

Spray drift as a critical driver of landscape-scale pesticide exposure: Coupling DAD-drift with SWAT+

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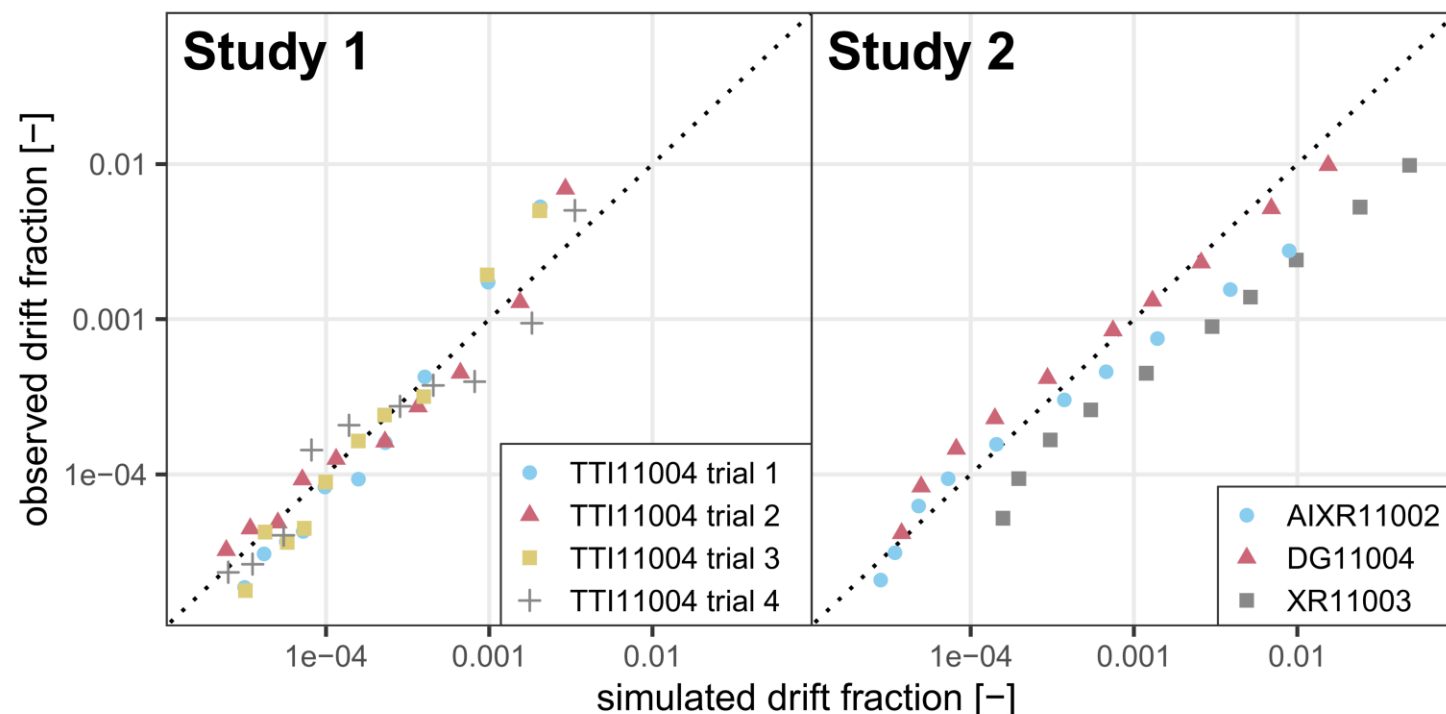
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- Catchment models resolve pesticide transport across whole landscapes ^[1–3]
 - Surface runoff, subsurface runoff, subsurface drainage, leaching ^[4,5]
 - Pesticide transport is driven by the simulated hydrology
- Spray drift is the exception: airborne, during application ^[6,7]
 - Direct and immediate entry into non-target areas, contributing substantially to surface water contamination ^[8,9]
 - Deposited mass assumed to remobilize later via the other pathways ^[10,11]

- Yet spray drift is not natively supported in catchment models ^[1–3]
 - Workarounds based on empirical drift curves ^[12]
 - 1-D curves on 2-D landscapes ^[13–15]
 - Wind reduced to two or four directions
 - Deposition restricted to stream surfaces
 - Spatial representation alone spreads predicted deposition by >4 orders of magnitude, widening with landscape complexity ^[16]
- Needed: a mechanistic, spatially explicit, couplable drift model for the landscape scale

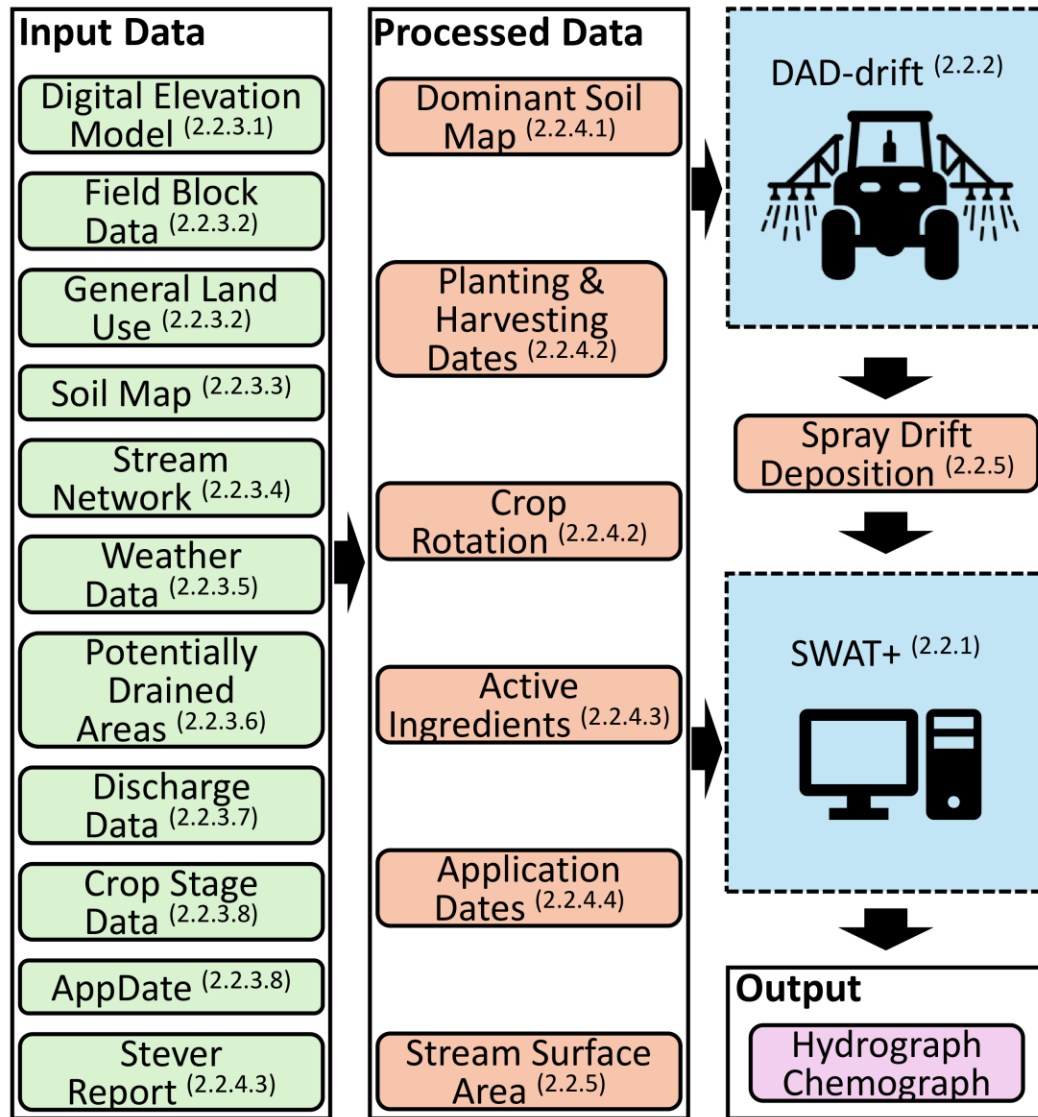
DAD-Drift:

- Mechanistic droplet model combined with 3D Gaussian puff model
- Sensitivity analysis shows realistic behavior
- Validation against two field studies [17,18]



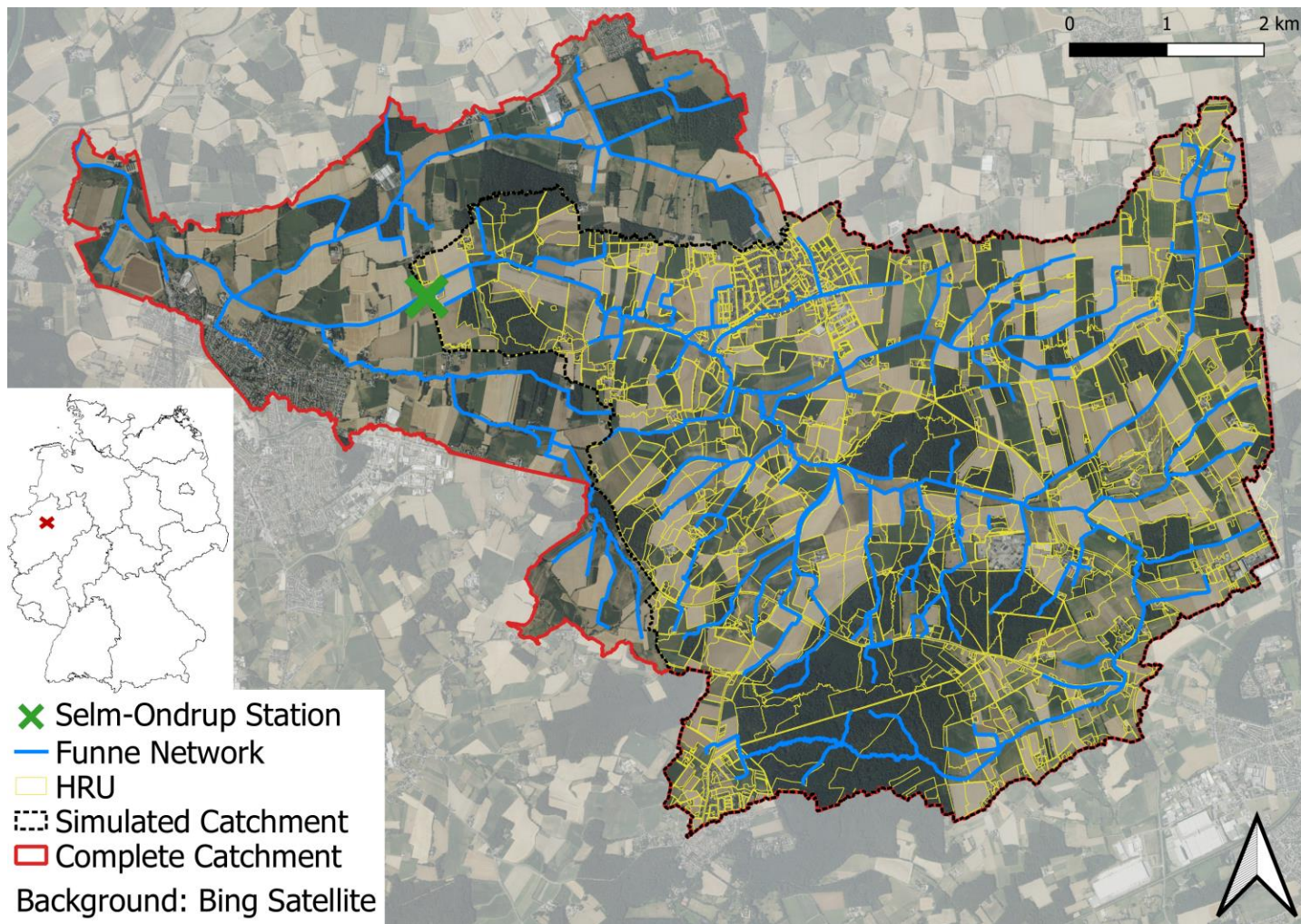
- One parameter set (7 scenarios & 4 nozzles)
- $R^2 = 0.931$
- No systematic bias out to 122 m

Modelling Framework



- Two models, one shared dataset
 - Same fields, same dates, same weather on both sides
- DAD-drift per application event
 - Into SWAT+ as channel point sources and pseudo-applications
- Built entirely from public data [19-28]

Catchment Model

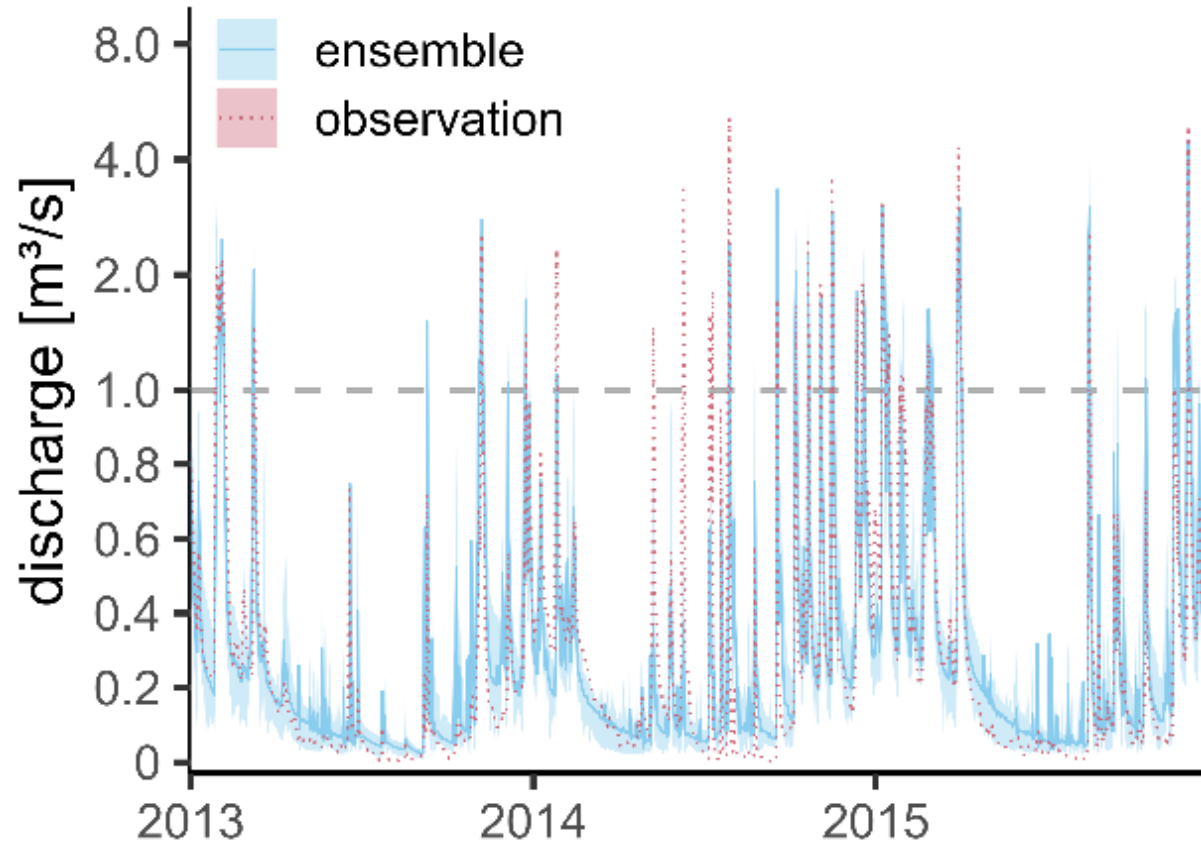


■ Funne catchment:

- 5440 ha, simulated 3866 ha
- >48 % agriculture, 97 % potentially drained
- Drains to a drinking water reservoir

■ Agricultural management:

- Real 5-year crop rotation per field
- Crop development from C2D2 ^[29]
- Harvest dates from AppDate ^[30]
- 7 active ingredients (2 fungicides, 5 herbicides)
- Application dates from a PAT ^[31]

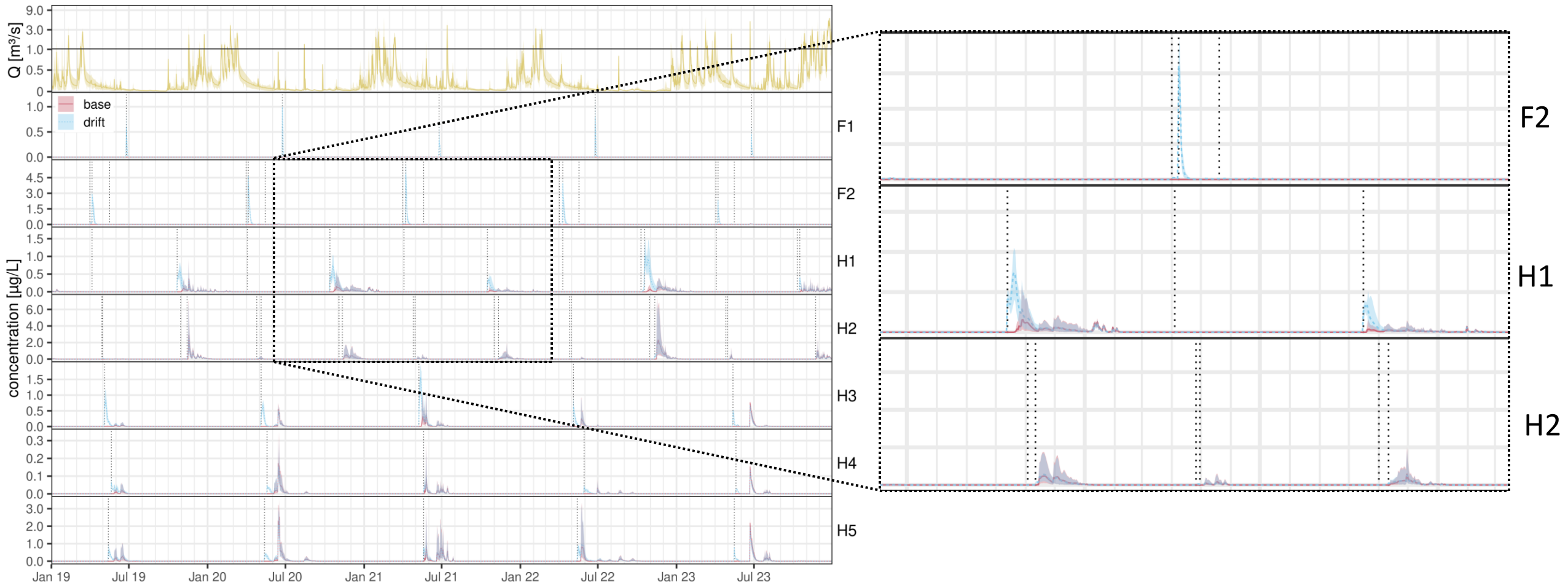


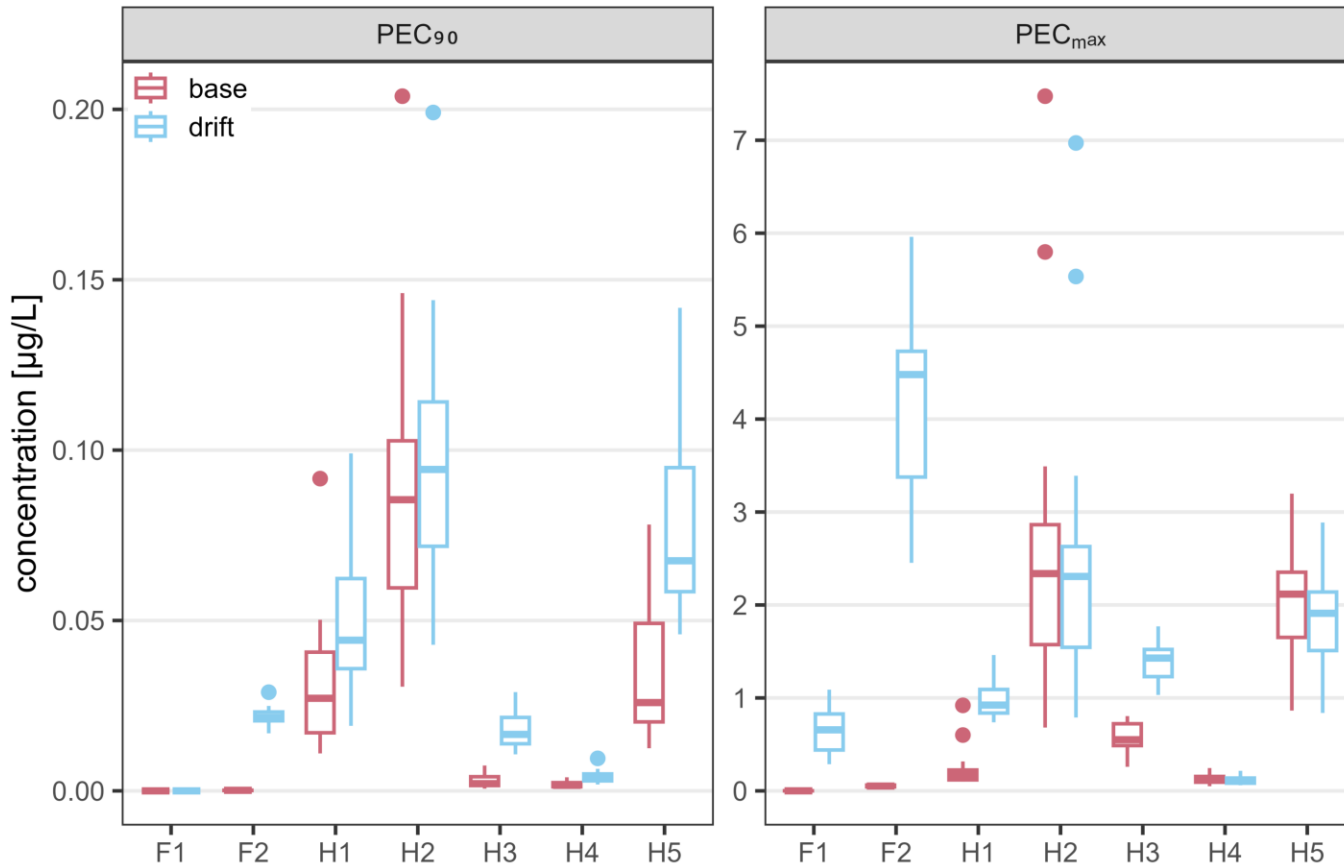
- Hydrological parametrization:
 - Screening and Sobol' GSA ^[32]: 158 → 43 → 19
 - LHS of 15 000 runs ^[33] → ensemble of 20 parameter sets:
 - top ten by NSE (peak flows)
 - top ten by KGE (overall balance)
- Parametrization:
 - NSE 0.71–0.79
 - KGE 0.77–0.86
 - PBIAS –3.2 to 8.7
- Validation:
 - NSE 0.51–0.80
 - KGE 0.61–0.86
 - PBIAS 6.4 to 25.6

Experiment:

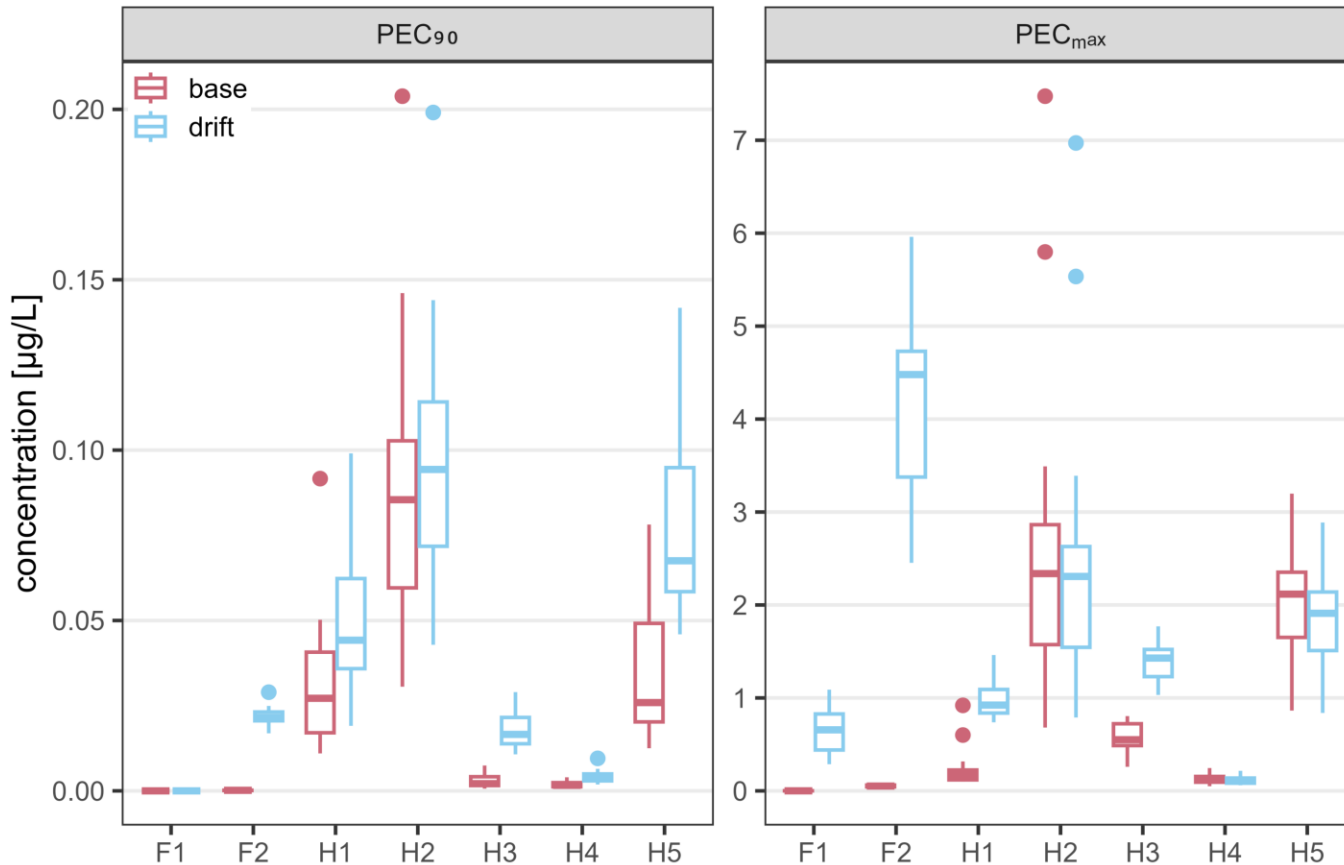
- Two setups, identical in every other respect:
 - Base: surface runoff, subsurface runoff, subsurface drainage, leaching
 - Drift: the same, plus spatially explicit DAD-drift deposition
- Application conditions:
 - Bare soil for herbicides, established canopy for fungicides
 - XR11003 nozzle, no drift-reducing, no buffer strips (worst case)
- Compared at the catchment outlet 2019-2023:
 - Daily PEC timeseries
 - $PEC_{\max}$
 - PEC_{90}

Drift Impact





- PECmax and PEC90 rise by 10 % to several orders of magnitude
- Drift dominates where hydrological transport is low (F1, F2)
- Drift adds peaks on top of existing transport (H1, H3)
- Drift marginal where hydrological transport already dominates (H2, H4, H5)
 - PECmax unchanged, PEC90 elevated



- All 20 parameter sets reproduce discharge equally well: equifinality ^[34]
- Box height = uncertainty from hydrological parameterization alone
- Drift dominates → relative spread shrinks (F1, F2)
- Hydrological transport dominates → spread persists (H2, H4, H5)
- A single calibrated parameter set understates exposure uncertainty

- Spray drift must be explicitly represented at landscape scale
 - Largest effect where hydrological transport is low
 - Parameterization uncertainty propagates into exposure, ensembles required
- Framework ready to quantify mitigation at catchment scale:
 - Buffer strips and drift-reducing nozzles
 - Critical source areas: which fields drive exposure
 - Application timing: where drift and runoff mitigation could potentially conflict
- Transferable to any catchment buildable from public data

Thank you for your attention!

Questions?

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DAD-drift model
Environ. Res. 2025



Spatial representation
Environ. Model. Softw. 2025



Catchment application
Environ. Pollut. 2026

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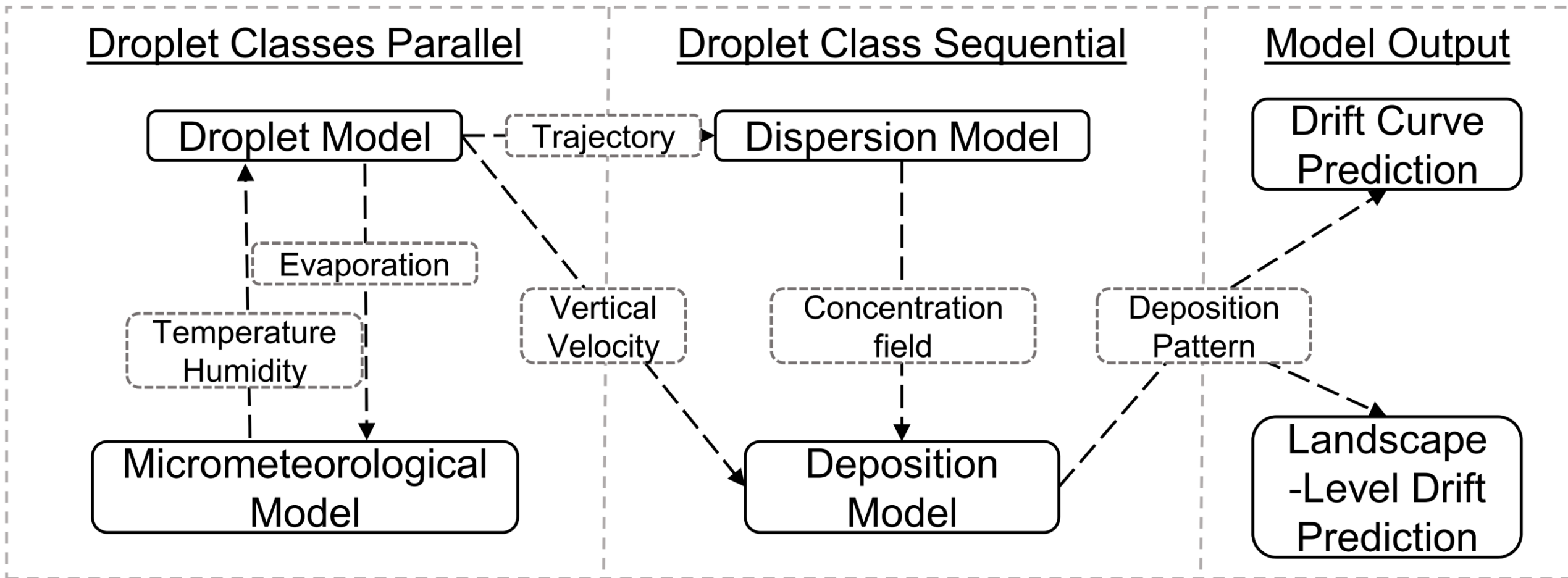
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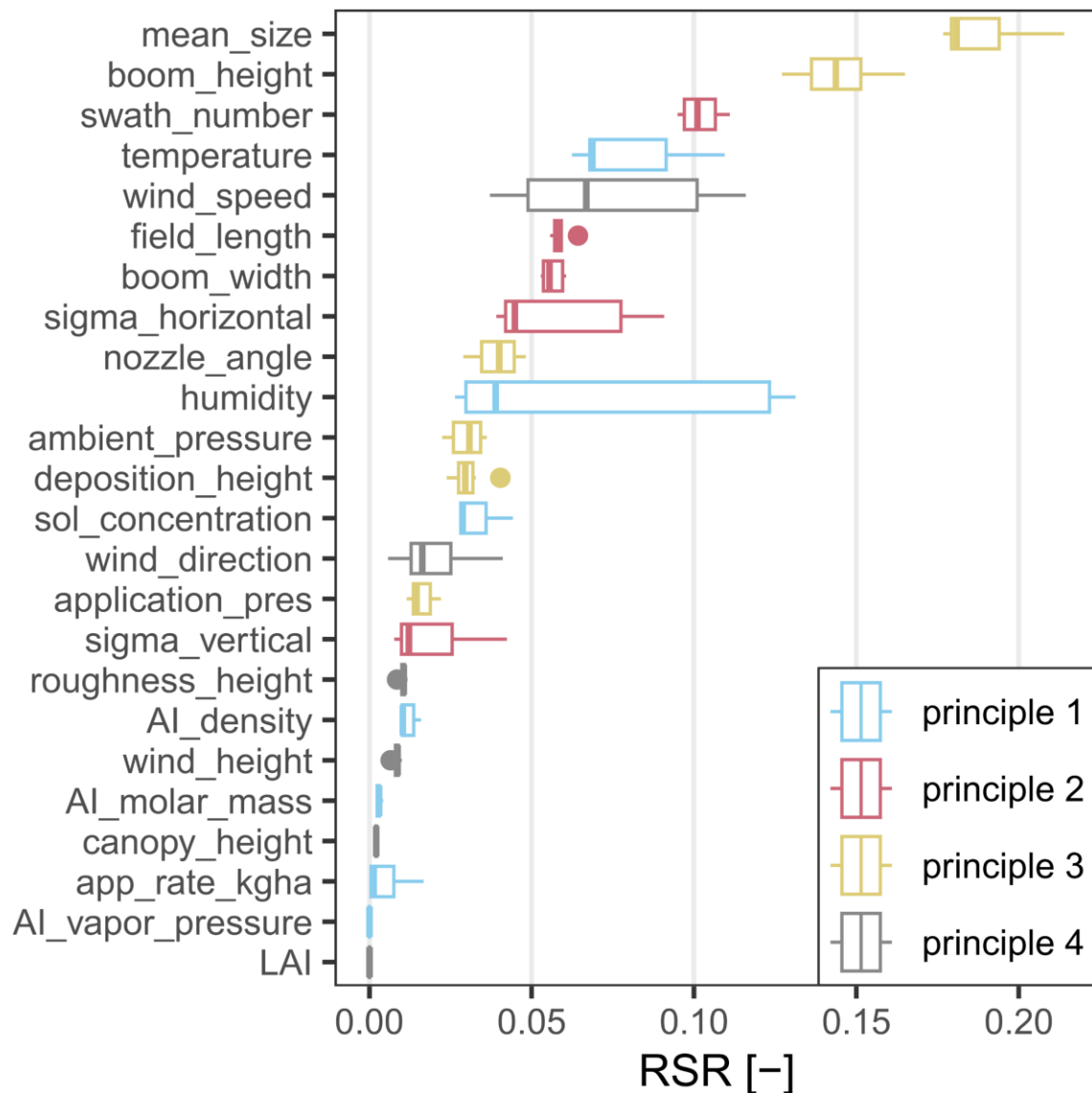
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	F1	F2	H1	H2	H3	H4	H5
Soil Adsorption Coefficient [(mg/kg)/(mg/L)]	2000	10000	500	10	200	75	150
Washoff Fraction [-]	0.3	0.1	0.2	0.2	0.4	0.5	0.1
Foliage Halflife [days]	1	18	10	5	5	8	10
Soil Halflife [days]	3	35	20	10	10	15	20
Solubility [mg/L]	275	2	45	40	1600	3500	10
Water Halflife [days]	1	1000	50	50	30	35	1000
Aquatic Volatilization Coefficient [m/day]	0	0	0	0	0	0	0
Molar Weight [g/mol]	350	375	350	450	280	450	210
Resuspension Velocity [m/day]	0	0	0	0	0	0	0
Settling Velocity [m/day]	0	0	0	0	0	0	0
Depth of the active benthic layer [m/day]	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Burial Velocity [m/day]	0	0	0	0	0	0	0
Benthic Halflife [days]	1000	25	100	50	1000	30	60
Plant Uptake [-/day]	0	0	0	0	0	0	0



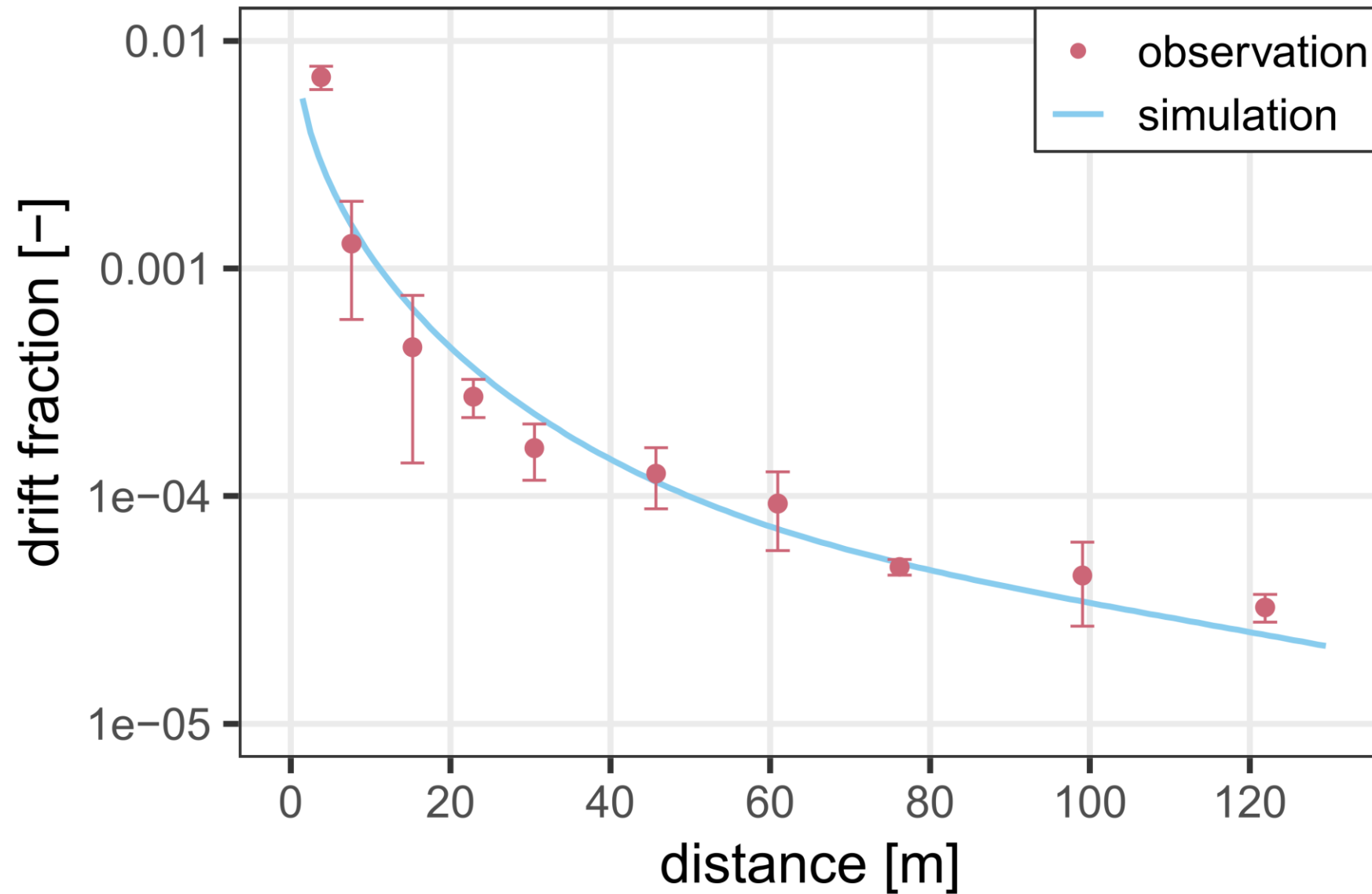


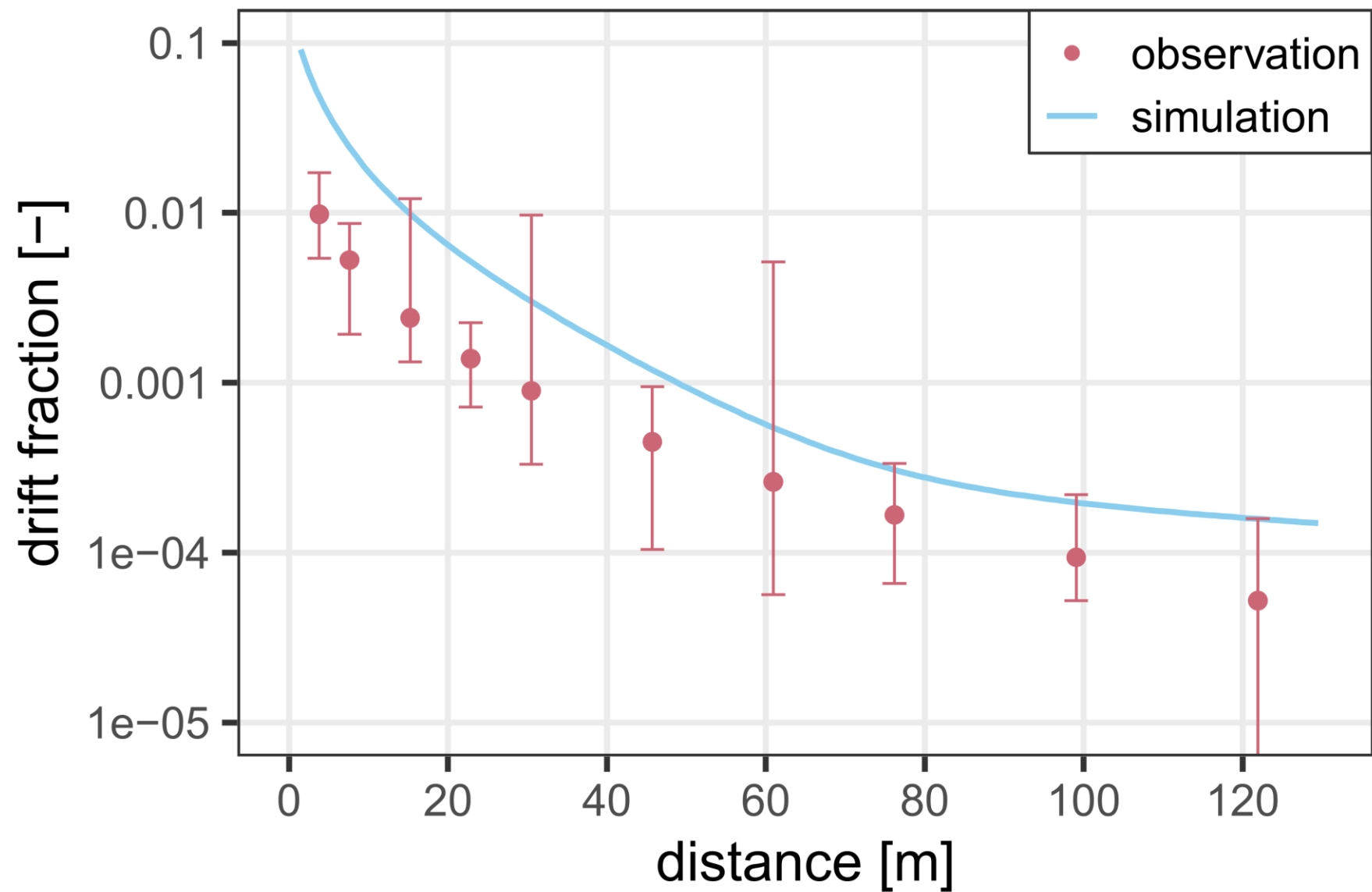
■ Most sensitive:

- Droplet size distribution
- Boom height
- Temperature
- Wind speed

■ Four mechanistic principles:

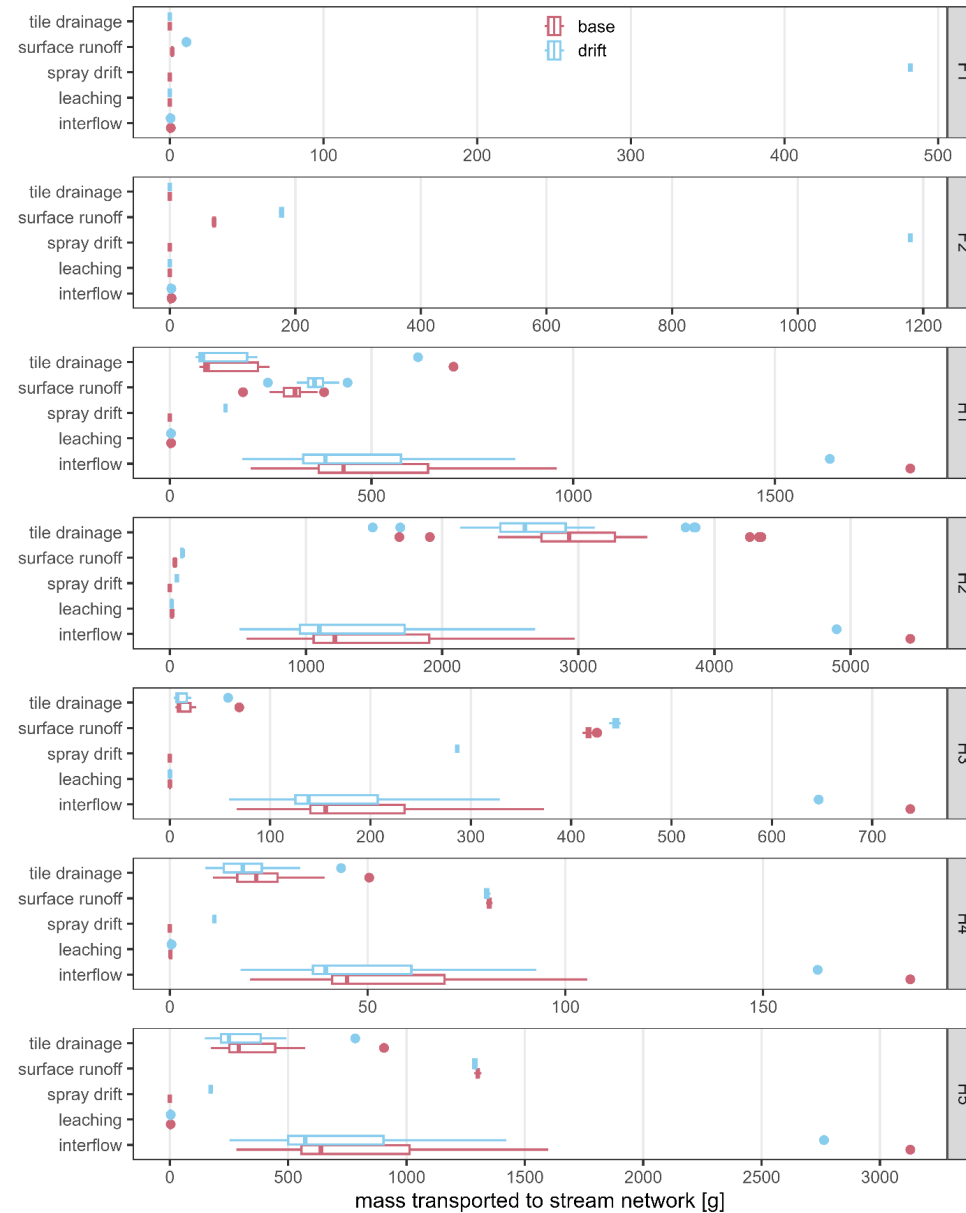
- Evaporation (1)
- Dispersion (2)
- Droplet travel time (3)
- Horizontal transport (4)





Distance [m]	Predicted drift fraction of XR11003 nozzle [-]	Predicted drift fraction of DG11004 nozzle [-]	Predicted drift fraction of AIXR11002 nozzle [-]	Drift reduction of DG11004 nozzle [%]	Drift reduction of AIXR11002 nozzle [%]
3.8	4.87E-2	1.55E-2	8.92E-3	68.3	81.7
7.6	2.42E-2	6.93E-3	3.89E-3	71.4	84.0
15.2	9.86E-3	2.58E-3	1.39E-3	73.9	85.9
22.9	5.17E-3	1.30E-3	6.75E-4	74.9	86.9
30.5	3.01E-3	7.43E-4	3.74E-4	75.3	87.6
45.7	1.19E-3	2.95E-4	1.44E-4	75.2	87.9
61.0	5.43E-4	1.41E-4	7.28E-5	74.1	86.6
76.2	3.07E-4	8.16E-5	4.80E-5	73.4	84.4
99.1	1.97E-4	4.97E-5	3.44E-5	74.8	82.6
121.9	1.58E-4	3.77E-5	2.81E-5	76.1	82.2
mean				73.7	85.0

Pesticide mass by transport pathway, base vs. drift — Fuchs et al., Environ. Pollut. 2026, Fig. S3



AI	Applied Mass [kg]		Deposition on Stream [g]	Exported Mass [g]		Exported Mass [%]	
	base	drift		base	drift	base	drift
F1	453.9	382.5	481.9	1.5	44.6	0.000	0.012
F2	1014.0	862.5	1179.4	72.0	1357.2	0.007	0.157
H1	591.5	529.8	138.1	986.0	1082.2	0.167	0.204
H2	191.7	173.5	51.8	4422.6	4054.5	2.307	2.337
H3	681.4	603.2	286.5	613.0	862.4	0.090	0.143
H4	36.7	32.4	11.3	155.7	154.3	0.424	0.477
H5	452.1	399.6	173.0	2479.0	2499.0	0.548	0.625

