Supplementary materials

Seamless mapping of long-term (2010-2020) daily global XCO$_2$ and XCH$_4$ from GOSAT, OCO-2, and CAMS-EGG4 with a spatiotemporally self-supervised fusion method

Yuan Wang $^1$, Qiangqiang Yuan $^{1,2,*}$, Tongwen Li $^3$, Yuanjian Yang $^4$, Siqin Zhou $^1$, Liangpei Zhang $^5$

Affiliations:

$^1$ School of Geodesy and Geomatics, Wuhan University, Wuhan, Hubei, 430079, China.

$^2$ The Key Laboratory of Geospace Environment and Geodesy, Ministry of Education, Wuhan University, Wuhan, Hubei, 430079, China.

$^3$ School of Geospatial Engineering and Science, Sun Yat-sen University, Guangzhou, Guangdong, 519082, China.

$^4$ School of Atmospheric Physics, Nanjing University of Information Science & Technology, Nanjing, Jiangsu, 210044, China.

$^5$ The State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, Wuhan, Hubei, 430079, China.

Email addresses:

whuwy0419@whu.edu.cn (Yuan Wang), qqyuan@sgg.whu.edu.cn (Qiangqiang Yuan), litw8@mail.sysu.edu.cn (Tongwen Li), yyj1985@nuist.edu.cn (Yuanjian Yang), zhouq@whu.edu.cn (Siqin Zhou), and zlp62@whu.edu.cn (Liangpei Zhang).

* Corresponding author:

Qiangqiang Yuan (qqyuan@sgg.whu.edu.cn).
Figure S1. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on bremen01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for RMSE, $\mu$, and $\sigma$. 
Figure S2. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on burgos01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO₂/XCH₄ for RMSE, \( \mu \), and \( \sigma \).
Figure S3. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), OCO-2 (middle), and fused results (right) on easttroutlake01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON XCO$_2$; Y: CAMS-EGG4/OCO-2/fused XCO$_2$. Unit: ppm to XCO$_2$ for RMSE, $\mu$, and $\sigma$. 
Figure S4. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), OCO-2 (middle), and fused results (right) on eureka01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. \( X: \text{TCCON XCO}_2; \ Y: \text{CAMS-EGG4/OCO-2/fused XCO}_2. \) Unit: ppm to XCO_2 for RMSE, \( \mu \), and \( \sigma \).
Figure S5. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT (middle), and fused results (right) on fourcorners01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/fused data. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for RMSE, $\mu$, and $\sigma$. 
Figure S6. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on garmisch01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for RMSE, $\mu$, and $\sigma$. 
Figure S7. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on hefei01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for RMSE, $\mu$, and $\sigma$. 
Figure S8. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), OCO-2 (middle), and fused results (right) on izana01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON XCO$_2$; Y: CAMS-EGG4/OCO-2/fused XCO$_2$. Unit: ppm to XCO$_2$ for RMSE, $\mu$, and $\sigma$. 
Figure S9. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on jpl02. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO₂/XCH₄ for RMSE, μ, and σ.
Figure S10. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on karlsruhe01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO₂/XCH₄ for RMSE, μ, and σ.
Figure S11. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on lauder02. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO₂/XCH₄ for RMSE, μ, and σ.
Figure S12. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on lauder03. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for RMSE, $\mu$, and $\sigma$. 
Figure S13. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on lamont01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for RMSE, $\mu$, and $\sigma$. 
Figure S14. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), OCO-2 (middle), and fused results (right) on nicosia01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON XCO₂; Y: CAMS-EGG4/OCO-2/fused XCO₂. Unit: ppm to XCO₂ for RMSE, μ, and σ.
Figure S15. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), OCO-2 (middle), and fused results (right) on nyalesund01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON XCO₂; Y: CAMS-EGG4/OCO-2/fused XCO₂. Unit: ppm to XCO₂ for RMSE, μ, and σ.
Figure S16. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on orleans01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for RMSE, $\mu$, and $\sigma$. 
Figure S17. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on paris01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for RMSE, $\mu$, and $\sigma$. 
Figure S18. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on parkfalls01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for RMSE, $\mu$, and $\sigma$. 
Figure S19. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on pasadena01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for RMSE, $\mu$, and $\sigma$. 
Figure S20. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on reunion01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO₂/XCH₄ for RMSE, μ, and σ.
Figure S21. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on rikubetsu01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO₂/XCH₄ for RMSE, μ, and σ.
Figure S22. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on saga01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO₂/XCH₄ for RMSE, μ, and σ.
Figure S23. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on tsukuba02. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO₂/XCH₄ for RMSE, μ, and σ.
Figure S24. Scatter-plots of the in-situ validation results for CAMS-EGG4 (left), GOSAT/OCO-2 (middle), and fused results (right) on xianghe01. Black dotted and red full lines stand for the 1:1 and fitted lines, respectively. X: TCCON data; Y: CAMS-EGG4/GOSAT/OCO-2/fused data. Unit: ppm/ppb to XCO₂/XCH₄ for RMSE, μ, and σ.
Figure S25. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on bremen01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 
Figure S26. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on burgos01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to $\text{XCO}_2/\text{XCH}_4$ for $\mu$ and $\sigma$. 
Figure S27. Scatter-plots of the time series for daily CAMS-EGG4, OCO-2, fused, and TCCON XCO₂ on easttroutlake01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm to XCO₂ for $\mu$ and $\sigma$. 
Figure S28. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on edwards01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 
Figure S29. Scatter-plots of the time series for daily CAMS-EGG4, OCO-2, fused, and TCCON XCO₂ on eureka01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm to XCO₂ for $\mu$ and $\sigma$.
Figure S30. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT, fused, and TCCON data on fourcorners01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 
Figure S31. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on hefei01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 
Figure S32. Scatter-plots of the time series for daily CAMS-EGG4, OCO-2, fused, and TCCON XCO₂ on izana01. The first and second numbers in the bracket represent \( \mu \) and \( \sigma \), respectively. Unit: ppm to XCO₂ for \( \mu \) and \( \sigma \).
Figure S33. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on jpl02. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 
Figure S34. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on karlsruhe01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 
Figure S35. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on lauder03. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 
Figure S36. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on lamont01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 


Figure S37. Scatter-plots of the time series for daily CAMS-EGG4, OCO-2, fused, and TCCON XCO$_2$ on nicosia01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm to XCO$_2$ for $\mu$ and $\sigma$. 
Figure S38. Scatter-plots of the time series for daily CAMS-EGG4, OCO-2, fused, and TCCON XCO₂ on nyalesund01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm to XCO₂ for $\mu$ and $\sigma$. 
Figure S39. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on orleans01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 
Figure S40. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on paris01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 


Figure S41. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on parkfalls01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 
Figure S42. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on pasadena01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 
Figure S43. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on reunion01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 
Figure S44. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on rikubetsu01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 


Figure S45. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on saga01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 
Figure S46. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on sodankyla01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 
Figure S47. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on tsukuba02. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to $XCO_2/XCH_4$ for $\mu$ and $\sigma$. 
Figure S48. Scatter-plots of the time series for daily CAMS-EGG4, GOSAT/OCO-2, fused, and TCCON data on xianghe01. The first and second numbers in the bracket represent $\mu$ and $\sigma$, respectively. Unit: ppm/ppb to XCO$_2$/XCH$_4$ for $\mu$ and $\sigma$. 