The Technion Center of Excellence in Exposure Science and Environmental Health

Wireless Distributed Environmental Sensor Networks for Air Pollution Measurement: The Promise and the Current Reality

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What Have We Learnt So Far?
(thanks to all the previous presenters !)

- New miniature cheap sensors for APs are here (to stay)
- They carry a lot of promise (yet to be delivered)
- … but have a lot of problems (childhood diseases)
- … and are NOT maintenance free (require periodical “care” & sophisticated data processing) ⇒ tailored applications
- General agreement: lab calibration is insufficient ⇒ field calibration
- *Collocation* calibration is sub-optimal ⇒ *in-situ* calibration is probably advantageous

What Have We Learnt So Far?
(thanks to all the previous presenters !)

Sensor readings are affected by:

- Meteorological conditions (T, RH, wind speed & direction)
- Land use/ land cover (vegetation/ canopy/ greenness, urban landscape, proximity to sources/roads)
- Environmental conditions (pollutant levels, cross sensitivity/ interference by pollutant mixtures)

⇒ Particle sensors are more reliable

Are We Interested in

- intra- (rather than inter-) neighborhood variability?
- calibration during deployment (continuous reporting)?

$\Rightarrow$ Calibration on-the-fly/ N2N (to ref.) OR to the sensor mean

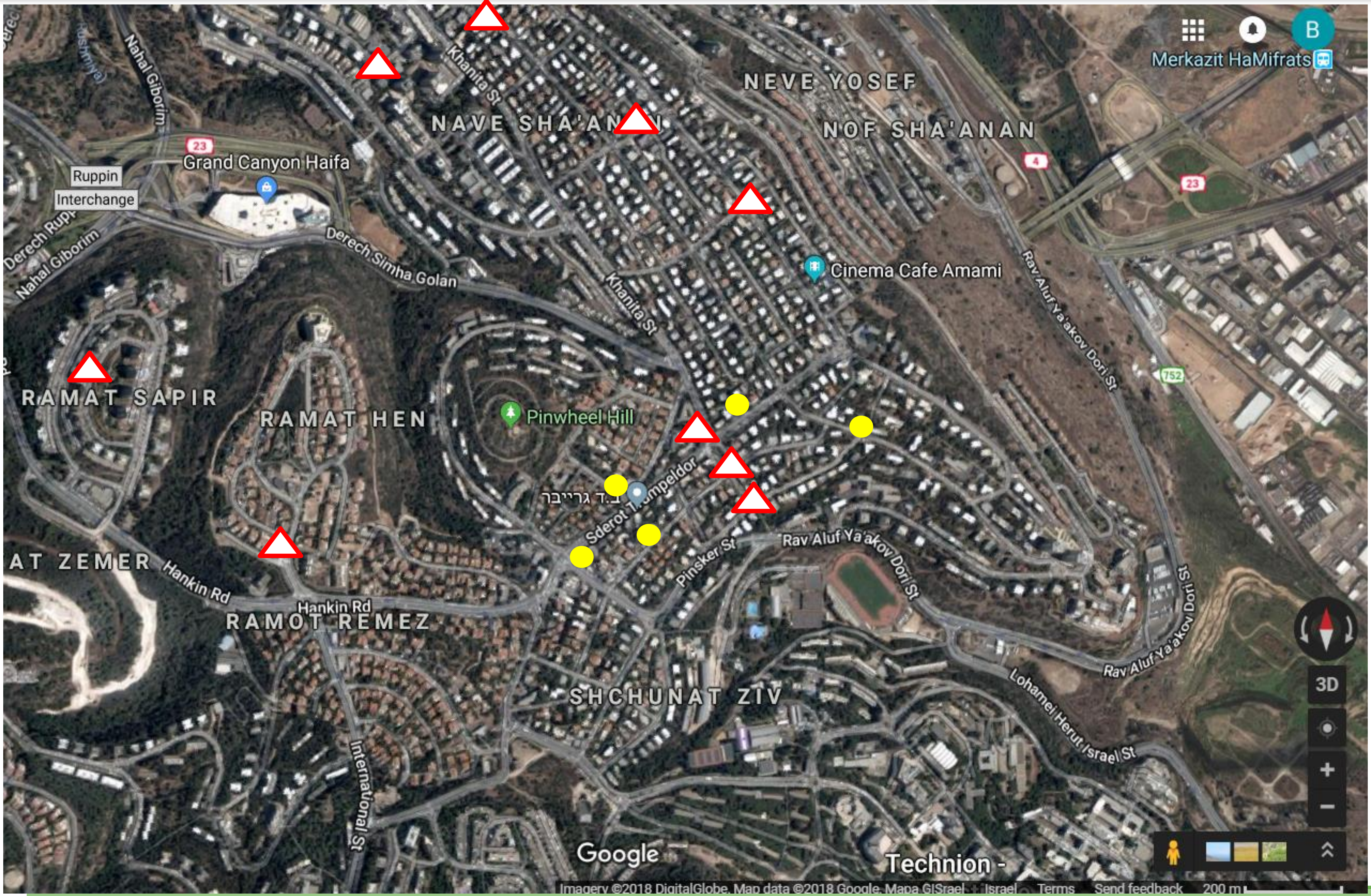
- source apportionment/ allocation?

$\Rightarrow$ Neighborhood "common" levels ($\neq$ urban background $\neq$ long range transport levels)

- specific applications?
- providing useful data products?

$\Rightarrow$ Set feasible expectations and "educate" the users

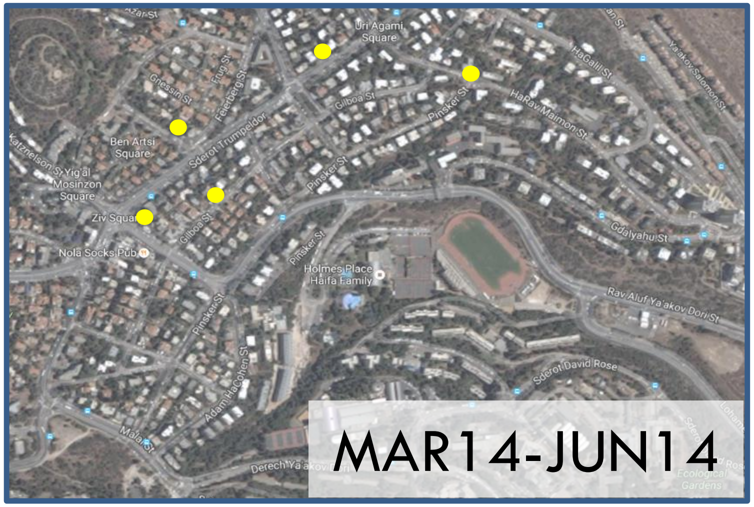
What Can We Learn about Our Neighborhood Using a WDESN ?



1st Example (Fine PNC)

Inter-nodal consistency	During collocation	During deployment
Correlation (*r*)	0.98-0.99	↓ 0.9-0.96
RMS difference (%)	8-16	
RMS difference after calibration* (%)	3.5 -11	↑ 19.5-33.6

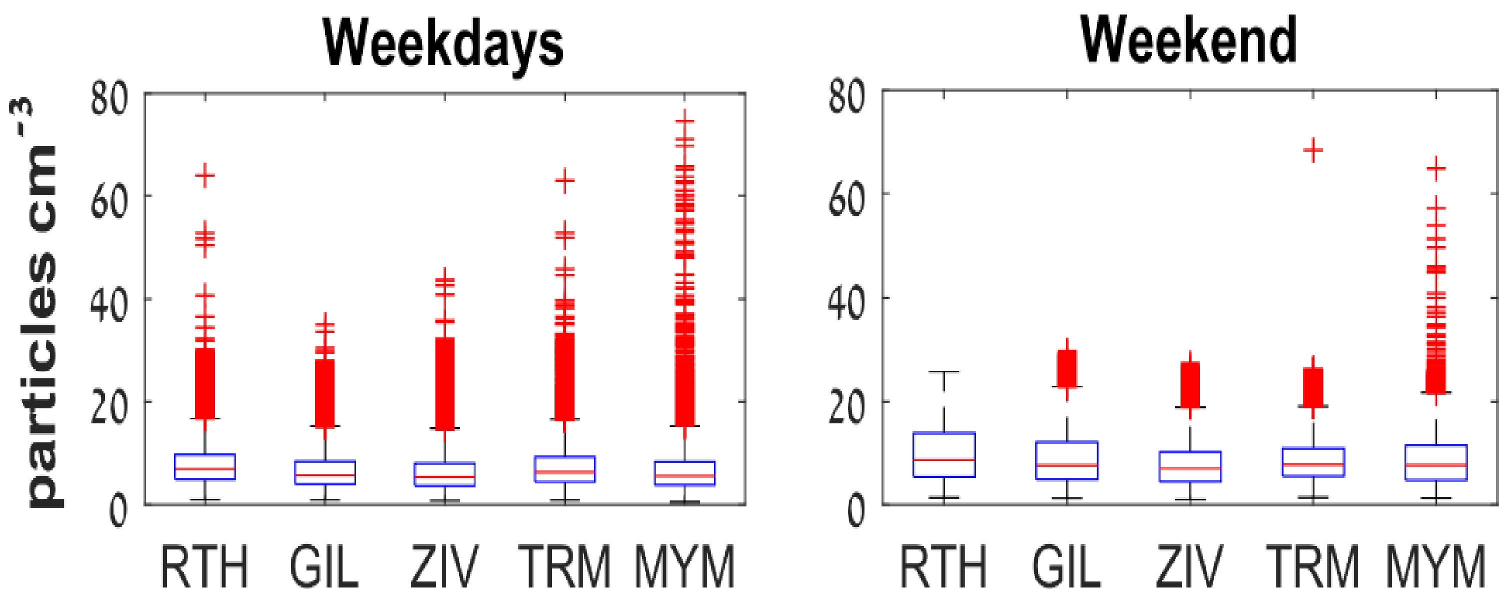
* LR to measurements by PCASP-X2 (DMT)



A network of 5 OPCs (Dylos), 150-300 m apart. 3 collocation periods (before, in between and after) & 2 deployment periods.

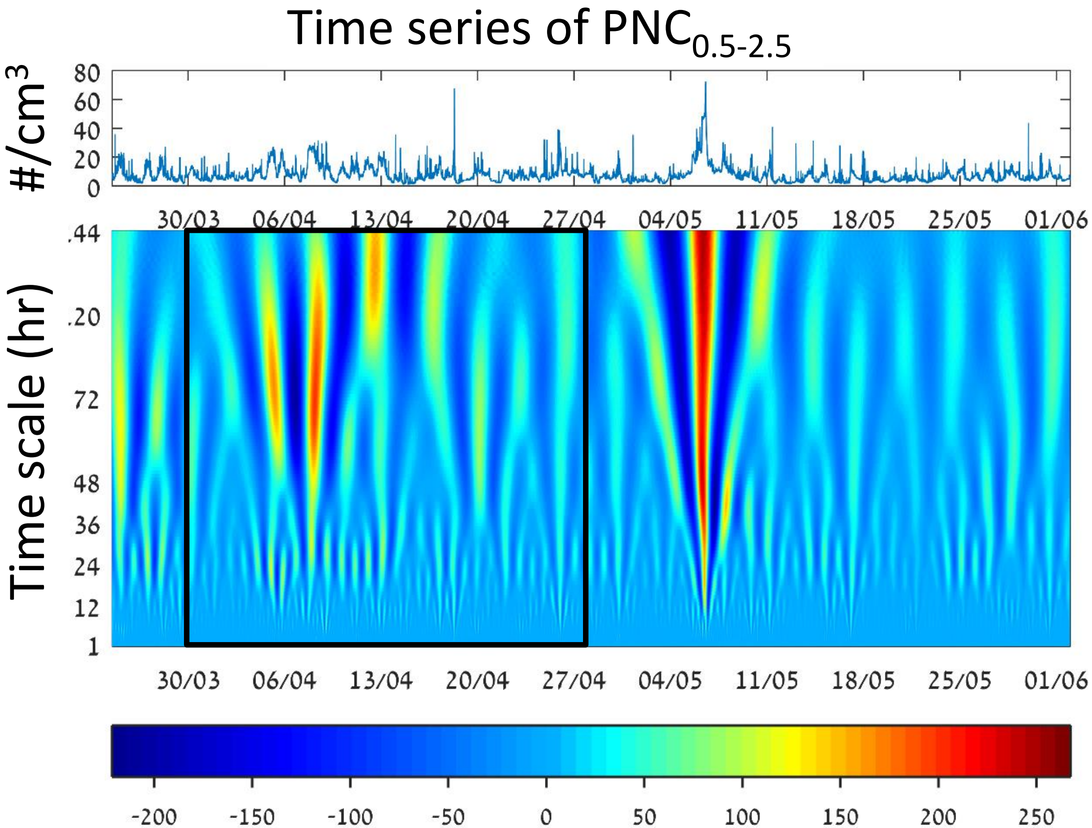
Signature of Human Activity?

Most of the spatial variability was found in the >95 percentile of the fine PNC

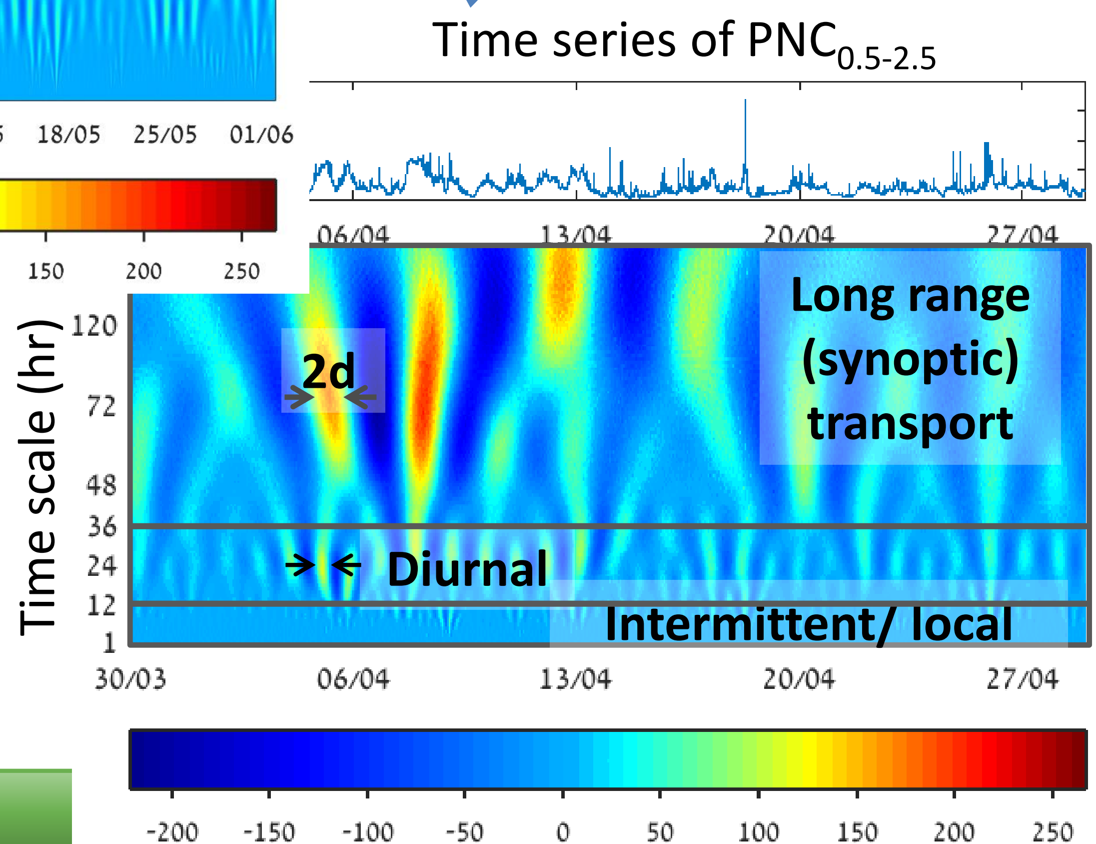


⇒ Is the variation related to anthropogenic activity (commute, commerce)?

Can Sources Be Identified ?



(continuous wavelet transform using the Morlet complex function)



Where is the human activity signature?

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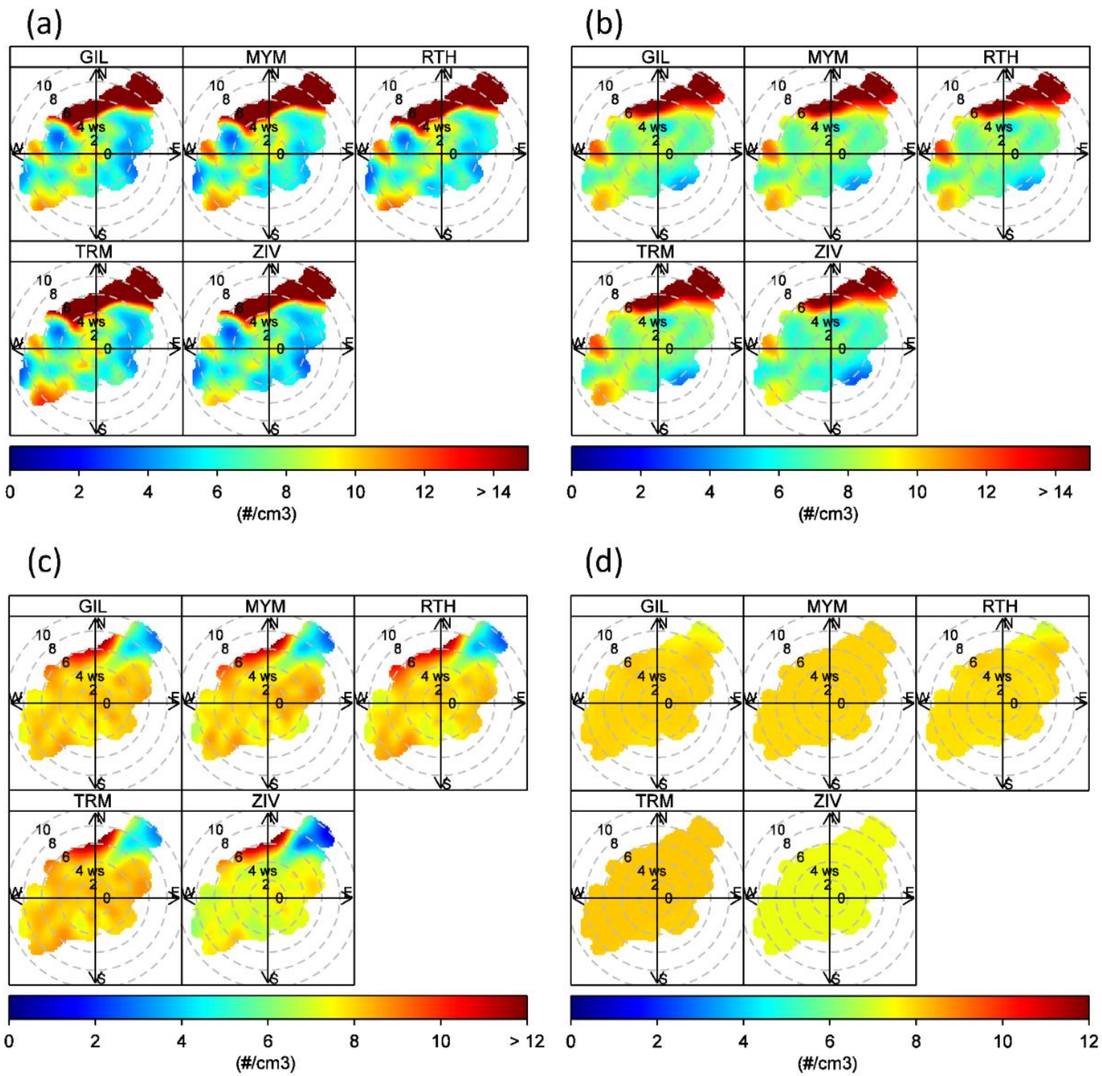
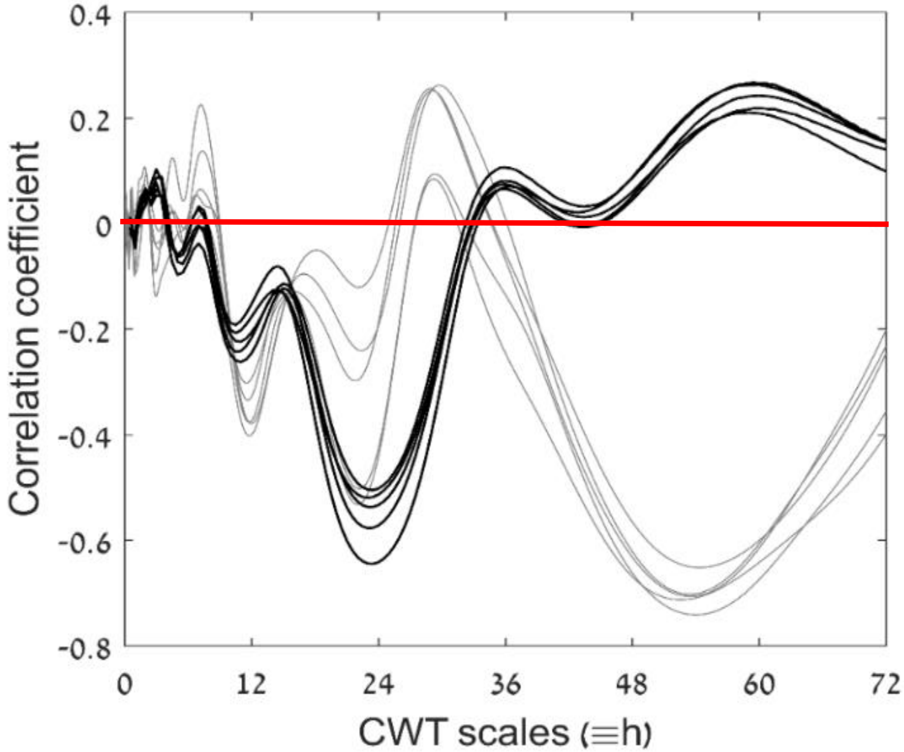
Does The Wind Field Result in Intra-Neighborhood Pollutant Variability ?



Polar plots of (a) mean PNC, and of reconstructed PNC time scales: (b) >24 h, (c) 6-12 h, (d) 1-4 h.

Neighborhood-scale variability in PNC is visible in the larger scales



Correlations between CWT reconstructed PNC and wind speed time series (different lines = locations, black / gray = time period).
(similar to coherence analysis)

- For synoptic (*t* >48 h) time scales, correlations show strong temporal (seasonal) but small spatial variation.

  positive correlations: long-range transport

  negative correlations: wind speed effect on dispersion.

- For daily (24 h) and (to less extent) half-daily (12 h) time scales, significant negative correlations - thermally driven dispersion processes (land-sea breeze, solar-driven vertical expansion/contraction of the ML ?)
- For <1 h time scales, correlation $\rightarrow 0$ - turbulent mixing ?

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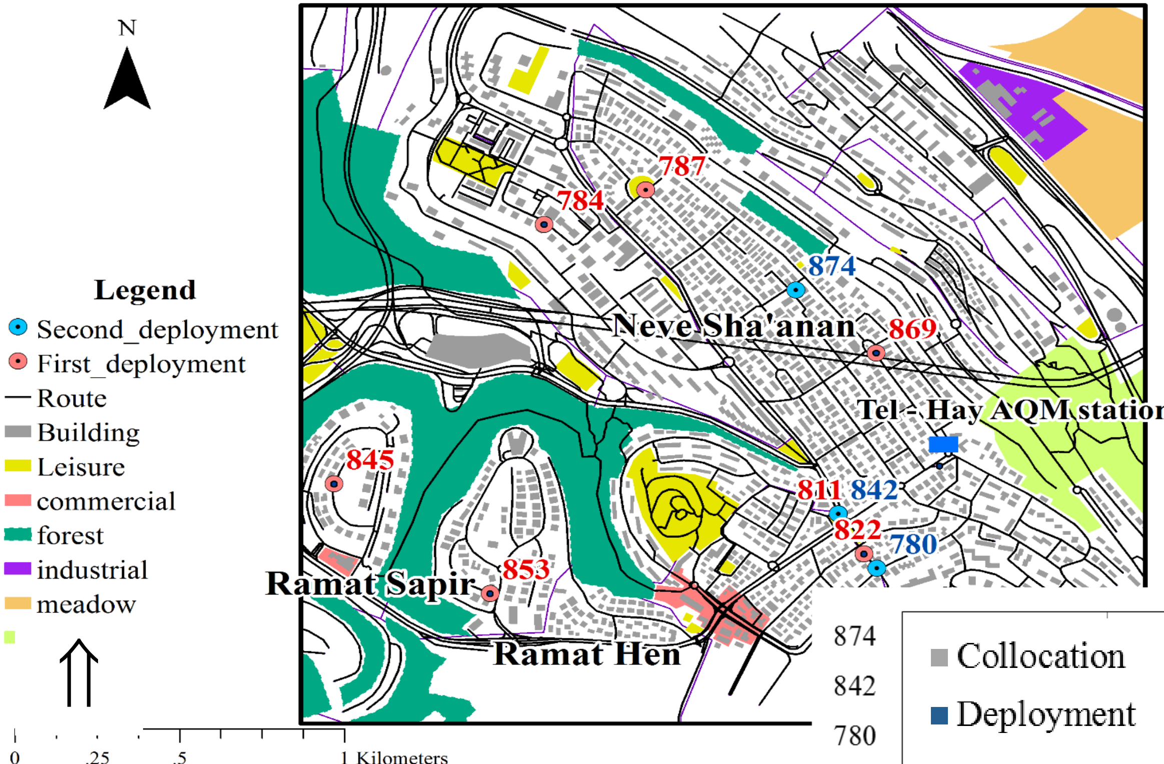
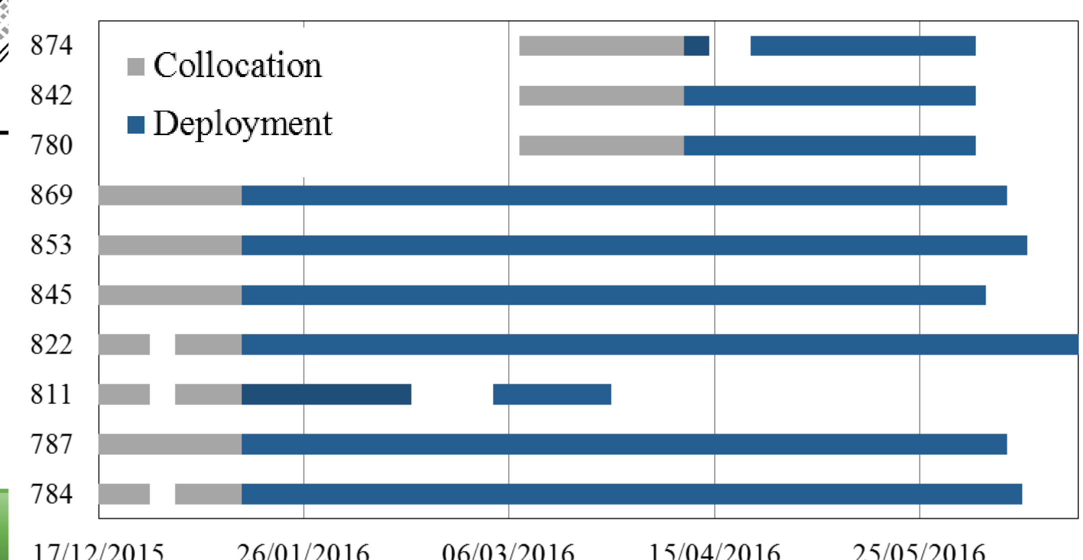
2[nd] Example ($PM_{2.5}$ and Fine PNC)



A network of 7 (+3) OPCs (AQMesh v3.5). Intra- and inter-neighborhood variability.



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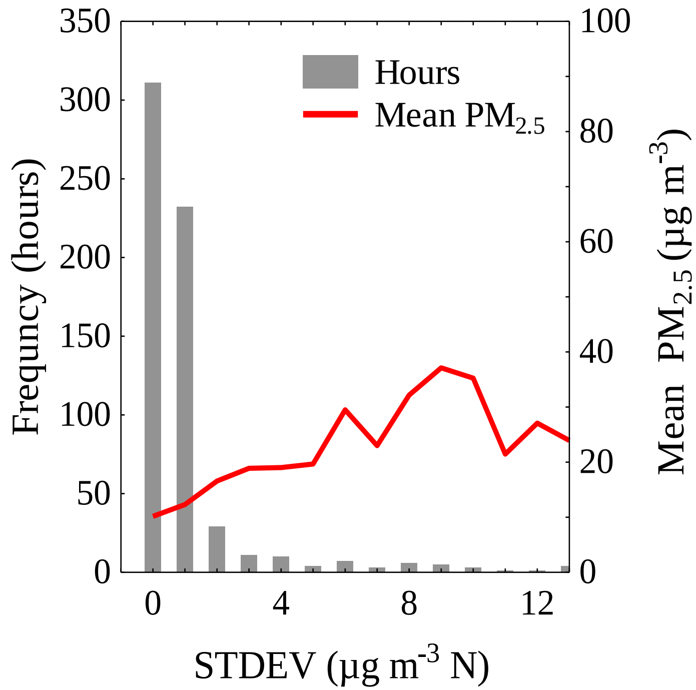
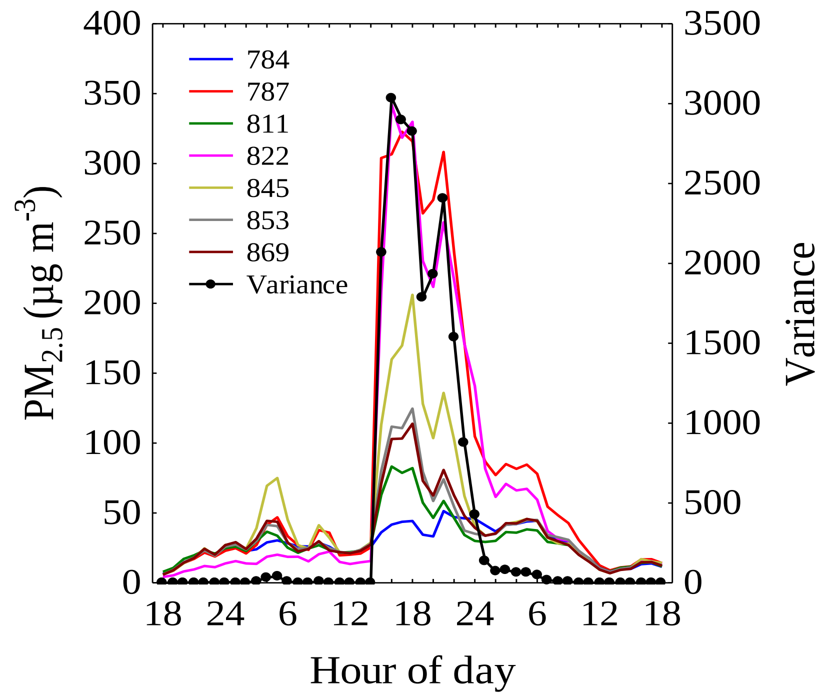
Focus on "Clean Days"





Inter-nodal variability (hourly records) among collocated OPCs (Dec 17, 2015 - Jan 14, 2016) and the corresponding mean hourly $PM_{2.5}$.

Variability of collocated OPC records before, during and after a dust storm (Dec 18-19, 2015).

⇒ focus on "clean" days

Inner Neighborhood Variability is Evident

Inter-nodal variation during both collocation and deployment (Dec 2015 - May 2016).

Pollutant	Calibration	Period	No. hours	No. nodes	Mean	F-statistics	Mean CV (%)
$PM_{2.5}$ ($\mu g\ m^{-3}$)	against hourly mean AQM $PM_{2.5}$	collocation	550	7	10.79	F(6,3430)=0.28	5.3
		deployment	2128	7	11.84	F(6,12450)=50.80	7.6
$PM_{2.5}$ ($\mu g\ m^{-3}$)	against hourly mean OPC $PM_{2.5}$	collocation	550	7	12.50	F(6,3430)=0.18	8.32
		deployment	2128	7	11.79	F(6,10692)=27.47	12.41
PNC (cm^{-3})	against hourly mean OPC PNC	collocation	550	6	1245.8	F(5,2890)=0.27	7.31
		deployment	2128	6	970.3	F(5,10790)=10.49	12.97

⇒ **Use of WDESN revealed significant neighborhood-scale variability on top of the sensors' measurement noise**

⇒ **Potentially important for epidemiological studies (as they benefit from inter-subject exposure variability)**

What Affects Intra-Neighborhood Particle Variability

(* = N.S.)			PNC (Calib. mean OPC)			$PM_{2.5}$ (Calib. AQM)			$PM_{2.5}$ (Calib. mean OPC)		
		No. hours	Mean (cm^{-3})	F-statistics	Mean CV (%)	Mean (mg/m^3)	F-statistics	Mean CV (%)	Mean (mg/m^3)	F-statistics	Mean CV (%)
Synoptic condition	Winter highs	298	824.3	F(5,1635) = 2.96	10.79	10.42	F(6,1931) = 2.32	9.29	10.93	F(6,1931) = 2.35	11.21
	Red Sea Troughs	479	1101.6	F(5,2571) = 2.08 *	13.46	10.09	F(6,3044) = 5.60	6.50	11.56	F(6,3044) = 3.72	14.24
	Winter storms	252	952.1	F(5,1369) = 12.14	14.76	10.03	F(6,1615) = 33.68	7.87	11.36	F(6,1615) = 26.66	15.56
Wind direction (˚)	North - East	360	967.8	F(5,1944) = 3.59	12.21	10.0	F(6,2298) = 8.01	7.31	11.13	F(6,2299) = 5.04	13.17
	South	431	990.6	F(5,2338) = 2.94	12.20	10.36	F(6,2765) = 9.18	7.56	11.56	F(6,2765) = 6.71	13.30
	West	634	922.3	F(5,3546) = 3.59	13.78	10.01	F(6,4186) = 28.4	8.21	10.93	F(6,4186) = 19.68	14.24
Wind speed (m/s)	0.5-1	264	1158.25	F(5,1440) = 1.99 *	15.75	10.98	F(6,1701) = 1.67 *	9.14	12.77	F(6,1701) = 1.48 *	16.21
	1.1.5	322	1094.31	F(5,1743) = 2.55	13.04	10.64	F(6,2064) = 3.66	7.79	12.3	F(6,2064) = 3.08	13.77
	1.5-2	305	890.12	F(5,1650) = 2.09 *	11.92	9.77	F(6,1949) = 10.04	7.15	10.43	F(6,1949) = 6.18	12.79
	2--3	325	836.08	F(5,1800) = 1.47 *	11.24	9.52	F(6,2121) = 14.38	6.95	10.06	F(6,2121) = 8.06	12.17
	3--5	219	847.70	F(5,1197) = 3.89	13.72	9.84	F(6,1414) = 17.78	8.28	10.4	F(6,1414) = 12.22	14.13
	>5	61	844.17	F(5,316) = 3.79	18.47	10.43	F(6,374) = 9.55	10.34	11.9	F(6,374) = 7.76	17.82

Summary

- AQ-WDESN technology carries a promise, however the technology **is not** matured for regulatory/ non-research quantitative applications.
- Nonetheless, it can be used **with caution** for qualitative/ educational/ demonstrational/ raising the public awareness purposes.
- AQ-WDESN is capable of **capturing spatiotemporal pollutant variability** (yet frequent field calibrations may be required to maintain consistent results).
- **No free lunch** - AQ-WDESN data must pass severe QA/QC procedures for any (most?) uses (including citizen science).

Thank you

Further reading:

- Moltchanov et al., Science of the Total Environment, 502:537–547, 2015.
- Fishbain et al., Science of the Total Environment, 575:639–648, 2017.
- Castell et al., Environment International, 99:293-302, 2017.
- Broday et al., Sensors, 17(10):2263-2280, 2017.
- Kizel et al., Environmental Pollution, 233:900-909, 2018.
- Etzion & Broday, J. Aerosol Sci., 117:118-126, 2018.

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