Improving the accuracy of personal RF measurements and characterisation of exposure levels in different environments across countries (ACCEDERA)

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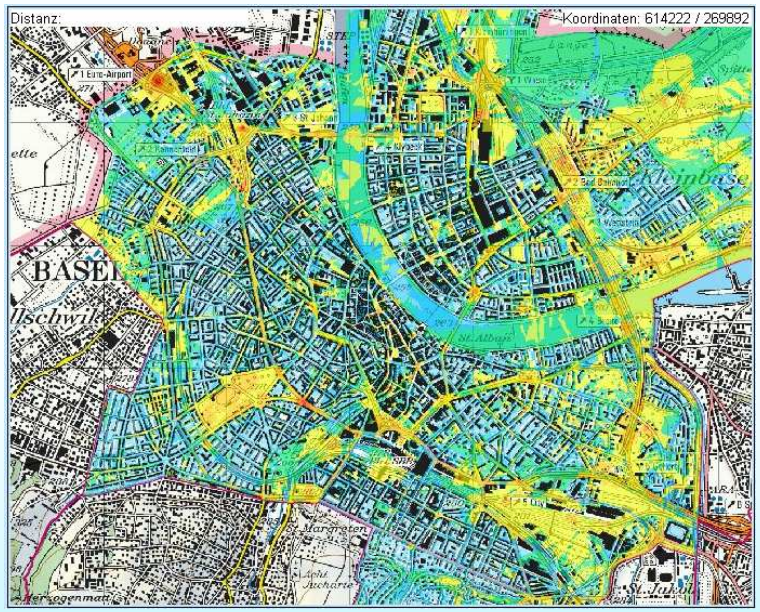
Objectives

1. To extend and further develop a prototype
   of a body-worn distributed RF exposure meter (BWDM)
2. To conduct measurements using the BWDM
   in various indoor and outdoor microenvironments
   in five different countries
3. To apply in parallel 2 other types of personal RF Exposimeters
   used in previous research.

WHO research agenda, 2011: improve exposure characterization

Three approaches for environmental EMF exposure monitoring

1. Modeling of fixed site transmitters



Bürgi et al, BioEM, 2010

+ efficient, illustrative
- no hotspots (W-Lan), femto/nano cells
- no individual behavior

2. Personal measurements

+ all sources including behavior

- data quality, manipulation
- selection bias
- no differentiation between own and other people's mobile phone
- body shielding

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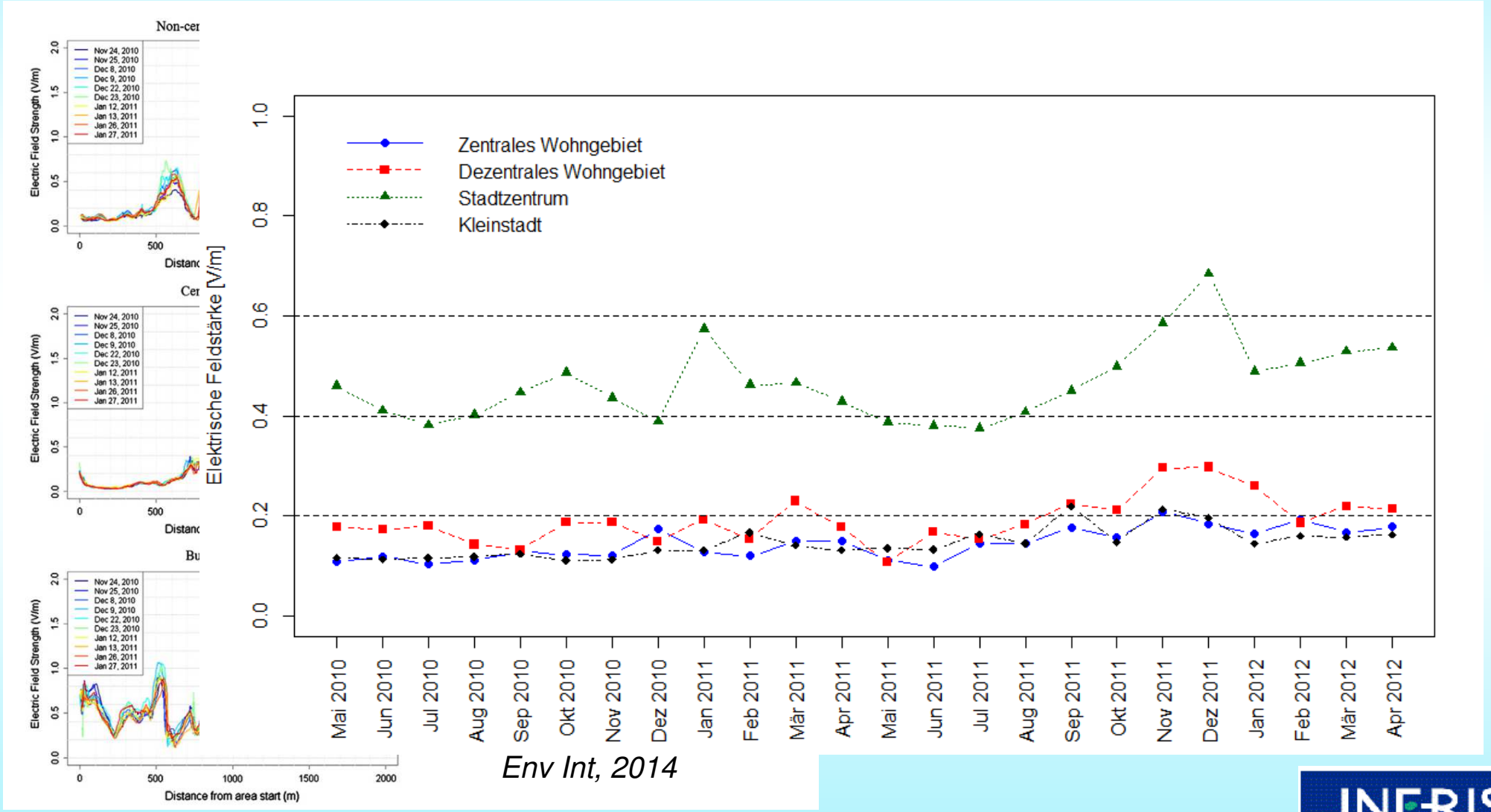
3. Microenvironmental survey

+ data quality, efficient,
+ no body shielding

- no individual behavior
- no residential measurements

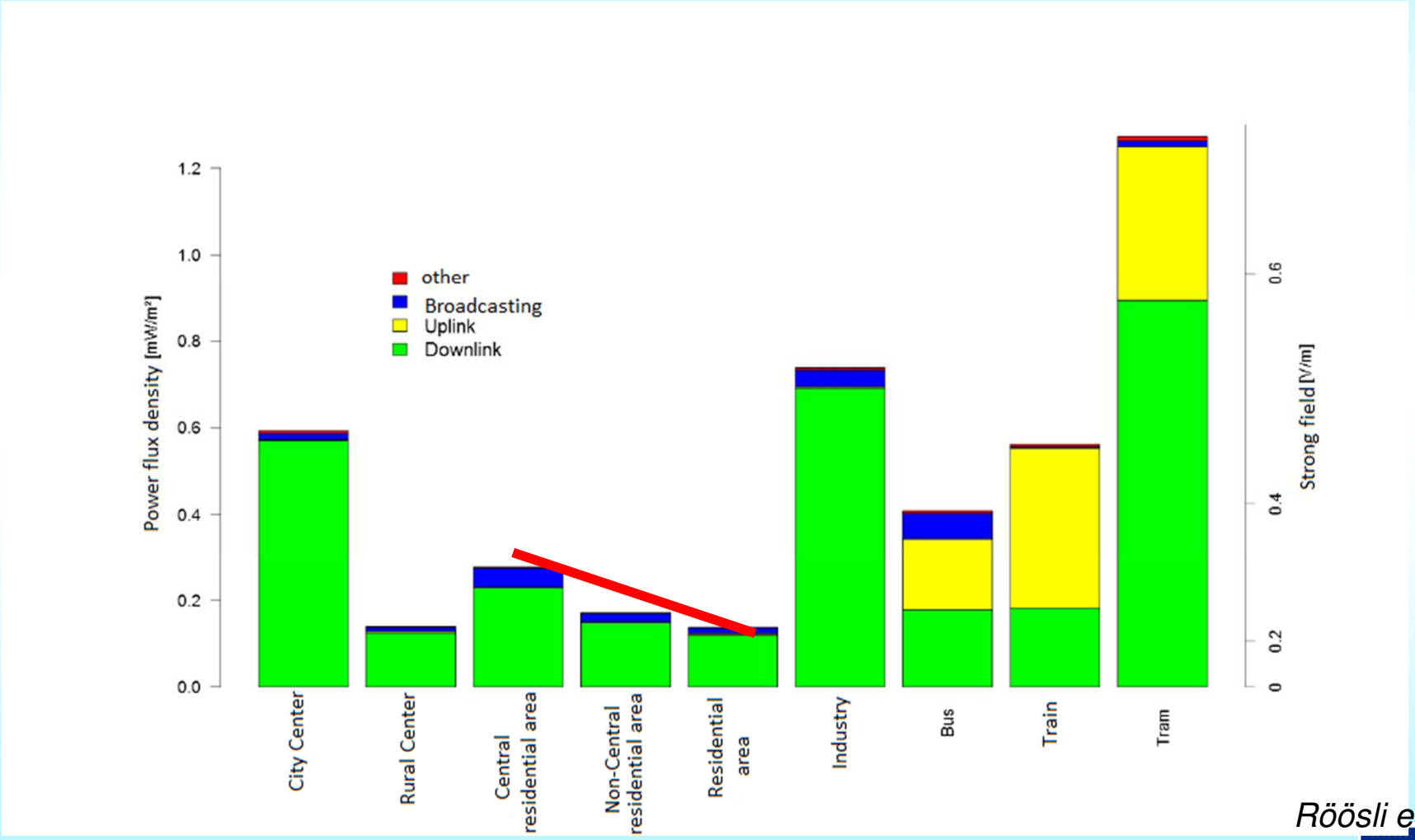
Unit of observation:
a functional area such as residential area, business area, public place, railway station, shopping center, tram, etc.

Reproducibility of microenvironmental



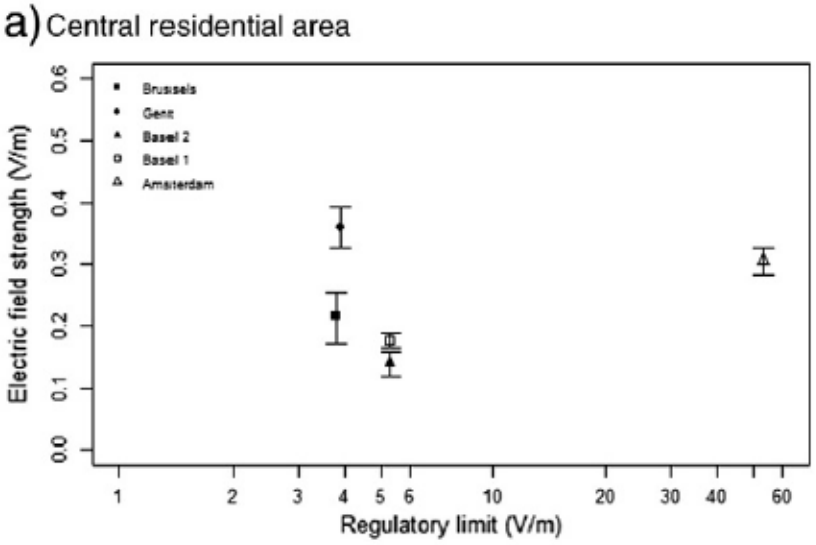
Env Int, 2014

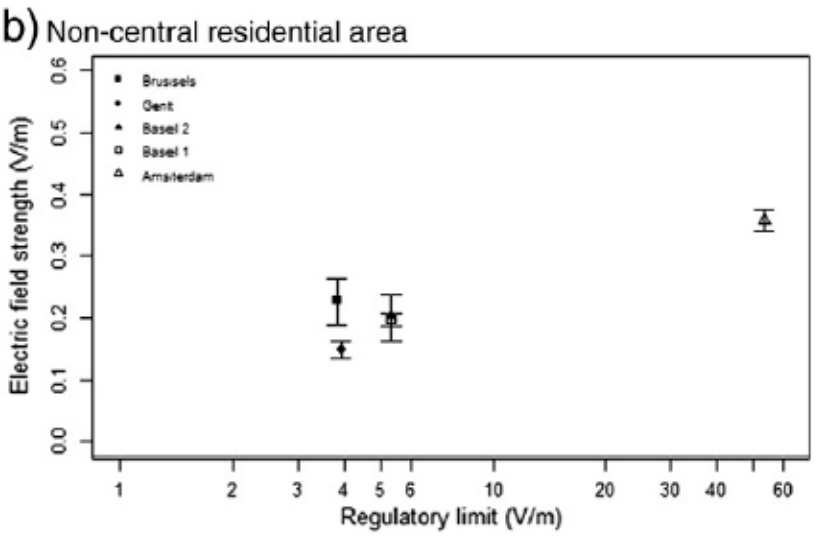
Spatial differences

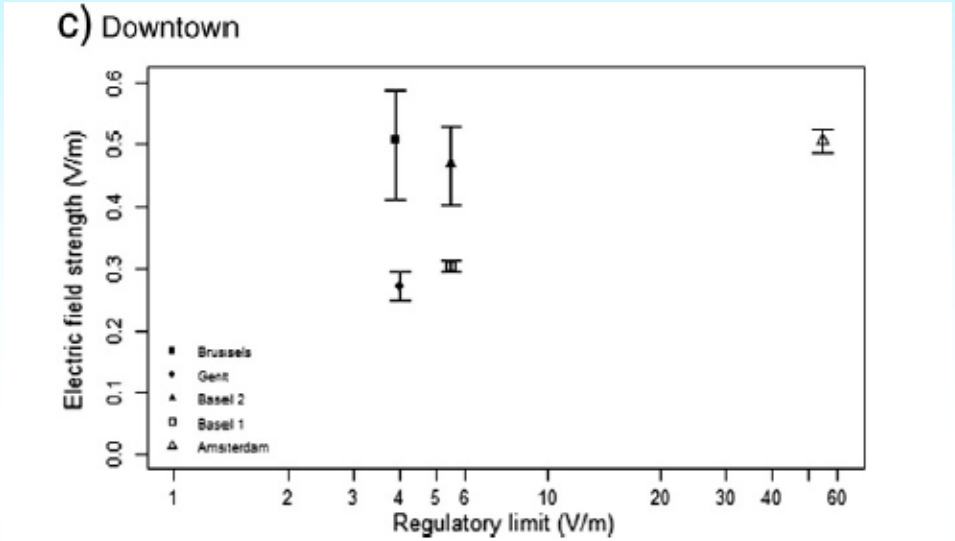


Röösli et al., 2015

Exposure vs. regulatory limits







■ Brussels
● Ghent
□ Basel 1
▲ Basel 2
△ Amsterdam

Urbinello et al., *Env Int, 2014*

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Types of exposure study

	Personal measurements with volunteers	**Microenvironmental survey**
Data quality	Not under control	Under control
Close to body sources	Part of measurements	Can be omitted
Body shielding	Partly not avoidable	Can be avoided
Behaviour of people	Considered	Not considered
Representativity	Selection bias	Sampling strategy

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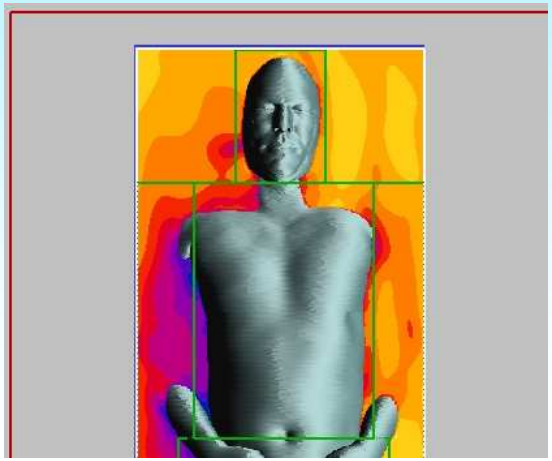
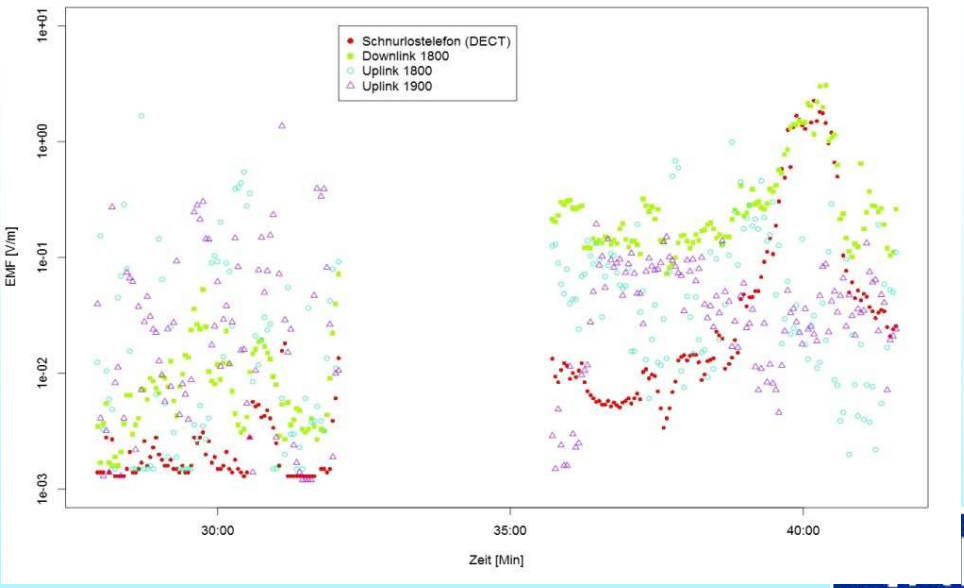
Challenges of exposimeters

1. Shielding of the body
2. Detection limit above environmental levels
3. Out of band response
4. Measurement accuracy - calibration



The solution: BWDM



Measurement Device: BWDM

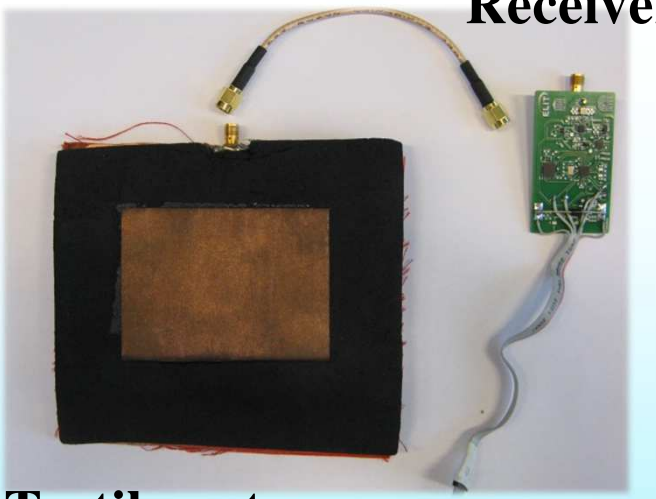
(Body-worn distributed RF meter)

Concept: Improved RF personal Exposure assessment using:

- Distribution of antennas on the body → lower uncertainty
- Separate antennas / frequency band → lower cross-talk
- Improvement of receiver electronics → More dynamic range

Pilot study: BWDM used for measurements in the GSM 900 DL band [1]

Receiver electronics



Textile antennas

Worn on the body

[1] P Vanveerdeghem, P Van Torre, A Thielens, J Knockaert, W Joseph, H Rogier. "Compact Personal Distributed Wearable Exposimeter", IEEE Sensors Journal, vol. 15, no. 8, pp. 4393-4401, 2015.

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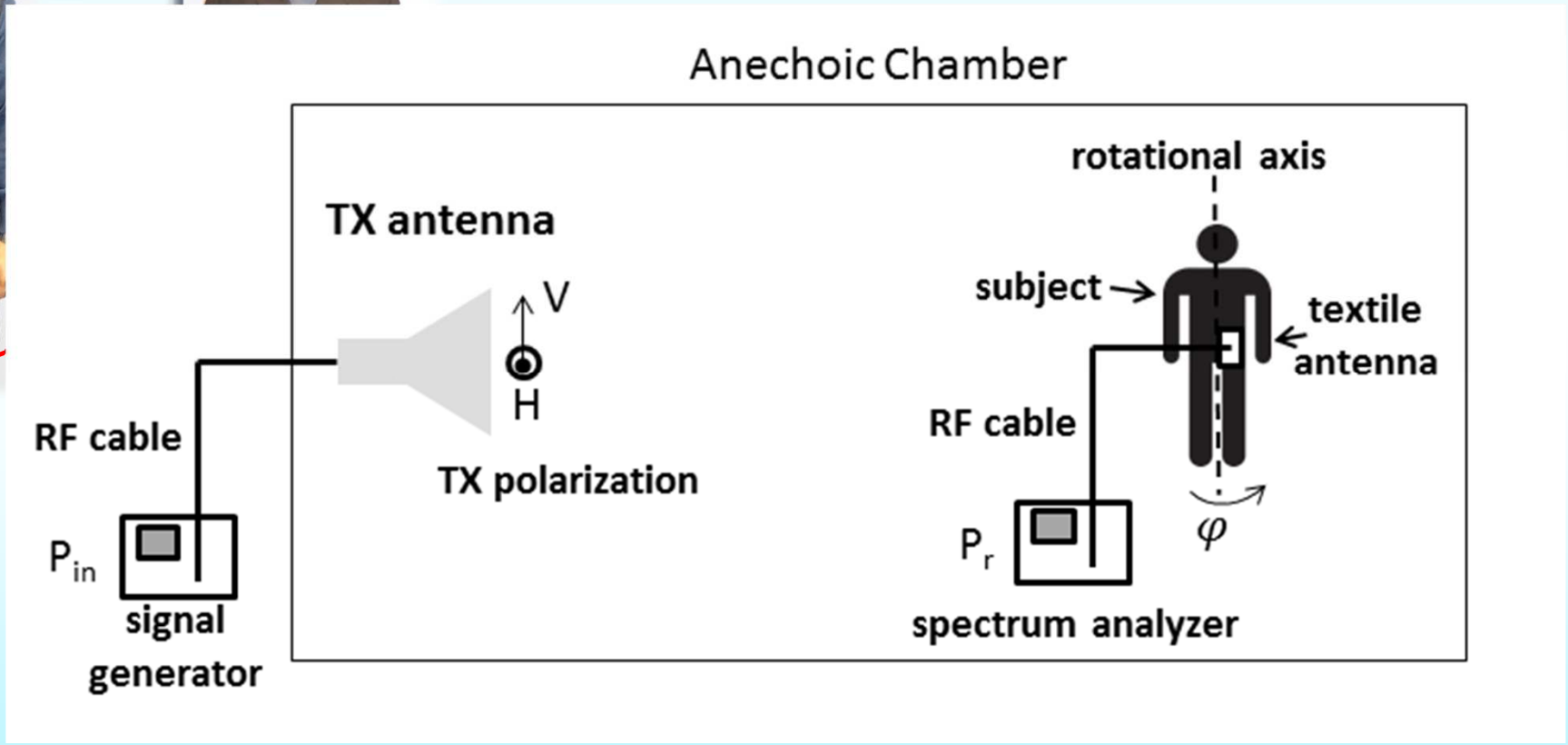
Measurement Device: BWDM

Integration into a garment

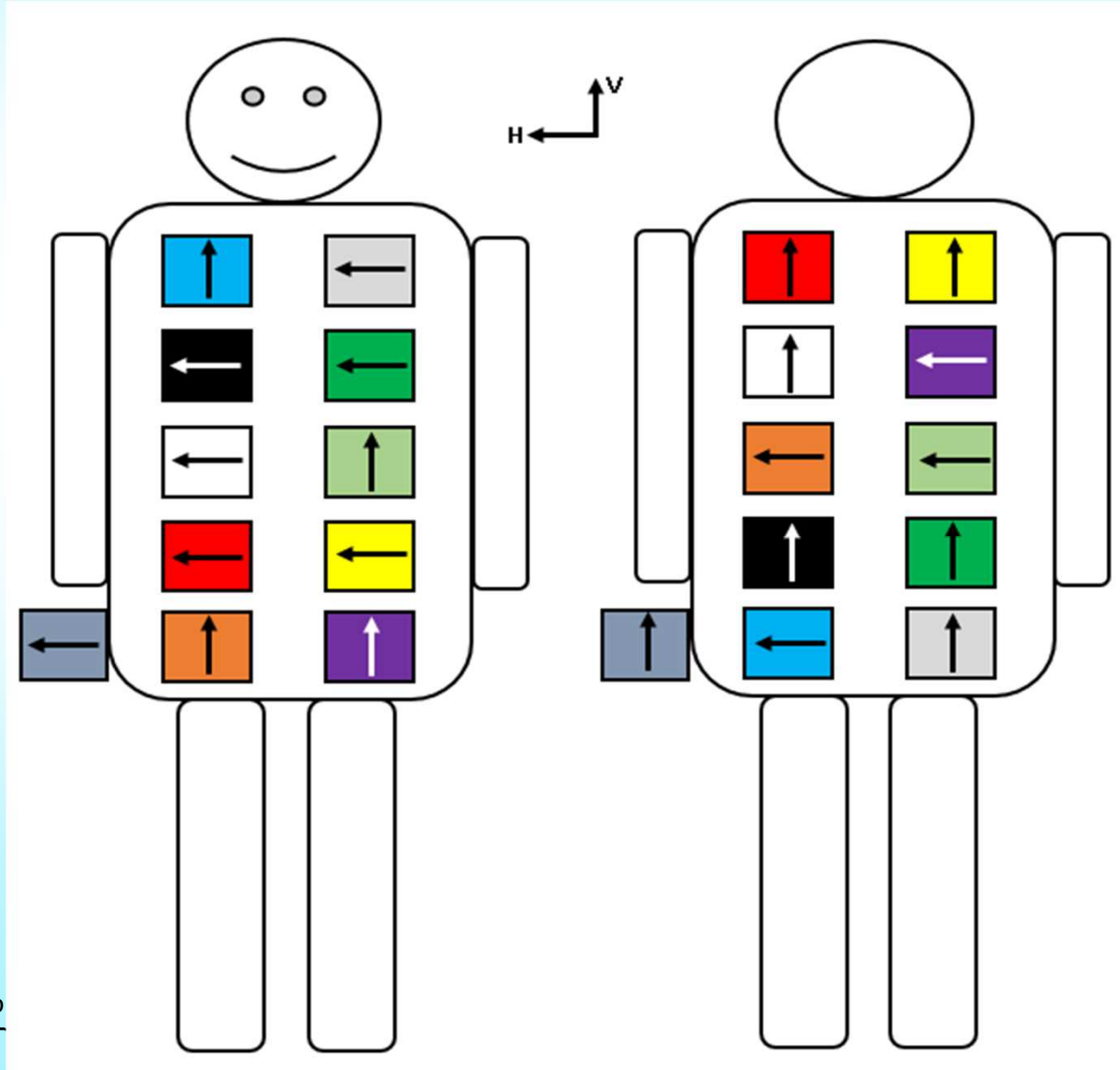
Antenna locations



Calibration and design

Optimized location of nodes and their polarization

GSM 1800 UL	LTE 2600
LTE 800	GSM 1800 DL
WiFi 5GHz	UMS UL
GSM 900 DL	DECT
GSM 900 UL	WiFi 2GHz
UMS DL	



Methods

Measurements conducted by a volunteer

Selection of 80 microenvironments per country

Ca. 15 minutes measurements per microenvironment

Measurements repeated within one month

Two measurement campaigns in each country

-> total 4 measurements per microenvironment

Microenvironments

Type of microenvironment	urban*	suburban	rural
outdoor areas			
downtown area	2	0	0
business area	2	2	0
shopping area	2	2	2
residential area	10	10	10
public places			
railway station	2	2	0
bus station	2	2	0
subway station	1	0	0
airport	1	0	0
shopping centre	2	2	0
children's playground	2	2	2
university	2	0	0
transportation mode			
trains	2	2	2
bus	2	2	2
metro	2	0	0
car	2	2	2
Total n	36	28	20

* Brussels, Amsterdam, Paris, Barcelona, Zürich

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Significance and expected impact

Reliable exposure data

Evaluation of commercial exposimeters

Input data for dose calculations

Evaluate the relevance of various sources

Input data for health impact assessment and risk communication

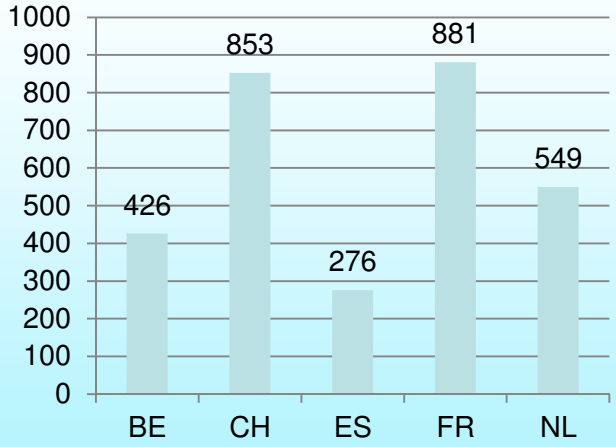
Evaluate the impact of different policies
e.g. precautionary limits in Switzerland, Belgium and partly France

The ACCEDERA measurements!

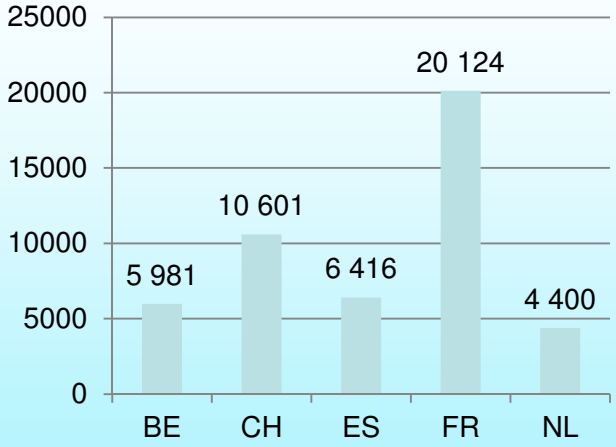
154 measurement days

2509 data files (and counting…)

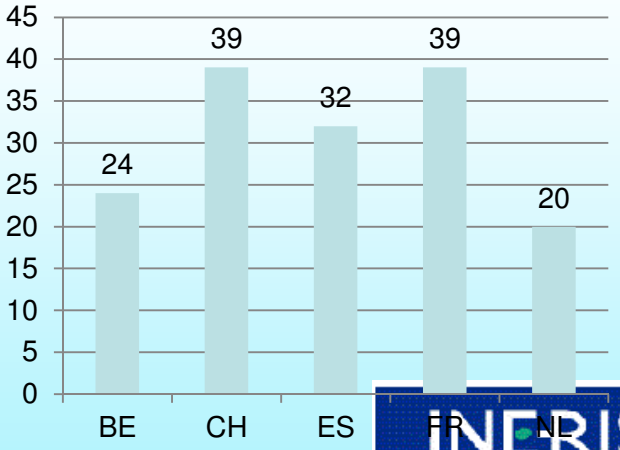
Number of diary entries made



Minutes of activities logged in diary



Number of days of fieldwork



Data completeness

Measurement data:

- ExpoM-RF files ← mostly complete
- EMEspy files ← many missing
- Vest files ← not usable as such
- Diary files

Microenvironment data:

- Overview of microenvironments + unique codes
- Based on diary files, add:
  - Unique_code
  - Direction
  - Poncho_index
  - Any remarks

Other data:

- Calibration data ← 1 file per person per round
- Detection limit data ← 1 file per person per round
- Vest design ← which node was where in the old version of the vest

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Next steps & time line

End of September 2018:

- Check the data overview:
  - Are all the data you collected listed here?
  - Put any missing data on the SwitchDrive & let (Stefan & Marloes) know!
- Check your overview of microenvironments:
  - Everything complete?
  - Add unique codes to compiled diary files (Marloes will send around)
- Respond to any other queries from Stefan & Marloes

End of October 2018:

- All measurement files organized at Swiss TPH, including:
  - Re-processed vest files (one file per node)
  - Calibration factors
  - Detection limits

Mid-end November 2018:

- Marloes will make available final merged files:
  - 1s time series for all measurements + microenvironment info
  - 4s time series for all measurements + microenvironment info

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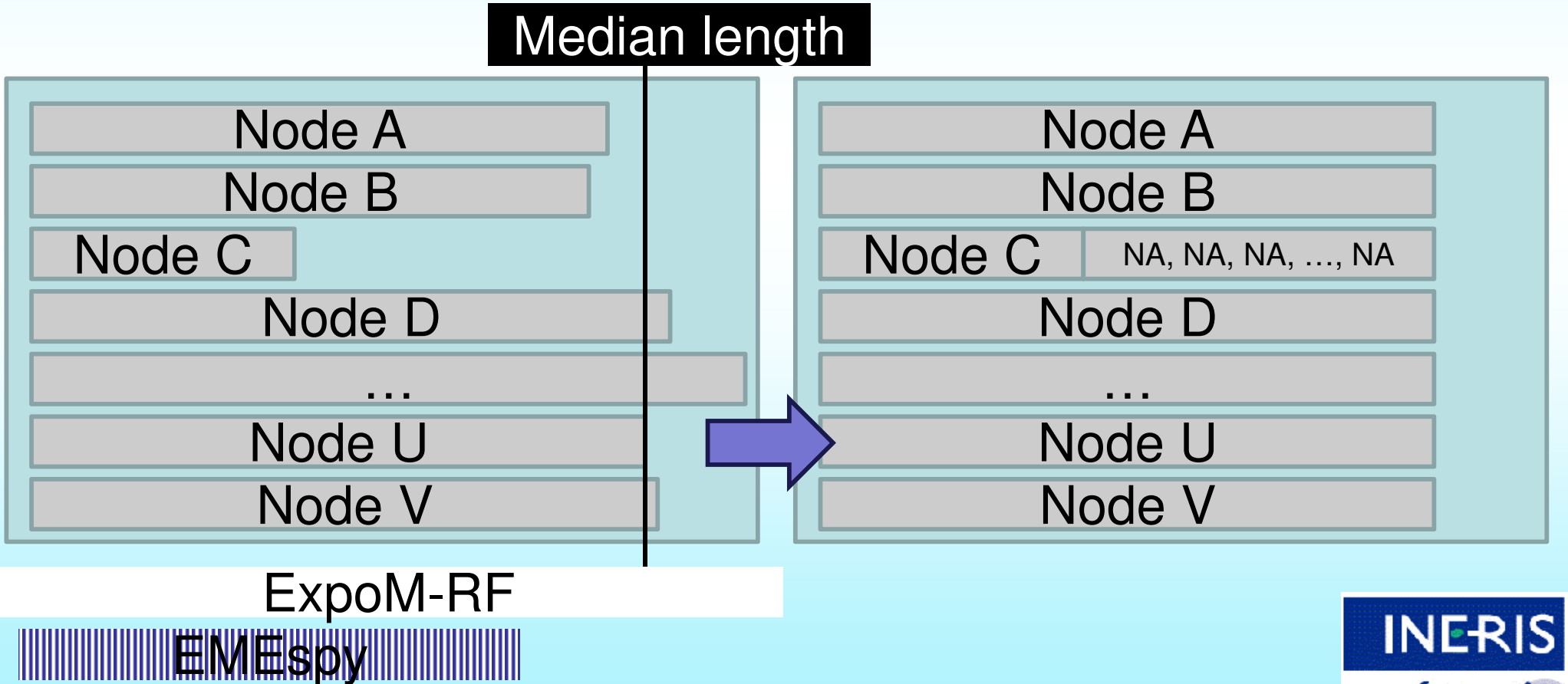
Time «bending» and synchronization

☺ stretching or compressing



ExpoM-RF

EMEspy

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16705	16728	813	16730	16712	16712
15697	15718	15660	15724	15704	15705
16592	16616	16556	16621	16600	16601
15217	15237	15183	15243	15223	15224
7207	7219	7194	7221	7211	279

Number of measurements by each node

	A	B	C	D	F	G	H	I	J	K	L	N	O	P	Q	R	S	T	U	V	median
2018_07_11	814	16714	16703	16705	16728	16685	16716	16724	16705	16728	813	16730	16712	16712	16728	16723	16683	16709	16695	16705	16711
2018_07_12	15691	15704	15698	15699	15712	15679	15708	15715	15697	15718	15660	15724	15704	15705	15728	15715	15677	15701	15688	15697	15703
2018_07_18	16588	16601	16594	16596	16608	16572	16604				16556	16621	16600	16601	16624	16611	16571	16596	16583	16592	16598
2018_07_19	15212	15223	15217	15220	15230	15198	15228				15183	15243	15223	15224	15246	15233	15197	15220	15208	15216	15222
2018_08_07	7206	7213	7208	7209	7214	7199	7222				7194	7221	7211	279	7231	7214	7197	7209	7203	7207	7209

%Of median length measured by each node

	A	B	C	D	F	G	H	I	J	K	L	N	O	P	Q	R	S	T	U	V	median
2018_07_11	-95.13%	0.02%	-0.05%	-0.04%	0.05%	-0.16%	0.03%	0.08%	-0.04%	0.10%	-95.13%	0.11%	0.01%	0.01%	0.16%	0.07%	-0.17%	-0.01%	-0.10%	-0.04%	0.00%
2018_07_12	-0.08%	0.01%	-0.03%	-0.03%	0.06%	-0.15%	0.03%	0.08%	-0.04%	0.10%	0.27%	0.13%	0.01%	0.01%	0.16%	0.08%	-0.17%	-0.01%	-0.10%	-0.04%	0.00%
2018_07_18	-0.06%	0.02%	-0.02%	-0.01%	0.06%	-0.16%	0.04%	0.08%	-0.04%	0.11%	-0.25%	0.14%	0.01%	0.02%	0.16%	0.08%	-0.16%	-0.01%	-0.09%	-0.04%	0.00%
2018_07_19	-0.07%	0.01%	-0.03%	-0.01%	0.05%	-0.16%	0.04%	0.07%	-0.03%	0.10%	-0.26%	0.14%	0.01%	0.01%	0.16%	0.07%	-0.16%	-0.01%	-0.09%	-0.04%	0.00%
2018_08_07	-0.04%	0.06%	-0.01%	0.00%	0.07%	-0.14%	0.04%	0.08%	-0.03%	0.14%	-0.21%	0.17%	0.03%	-96.13%	0.17%	0.07%	-0.17%	0.00%	-0.08%	-0.03%	0.00%

- Stretch / compress time to median file length:
  - If node is not shorter than 95% of the median length (of 20 / 22 nodes)
  - Duplicate / remove *n* observations:
    - Where *n* is the difference between the length of that any node[i] and the median length

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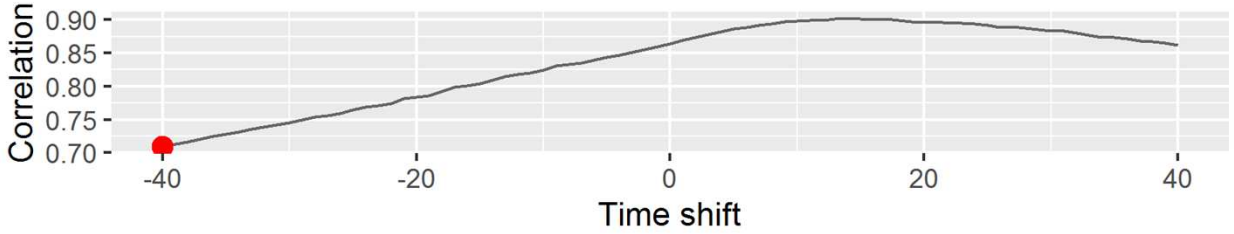
Different nodes are offset by up to 65 seconds because of imperfect elapsed second counting

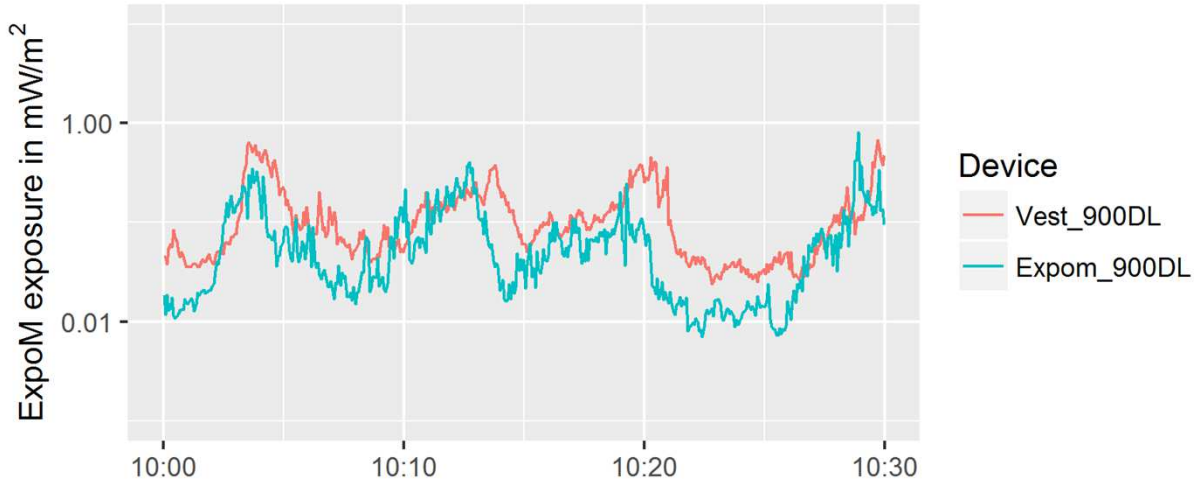
Every 1.000 s	Every 999ms	Every 1001ms
0	0	0
1	0.999	1.001
2	1.998	2.002
3	2.997	3.003
4	3.996	4.004
5	4.995	5.005
6	5.994	6.006
7	6.993	7.007
8	7.992	8.008
9	8.991	9.009
10		
...	...	
4991		
4992		
4993		
4994		
4995		
4996		
4997		
4998		
4999		
5000		

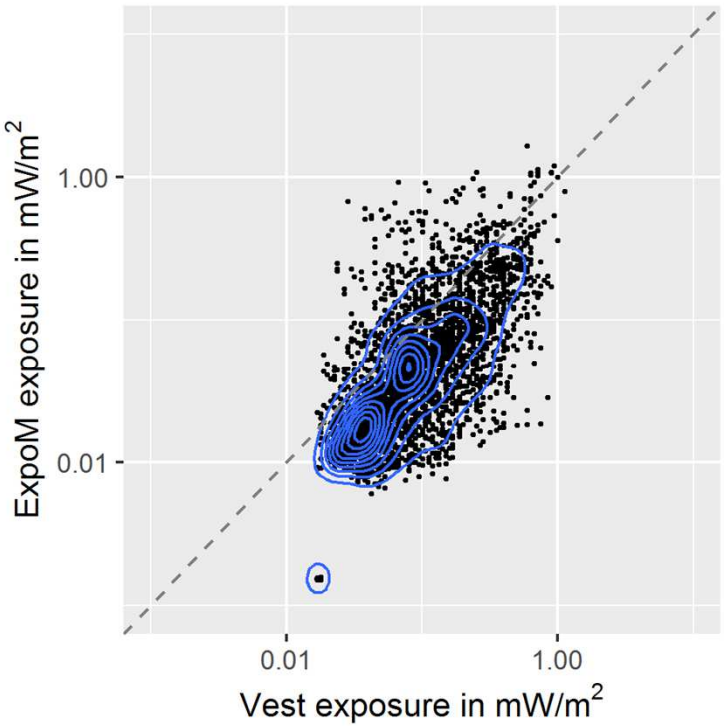
Assume we have an ideal node A which measures every 1000 ms, and a node B measuring every 999 ms and a node C which measures every 1001 ms.
Then, if we measure with each node for 100 minutes,
we would have 6000 samples for node A:
- For series B (which would have measured 6006 times in 6000 seconds), we should remove samples 500, 1501, 2502, 3503, 4504 and 5505, thereby compressing time as registered by this node?
- For series C (which would have measured 5994 times in 6000 seconds), we should duplicate samples 500, 1499, 2498, 3497, 4496 and 5495, thereby stretching time as registered by this node?

Synchronize time series

Based on highest correlation between DL900 in all instruments







Detection limits

Detection limits (DL) are different for:

- Expom-RF, varies per:
  - Frequency band
- EMEspy
  - DL of EMEspy… ☹
- Vest, and within the vest they are different per:
  - Node
  - Front / back
  - Round
  - Fieldworker

Options for dealing with measurements < LOD (or > LOD):

- Do nothing (easy)
- Replace by LOD/2 or LOD/sqrt(2) or some other constant value
- Do the ExpoM-RF method we've been publishing
  - ½ of lower LOD if below, cap to upper LOD if above (on V/m scale)
- Something more complicated
  - ROS imputation (MASS package or other) ← only summary statistics
  - Multiple (robust) imputation of the time series
  - Other ideas?

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Other questions

Comparison between instruments:

- On-the-second exact comparison between instruments? ← May be hard!
- Or compare the 4s average for the vest to the and 1s average for expom and emespy?
    - Average? Geometric average? Median?

Do we want to calculate a total of all bands? What should that total consist of?

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Frequency bands measured by all the different devices. All those things «aligned» are common enough to compare across instruments.

Detailed description of the band names of the different instruments (and what X can be)

The following table gives a better overview of what X can be for each of the instruments. They all measure slightly different frequency bands and sometimes the ranges differ as well. Bands are aligned by what I felt was "enough in common" to be comparable across instruments.

X	Expom_band_name	Expom_frequencies	Vest_band_name	Vest_frequencies	Emespy_band_name	Emespy_frequencies
FM	FM Radio	87.5-108 MHz			FM	87-107 MHz
TV3					TV3	174-223 MHz
TETRA1					TETRA I	380-400 MHz
TETRA2					TETRA II	410-430 MHz
TETRA3					TETRA III	450-470 MHz
TV	TV	470-790 MHz			TV4&5	470-770 MHz
DL800	Mobile 800 MHz Downlink	791-821 MHz	X800MHz	790-821 MHz	LTE 800 (DL)	791-821 MHz
UL800	Mobile 800 MHz Uplink	832-862 MHz			LTE 800 (UL)	832-862 MHz
UL900	Mobile 900 MHz Uplink	880-915 MHz	X900MHz_UL	879-915 MHz	GSM + UMTS 900(UL)	880-915 MHz
DL900	Mobile 900 MHz Downlink	925-960 MHz	X900MHz_DL	921-960 MHz	GSM + UMTS 900(DL)	925-960 MHz
UL1800	Mobile 1.8 GHz Uplink	1710-1785 MHz	X1800MHz_UL	1710-1785 MHz	GSM 1800 (UL)	1710-1785 MHz
DL1800	Mobile 1.8 GHz Downlink	1805-1880 MHz	X1800MHz_DL	1805-1880 MHz	GSM 1800 (DL)	1805-1880 MHz
DECT	DECT	1880-1900 MHz	DECT	1880-1900 MHz	DECT	1880-1900 MHz
UL2100	Mobile 2.1 GHz Uplink	1920-1980 MHz	X2100MHz_UL	1900-1980 MHz	UMTS 2100 (UL)	1920-1980 MHz
DL2100	Mobile 2.1 GHz Downlink	2110-2170 MHz	X2100MHz_DL	2110-2170 MHz	UMTS 2100 (DL)	2110-2170 MHz
WIFI2G	ISM 2.4 GHz	2400-2485 MHz	WIFI_2G	2400-2485 MHz	WIFI 2G	2400-2483.5 MHz
UL2600	Mobile 2.6 GHz Uplink	2500-2570 MHz			LTE 2600 (UL)	2500-2570 MHz
DL2600	Mobile 2.6 GHz Downlink	2620-2690 MHz	X2600MHz	2620-2690 MHz	LTE 2600 (DL)	2620-2690 MHz
WIMAX	Mobile 3.5 GHz	3400-3600 MHz			WIMax	3300-3900 MHz
WIFI5G	WiFi 5 GHz	5150-5875 MHz	WIFI_5G	5150-5875 MHz	WIFI 5G	5150-5850 MHz
TOTAL	Total				TOTAL	

Handy packages

Package name	Description	Functions used
EMFtools [a]	Helpful tools for research on the epidemiology of electromagnetic fields, 2017.	• import_expom_RF: Conveniently importing ExpoM-RF files into R from either .txt or .xlsx format. • import_emespy: Importing (typically very huge) EME spy files into R from .xls format without java errors. • import_vest: Specify the folder and this functions pulls all 20 (22) node.csv's and stretches / compresses them to size. Probably not useful outside of this project, but who knows… • correct_crosstalk: developed for GERoNiMO / ZüMe
SenseOfTime [b]	Helps to make sense of time: straighten out messy time series data from real-time sensors and measurement instrument, 2018.	• synchronize: The function takes two times series of measurements by different devices or from different points, between which you expect a correlation. It seems to be always the case that the timestamp of one device is just a little off and the signals are misaligned when we plot them, preventing an accurate calculation of the correlation between the two. This function fixes the misalignment by synchronizing the syncfile to give the highest correlation with the basefile.

a https://github.com/MarloesEeftens/EMFtools

b https://github.com/MarloesEeftens/SenseOfTime

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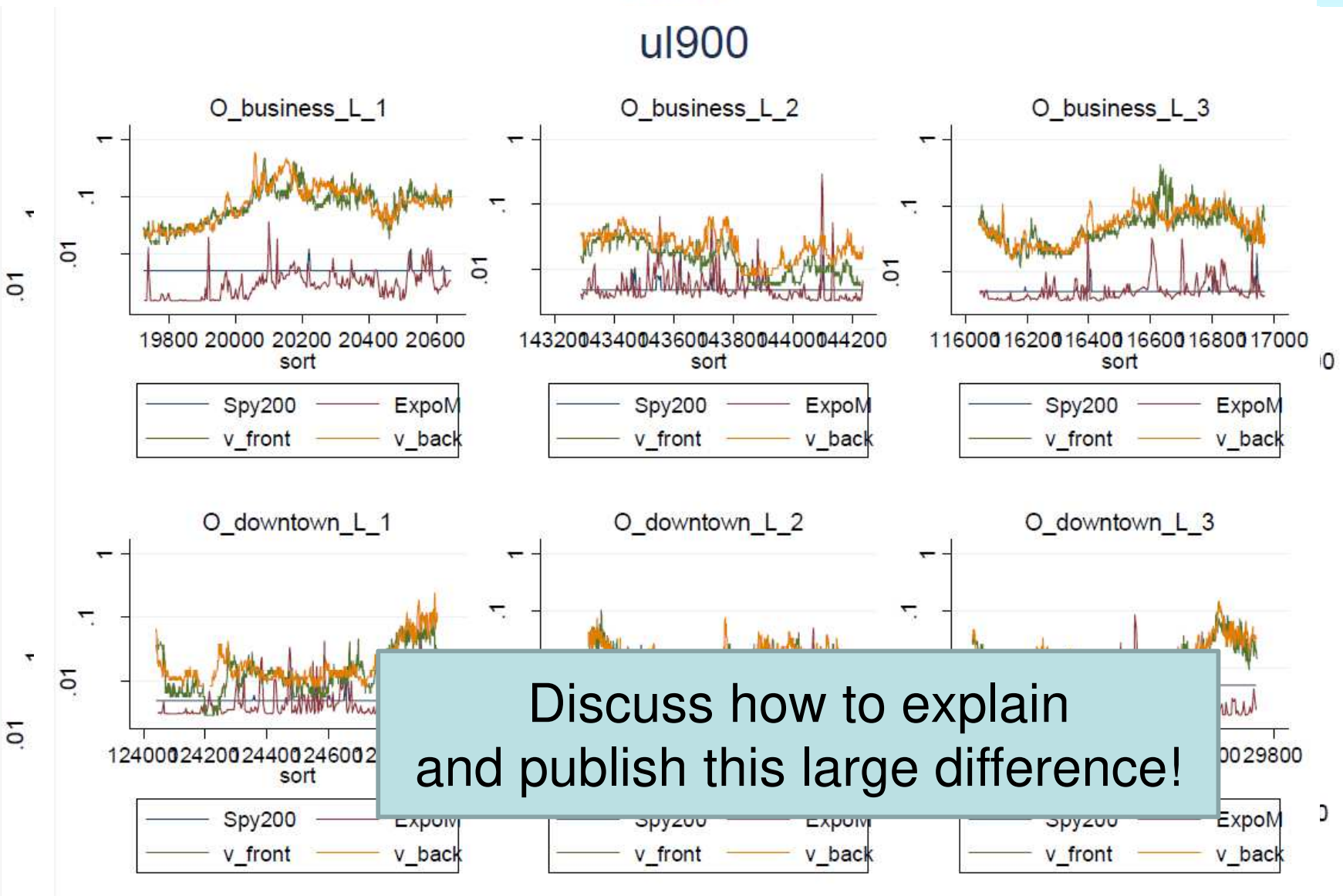
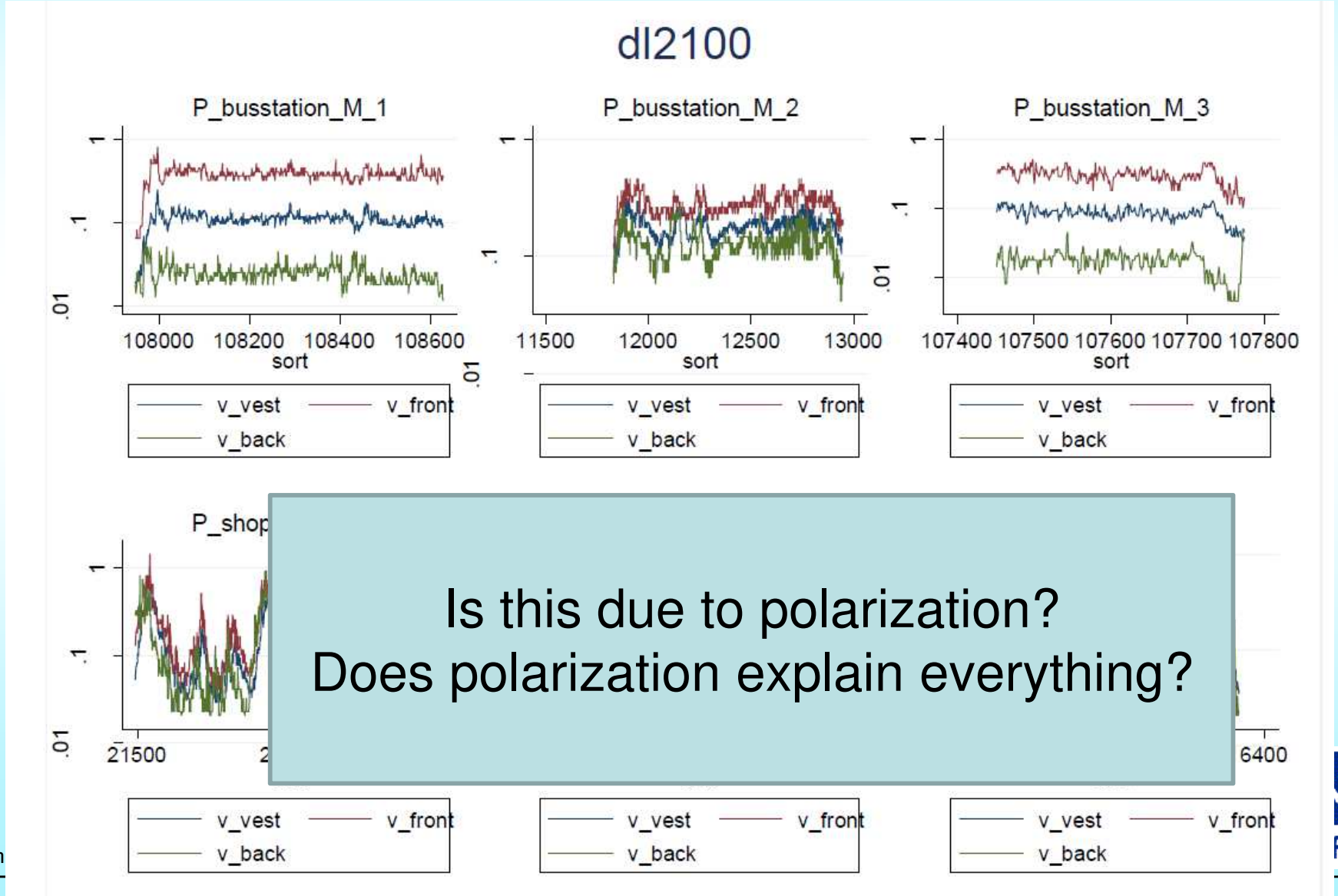
First raw results: UL values measured by the vest are much higher than in ExpoM and EME spy



Discuss how to explain
and publish this large difference!

The same antenna in the back may measure consistently higher/lower than the same sensor in the front.



What to do with measurements under the detection limit?

In previous version, both the front and the back measurement were sometimes higher than the mean between them.

	A	B	C	D	E	F
1	Original			Corrected		
2	Front	Back	Geometric average	Front	Back	Geometric average
3	1	1	1			
4	1	1	1			
5	1	1	1			
18	1	1	1			
19	1.367746788	1.337594059	1.352586403	12.24744871	10.24695077	3.347033582
20			Comparable to the other averages			This is much lower!!

How to deal with detection limits
for all 3 devices? In a harmonized way?

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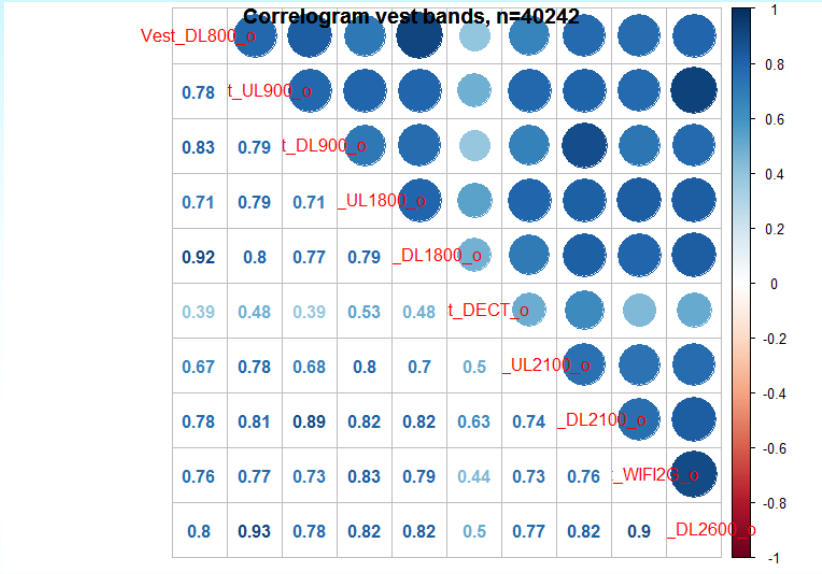
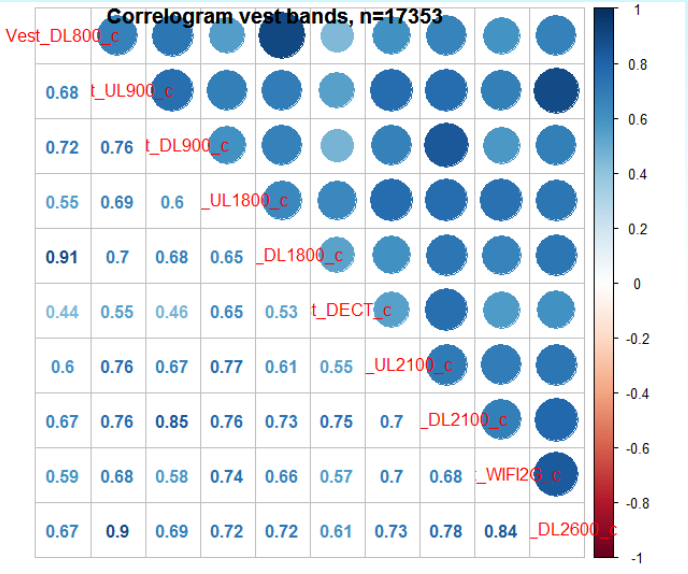
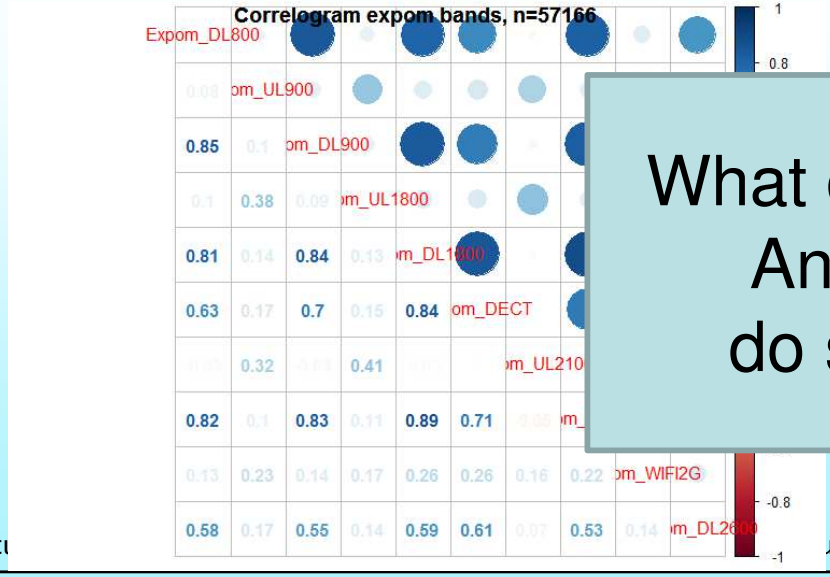
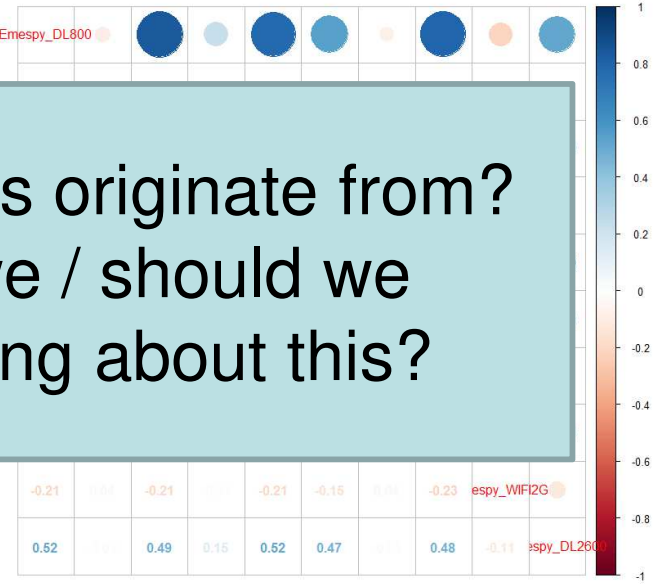
Correlations in vest are much higher than in ExpoM and ME









What does this originate from?
And can we / should we
do something about this?

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Publications

"Four publications foreseen for this project:"

1. A description of the measurement devices and the influence of body morphology on the devices' recordings including validation and calibration data from the laboratory (paper 1, published)
2. R. Aminzadeh et al. "The Effect of Antenna Polarization and Body Morphology on the Measurement Uncertainty of a Wearable Multi-Band Distributed Exposure Meter", Annals of Telecommunications 2018: Major revisions due 13 Oct 2018.
3. R. Aminzadeh et al. "A Multi-Band Wearable Distributed Exposure Meter for Personal Radio-Frequency Dosimetry in Diffuse Indoor Environments", to be submitted by the end of September 2018.
4. An uncertainty analysis: pooled comparison of BWDM measurements with EXPOM and EME SPY measurements (Anke)
5. Comparing contribution of uplink exposure compared to downlink exposure in various microenvironments (?)
6. A pooled analysis of environmental RF-EMF exposure levels in various microenvironments in five European countries and the contribution of different sources to the total RF-EMF exposure (Marloes)

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