Supplement of

A 10-year global monthly averaged terrestrial net ecosystem exchange dataset inferred from the ACOS GOSAT v9 XCO₂ retrievals (GCAS2021)

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**Text S1: Method for calculating prior and posterior uncertainties**

The posterior and prior uncertainties are calculated based on the prior and posterior perturbations of \( X^b \) and \( X^a \), which are calculated using equation (S1) ~ (S5). \( X^b \) is perturbed from the prior flux \( X^p \) with a Gaussian random distribution \( \delta_i \) and a set of scaling factors \( \lambda \). \( \delta_i \) has a mean of 0 and a standard deviation of 1, and \( \lambda \) represents the uncertainty of each prior flux. After constrained using satellite XCO₂ observations, the perturbed flux of \( X^b \) is changed to \( X^a \) according equation (S2) ~ (S5). In these equations, \( H \) is the observation operator that maps the state variable from model space to observation space; \( R \) is observation error covariance, \( P^b \) is the background error covariance; \( K \) and \( \tilde{K} \) are the Kalman gain matrix of the ensemble mean and ensemble perturbation, respectively. Equation (S2) ~ (S5) are solved in the EnSRF module in our system. In this study, the fluxes are independently perturbed with a spatial resolution of \( 3^\circ \times 3^\circ \), while \( X^b \) and \( X^a \) have a spatial resolution of \( 1^\circ \times 1^\circ \), that means the fluxes \( X \) within each \( 3^\circ \) grid have the same perturbation factor \( (\lambda \times \delta_i) \).

In addition, we use a data assimilation window of 1 week, namely the time interval of \( X^b \) and \( X^a \) is 1 week.

\[
X^b_t = X^b + \lambda \times \delta_i \times X^b, \quad i = 1, 2, \ldots, N
\]

\[
X^a_t = X^a + (X^b_t - X^b) - \tilde{K}H(X^b_t - X^b)
\]

\[
\tilde{K} = (1 + \frac{R}{HPH^T + R})^{-1}K
\]

\[
P = \frac{1}{n-1} \sum_{i=2}^{n} (X^b_t - X^b)(X^b_t - X^b)^T
\]

For the uncertainty \( \sigma \) in a defined region during a time period (monthly or annual), we firstly aggregate each perturbed flux \( i \) at each time step \( t \) (DA window) to \( F_{i,t} \) according to equation (S6), where \( j \) is the identifier of grid located in this region, and \( m \) is the number of grid in this region. Then, the uncertainty of the regional flux at each time step \( u_t \) is given by the standard deviation of \( F_{i,t} \) according to equation (S7). Finally, the uncertainty \( \sigma \) during this time period is estimated following equation (S8), where \( T \) denotes the time steps within this period.

\[
F_{i,t} = \sum_{j=1}^{m} X_{j,i,t}
\]

\[
u_t = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (F_{i,t} - \bar{F}_t)^2}
\]

\[
\sigma = \sqrt{\sum_{t=1}^{T} u_t \times u_t}
\]
Figure S1: The change rate of fossil fuel and cement carbon emissions in each region in 2019 compared with 2018

Figure S2: Comparisons between this study and GCP2020 for the estimates of annual (a) NBE and (b) AGR from 2010 to 2019
Figure S3: Monthly variations of (a) XCO₂ and (b) NBE in tropical latitudes (TL, 30° S ~ 30° N) in 2015 and 2019 (because GOSAT lacks data in January 2015, XCO₂ for each month is its change relative to February. It could be found that the carbon sinks in January-August and September-December 2019 were significantly smaller and stronger than those in the same period in 2015, respectively. Correspondingly, compared with 2015, GOSAT has higher XCO₂ in March - August, and lower ones in September-December in 2019. Although OCO-2 has a similar pattern, compared with 2015, the XCO₂ increase in March-August is significantly smaller than that of GOSAT, while the decrease in September-December is significantly higher than that of GOSAT. The annual mean GOSAT XCO₂ in 2019 is higher than that in 2015, while OCO-2 is the opposite)

Figure S4: Global distributions of the mean differences between the prior and posterior NEE averaged from 2010 to 2019
Figure S5: Differences between the prior and posterior NEE in each TRANSCOM 3 regions

Figure S6: Comparison of NBE between this study and CMS-Flux NBE 2010 for the periods of 2010-2014 and 2015-2018

Figure S7: Changes in posterior NBE relative to prior fluxes in southern Africa (positive means source increase)
Figure S8: Anomaly of monthly NEE in the pantropical area (30°S ~ 30°N)

Figure S9: Interannual variations of the prior and posterior NEE in each TRANSCOM 3 region and in the global scale. (a, Boreal North America; b, Temperate North America; c, Tropical South America; d, Temperate South America; e, Northern Africa; f, Southern Africa; g, Boreal Asia; h, Temperate Asia; i, Southeast Asia; j, Australia; k, Europe; l, Globe)
Figure S10: The spatial patterns of NEE anomaly in each year (gC m⁻² yr⁻¹)
Figure S11: Time series of monthly averaged biases between observations and simulations and the frequency distribution of the biases in the 7 regions and MLO site (the black dotted line represents the linear trend of the biases between the observations and the posterior simulations)

Figure S12: Inter-annual variations of the global averaged annual mean bias (error bar represents standard deviation of monthly mean biases in one year; the dotted line is its linear trend)
Figure S13: Global mean monthly XCO₂ from 2010 to 2019 (the small figure shows the annual mean biases and bias increment in each year)
| Locations | Site | Lab id | Lat   | Lon   | BIAS  | MAE   | RMSE  | CORR | No. of data |
|-----------|------|-------|-------|-------|-------|-------|-------|------|-------------|
| High latitudes |     |       |       |       |       |       |       |      |             |
| alt       | 1    | 82.45 | 297.49| 0.7   | 1.54  | 2.07  | 0.98  | 518  |             |
| brw       | 1    | 71.32 | 203.39| 0.29  | 2     | 2.61  | 0.97  | 555  |             |
| crv       | 1    | 64.99 | 212.4 | 0.47  | 2.79  | 3.52  | 0.93  | 1260 |             |
| ice       | 1    | 63.4  | 339.71| 0.56  | 1.63  | 2.01  | 0.96  | 161  |             |
| pal       | 1    | 67.97 | 24.12 | -0.04 | 2.53  | 3.34  | 0.96  | 438  |             |
| sum       | 1    | 72.6  | 321.58| 0.35  | 1.27  | 1.54  | 0.99  | 506  |             |
| tik       | 1    | 71.6  | 128.89| 0.88  | 1.83  | 2.44  | 0.97  | 500  |             |
| zep       | 1    | 78.91 | 11.89 | 0.88  | 1.83  | 2.44  | 0.97  | 500  |             |
| North America |     |       |       |       |       |       |       |      |             |
| amt       | 1    | 45.03 | 291.32| 1.97  | 3.26  | 4.07  | 0.95  | 1356 |             |
| bao       | 1    | 40.05 | 255   | -0.8  | 2.49  | 3.28  | 0.86  | 1754 |             |
| bmw       | 1    | 32.26 | 295.12| 1.69  | 1.99  | 2.58  | 0.97  | 397  |             |
| hsu       | 1    | 41.03 | 235.65| -0.24 | 2.67  | 3.46  | 0.9   | 69   |             |
| inx       | 1    | 39.8  | 273.98| 0.51  | 3.79  | 4.66  | 0.93  | 409  |             |
| key       | 1    | 25.67 | 279.84| 0.49  | 1.65  | 2.38  | 0.96  | 413  |             |
| lef       | 1    | 45.95 | 269.73| 0.69  | 3     | 3.8   | 0.95  | 1611 |             |
| mbn       | 1    | 43.98 | 238.31| 0.15  | 1.59  | 2.11  | 0.96  | 1500 |             |
| mex       | 1    | 18.98 | 262.69| 0.97  | 1.27  | 1.66  | 0.98  | 387  |             |
| mwo       | 1    | 34.22 | 241.94| -0.81 | 2.24  | 3.11  | 0.92  | 3185 |             |
| nwr       | 1    | 40.05 | 254.41| 0.06  | 1.6   | 2.15  | 0.96  | 489  |             |
| sct       | 1    | 33.41 | 278.17| 0.47  | 3.22  | 4.05  | 0.93  | 1689 |             |
| sgp       | 1    | 36.61 | 262.51| 0.72  | 3.28  | 3.99  | 0.93  | 437  |             |
| str       | 1    | 37.76 | 237.55| 0.05  | 2.35  | 3.09  | 0.94  | 4842 |             |
| thd       | 1    | 41.05 | 235.85| -1.05 | 2.35  | 3.13  | 0.91  | 330  |             |
| uta       | 1    | 39.9  | 246.28| 1.5   | 2.54  | 3.23  | 0.94  | 462  |             |
| wbi       | 1    | 41.72 | 268.65| 1.33  | 3.43  | 4.32  | 0.94  | 1645 |             |
| wgc       | 1    | 38.26 | 238.51| -0.09 | 3.34  | 4.14  | 0.9   | 1238 |             |
| wkt       | 1    | 31.31 | 262.67| 0.58  | 2.47  | 3.2   | 0.93  | 1326 |             |
| Europe    |     |       |       |       |       |       |       |      |             |
| bgu       | 11   | 41.97 | 3.23  | -0.3  | 2.74  | 3.45  | 0.92  | 223  |             |
| cib       | 1    | 41.81 | 355.07| 0.35  | 2.99  | 3.72  | 0.92  | 406  |             |
| fkl       | 11   | 35.34 | 25.67 | 0.49  | 2.41  | 2.97  | 0.94  | 207  |             |
| hnb       | 1    | 47.8  | 11.02 | 2.61  | 4.3   | 5.04  | 0.92  | 394  |             |
| hun       | 1    | 46.95 | 16.65 | 0.65  | 3.62  | 4.42  | 0.94  | 426  |             |
| lmb       | 1    | 35.52 | 12.62 | 0.58  | 1.91  | 2.4   | 0.96  | 415  |             |
| mhd       | 1    | 53.33 | 350.1 | 0.2   | 1.52  | 2.15  | 0.97  | 474  |             |
| oxf       | 1    | 50.03 | 11.81 | -0.13 | 3.3   | 4.07  | 0.91  | 360  |             |
| pdm       | 11   | 42.94 | 0.14  | -0.44 | 1.82  | 2.35  | 0.95  | 170  |             |
| East Asia |     |       |       |       |       |       |       |      |             |
| dsi       | 1    | 20.7  | 116.73| 0.87  | 2.29  | 2.92  | 0.94  | 376  |             |
| lnn       | 1    | 23.47 | 120.87| 1.06  | 2.33  | 3.15  | 0.95  | 384  |             |
| tap       | 1    | 36.74 | 126.13| 1.52  | 3.5   | 4.41  | 0.92  | 411  |             |
| umm       | 1    | 44.45 | 111.1 | -0.41 | 2.79  | 3.57  | 0.93  | 453  |             |
|       |   |       |   |   |   |   |       |
|-------|---|-------|---|---|---|---|-------|
|       |   |       |   |   |   |   |       |
| South America |   |       |   |   |   |   |       |
| nat   | 1 | -5.8  | 324.81 | 0.11 | 1.09 | 1.52 | 0.97 | 331 |
| rpb   | 1 | 13.16 | 300.57 | 0.36 | 0.72 | 0.95 | 0.99 | 511 |
| ush   | 1 | -54.85 | 291.69 | 0.24 | 0.64 | 0.88 | 0.99 | 206 |

| Africa |   |       |   |   |   |   |       |
| ask   | 1 | 23.26 | 5.63  | 0.01 | 0.65 | 0.83 | 1   | 474 |
| cpt   | 1 | -34.35 | 18.49 | 0.53 | 0.66 | 0.9  | 0.99 | 241 |
| nmb   | 1 | -23.58 | 15.03 | -0.11 | 0.78 | 1.09 | 0.99 | 403 |
| sey   | 1 | -4.68 | 55.53  | 0.57 | 0.81 | 1.2  | 0.99 | 416 |
| wis   | 1 | 29.96 | 35.06  | 0.17 | 1.98 | 2.57 | 0.95 | 479 |

| Australia |   |       |   |   |   |   |       |
| bhd   | 1 | -41.41 | 174.87 | -0.01 | 0.71 | 1.13 | 0.99 | 144 |
| cfa   | 2 | -19.28 | 147.06 | -0.03 | 0.92 | 1.27 | 0.99 | 176 |
| cgo   | 1 | -40.68 | 144.69 | 0.02 | 0.46 | 0.82 | 0.99 | 337 |
| gpa   | 2 | -12.25 | 131.04 | 1.29 | 2.23 | 2.71 | 0.92 | 64  |

|       |   |       |   |   |   |   |       |
| asc   | 1 | -7.97  | 345.6  | 0.57 | 0.73 | 0.91 | 1   | 836 |
| azr   | 1 | 38.77  | 332.62 | 0.29 | 1.57 | 2.02 | 0.96 | 218 |
| cba   | 1 | 55.21  | 197.28 | -0.91 | 2.08 | 2.82 | 0.96 | 808 |
| chr   | 1 | 1.7    | 202.85 | 0.59 | 0.85 | 1.07 | 0.99 | 249 |
| crz   | 1 | -46.43 | 51.85  | 0.1  | 0.32 | 0.41 | 1   | 396 |
| cya   | 2 | -66.28 | 110.52 | 0.24 | 0.31 | 0.39 | 1   | 222 |
| eic   | 1 | -27.16 | 250.57 | 0.16 | 0.91 | 1.39 | 0.98 | 342 |
| gmi   | 1 | 13.39  | 144.66 | 0.41 | 1.07 | 1.58 | 0.98 | 525 |
| hba   | 1 | -75.61 | 333.79 | 0.34 | 0.4  | 0.47 | 1   | 323 |
| izo   | 1 | 28.31  | 343.5  | 0.59 | 1.06 | 1.44 | 0.99 | 483 |
| kum   | 1 | 19.56  | 205.11 | -0.18 | 1.25 | 1.79 | 0.98 | 718 |
| maa   | 2 | -67.62 | 62.87  | 0.36 | 0.38 | 0.46 | 1   | 239 |
| mid   | 1 | 28.21  | 182.62 | 0.54 | 1.34 | 1.73 | 0.98 | 465 |
| mlo   | 1 | 19.54  | 204.42 | 0.22 | 0.61 | 0.8  | 1   | 637 |
| mqa   | 2 | -54.48 | 158.97 | 0.17 | 0.4  | 0.55 | 1   | 242 |
| psa   | 1 | -64.92 | 296    | 0.21 | 0.38 | 0.47 | 1   | 466 |
| rk1   | 426 | -29.2 | 182.1  | -0.07 | 0.58 | 0.7  | 1   | 49  |
| shm   | 1 | 52.71  | 174.13 | -0.2 | 2.07 | 2.76 | 0.96 | 429 |
| smo   | 1 | -14.25 | 189.44 | 0.37 | 0.57 | 0.76 | 1   | 798 |
| spo   | 1 | -89.98 | 335.2  | 0.3  | 0.35 | 0.41 | 1   | 494 |
| syo   | 1 | -69.01 | 39.59  | 0.28 | 0.34 | 0.4  | 1   | 237 |

|       |   |       |   |   |   |   |       |
|       |   |       |   |   |   |   |       |
|       | All| 0.35  | 1.76  | 2.28 | 0.96 | -    |       |