



What Fluorescence-Mie-Raman Lidar (**FLUMIRA**) reveals about atmospheric aerosols across seasons and cities ?

Remote Sensing
Laboratory

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1. Motivation

2. Instruments

- Mie-Raman Fluorescence Lidar

3. Methods

- Lidar Equations
- Datasets Categorization
- Applied constrains (focus on local aerosol, ABLH)

4. Results

- Importance of Fluorescence
- Importance of water vapor
- Typing

5. Conclusion

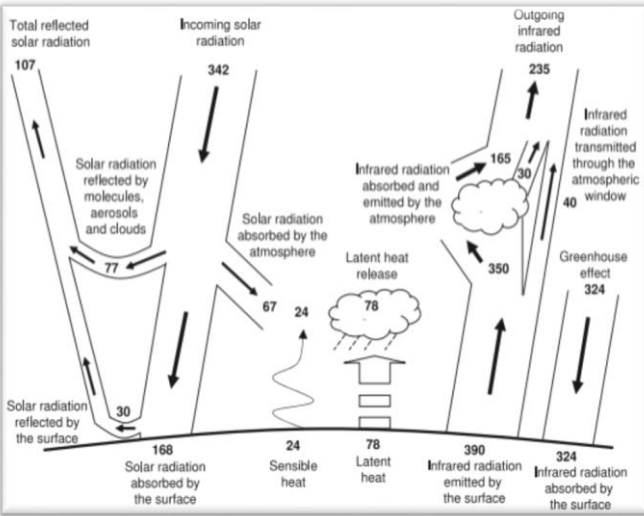


Illustration of Earth's energy budget on the surface and in the atmosphere in Wm⁻² (Boucher, 2015)

Aerosol characterization is essential for understanding:

Air quality

→ Aerosols directly affect human health and visibility.

Climate

→ Aerosol is an atmosphere components

→ Aerosols influence the Earth's radiative balance.

→ They remain a major source of uncertainty in climate forcing assessments

How can aerosol characterization be improved?

→ Lidar provides vertically resolved information on aerosols in the atmosphere.

Why Fluorescence?

Synergy of fluorescence + Mie-Raman

Improve aerosol typing

Increase sensitivity to biological aerosol

Synergy of fluorescence + water vapor + Mie-Raman, support the study:

aerosol hygroscopic growth

aerosol-cloud interactions

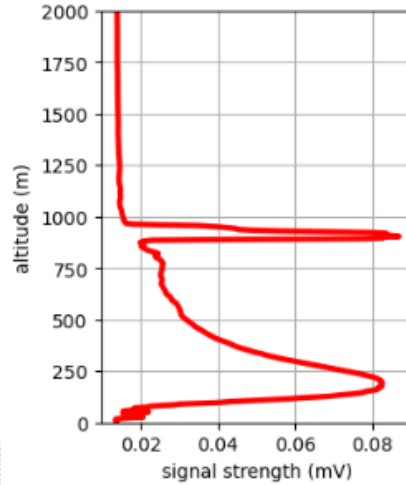
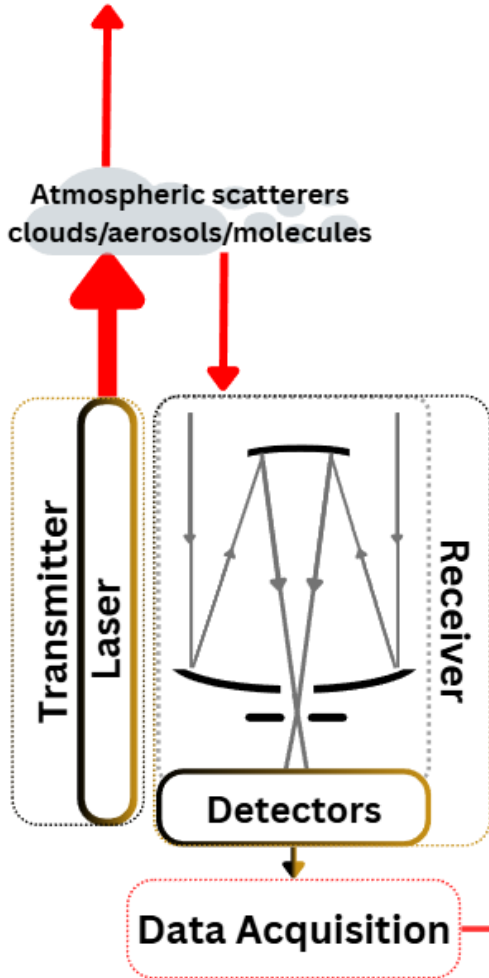


Introduction

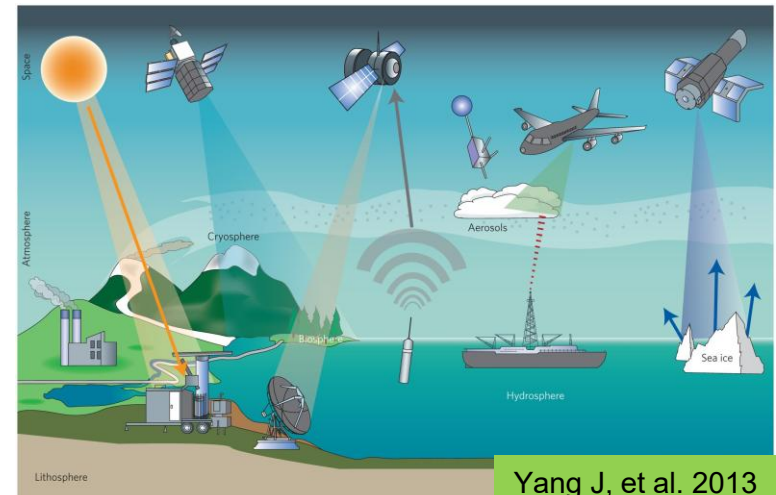
Light Detection and Ranging (LIDAR)

$$d = ct/2$$

d = distance to the scatterers (m)
 c = constant speed of light ($\frac{m}{s}$)
 t = recorded time (s)



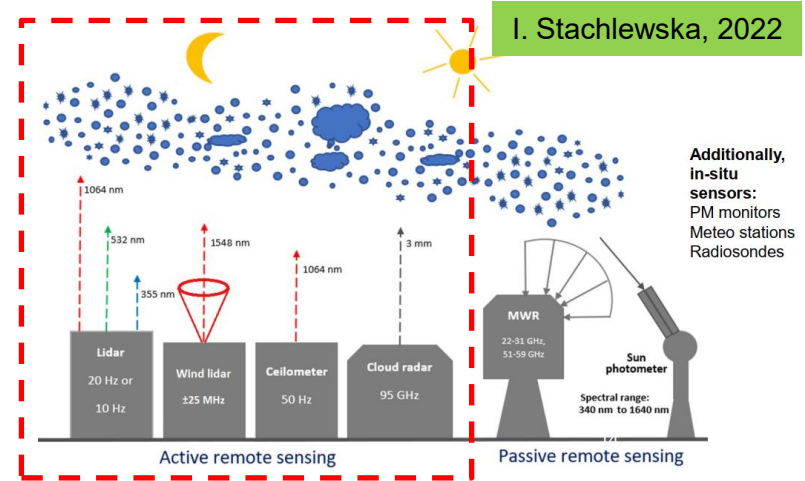
Lidar can be deployed in different platforms



Yang J, et al. 2013



Lidar for Atmospheric Studies

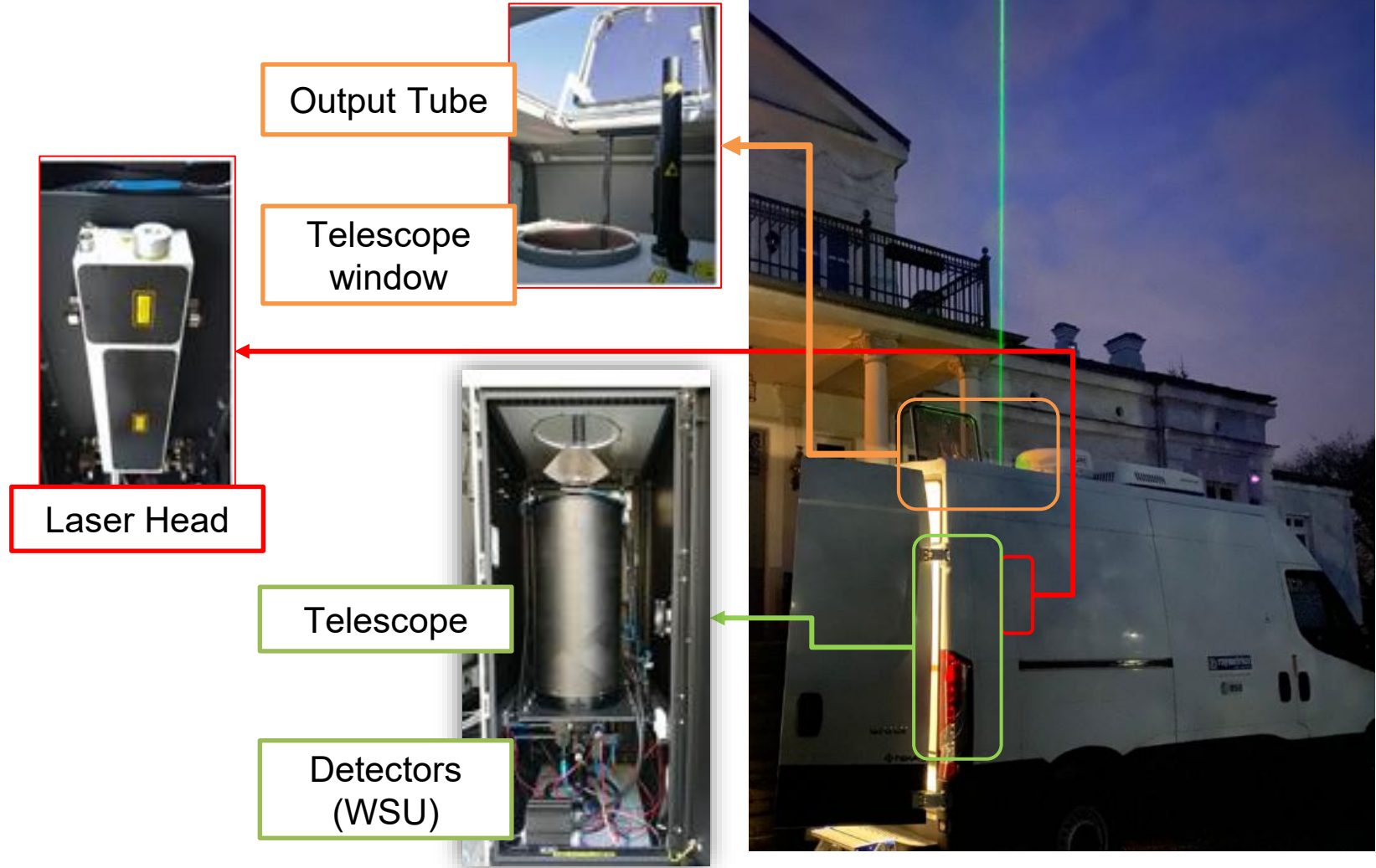


‘different interactions, different applications’

Interaction	Applications
Elastic Rayleigh & Mie Scattering	Aerosol & Cloud
Raman scattering	Nitrogen, oxygen, water vapor, temperature
Fluorescence	Organic matter in troposphere
Absorption	Gas particles (e.g. ozone)
Multiple Scattering	Clouds & fogs
Resonance Fluorescence scattering	Atoms, free-alkali, ions, molecules
Doppler Effect	Wind, turbulence, aerosols

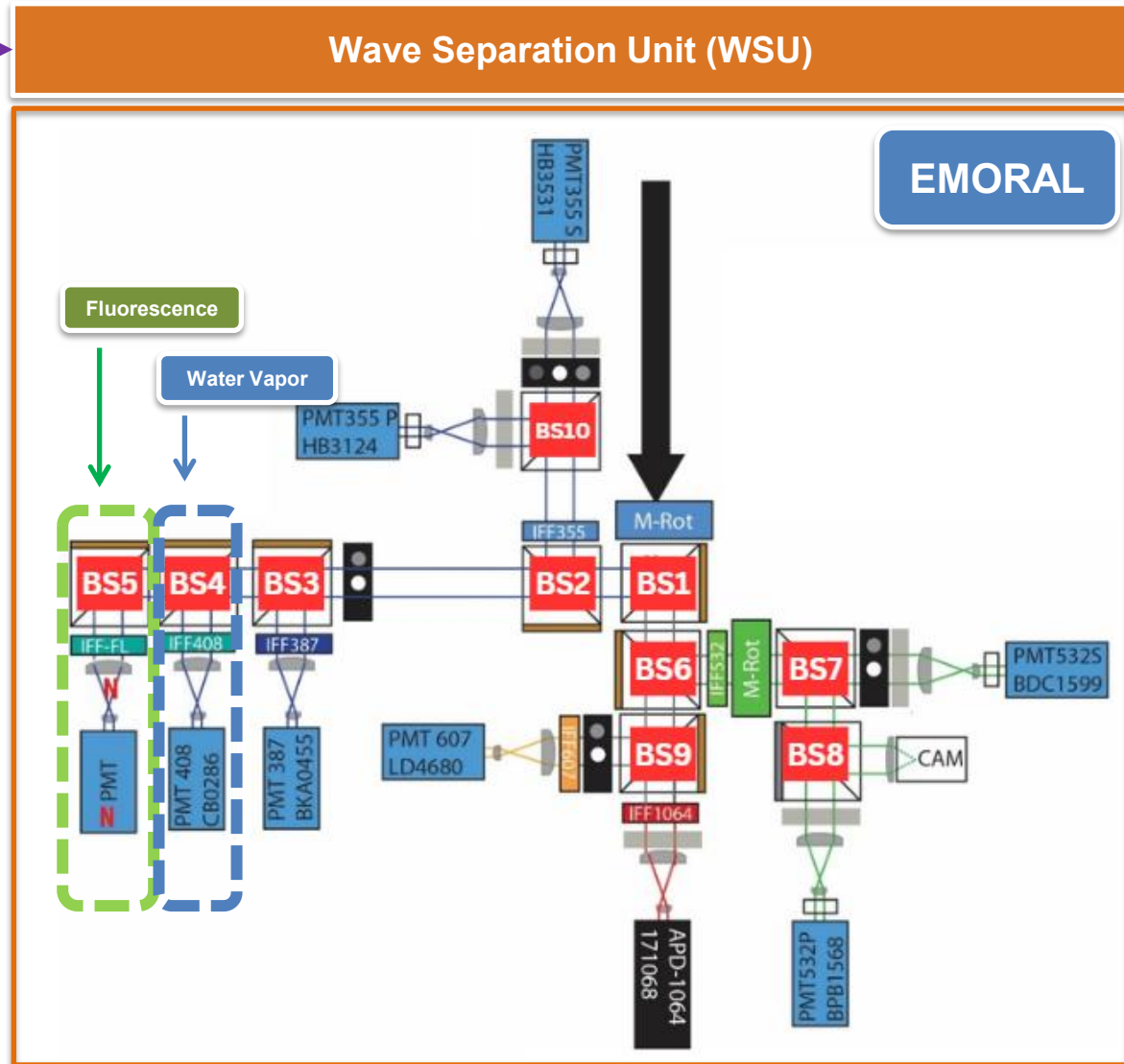
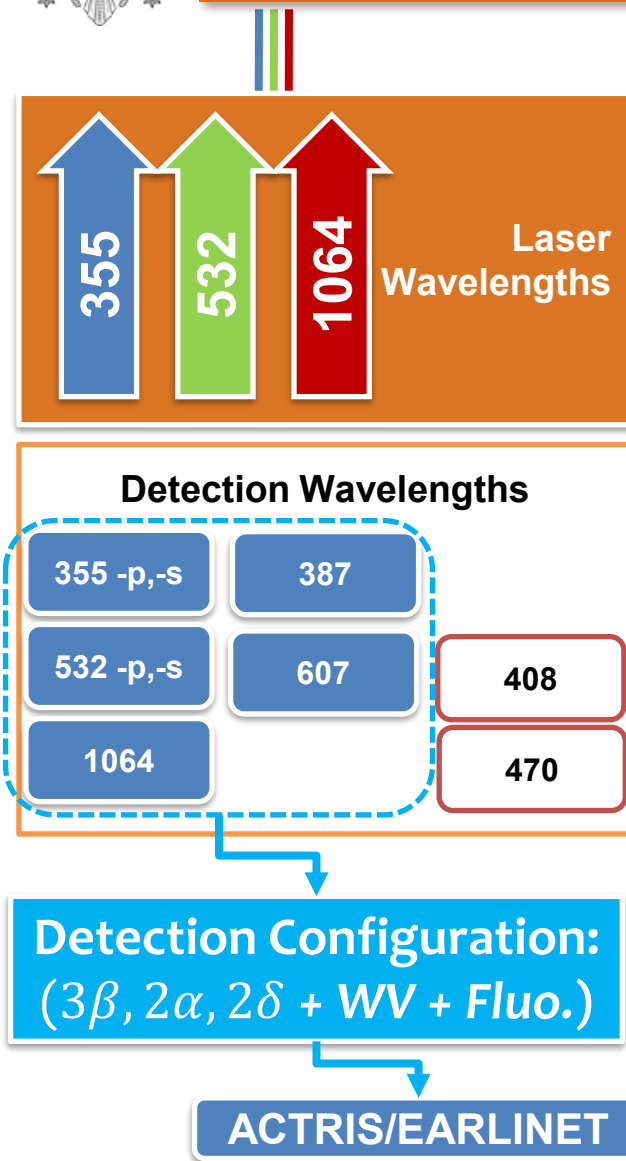


ESA Mobile Raman Lidar (EMORAL)



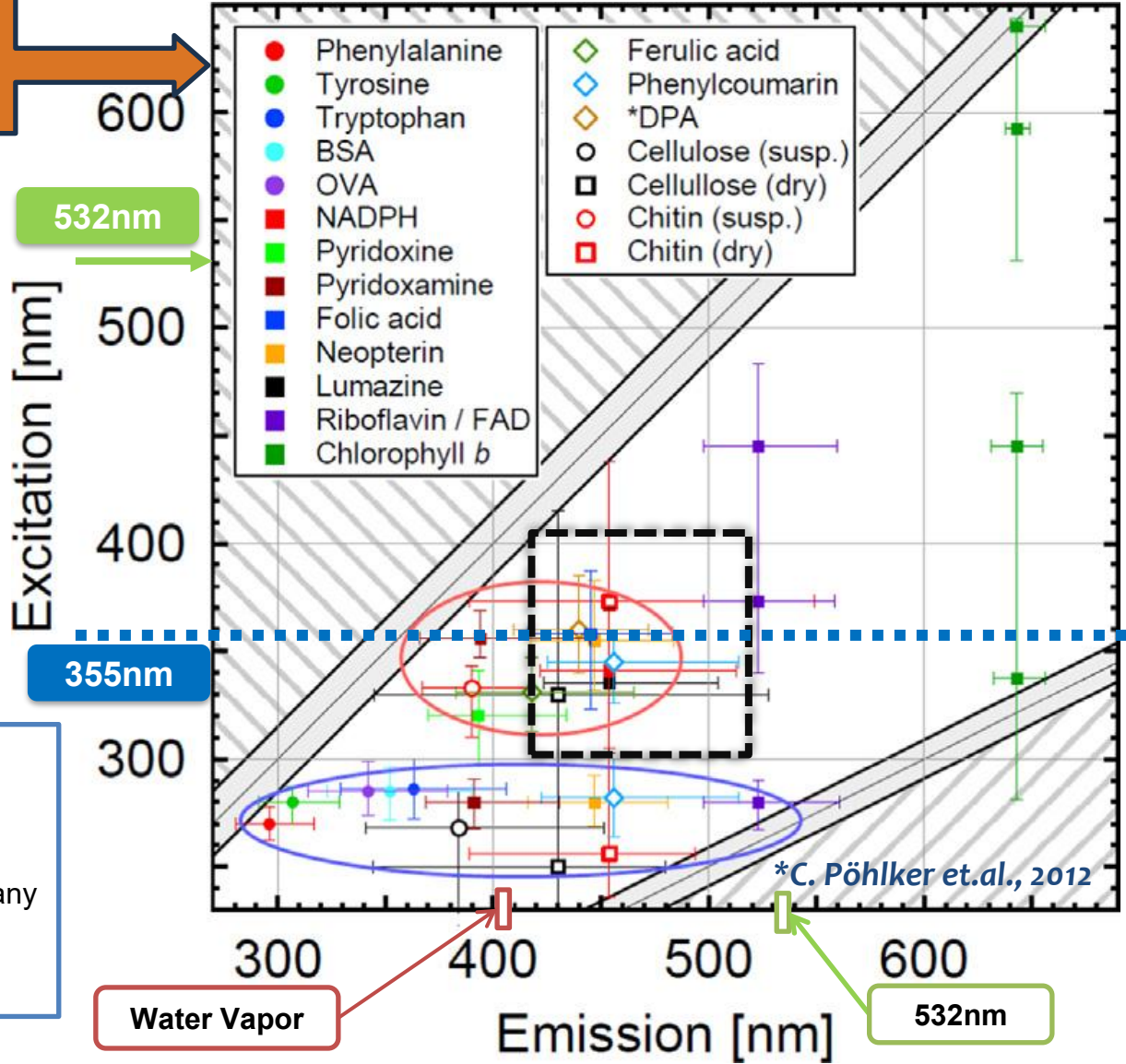


Instrument





Why 470nm (± 50 nm)?



Laser wavelength at 355nm excite many bio-fluorophores

420-520nm band cover emission from many bio-fluorophores

Water Vapor

532nm

*C. Pöhlker et al., 2012



- * Ansmann et al., 1992
- ** Veselovskii et al., 2022
- *** Stachlewska et.al. 2017

Lidar Equations

Lidar Equations (Elastic, Raman)*

$$P_L(z) = K_L \frac{O(z)}{z^2} [\beta_L^a(z) + \beta_L^m(z)] \times \exp \left\{ -2 \int_0^z [\alpha_L^a(\xi) + \alpha_L^m(\xi)] d\xi \right\}$$

$$P_R(z) = K_R \frac{O(z)}{z^2} N_R(z) \frac{d\sigma_R(\pi)}{d\Omega} \times \exp \left\{ - \int_0^z [\alpha_L^a(\xi) + \alpha_L^m(\xi) + \alpha_R^a(\xi) + \alpha_R^m(\xi)] d\xi \right\}$$

Optical Products
(3β, 2α, 2δ)

Lidar Ratio → $S(\alpha_\lambda, \beta_\lambda)$
Angstrom Exponent → $A_\alpha(\alpha_{\lambda_1}, \alpha_{\lambda_2})$
Aerosol Optical Depth → $AOD(\alpha_\lambda)$

Lidar Equations (Fluorescence)**

$$P_F = O(z) \frac{1}{z^2} T_L \int_{\lambda_{\min}}^{\lambda_{\max}} \int_{r_{\min}}^{r_{\max}} C_F(\lambda) \times \frac{dN(r)}{dr} \times \frac{d\sigma_F}{d\lambda}(\lambda, r) \times \exp \left\{ - \int_0^z [\alpha_L^a(\xi) + \alpha_L^m(\xi)] d\xi \right\} dr d\lambda$$

$$\beta_F = \frac{C_R P_F}{C_F P_R} N_R \sigma_R \frac{T_R}{T_F} \quad 1$$

$$G_F = \frac{\beta_F}{\beta_L} \quad 2$$

Fluorescence Capacity

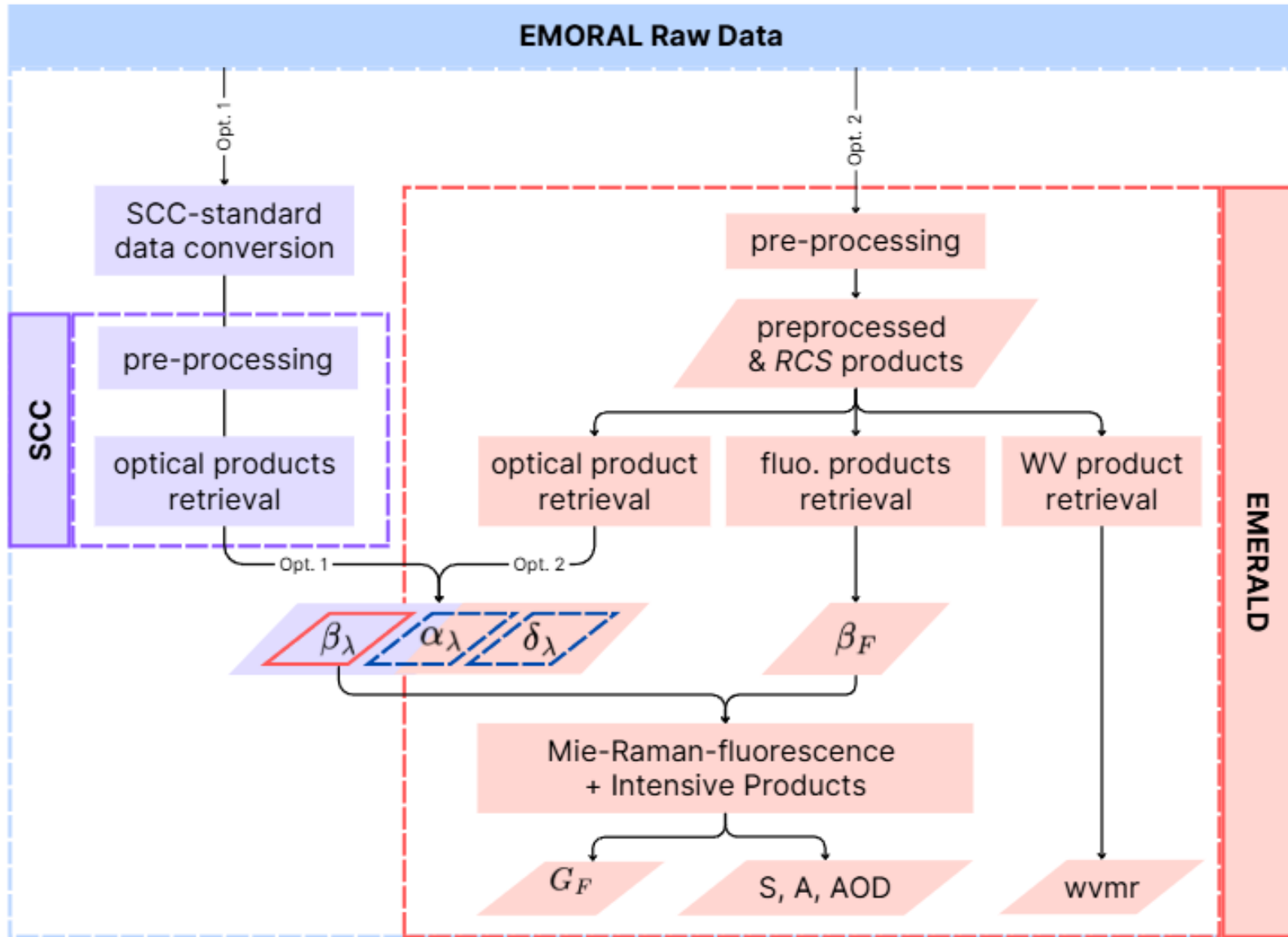
Water Vapor Mixing Ratio***

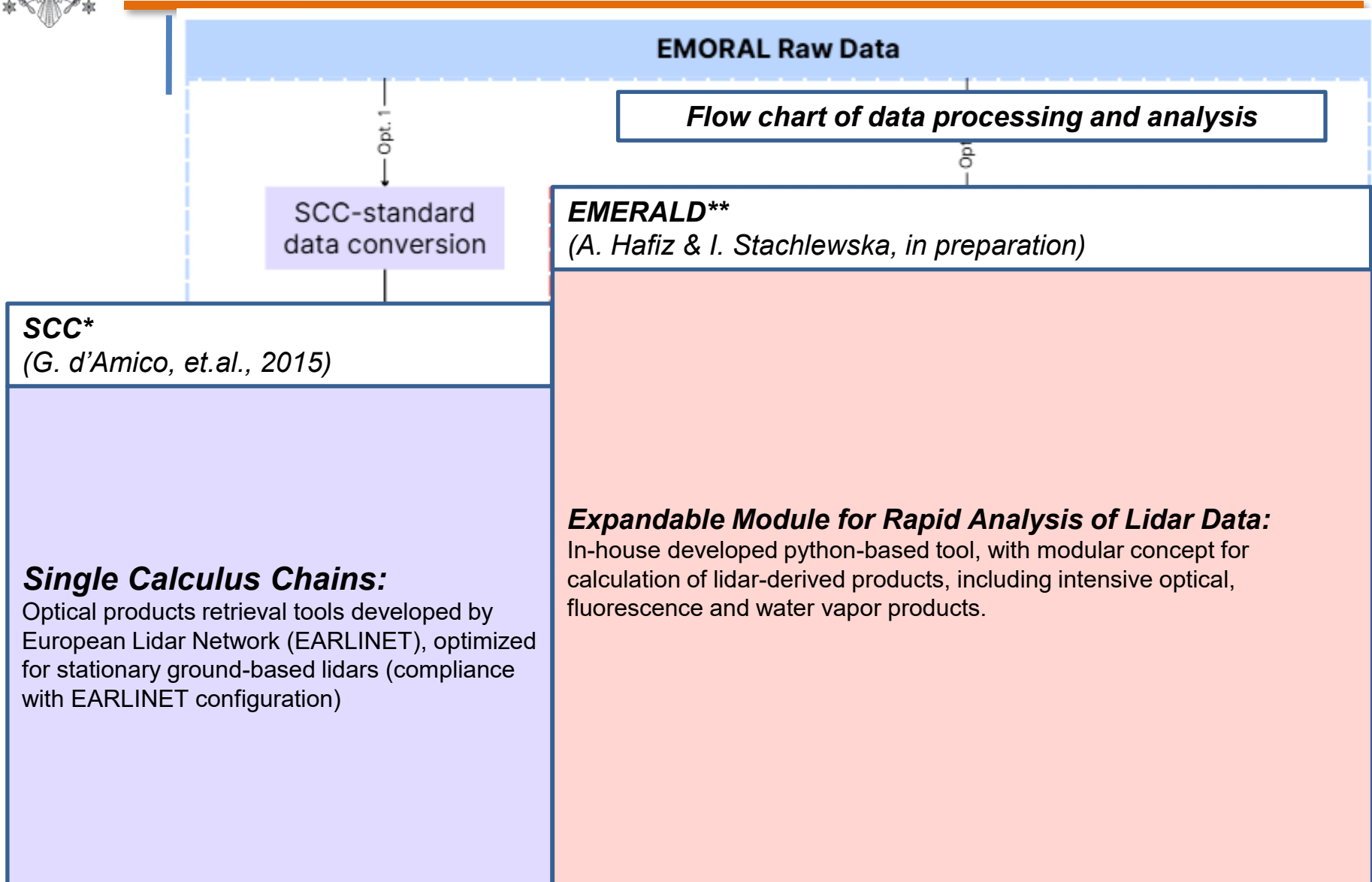
$$WVMR(z) = \frac{K_{387} P_{R407}}{K_{407} P_{R387}} \times \exp \left\{ \int_0^z [\alpha_{407}^{total}(\xi) + \alpha_{387}^{total}(\xi)] d\xi \right\}$$

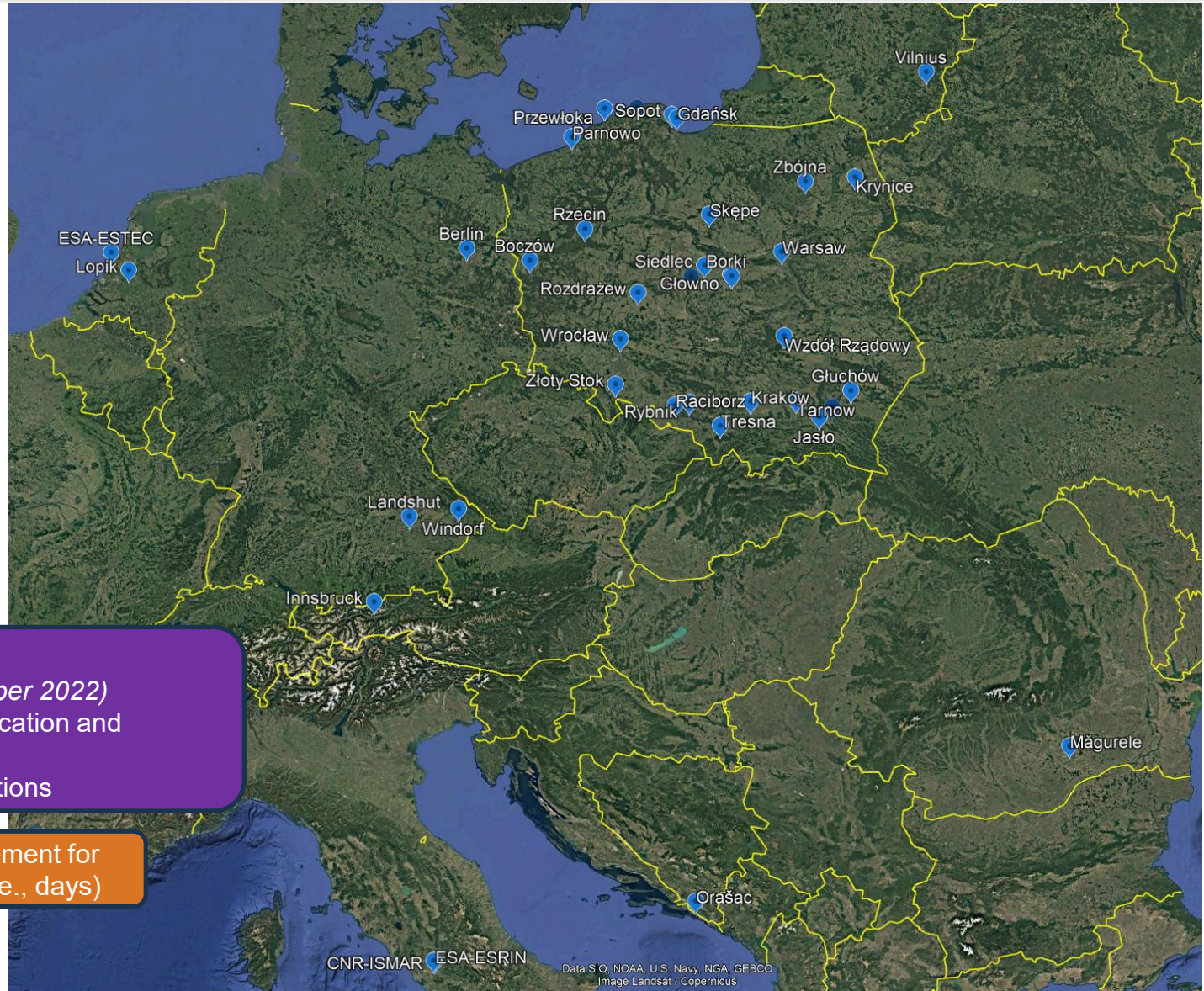
Relative Humidity: RH(z)



Flow chart of data processing and analysis







57 field campaigns:

Since fluorescence (September 2022)

- Different geographical location and condition
- Different seasonal conditions

Including short-term measurement for EarthCare cal/val activities (i.e., days)



For simplicity, sites were grouped measurement sites into urban and rural categories using a broad environmental classification:

- **urban** includes locations influenced by city emissions
- **rural** refers to sites outside major urban influence and more representative of background conditions

What we characterize:

- Fluorescence backscatter signal (high or low)
- Fluorescence backscatter & Water Vapor correlation
- Aerosol Types based on Fluorescence

Applied constrains:

- 1) Aerosol within boundary layer only
Upper cut off at boundary top
- 2) Lower Cut off at 500m

Mind that:
Raman, Water Vapor, and Fluorescence
only at Nighttime

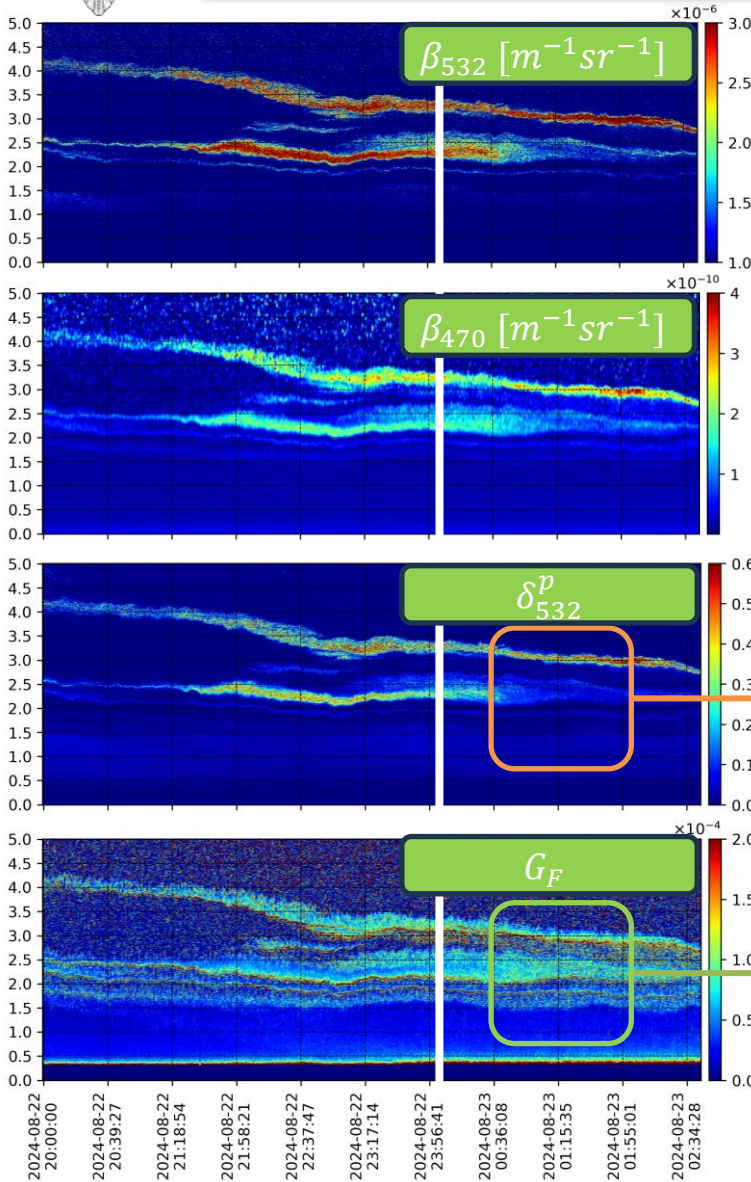


- Results -

Number of measurements for each category

Season/Type	Urban	Rural
Winter	5	3
Spring	6	6
Summer	12	11
Fall	7	7

***We only present part of these datasets
Full datasets analysis will be included in publication under preparation***

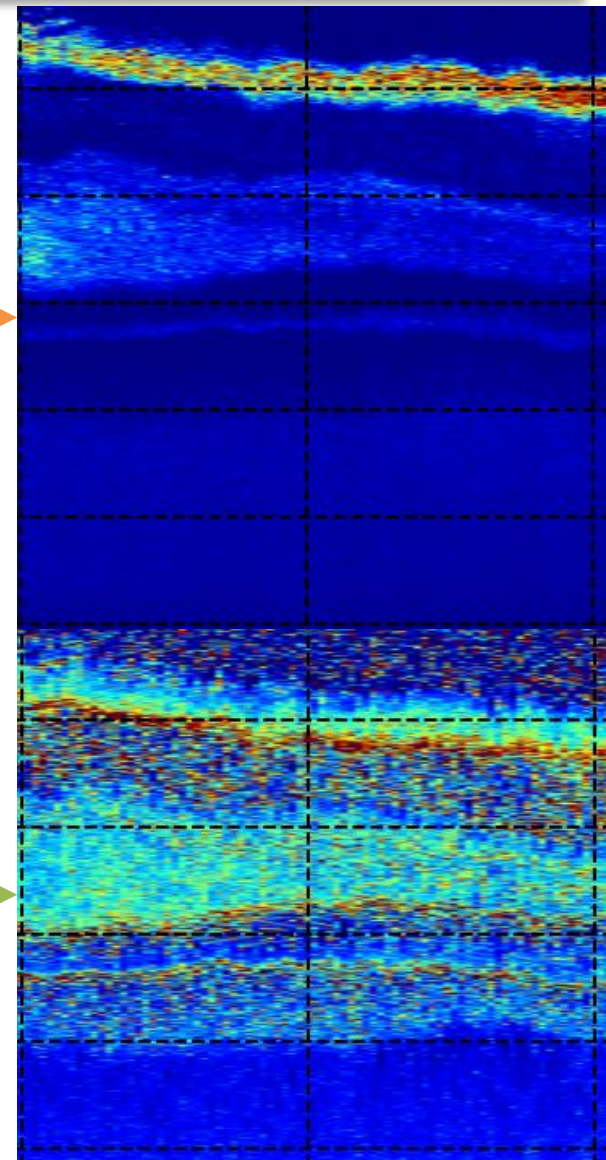


Urban (Summer)
Wroclaw, Poland

At first:
No obvious no obvious added values
But,
If we look closer to δ_p & G_F
We can see the difference

More visible example in other case ...

**High spatio-temporal resolution quasi products*





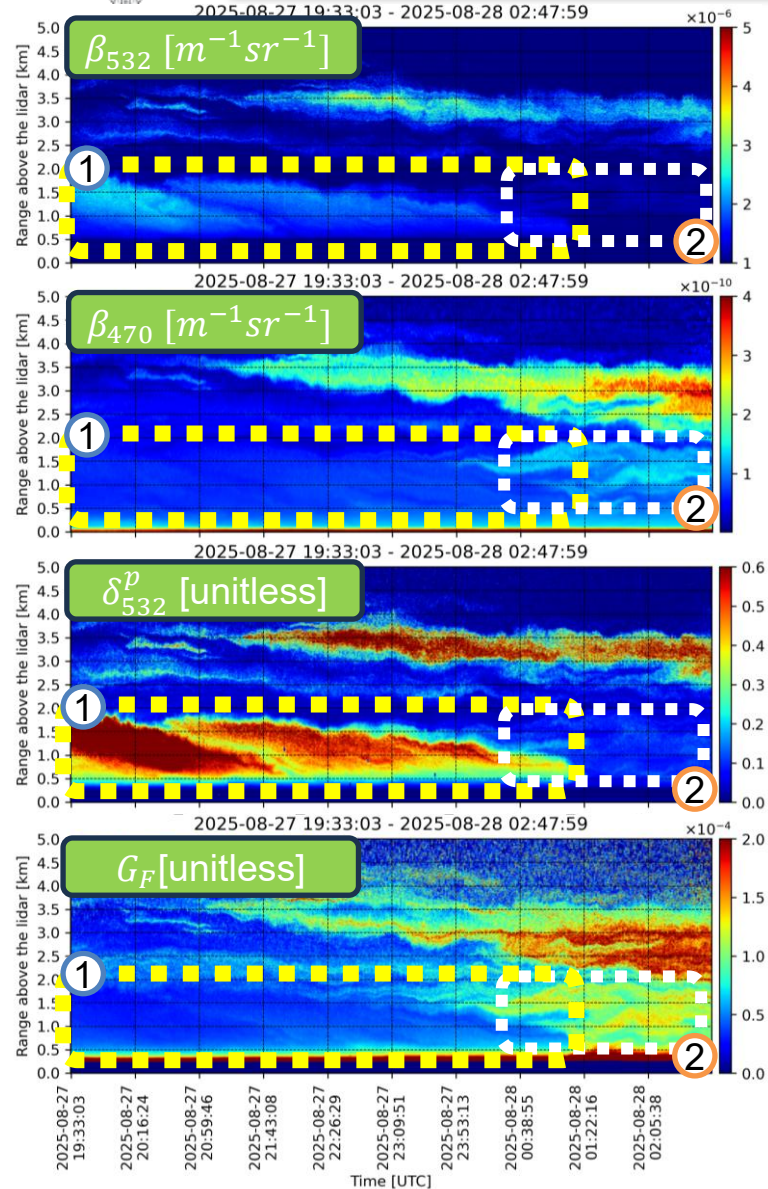
Rural (Summer)
Uniejow, Poland

Case 1.

We observed quite a strong signal at elastic parameters (β_{532} & δ_p^{532}) and no fluorescence signals
→ High depolarization indicate non-spherical aerosols

Case 2.

We observed quite weak β_{532} and low depolarization, δ_p^{532} and strong fluorescence signals
→ Indicating the layer could be bio-aerosol





Products - Vertical Profiles

Urban (Summer)

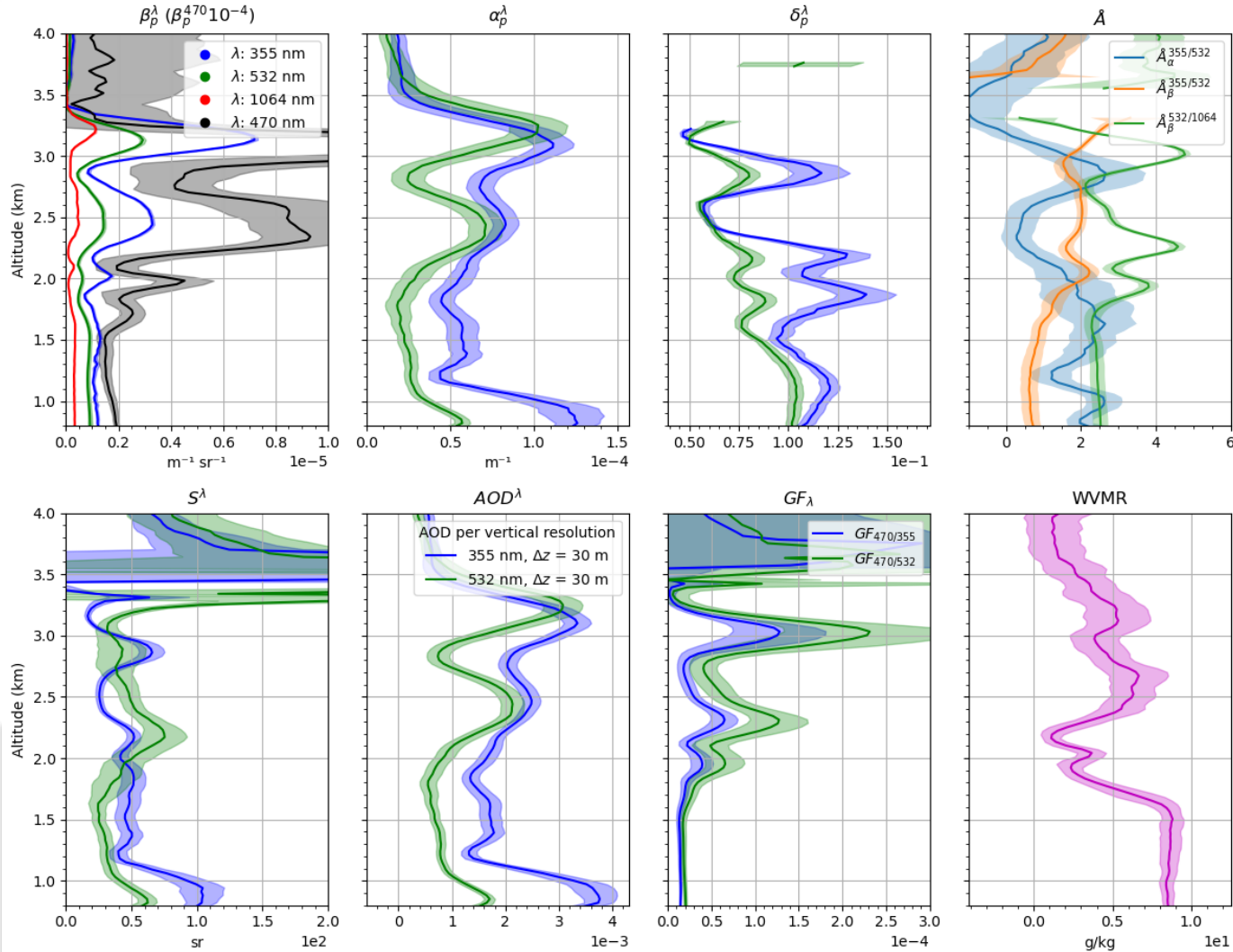
Wroclaw, Poland

23 August 2024

01:00 – 02:00 UTC

Retrieval & plotting:

- 1 hour temp. averaging
- Additional cut-off applied, i.e., if error > 50% (not applied to β_p^{470} & G_F yet)



Legends

β : backscatter coefficients

α : extinction coefficients

δ : depolarization ratios

S: lidar ratios

AOD: Aerosol Optical Depth

GF: Fluorescence Capacity

\AA : Angstrom Exponents

WVMR: water vapor mixing ratio



Layer Average Properties

Dataset Note:

- Nighttime mean
- EMERALD product only (high vertical temporal resolution)

Fluorescence backscatter:

Both Fall & Winte campaigns have low β_p^{470} , with winter case shown more frequent variability

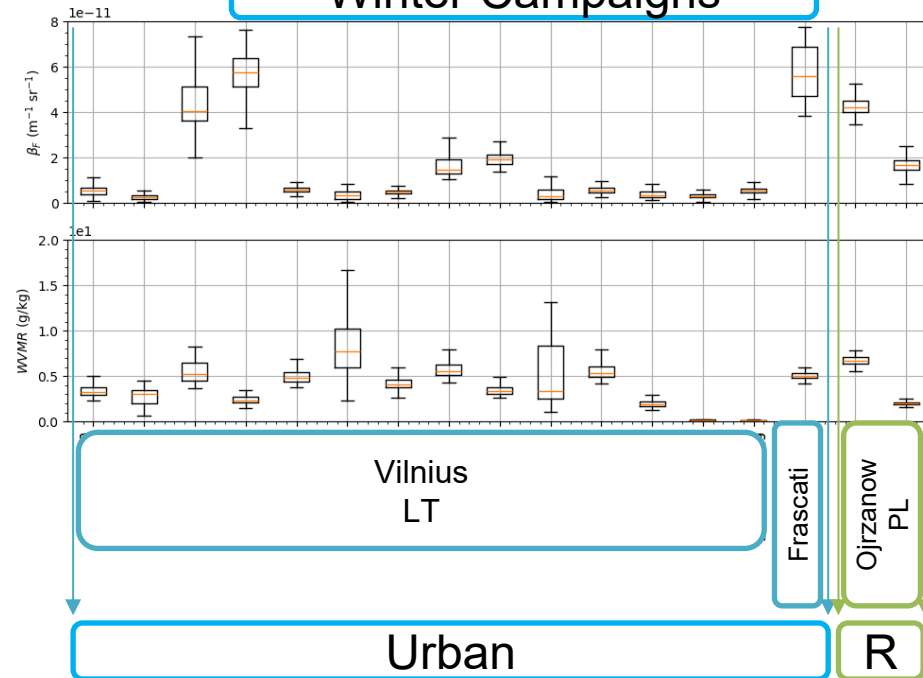
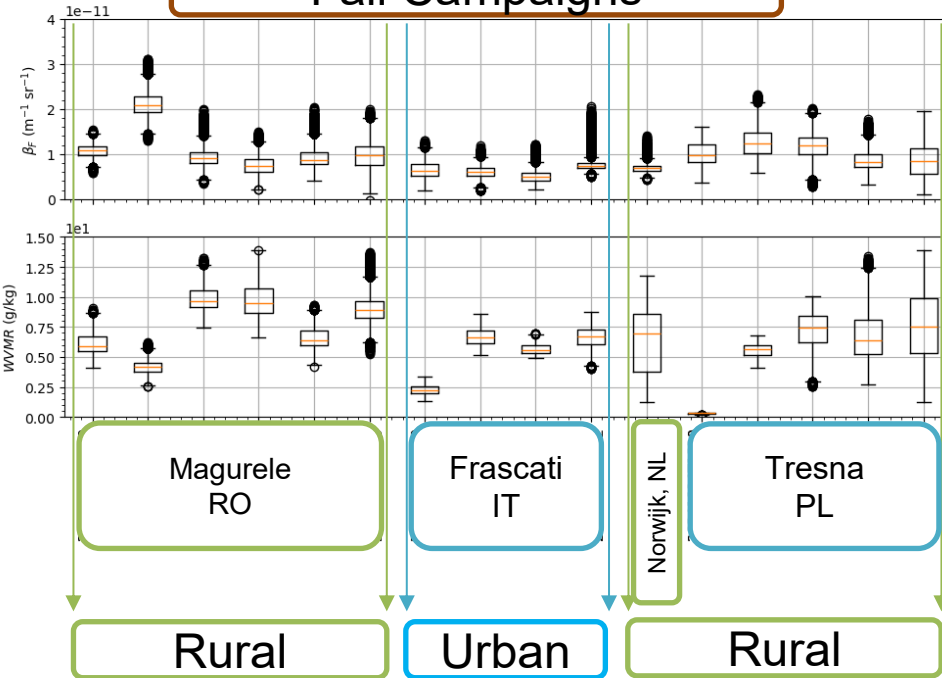
Water Vapor:

Both Fall & Winte campaigns have moderate values, with variability observed in both season

Note: Some datasets show <1 due to dataset calculated with older version of EMERALD → Need reprocessing!

Fall Campaigns

Winter Campaigns



Mind the y-axis scale



Layer Average Properties

Dataset Note:

- Nighttime mean
- EMERALD product only (high vertical temporal resolution)

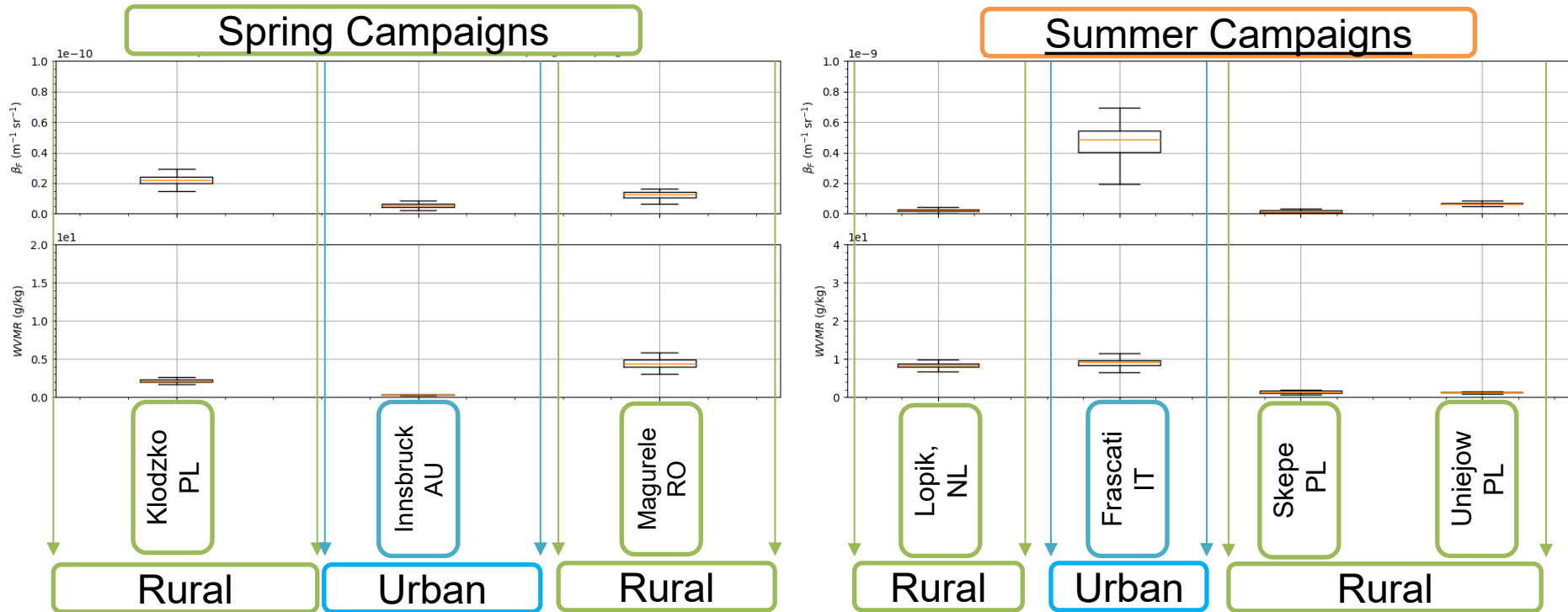
Fluorescence backscatter:

Summer campaign, shown large different between rural and urban
Spring, shown low values

Water Vapor:

Summer campaigns have moderate values
Spring campaigns → dry condition

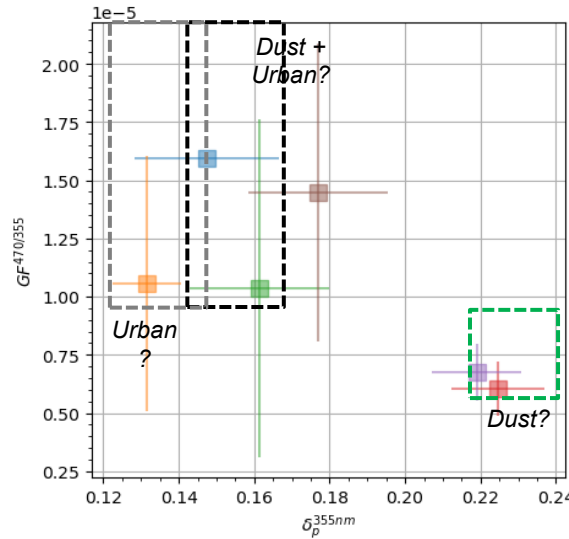
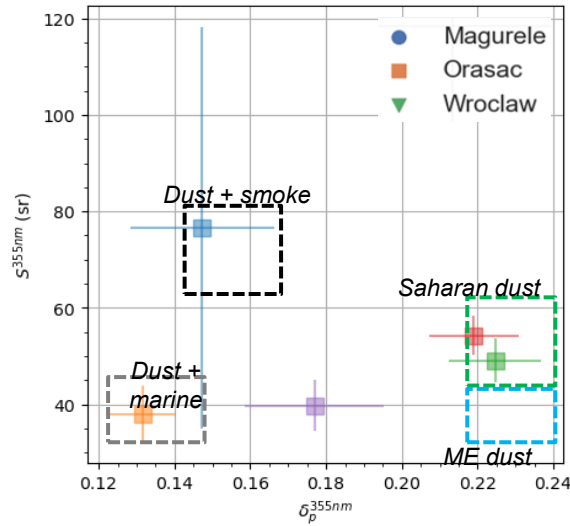
Note: Some datasets show <1 due to dataset calculated with older version of EMERALD → Need reprocessing!



Mind the y-axis scale



Aerosol Typing (example)



Magurele, Romania (Fall)
 Orasac, Croatia (Fall)
 Wroclaw, Poland (Summer)
 Frascati, Italy (Summer)

Nighttime mean

The squared ranges based on:
 * Veselovskii et al., 2022
 ** A. Floutsi et al., 2013; D. Wang et al., 2020

Plan:
 Typing validation across multiple parameters, GF, S, δ_p , AE, etc.
 Target to build summary table, consisting of observed aerosol type across different location

Season/Type	Urban	Rural
Winter
Spring
Summer	dust, dust+urban	
Fall		urban, dust+marine



- We started a study to what Fluorescence-Mie-Raman Lidar (FLUMIRA) can reveal about **aerosols across seasons and cities**
- We have shown how fluorescence can provide different information from Mie-Raman Lidar
- With current analyzed datasets, **temporary conclusion**:
 - Both Fall & Winter campaigns have low β_p^{470} , with winter case shown more frequent variability
 - Fall campaigns: Rural sites shown higher fluorescence signals (but still in low regime)
 - Both Fall & Winter campaigns have moderate values
 - Summer campaign, shown large β_p^{470} different between rural and urban
 - Spring campaigns show low β_p^{470}
 - Water Vapor indicate Summer campaigns have moderate values, Winter campaigns mainly in dry condition
- Water vapor and fluorescence correlation: No conclusive correlation observed, due to limited calculated data points
- Fluorescence capacity, G_F allows for new typing scheme to complement existing approaches

Plan:

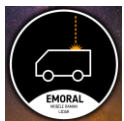
- To analysis the rest of datasets, and extract the conclusion
- To optimize the categorization of datasets, i.e., separating coastal area
- Optimization in the data analysis tool



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RS-Lab Team:

I. Stachlewska, L. Janicka, D.M. Szczepanik, M. Karasewicz, W. Kumala, R. Fortuna, P. Poczta, K. Gabzdyl, I. Okraska, E. Ugboma, A. Hafiz, D. Wang, Z. Rykowska, M. Szczyrba, M. Winikowski and A. Tomczak





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