Observing ocean tidal loading with GNSS

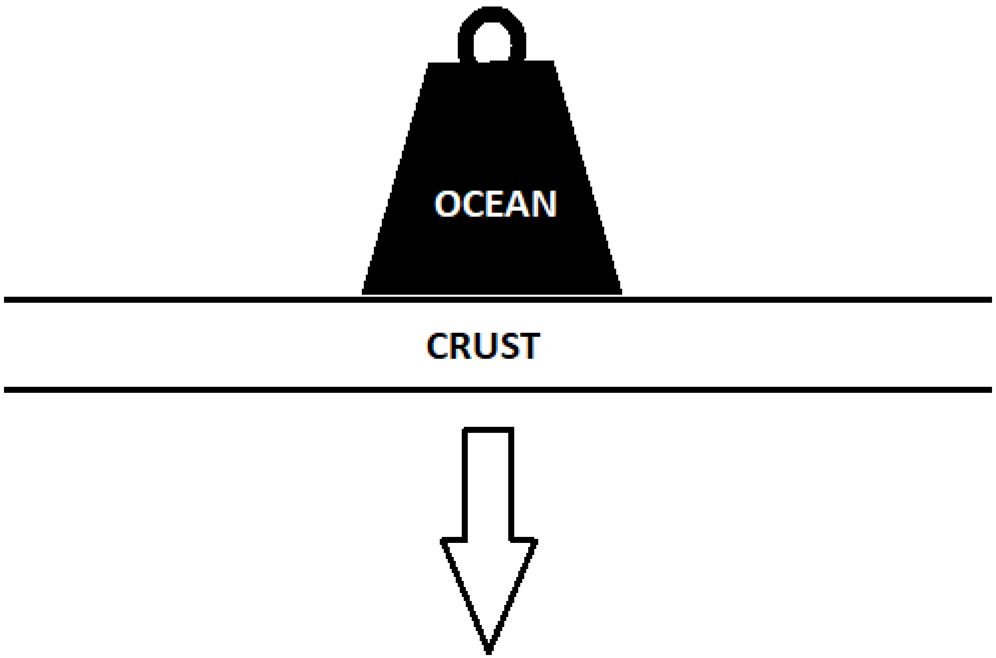
Agenda

1. Ocean tidal loading
2. Aims for the thesis
3. Results
4. Why is OTL important?
5. Questions

What is ocean tidal loading?

Image: Cathy Horellou

Ocean tidal loading



Tidal constituents - many tides

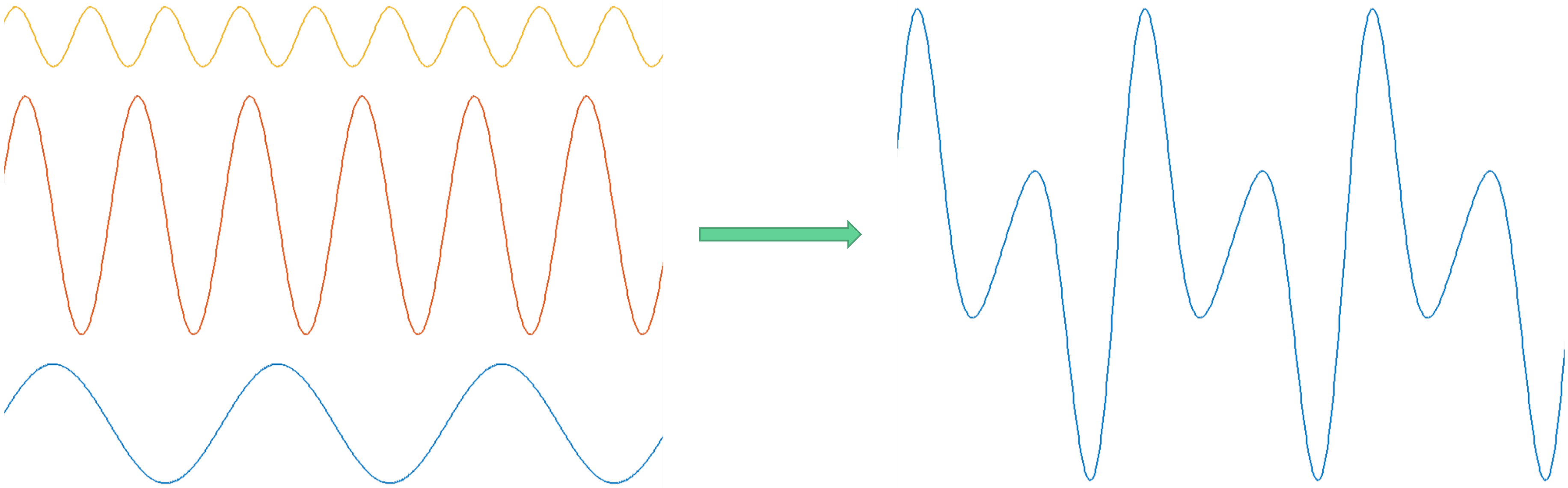


Image: Cathy Horellou

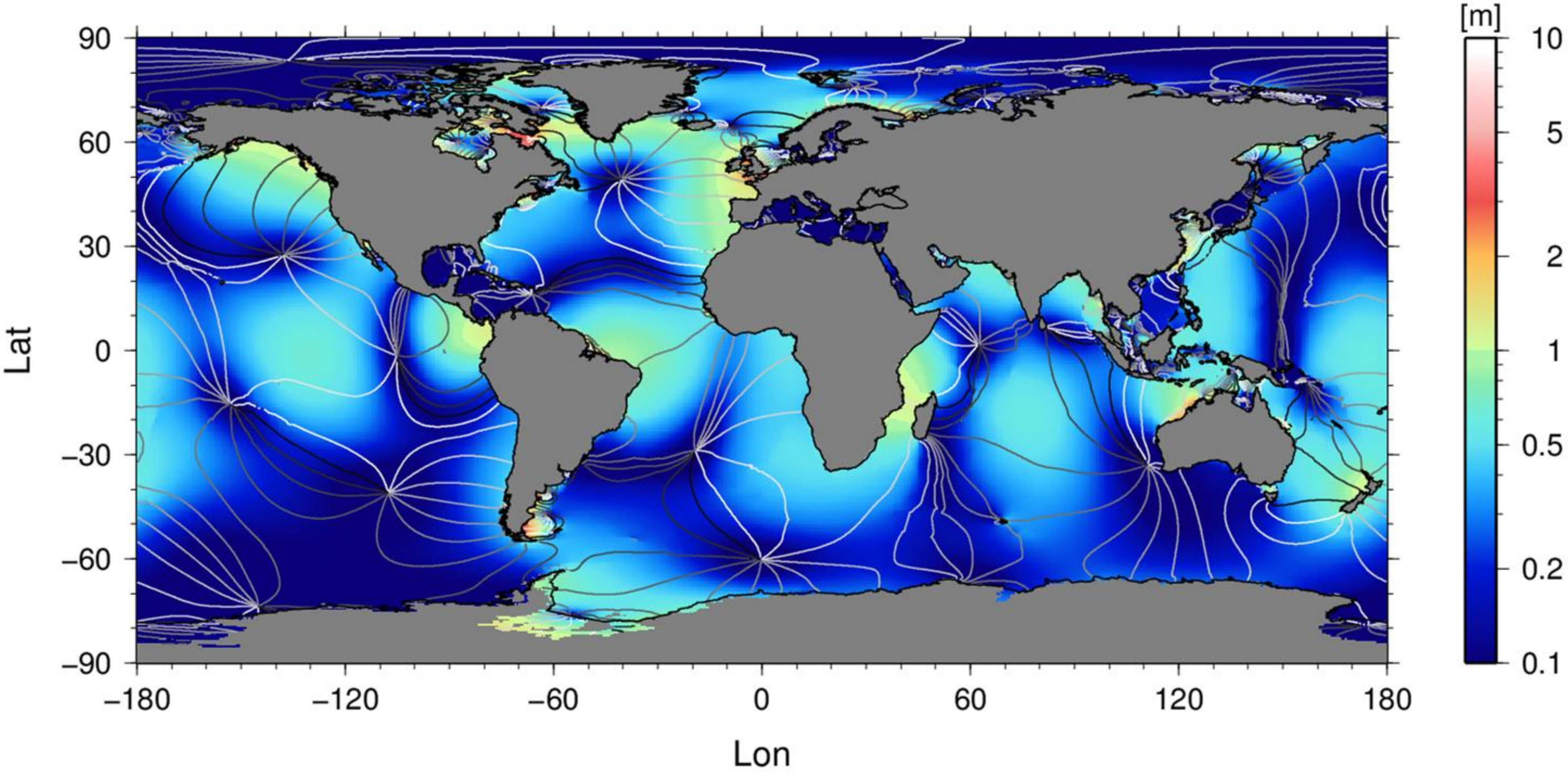


Image: Hans-Georg Scherneck

OTL models

Earth model

Ocean tide model

Model of ocean tidal loading

GNSS - Global Navigation Satellite System

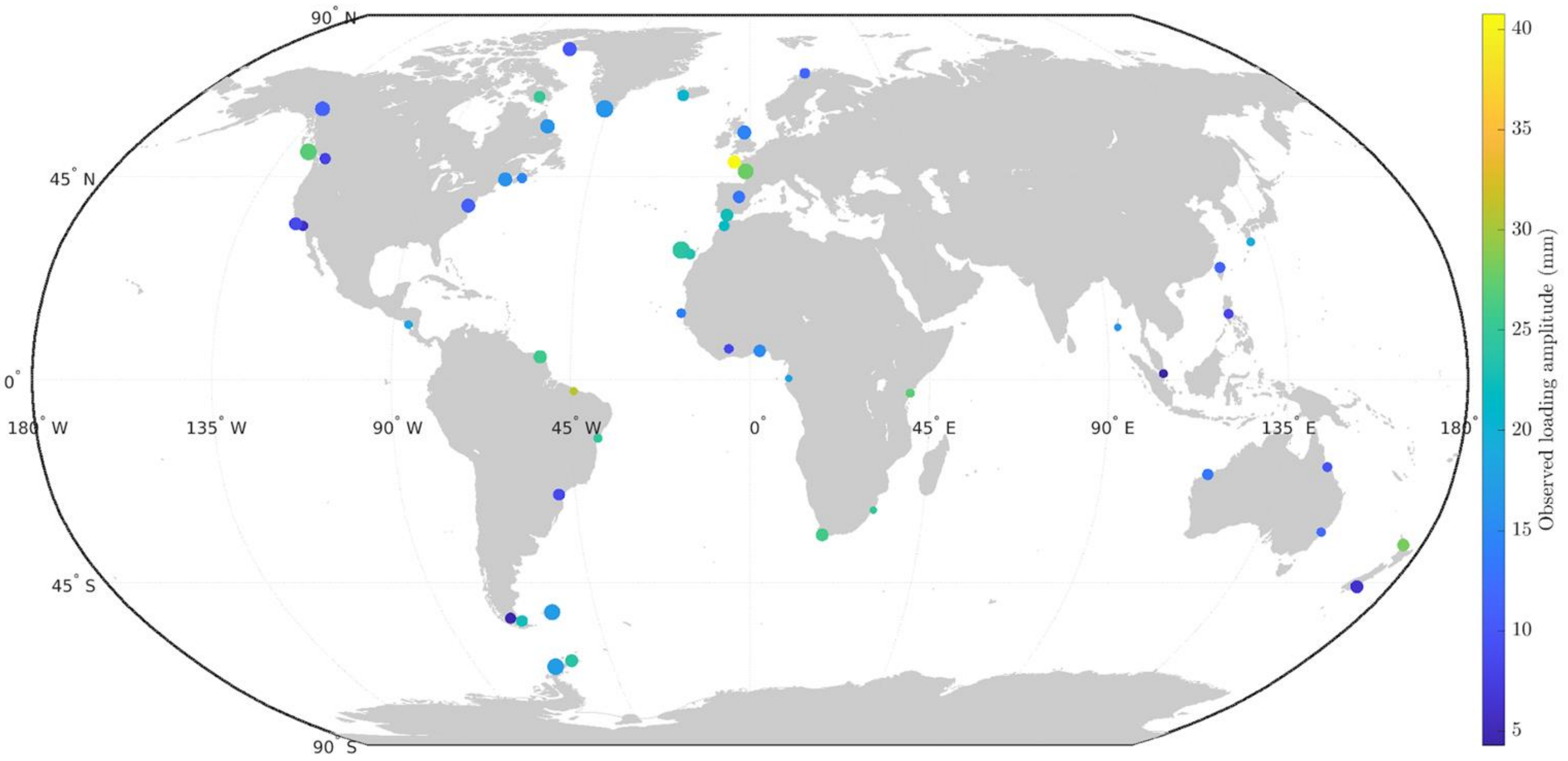
Images: Wikimedia, Alpsdake

Aims for the master thesis

1. Observe OTL with GNSS
2. Compare observations to 4 OTL models

Results

Observed OTL amplitude, M2 constituent



Summary of results

- Similar results in all 4 OTL models
- GNSS observations are useful for evaluation of OTL models (lunar tides)
    - The difference between models and GNSS observations is 0-2 mm
    - The mean uncertainty is 0.4 mm
- Perturbations are a problem in solar tides
- Adjustments to Earth models could improve OTL predictions
- OTL measurements might be usable for testing Earth models

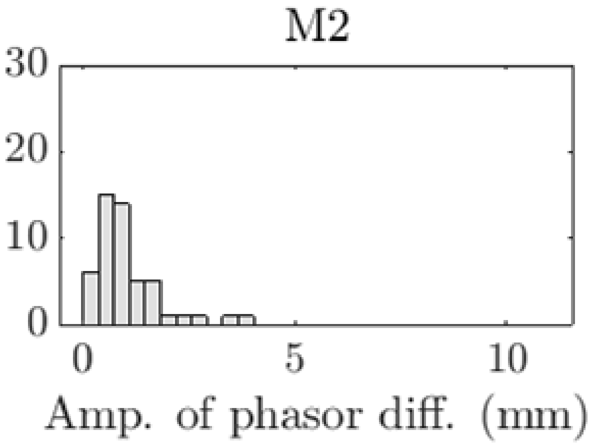
Ocean tidal loading: **amplitude** and **phase**

How many **mm** does the crust move?

When does the effect happen?

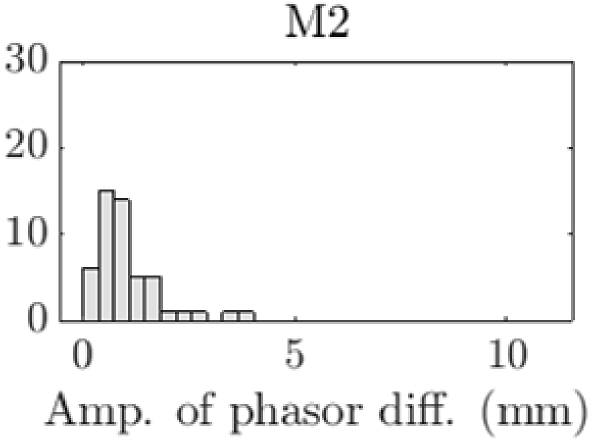
Difference between observation and model

Total difference in mm

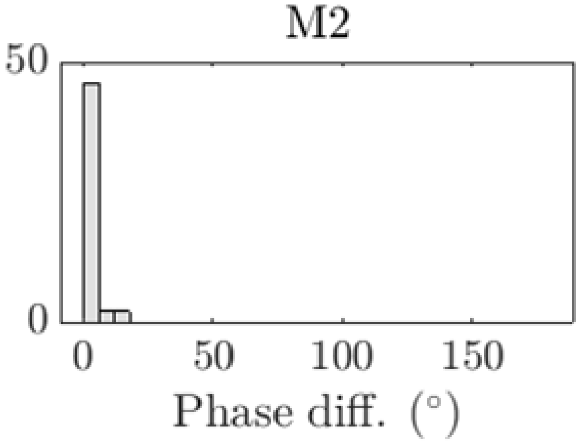


Difference between observation and model

Total difference in mm



Phase difference

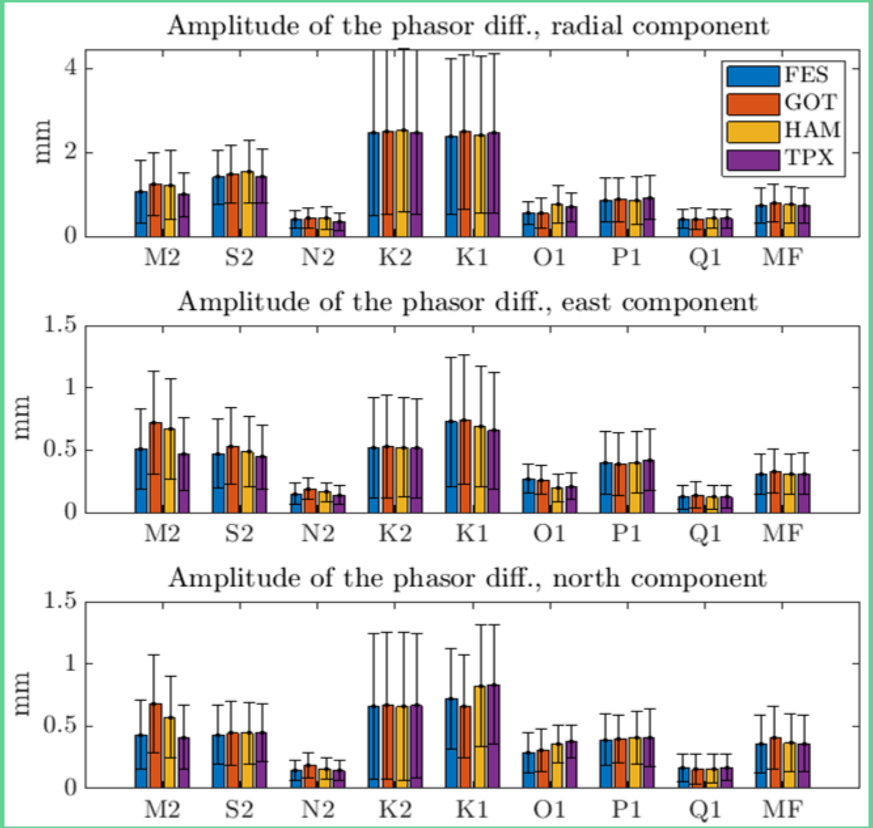


Why is this important?

- GNSS is a powerful tool for geodetic measurements
- OTL models are used in high accuracy GNSS measurements
  - To remove OTL effects
  - To create accurate data used in position determination

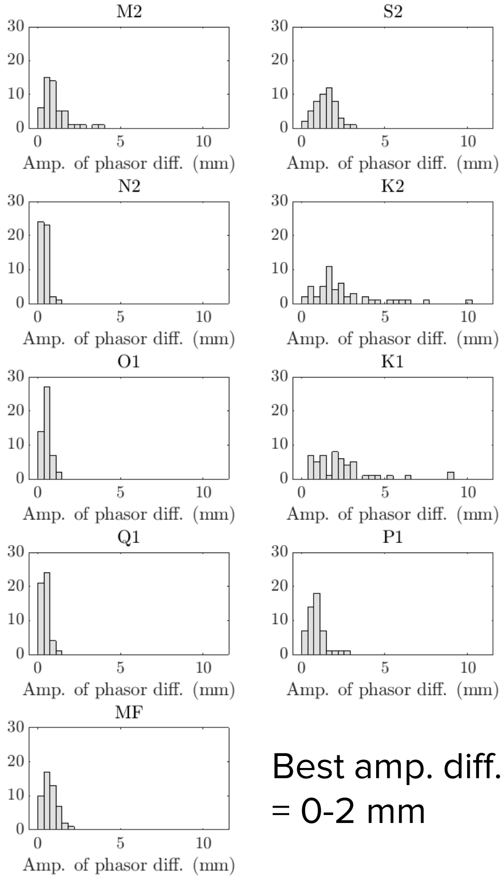
Questions/discussion

Mean amplitude difference for our 4 models



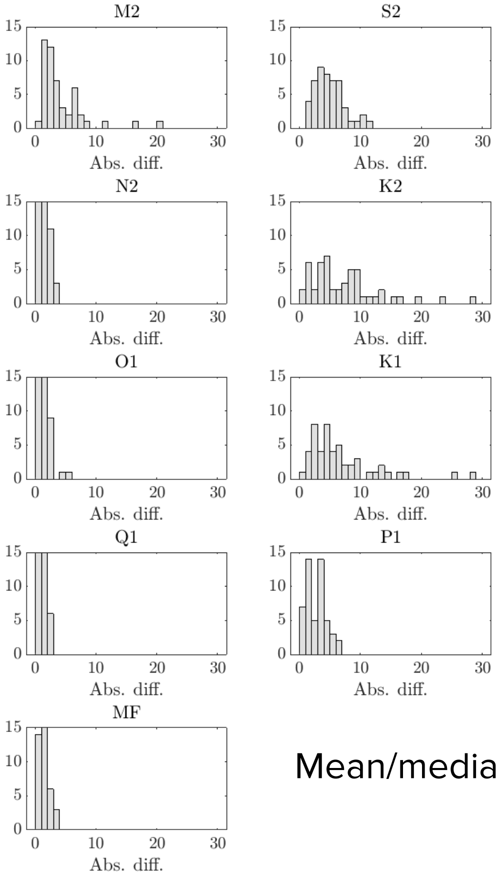
⇒ Similar performance in all 4 models

Amplitude of difference



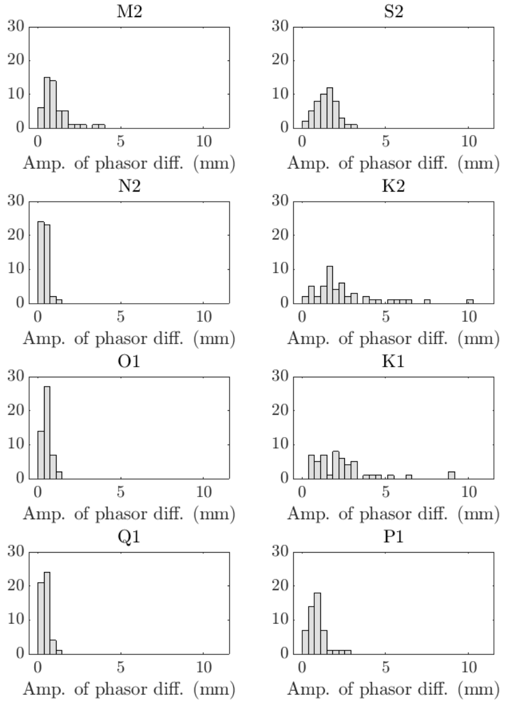
Best amp. diff. = 0-2 mm

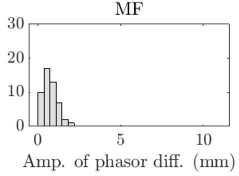
Absolute difference



Mean/median σ = 0.4 mm

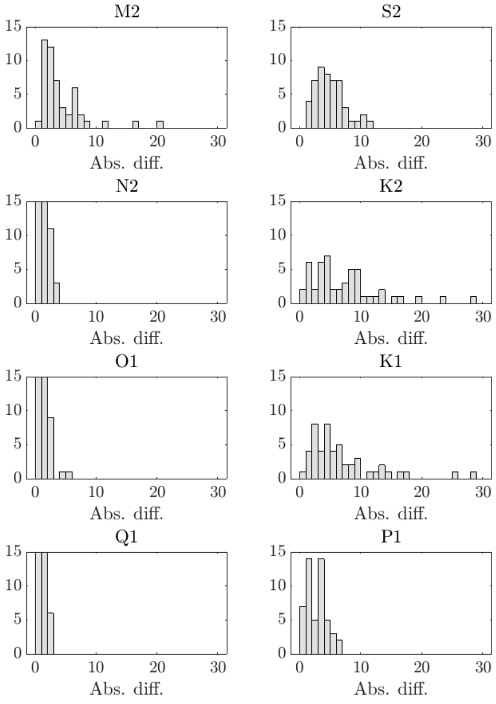
Amplitude of difference

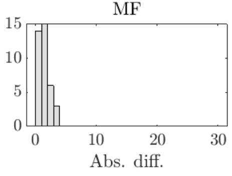




Best amp. diff. = 0-2 mm

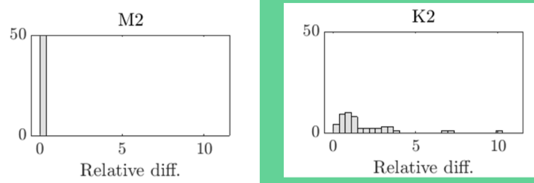
Absolute difference



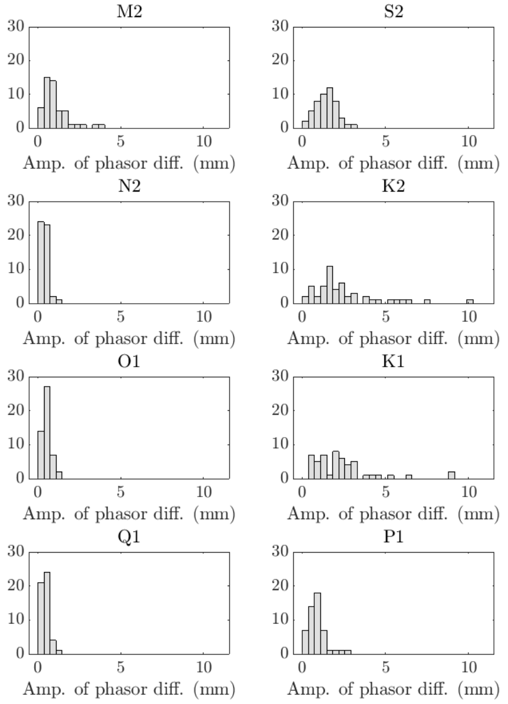


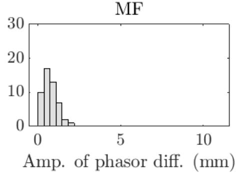
Mean/median σ = 0.4 mm

Relative difference



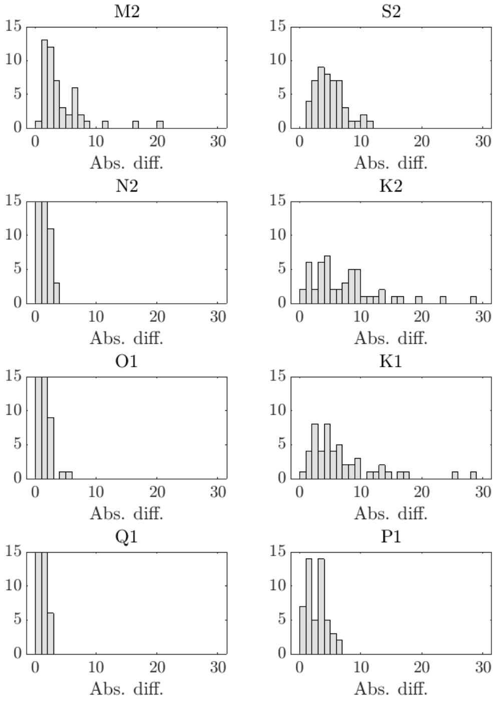
Amplitude of difference

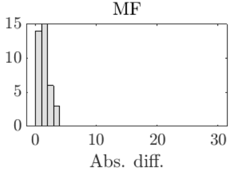




Best amp. diff. = 0-2 mm

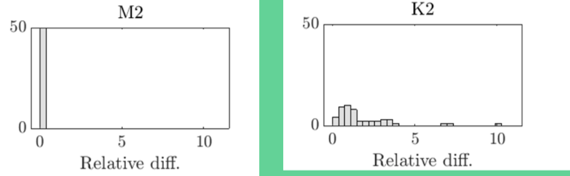
Absolute difference





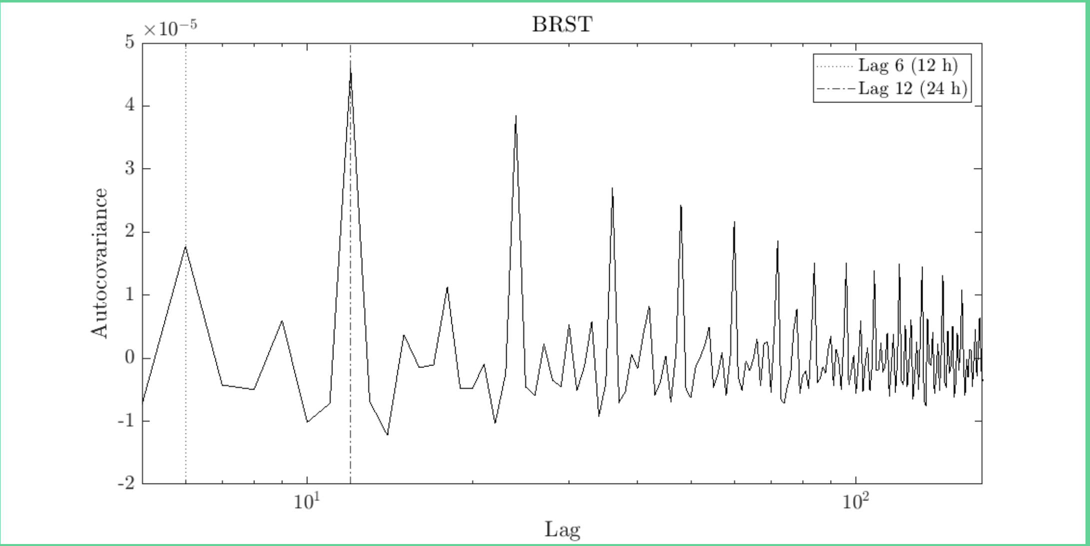
Mean/median σ = 0.4 mm

Relative difference



- GNSS observations are useful for evaluation of OTL models
- The difference between models and observations is 0-2 mm

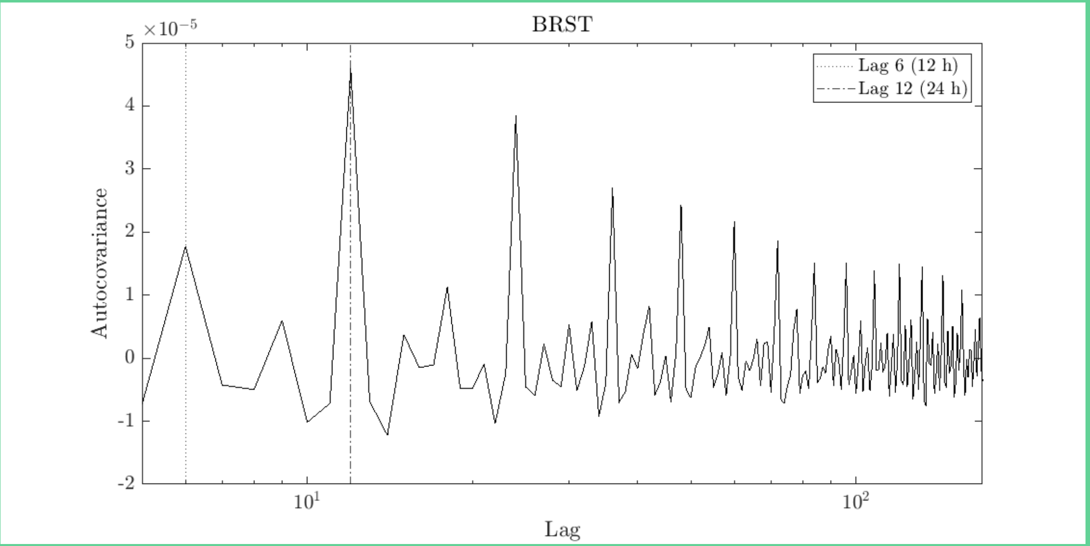
Autocovariance of residual time series



Periodic signal at 12 and 24 h in most sites

⇒ Solar driven perturbations

Autocovariance of residual time series

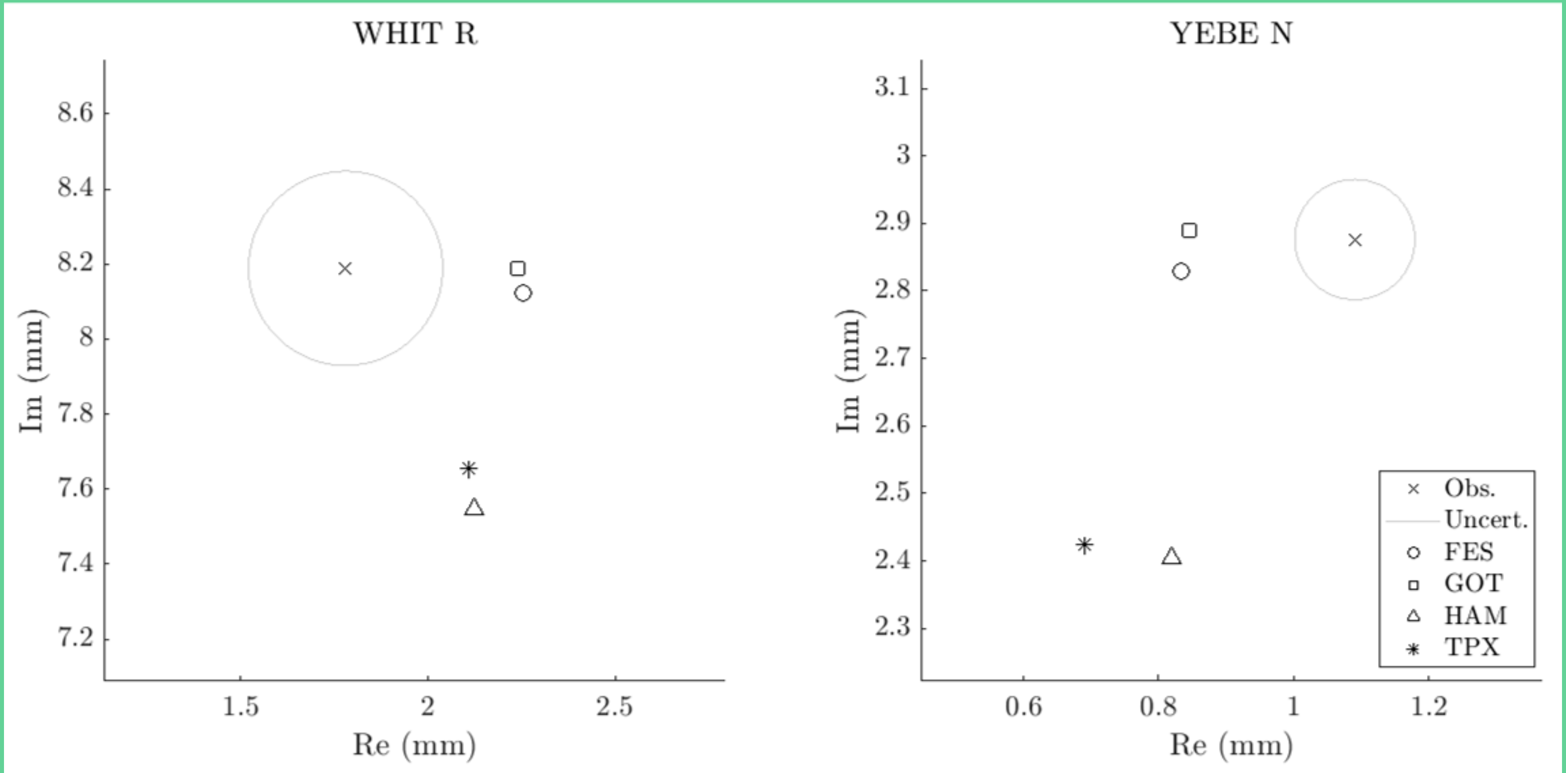


Periodic signal at 12 and 24 h in most sites

⇒ Solar driven perturbations

- Changes to the tidal analysis to reduce solar driven perturbations are needed

Image: Wikimedia, Javiersanp



WHIT R
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
Im (mm)
1.5
2
2.5
Re (mm)
YEBE N
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
Im (mm)
0.6
0.8
1
1.2
Re (mm)
Obs.
Uncert.
FES
GOT
HAM
TPX

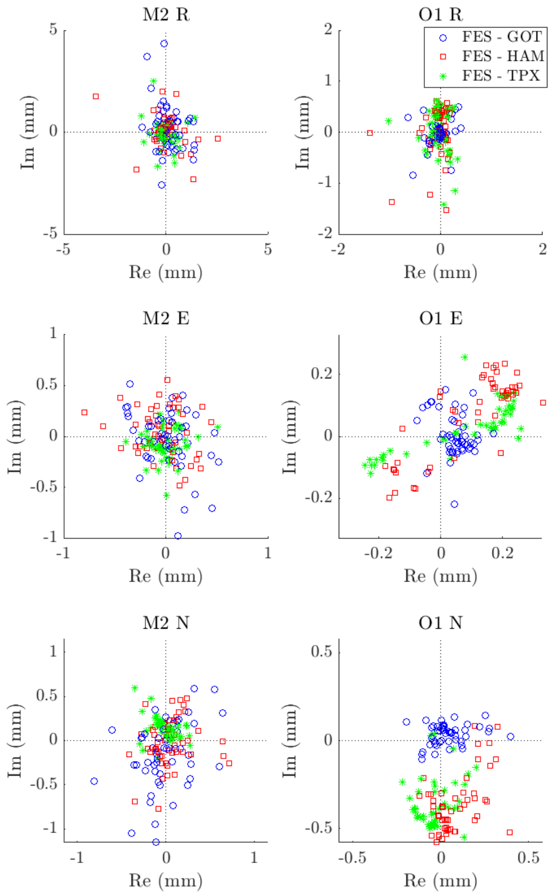

M2 R
O1 R
FES - GOT
FES - HAM
FES - TPX
M2 E
O1 E
M2 N
O1 N
Re (mm)
Im (mm)

Table 4.1: *The amplitude of the radial component of S_1 constituent at all 50 sites (in mm).*

Site	Amp.	Site	Amp.	Site	Amp.	Site	Amp.	Site	Amp.
MANA	0.165	DUND	1.016	FALK	1.629	MAL2	2.277	LPAL	4.004
SFER	0.198	PBRI	1.101	RABT	1.637	PALM	2.401	PIMO	4.025
NTUS	0.440	BARH	1.109	MORP	1.727	OHI3	2.429	RBAY	4.027
QAQ1	0.621	HLFX	1.117	VNDP	1.757	MAS1	2.622	NKLG	4.040
SYDN	0.634	PARC	1.156	YEBE	1.800	IQAL	2.678	HNUS	4.241
RIO2	0.799	TRO1	1.193	HNPT	2.054	WHIT	2.715	SALU	4.444
AUCK	0.813	THU2	1.208	BRST	2.100	BJCO	2.838	KARR	4.456
GMSD	0.818	OUS2	1.333	LROC	2.118	KOUG	3.372	TCMS	5.116
UCLP	0.860	REYK	1.540	TOW2	2.128	UFPR	3.466	SAVO	5.946
NAIN	0.988	CHWK	1.613	HOLB	2.195	YKRO	3.522	DAKR	6.019

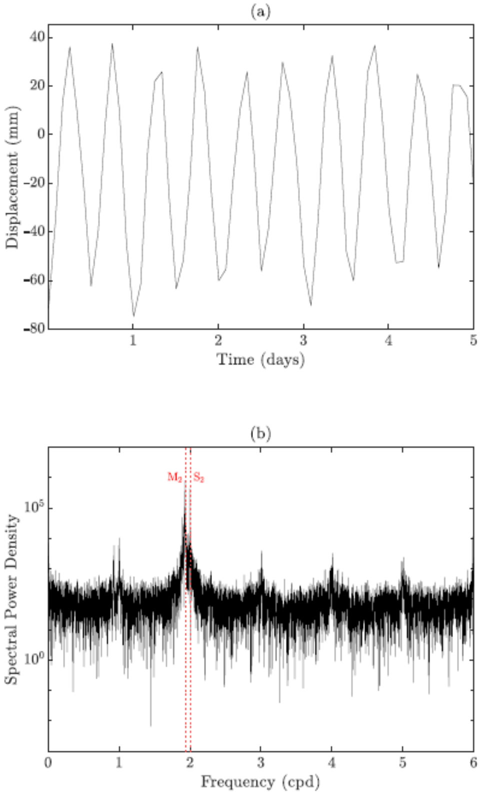
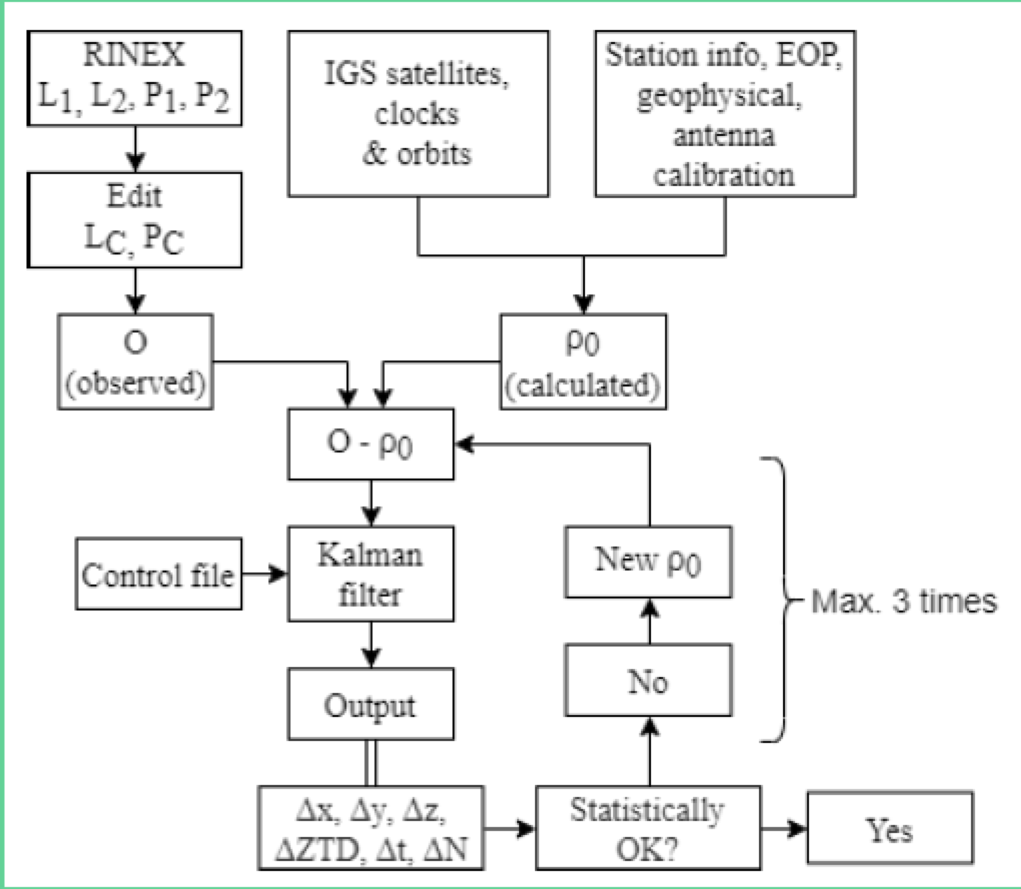


Figure 2.1: *Example of a time series containing a periodic signal caused by ocean loading. (a) shows the 5 day long time series. The spectral density of the time series is displayed in (b), and the peaks show the presence of several periodic signals, i.e. ocean loading constituents (the M_2 and S_2 constituents have been marked). The time series is from the GNSS station BRST.*



RINEX
L1, L2, P1, P2
IGS satellites, clocks & orbits
Station info, EOP, geophysical, antenna calibration
Edit
LC, PC
O (observed)
ρ0 (calculated)
O - ρ0
Control file
Kalman filter
Output
Δx, Δy, Δz, ΔZTD, Δt, ΔN
Statistically OK?
Yes
No
New ρ0
Max. 3 times

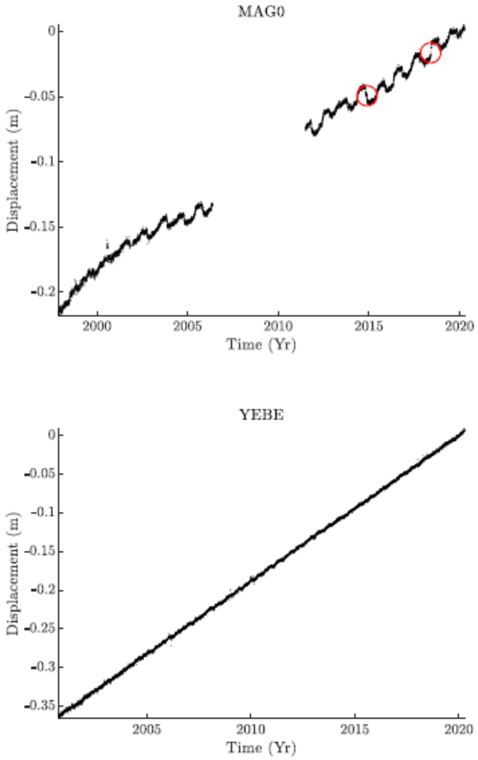


Figure 3.1: *Time series from GNSS stations MAG0 and YEBE. The MAG0 time series contains many jumps (two examples indicated by red circles). It is therefore unsuitable for ocean tidal loading measurements. The YEBE time series contains no such jumps however, and was therefore one of the chosen stations with good data quality.*

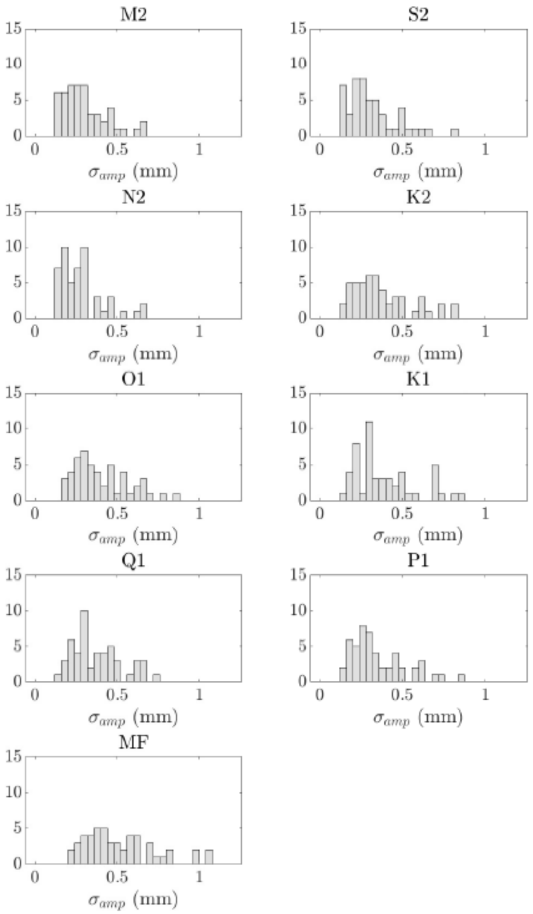


Figure 4.6: *Histograms of the amplitude uncertainty σ_{amp} of the observed ocean tidal loading for each constituent.*

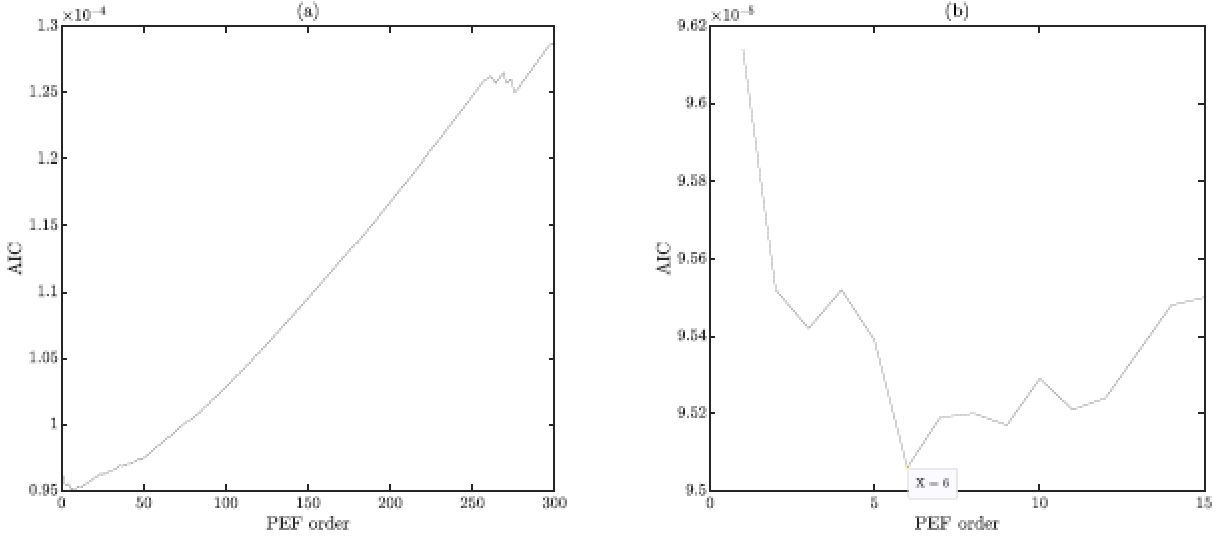
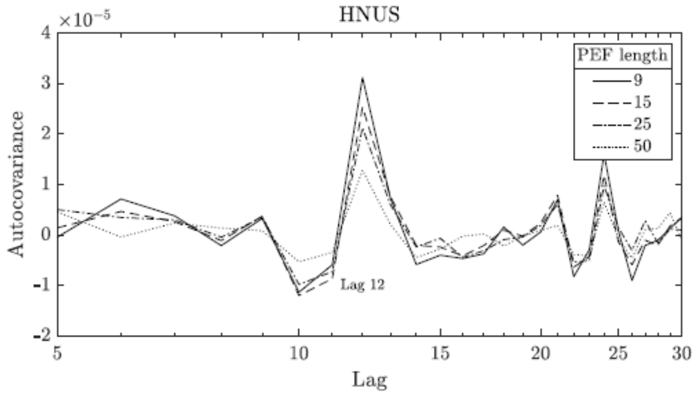


Figure B.1: *The Akaike Information Criterion (AIC) for determining the maximum entropy order of urtapt's PEF. The minimum AIC at PEF order 6 shows that this is the maximum entropy PEF order. Radial component of the ONSA station.*



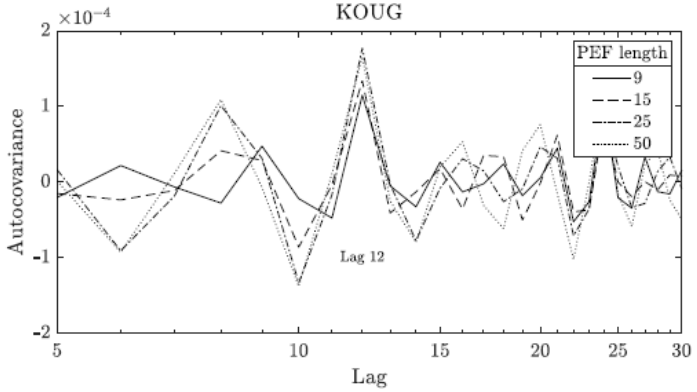
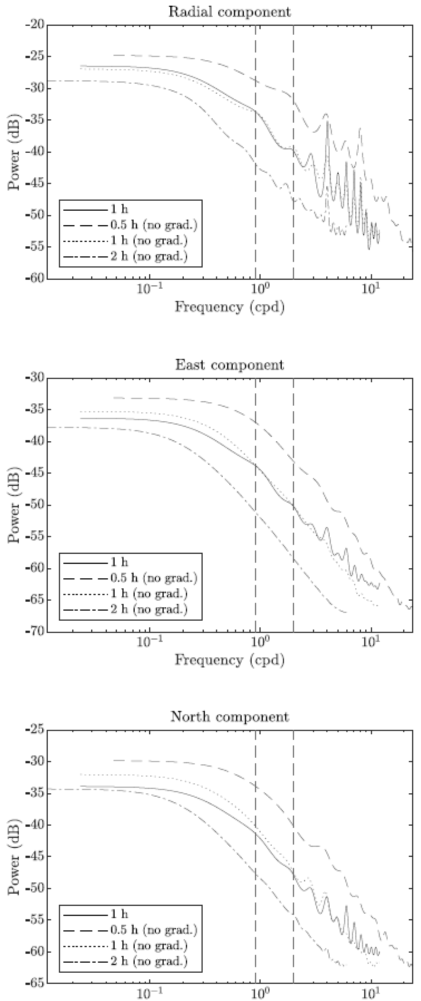
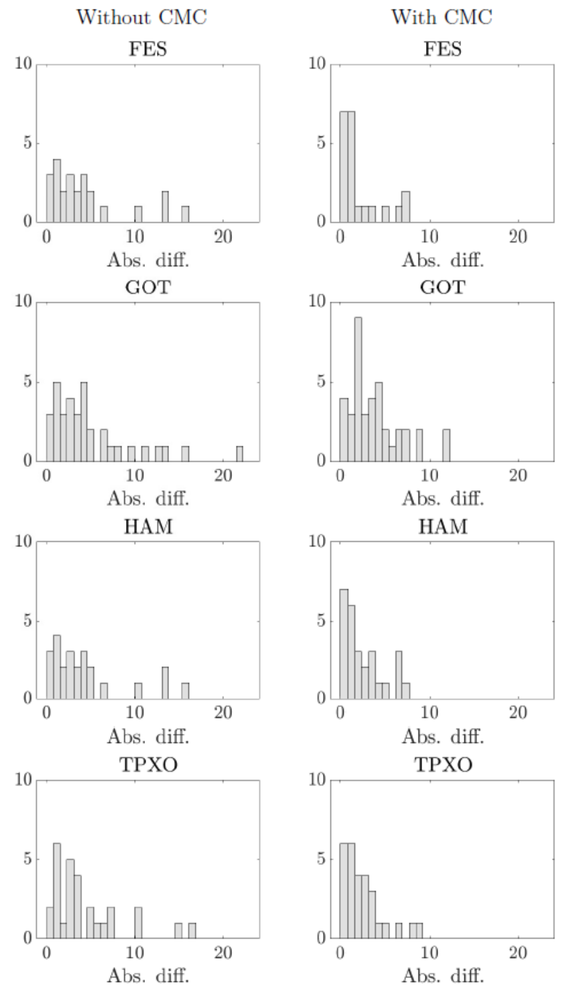


Figure B.2: *The autocovariance of the filtered residuals from the urtapt output yielded by analysing GNSS time series from stations HNUS and KOUG. Four PEF lengths were used: 9, 15, 25 and 50. The autocovariance at lag 12 (1 cyc./day) is lowest at PEF length 50 for HNUS, and 9 for KOUG.*


Radial component
Power (dB)
Frequency (cpd)
1 h
0.5 h (no grad.)
1 h (no grad.)
2 h (no grad.)
East component
Power (dB)
Frequency (cpd)
1 h
0.5 h (no grad.)
1 h (no grad.)
2 h (no grad.)
North component
Power (dB)
1 h
0.5 h (no grad.)
1 h (no grad.)
2 h (no grad.)



Without CMC
With CMC
FES
GOT
HAM
TPXO
Abs. diff.