

Configuring urban CO₂ inversions: transport, resolution and sensor-network trade-offs in Glasgow

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01 Why configuration matters

Top-down CO₂ estimates give cities an independent check on progress towards net zero. Urban inversions, however, depend on how the transport model is driven, how finely it resolves the city, and where sensors are placed. We test each of these choices for Glasgow in December 2023, a high-emission winter month with stable boundary layers and high domestic heating demand.

02 Inversion framework

WRF meteorology

Forcing: ERA5 or GDAS · PBL: YSU, MYNN3 or BouLac · Grid: 3000, 1000 or 333 m

↓

STILT footprints

Surface sensitivity of each sensor to upwind emissions: $\Delta C = \text{footprint} \times \text{flux}$

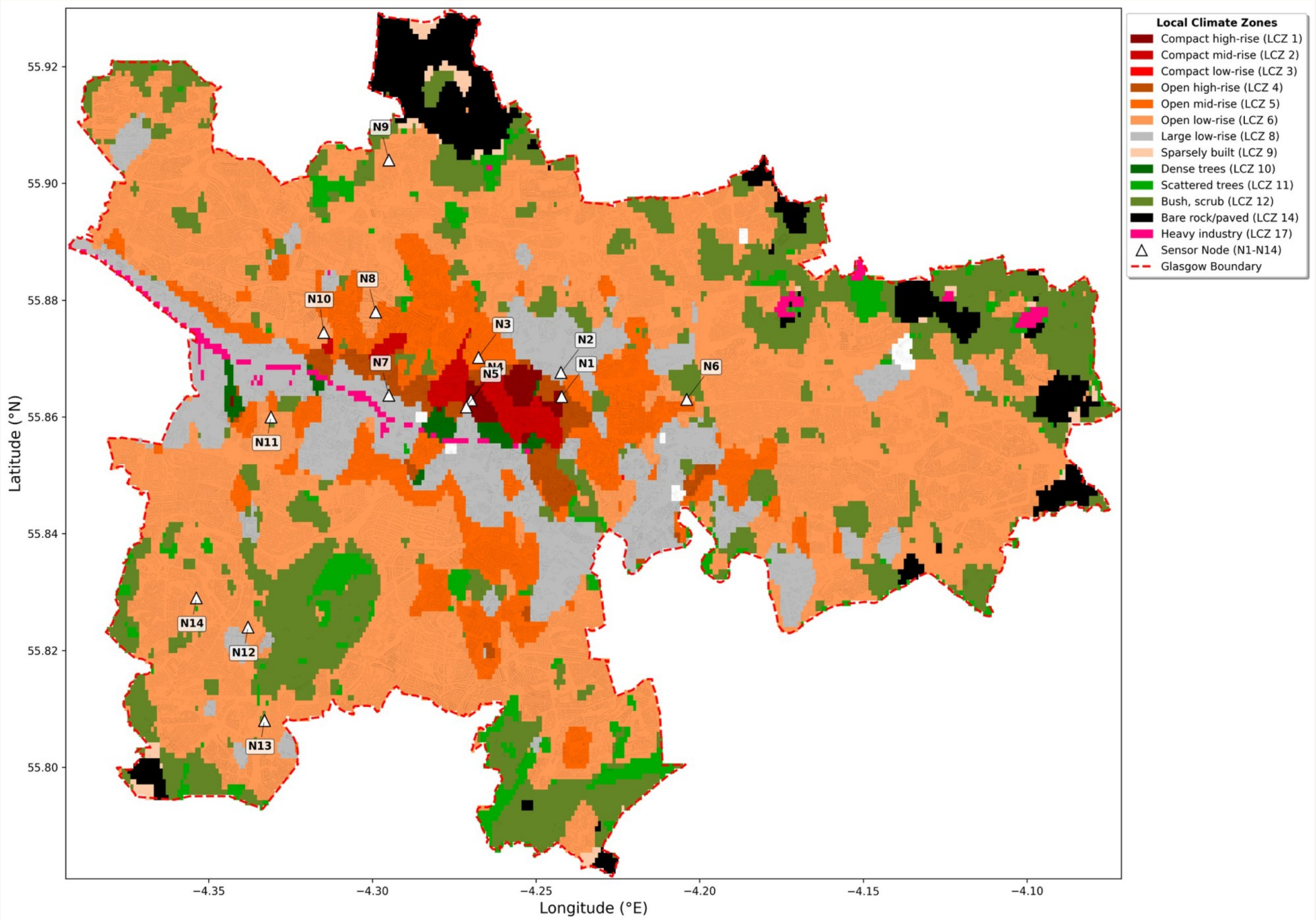
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Bayesian inversion

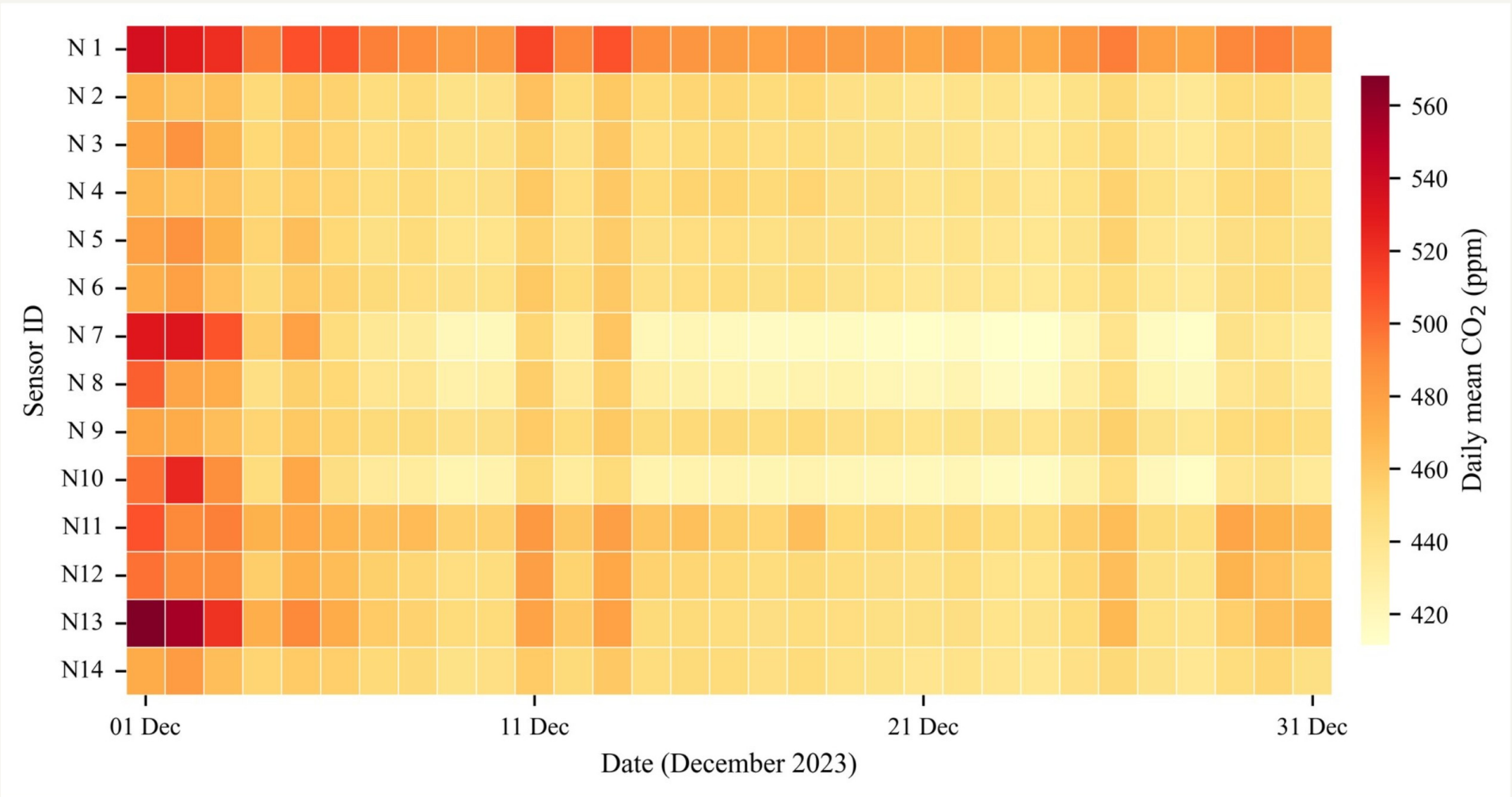
NAEI prior + BEACO₂N CO₂ → posterior fluxes and uncertainty · Network: 1, 5, 10 or 14 nodes

$$\hat{x} = x_a + BH^T (HBH^T + R)^{-1} (y - Hx_a)$$

03 Glasgow BEACO₂N network

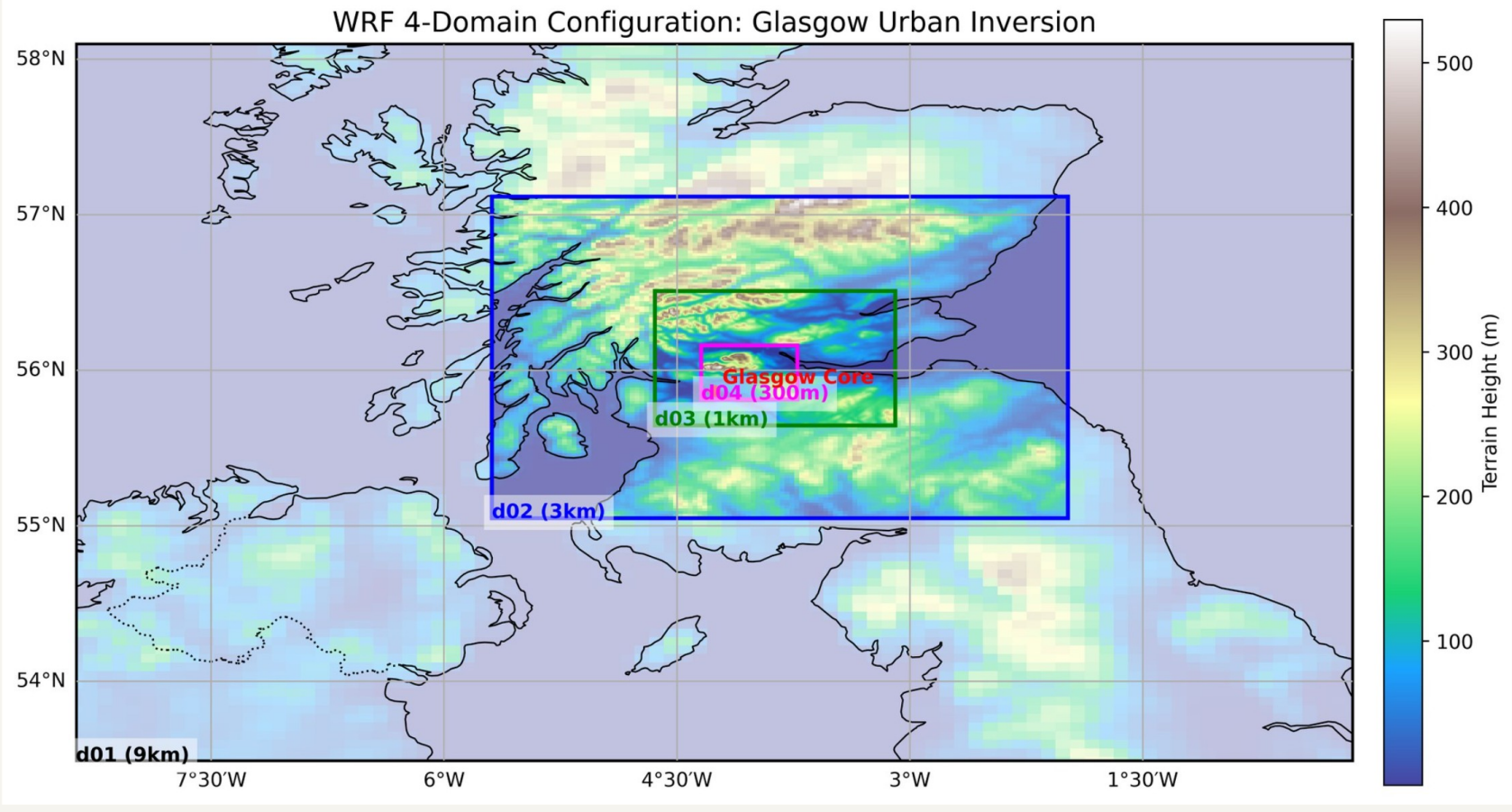


Fourteen nodes (N1–N14) over local climate zones, from the compact city centre to the suburban south-west.



Daily mean CO₂ (ppm) at each node, December 2023.

04 Meteorological forcing: ERA5 over GDAS



Nested WRF domains: 9 km, 3 km, 1 km and ~333 m over Glasgow.

ERA5 reanalysis produced a better WRF simulation than GDAS as boundary forcing. The largest gains were in wind speed and boundary-layer height, the two variables that most directly control source–receptor footprint sensitivity.

WHY IT MATTERS

Under stable winter boundary layers, small errors in wind speed or mixing height change which parts of the city each sensor “sees”, and the inversion assigns emissions to the wrong places.

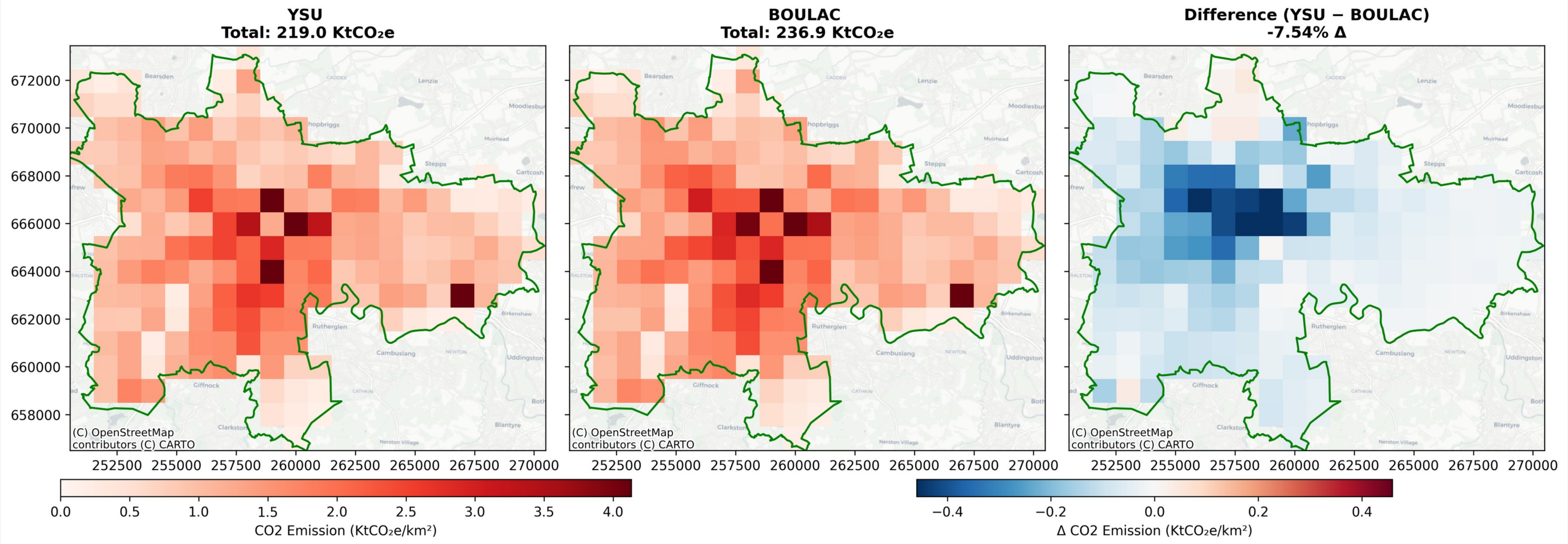
05 Boundary-layer physics: BouLac over YSU

Of three PBL schemes, the local TKE-based BouLac scheme best reproduced observed surface winds and boundary-layer dynamics. The non-local YSU scheme systematically underestimated wind speed, which degraded footprints and lowered cumulative December emissions. BouLac totals sit closest to the ODIAC and EDGAR inventories.

236.9
kt CO₂e, BouLac

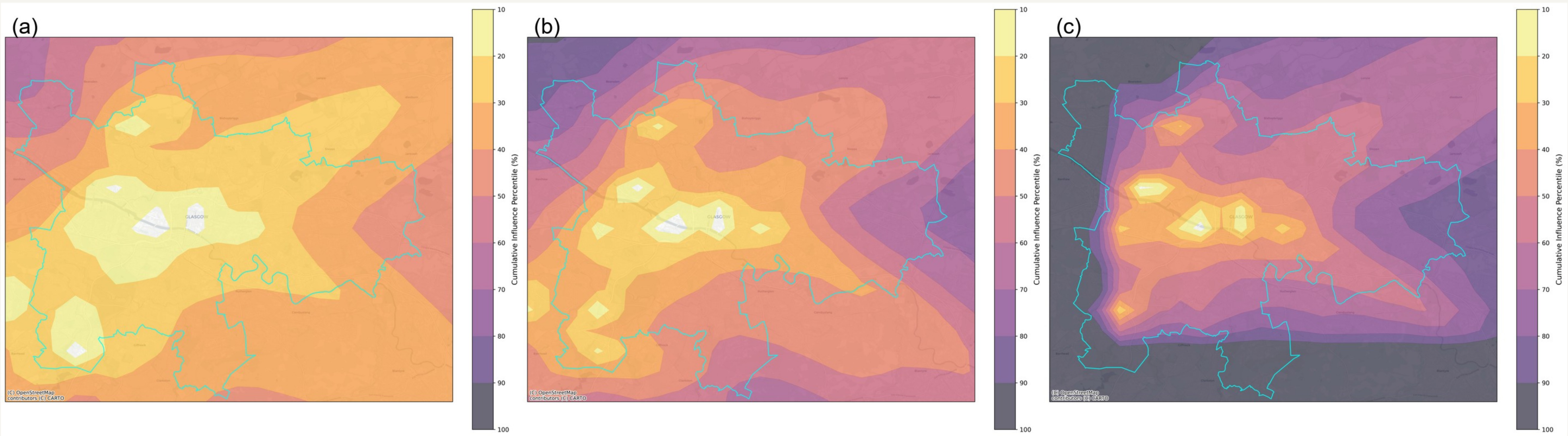
219.0
kt CO₂e, YSU

–7.5%
YSU relative to BouLac

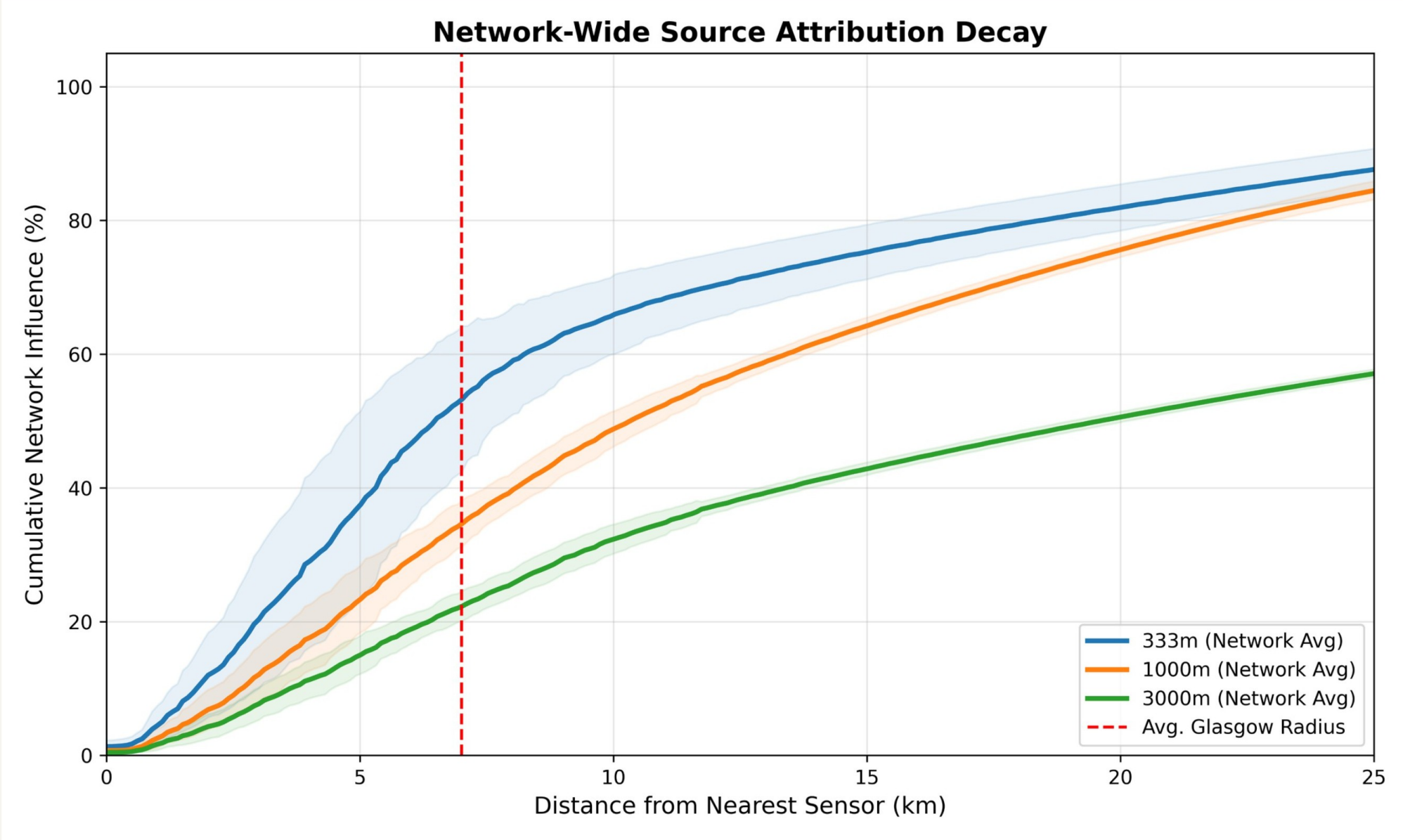


Posterior December 2023 emissions (kt CO₂e km^{–2}) with YSU and BouLac, and their difference. The YSU deficit is concentrated in the city centre.

06 Model resolution: 1 km is the sweet spot



Cumulative network influence at (a) 3000 m, (b) 1000 m and (c) 333 m. Finer grids concentrate sensitivity close to the nodes.



Influence against distance from the nearest node; dashed line marks the mean Glasgow radius.

Posterior uncertainty reduction peaks at 1 km. At 333 m the state vector has about nine times more grid cells, but the network adds no extra observational constraint, so the gain falls back.

POSTERIOR UNCERTAINTY REDUCTION

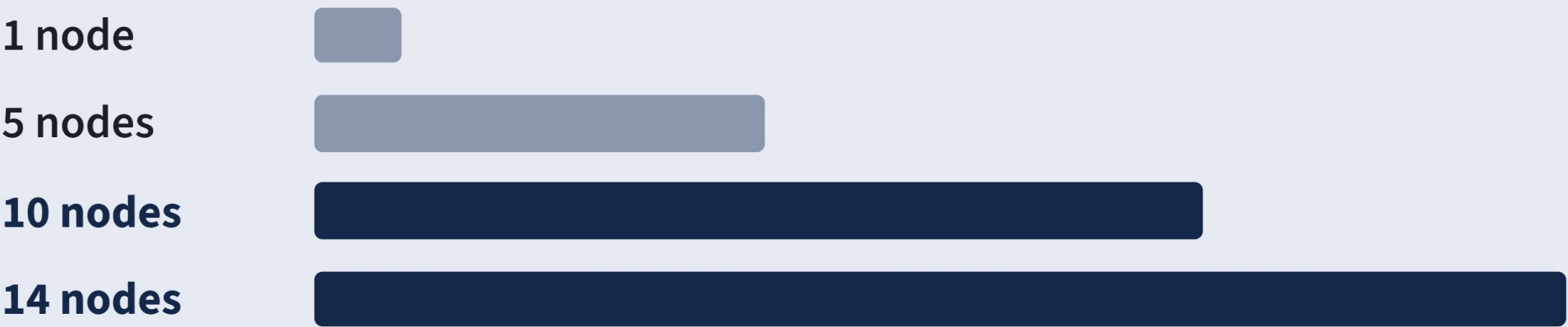
3000 m **14.4%**

1000 m **21.7%**

333 m **18.1%**

07 How many sensors?

With 10–14 well-distributed nodes, from the urban core to the suburban edge, cumulative December emissions converge to within 5% of independent reference inventories.



08 Recommended configuration for UK urban WRF–STILT inversions

FORCING

ERA5

Better winds and boundary-layer height than GDAS

PBL SCHEME

BouLac

YSU underestimates city emissions by 7.5%

RESOLUTION

1 km

Largest uncertainty reduction; 333 m adds no gain

NETWORK

≥10 sensors

Spread from urban core to suburban periphery

Prior: UK National Atmospheric Emissions Inventory (NAEI). Reference inventories: ODIAC, EDGAR. Observations: BEACO₂N Glasgow network, University of Strathclyde.