Lidar-derived Vertical Aerosol Fluxes in Boundary Layer

mgr Maciej Karasewicz
dr hab. Iwona S. Stachlewska, prof. ucz.

Remote Sensing Laboratory, Atmospheric Physics Department, Institute of Geophysics, Faculty of Physics, University of Warsaw.

email: maciej.karasewicz@fuw.edu.pl

Remote Sensing Laboratory

Introduction

Aerosol Fluxes

- The **resuspension** (emission) and **sedimentation** (deposition) processes known as exchanges of atmospheric aerosols **fluxes** vary depending on the ecosystem environment (Fowler et al., 2009).

- Vertical aerosol fluxes can be studied using the Eddy Covariance technique, using in-situ instruments (Järvi et al., 2009). Based on Reynolds decomposition, the measured atmospheric parameter *b* and vertical velocity can be decomposed into the sum of the mean value and the fluctuation component. Thus fluxes can be described as the temporal mean of the fluctuating parts, i.e., the value of their covariance.

$$F_b = \overline{b'w'}$$

- Depending on the sign of the covariance, the transport of the atmospheric parameter is either upwards or downwards, corresponding to **resuspension** (positive covariance) or **sedimentation** (negative covariance) processes, respectively.

source: U.S. Department of Energy Atmospheric Radiation Measurement (ARM) user facility

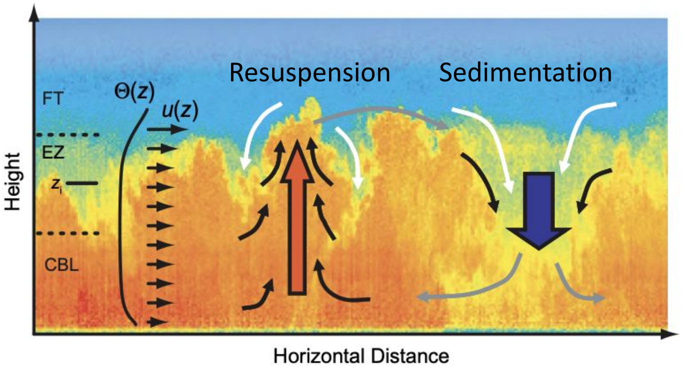
Introduction

Aerosol Fluxes

- An alternative to this technique is the use of Doppler lidar measurements (Engelman et al., 2008). In this case the particle backscatter coefficient (β) as proportional to aerosol mass concentration is considered as a atmospheric parameter b.

$$F_b = \overline{\beta' w'}$$

- The use of Doppler lidar measurements in combination of EC technique can provide information in larger extent of altitudes across the atmospheric boundary layer (ABL).



Source: Engelmann PhD thesis, 2009

- Quasi-particle backscatter coefficient, βp^{quasi} (Baars et al., 2017; Wang et al., 2020) can be used instead, with the advantage that it can be applied when a reference aerosol-free region is not available.

Instrumentation

StreamLine XR (Halo Photonics) Doppler Lidar System

- Products: radial velocity and Signal to Noise ratio (SNR)
- Emission: 1500 nm
- Range resolution: 30 m
- Temporal resolution:
  - 1s (stare, vertical mode)
  - 2 times per hour (VAD, horizontal scans)

Instruments are installed at the roof-platform of the Warsaw Observatory Station (WOS) and serves as part of CLOUDNET-ACTRIS Research Infrastructure. The data in RRT (real real time) is available on: https://cloudnet.fmi.fi

A more detailed description can be found in Pearson et al. 2009

Source: halo-photonics

Disdrometer OTT Parsivel^2

- Products: Precipitation intensity
  - Size
  - Speed

Source: IGF website

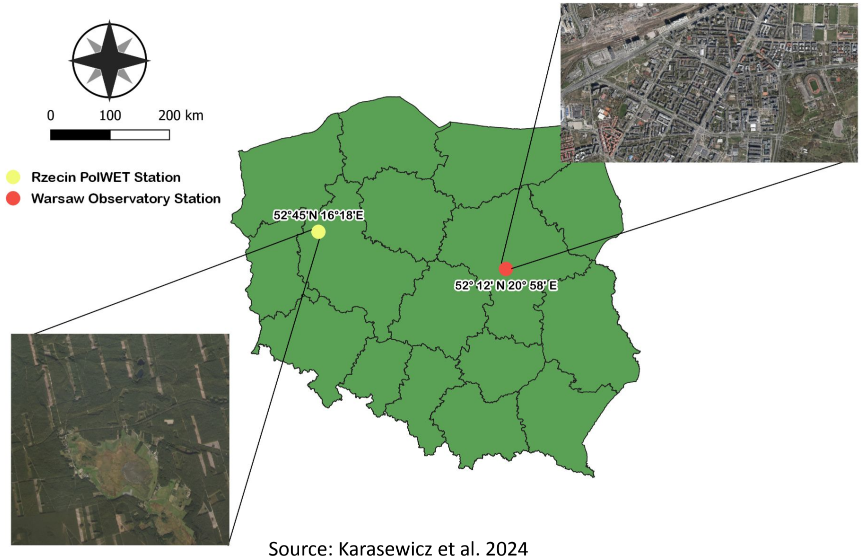
Previous studies

POLIMOS: Technical assistance for Polish Radar and Lidar Mobile Observation System

Trans National Access: Implementation of Combined lidar techniques for the retrieval of Aerosol fluxes in Rural and Urban Sites (ICARUS)

- The main objective of the proposal was the characterization of aerosol particle fluxes between rural Rzecin (Summer 2018, POLIMOS campaign) and urban Warsaw (Summer 2022) sites by using DL+DL method

- The data analysis showed that in **Warsaw case the resuspanesion is dominating** and in case of Rzecin the sedimentation was dominating instead. Additionally most of the fluxes were falling around 0 cm/s (**non-significant resuspension/sedimentation**) in both of the cases



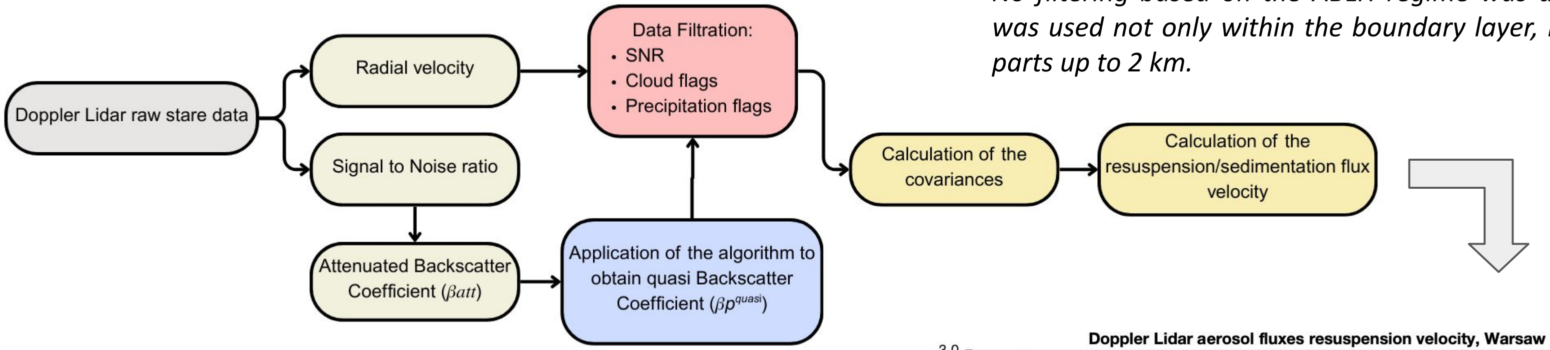
Source: Karasewicz et al. 2024

Methodology

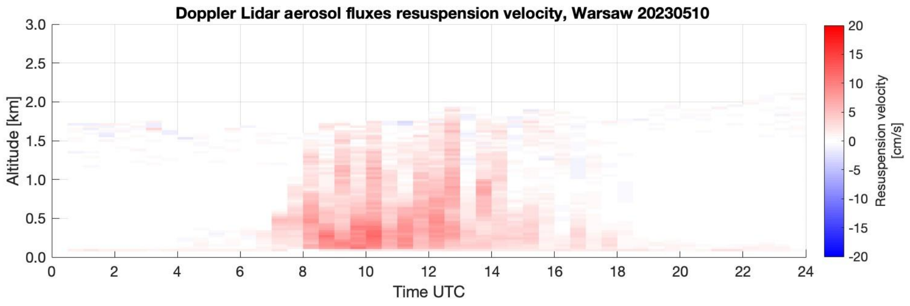
Aerosol Fluxes

The detrending process to isolate the fluctuating component was performed using a linear method.

No filtering based on the ABLH regime was applied. The algorithm was used not only within the boundary layer, but also for the upper parts up to 2 km.



The data analysis in this work consists of 2 years of long-term observational data from 2022/23 in Warsaw Observatory Station WOS.

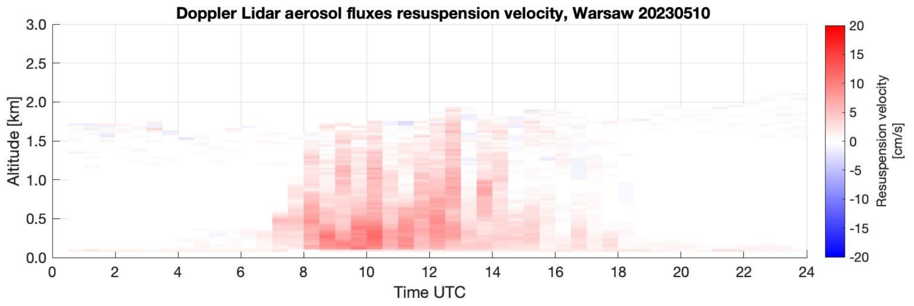


Markowicz, K., Janicka, Ł., & Stachlewska, I. (2025). Disdrometer data from Warsaw for 2022/23. ACTRIS Cloud remote sensing data centre unit (CLU). https://hdl.handle.net/21.12132/1.57d72d0494f445e5

Data analysis

Data grouping

1.



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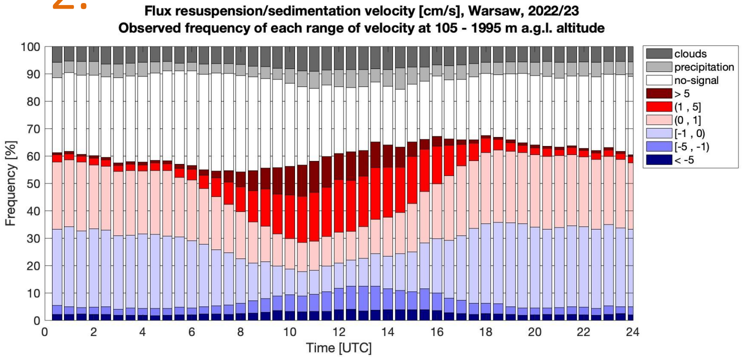

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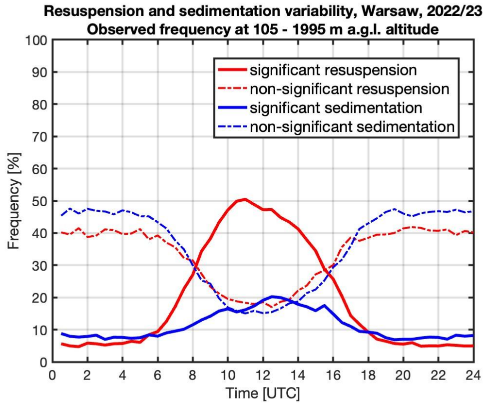
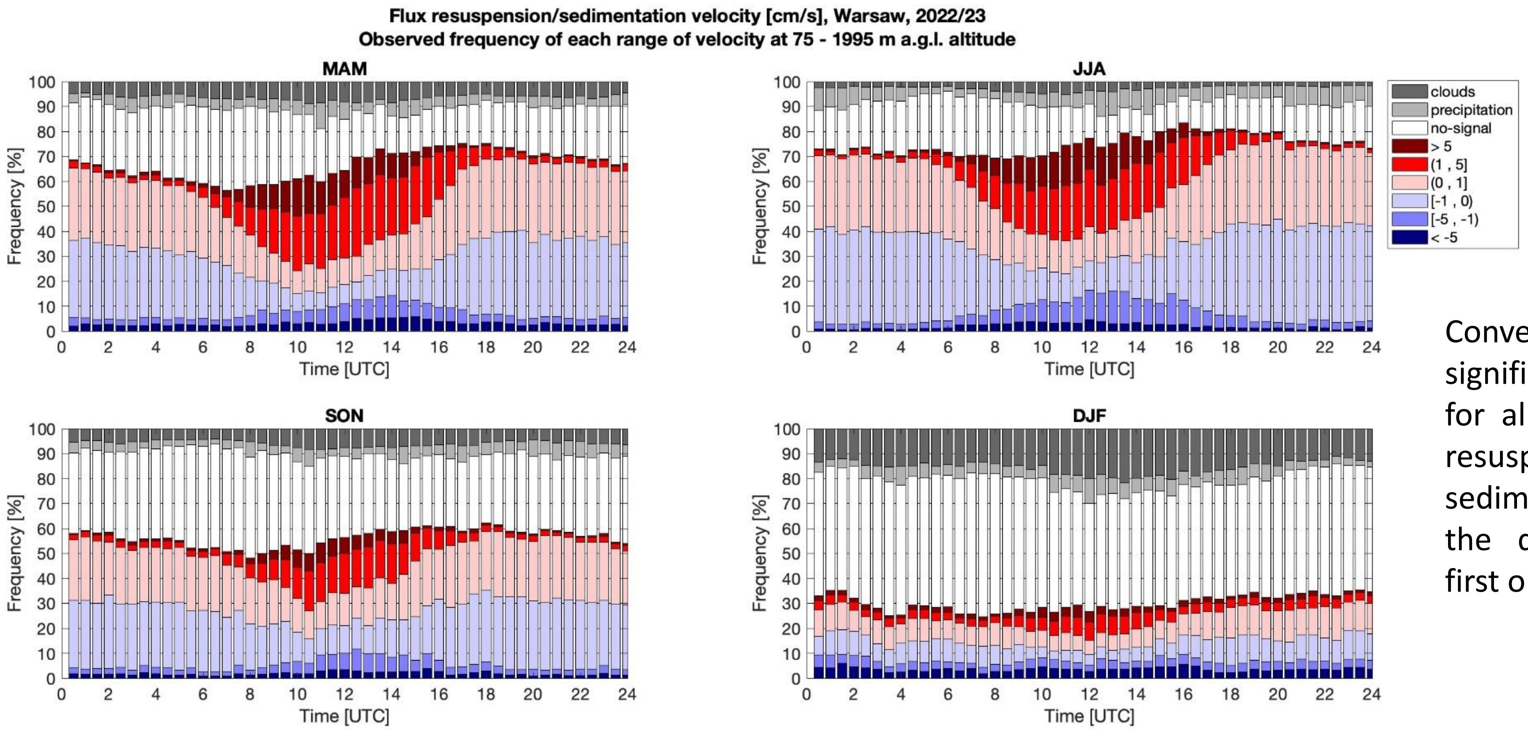


1. Calculations of the fluxes velocities (velocity scale) for each of the measurement days.
2. Grouping according to the observed occurring frequency of precipitation, clouds and aerosol fluxes for fixed database and altitude (in this case 105-1995 m a.g.l. altitude and 2 years of measurements).
3. Grouping the aerosol fluxes into modes which are representing the resuspension/sedimentation velocities:
   a. significant: v > 1 or v < -1 [cm/s],
   b. non-significant: -1 ≤ v ≤1 [cm/s]

Data analysis

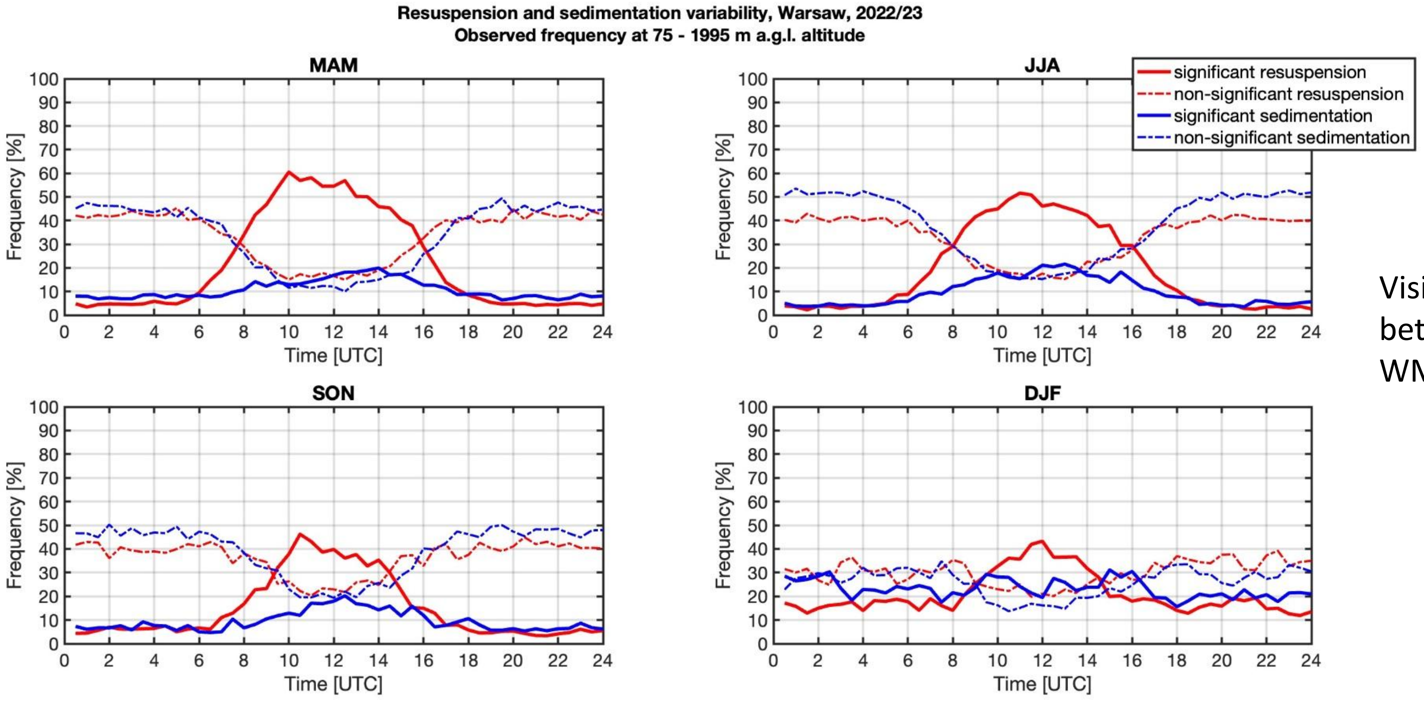
Aerosol Fluxes



Convection-related significant fluxes visible for all seasons both for resuspension and sedimentation but with the dominance of the first one

Data analysis

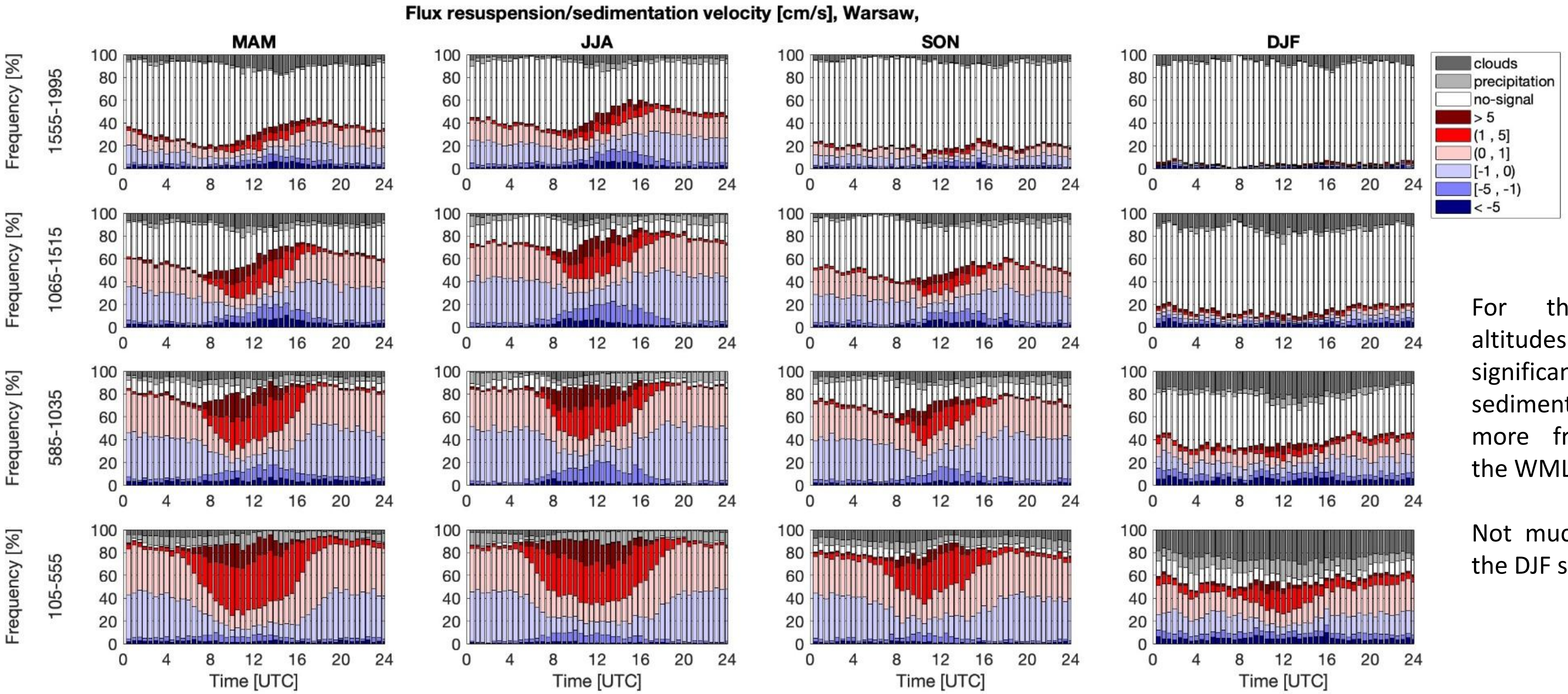
Aerosol Fluxes



Visible strong differences between the NL+RL, TL and WML for all of the seasons

Data analysis

Aerosol Fluxes

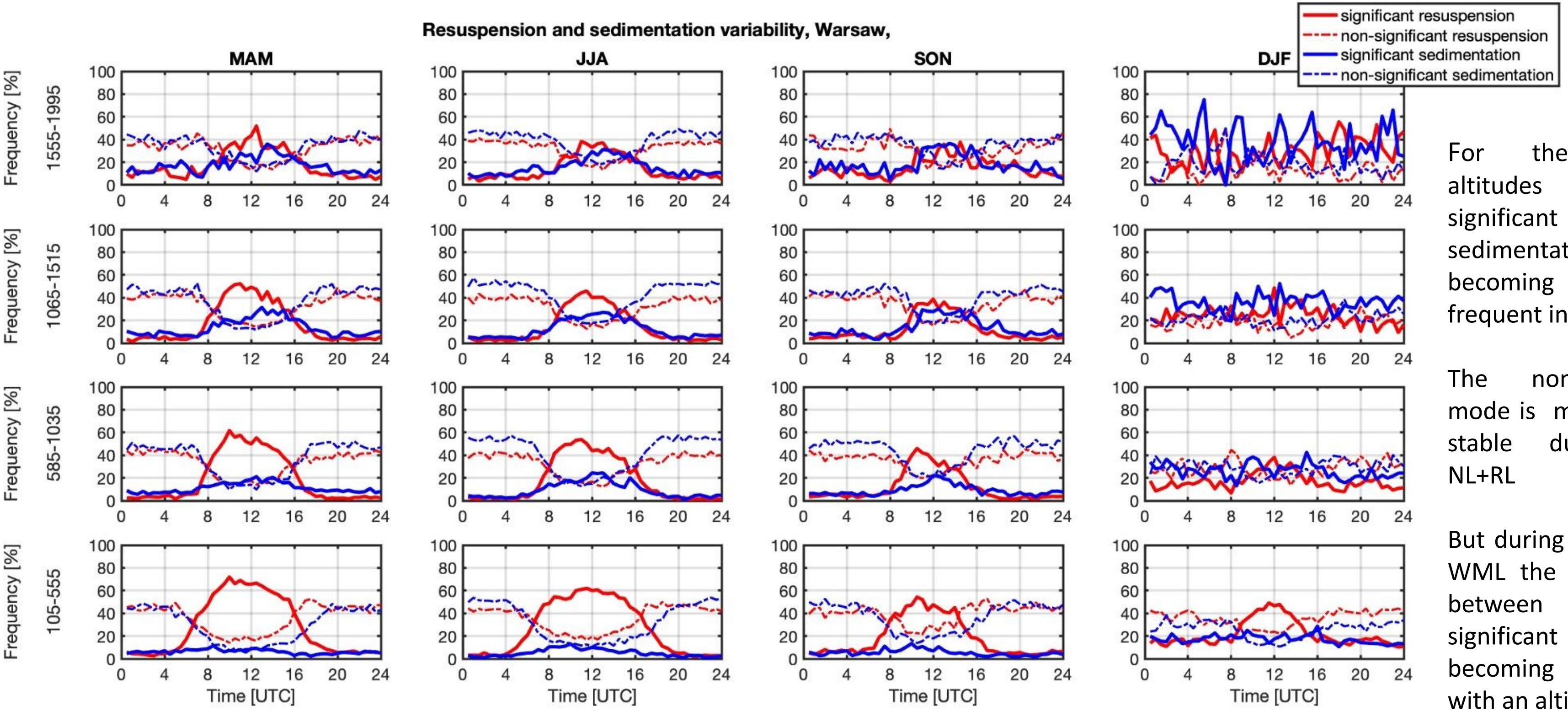


For the higher altitudes the significant sedimentation is more frequent in the WML

Not much data for the DJF season

Data analysis

Aerosol Fluxes



For the higher altitudes the significant sedimentation is becoming more frequent in the WML.

The non-significant mode is more or less stable during the NL+RL

But during the TL and WML the differences between them and significant modes are becoming smaller with an altitude

Data analysis

Aerosol Fluxes - MAM

WML	Non-significant sedimentation	Non-significant resuspension	Significant sedimentation	Significant resuspension	Sedimentation	Resuspension
1555 - 1995	18,54%	18,37%	27,36%	35,73%	45,90%	54,10%
1065 - 1515	17,62%	19,20%	25,29%	37,89%	42,91%	57,09%
585 - 1035	17,50%	20,63%	17,37%	44,50%	34,87%	65,13%
105 - 555	11,40%	23,59%	6,80%	58,21%	18,20%	81,80%
TLsr						
1555 - 1995	32,55%	32,62%	16,82%	18,01%	49,37%	50,63%
1065 - 1515	33,46%	32,08%	12,11%	22,35%	45,57%	54,43%
585 - 1035	31,39%	29,27%	11,58%	27,76%	42,97%	57,03%
105 - 555	22,75%	27,82%	7,55%	41,88%	30,30%	69,70%
TLss						
1555 - 1995	36,71%	32,50%	17,51%	13,29%	54,22%	45,78%
1065 - 1515	43,38%	35,23%	13,28%	8,11%	56,66%	43,34%
585 - 1035	45,58%	37,51%	9,81%	7,10%	55,39%	44,61%
105 - 555	31,52%	48,23%	3,91%	16,33%	35,44%	64,56%
NL + RL						
1555 - 1995	40,77%	37,84%	12,03%	9,37%	52,80%	47,20%
1065 - 1515	46,61%	41,36%	8,06%	3,97%	54,67%	45,33%
585 - 1035	47,56%	41,90%	7,81%	2,73%	55,37%	44,63%
105 - 555	47,56%	41,90%	7,81%	2,73%	55,37%	44,63%

- During WML the resuspension is dominating at **all** altitudes
- **No huge differences** in occurring frequencies for non-significant velocities during NL+RL

	Spring (MAM) Autumn (SON)	Summer (JJA)	Winter (DJF)
Daytime	05:00–17:00	04:00–19:00	06:00–15:00
Nighttime	19:00–04:00	20:00–03:00	16:00–06:00
Well-mixed layer (WML)	12:00–16:00	12:00–17:00	12:00–14:00
Transition layer (TL) sunrise	05:00–11:00	03:00–11:00	06:00–11:00
Transition layer (TL) sunset	17:00–19:00	16:00–20:00	15:00–16:00
Nocturnal and residual layer (NL, RL)	20:00–04:00	21:00–02:00	17:00–05:00

Source: Wang et al., 2019

Data analysis

Aerosol Fluxes - JJA

WML	Non-significant sedimentation	Non-significant resuspension	Significant sedimentation	Significant resuspension	Sedimentation	Resuspension
1555 - 1995	24,81%	21,60%	25,48%	28,11%	50,29%	49,71%
1065 - 1515	27,04%	20,51%	22,22%	30,23%	49,26%	50,74%
585 - 1035	25,14%	22,47%	17,20%	35,19%	42,34%	57,66%
105 - 555	15,43%	26,07%	7,04%	51,45%	22,48%	77,52%
TLsr						
1555 - 1995	39,98%	33,51%	13,29%	13,23%	53,27%	46,73%
1065 - 1515	41,85%	32,38%	11,43%	14,35%	53,28%	46,72%
585 - 1035	38,54%	31,14%	9,20%	21,12%	47,74%	52,26%
105 - 555	30,25%	31,64%	6,62%	31,49%	36,87%	63,13%
TLss						
1555 - 1995	40,04%	32,80%	15,10%	12,06%	55,14%	44,86%
1065 - 1515	45,76%	32,37%	11,71%	10,16%	57,47%	42,53%
585 - 1035	46,42%	34,44%	8,24%	10,90%	54,66%	45,34%
105 - 555	30,47%	42,42%	4,25%	22,86%	34,72%	65,28%
NL + RL						
1555 - 1995	45,96%	37,62%	9,91%	6,51%	55,86%	44,14%
1065 - 1515	52,04%	38,87%	5,84%	3,25%	57,87%	42,13%
585 - 1035	54,22%	40,52%	3,59%	1,66%	57,81%	42,19%
105 - 555	50,61%	44,16%	2,01%	3,21%	52,62%	47,38%

- During WML the resuspension is dominating at **almost all** altitudes
- **Much higher** occurring frequency of sedimentation for non-significant velocities during NL+RL

	Spring (MAM) Autumn (SON)	Summer (JJA)	Winter (DJF)
Daytime	05:00–17:00	04:00–19:00	06:00–15:00
Nighttime	19:00–04:00	20:00–03:00	16:00–06:00
Well-mixed layer (WML)	12:00–16:00	12:00–17:00	12:00–14:00
Transition layer (TL) sunrise	05:00–11:00	03:00–11:00	06:00–11:00
Transition layer (TL) sunset	17:00–19:00	16:00–20:00	15:00–16:00
Nocturnal and residual layer (NL, RL)	20:00–04:00	21:00–02:00	17:00–05:00

Source: Wang et al., 2019

Data analysis

Aerosol Fluxes - SON

WML	Non-significant sedimentation	Non-significant resuspension	Significant sedimentation	Significant resuspension	Sedimentation	Resuspension
1555 - 1995	22,49%	20,16%	31,96%	25,39%	54,45%	45,55%
1065 - 1515	24,22%	21,18%	26,17%	28,42%	50,40%	49,60%
585 - 1035	30,28%	27,34%	16,07%	26,31%	46,35%	53,65%
105 - 555	23,10%	35,17%	6,11%	35,61%	29,22%	70,78%
TLsr						
1555 - 1995	39,16%	34,82%	14,69%	11,33%	53,85%	46,15%
1065 - 1515	41,66%	35,81%	10,69%	11,84%	52,35%	47,65%
585 - 1035	41,76%	33,25%	8,27%	16,72%	50,04%	49,96%
105 - 555	30,14%	34,58%	7,28%	28,01%	37,41%	62,59%
TLss						
1555 - 1995	35,37%	30,01%	15,80%	18,83%	51,16%	48,84%
1065 - 1515	44,65%	34,46%	13,47%	7,43%	58,11%	41,89%
585 - 1035	50,33%	38,03%	7,46%	4,18%	57,79%	42,21%
105 - 555	42,45%	47,10%	3,10%	7,36%	45,54%	54,46%
NL + RL						
1555 - 1995	39,17%	35,56%	14,13%	11,15%	53,30%	46,70%
1065 - 1515	45,73%	40,86%	8,51%	4,89%	54,25%	45,75%
585 - 1035	50,21%	40,07%	6,21%	3,52%	56,41%	43,59%
105 - 555	47,41%	42,89%	4,18%	5,51%	51,60%	48,40%

- During WML the resuspension is dominating at **lower** altitudes
- **higher occurring** frequency of sedimentation for non-significant velocities during NL+RL

	Spring (MAM) Autumn (SON)	Summer (JJA)	Winter (DJF)
Daytime	05:00–17:00	04:00–19:00	06:00–15:00
Nighttime	19:00–04:00	20:00–03:00	16:00–06:00
Well-mixed layer (WML)	12:00–16:00	12:00–17:00	12:00–14:00
Transition layer (TL) sunrise	05:00–11:00	03:00–11:00	06:00–11:00
Transition layer (TL) sunset	17:00–19:00	16:00–20:00	15:00–16:00
Nocturnal and residual layer (NL, RL)	20:00–04:00	21:00–02:00	17:00–05:00

Source: Wang et al., 2019

Data analysis

Aerosol Fluxes - DJF

WML	Non-significant sedimentation	Non-significant resuspension	Significant sedimentation	Significant resuspension	Sedimentation	Resuspension
1555 - 1995	20,93%	11,42%	38,10%	29,55%	59,03%	40,97%
1065 - 1515	16,40%	11,67%	39,15%	32,77%	55,55%	44,45%
585 - 1035	22,33%	18,84%	27,55%	31,29%	49,87%	50,13%
105 - 555	13,78%	25,55%	17,62%	43,05%	31,40%	68,60%
TLsr						
1555 - 1995	25,29%	20,30%	31,42%	23,00%	56,70%	43,30%
1065 - 1515	21,77%	19,01%	33,34%	25,88%	55,11%	44,89%
585 - 1035	26,28%	29,02%	26,83%	17,87%	53,11%	46,89%
105 - 555	24,85%	29,54%	19,92%	25,69%	44,78%	55,22%
TLss						
1555 - 1995	12,78%	11,64%	46,39%	29,19%	59,17%	40,83%
1065 - 1515	18,47%	12,64%	38,81%	30,07%	57,28%	42,72%
585 - 1035	26,93%	22,50%	33,05%	17,52%	59,98%	40,02%
105 - 555	21,63%	34,66%	22,28%	21,43%	43,91%	56,09%
NL + RL						
1555 - 1995	15,77%	10,33%	40,50%	33,40%	56,27%	43,73%
1065 - 1515	23,29%	19,21%	36,60%	20,90%	59,89%	40,11%
585 - 1035	32,06%	30,21%	24,39%	13,34%	56,44%	43,56%
105 - 555	29,55%	40,41%	14,96%	15,08%	44,51%	55,49%

- During WML the resuspension is dominating at **lower** altitudes
- **higher occurring** frequency of sedimentation for significant velocities during NL+RL
- Need to take into account the non-availability of the data in higher altitudes

	Spring (MAM) Autumn (SON)	Summer (JJA)	Winter (DJF)
Daytime	05:00–17:00	04:00–19:00	06:00–15:00
Nighttime	19:00–04:00	20:00–03:00	16:00–06:00
Well-mixed layer (WML)	12:00–16:00	12:00–17:00	12:00–14:00
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Transition layer (TL) sunset	17:00–19:00	16:00–20:00	15:00–16:00
Nocturnal and residual layer (NL, RL)	20:00–04:00	21:00–02:00	17:00–05:00

Source: Wang et al., 2019

Summary & Outlook

Summary

- Resuspension and sedimentation processes depend on the:
  - the different seasons,
  - diurnal cycle
    - Convection-related significant fluxes visible for all seasons both for resuspension and sedimentation but with the dominance of the first one during WML
    - During NL+RL the dominance of the non-significant fluxes is present.
    - During the TL layers the transition of the dominance of non and significant modes appeared
  - altitude
    - For the higher altitudes the significant sedimentation is more frequent in the WML
    - But during the TL layers and WML the differences between non and significant mode are becoming smaller with an altitude

- *To sum up, the resuspension is dominating in urban environment what matched with the previous results.*

Outlook

- First-ever characterization of vertical aerosol fluxes in an urban environment based on WOS long-term measurements was provide.

- Additional data filtration regarding other aerosol types and hygroscopic growth is still needed.

- Similar study can be conducted with other parameters of the atmosphere such as with the profiles of *T* and *RH* from Microwave Radiometer

- Obtained results could be an input for the simulations of the turbulent transport within the ABL

Thank you

I would like to thank Prof. Iwona Stachlewska for the opportunity to collaborate. I also extend my gratitude to the members of the RS-Lab for their assistance with the presented work. Warsaw site is a part of the ACTRIS-ERIC research infrastructure.

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