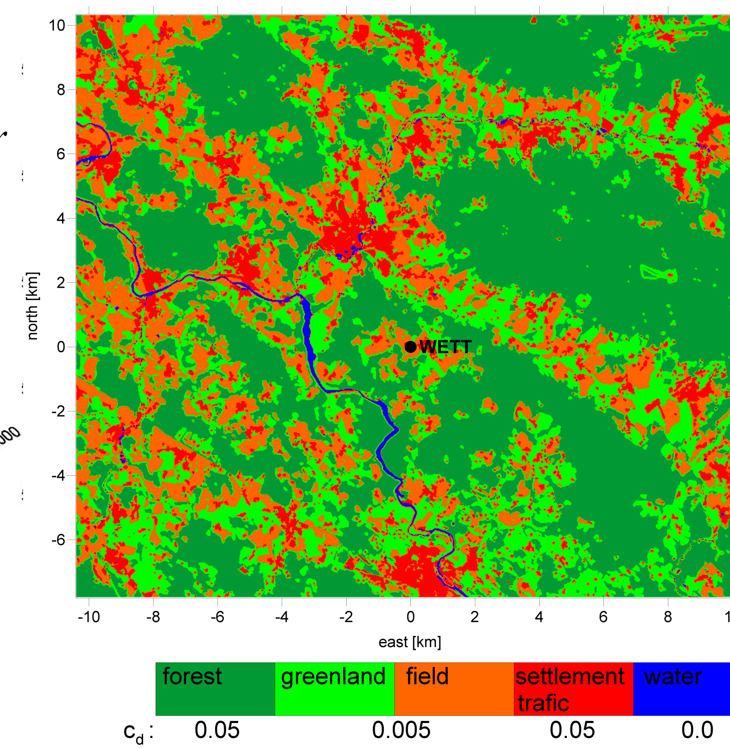
$$F_w(i,j) = F_{p(i,j)} + F_{r(i,j)}$$

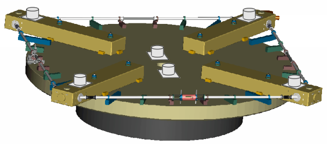
$$F_w(i,j) = \frac{\rho}{2} c_d v^2 A_{i,j} + \frac{\rho}{2} c_{d(i,j)} v^2 A_0$$

F_w -acting wind force
ρ -Air density (1.23 kg/m³)
c_d -‚drag coefficient'
v -wind velocity
A -wind loaded Area



$$F_p \ll F_r$$





Local wind effects – FE-Model

Introduction

Signals

Tides

Earth Rotation

Sagnac Signals

Hardware

Data

Stability

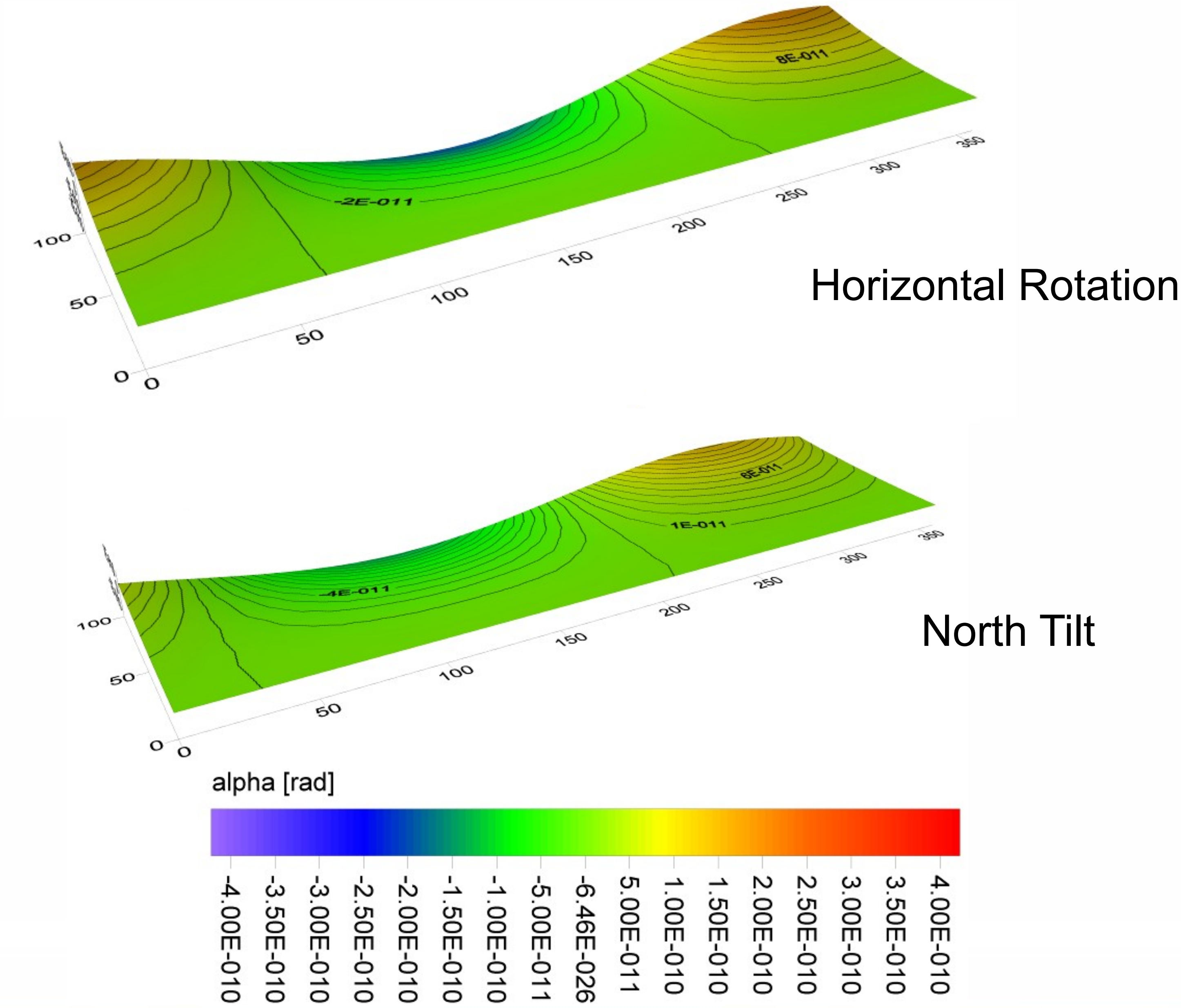
Meteorological effects

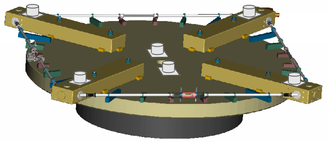
Seismology

Actual Stability

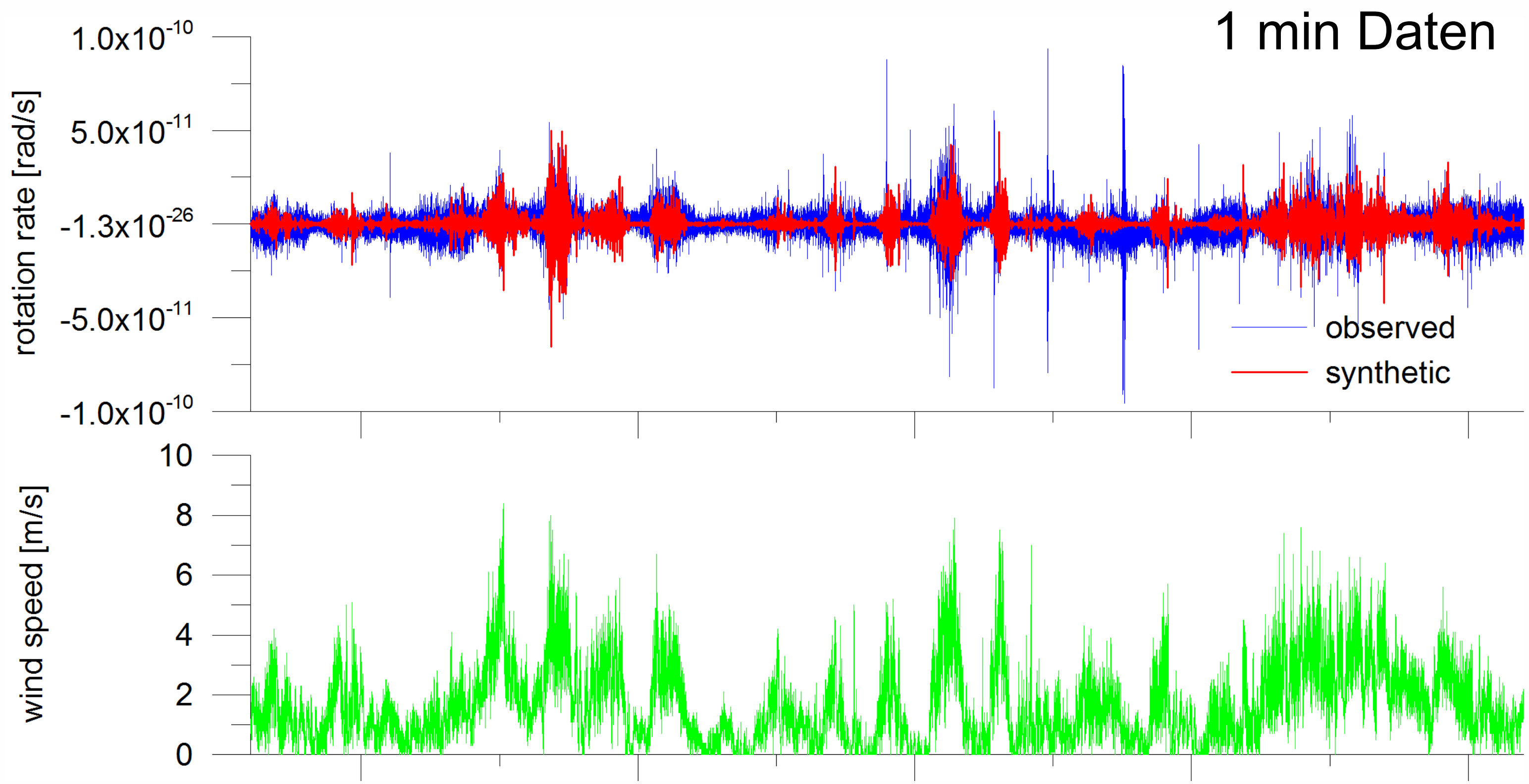
Conclusion

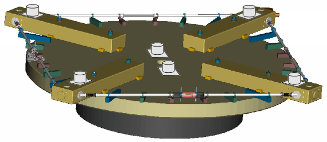
Outlook



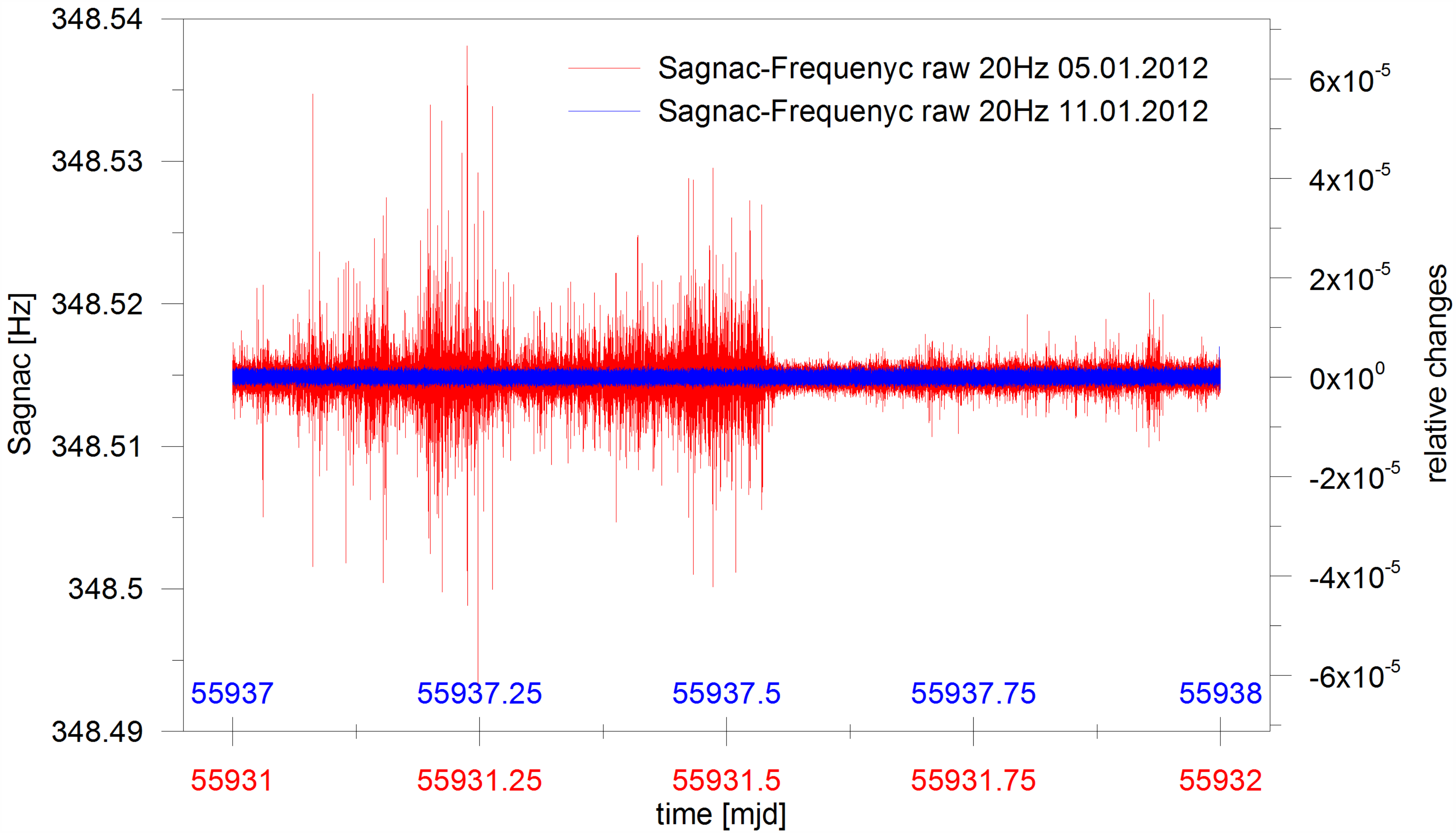


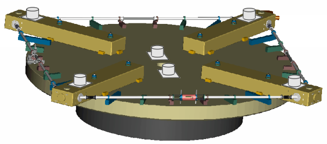
Local wind effects – FE-Model





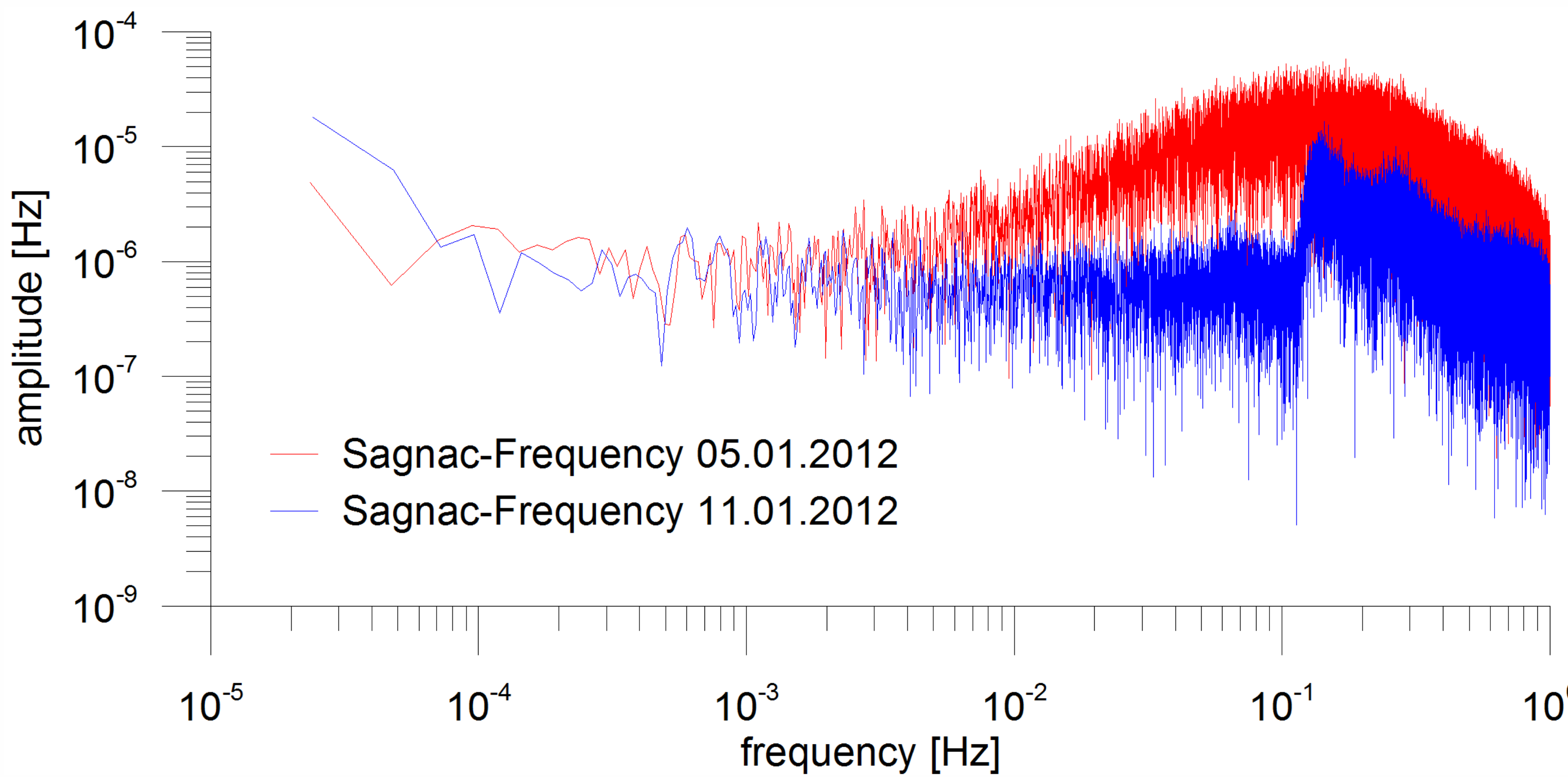
Local wind effects – 1 Sec. Data

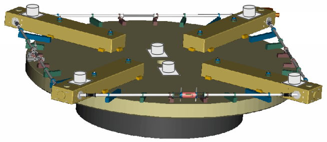




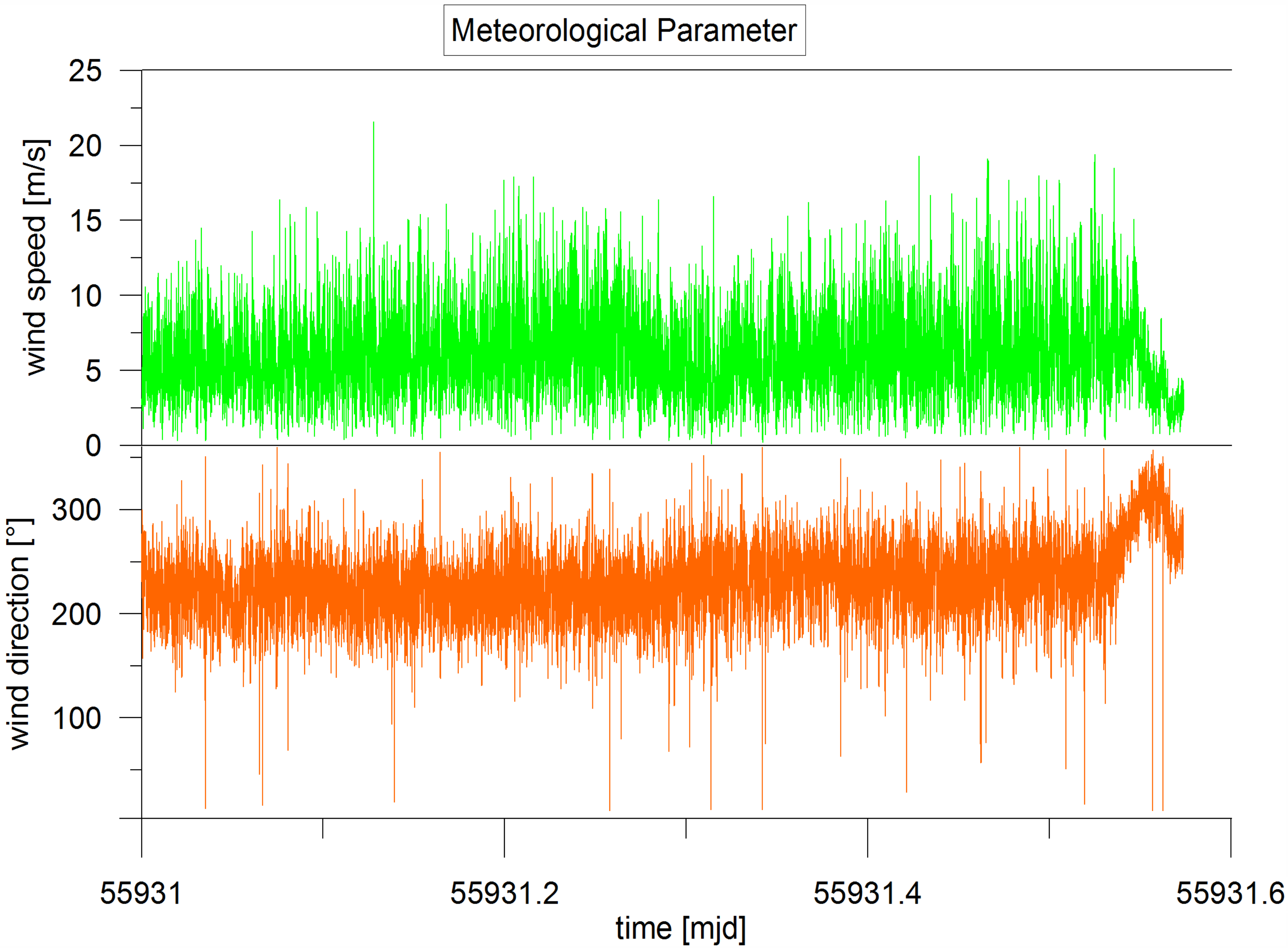
Local wind effects – 1 Sec. Data

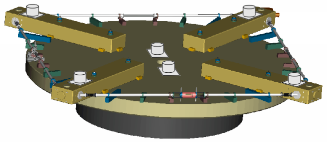
- Introduction
- Signals
- Tides
- Earth Rotation
- Sagnac Signals
- Hardware
- Data
- Stability
- **Meteorological effects**
- Seismology
- Actual Stability
- Conclusion
- Outlook



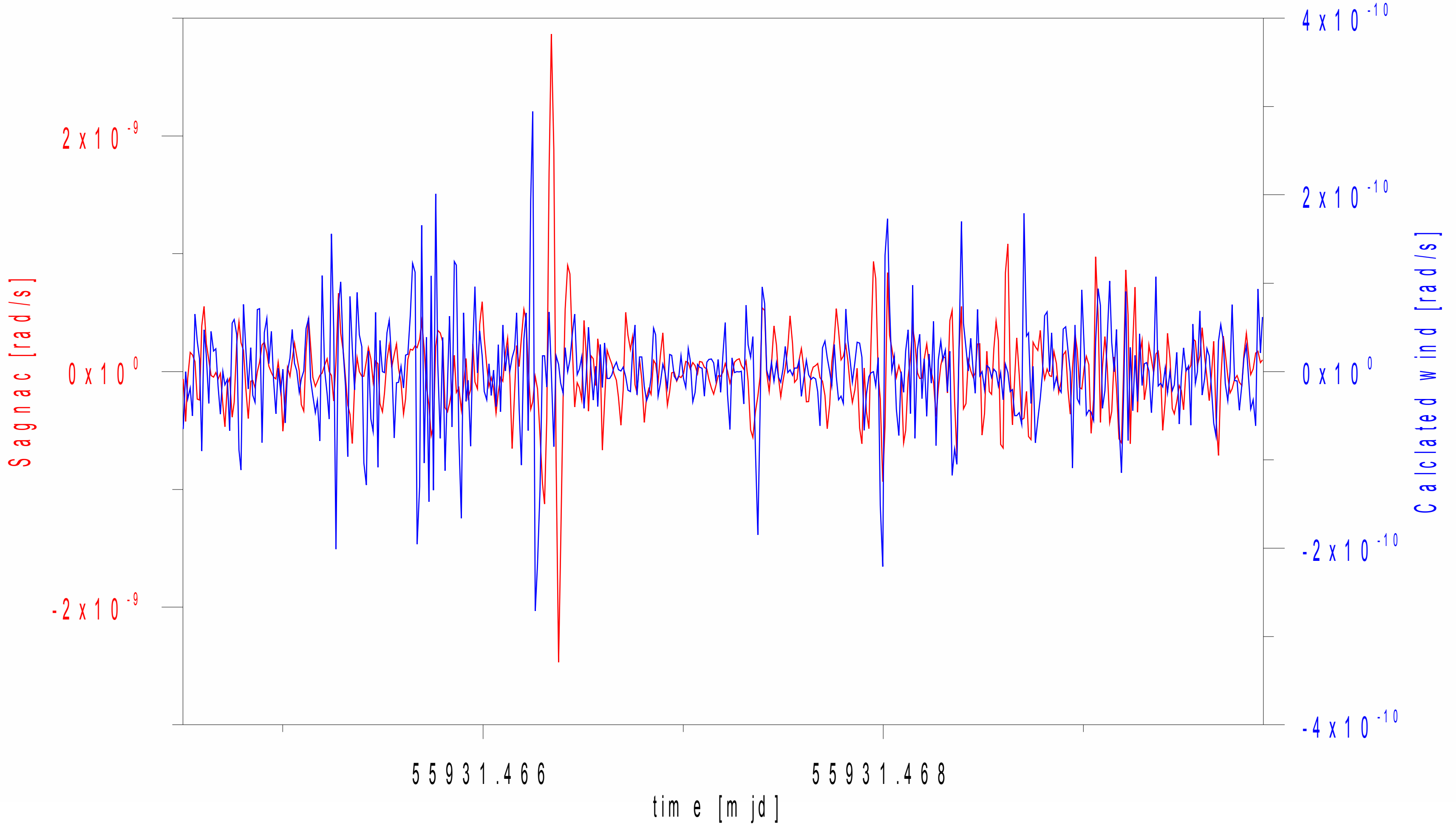


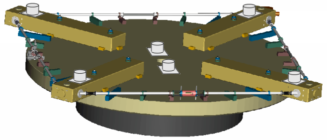
Local wind effects – 1 Sec. Data – Wind



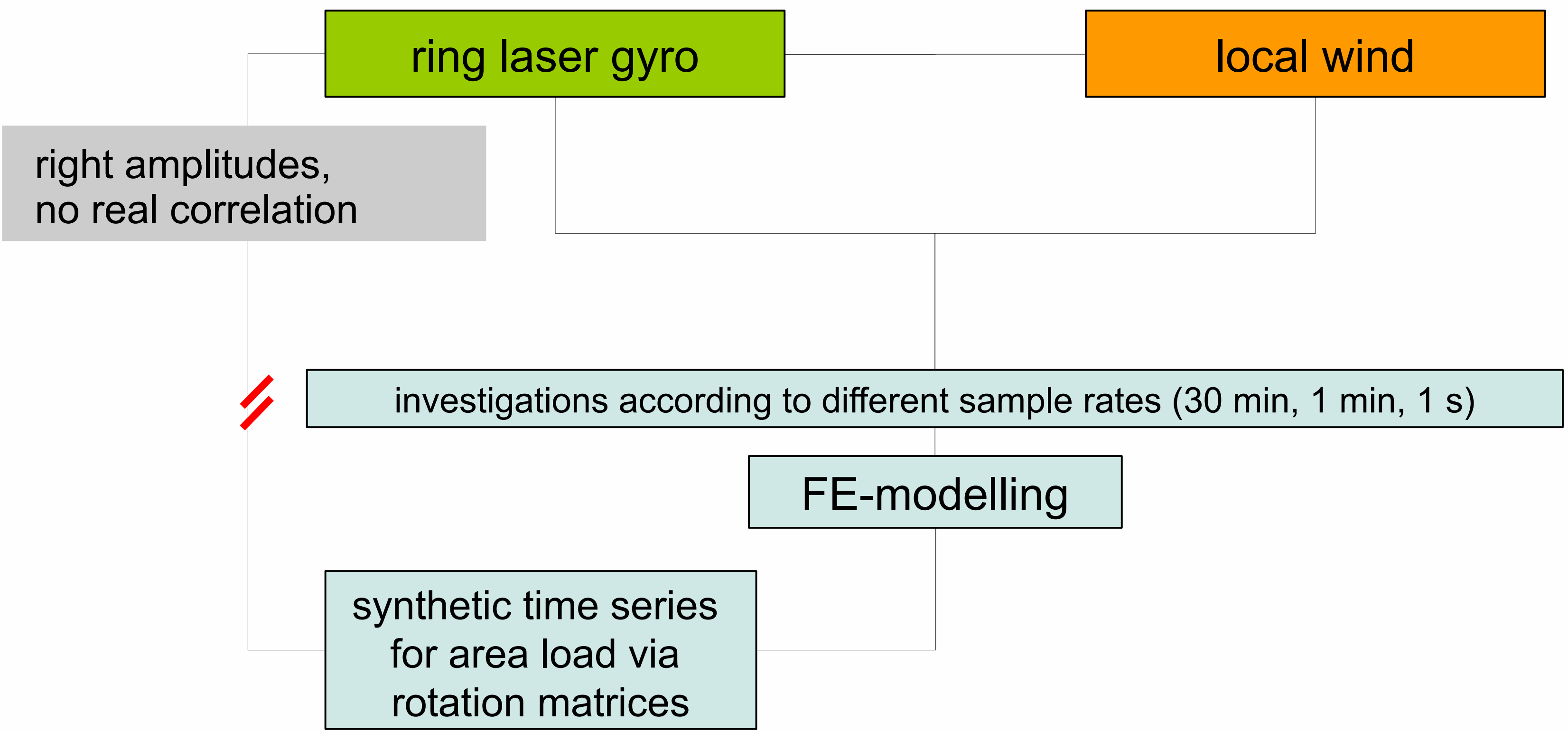


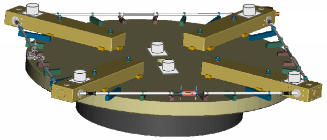
Local wind effects – 1 Sec. Data





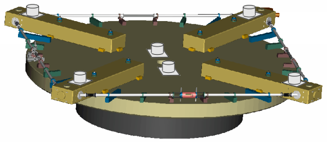
Local wind effects



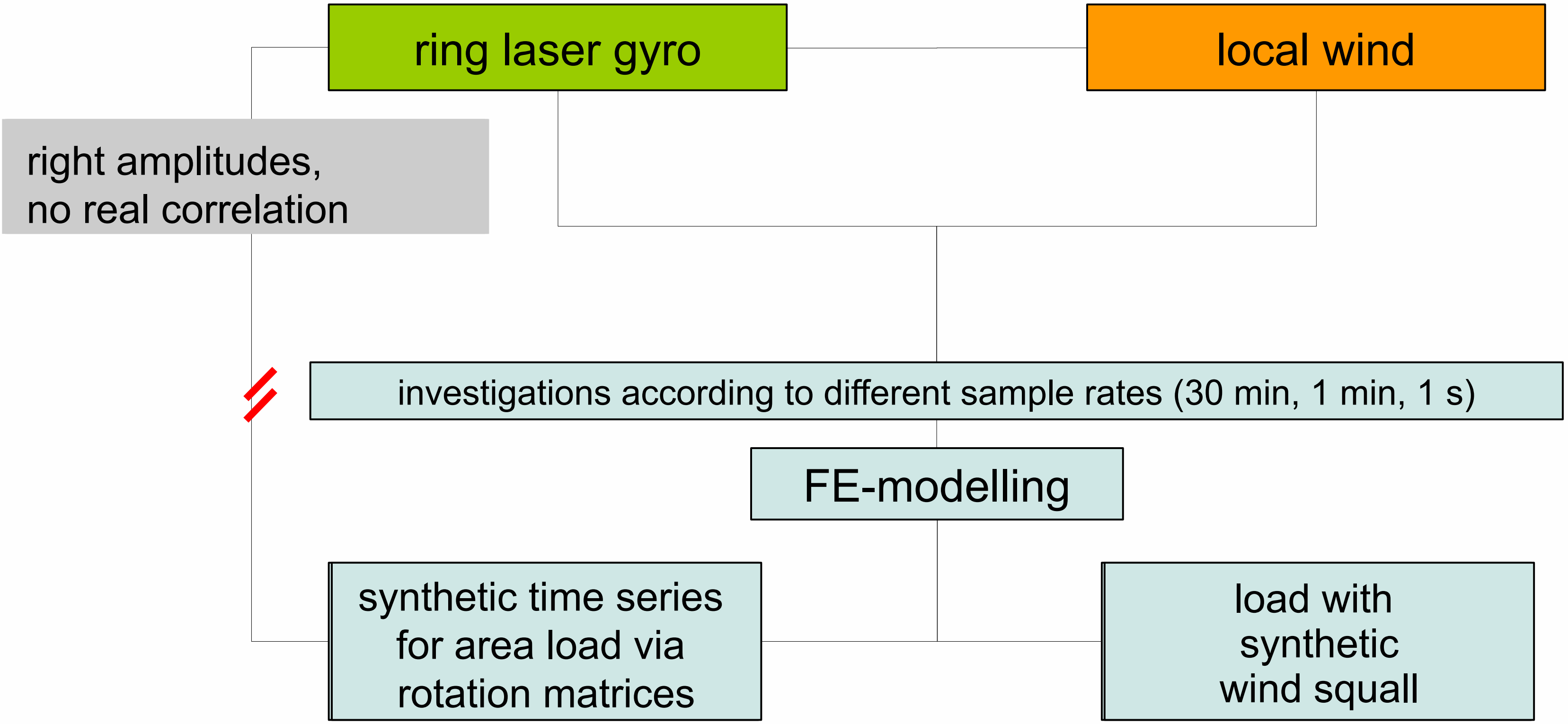


Locale wind effects

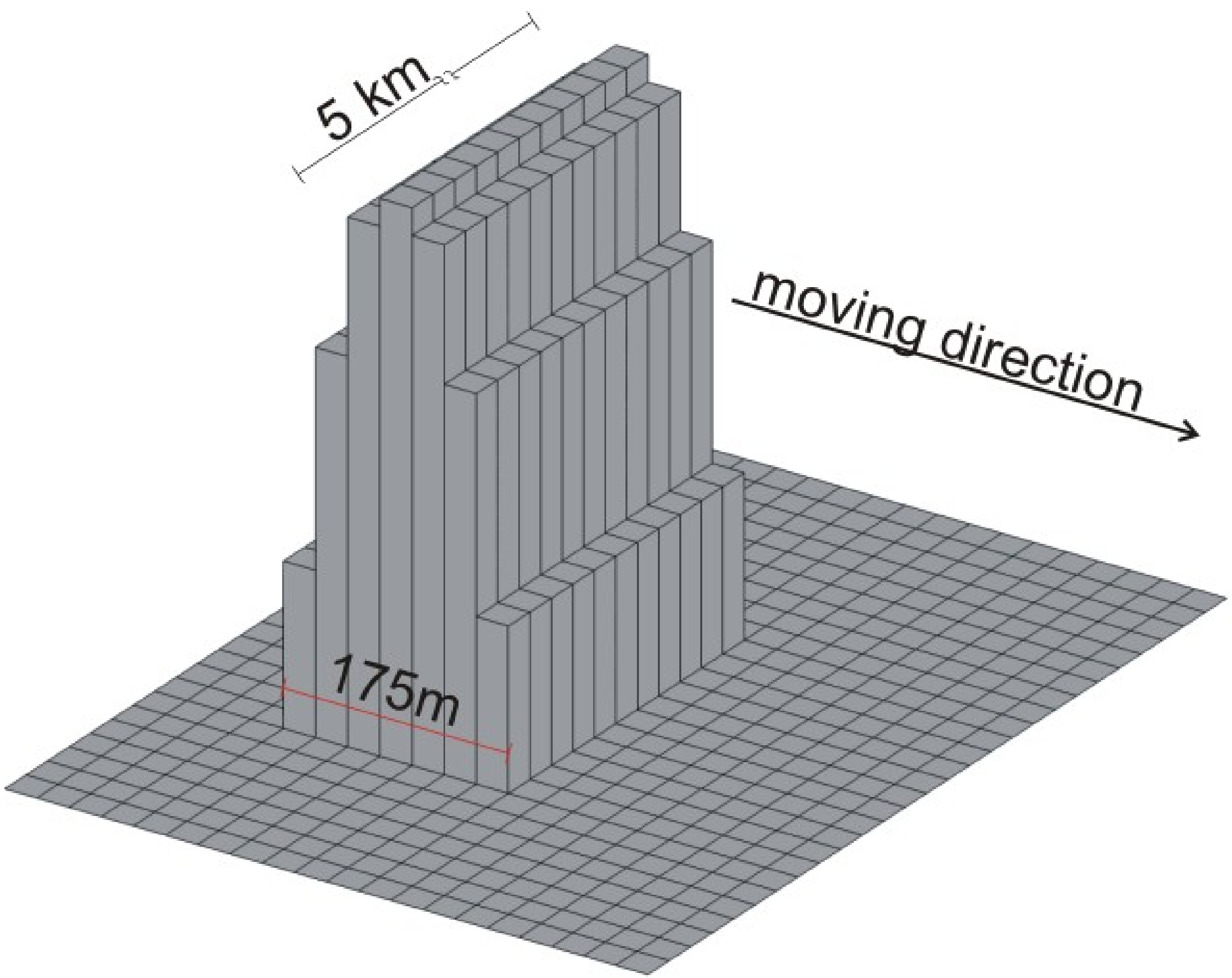
- amplitudes in the right order of magnitude
- deformation velocity ~4km/s (seismic) → instantaneous
- no correlation
  - additional def. due to e.g. marine micro seismic
  - phase shift due to wind squall, caused by distance of about 300 m of metrological station
  - incoherent waves in the soil
- small scaled effect

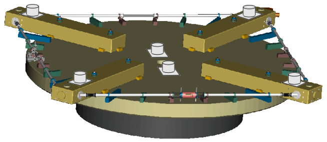


Local wind effects

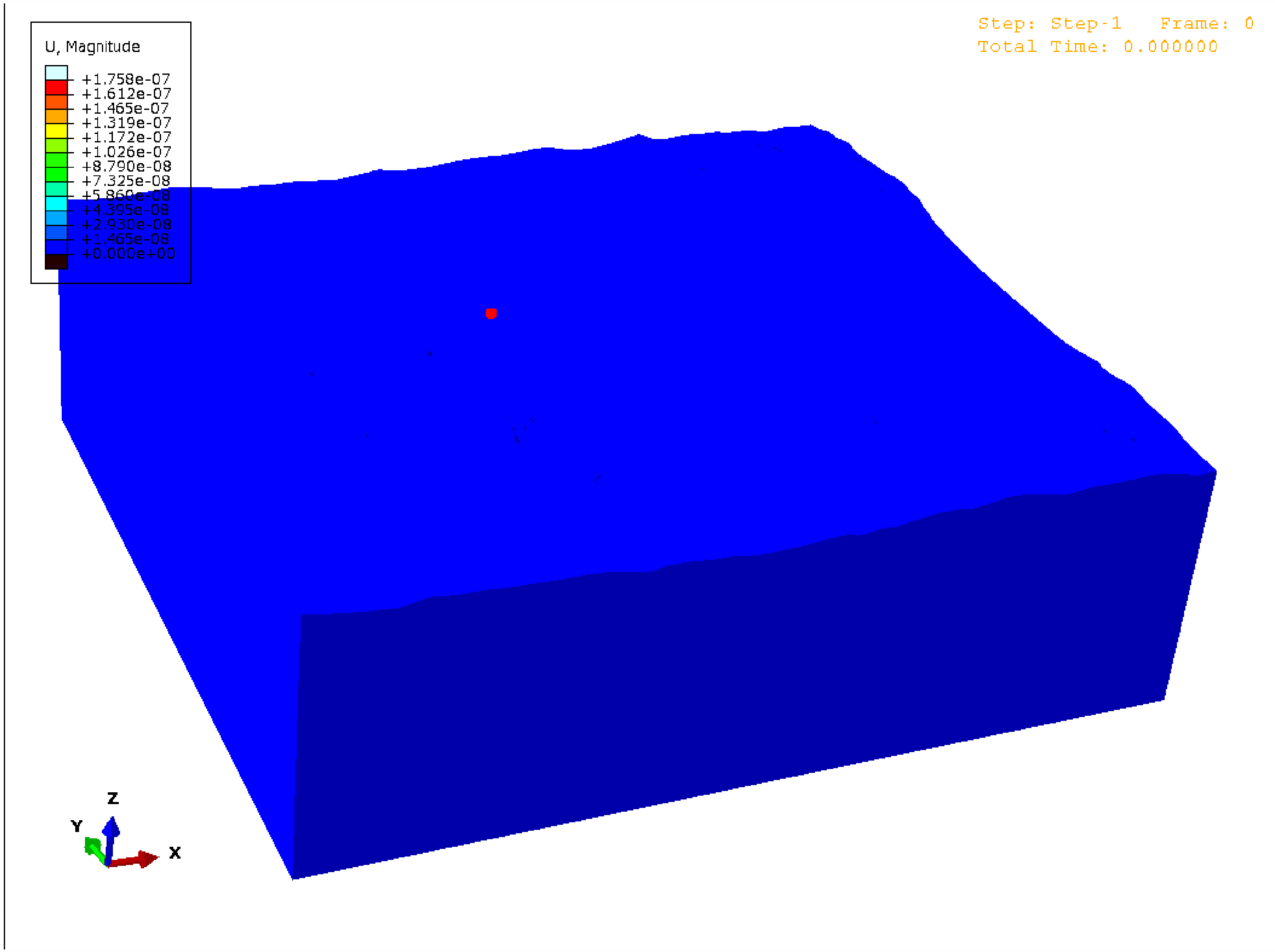


Local wind effects

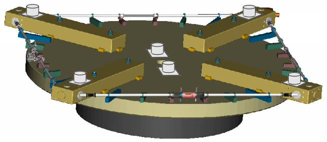




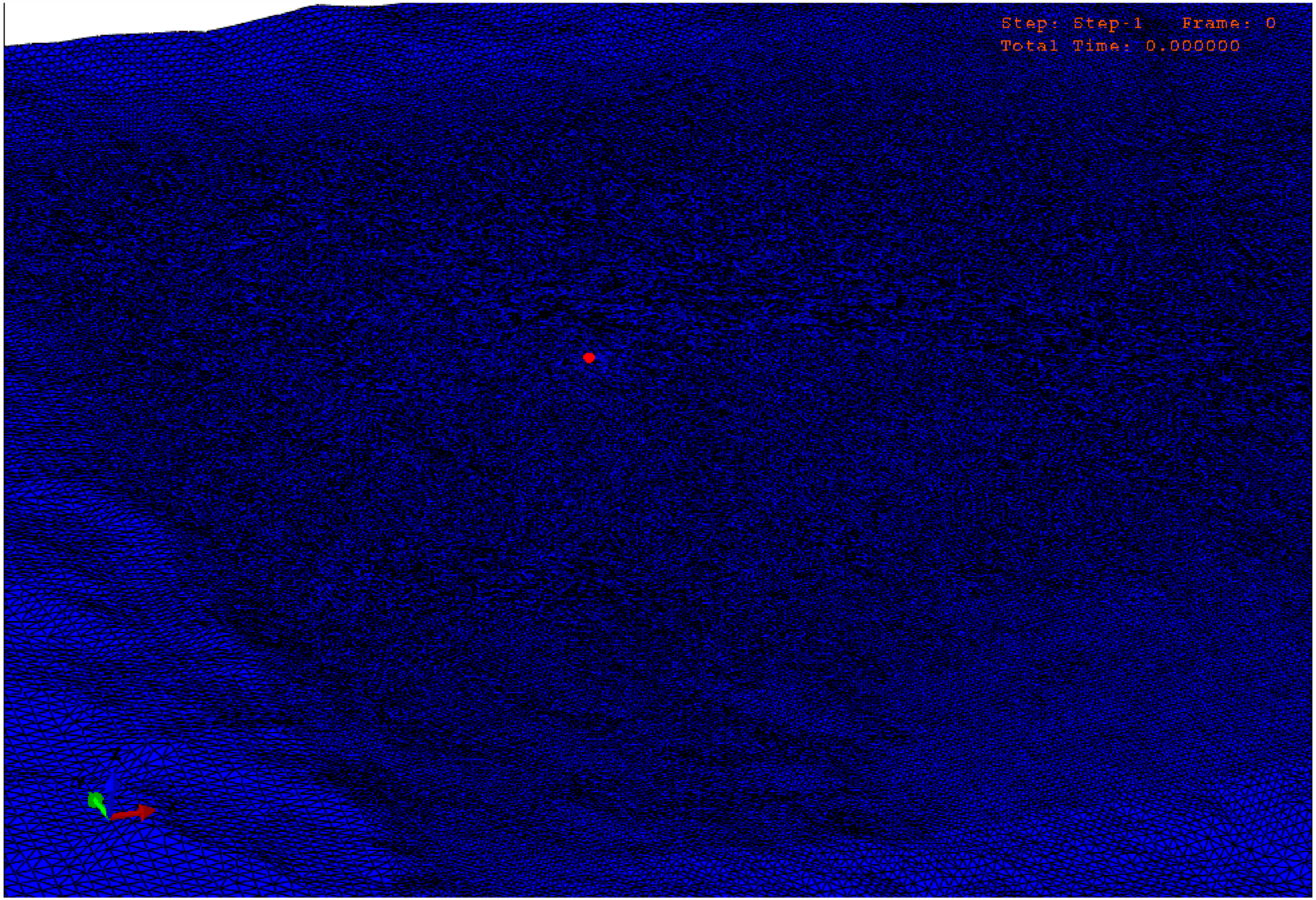
Local wind effects

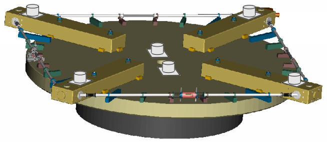


Introduction
Signals
Tides
Earth Rotation
Sagnac Signals
Hardware
Data
Stability
Meteorological effects
Seismology
Actual Stability
Conclusion
Outlook

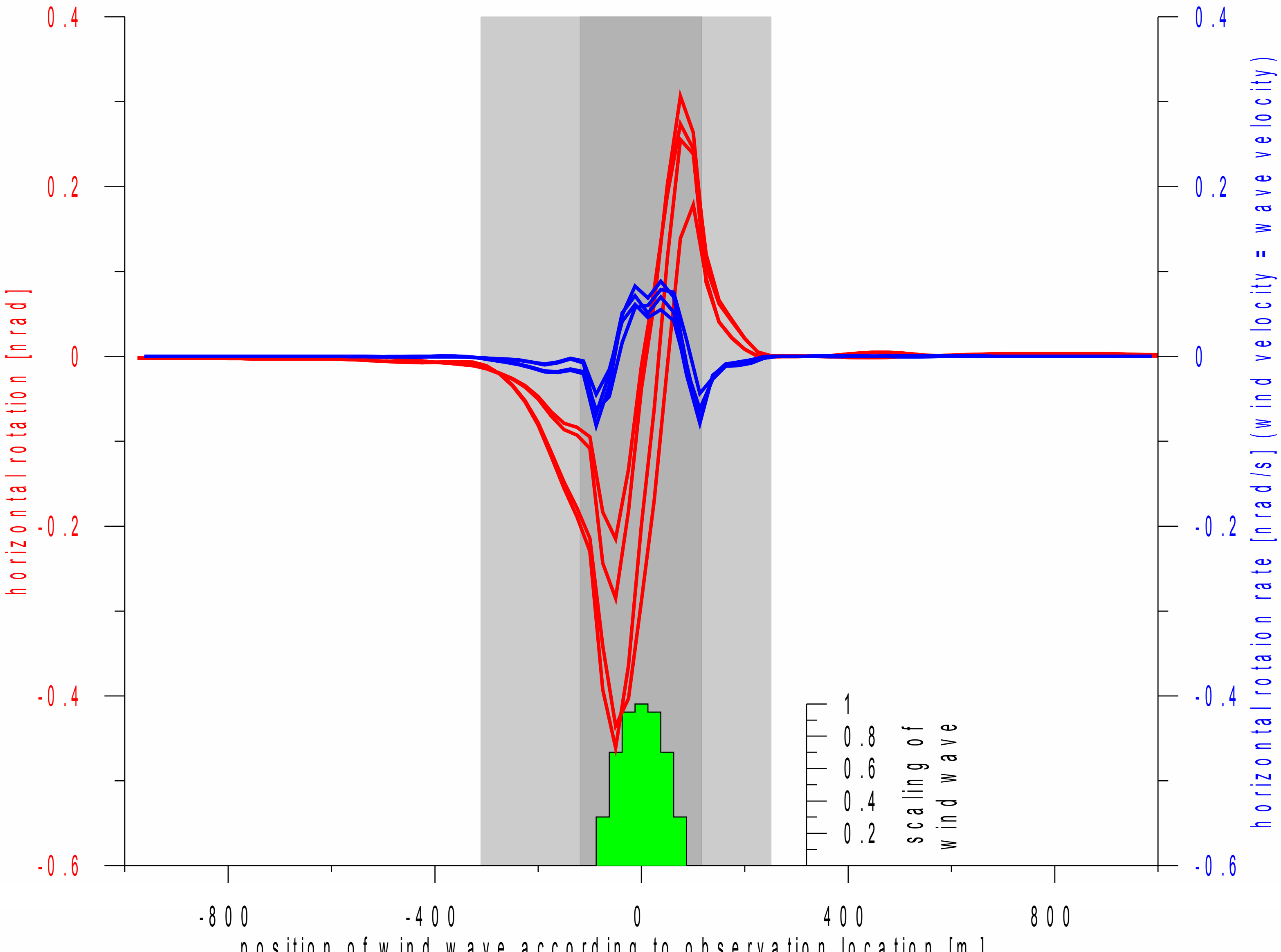


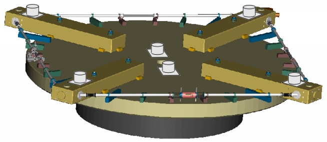
Local wind effects



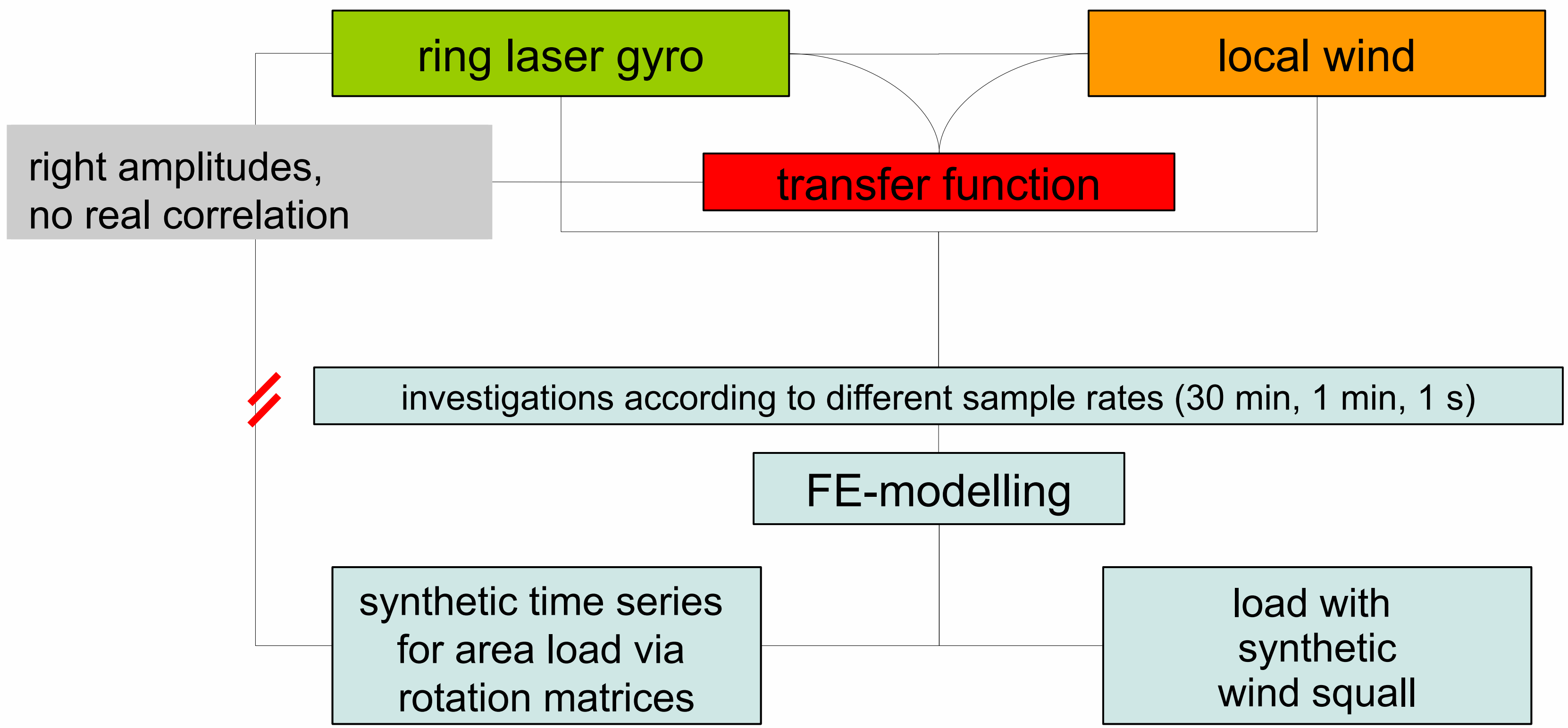


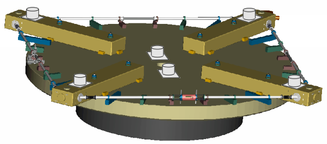
Local wind effects





Local wind effects





Introduction

Signals

Tides

Earth Rotation

Sagnac Signals

Hardware

Data

Stability

Meteorological effects

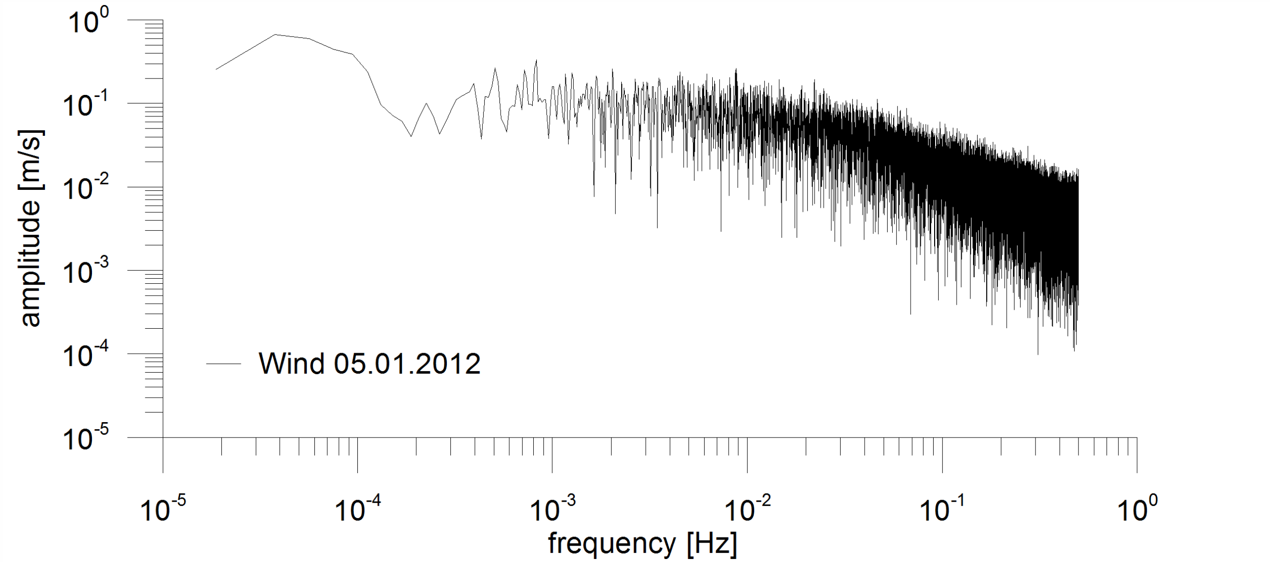
Seismology

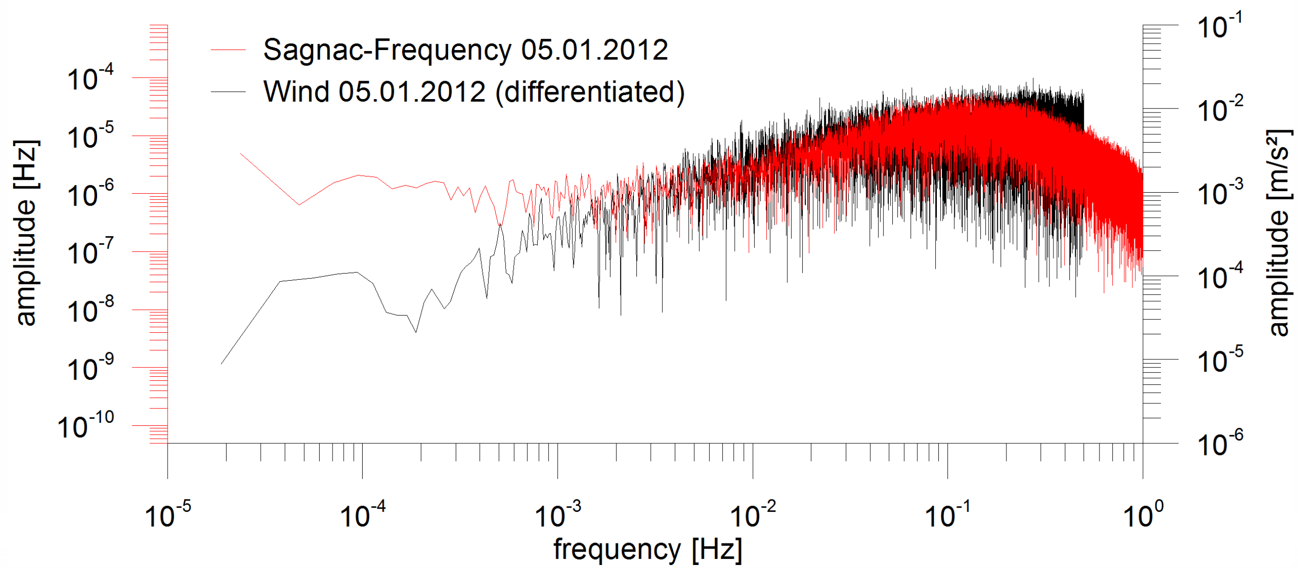
Actual Stability

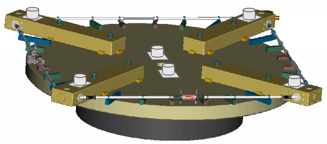
Conclusion

Outlook

Local wind effects

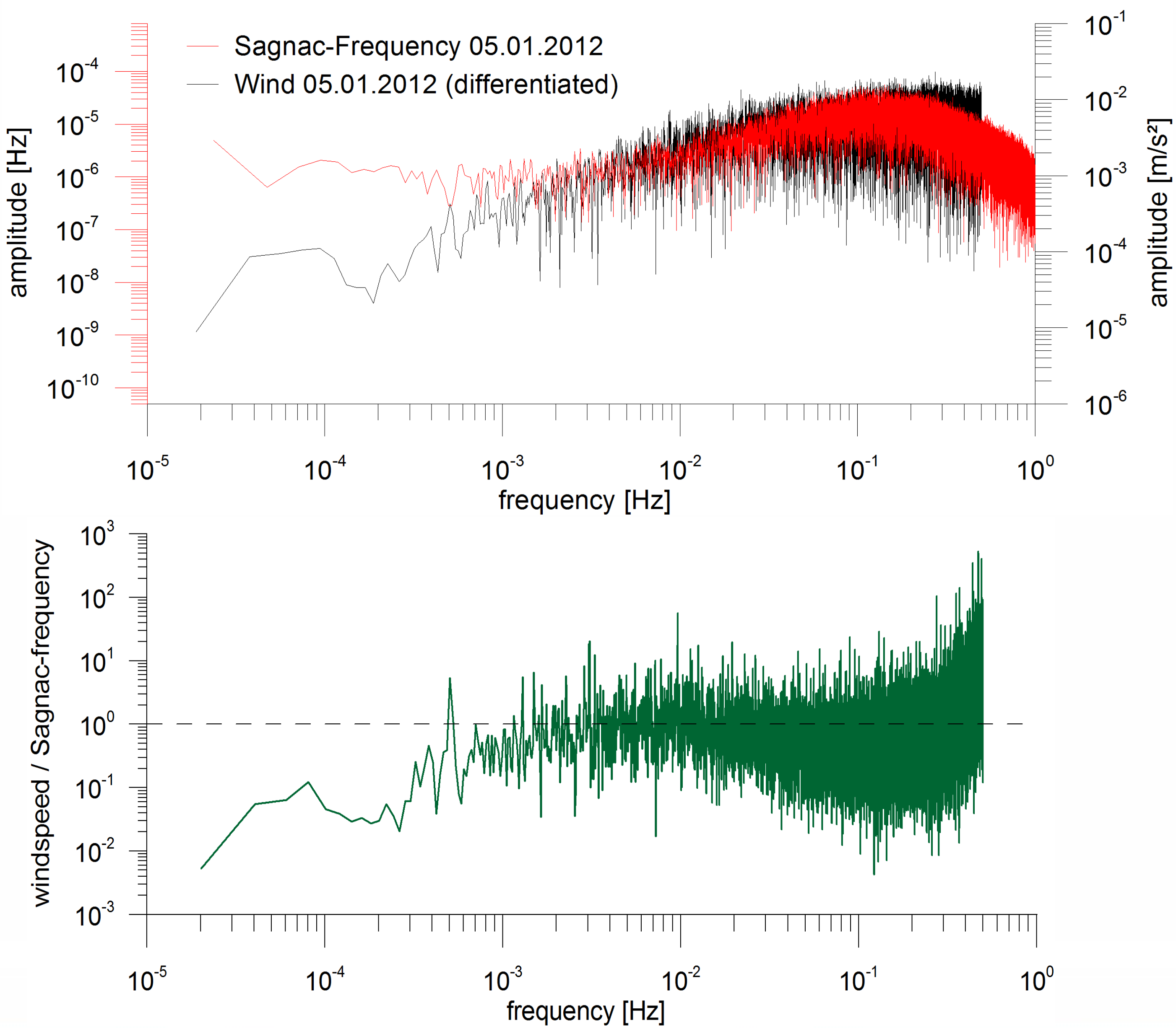


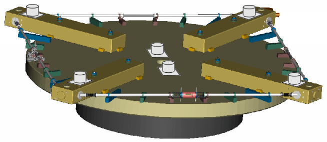




Introduction
Signals
Tides
Earth Rotation
Sagnac Signals
Hardware
Data
Stability
Meteorological effects
Seismology
Actual Stability
Conclusion
Outlook

Local wind effects





Local wind effects

Rotation-matrices → time series | wind squall | transfer function

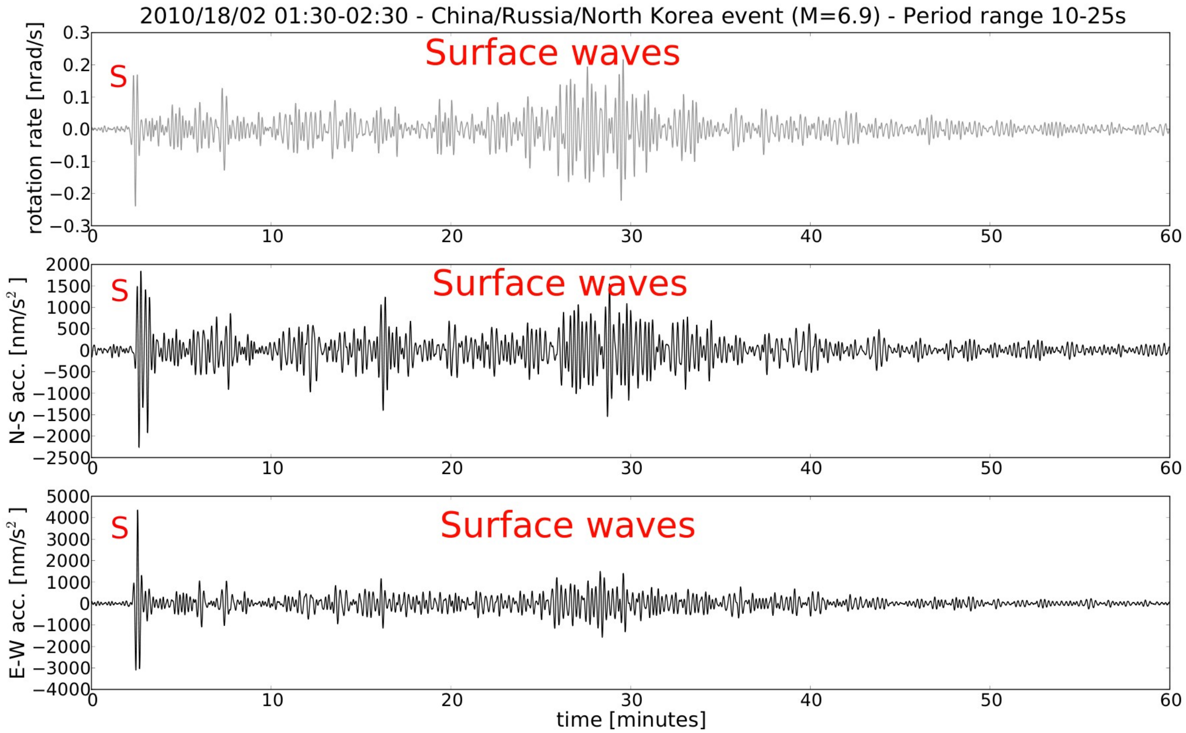
→ Wind acts small scaled (~250 m)

→ affecting factors:

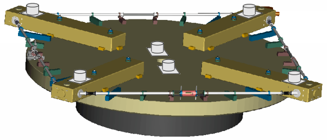
- → building density
- → topography
- → Wind distribution
- → additional deformation (moving trees)

→ soil acts as ‚bad' low pass filter

Seismology – direction estimation

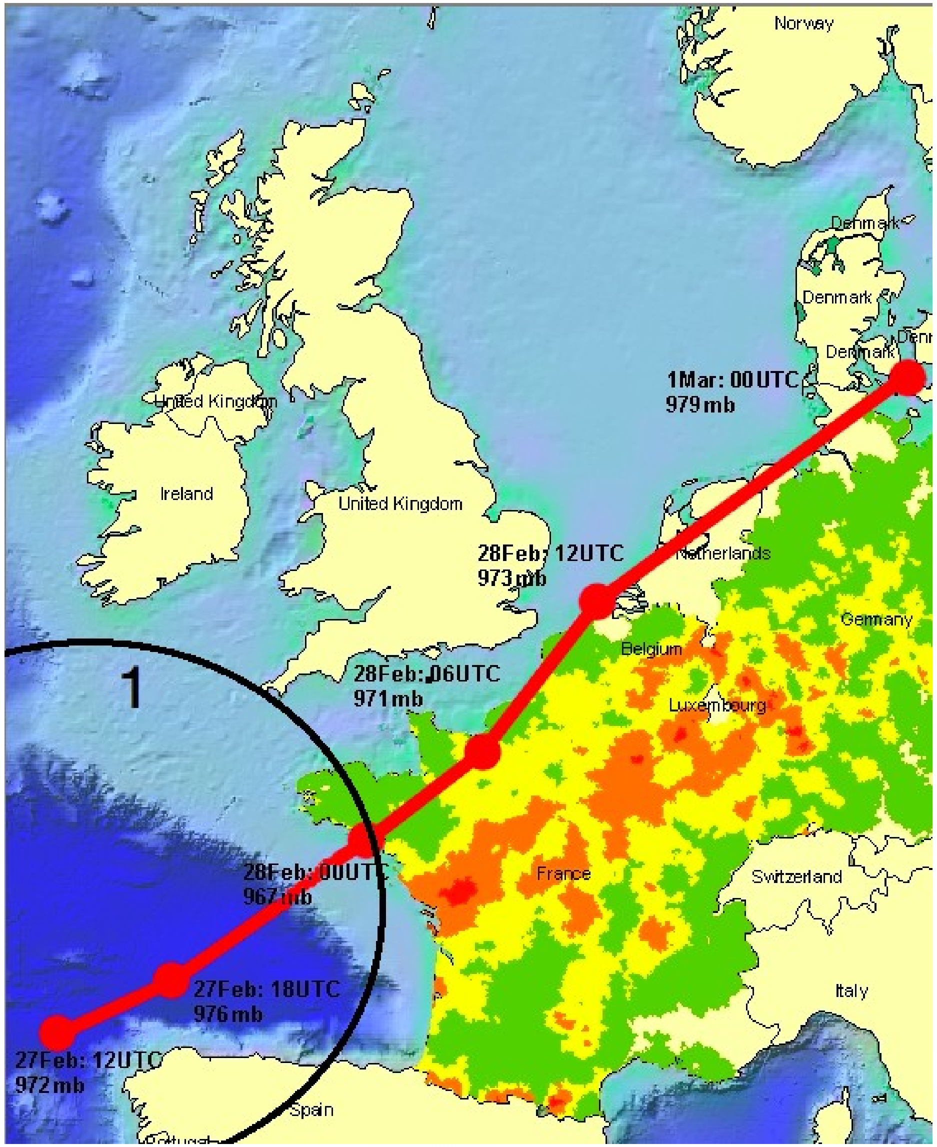


Gaebler 2010



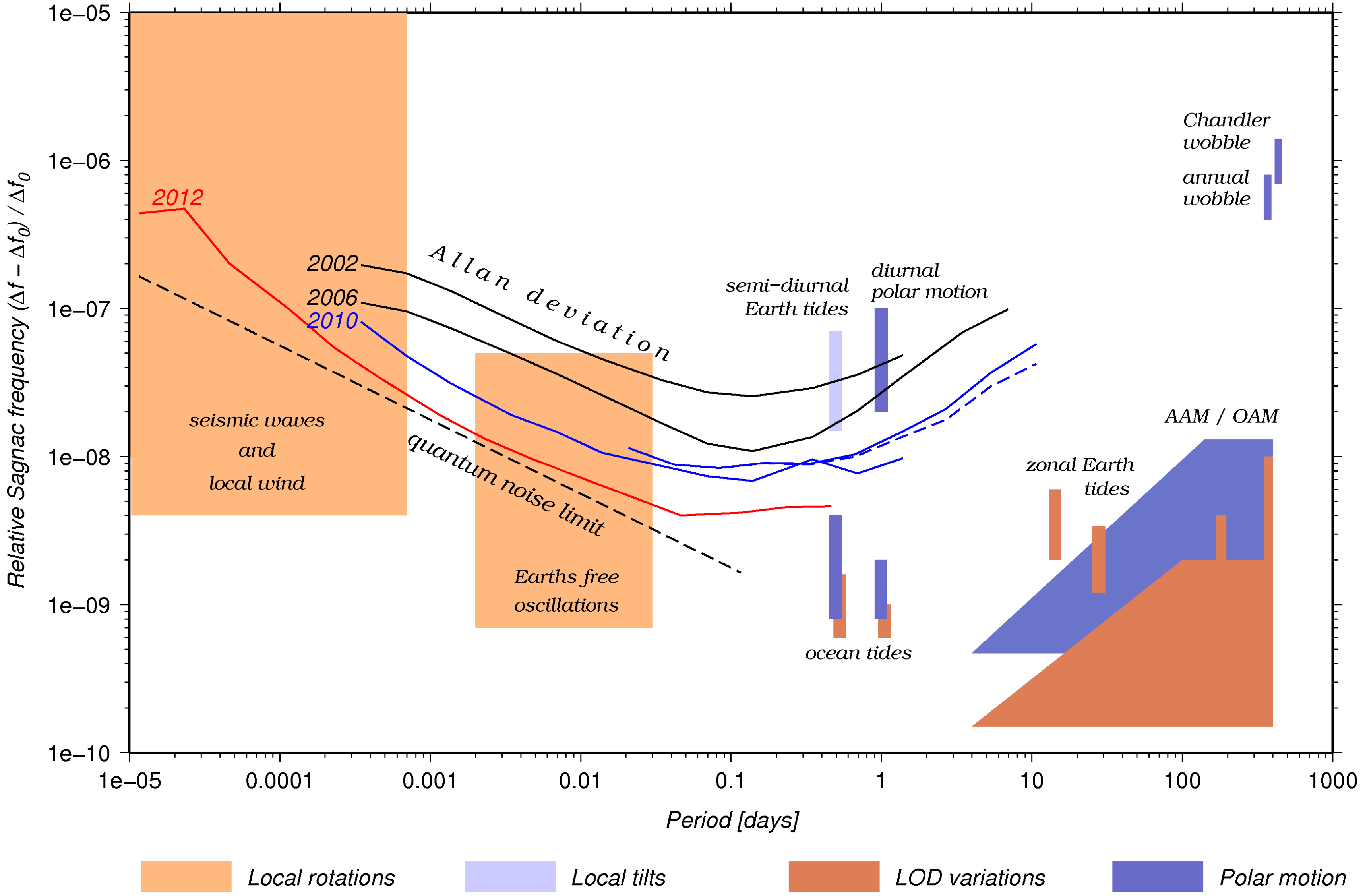
Seismology – direction estimation

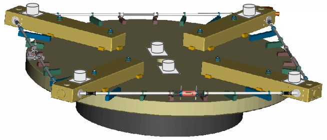
→ Marine micro seismic



Gaebler 2010

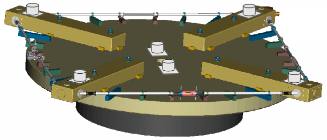
Actual stability





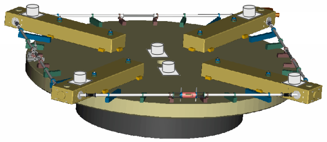
Conlusion

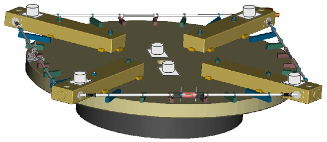
- in principle all signals in ring laser data identified
- effects caused by wind / meteorological can be neglected



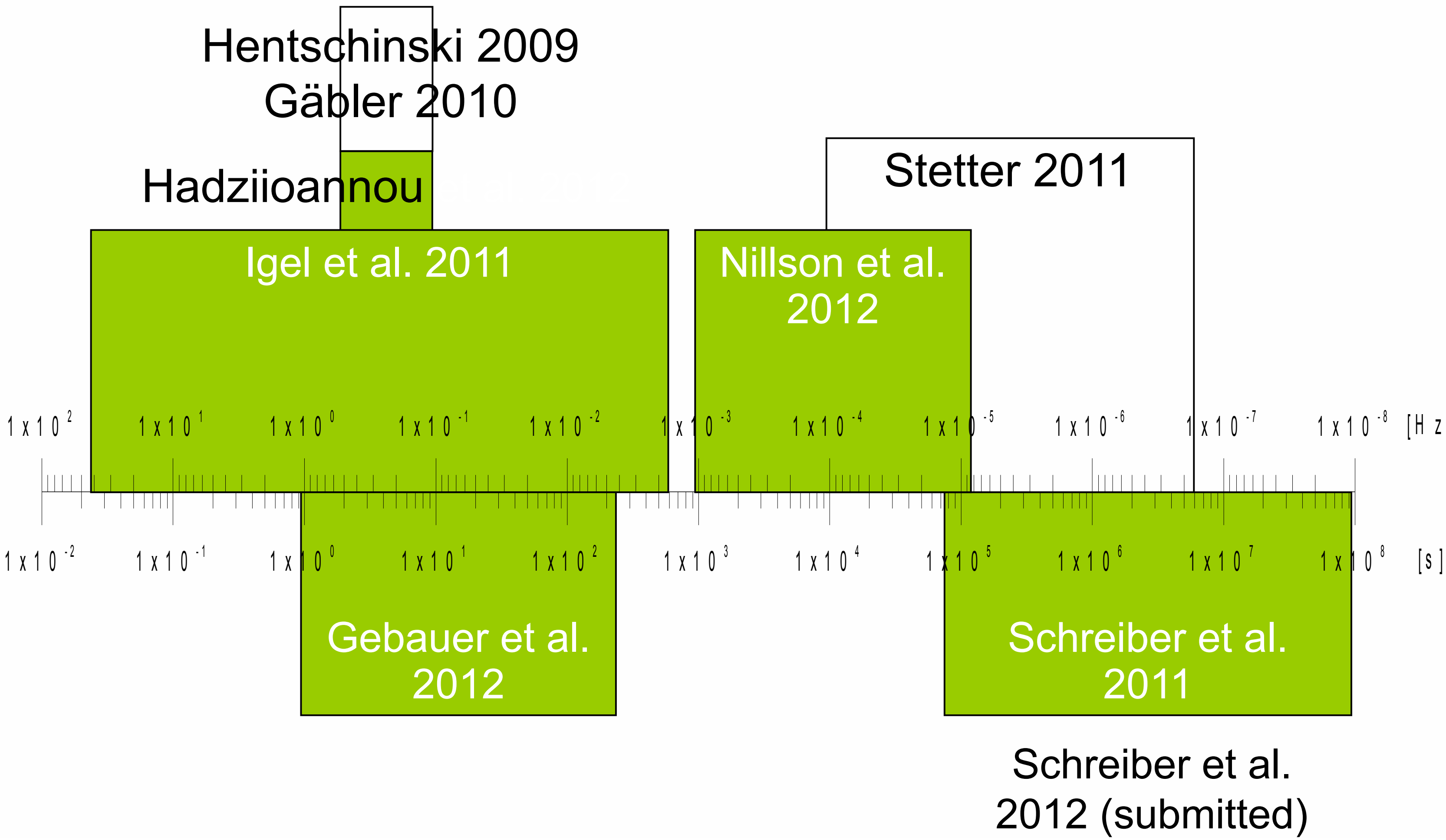
Outlook

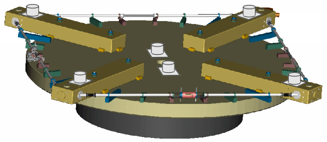
- data analysis (models, …)
- long term stability (instrumental effects) → frequency-comb
  - local orientation (vertical RLG)
  - mirrors
  - backscatter
  - laser
  - …
- ‚frequency-comb' + ‚RGL' = ‚precise clock'



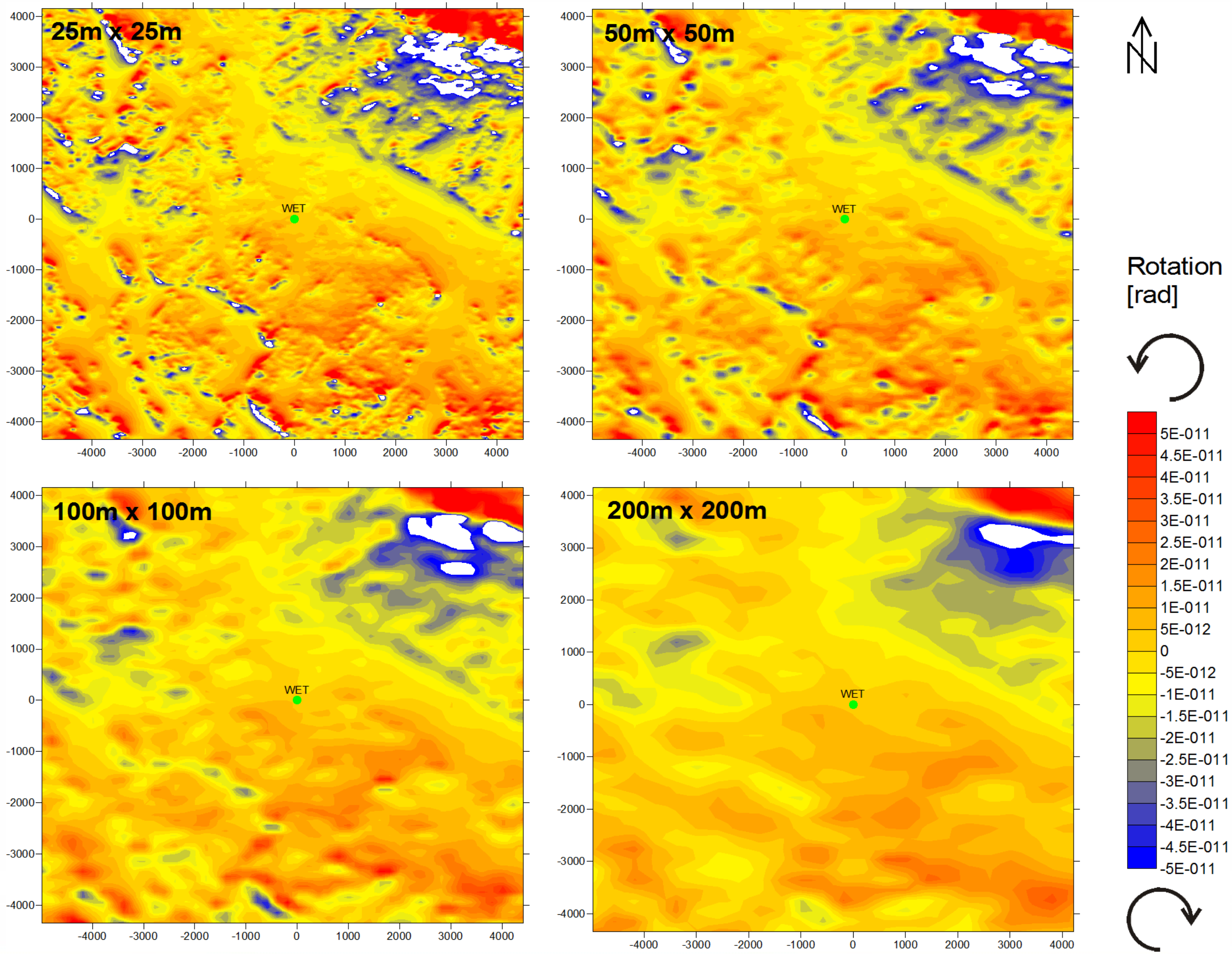


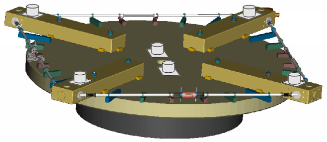
Veröffentlichungen





Rotation Effect





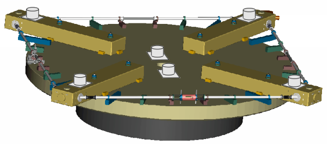
Regionale Investigation

FE-Model: (ANSYS)
980km x 980km x 100km
512000 Tetrahedrons
→ Barometric pressure
→ Wind

(Velikoseltsev, 2009)

Result:
→ Calculated effect some Orders of magnitude to small

Conclusion:
→ Grid spacing too rough
→ Regional effect to small



Backscatter

$$\Delta f = \frac{4A}{\lambda P} n \cdot \sqrt{\Omega^2 - \omega_L^{\ 2}} \qquad \omega_L = \frac{c\lambda^2 \sqrt{r}}{32\pi A d}$$