Designing sensor networks to resolve spatio-temporal urban temperature variations: fixed, mobile or hybrid?

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List of content

**Calculation of root mean square error**

**Table S1.** RMSEs (°C) of monthly mean temperatures measured by different networks over the four cities.

**Table S2.** Correlation coefficients between the PDF of $T_2$ during 1400-1600 local time from 95 EDF/MMN sensors and the PDF from the full WRF temperature dataset.

**Figure S1.** Relations between WRF-simulated monthly mean temperature and surface impervious fractions over the 10% hottest grids within individual bins. (a) $T_2$ and (b) $T_s$.

**Figure S2.** Measured temperature by 95 randomly distributed fixed sensors in (a) NYC, (b) Chicago, (c) Pittsburgh, and (d) Phoenix.

**Figure S3.** Probability density function of $T_2$ between 1400 and 1600 local time measured by 95 EDF and MMN sensors (lines) in Chicago over grids with impervious fractions of (a) 0.10 – 0.15, (b) 0.35 – 0.40, (c) 0.60 – 0.65, and (d) 0.85 – 0.90.

**Figure S4.** Mean correlation coefficient between the measured PDF of $T_2$ and the PDF from the full WRF temperature dataset during 1400-1600 local time averaged over four studied cities.

**Figure S5.** Measured extreme temperatures by 95 sensors with EDF (blue) and MMN (red) networks. (a) $T_{2\text{max}}$ in Phoenix, (b) $T_{2\text{max}}$ in Chicago, (c) $T_{2\text{ext}}$ in Phoenix, and (d) $T_{2\text{ext}}$ in Chicago.
**Calculation of root mean square error**

For each network strategy with a certain number of sensors, the root mean square error (RMSE) of measured monthly mean temperature is given by:

$$RMSE = \frac{\sum_{i=1}^{20} \left[ \sum_{j=1}^{N} (T_{ij,mea} - T_{ij,WRF})^2 / N \right]^{1/2}}{20}$$

where $i$ stands for the $i^{th}$ independent run, $j$ stands for the $j^{th}$ bin of impervious fraction, $N$ is the total number of bins, $T_{ij,mea}$ is the averaged monthly mean temperature over the sensors within the $j^{th}$ bin by a network strategy, and $T_{ij,WRF}$ is the averaged monthly mean temperature over all grids within the $j_{th}$ bin based on the full WRF dataset (the true value).

Note that $T_{ij,mea}$ can be missing for some bins when using the randomly distributed fixed (RDF) sensors. In this case, $T_{ij,mea}$ will be taken from nearby bins as $T_{i(j-1),mea}$ or $T_{i(j+1),mea}$, whichever leads to a larger deviation from $T_{ij,WRF}$. With sensors covering the full range of impervious fractions, EDF and WDF networks do not have such problems. To obtain $T_{ij,mea}$ from mobile networks (MMN), temperature observations over the $j^{th}$ bin of impervious fraction from all sensors will be combined and then averaged regardless of the measurement time.
Table S1. RMSEs (°C) of monthly mean temperatures measured by different networks over the four cities.

| Measurement network | Number of sensors | NYC   | Chicago | Pittsburgh | Phoenix |
|---------------------|-------------------|-------|---------|------------|---------|
|                     |                   | $T_s$ | $T_2$   | $T_s$ | $T_2$ | $T_s$ | $T_2$ | $T_s$ | $T_2$ |
| RDF                 | 19                | 0.80  | 0.79    | 0.79 | 0.80 | 0.74 | 0.74 | 0.85 | 0.80 |
|                     | 38                | 0.70  | 0.71    | 0.60 | 0.61 | 0.64 | 0.63 | 0.70 | 0.67 |
|                     | 57                | 0.58  | 0.56    | 0.58 | 0.59 | 0.51 | 0.51 | 0.64 | 0.61 |
|                     | 76                | 0.46  | 0.46    | 0.54 | 0.55 | 0.47 | 0.47 | 0.45 | 0.43 |
|                     | 95                | 0.40  | 0.38    | 0.37 | 0.37 | 0.38 | 0.38 | 0.41 | 0.39 |
| EDF                 | 19                | 0.47  | 0.43    | 0.38 | 0.39 | 0.33 | 0.34 | 0.59 | 0.50 |
|                     | 38                | 0.38  | 0.40    | 0.31 | 0.38 | 0.28 | 0.27 | 0.44 | 0.37 |
|                     | 57                | 0.35  | 0.32    | 0.29 | 0.29 | 0.26 | 0.25 | 0.38 | 0.31 |
|                     | 76                | 0.30  | 0.29    | 0.28 | 0.29 | 0.26 | 0.25 | 0.36 | 0.30 |
|                     | 95                | 0.30  | 0.28    | 0.27 | 0.27 | 0.25 | 0.24 | 0.30 | 0.28 |
| WDF                 | 19                | 0.47  | 0.45    | 0.38 | 0.39 | 0.33 | 0.34 | 0.59 | 0.50 |
|                     | 38                | 0.45  | 0.43    | 0.35 | 0.39 | 0.32 | 0.30 | 0.48 | 0.46 |
|                     | 57                | 0.43  | 0.38    | 0.34 | 0.36 | 0.29 | 0.29 | 0.42 | 0.40 |
|                     | 76                | 0.39  | 0.36    | 0.31 | 0.35 | 0.28 | 0.28 | 0.35 | 0.35 |
|                     | 95                | 0.36  | 0.31    | 0.32 | 0.33 | 0.27 | 0.27 | 0.34 | 0.35 |
| MMN                 | 19                | 0.43  | 0.39    | 0.44 | 0.36 | 0.48 | 0.40 | 0.70 | 0.31 |
|                     | 38                | 0.32  | 0.30    | 0.34 | 0.28 | 0.30 | 0.27 | 0.63 | 0.27 |
|                     | 57                | 0.31  | 0.29    | 0.27 | 0.25 | 0.27 | 0.25 | 0.48 | 0.25 |
|                     | 76                | 0.30  | 0.28    | 0.26 | 0.25 | 0.27 | 0.24 | 0.42 | 0.25 |
|                     | 95                | 0.26  | 0.25    | 0.24 | 0.23 | 0.24 | 0.23 | 0.35 | 0.23 |
Table S2. Correlation coefficients between the PDF of $T_2$ during 1400-1600 local time from 95 EDF/MMN sensors and the PDF from the full WRF temperature dataset.

| Range of impervious fractions | NYC EDF | NYC MMN | Chicago EDF | Chicago MMN | Pittsburgh EDF | Pittsburgh MMN | Phoenix EDF | Phoenix MMN |
|-------------------------------|---------|---------|-------------|-------------|----------------|----------------|-------------|-------------|
| 0 – 0.05                      | 0.98    | 0.79    | 0.94        | 0.93        | 0.96           | 0.96           | 0.97        | 0.97        |
| 0.05 – 0.1                    | 0.96    | 0.90    | 0.96        | 0.90        | 0.94           | 0.97           | 0.95        | 0.97        |
| 0.1 – 0.15                    | 0.97    | 0.92    | 0.91        | 0.82        | 0.92           | 0.94           | 0.98        | 0.94        |
| 0.15 – 0.2                    | 0.97    | 0.96    | 0.92        | 0.90        | 0.93           | 0.95           | 0.96        | 0.94        |
| 0.2 – 0.25                    | 0.98    | 0.97    | 0.96        | 0.89        | 0.95           | 0.95           | 0.97        | 0.96        |
| 0.25 – 0.3                    | 0.95    | 0.92    | 0.97        | 0.93        | 0.90           | 0.96           | 0.96        | 0.96        |
| 0.3 – 0.35                    | 0.96    | 0.96    | 0.97        | 0.85        | 0.96           | 0.93           | 0.96        | 0.94        |
| 0.35 – 0.4                    | 0.97    | 0.95    | 0.92        | 0.92        | 0.96           | 0.94           | 0.96        | 0.95        |
| 0.4 – 0.45                    | 0.94    | 0.96    | 0.96        | 0.91        | 0.95           | 0.97           | 0.97        | 0.97        |
| 0.45 – 0.5                    | 0.96    | 0.96    | 0.95        | 0.94        | 0.94           | 0.95           | 0.97        | 0.95        |
| 0.5 – 0.55                    | 0.96    | 0.97    | 0.94        | 0.96        | 0.97           | 0.95           | 0.96        | 0.94        |
| 0.55 – 0.6                    | 0.95    | 0.96    | 0.96        | 0.96        | 0.90           | 0.93           | 0.97        | 0.96        |
| 0.6 – 0.65                    | 0.96    | 0.96    | 0.94        | 0.97        | 0.96           | 0.90           | 0.97        | 0.96        |
| 0.65 – 0.7                    | 0.88    | 0.97    | 0.95        | 0.96        | 0.95           | 0.86           | 0.97        | 0.96        |
| 0.7 – 0.75                    | 0.96    | 0.97    | 0.96        | 0.96        | 0.97           | 0.90           | 0.96        | 0.97        |
| 0.75 – 0.8                    | 0.97    | 0.97    | 0.87        | 0.94        | 0.97           | 0.80           | 0.97        | 0.97        |
| 0.8 – 0.85                    | 0.92    | 0.97    | 0.92        | 0.96        | 0.94           | 0.84           | 0.97        | 0.97        |
| 0.85 – 0.9                    | 0.97    | 0.97    | 0.92        | 0.95        | 0.97           | 0.77           | 0.97        | 0.94        |
| 0.9 – 0.95                    | 0.95    | 0.98    | 0.96        | 0.95        | 0.98           | 0.77           | 0.94        | 0.95        |
Figure S1. Relations between WRF-simulated monthly mean temperature and surface impervious fractions over the 10% hottest grids within individual bins. (a) $T_2$ and (b) $T_s$. The group of impervious fractions $< 0.05$ is the reference point.
Figure S2. Measured temperature by 95 randomly distributed fixed sensors in (a) NYC, (b) Chicago, (c) Pittsburgh, and (d) Phoenix. Thick lines are the relations computed from the full WRF dataset over all grids (the truth), and each thin line represents one realization of the measurement network. All lines are averages over all the grid cells within individual bins.
Figure S3. Probability density function of $T_2$ between 1400 and 1600 local time measured by 95 EDF and MMN sensors (lines) in Chicago over grids with impervious fractions of (a) 0.10 – 0.15, (b) 0.35 – 0.40, (c) 0.60 – 0.65, and (d) 0.85 – 0.90. The bars are estimated from all grid cells in WRF. The PDF shifts towards high temperatures as the impervious fraction increases, and PDFs estimated from 95 EDF and MMN sensors capture the profiles computed from the full WRF temperature dataset. Correlation coefficients for individual bins are summarized in Table S2.
Figure S4. Mean correlation coefficient between the measured PDF of $T_2$ and the PDF from the full WRF temperature dataset during 1400-1600 local time averaged over the four studied cities.
Figure S5. Measured extreme temperatures by 95 sensors with EDF (blue) and MMN (red) networks. (a) $T_{2\text{max}}$ in Phoenix, (b) $T_{2\text{max}}$ in Chicago, (c) $T_{2\text{ext}}$ in Phoenix, and (d) $T_{2\text{ext}}$ in Chicago. Black lines are the relations computed from the full WRF dataset, and each thin line represents one realization.