A near-real-time estimation method for FFCO$_2$ emissions from China based on atmospheric observations at HAT and YON

The National Institute for Environmental Studies (NIES) and Japan Meteorological Agency (JMA) have been conducting in-situ observations of atmospheric CO$_2$ and CH$_4$ concentrations on Hateruma Island (HAT, 24.06°N, 123.81°E) and Yonaguni Island (YON, 24.47°N, 123.01°E) in Japan since the middle of the 1990s. The observed CO$_2$ and CH$_4$ frequently showed relatively large synoptic-scale variations (Fig. 1) because the continental air masses with elevated CO$_2$ and CH$_4$ concentrations are often transported to the islands from late autumn to early spring due to the influence of the East Asian monsoon. Analyses of the footprint region for the atmospheric observations at HAT and YON revealed that these elevated concentrations were mostly derived from the emissions from China. In addition, there is a considerable similarity in the temporal variations between CO$_2$ and CH$_4$, suggesting that the flux distributions in East Asia are similar to each other. Therefore, we can make a simple assumption that the variability ratio between CO$_2$ and CH$_4$ for the synoptic scale variations (ΔCO$_2$/ΔCH$_4$ ratio) reflects the CO$_2$/CH$_4$ emission ratio in China because calculating the variability ratio cancels out the transport influences. In fact, previous studies (Tohjima et al., 2014; 2020; 2022) revealed that the monthly averages of the ΔCO$_2$/ΔCH$_4$ ratios during three months (January, February, March) increased gradually from 2000 to 2010, when the Chinese economic activity showed unprecedented growth (Fig. 2). Furthermore, the ΔCO$_2$/ΔCH$_4$ ratio showed an abrupt decrease in February 2020, when a considerable reduction in the fossil fuel-derived CO$_2$ (FFCO$_2$) emissions was estimated due to a severe nationwide lockdown implemented in China (Fig. 2).

To investigate the relationship between the atmospheric ΔCO$_2$/ΔCH$_4$ ratios and the CO$_2$/CH$_4$ emission ratio in China for January, February, and March, we simulated the atmospheric CO$_2$ and CH$_4$ at HAT by using an atmospheric transport model (NICAM-TM, Niwa et al. 2011) and a full set of surface CO$_2$ and CH$_4$ fluxes. We found a linear relationship between the simulated ΔCO$_2$/ΔCH$_4$ ratios and FFCO$_2$/CH$_4$ emission ratios in China (Fig. 3). Therefore, we could convert the observed ΔCO$_2$/ΔCH$_4$ ratios to the FFCO$_2$/CH$_4$ emission ratios in China by using this linear relationship. Then, we calculated the change rate of the FFCO$_2$/CH$_4$ emission ratios compared to the corresponding averages for the preceding 9-year period (2011-2019), during which relatively stable ΔCO$_2$/ΔCH$_4$ ratios were observed. We can read the rate of change in the FFCO$_2$/CH$_4$ emission ratio as the rate of change in the FFCO$_2$ emissions from China under an additional assumption that there are no inter-annual variations in the biospheric CO_2 and CH_4 fluxes. Finally, we computed the weighted averages of the estimated change rate for HAT and YON.

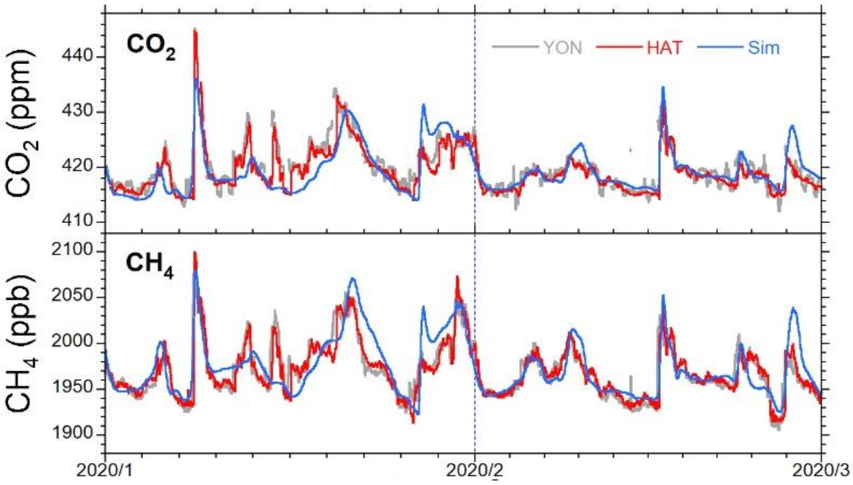

Fig. 1. Time series of atmospheric CO_2 (top) and CH_4 (bottom) hourly mole fractions. The data obtained at YON (grey lines) and HAT (red lines) for January-February, 2020 are depicted. The simulated CO_2 and CH_4 for HAT are also plotted as blue lines.

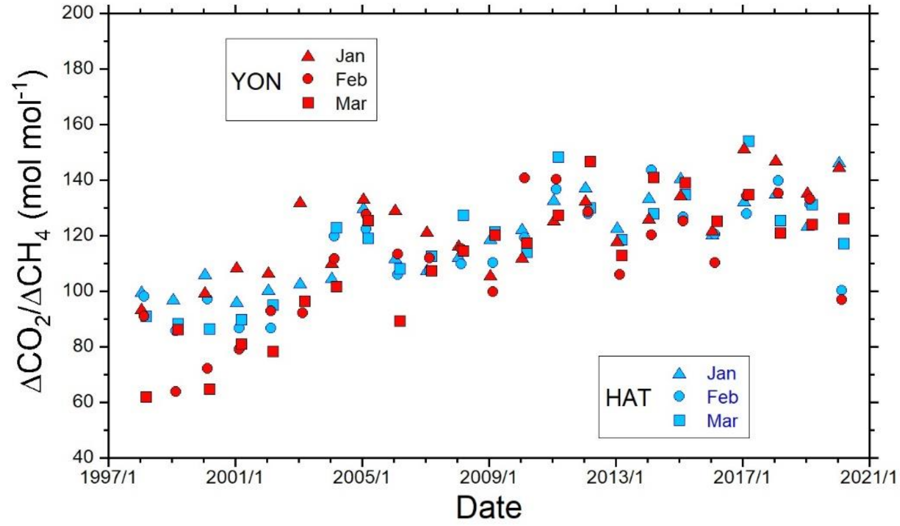

Fig. 2. Temporal change in the $\Delta CO_2/\Delta CH_4$ variability ratio observed at YON (red) and HAT (blue). Each symbol represents the monthly average (Triangle: Jan.; Circle: Feb.; Square: Mar.). The monthly $\Delta CO_2/\Delta CH_4$ ratios increased gradually during 2000-2010, when the Chinese economy showed unprecedented growth, and decreased markedly in February 2020, when a severe nationwide lockdown was implemented in

China.

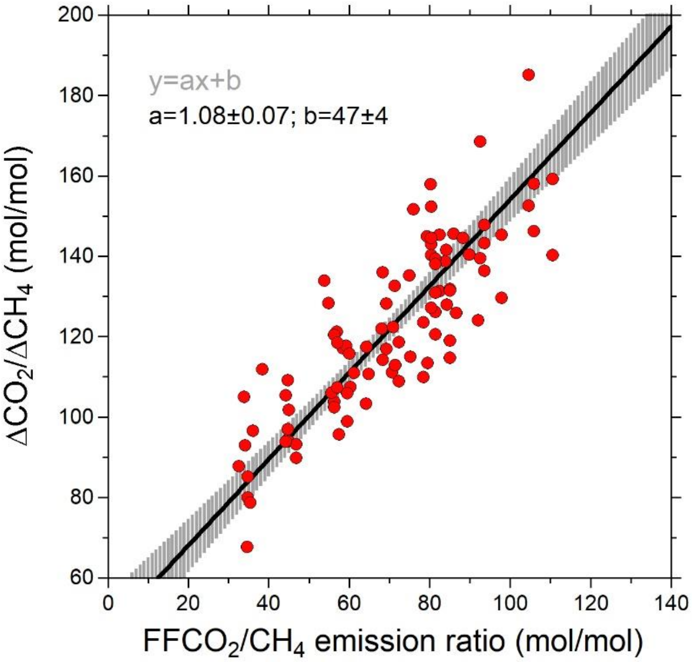

Fig. 3. Scatter plot between the $FFCO_2/CH_4$ emission ratios in China and the simulated $\Delta CO_2/\Delta CH_4$ ratios for HAT. The red line represents the linear regression line. The values for “a” and “b” in the figure represent the related slopes and y-axis intercepts, respectively. The gray vertical bars are estimated uncertainties (1σ) for the regression line based on the total $FFCO_2$ data.

How to compute the variability ratio?

The variability ratio, $\Delta CO_2/\Delta CH_4$, can be computed as a correlation slope of a scatter plot of the consecutive time series of the two species within a certain time window. We computed the slope by reduced major axis regression (RMA). We also computed the standard deviations (σ_{CO2}) and the correlation coefficient (R) at the same time. We repeated these calculations for the whole data set by shifting the time window by one hour. Then, we used the correlation slopes that met the selection criteria (σ_{CO2} >0.1ppm and R>0.7) to compute the monthly average or the moving averages of $\Delta CO_2/\Delta CH_4$. As for the time window for the correlation analysis, we used a duration of 24 hours for HAT, while a longer duration of 84 hours was used for YON to suppress the influences from the local biospheric CO_2 exchanges (Tohjima et al., 2022).

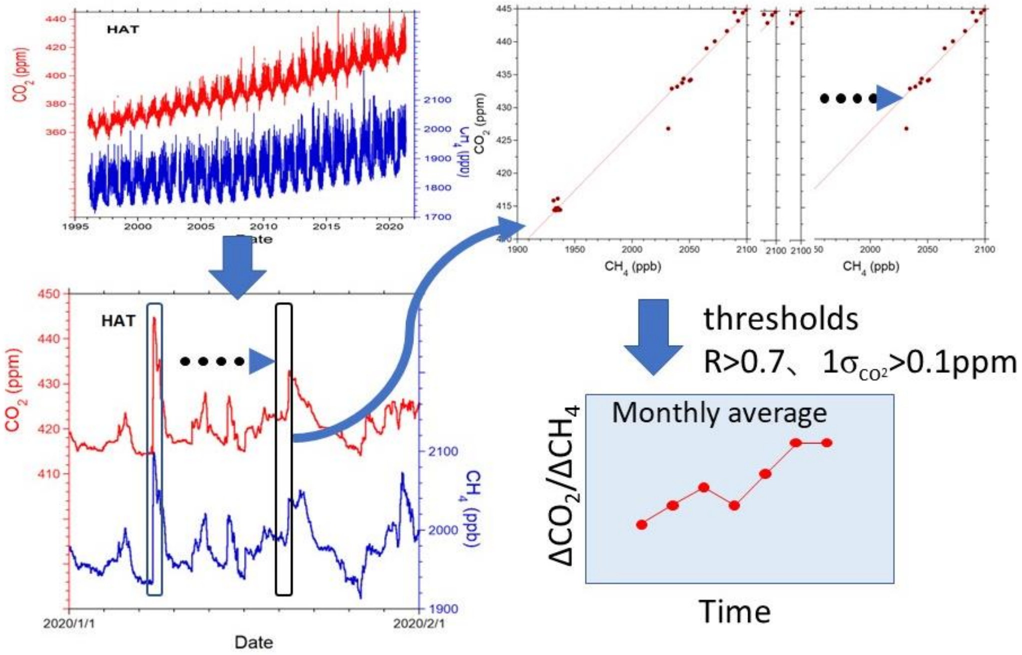

Fig. 4. Schematic diagram of the data processing procedure for the $\Delta CO_2/\Delta CH_4$ variability ratio.

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