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Effects of Environmental Parameters on PV Soiling

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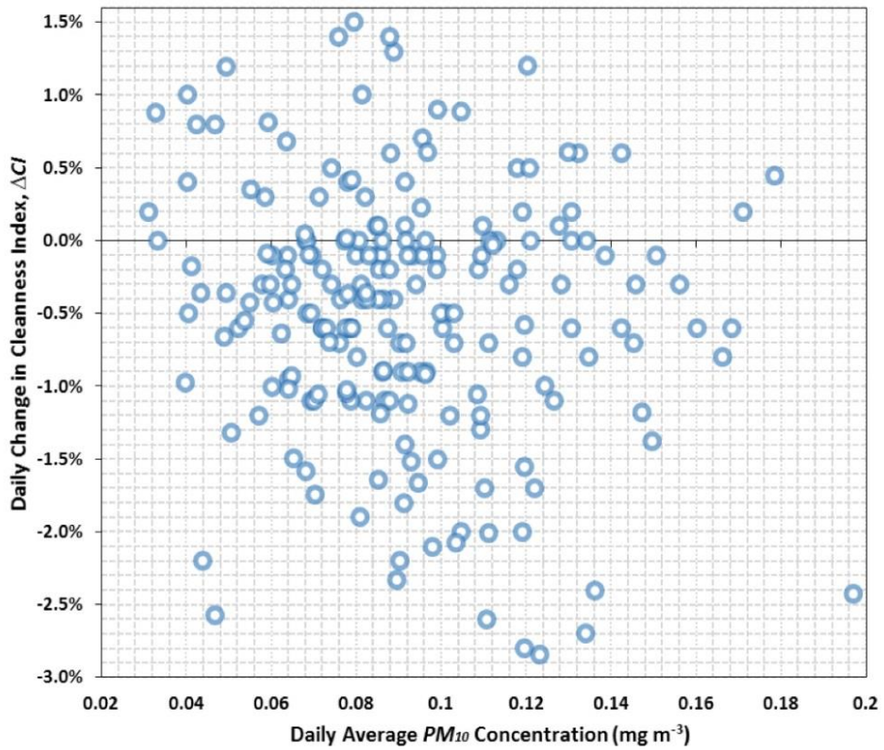
What causes PV soiling?

- Soiling is a major issue for PV in desert environments
- Qatar: Daily soiling loss ~0.4 %/day
- What causes soiling rate to vary from day to day?
- Intuitively, linked to environmental parameters, e.g.:
  - airborne particulate matter (PM)
  - wind speed (WS) & direction
  - relative humidity (RH)
- However, low correlations historically found in field studies
- Hypothesis: low correlations are partly due to <u>daily</u> soiling measurement
- Goal: Measure soiling in same time-scale as environmental parameters



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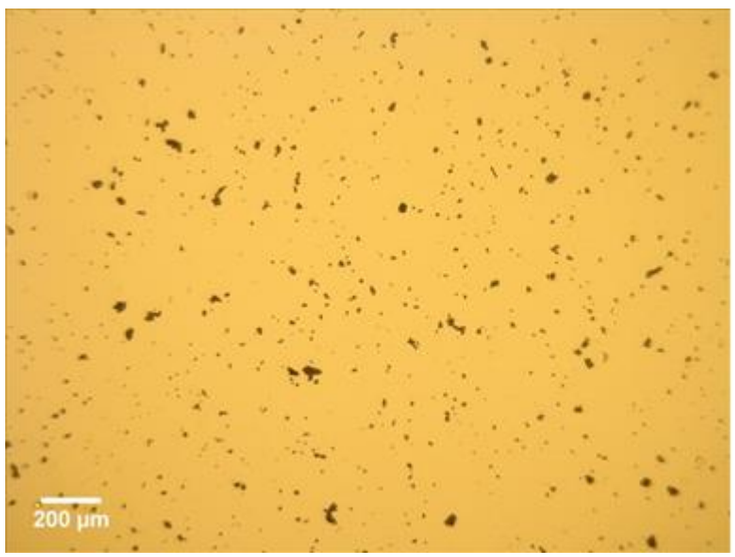
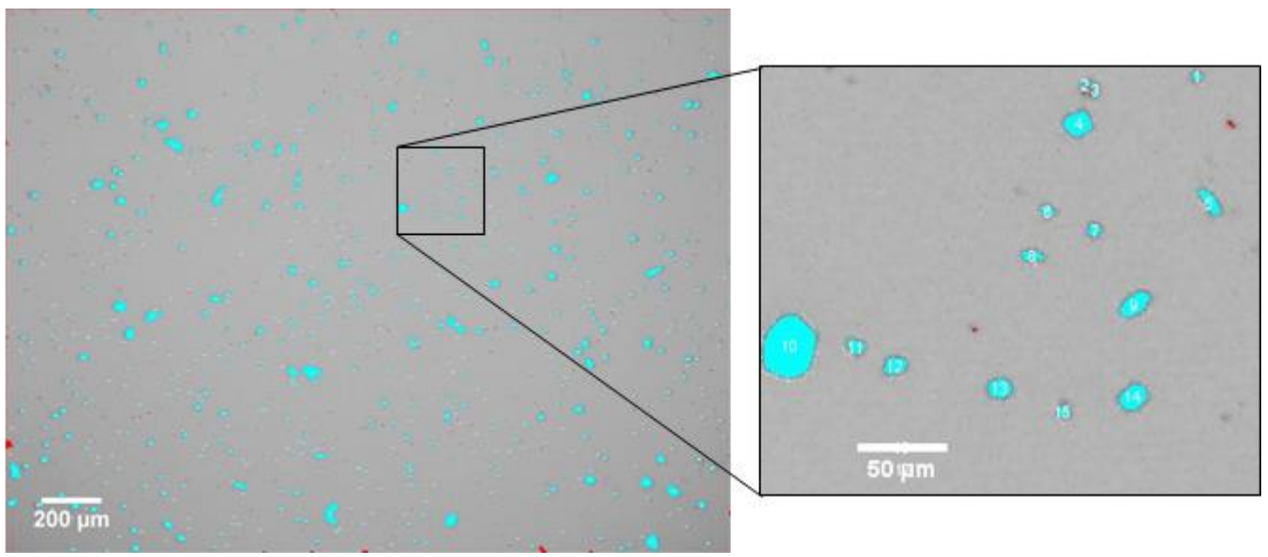
Outdoor soiling microscope (OSM)

- "Outdoor soiling microscope" OSM developed using inexpensive, low-power microscope with back-light
- Reliable sizing of particles > ~4 µm
- Separate measurement of particle deposition and detachment
- Operates day and night
- Soiling measurements every 10 minutes (as short as several seconds possible)
- Also used to observe condensation

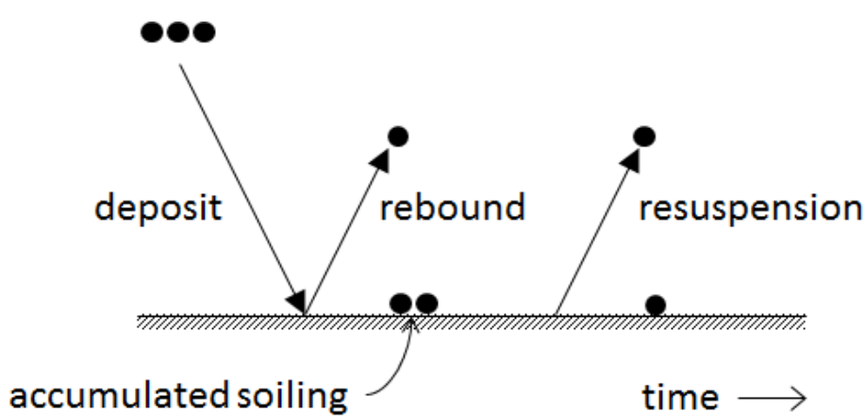


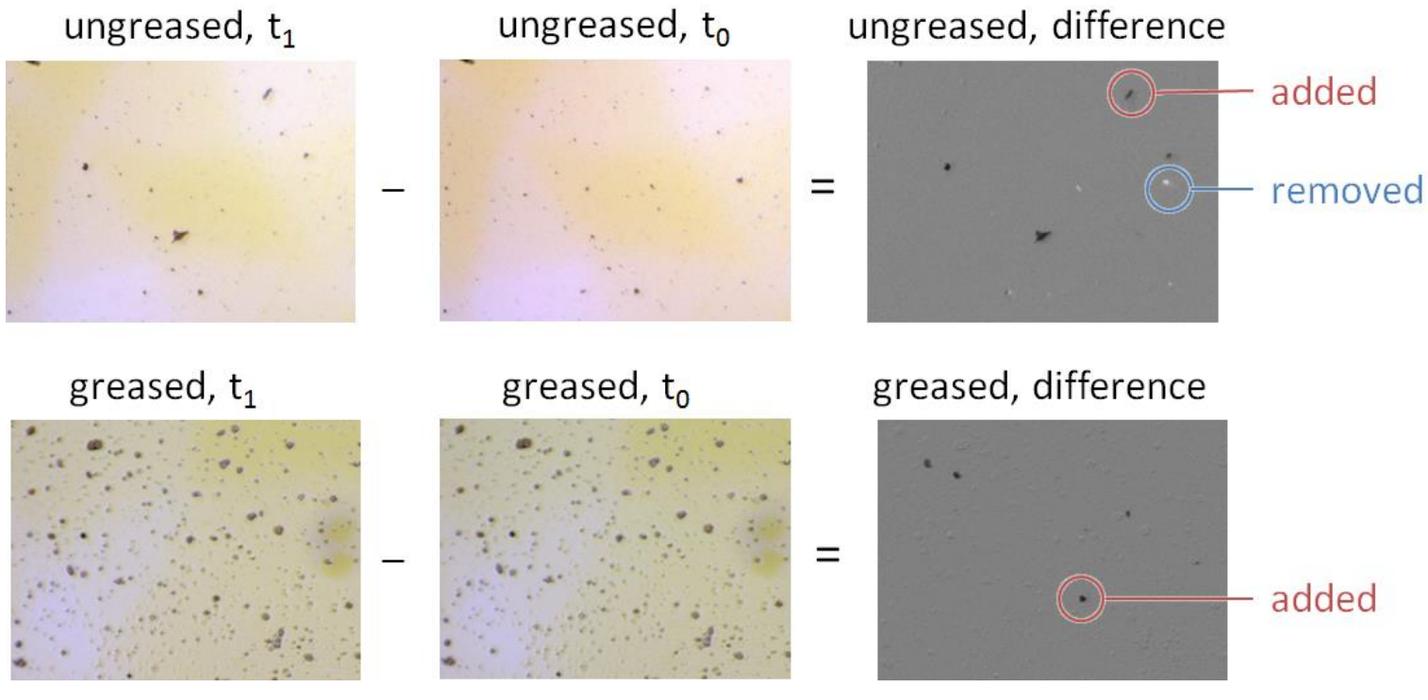


Individual Dust Flux Measurement

Pair of greased/ungreased OSMs →
quantify individual dust fluxes

Deposition = dust added to greased coupon
Resuspension = dust removed from ungreased coupon
Rebound = difference between dust added to greased and ungreased coupons

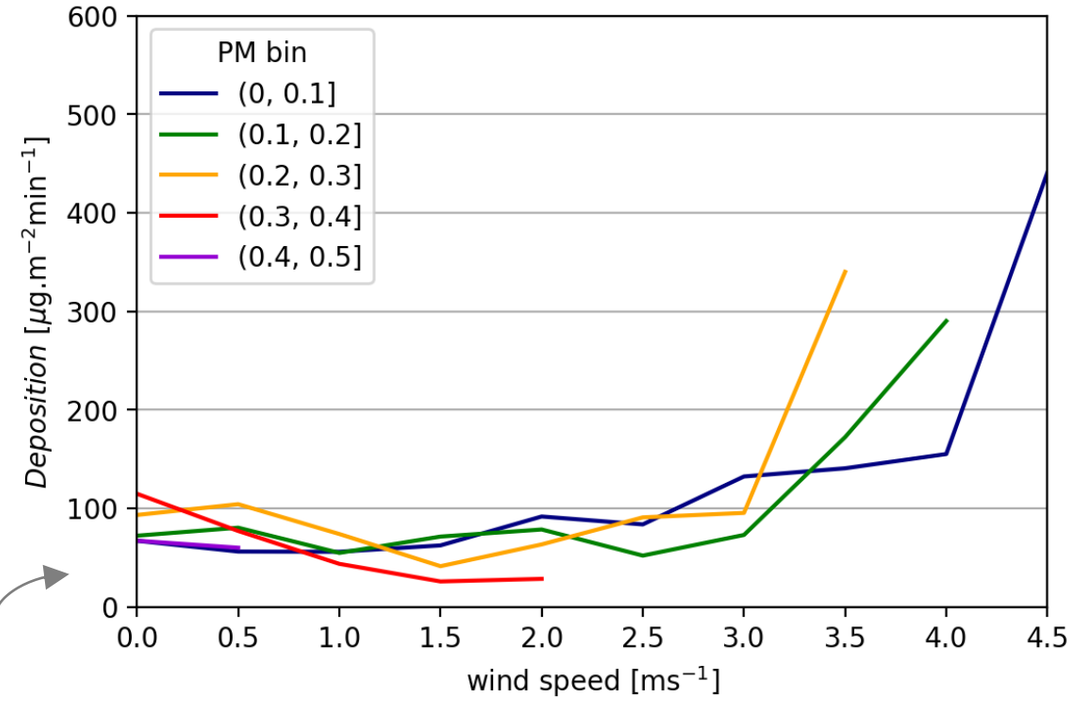


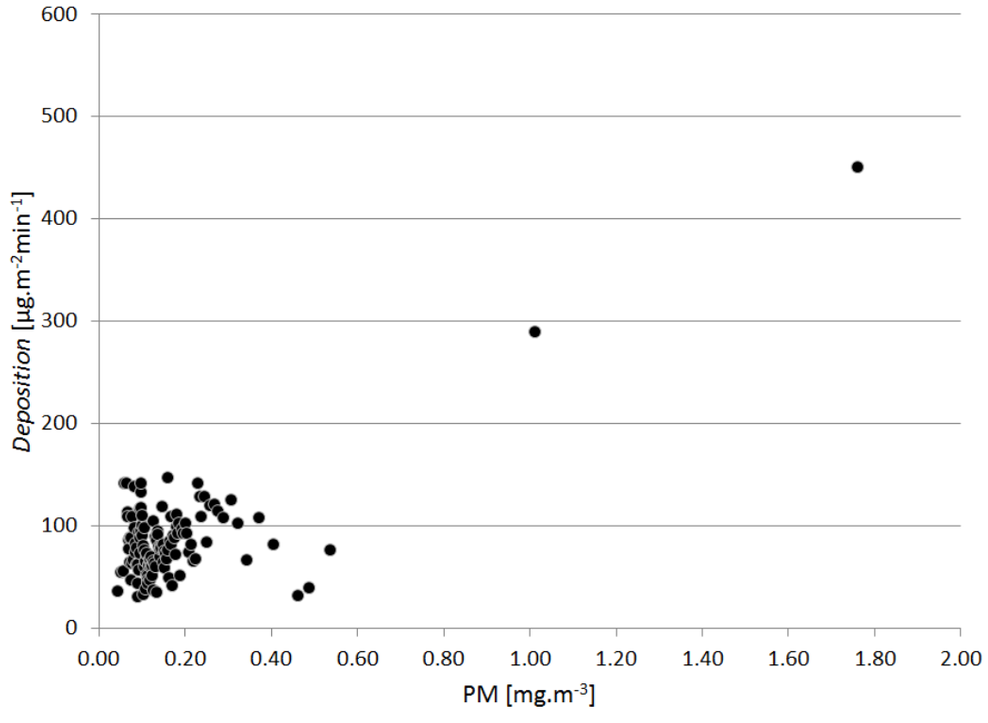


Results – Causes of Deposition

- Field study at Solar Test Facility in Qatar
- 51 days, 6186 “observations” (10-minute periods)

- Theory:
  gravity deposition ∝ PM
  inertial deposition ∝ PM, *f*(WS)
- *Deposition* was dominated by WS, and showed unexpected “threshold” behavior at ~3 ms^{-1}
- This behavior not due to PM
- Unexpectedly PM had no influence until air was extremely dusty
  → PM measmnt. accuracy when low?

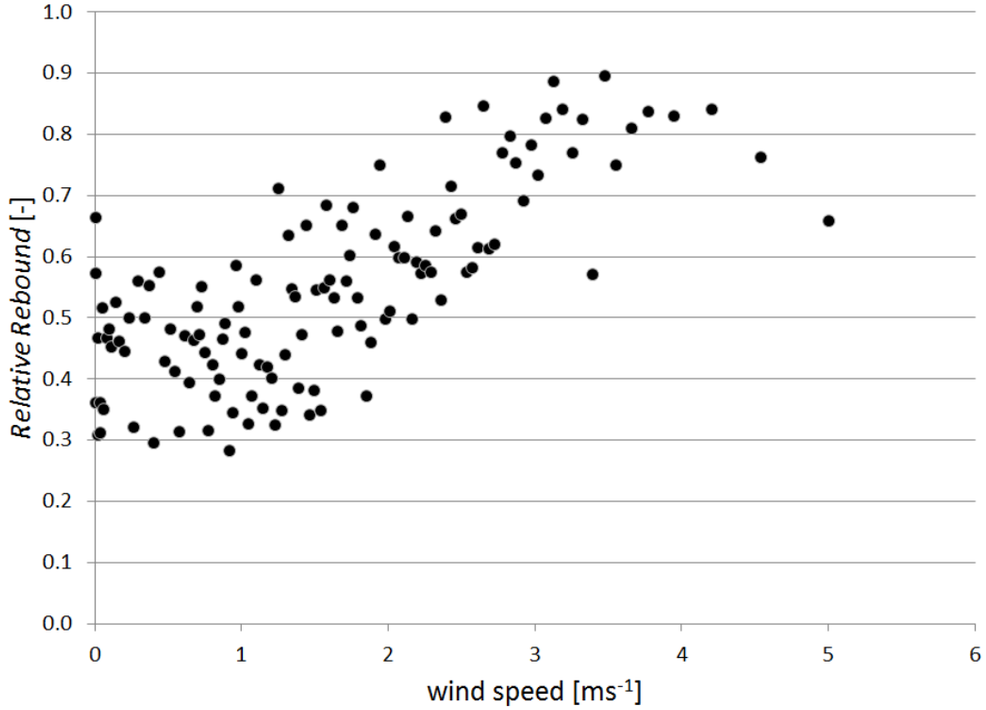


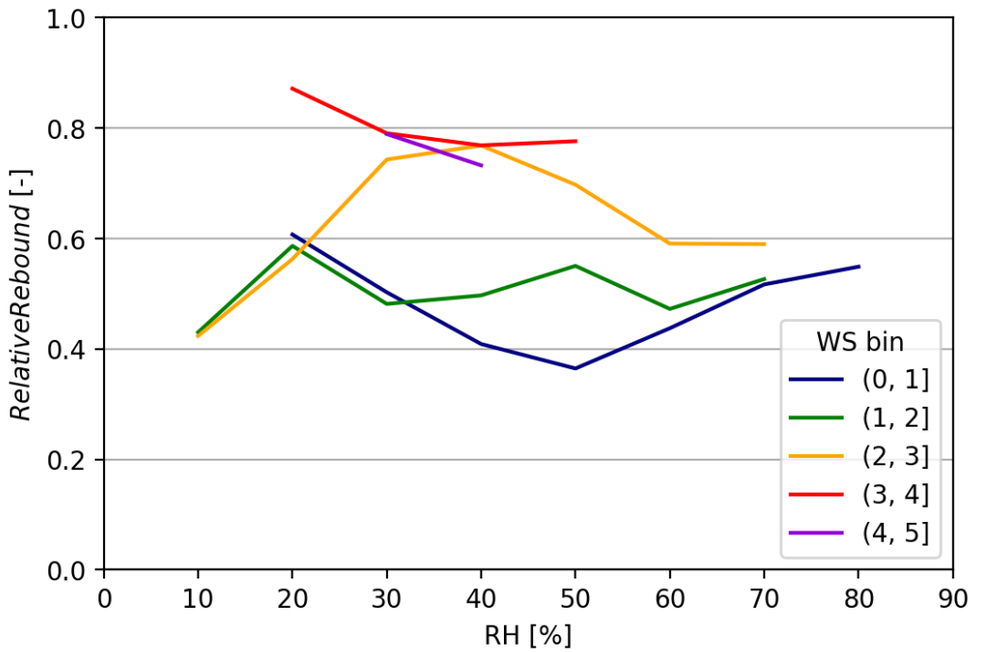


Results – Causes of Rebound

- Rebound characterized by *Relative Rebound* — fraction of deposition that immediately detached

- Theory:
  kinetic energy vs. work of adhesion
  Rel. Rebound $\propto$ *f*(WS, RH)
- *Rel. Rebound* strongly influenced by WS
- Unexpectedly high at zero WS
  → adhesion is not immediate
- Unexpected decrease at high WS
  → ineffective grease?
- Unexpectedly independent of RH
  → capillary adhesion not immediate

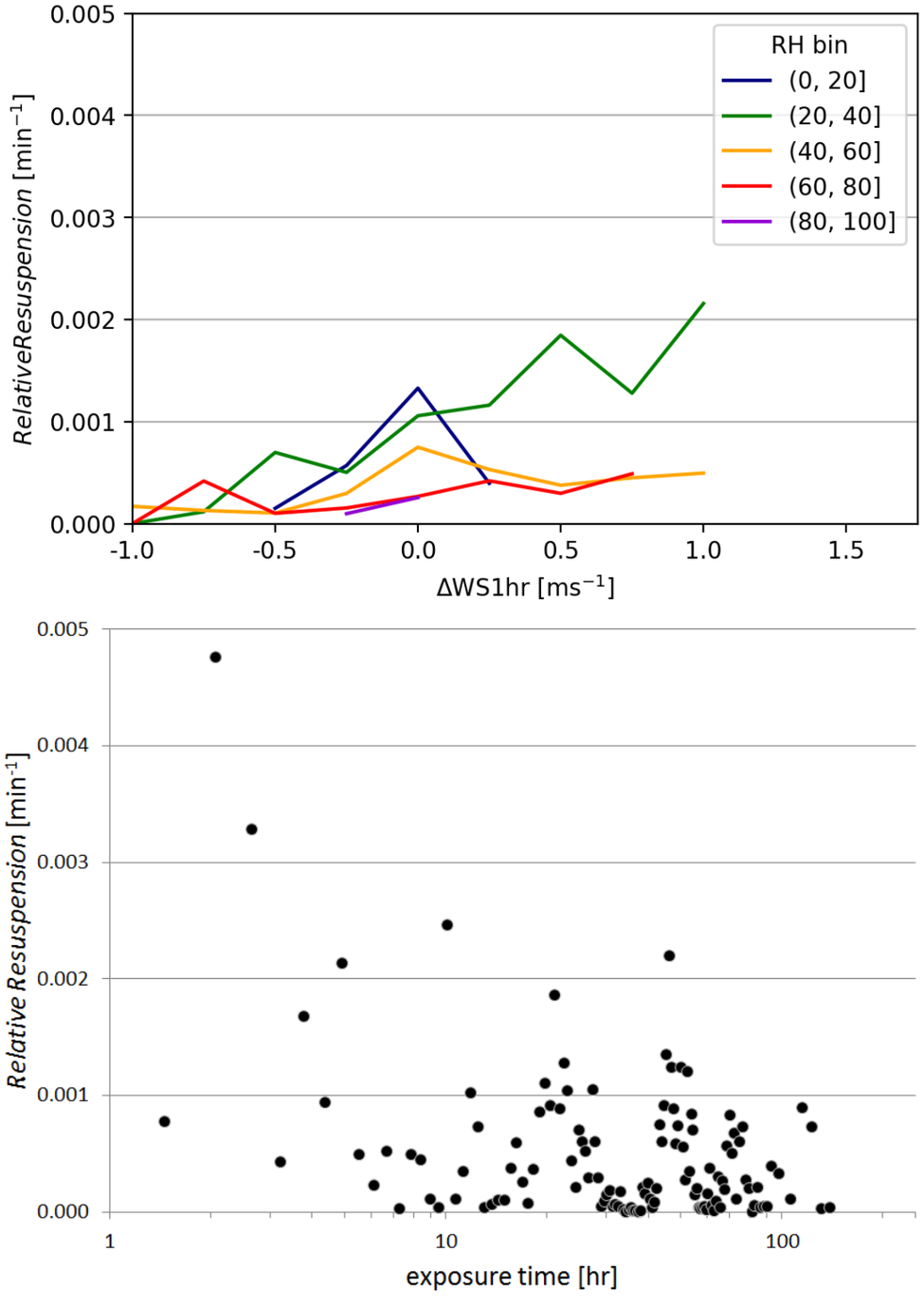




Results – Causes of Resuspension

- Resuspension characterized by *Relative Resuspension* — fraction of surface coverage that detaches per minute

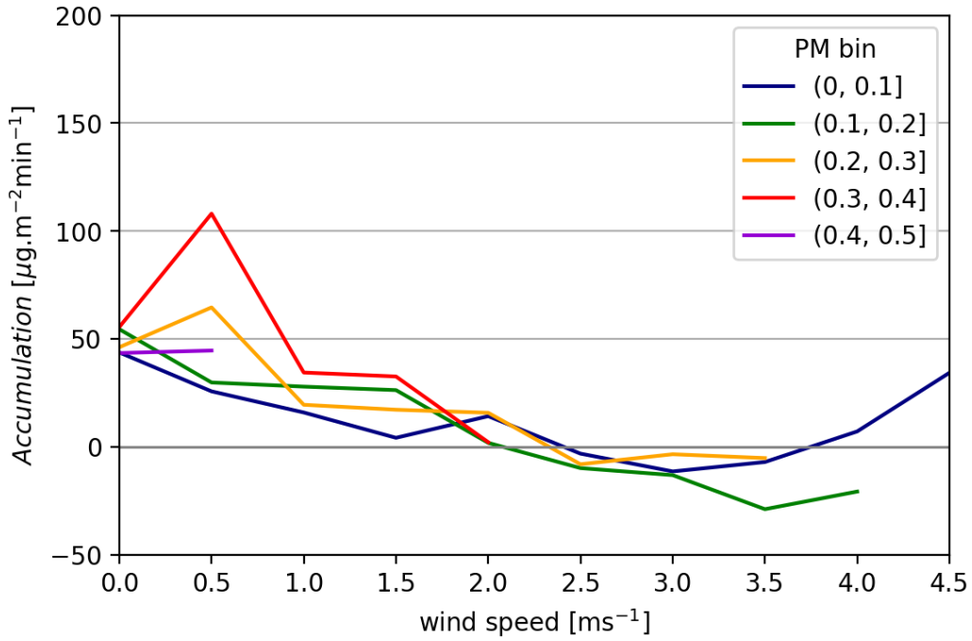
- Theory:
  aerodynamic drag vs. adhesion force
  Rel. Resusp. $\propto$ *f*(WS, RH)
- ΔWS better predictor of *Rel. Resusp.* than WS
- RH does suppress *Rel. Resusp.*
  → capillary adhesion
- *Rel. Resusp.* range decreases with exposure time
  → cementation

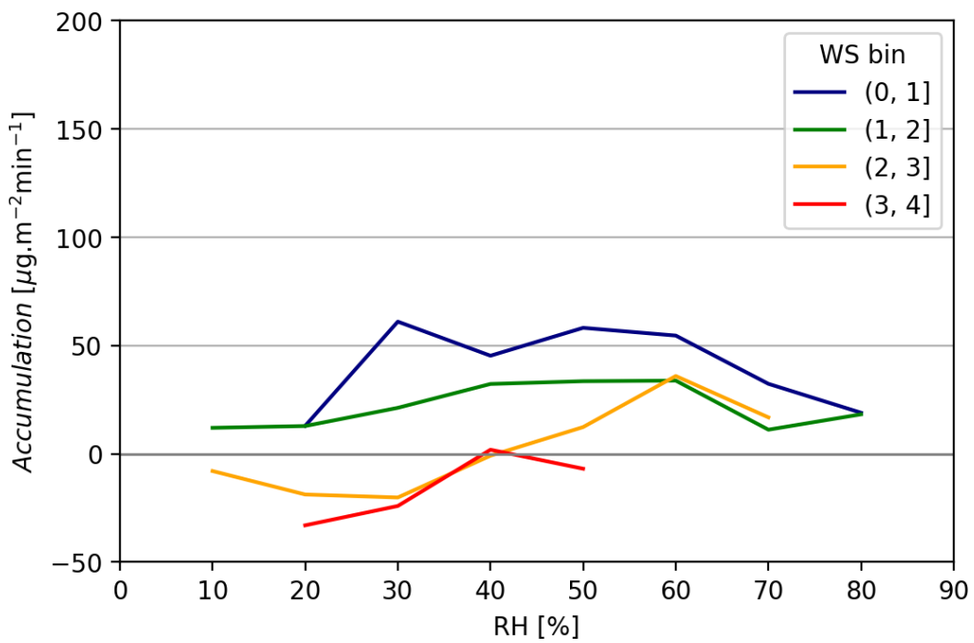


Results – Net Effect on Accumulation

- *Accumulation* is the net result of deposition, rebound and resuspension

- WS has strongest influence on *Accum.*
- Regardless of PM,
  - WS < ~2 ms^{-1} → more soiled
  - WS > ~2.5 ms^{-1} → cleaner
- RH has weak, conditional influence:
  - low WS: RH doesn't effect *Accum.*
  - higher WS: RH increases *Accum.*
- PM only increases *Accumulation* when air becomes very dusty (~0.3 $mg.m^{-3}$)

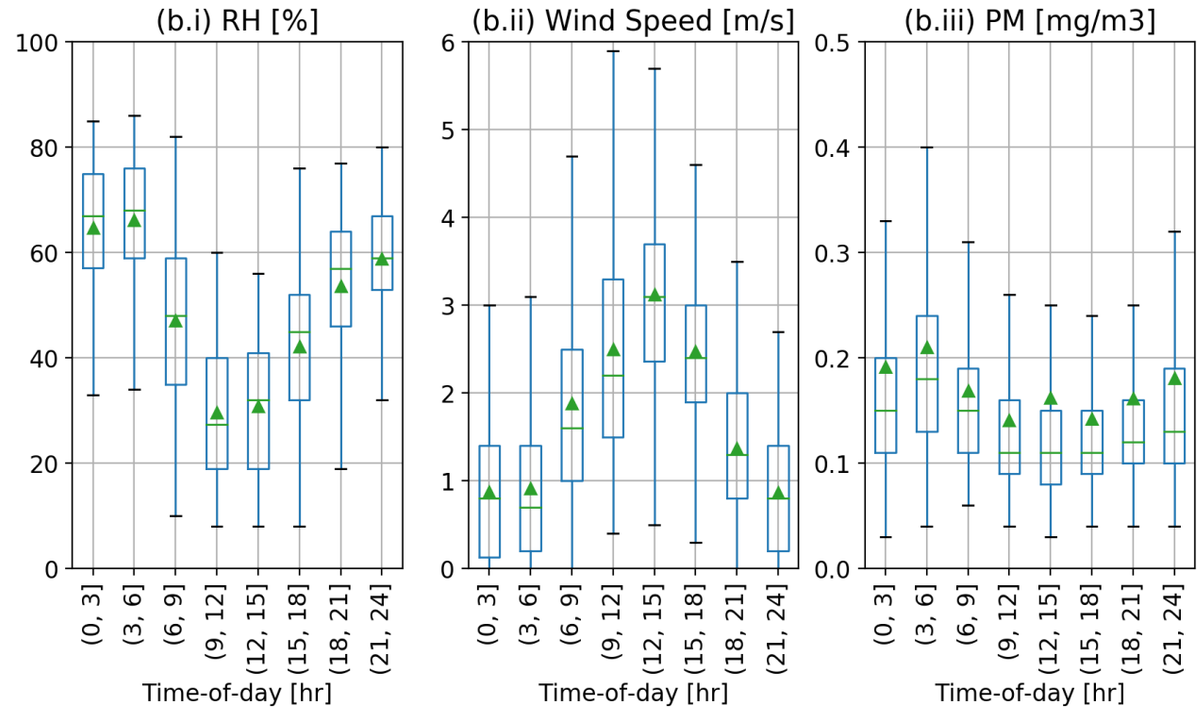




Results – Time-of-Day Variation

- Environmental parameters had regular daily patterns

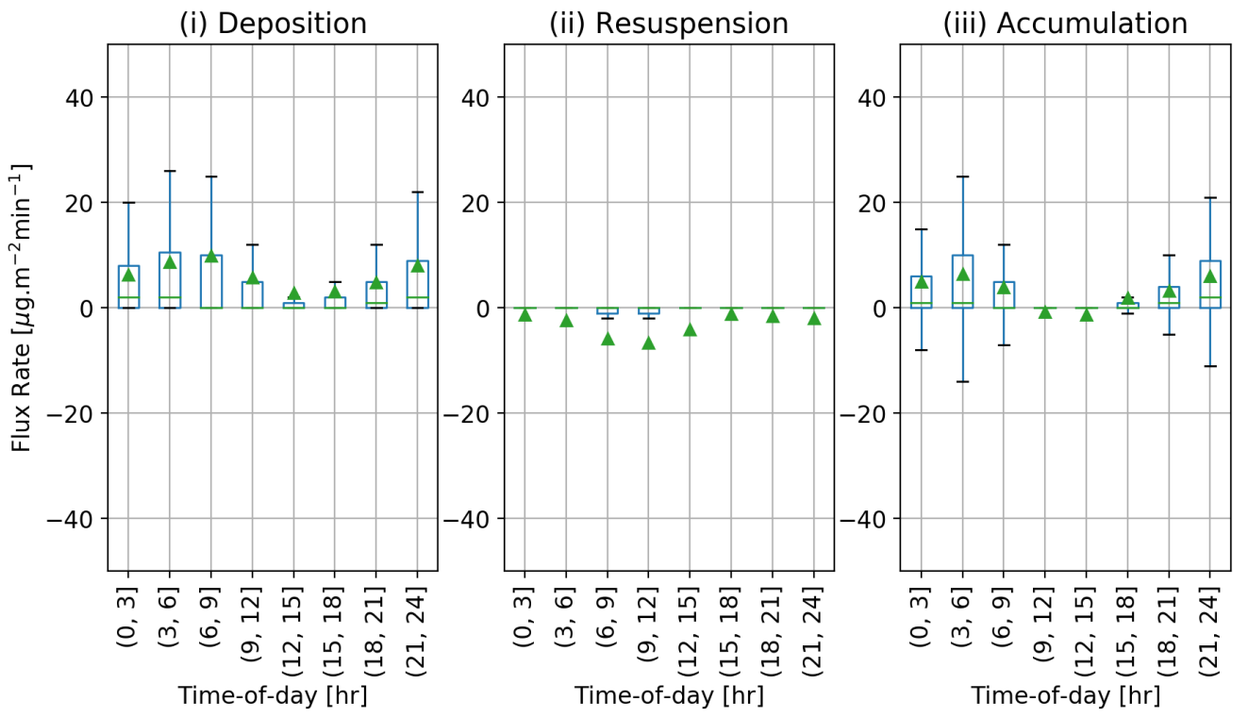
  Night — higher RH, lower WS
  Day — lower RH, higher WS



- …Thus so did dust fluxes

  Night — greatest deposition
  Day — greatest resuspension

  → Soiling mainly accumulated in the night. ~Zero in middle of day.



Conclusion & Next Steps

- Outdoor Soiling Microscope useful for measuring dust flux rates in short time-scale, in natural conditions
- Main causes of flux rate variations:
  - Deposition —wind speed, ~PM
  - Rebound — wind speed
  - Resuspension — ΔWS, RH, exposure
  - Accumulation — WS, ~RH, ~PM
- Regular weather patterns → soiling mainly accumulated during the night

- Results suggest reducing soiling by developing “smart” tracker:
  - Night — vertical
  - Day — algorithm to optimize irradiation and soiling