Monitoring the world's tallest sculpted building through GPS observables

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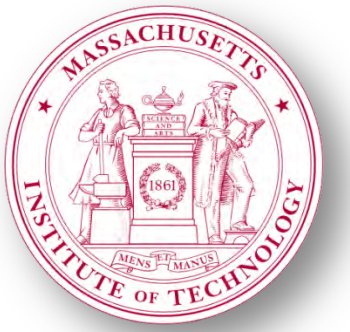


Overview

- part of a research project on the sustainability of the Kuwait built infrastructures in collaboration with CEE (MIT) and KISR (Kuwait).

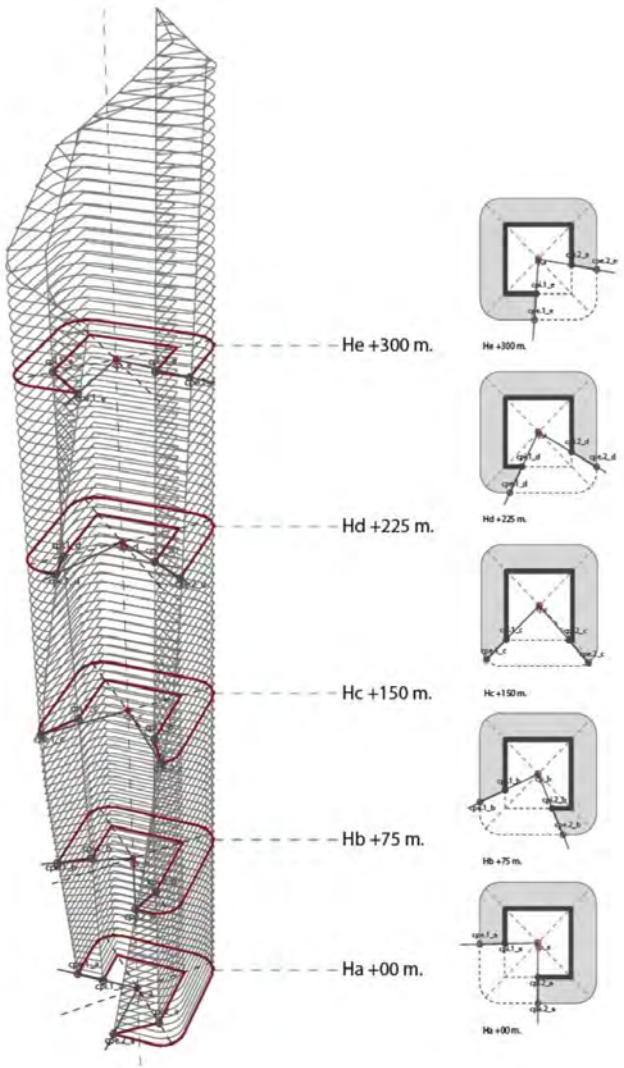
– GPS monitoring of the Al-Hamra tower (world's tallest sculpted building)

- Logistics of the installations and data quality
- Daily averaged position estimates and their correlation with temperature.
- Sub-daily position estimates (6-hours averaged) and multipath impact
- Observations of building fundamental modes with 1-Hz GPS measurement

Al-Hamra Tower Kuwait

- World's tallest sculptured building
- Concrete core with glass curtain wall. South facing stone clad exterior
- Designed by Skidmore, Owings & Merrill (SOM) Chicago

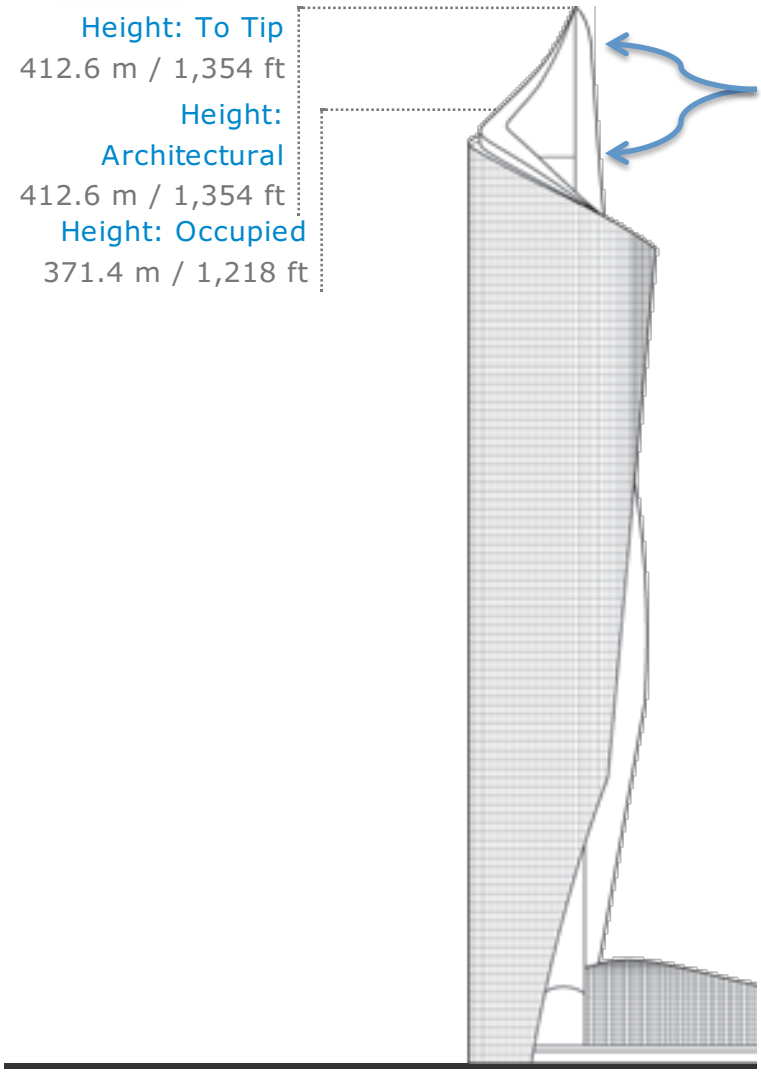
Sectional views



The curtain wall rotates as you move up the building.

Stone cladding on concrete core faces approximately south.

GPS locations



2 GPS sites at Al-Hamra tower

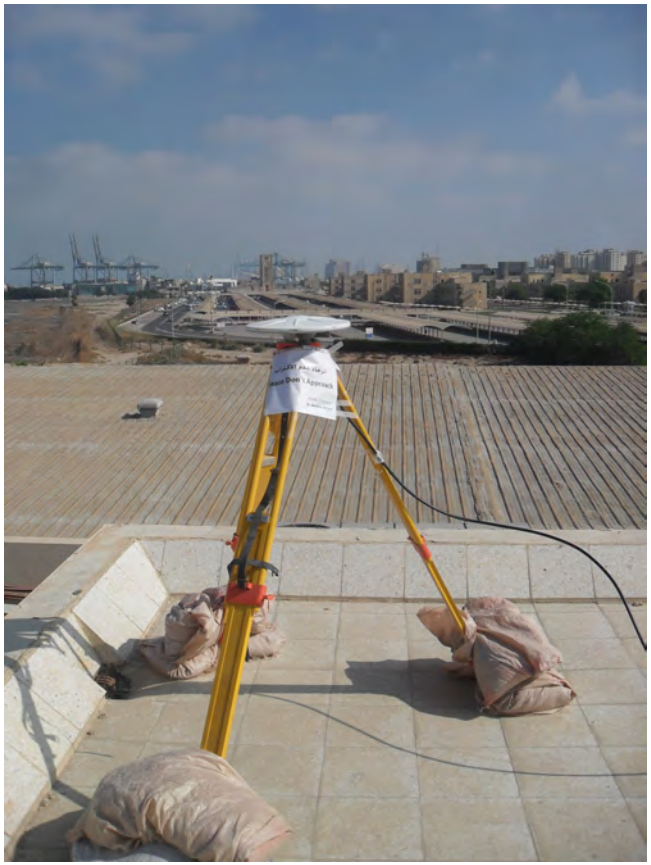
-80th floor ~ 370 m

-86th floor ~ 410 meters

1 GPS site at KISR seismology building

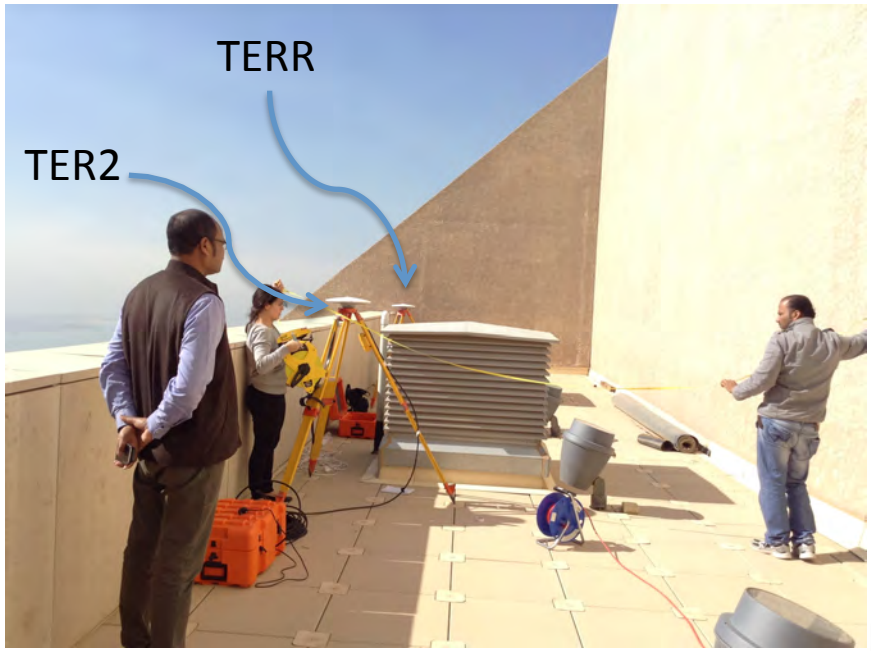
KISR reference site

KISR site: Sky is clear except for some obstructions from building to the North-West. Temporary location waiting for permanent installation).



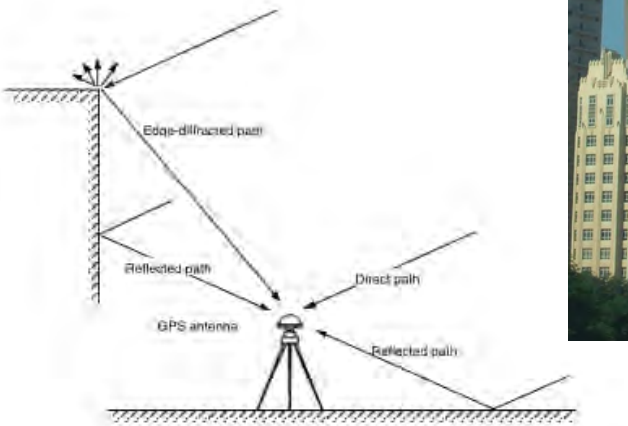
Also use the KUWT site at Kuwait University

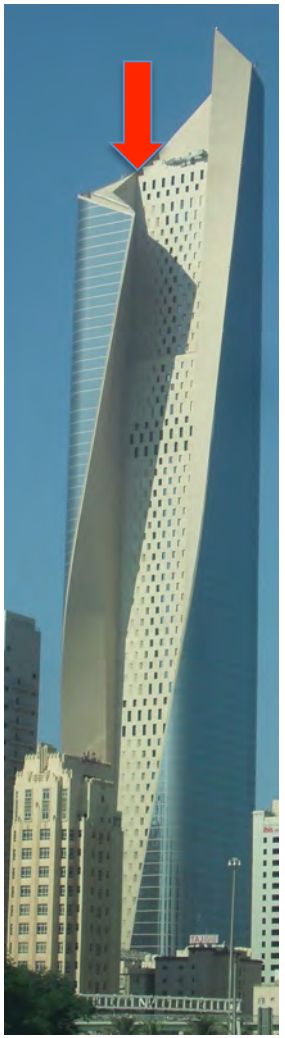
Al-Hamra Terrace sites



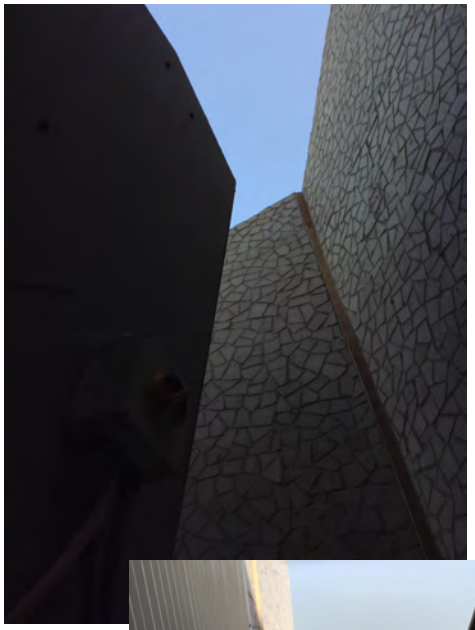
Multipath effects position estimates for sub-daily positions (diurnal building changes, earthquake surface waves)

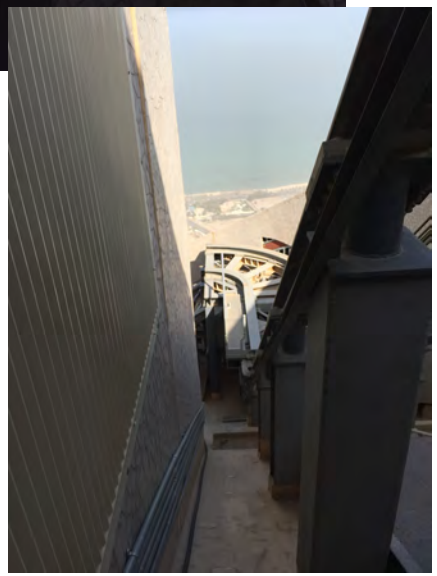
Blockage of sky makes the geometry poor at certain times of day

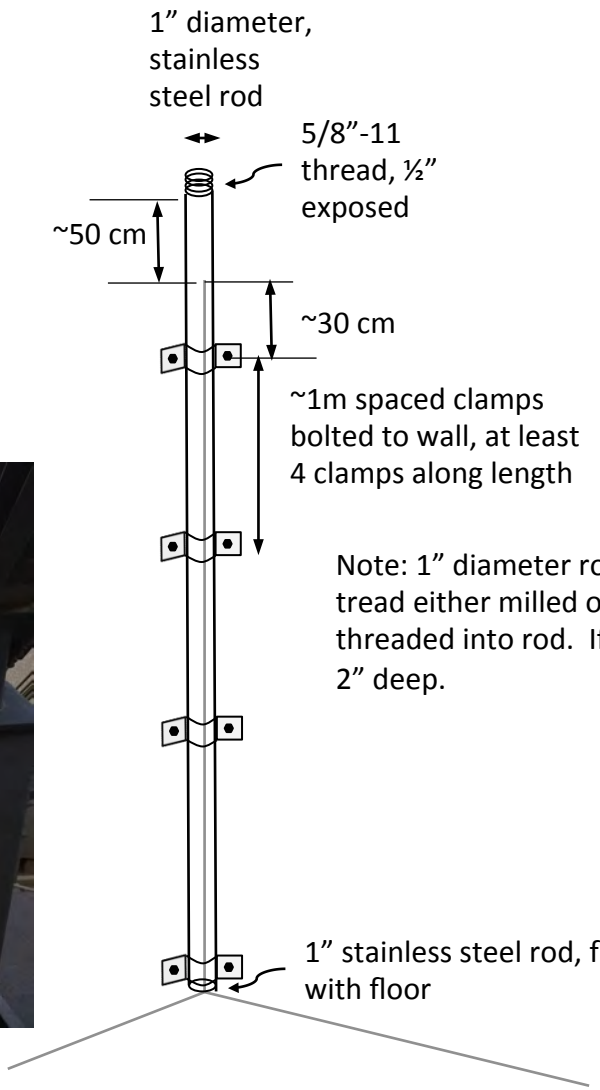


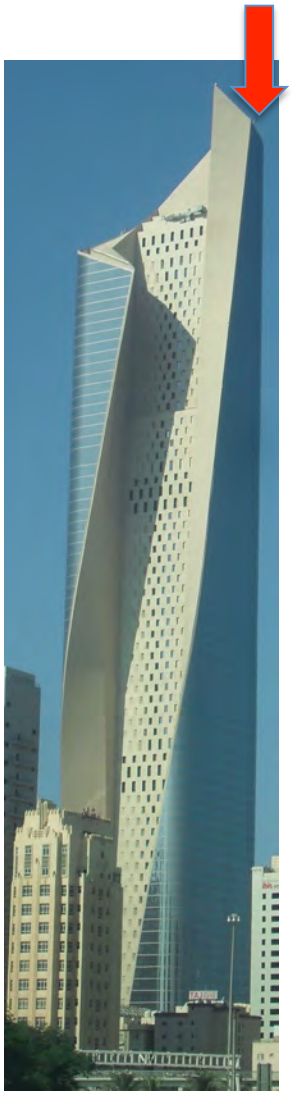


86th floor site ALHR





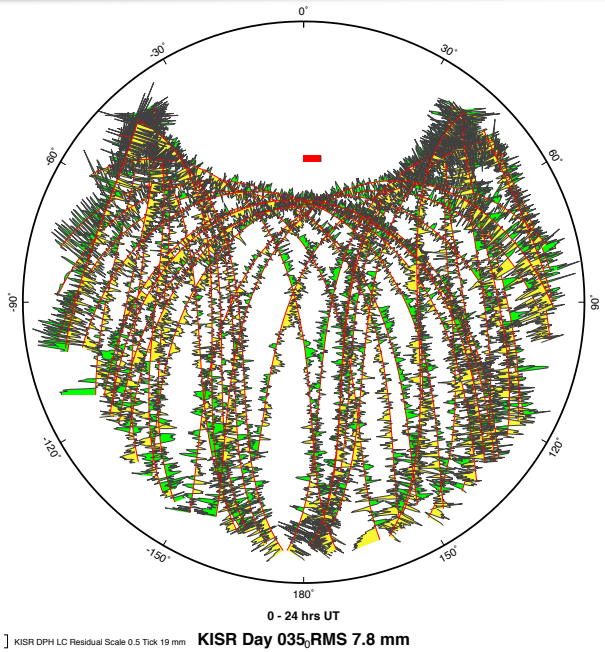




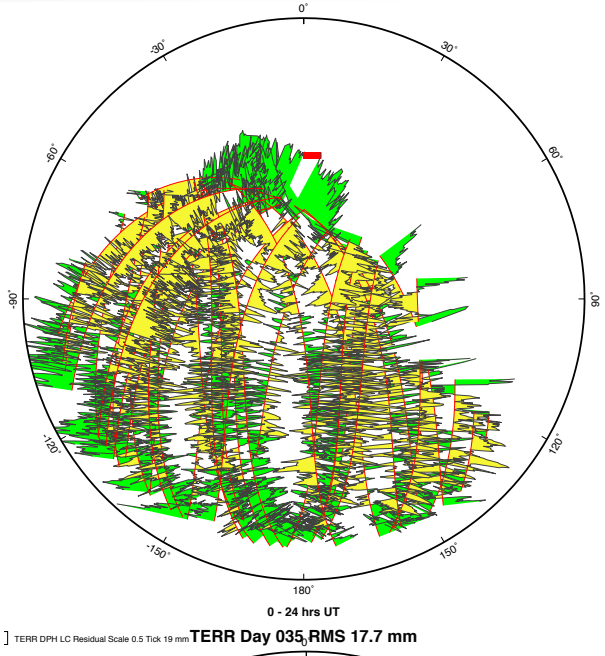
Sky plots of phase residuals

Red bar is 20 mm

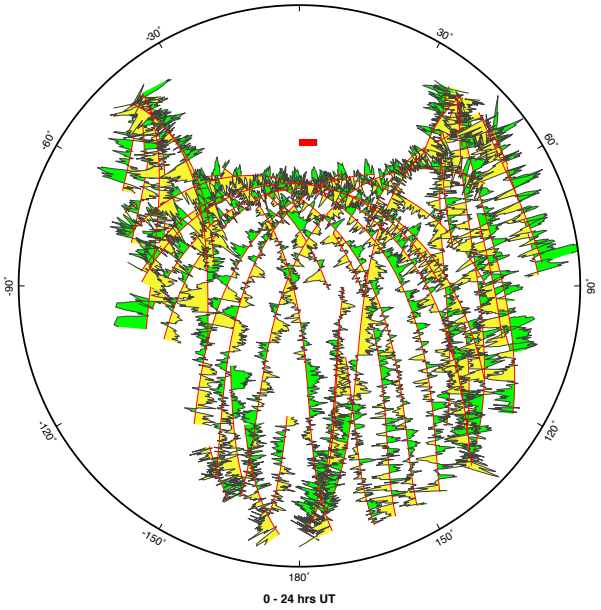
KISR



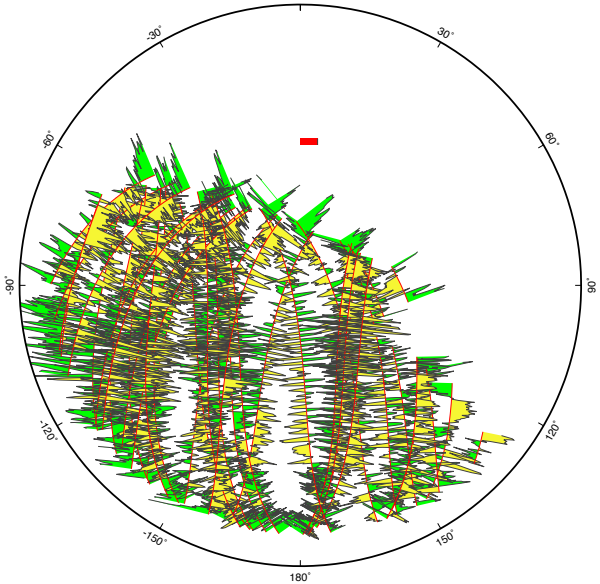
AL-HAMRA TERRACE



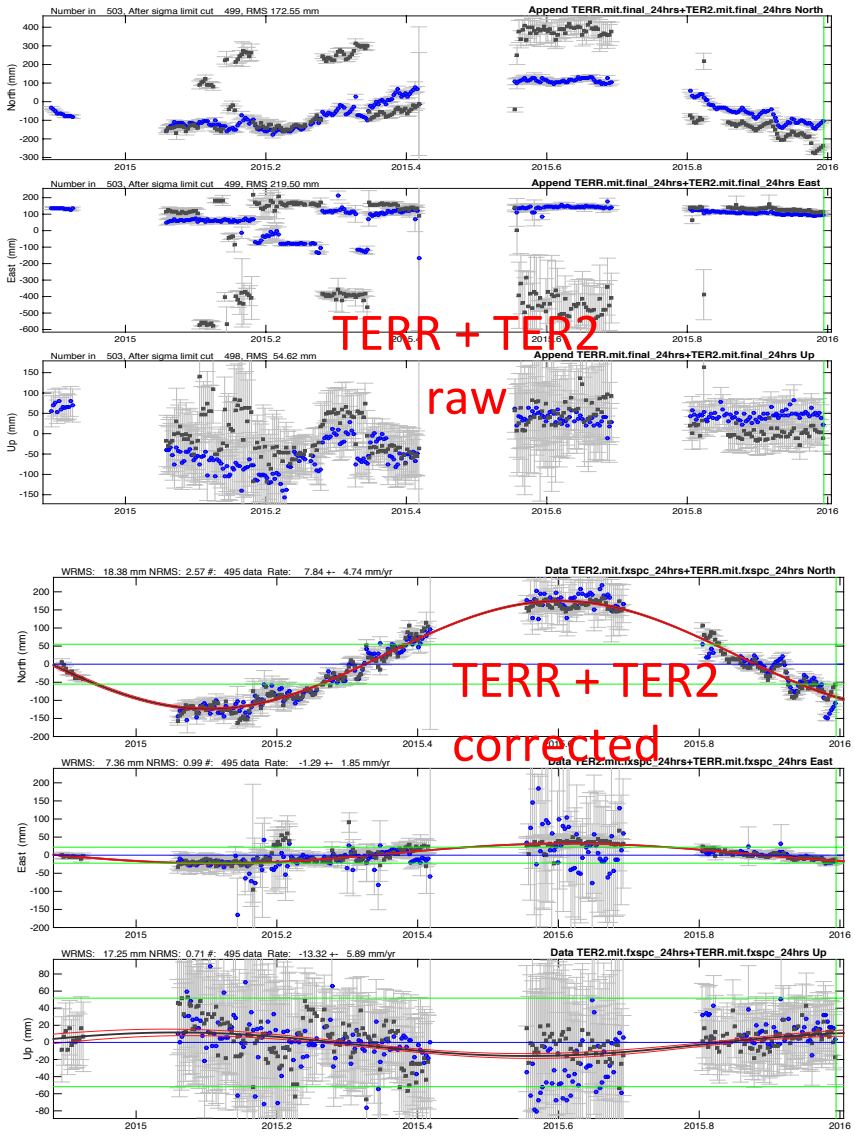
86th Floor ALHR



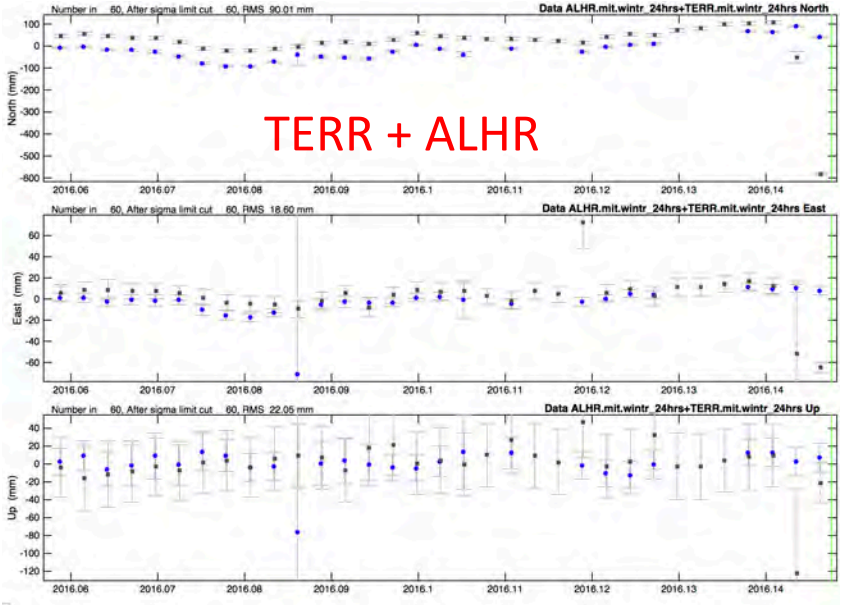
AL-HAMRA TERRACE 2



Long term motion of the Al-Hamra tower



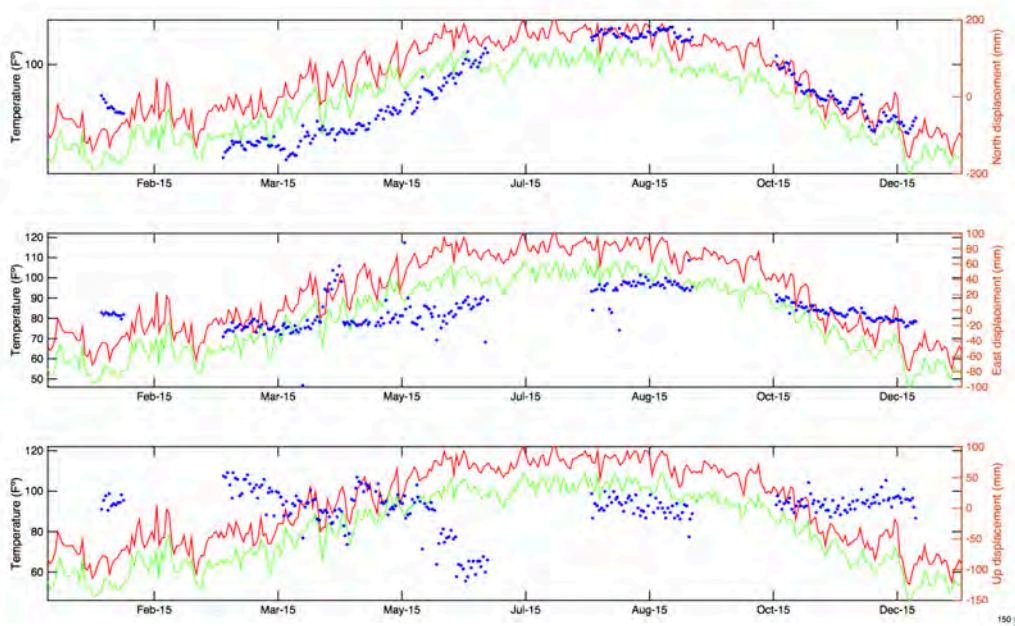
Breaks in the raw estimates are due to tripods being disturbed. Data gaps are power loss



Strong seasonal motion of the building

New site ALHR shows same seasonal motion as TERR

Comparison of long term motion with temperature

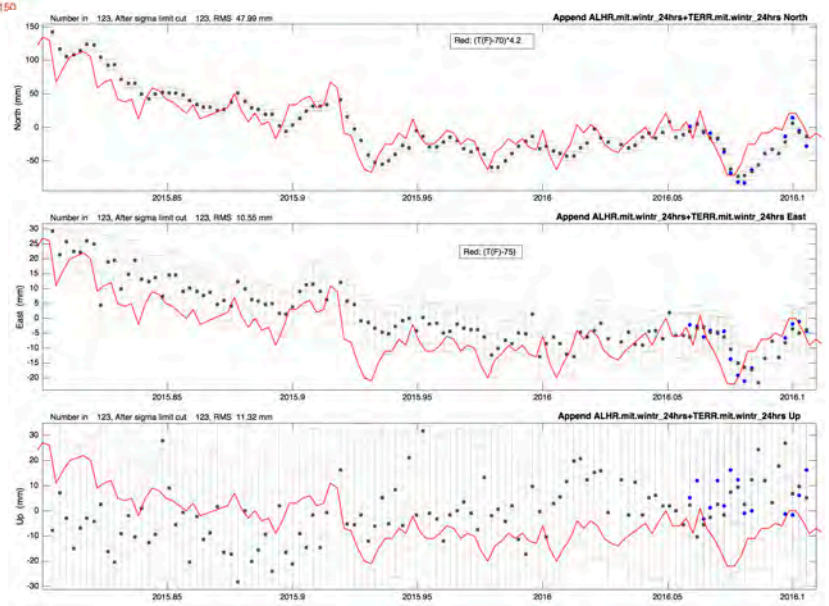


Temperature and North-South motion appear to be correlated

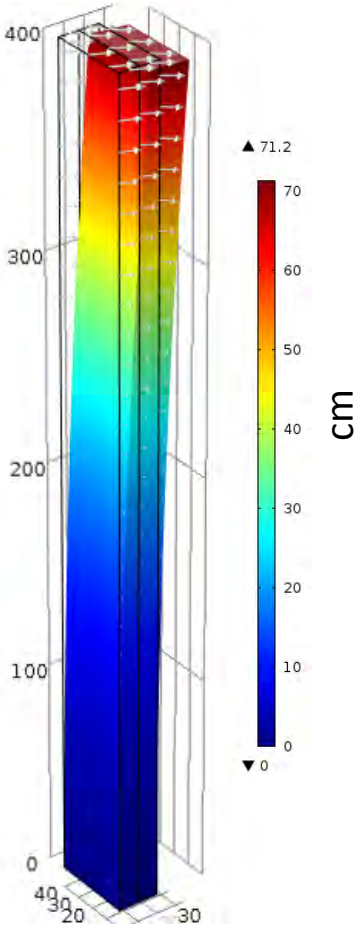
The lag in building response seems to be a few days

Temperature range 12-30 deg.

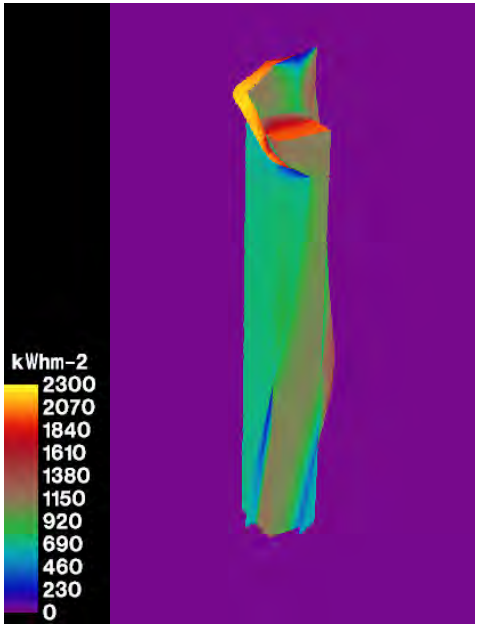
Detail between November 2015 and January 2016



Thermal Model of Al-Hamra

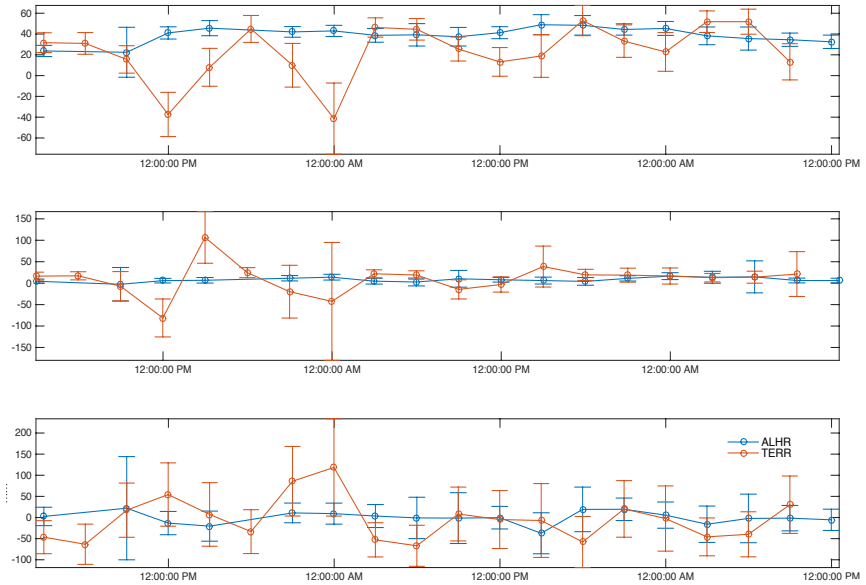


Bimetallic strip deformation for 1° C difference between the south and north wall



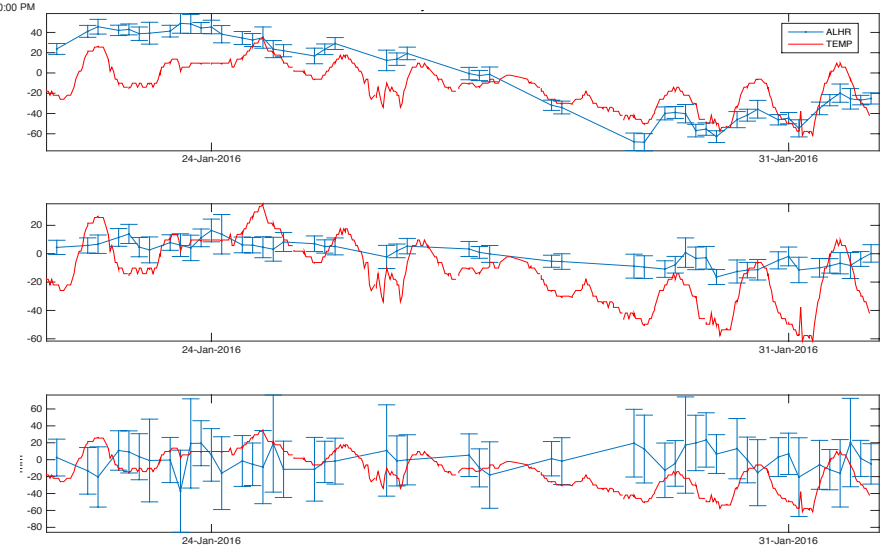
Solar radiation variation during the year

Sub-daily motion of the Al-Hamra tower



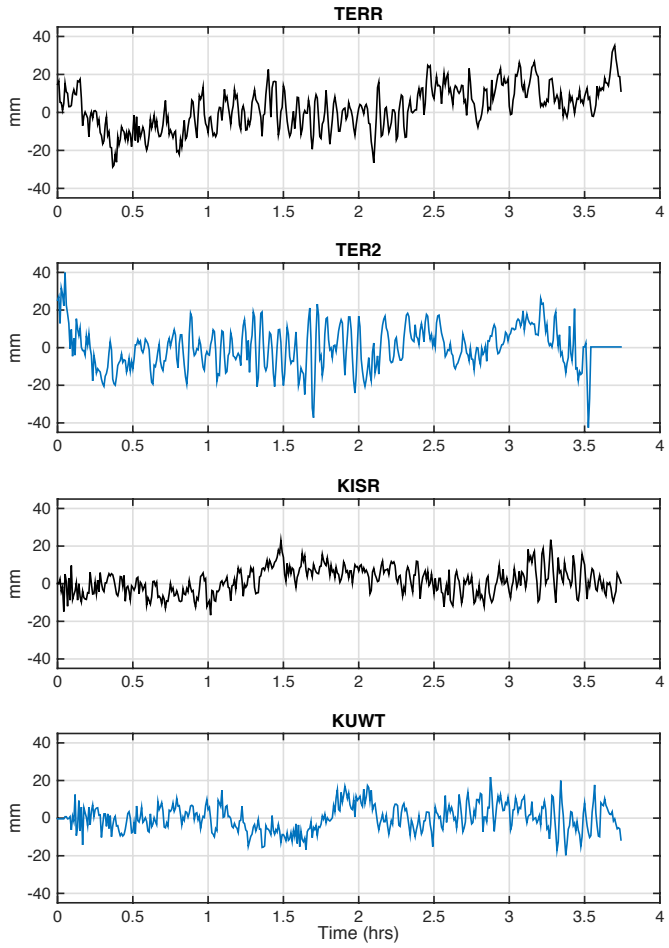
6-hour averaged solutions for ALHR (*blue*) and TERR (orange) sites

TERR sites shows larger errors due to multipath

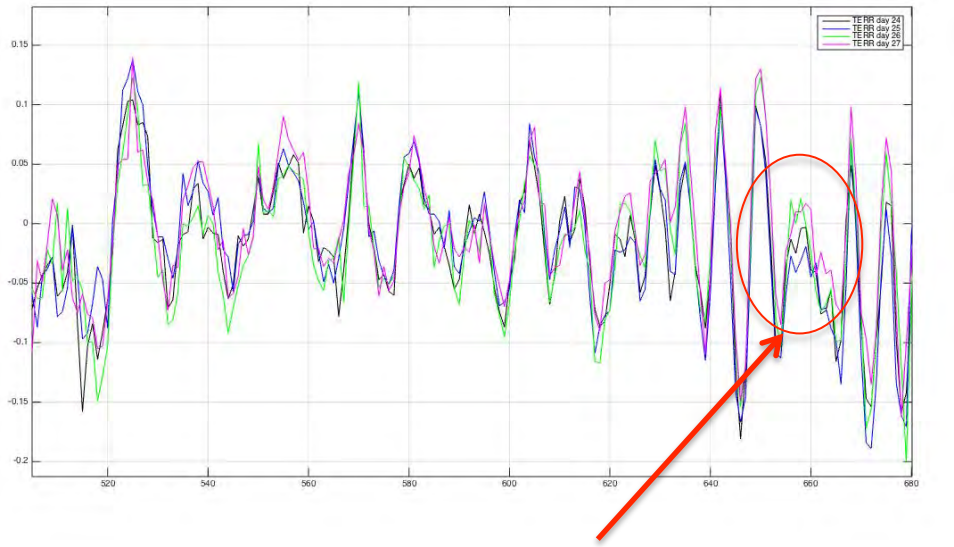


Sub-daily motion of ALHR (*blue*) shows a dependence with temperature (red)

Analysis of multipath through phase residuals

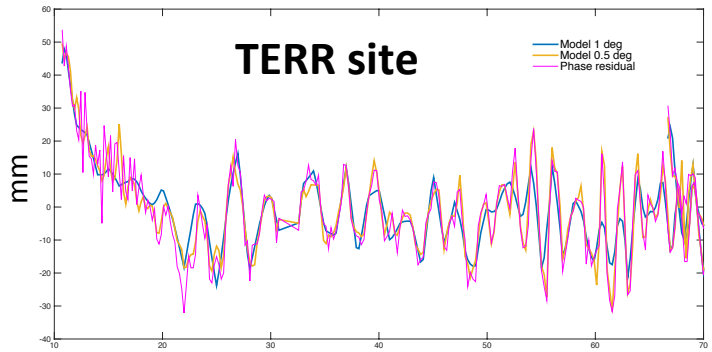


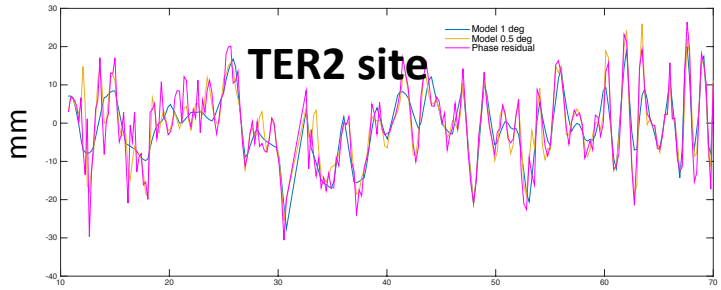
TERR phase residual for 4 consecutive days corrected for the sidereal day



atmospheric effects,
motion of the building?

Multipath correction



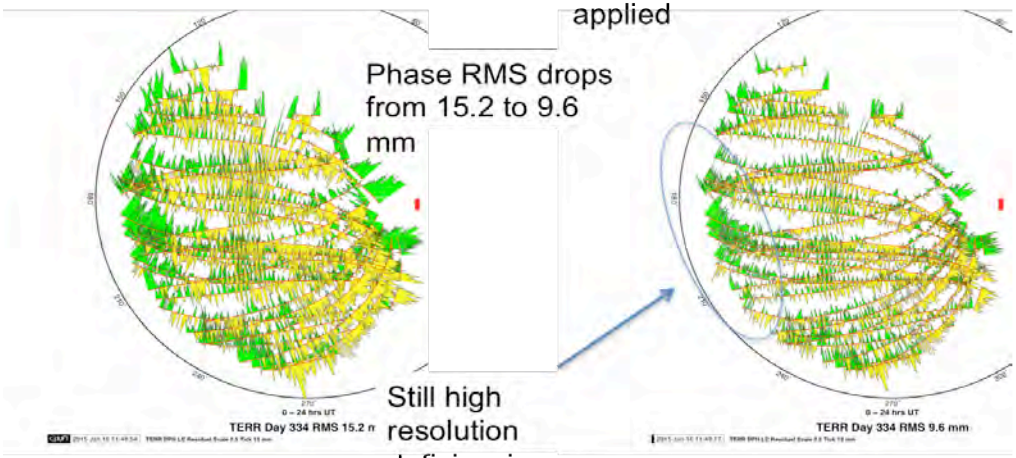


1 degree models are not sufficient to reduce the high frequency component of multipath

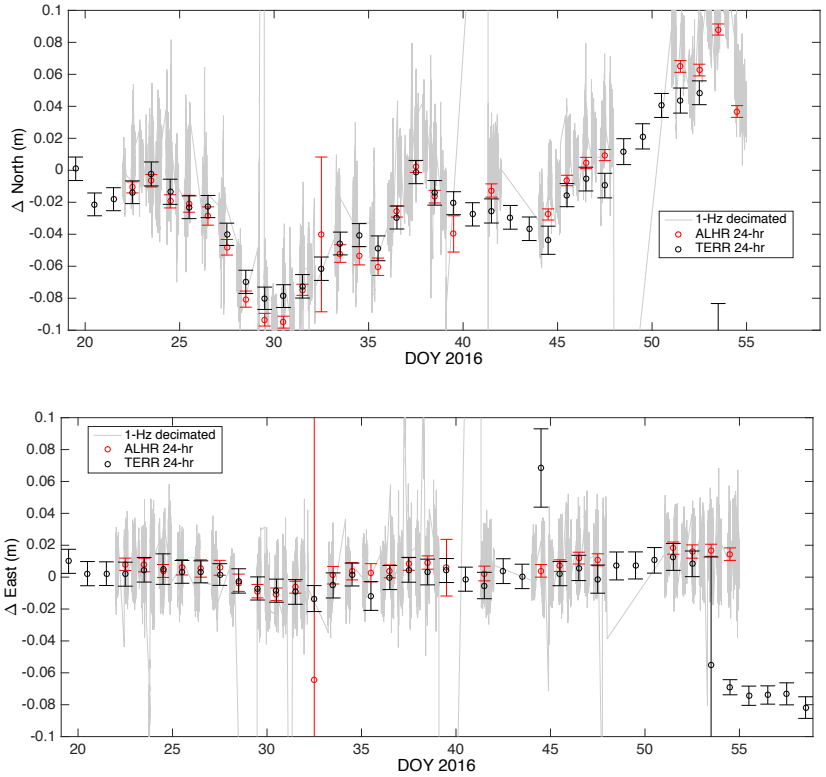
1 degree and 0.5 degree spaced model of the phase residuals for sub-daily estimates

Before multipath model applied

After multipath model, based on 4-averages of residuals is applied

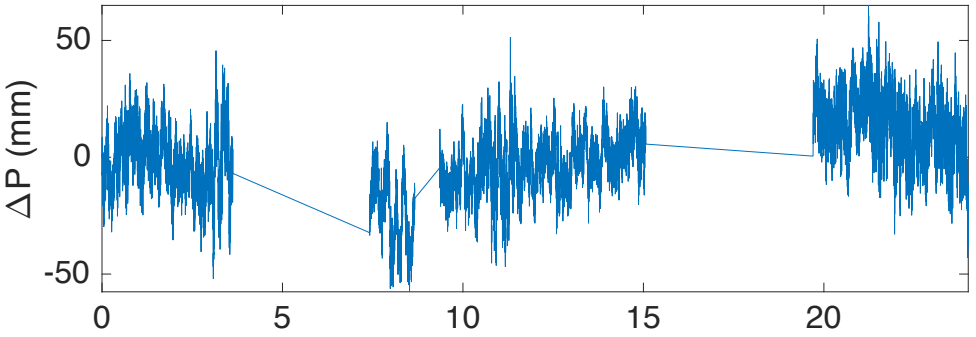


1-Hz solutions

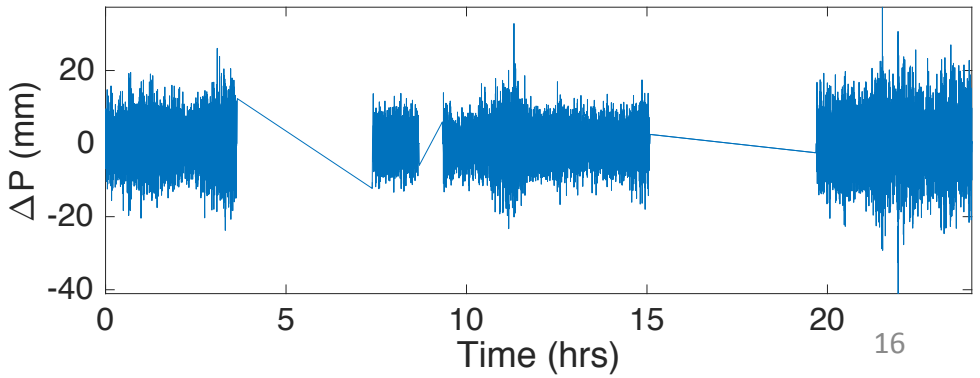


Comparison 1 Hz solutions and 24 hr solutions for TERR and ALHR sites

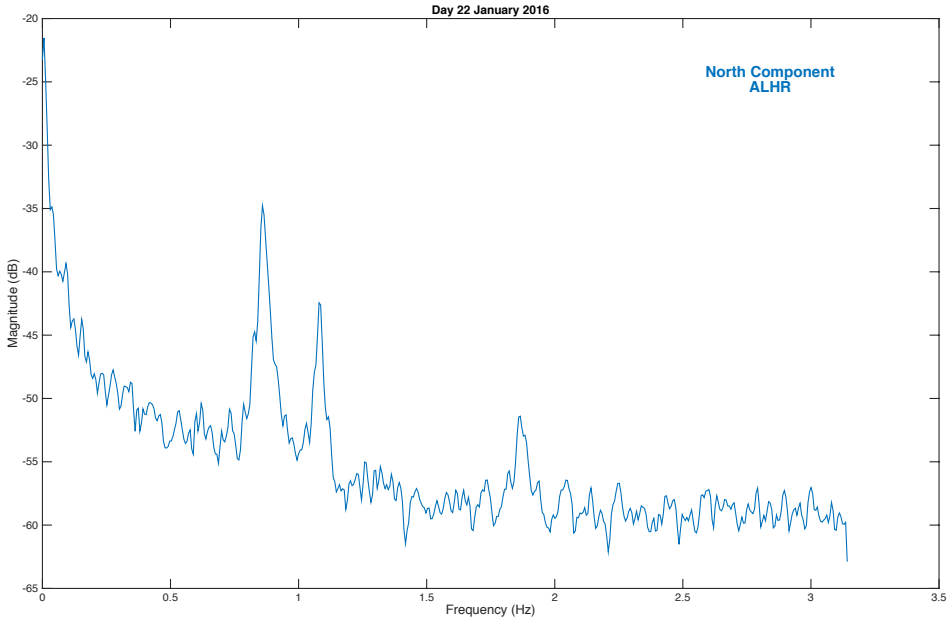
Time series of North position changes at 1-Hz rate.



High filtered. 1-minute moving average smoothed signal removed.



Fundamental modes of Al-Hamra



Comparison between mode frequencies from GPS, seismic ambient noise and Finite element model.

Mode	FE Period (sec)	Ambient noise (sec)	GPS (sec)
North/South	7.87	7.09	7.27
East/West	5.78	5.65	5.82
Torsional	3.34	3.29	3.38

CONCLUSIONS

1. Seasonal motion of the building

- Current GPS results reveal interesting motions of the terrace level near the top of the building
- Strong temperature correlation with daily averaged and sub-daily motions of building
- Simple models need ~5°C temperature differences across building

CONCLUSIONS

2. 1 Hz solutions

- Fundamental modes of building deformation clearly seen in high rate GPS results. Day-to-day variability suggest this is not a GPS artifact
- 1 Hz solutions will be used to study the wind response of the building
- We hope to see mode responses (5-7 second periods) to surface waves from large earthquakes in the Zagros mountains in Iran.

CONCLUSIONS

3. Multipath Analysis

- Al-Hamra terrace sites show a complex pattern of high frequency signals

- These signals repeat every day with a time shift consistent with sidereal day, but there is a complexity associated with atmospheric delay variations and possible building motion during the day

- Phase center models at 0.5 degree better reproduce the phase residuals. We will be incorporating more refined models into the data processing. These models will impact the estimates of the high frequency motions of the building (less than 1 hour).

Thanks!