

Radiation fog in the Strzyżów Valley

Characterizing radiation fog microphysics and radiative properties: from in situ and balloon observations to radiative closure using dual-level solar measurements

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- 1 Nurowska K., Makuch P., Markowicz K.M. (2025) Measurement report: Microphysical and optical characteristics of radiation fog – a study using in situ, remote sensing, and balloon techniques. *Atmos. Chem. Phys.*, 25(20), 13493–13525, doi:10.5194/acp-25-13493-2025.
- 2 Nurowska K., Markowicz K.M. (2026) Radiometric retrieval of LWP and COD in radiation fog using dual-height observations, and the observability of R_{eff} . *Remote Sensing*, 18(19), 3306, doi:10.3390/rs18193306.

IGF UW seminar, 16.10.2026

Outline

- 1 Why fog
- 2 Site and instruments
- 3 Inside a radiation fog: three nights
- 4 From three nights to six years: the inverse problem
- 5 Conclusions

Why fog matters

- Aviation: fog is the **second most dangerous** weather factor in US aviation accidents (14% of weather-related accidents, NTSB)
- 30–35% of cancelled flights are visibility-related (Stevens 2019)
- Affects road transport
- Radiation fog is **local**: valley-scale, sub-grid for NWP

The data gap

Almost no *in situ* data from the lowest 100 m of a fog: too low for aircraft, too high for surface sensors.

Quantities used in this talk

Fog microphysics (balloon, in situ)

- N_c : droplet number concentration [cm^{-3}]
- LWC: **liquid water content**, mass of droplet water per volume of air [g m^{-3}]
- $\text{LWP} = \int \text{LWC} dz$: **liquid water path**, water in the whole fog column [g m^{-2}]
- $R_{\text{eff}} = \int r^3 n(r) dr / \int r^2 n(r) dr$: **effective radius** [μm]
- **vDSD: volume droplet size distribution**: which sizes carry the water
- CTH: fog (cloud) top height [m above ground]

Fog radiation (radiometers)

- COD: **optical depth**, extinction integrated through the fog; direct light attenuated by $e^{-\text{COD}}$.
Visible (droplets $\gg \lambda$): $\text{COD} \approx 1.5 \text{LWP} / R_{\text{eff}}$
smaller in the thermal IR
- $\varepsilon = 1 - e^{-\text{COD}}$: **longwave emissivity**, fraction of black-body emission the layer emits = fraction of the ground's LW it absorbs
- ΔLW , ΔSW : downward LW, SW flux, upper minus lower station [W m^{-2}]

Radiation fog: mechanism, thin versus thick

Formation

- Clear sky, weak wind, stable boundary layer
- Radiative cooling of the ground cools the air above it
- Fog grows **from below**, rarely above 200 m

The longwave emissivity ε decides where the cooling happens

Not all fogs complete the transition

Thin versus thick fog: two regimes, one transition

THIN regime: $\varepsilon < 1$, shallow and stable. LW from the ground **still escapes**; the fog is **cooled from the ground**.

THICK regime: $\varepsilon \approx 1$. The fog radiates back to the ground; the cooling **moves to the fog top**; the layer **mixes and deepens**.

Opacity is necessary, not sufficient: the top cooling must first erode the inversion inside the fog; the **transition takes hours**.

LWP for opacity: 15 g m^{-2} (Costabloy 2025) or 30 g m^{-2} (Wærsted 2017)

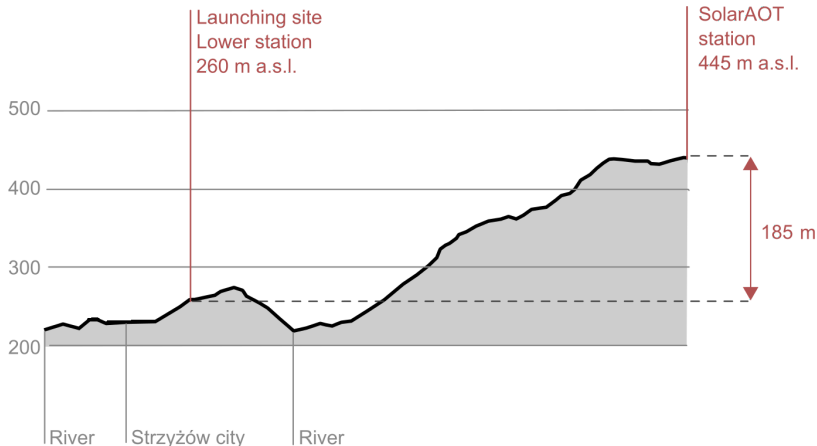
What we can measure versus what we need

- **Microwave radiometer:** expensive, few sites; LWP noise typically of order $10\text{--}20 \text{ g m}^{-2}$, comparable with the LWP of a thin fog; the profile below $\sim 100 \text{ m}$ is poorly resolved
- **Cloud radar:** expensive; reflectivity scales with the **sixth power** of droplet diameter, so a thin fog with $5\text{--}10 \mu\text{m}$ droplets gives a weak signal
- **Lidar / ceilometer:** signal quickly attenuated in fog
- **Satellite (BTD):** coarse pixels, no view below higher cloud, day/night gaps
- **AERI** (Atmospheric Emitted Radiance Interferometer): spectral LW radiances; few units, needs an operator

Two questions of this talk

- 1 What does the **inside** of a thin radiation fog look like?
campaign, Nurowska et al. (2025), ACP
- 2 Can two pairs of **broadband radiometers** deliver LWP continuously for years?
Nurowska and Markowicz (2026), Remote Sensing

The Strzyżów valley site



SolarAOT_{lower}: Wisłok valley

49°52'18"N, 21°48'26"E

SolarAOT_{upper}: hilltop
49°52'43"N, 21°51'41"E

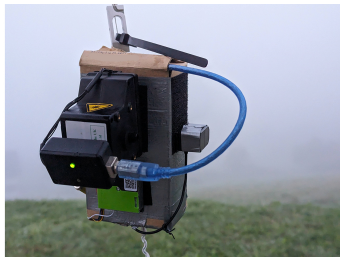
4.06 km horizontal,
azimuth 82°

Fog fills the valley; the upper station stays **above** it.

Lower station and the tethered balloon



(a)



(b)

Campaign 8–11 Sept 2023

74 soundings, 41 with OPC-N3; ~15 min each, up to 100–150 m

OPC-N3 calibrated against the ShadowGraph (LWC, R_{eff} , N_c)

SolarAOT_{lower} (260 m a.s.l., in the fog)

- ShadowGraph at the ground (Oxford Lasers VisiSize)
- **Tethered balloon**
 - ▶ Helium balloon ~1.5 m, Vaisala TTW111 winch, payload 2 m below
 - ▶ **OPC-N3**: 24 bins, 0.35–40 μm ; in fog bins 7–24 ($> 1.15 \mu\text{m}$)
 - ▶ Vaisala radiosonde RS41
 - ▶ additional p, T and RH sensor (GY-63 MS5611, HYT939)
 - ▶ optical PM sensor (SPS30),
 - ▶ visibility sensor (TFMini),
 - ▶ miniature aethalometer (AE-51)

Two stations: the configuration of the second paper

SolarAOT^{upper} (445 m a.s.l., above the fog)

CMP21 pyranometer	retrieval input
Eppley PIR pyrgeometer	retrieval input
CIMEL sun photometer (AERONET)	aerosol
Aurora 4000 nephelometer, AE-31 aethalometer	aerosol
CMP21: 285–2800 nm; PIR: 4–50 μm ; 42 s	

↕ 185 m vertical, 4.06 km horizontal

SolarAOT_{lower} (260 m a.s.l., in the fog)

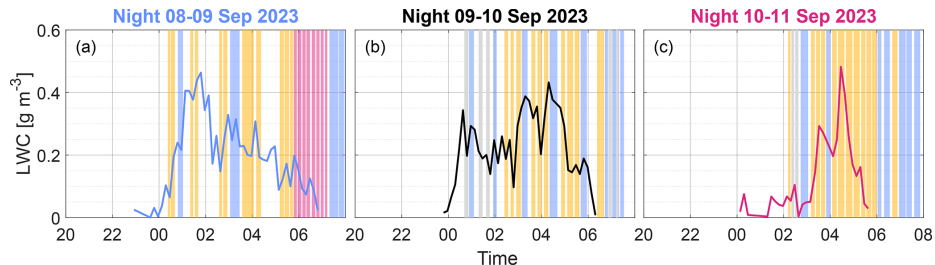
CNR4 net radiometer	retrieval input
CNR4: SW 305–2800 nm, LW 4.5–42 μm ; 36 s	

This **dual-height radiometer pair** (CMP21 + PIR above, CNR4 below) is the configuration used in the retrieval paper.

Inside a radiation fog

three nights

Three nights: overview

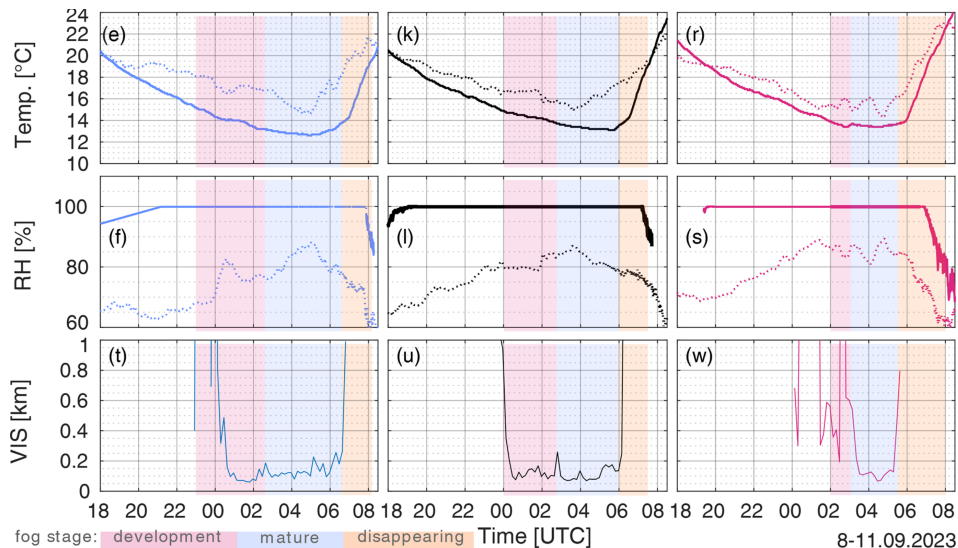


LWC at the ground (ShadowGraph). Vertical lines: balloon soundings, colour = payload set-up: yellow ochre OPC-N3, blue radiosonde, pink OPC-N3 + radiosonde, gray problems with the data.

Night (UTC)	Development	Mature	Dissipation
8–9 Sept	23:00–02:34 (5)	02:34–06:42 (13)	06:45–07:00 (2)
9–10 Sept	from 00:00 (not profiled)	02:45–06:42 (13)	06:30–07:30 (5)
10–11 Sept	02:00–03:02 (2)	03:10–05:30 (8)	05:30–06:00 (2)

(n) = number of balloon soundings. Saharan dust 8–10 Sept (AE 0.5), cleaner air on 11 Sept (AE 1.0).

Meteorological overview



Thin or thick regime? Costablos et al. (2025) criteria

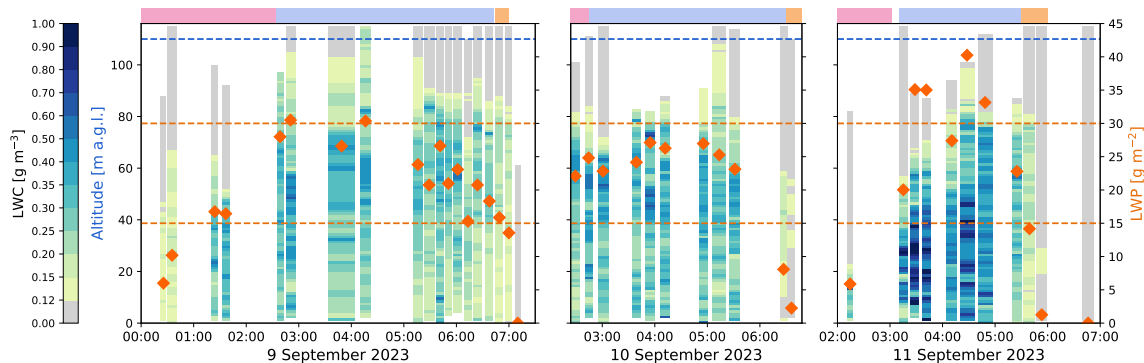
Thick fog if all hold:

- ① $|LW_{net}| < 5 \text{ W m}^{-2}$ at the surface
 - ② $T(50 \text{ m}) < T(25 \text{ m})$
 - ③ $\text{TKE} > 0.10 \text{ m}^2 \text{ s}^{-2}$ (not measured)
 - ④ $\text{CTH} > 110 \text{ m}$
 - ⑤ $\text{LWP} > 15 \text{ g m}^{-2}$
($\text{LWP} > 30 \text{ g m}^{-2}$ Waersted 2017)
- 4 of 5 criteria tested (no TKE)
 - $\text{LWP} > 15$: all mature profiles; > 30 : night 3 and twice night 1
 - $T(50) < T(25)$: nights 1–2 near-neutral lower layer, inversion starting inside the fog at 50–70 m; night 3: isothermal below 50 m, no mixed layer
 - 3 of 4 met twice, 9 Sept **02:38** (LW_{net} , T , LWP) and **04:16** (LW_{net} , CTH , LWP); never all four

Result

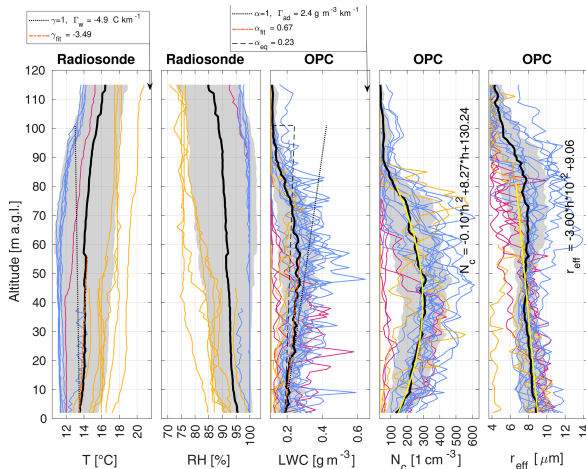
Transition to the thick regime **started but was not completed**: LW_{net} closed only on night 1, the mixed layer never reached the fog top, $\text{CTH} > 110 \text{ m}$ once.

LWC with height across the three nights



- Dashed: CTH = 110 m, LWP = 15 and 30 g m⁻²; bars: development, mature, dissipation; CTH mean ~83 m, max 115 m
- LWP from OPC-N3 bins 7-24 ($r = 1.15\text{--}20\text{ }\mu\text{m}$ mature stage 15-40 g m⁻², six soundings > 30

Vertical profiles, night 1 (8–9 Sept)

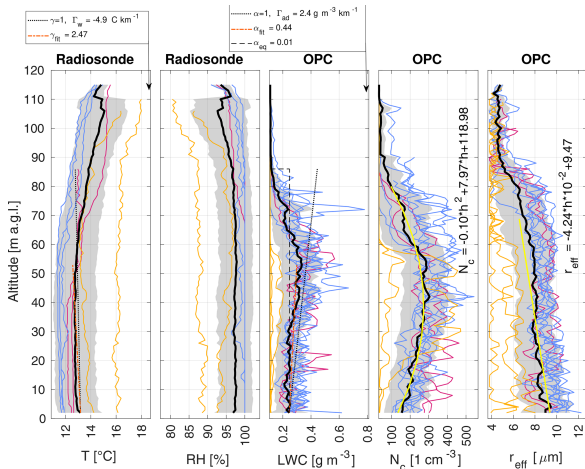


Different colors indicating different stages of fog evolution:

pink corresponds to the formation stage, blue to the mature stage, and yellow ochre to the dissipation stage.

- max CTH: 110 m, the deepest fog
- LWC max: 0.30 g m^{-3} at 56 m in mature stage
- LWP: $6 \rightarrow 16 \text{ g m}^{-2}$ in development, $15\text{--}30 \text{ g m}^{-2}$ in mature stage
- N_c : max 410 cm^{-3} at 48 m, one maximum
- R_{eff} : $9.2 \mu\text{m}$ at the ground
- T : near-neutral to 50–70 m; **27–60 m of fog (30–55% of depth) inside the inversion**

Vertical profiles, night 2 (9–10 Sept)

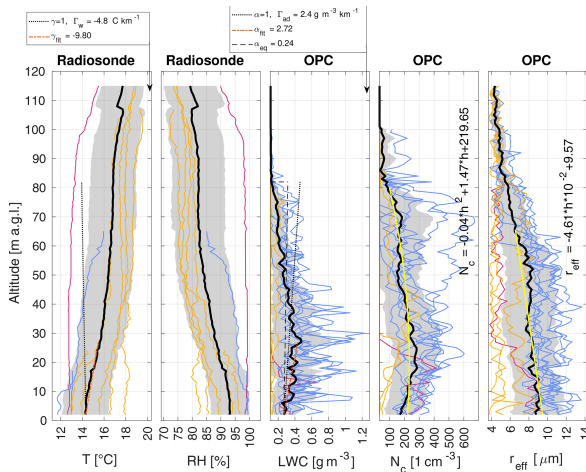


Different colors indicating different stages of fog evolution:

pink corresponds to the formation stage, blue to the mature stage, and yellow ochre to the dissipation stage.

- Development **not profiled**
- max CTH: 87 m
- LWC max: 0.40 g m^{-3} at 53 m (mature)
- LWP: **23–27 g m^{-2} in mature stage**
- N_c : max 345 cm^{-3} , one maximum
- R_{eff} : $\sim 9.0 \text{ } \mu\text{m}$ at the ground
- T : near-neutral to 50–70 m; only **10–22 m of fog (10–30%) inside the inversion** but LW_{net} never closed

Vertical profiles, night 3 (10–11 Sept)



- Fast development: $0.05 \rightarrow 0.30 \text{ g m}^{-3}$ in 23 min
- max CTH: 83 m
- LWC max: 0.67 g m^{-3} at 27 m (mature);
- LWP: max 40 g m^{-2} (11 Sept 04:27), four soundings $> 33 \text{ g m}^{-2}$
- N_c : 377 cm^{-3} at 25 m **two maxima**, ($\sim 25\%$ and $\sim 88\%$ of CTH)
- R_{eff} : $10.0 \mu\text{m}$ at the ground
- T : not decreasing with height

Different colors indicating different stages of fog evolution:

pink corresponds to the formation stage, blue to the mature stage, and yellow ochre to the dissipation stage.

What drives LWC: droplet number, not droplet size

Observed in the three fogs

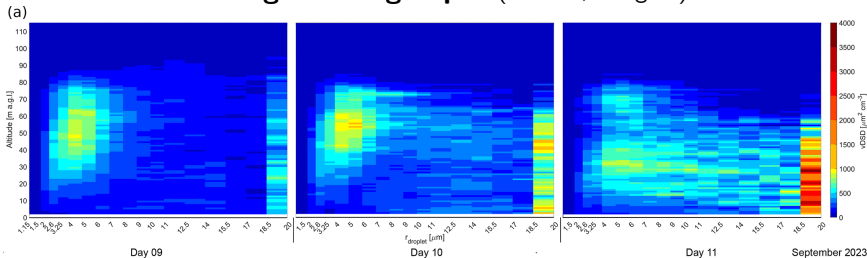
- LWC rises together with N_c
- R_{eff} stays constant or slightly decreases with height
- $\Rightarrow$ growth by **activation** of new CCN, not by growth of existing droplets
- Consistent with Okita (1962), Egli et al. (2015)

Interpretation

The aerosol (number, hygroscopicity) controls how fast the fog gains water.

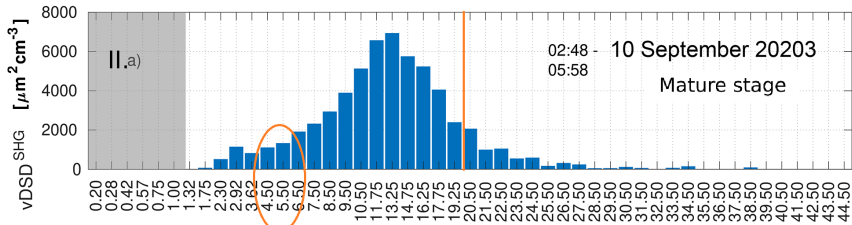
Two droplet regimes: at the ground and higher in the fog

Through the fog depth (balloon, 3 nights)



(a) vDSD OPC-N3, the **second regime** ($r \approx 4\text{--}5\text{ }\mu\text{m}$) appears **higher in the fog**

At the ground (mature stage, night 2)



vDSD ShadowGraph
one broad mode, no
separate regime

Two dominant droplet regimes: what they mean

- Small droplets: $r \approx 4\text{--}5\ \mu\text{m}$
- Large drops: $r > 18.5\ \mu\text{m}$, mostly near the ground
- Lowest 10 m: large drops carry **up to 40%** of LWC
- Sedimentation $\sim 4\ \text{cm s}^{-1}$: 100 m cleared in $\sim 7\ \text{min}$

Implication

Single-mode bulk microphysics schemes miss the large-drop regime, and with it the deposition of fog water at the surface.

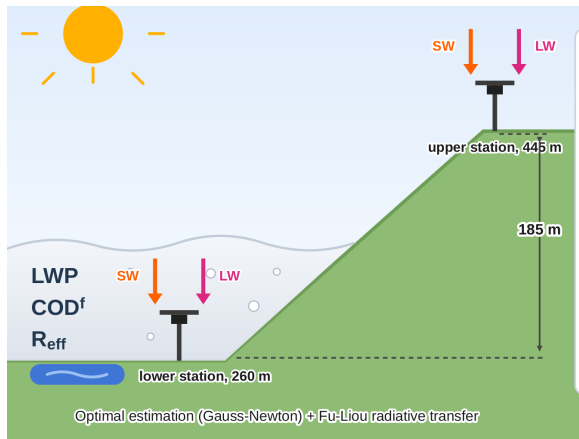
Inside a thin radiation fog: take-home

- 1 Low-cost OPC-N3 on a balloon, calibrated against a ShadowGraph, resolves the vertical structure: LWC $0.2\text{--}0.4\text{ g m}^{-3}$, N_c up to 300 cm^{-3}
- 2 R_{eff} $8\text{--}10\text{ }\mu\text{m}$ near the ground, constant or slightly decreasing with height
- 3 LWC growth driven by droplet number (activation)
- 4 LWP $30\text{--}40\text{ g m}^{-2}$ ($\varepsilon \approx 0.99$), LW-opaque above ~ 30 : the transition to the thick regime started (near-neutral lower layer) but was not completed before sunrise

the inverse problem

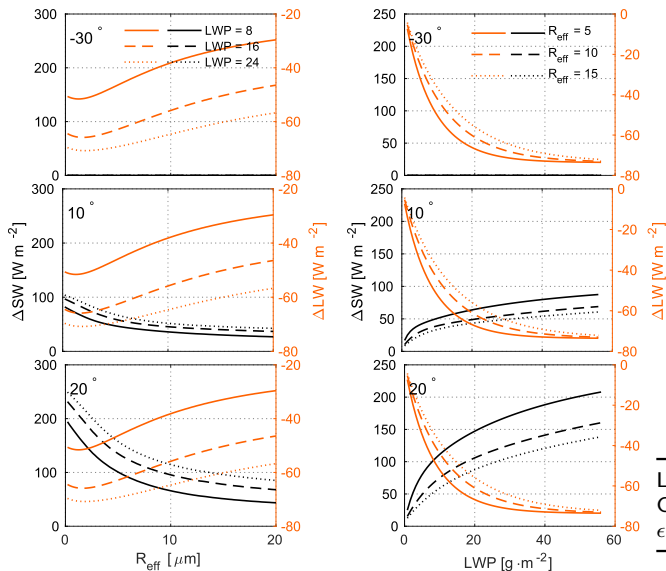
From three nights to six years

Dual-height observations: what the two stations see



- Observation vector (upper minus lower):
 $\mathbf{y} = [LW_{185}^{\downarrow} - LW_0^{\downarrow}; SW_{185}^{\downarrow} - SW_0^{\downarrow}]$
- SolarAOT^{upper} (185 m) gives the sky above the fog, SolarAOT_{lower} (0 m) sits under it
- Fog attenuates SW: $\Delta SW^{\downarrow} > 0$; fog emits at near-surface T : $\Delta LW^{\downarrow} < 0$
- LWP 8–40 g m⁻²: $|\Delta LW^{\downarrow}| \approx 20\text{--}80 \text{ W m}^{-2}$, $|\Delta SW^{\downarrow}| \approx 100\text{--}250 \text{ W m}^{-2}$, well above calibration errors
- Night ($el < 10^\circ$): LW only $\rightarrow$ LWP
Day ($el \geq 10^\circ$): LW + SW $\rightarrow$ LWP, R_{eff}

Sensitivity of ΔSW and ΔLW to LWP and R_{eff}



- Rows: sun elevation -30° , 10° , 20° ;
- black ΔSW , orange ΔLW
- Left: R_{eff} for LWP 8 / 16 / 24 g m^{-2} ;
- Right: LWP for R_{eff} 5 / 10 / 15 μm
- Larger R_{eff} at fixed LWP $\rightarrow$ smaller COD $\rightarrow$ smaller $|\Delta SW|$, $|\Delta LW|$
- ΔLW flattens above $\approx 30 \text{ g m}^{-2}$: saturation

$\epsilon = 1 - e^{-\text{COD}}$: longwave emissivity, fraction of black-body emission the layer emits

LWP [g m^{-2}]	8	16	24	30	36	40
COD	1.16	2.31	3.47	4.39	5.20	5.78
ϵ	0.685	0.901	0.969	0.988	0.995	0.997

Forward model $H(x)$: Fu–Liou with a fog layer

- Prior from the ShadowGraph: LWP 19.2 g m^{-2} , $R_{\text{eff}} = 10.8 \mu\text{m}$ (evaluation data: OPC-N3 on the balloon, never used in the retrieval)
- **Fu–Liou** 1-D: correlated- k gases, δ -four-stream solver
- Profiles: **ERA5** (37 levels) + local grid: **10 m inside the fog**, 50 m up to 1 km
- Fog: **80 m homogeneous layer**; stations at 0 and 185 m
- Droplets: **log-normal**, $\sigma_g = 1.88$ (fit to balloon spectra) $\Rightarrow$ one free parameter, R_{eff}

$$n(r) = \frac{N_c}{\sqrt{2\pi} r \sigma_{\ln}} \exp \left[-\frac{(\ln r - \ln r_g)^2}{2\sigma_{\ln}^2} \right] \quad R_{\text{eff}} = r_g \exp\left(\frac{5}{2}\sigma_{\ln}^2\right)$$

- **Mie**: extinction, SSA, g , COD^f (550 nm) from LWP and R_{eff}
- **Cloud above the fog** (upper LW $>10\%$ off clear sky): 1 km layer at 600 hPa, COD fitted to upper LW

Optimal estimation (OE) 1/3: what we measure, what we want

$$\underbrace{\mathbf{y}}_{\text{measured}} = \underbrace{H(\mathbf{x})}_{\text{Fu-Liou}} + \underbrace{\boldsymbol{\epsilon}}_{\text{noise}}$$

- **Measured:** $\mathbf{y} = [\Delta LW^\downarrow, \Delta SW^\downarrow]^T$, upper (185 m) minus lower (0 m); night: $\Delta LW^\downarrow$ only
- **Wanted:** $\mathbf{x} = [\text{LWP}, R_{\text{eff}}]^T$
- **Forward model H :** state $\rightarrow$ flux differences the radiometers should see

OE 2/3: the cost function, prior term

$$J(\mathbf{x}) = (\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}_b) + (\mathbf{y} - H(\mathbf{x}))^T \mathbf{R}^{-1}(\mathbf{y} - H(\mathbf{x}))$$

$$\mathbf{x}_b = \begin{pmatrix} 19.17 \text{ g m}^{-2} \\ 10.79 \mu\text{m} \end{pmatrix}$$

$$\mathbf{B} = \begin{pmatrix} 10.72^2 & 12.96 \\ 12.96 & 1.92^2 \end{pmatrix}$$

- Penalises distance from the **prior** $\mathbf{x}_b$, in units of its uncertainty $\mathbf{B}$
- Source: **ShadowGraph** in fog at SolarAOT_{lower}, Sept 2023; LWP = LWC $\times$ 80 m
- $\sigma_{\text{LWP}} = 10.72 \text{ g m}^{-2}$, $\sigma_{R_{\text{eff}}} = 1.92 \mu\text{m}$, correlation 0.63

OE 3/3: the cost function, observation term

$$J(\mathbf{x}) = (\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x}_b) + (\mathbf{y} - H(\mathbf{x}))^T \mathbf{R}^{-1} (\mathbf{y} - H(\mathbf{x}))$$

Degrees of freedom for signal (DFS)

DFS = number of independent pieces of information the measurement adds to the prior: between 0 and the number of measurements (**1** at night, **2** by day).

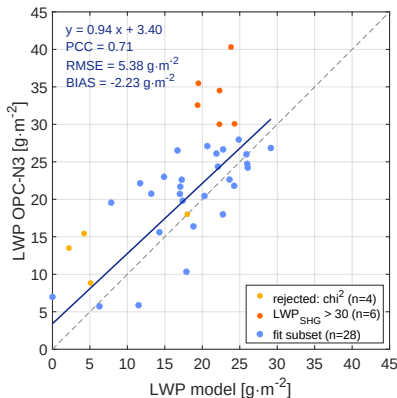
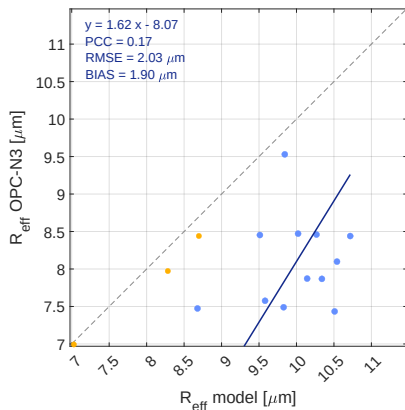
DFS ≈ 1 (night) or ≈ 2 (day): the **data decide**. DFS ≈ 0 : the **prior is returned**.

Computed per case from the model slopes, **B** and **R**

$$\mathbf{R} = \begin{pmatrix} \sigma_{\Delta LW}^2 & 0 \\ 0 & \sigma_{\Delta SW}^2 \end{pmatrix}$$

- Night: **R** is **1**×**1**; day: **2**×**2**, diagonal
- Typical σ_R : night **5.1**; day **6.2** (LW), **10.3** (SW) W m^{-2}
observation error covariance

Independent evaluation of the retrieval against the balloon



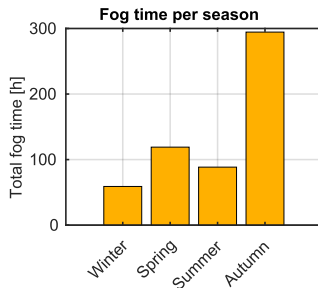
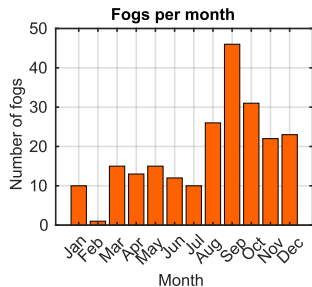
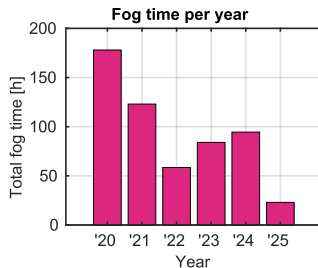
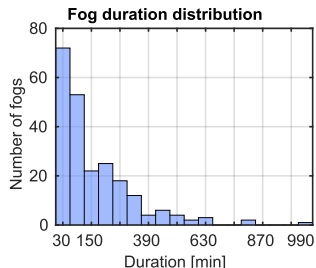
- 38 campaign cases, 34 pass $\chi^2_{0.95,m}$: 12 day (2-D), 22 night (1-D)
- LWP vs balloon OPC-N3, $n = 28$: PCC 0.71, RMSE $5.4 \text{ g}\cdot\text{m}^{-2}$, bias $-2.2 \text{ g}\cdot\text{m}^{-2}$, $y = 0.94x + 3.40$
- R_{eff} : PCC 0.17, RMSE $2.03 \mu\text{m}$, bias $+1.90 \mu\text{m}$

**How to go from 3 nights
to six years**

Fog detection and case selection

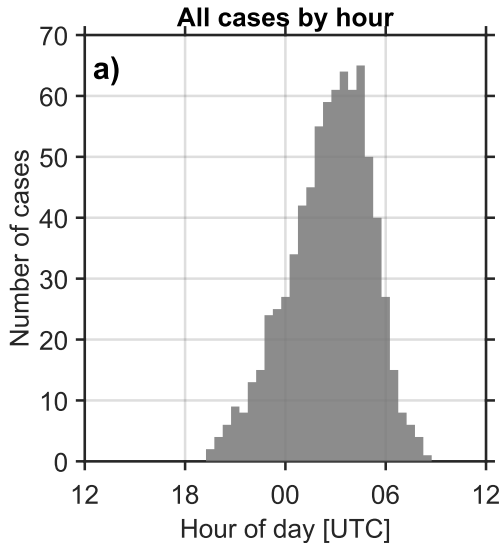
- **Detector:** ground OPC-N3 at SolarAOT_{lower} (not used in the retrieval): R_{eff} above the **2.6 μm threshold**, 10-min running mean
- Fog = threshold exceeded for **≥ 25 of 30 min**; fixed threshold = 98.5th percentile of six years; camera: 90% agreement
- **Case** = 30-min interval;
- **Episode** = consecutive cases
- Upper station in cloud ($\text{RH} > 95\%$ and $\epsilon_{\text{top}} > 0.95$): **217 cases excluded (22%)**
- **Cloud above** the fog: COD fitted to the upper LW; by day then LWP only

Fog occurrence and duration, 2020–2025



- 224 episodes on 153 days, 561 h of fog;
- September 46 events, October 31;
- Mean 150 min;
- median 90 min;
- longest 18 h (from 8 Nov 2020, 23:00 UTC);
- Short (≤ 3 h) 158;
- medium 46;
- long (> 6 h) 20.
- Per year: 64 events in 2020 ... 5 in 2025

Diurnal cycle of fog



- Most fog between 18:00 and 06:00 UTC;
- peak around 03:15;
- decline after 04:15;
- long fogs 22:00 → 05:45;
- medium 00:15 → 04:30;
- short 01:20 → 02:30.

From 1122 fog cases to 770 retrievals

Case funnel (30-min cases)

- 1122 fog cases; 53 without data → 1069 retrieved (916 night, 153 day) → 987 pass
- −217 upper station in cloud → **770** (72%): 677 night, 93 day
- Cloud above: 360 (47%); 40 cases with R_{eff}

The observability of R_{eff}

- Joint retrieval possible in only 40 cases (day, $\text{el} \geq 10^\circ$, no cloud above)
- Retrieved R_{eff} stays at the prior ($10.79 \mu\text{m}$) within uncertainty ($\sigma_{\text{post}} 1.8$ vs prior $1.9 \mu\text{m}$, DFS for $R_{\text{eff}} \approx 0$)
- **Reason:** both broadband fluxes respond mainly to $\text{COD} \propto \text{LWP}/R_{\text{eff}}$; their responses to LWP and R_{eff} are nearly proportional
- **Solution:** smaller errors ($\approx 1 \text{ W m}^{-2}$) in both channels $\rightarrow$ beyond broadband radiometry

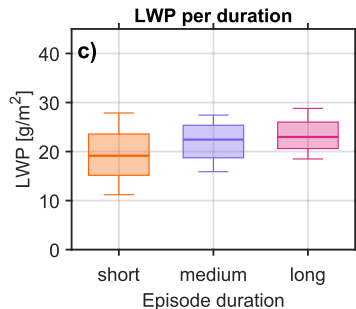
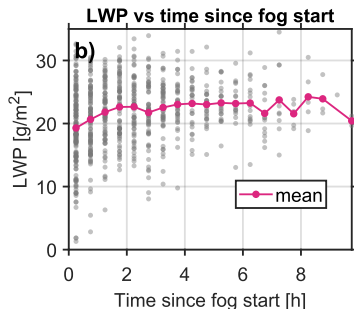
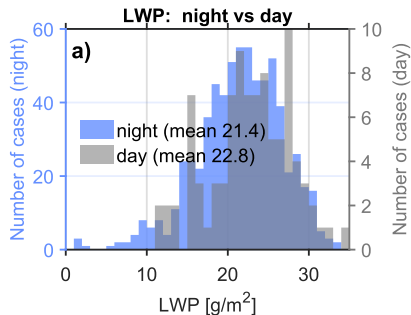
R_{eff} is prior-dominated

The missing constraint lies in the instrument class, not in the fog.

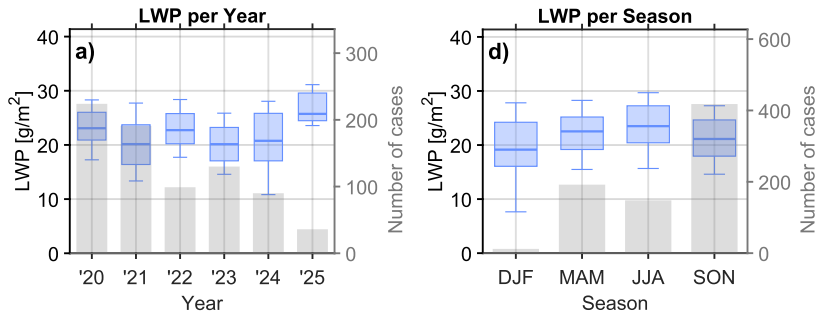
R_{eff} must come from the prior or in situ data.

LWP statistics

- Mean $21.6 \pm 5.3 \text{ g m}^{-2}$ (median 22.0); night 21.4 ± 5.3 , day 22.8 ± 5.1
- Short 19.5, medium 21.8, long 23.3 ($p < 0.01$)
- Onset 19.3, then $+1.7 \text{ g m}^{-2} \text{ h}^{-1}$ for 2 h 15 min, then nearly flat
- $\text{DFS}_{\text{LWP}} 0.64 \pm 0.24$ (no cloud 0.79, cloud 0.47)



Seasonal and interannual variability



- Median LWP: DJF 19.1, MAM 22.5, JJA 23.5, SON 21.1 g m^{-2} ;
- Median years 20.1–25.7
- Prior compresses contrasts: with $\mathbf{B}' = 4\mathbf{B}$ seasonal spread 4.4 $\rightarrow$ 7.5 g m^{-2} , interannual 5.6 $\rightarrow$ 8.5

Radiative impact of fog in the valley is controlled by the frequency of fog, not by the COD^f of single events.

Conclusions

Inside a thin radiation fog (ACP 2025)

- Vertical structure resolved with low-cost balloon sensors: LWC $0.2\text{--}0.4\text{ g m}^{-3}$, N_c up to 300 cm^{-3} , r_{eff} $8\text{--}10\text{ }\mu\text{m}$, CTH $\approx 85\text{ m}$
- Two droplet regimes: $4\text{--}5\text{ }\mu\text{m}$ and $>18.5\text{ }\mu\text{m}$
- LWC grows mainly through droplet activation (N_c)
- LWP $20\text{--}40\text{ g m}^{-2}$, LW-opaque above ~ 30 ; transition to the thick regime started (near-neutral lower layer) but not completed before sunrise

Two radiometer pairs, six years (RS 2026)

- LWP is the only reliably retrieved parameter: PCC 0.71, RMSE 5.4 g m^{-2} ; DFS_{LWP} 0.64 (2020–2025) to ≈ 0.9 (campaign, day)
- 2020–2025: LWP $21.6 \pm 5.3\text{ g m}^{-2}$, COD^f 3.1 ± 0.8 , stable across seasons and years
- Saturation above $\approx 30\text{ g m}^{-2}$
- R_{eff} prior-dominated
- Complements rather than replaces MWR and cloud radar

- Radiometers and in situ sensors (OPC-N3, RS41, visibility) on drones: SW and LW closure inside the fog, at heights unreachable from the ground
- Deployment in existing radiometric networks wherever a valley–hilltop pair gives two heights: a low-cost, unattended fog monitor, also at night
- MWR and radiometer pair fail at opposite ends: MWR below 10 g m^{-2} , broadband LW above $\approx 30 \text{ g m}^{-2}$: a natural combination
- Continuous LWP with a per-case DFS: constraints for NWP and fog parameterisations (thin-to-thick transition), possibly data assimilation

Thank you for your attention

- Nurowska, Makuch, Markowicz (2025), *Atmos. Chem. Phys.*, 25, 13493–13525, doi:10.5194/acp-25-13493-2025
- Nurowska, Markowicz (2026), *Remote Sensing*, 18(19), 3306, doi:10.3390/rs18193306
- Campaign data (Sept 2023): doi:10.58132/WPKQNT (Dane Badawcze UW)
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