Long-term observations at the Geodynamic Observatory Moxa: Can we identify evidence for climate change?

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Introduction

Longterm geophysical recordings of natural Earth's parameters may - besides other signals - contain past and ongoing shallow subsurface temperature fluctuations, as they are occurring e.g. when groundwater moves, due to fluid infiltration after strong rainfall events, or when climate changes. Variations of the Earth's gravity field can be observed employing superconducting gravimeters. Besides free oscillations of the Earth and hydrological effects, the tides of the solid Earth are the strongest signals found in such time series. Tidal analysis of the main constituents leads to obtaining the indirect effect for all tidal waves which is mainly controlled by the loading effect of the oceans.
The Geodynamic Observatory Moxa of the Friedrich-Schiller University of Jena, Germany, is an ideal site for long-term monitoring of various natural physical parameters of the Earth and their fluctuations, as it is located in a remote area and thus only very little ambient noise affects its recordings. Among the instrumentation (cf our companion poster presenting the observatory and its instrumental capabilities) is the superconducting gravimeter CD-034 as well as an optical fibre and a water level gauge mounted in a 96 m deep borehole on the ground of the observatory.
Here we use time series of both types of instrumentation to discuss potential identification of climate fluctuations.

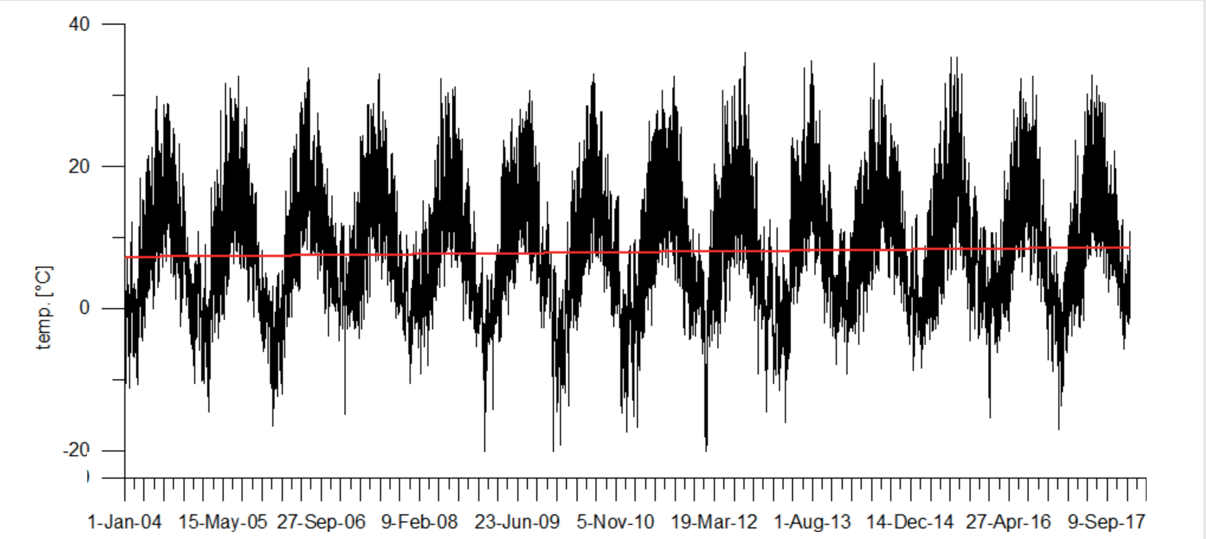

Fig. 1.1: Air temperature measured at the Geodynamic Observatory Moxa between 2004 and to 2017. Red line is the linear trend. Average annual temperature increase is about 0.095°C/year during this time period.

Geodynamic Observatory Moxa

The Geodynamic Observatory Moxa of the Friedrich-Schiller University of Jena is located about 30 km south of Jena in the Thuringian Slate Mountains (Fig. 1.2). Due to its isolated location and the possibility of subsurface installations in a gallery or in boreholes, Moxa observatory provides excellent conditions for long term observations.
Moxa observatory is equipped with various geophysical sensor systems to observe transients signals of the local gravity field (superconducting Gravimeter CD-034, LCR-ET-18), deformation (altogether three laser strain meters, ASKANIA borehole tilt meters, Ilmenau tilt meter,) and of subsurface temperatures (optical glass fibre in a 96 m deep borehole). These systems are complemented e.g. through temperature sensors placed within the gallery, water level gauges and a climate station to record environmental parameters. All recorded time series show high signal to noise ratios for a large range of frequencies.

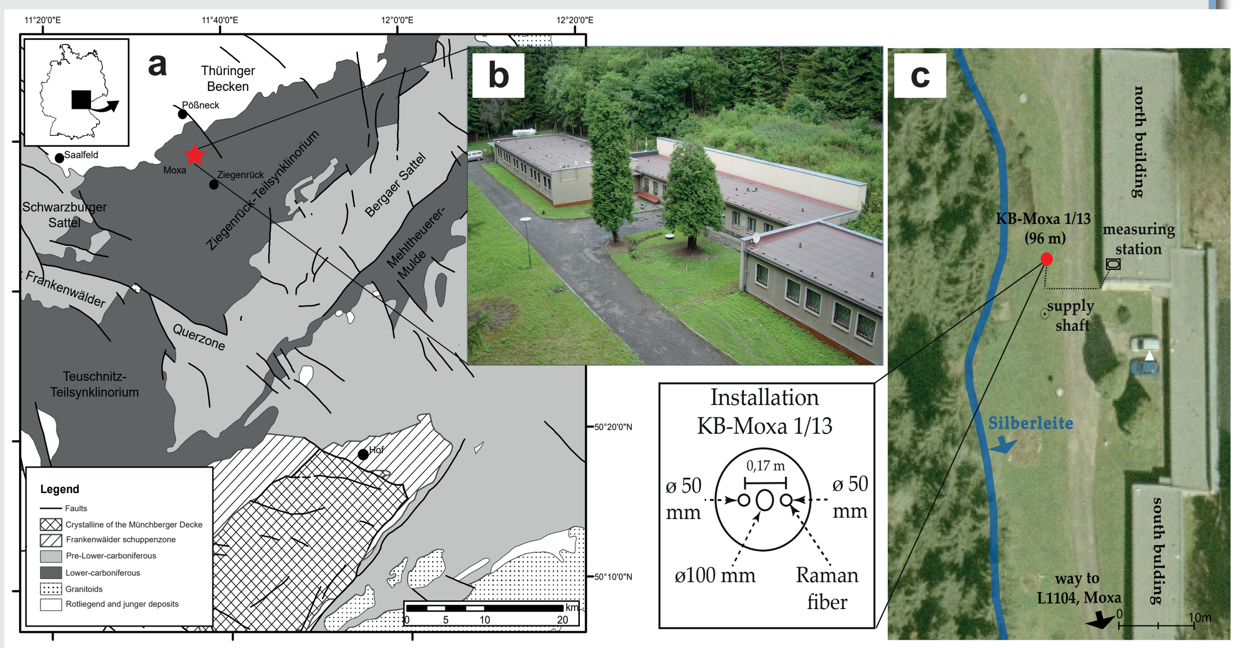

Fig. 1.2: a) Map showing the location of the Geodynamic Observatory Moxa, b and c) Observatory building (picture taken from SW (b) and from above (c). Borehole KB-Moxa 1/13 (96m deep) west of the observatory (see Fig. 2.1) is indicated by the red dot. Creek Silberleite is further to the West.

Literature

DKK, KDM (2019): Zukunft der Meeresspiegel. Broschüre des Deutschen Klima Konsortiums und dem Konsortium Deutsche Meeresforschung. Hrsgb. Weidinger (DKK) und Konitzer (KDM), 31 S.
URL: https://www.apsensing.com/de/technologie/dts/, Timestamp: 16.03.2017.
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Methe, P., Goepel, A., Jahr, T. & Kukowski, N. (2013): First results of a recent scientific drilling campaign at the Geodynamic Observatory Moxa. Techn. Ber., Friedrich Schiller Universität.

Acknowledgment

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Distributed Fiber Optic Temperature Sensing (DTS)

Borehole setup

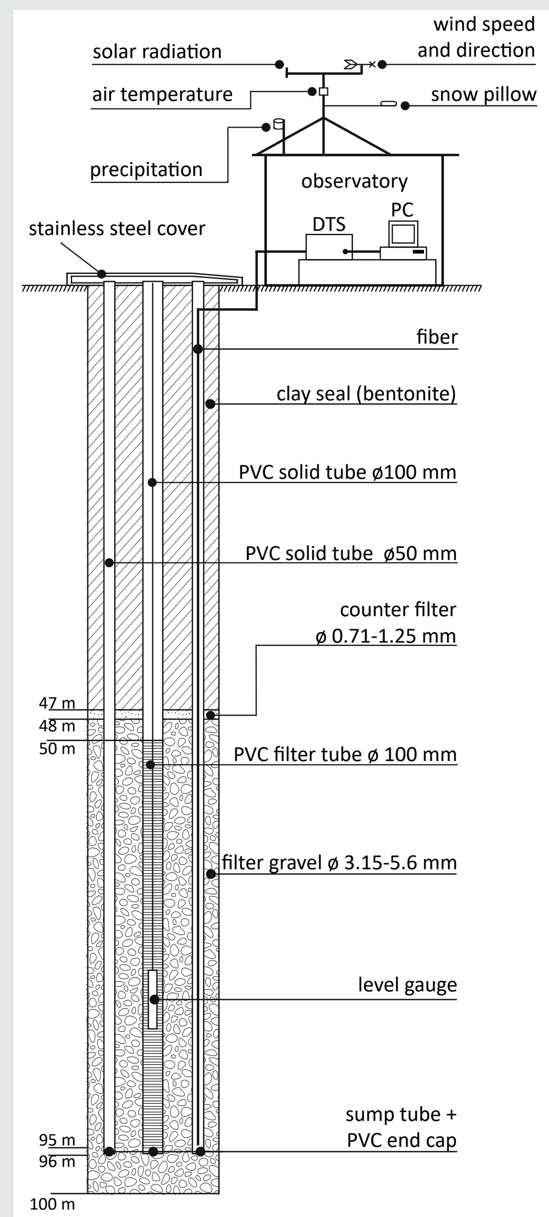

Fig. 2.1. : Sketch illustrating equipment of the borehole KB-Moxa 1/13 with partly slotted plastic tubes containing the fibre and pressure gauges (Methe et al., 2013).

Method

The Distributed Fiber Optic Temperature Sensing (DTS) technology utilises the Raman - effect to measure temperatures along the fibre in high spatial (about 0.5 m in our case) and temporal (every 15 min) resolution. The Raman effect is the inelastic dispersion of light on molecules, which causes a change of the frequency of the dispersed light and results in a so-called Raman spectrum (Fig. 2.2). To create temperature from these signals, it is necessary to compare the intensities of the anti-Stokes-Raman dispersion with the Stokes-Raman dispersion. In Moxa, there is an interrogator with a Neodymium endowed laser, which uses a wavelength of 1064 nm. The reflected light is split into the Stokes bands and the anti-Stokes bands. The relation between the two bands is converted into temperature values by means of a calibration function (Hurtig et al., 1996). In addition to the temperature measurements, the groundwater level is monitored with a Beaver ATP10 (Aquitronic) sensor every thirty minutes in the same borehole.

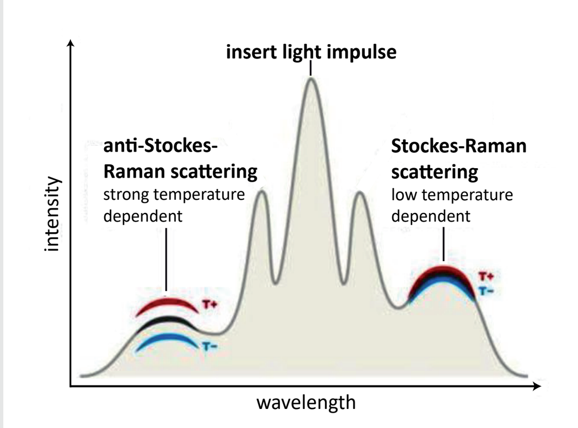

Fig. 2.2: Spectrum of the Stokes-, Rayleigh- and anti-Stokes lines (www.apsensing.com/de/technologie/dts/) .

Results

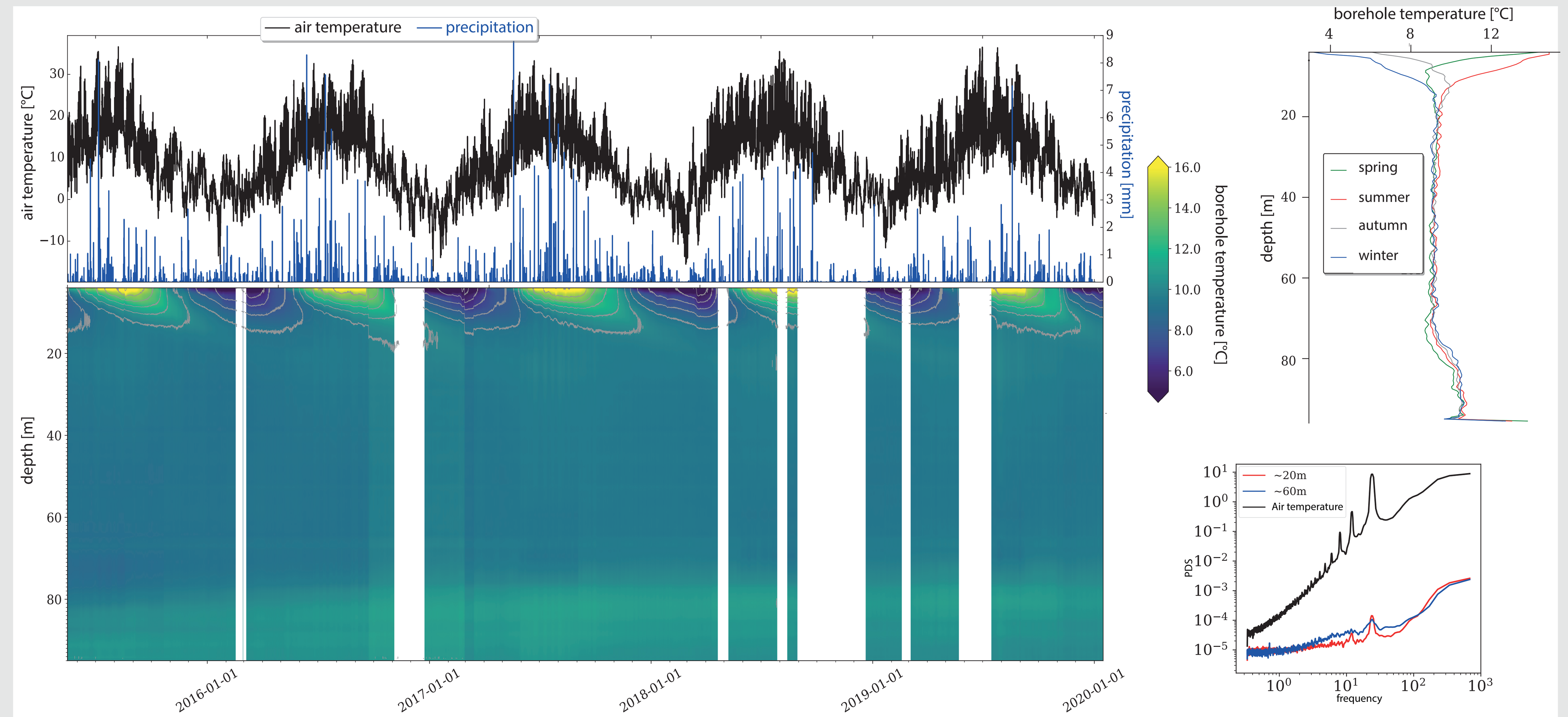

Fig. 2.3: Long term borehole temperature measurement (lower diagram) with air temperature and precipitation as recorded by the climate station (upper diagram). On the right side, individual temperature-depth measurements in spring, summer, autumn and winter extracted from the entire data set are shown together with Power Density Spectra of air temperature and temperature-different depth intervals.

The records of the first five years of continuous temperature recordings reveal seasonal temperature fluctuations down to a depth of about 20 m and diurnal temperature signals down to approximately 1.2 m (Fig. 2.3). Precipitation events may influence subsurface temperature down to a depth as deep as 15 m. Besides these, the most prominent temperature anomalies were detected at two depth intervals at about 20 m and 77 m below the surface. These anomalies most probably result from enhanced groundwater flow. Recordings of deformation from laser strain meter systems installed in a gallery at Moxa, which are highly sensitive to pore pressure fluctuations, help to identify and quantify potential causes of the observed temperature fluctuations.

Gravimetry

Gravimetry setup

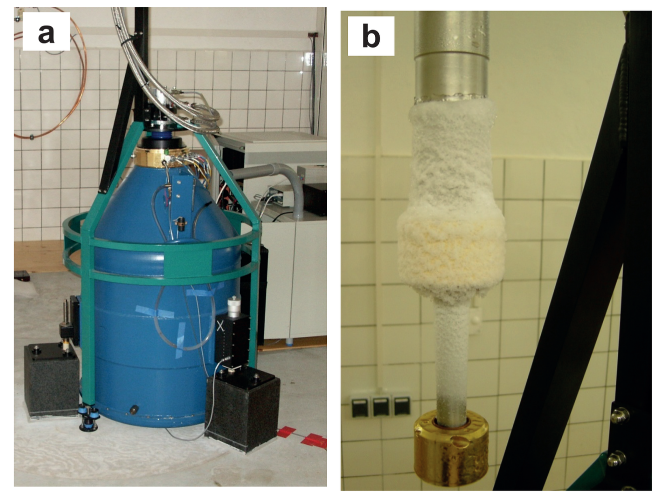

Fig. 3.1: a) Superconducting gravimeter GWR CD-034 of FSU Jena. b) Cold-head of gravimeter enabling reduction of helium evaporation rate to a He-refill interval (125 litres Dewar vessel) of approx. 1.5 years.

In spring 1999, the superconducting gravimeter GWR CD-034 was installed in the building of the observatory. Thus, today, more than 20 years of gravity data time series are available for both sensor systems (Fig. 3.1). Comparative studies in the framework of GGP (Global Geodynamics Project) and IGETS (International Geodynamic and Earth Tide Service) revealed that the quality of data recorded in Moxa belongs to best worldwide. An important focus of data correction was on the improvement of identifying local and regional hydrological influences including a comparison with satellite data (GRACE), which confirms the reliability of procedures applied to correct for hydrological effects developed at Moxa.

Method and Ocean surface

The gravity effect of ocean tidal loading is an important part of the so-called tidal parameter resulting from tidal analysis (Fig. 3.2). Maps of increasing SSH (Sea Surface Hight) show, that the hight changes are not homogeneously distributed globally: there are also regions showing decreasing levels (Fig. 3.3). This may also cause a change of ocean loading and thus the results of tidal analyses. This leads to the question whether it is possible to detect this change by means of superconducting gravimeter data?

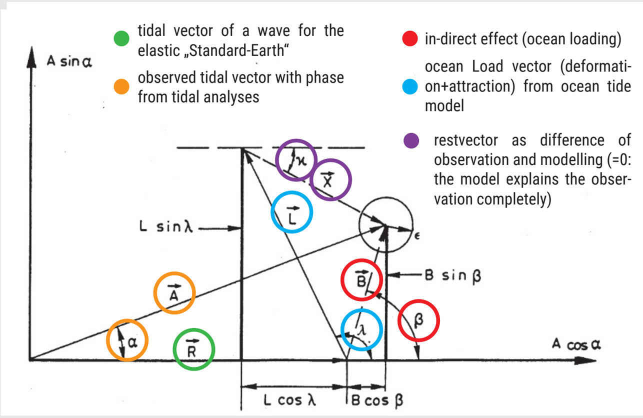

Fig. 3.2: Sketch illustrating the results of the tidal analysis, revealing that it is clearly influenced by the tidal ocean loading effect (attraction and deformation).

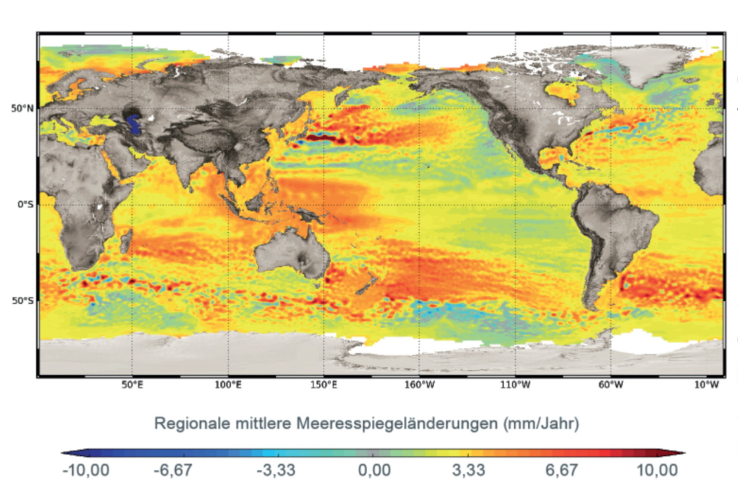

Fig. 3.3: SSH changes from 1993-2017 as observed by satellites. Both, increasing and decreasing levels are observed (DKK, Dec. 2019).

Results and Discussion

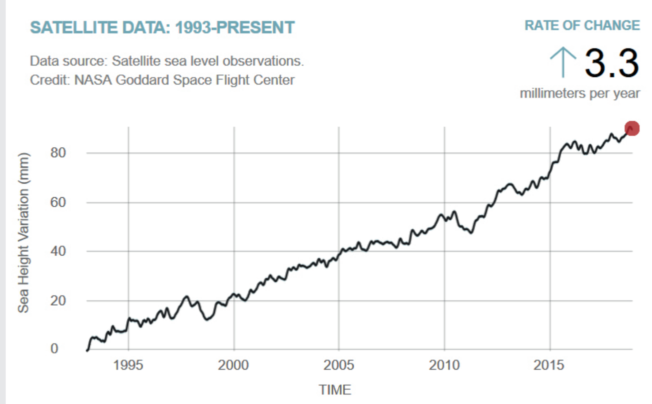

Fig. 3.4: SSH changes from 1993-2017 as observed by satellites. Mean change rate differs between 3.0 and 3.6, here its given by 3.3 (NASA, 2018).

Main tidal diurnal waves K1 and O1 have been analysed (using one year time series) for 18 years. Parameter changes are given in Table1 (δ-Variat., last row). A slight increase of these parameters is observed.

Tab. 3.1: Observed and modelled tidal parameters for main tidal constituents (mOTM: modified Ocean Tide Model).

	δO1	Phase O1	δK1	Phase K1
Org. OTM	1,14898	219,9	1,13651	297,9
mod. OTM	1,14976	220,7	1,13707	298,4
δ-variat. per year (mOTM)	5,56E-05	0,06	4,01E-05	0,04
δ-variat. per year (observ.)	3,82E-06		3,79E-06	

The modelled ocean tides (indicated by blue vector in Fig. 3.2 and first row in Table 3.1) have been modified using data as shown in Fig. 3.3. The new tidal parameters (second row, mod. OTM, in Table 3.1) allow to estimate the gradient (Parameter change per year). The result (mid row in Table 3.1) shows that gradients obtained in this way are approx. 10-times stronger than observed ones. Thus, we need new and better ocean tide models. However, this also clearly shows how sensitive tidal parameters are against SSH changes.

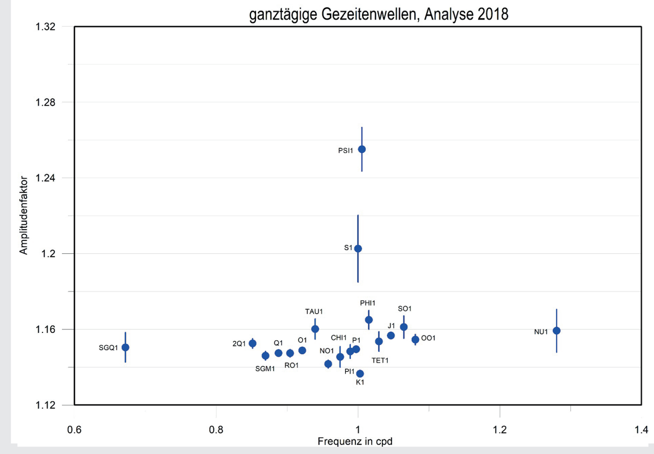

Fig. 3.5: Tidal parameters analysed for a one year time series. Resonance of Earth's core is clearly visible and the main waves O1 and K1 are very stable over the years.

Tidal analyses of semi diurnal waves yield a clear periodic signal for the parameter variation for the main tidal constituents M2. A correlation with El Niño and La Niña effects and correlated SSH changes seems to be present, however, finally the true reason was a purely methodical one: close to the M2 frequency there are other tidal waves. Therefore the periodicity in the curve is caused by beats only, not by changes in SSH.

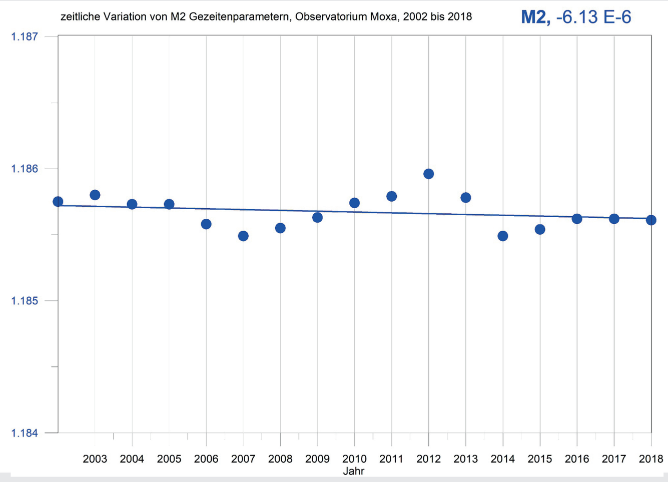

Fig. 3.6: Changes of M2 parameters over 18 years. The periodic change is caused by beats of neighboring frequencies. This is a purely methodical effect, not due to a change of ocean loading. ocean loading.

Conclusion and Outlook

DTS

The findings derived from borehole temperature measurements at Moxa Geodynamic Observatory are summarized in Fig. 3.1. and in the following:

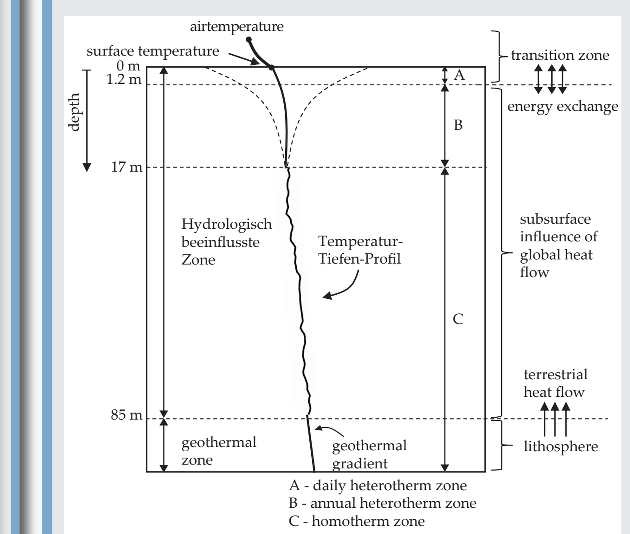

Fig. 3.1: Thermal profile for the subsurface of the observatory.

1) Seasonal temperature changes can be identified down to a depth of about 20 m (annually heterothermal zone). The homothermal zone begins approximately at this depth.

2) Between 0 - 85 m the subsurface is influenced by solar heat flow. Beneath this depth, temperature is mainly influenced by heat transport from below.

3) The first five years of recording have revealed that a Raman optical fibre is suitable for long term temperature measurements in boreholes. The thermal regime in the borehole can be decrypted by means of the Raman fibre.

To improve interpretation of we need longer time series.

Gravimetry

Due to climate change the mean SSH of the oceans worldwide will increase, but also decreasing parts exist. Due to changed water mass distributions also the ocean tides will change. As tidal parameters, resulting from gravity data analyses, reflect also the ocean loading effect, they will also change over longer periods. With superconducting gravimetersit is possible to observe and separate these changes in tidal parameters. Our first results show the high sensitivity of the parameters against the changes of the ocean loading effect.

To improve the interpretation of gravity observation we need a new current ocean tide model. Such a model is then the basis of estimating ocean loading. The changes can then be studied with higher significance.