Melbourne and Singapore: how climate shapes air monitoring and plant stress

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Using geometric morphometrics to analyse *Tropaeolum majus* under climate-dependent humidity (JMSS)
Optimising PM2.5 sensor design with regards to climate-dependent meteorological transport across cities (NUSH)

Background

By **2050**, two-thirds of people will live in cities (UN DESA, 2018), which are often hotter and drier than their surroundings (Oke et al., 2017). Leaf colour can flag plant stress (Spafford et al., 2023), and street-tree leaves already serve as low-cost air-pollution samplers (Hofman et al., 2017). The project investigated how Melbourne and Singapore's climates affect plant stress and air monitoring sensor optimisation.

It was hypothesised that lower humidity would result in lower greenness and growth, slightly altering general leaf shape. It was also predicted that weather-informed PM 2.5 (air particulate < 2.5µm) sensor placement would benefit Melbourne more due to greater variability in weather.

	Melbourne	Singapore
Climate	Temperate	Tropical
Typical humidity	~52% Relative Humdity	~82% Relative Humidity
Daytime high	~14-26 °C (mean)	31–33 °C
PM2.5 sensors	<20 official	~60
Our terrarium humidity	52–54% RH	90–96% RH

Table 1. Comparison of city climates

Approach

Biological approach:

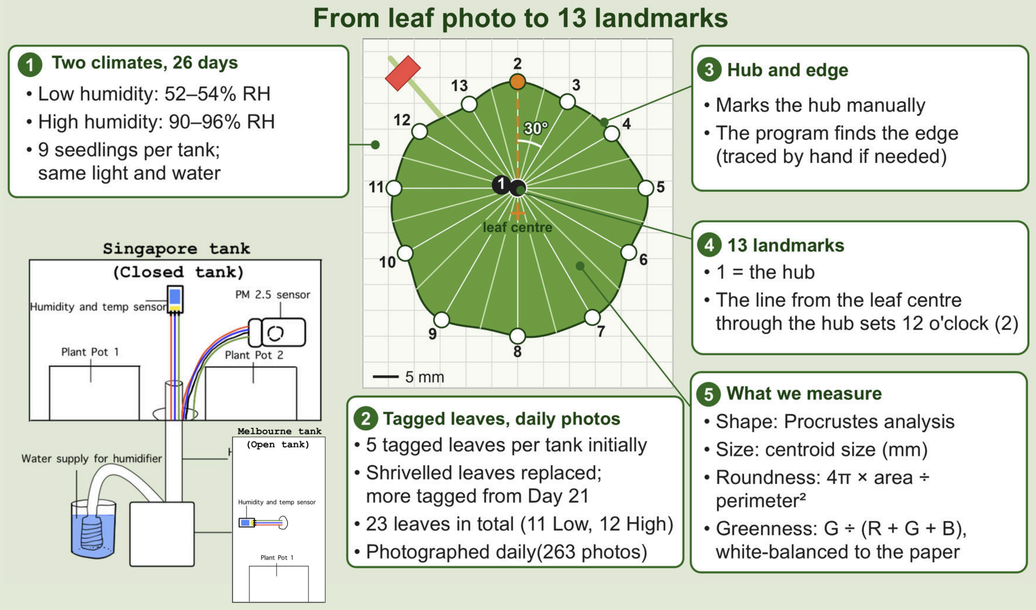


Figure 1. the hub (1) plus 12 edge points every 30°.(2). The leaf is a drawing. Unlike oval Ficus leaves (field work), nasturtium's round leaf has a central hub, giving every landmark a fixed reference for morphometrical analysis. **From leaf photo to 13 landmarks**

Computational approach:

1. **Grids & data (2021–25):** Overlaid 2×2 km land grids on Singapore (177 cells, 655 km²) and Melbourne (706 cells, 2,611 km²) using hourly ERA5 winds and boundary-layer height (BLH), WorldPop population, and station PM2.5.
2. **Weather regimes & split:** Clustered daily 6-h winds and BLH (k-means clustering, k=3) into frequency-weighted monsoon (SGP) and frontal (MEL) regimes; sampled 63 days/city (2021–24 train; 2025 test).
3. **Transport & emissions:** Simulated daily PM2.5 via a calibrated 2D advection–diffusion model (21 scenarios/day:population base, lognormal area noise, and Poisson point sources).
4. **Network optimisation:** Using Ordinary Kriging interpolation ($\sigma=0.25\sigma_{city}$), selected NN sensors on training maps via Greedy RMSE minimisation and QR pivoting vs. evenly spaced, random, and existing networks.
5. **Evaluation & budgets:** Scored networks on 2025 test days at real budgets (SGP N=22, MEL N=8),equal counts, and equal densities (sensors/100 km²), sweeping N=5–40(SGP) and 5–160 (MEL) for diminishing returns.
6. **Regime & emission tests (L0–L5):** Tested regime-specific networks for cross-weather penalties and evaluated six emission-predictability tiers from L0 (fixed population emissions) to L1–L5 (adding area noise, fixed sources, and random hotspots).

Results + Discussion

Leaf greenness in each period

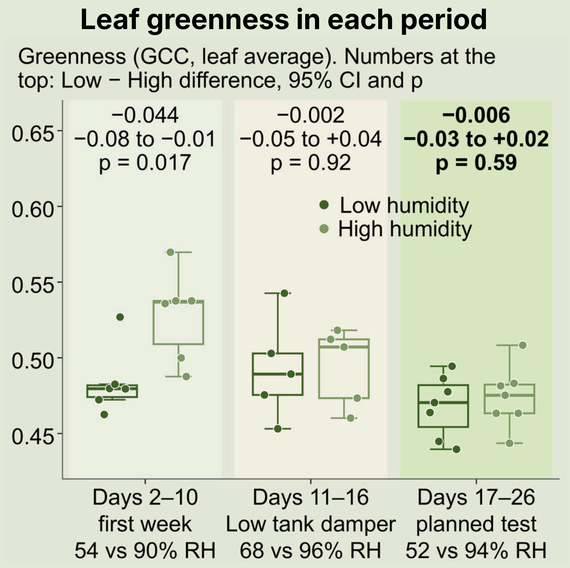


Figure 2. Low-humidity leaves were less green on Days 2–10 (p = 0.017), but not in the planned test on Days 17–26 (p = 0.59), partly because high-tank leaves also dulled. **Dry-tank leaves were less green early.**

Average leaf shape in each tank

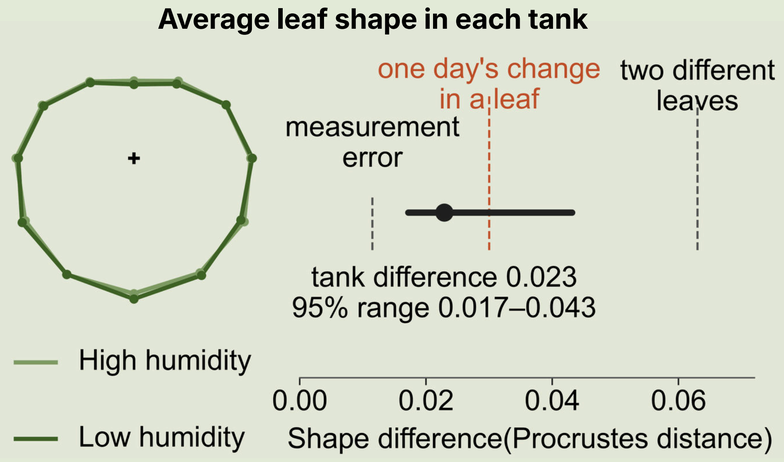


Figure 4. Left: the average leaf outline in each tank over Days 2–26. Right: the tanks differed by a Procrustes distance of only 0.023 (p = 0.28) - much less than the difference between any two leaves in the same tank (0.06).**No detectable shape difference.**

Leaf size over 26 days

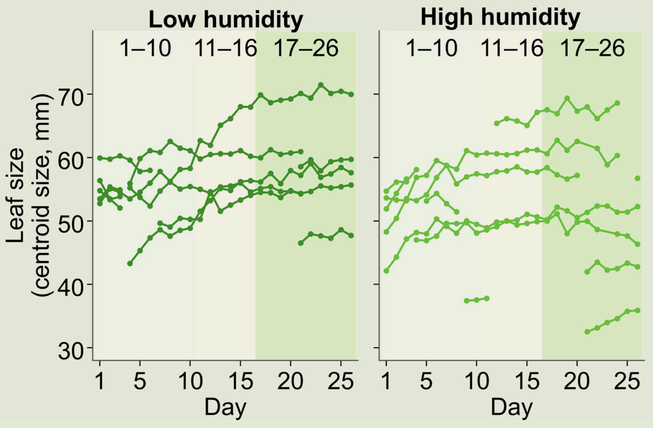


Figure 3. Each line is one leaf's size (centroid size, mm) over 26 days: dry tank left, humid tank right. No period differed (all p > 0.2), and roundness was also similar (p = 0.15). **Growth slowed equally in both tanks as leaves matured.**

Leaf colour: Dry air caused an initial decline in leaf greenness, but this difference disappeared over time, suggesting short-term rather than persistent stress. Gradual dulling in the humid tank may reflect heat stress, as temperatures exceeded 40°C on 10 days, well above nasturtium's optimal 15–20°C range.

Leaf shape: Leaf shape remained similar between treatments (Procrustes distance = 0.023, p = 0.28), consistent with the prediction that mature leaf outlines would not change substantially. The image-analysis error (0.012) was below the observed difference between individual leaves (0.06).

Map error by placement strategy and gain from weather informed placement

Singapore

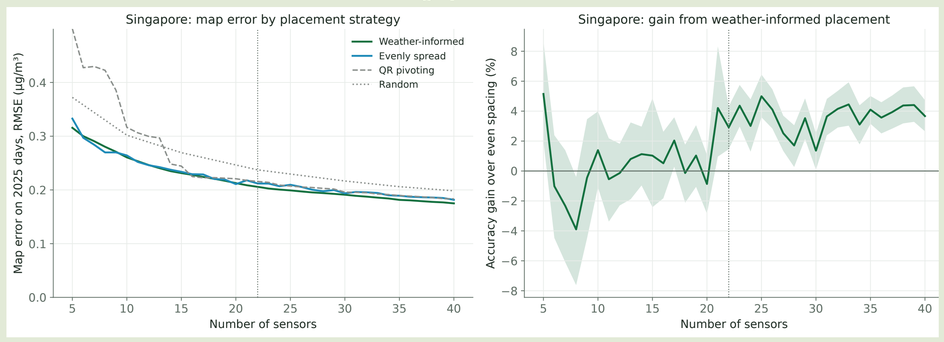


Figure 6. (Singapore) RMSE Error is slightly higher for a spatially balanced network than weather-informed placement.

Melbourne

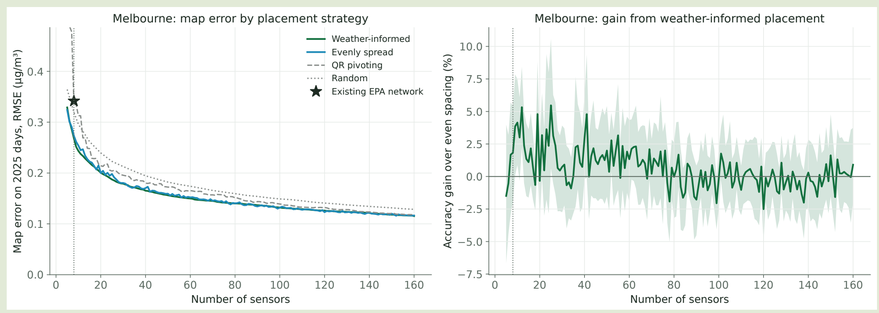


Figure 7. (Melbourne) RMSE Error is approximately the same for a spatially balanced network than weather-informed placement.

Accuracy gain: Weather-informed placement reconstructs PM2.5 maps 10–50% better than even spacing when emission sources are at least somewhat predictable, and about 0–3% better when they relocate randomly.
Cross-border comparison: Contrary to our hypothesis, Melbourne does not benefit more from weather-informed placement than Singapore. The best explanation for why this is the case could be due to sensor density rather than weather predictability. As Melbourne is 13-14x larger than Singapore, even with the same number of sensors, it is difficult to achieve similar coverage.
Point of diminishing returns: This is at about 4 sensors per 100 square kilometers (about 5km apart) in both cities. Past this density, there is not much justification for additional sensors.

Accuracy gain over spatially balanced network

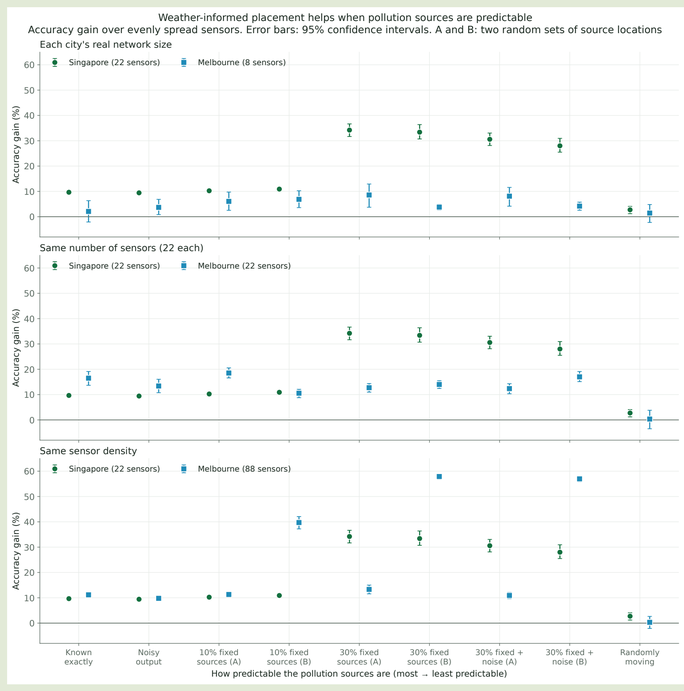


Figure 5. View top of graph for analysis. x-axis: predictability of the pollution source.

Limitations

Limitations:

- **Design**: We had one tank per condition, and the humid tank also ran hotter (max 48 °C vs 39 °C), so heat and humidity effects can't yet be separated. Our next trial will control temperature.
- **Conditions**: The humid tank was more humid than Singapore's average.
- **Sampling**: Replacing the most damaged dry-tank leaves may understate dry-air effects.
- **Grid size:** We only used 2 × 2 km grids, so we couldn't test how RMSE changes at finer resolutions. Our next simulation will use 0.5 × 0.5 km grids.
- **Wind data:** ERA5 wind data comes in cells about 30 km wide, coarse for a city as small as Singapore. This may have made Singapore's pollution look more predictable than it is. We plan to rerun the experiment with finer wind data if we can get it.

Conclusion

Sensors: Weather-informed placement benefits Singapore more the Melbourne only when pollution source locations are known. The benefit of weather-informed placement does not shrink as networks grow.
Leaves: Grown nasturtium leaves kept their shape in Melbourne-like and Singapore-like humidity over 26 days. Dry air caused a short shock in the first week (duller leaves, more leaves lost), but a test planned in advance found no lasting colour difference, even when the humidity gap was largest.
Together: Climate changes how pollution moves through a city and how its plants are stressed, so neither a sensor network nor a plant sign can be copied from one city to another without checking it there
Combined impact: Cities with few sensors, such as Melbourne with fewer than 20 official monitored sensors, need every sensor optimally placed. They cannot yet rely on leaves as humidity estimates at this stage yet. Our methods provide cities with a weather-aware sensor placement, and a fair way to test which leaf signs can be trusted.

References

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Oke, T. R., Mills, G., Christen, A., & Voogt, J. A. (2017). Urban climates. Cambridge University Press.
Spafford, L., MacDougall, A. H., Vitasse, Y., Filippa, G., Richardson, A., Steenberg, J., & Lever, J. J. (2023). Leaf phenology as an indicator of ecological integrity. Ecosphere, 14(5), Article e4487.
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