Atmospheric CH_4 at regional stations of the Korea Meteorological Administration/ Global Atmosphere Watch Programme: measurement, characteristics and long-term changes of its drivers

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1. Introduction

- Atmospheric methane (CH_4) is an important greenhouse gas and is one of the main drivers of climate change on Earth. The global atmospheric CH_4 abundance was 1889±2 ppb in 2020, increasing by 2.6 times since 1750 (~722 ppb, pre-industrial period)
- CH_4 emission reduction may thus be an effective method to partially mitigate climate change due to its shorter lifetime (~9 year).
- To reduce the atmospheric CH_4 burden, its emissions and sinks must first be quantified. Because of its diverse sources (agriculture, waste, fossil fuels, and biomass burning) in different regions, high resolution, quality data can help quantify the atmospheric CH_4 budget.
- In this paper, we present CH_4 data quality procedures and processing methods at three KMA monitoring stations, including measurement uncertainties. We analyzed the characteristics of CH_4 at the KMA stations from 2016 to 2020 and compared the data with those collected at other stations in East Asia: the global background WMO/GAW station in Waliguan (WLG, 36.28°N, 100.90°E, 3810 m), China; and the WMO/GAW station at Ryori (RYO, 39.03°N, 141.82°E, 260 m) in Japan, which reflects the global growth rate (Watanabe et al., 2000). In addition, we investigated the changes in CH_4 enhancement from 1999 to 2021 and analyzed the source regions based on measurements of $\delta C_{(CH4)}$ in flask-air samples to trace the major source changes. Furthermore, this study can serve as a reference for KMA data archived at the World Data Centre for Greenhouse Gases.

2. Experiment

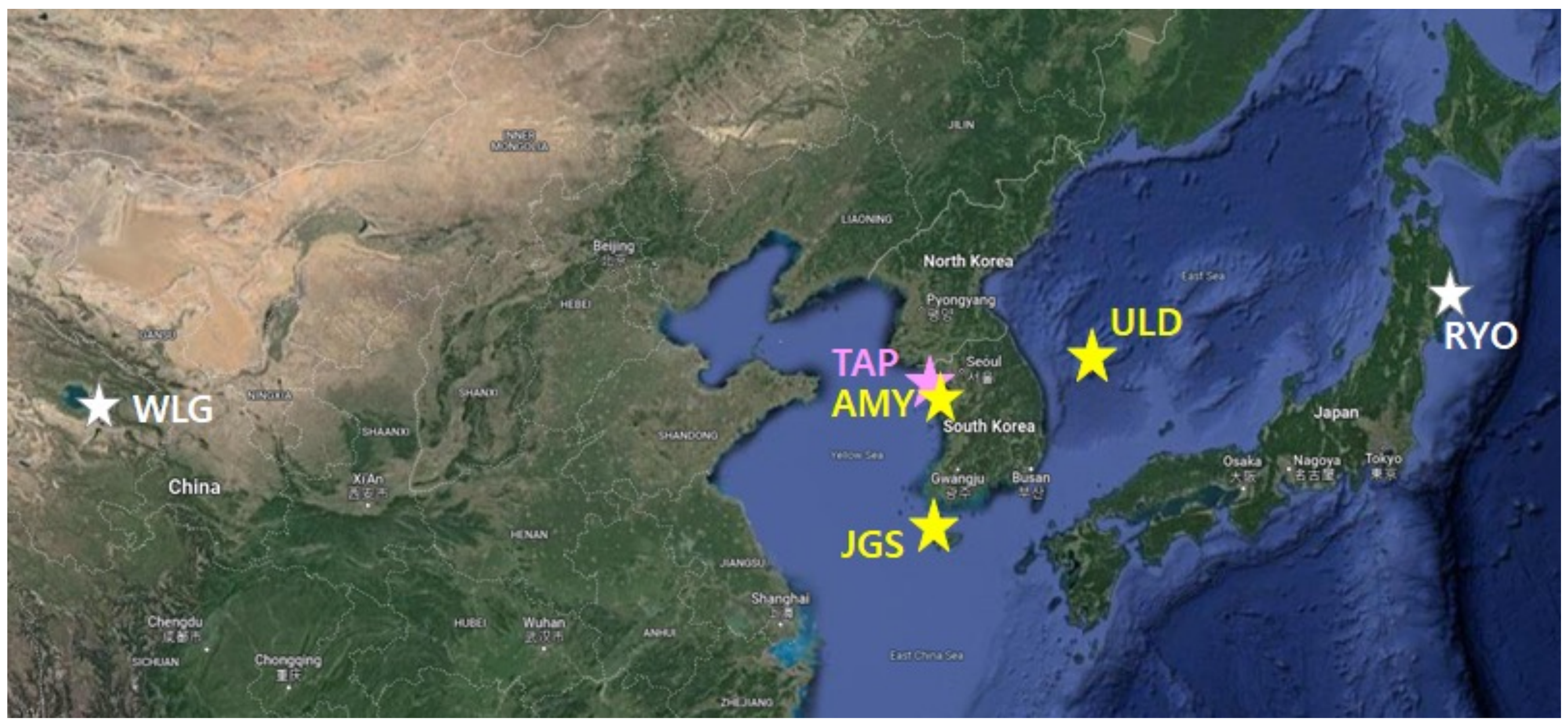


Figure 1. Locations of KMA CH_4 monitoring stations in Korea: Anmyeondo (AMY), Jejudo Gosan Suwolbong (JGS) and Ullengdo (ULD). Tae-an Peninsula (TAP, 36.74°N, 126.13°E), part of NOAA's flask-air sampling network, is 28 km from AMY in South Korea. Mt. Waliguan (WLG, 36.28°N, 100.90°E) and Ryori (RYO, 39.03°N, 141.82°E) are located in China and Japan, respectively. (Google)

Table 1. Information on the three KMA CH_4 monitoring stations in Korea

Station (ID)	Longitude Latitude Altitude	Inlet height (period)	Instrument Model (period)	Drying method (period)	Standard scale (period)
Anmyeondo (AMY)	126.32°E 36.53°N 47 m a.s.l	20 m (1999 to 2004)	GC-FID (1999 to 2016 Feb)	Three step dehumidification system 1) –4°C cold trap 2) Nafion™ 3) $Mg(ClO_4)_2$ (1999 to 2011)	KRISS (1999 to 2011)
		40 m (since 2004)	CRDS 2301 (2016 Feb to present)	Cryogenic system (since 2012)	WMO-X2004A (2012 to present)
Jejudo Gosan Suwolbong (JGS)	126.16°E 33.30°N 71.47 m a.s.l	6 m (2012 to 2017)	CRDS 1301 (2012 to 2019)	Cryogenic system	WMO-X2004A (2012 to present)
		12 m (since 2017)	CRDS 2401 (since 2020)		
Ulleungdo* (ULD)	130.90°E 37.48°N 220.9 m a.s.l	10 m (since 2012)	CRDS 2401 (since 2012)	Cryogenic system	WMO-X2004A (2012 to present)

Table 2. Uncertainty estimates for measurements of CH_4 at each station from 2016 to 2020. Units are ppb. All terms are 68% confidence intervals

Uncertainty terms	AMY	JGS	ULD
U_{h2o}	0.006	0.006	0.008
U_p	0.157	0.120	0.351
U_r	0.578	0.365	2.323 (0.710*)
U_{scale}	0.323	0.323	0.323
U_T	0.778	0.728	2.352 (0.801*)

– $(U_T)^2 = (U_{h2o})^2 + (U_P)^2 + (U_r)^2 + (U_{scale})^2$, where U_T is the total measurement uncertainty in the reported dry-air mole fractions; U_{h2o} is the uncertainty from the drying system; U_p is repeatability; U_r is reproducibility; and U_{scale} is the uncertainty of propagating the WMO-X2004A CH_4 scale to working standard gases.

3. Local/regional effects on observed CH_4

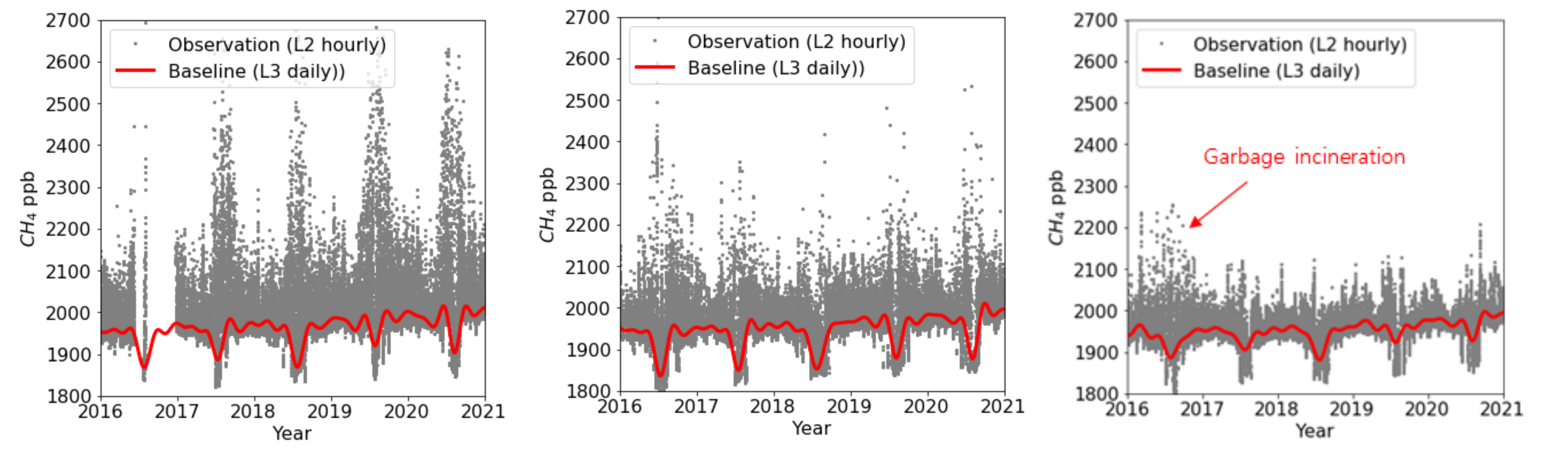


Figure 2. L2 hourly (grey scatters, observation) and fitted L3 daily data (red line, Baseline) at (a) AMY, (b) JGS, and (c) ULD from 2016 to 2020.

- CH_{4XS} was greatest in the order AMY (55.3±37.7 ppb) > JGS (24.1±10.2 ppb) > ULD (7.4±3.9 ppb) from 2016 to 2020.
- All stations showed largest CH_{4XS} in summer (June, July, August) with 109.6 ± 23.8 ppb at AMY, 37.0 ± 2.1 ppb at JGS and 12.2 ± 3.7 ppb at ULD. Conversely, the smallest values were observed as 25.6 ± 2.4 ppb at AMY and 18.8 ± 4.1 ppb at JGS in spring (March, April, May), while the lowest value of 7.5 ± 0.4 ppb at ULD was observed in winter (December, January, February).

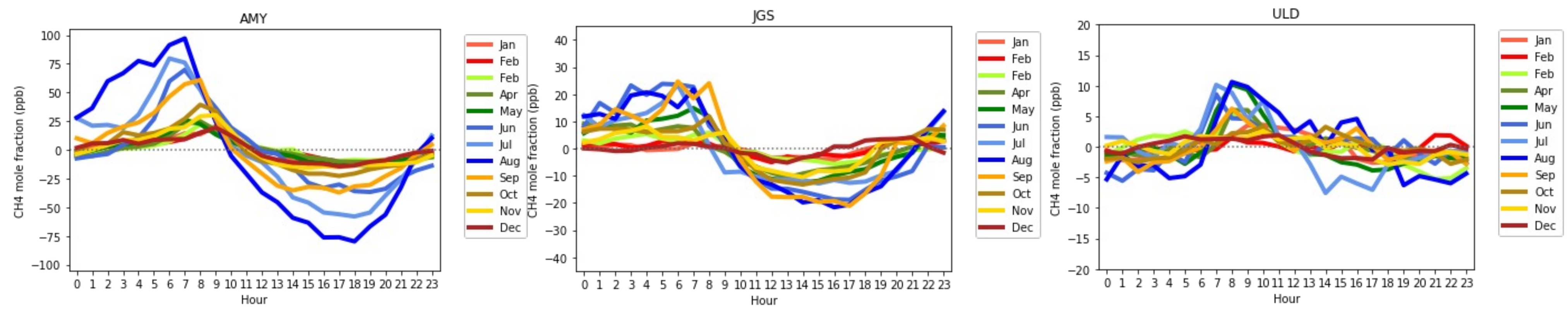
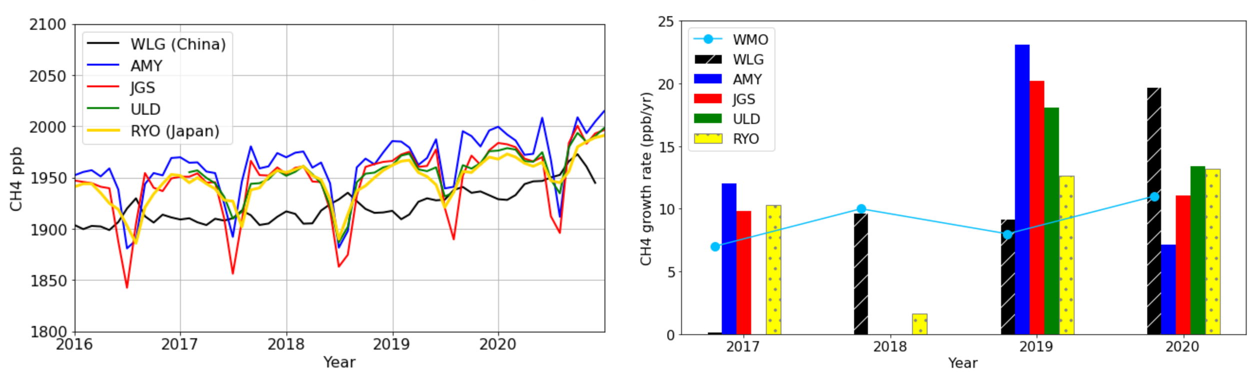


Figure 3. Mean diurnal variations of CH_4. Values show the average departure from the daily mean in each month at (a) AMY and (b) JGS from 2016 to 2020 and (c) at ULD from 2017 to 2020.

- Among the three stations, the mean diurnal variation in every month was greatest at AMY (69.5±49 ppb) and smallest at ULD (7.6±4.2 ppb), while it was 24.7±14.4 ppb at JGS.
- AMY is close to rice paddies (110 km²), which are the major source of CH_4 in summer. JGS and ULD are not close to waterlogged paddies. However, high temperatures stimulate greater emissions from sources such as agriculture, livestock, and wetlands, thus affecting emissions at both stations.

4. Comparison with other East Asian stations: annual mean, seasonal amplitude, and growth rate



-Annual CH_4 mean was the highest at AMY and the lowest at WLG.
- Seasonal amplitudes followed the order JGS > AMY > ULD>RYO> WLG

Figure 4. Time series of (a) monthly mean CH_4 and (b) annual growth rate at WLG, AMY, JGS, ULD, and RYO. The growth rate reported by WMO (WMO, 2021) is overlaid on (b) and this value is calculated as the change in annual mean from the previous year.

5. Long-term records of CH_4 and its drivers in East Asia

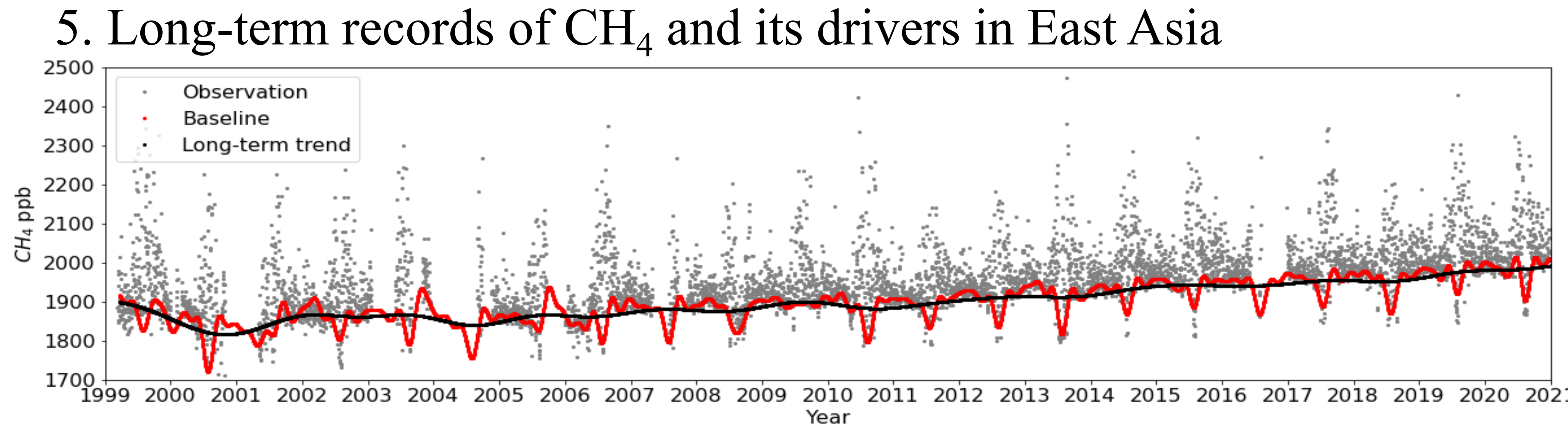
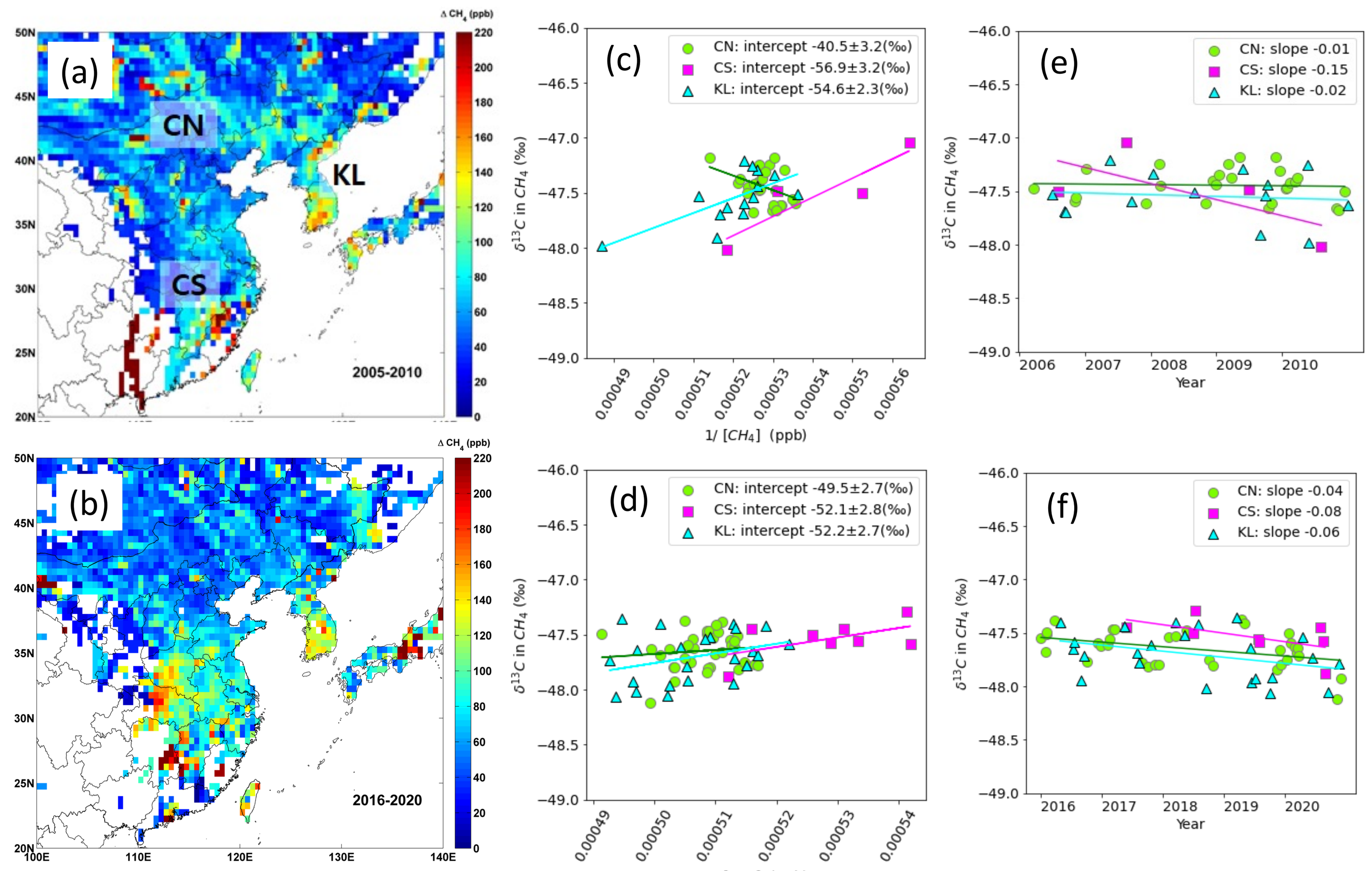


Figure 5. Time series of CH_4 (L2 daily, grey), baseline (L3 daily, red), and long-term trend (black) observed at AMY from 1999 to 2020.



-CH_4xs from CS and KL were enhanced and remain constant respectively while that from CN became weaker in 2016–2020 compared with that in 2006–2010.
- AMY and global growth rates were renewed in 2006 and during 2006–2010; the increasing trend could be linked to mixed biogenic and fossil fuel sources in East Asia. However, the recent accelerated increase in CH_4 emissions during 2016–2020 is more related to biogenic sources such as agriculture and wetland

Figure 6. PSS analysis from (a) 2006 to 2010 and (b) 2016 to 2020. "Keeling" plots for (c) 2006 to 2010 and (d) 2016 to 2020. Time series of $\delta^{13}C_{(CH4)}$ from (e) 2006 to 2010 and (f) 2016 to 2020