

Supplementary Materials for the manuscript:

Ship- and aircraft-based XCH₄ over oceans as new tool for satellite validation

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Table S1. The monthly averaged (Avg.) values and the standard deviation (SD.) of the ship (TF5 + RYF) and aircraft (CONTRAIL, JMA) CH₄ retrievals for the latitude range 30–40° N, 2014–2018.

Date (MM/YY)	Avg. Ship (ppb)	SD	Avg. CONTRAIL (ppb)	SD	Avg. JMA (ppb)	SD
01/14	1911.88	22.32	1849.78	–	1864.27	12.77
02/14	1912.87	20.97	1819.17	4.82	1863.00	4.77
03/14	1912.29	22.70	1823.12	35.43	1848.41	1.70
04/14	1894.78	17.63	1830.18	9.54	1901.39	9.06
05/14	1899.00	19.53	1859.78	4.58	1866.14	5.31
06/14	1874.29	26.54	1835.12	24.31	1902.32	41.68
07/14	1850.98	48.33	1858.10	45.71	1860.88	5.71
08/14	–	–	1926.37	13.18	1849.49	22.86
09/14	1906.50	18.85	1875.08	15.76	1904.06	13.01
10/14	–	–	1857.87	24.53	1861.20	3.83
11/14	1918.22	21.45	1841.12	4.72	1875.52	16.61
12/14	–	–	1868.75	4.01	1869.44	11.09
01/15	1926.10	18.97	1839.24	–	1866.90	10.58
02/15	1910.27	21.52	–	–	1870.13	2.50
03/15	1921.68	16.11	1798.99	38.85	1875.83	22.15
04/15	1913.80	19.40	1874.58	13.98	1866.57	2.57
05/15	1873.06	22.73	1849.33	5.85	1883.20	–
06/15	1902.90	21.22	1864.78	12.98	1886.12	42.02
07/15	1889.90	56.52	1889.69	50.37	1832.81	6.76
08/15	1926.21	5.36	1937.76	4.24	1865.06	6.70
09/15	1904.98	24.37	1878.28	4.48	1907.63	16.36
10/15	1929.14	0.43	1906.05	64.92	1868.59	12.19
11/15	1926.82	19.40	1880.53	6.09	1866.72	6.65
12/15	1925.95	33.62	1865.46	–	1855.40	8.41
01/16	1930.00	17.00	1843.93	–	1911.30	25.71
02/16	1935.95	22.61	1868.06	–	1867.52	9.93
03/16	1931.31	15.79	1776.80	–	1889.40	6.19
04/16	1928.00	16.43	1885.82	–	1876.10	6.26
05/16	1924.12	10.01	1856.02	–	1872.29	8.06
06/16	1900.86	28.69	1885.82	–	1886.64	12.56
07/16	1839.39	24.46	1880.24	–	1862.84	13.98
08/16	1843.62	26.93	1908.36	–	1933.40	11.18
09/16	–	–	1853.93	17.71	1868.15	16.12
10/16	1922.31	21.85	1908.37	–	1885.88	4.68

11/16	1959.41	51.48	1862.22	-	1934.09	23.26
12/16	1951.06	13.23	1863.37	-	1878.04	10.62
01/17	1960.30	28.82	1851.73	-	1880.64	12.79
02/17	1944.06	7.95	1841.03	-	1883.71	11.01
03/17	1940.94	11.44	1853.57	-	1878.47	9.26
04/17	1953.93	31.33	-	-	1880.51	14.57
05/17	1942.01	15.67	1861.05	8.31	1877.19	14.99
06/17	1941.09	27.10	-	-	1903.56	31.69
07/17	1855.56	6.75	1907.71	15.57	1904.76	24.32
08/17	1867.59	29.46	-	-	1882.88	26.15
09/17	1877.14	53.44	-	-	1928.14	27.86
10/17	1925.01	12.08	-	-	1911.96	3.55
11/17	1937.78	10.75	-	-	1888.78	14.24
12/17	1950.89	13.06	1900.12	20.41	1871.62	4.97

20 **Table S2.** The monthly averaged (Avg.) values and the standard deviation (SD.) of the ship (TF5 + RYF) and aircraft (CONTRAIL, JMA) CH₄ retrievals for the latitude range 20–30° N, 2014–2018.

Date (MM/YY)	Avg. Ship (ppb)	SD	Avg. CONTRAIL (ppb)	SD	Avg. JMA (ppb)	SD
01/14	1893.15	21.67	1841.28	9.28	1833.83	2.39
02/14	1893.30	22.18	1828.02	9.25	1858.06	0.96
03/14	1896.03	23.46	1844.57	26.37	1849.20	4.61
04/14	1883.92	16.24	1828.67	8.57	1869.98	20.32
05/14	1900.21	17.08	1842.14	13.07	1826.60	6.37
06/14	1837.59	34.45	1841.72	7.56	1863.58	51.56
07/14	1837.29	32.87	1868.02	33.70	1902.80	8.05
08/14	1812.08	9.77	1855.44	40.23	1830.20	1.58
09/14	1857.46	38.10	1844.46	23.87	1904.73	24.40
10/14	–	–	1852.64	14.19	1865.34	2.23
11/14	1888.57	19.65	1853.68	15.58	1850.20	5.51
12/14	–	–	1853.77	–	1845.23	4.82
01/15	1901.44	20.88	1851.36	12.93	1849.55	3.27
02/15	1917.96	21.89	1835.73	13.07	1895.75	17.80
03/15	1895.19	23.63	1837.05	25.12	1848.24	5.70
04/15	1878.52	22.32	1849.69	19.18	1860.86	7.22
05/15	1851.58	22.46	1843.46	11.08	1841.12	15.34
06/15	1837.36	18.91	1878.52	17.49	1849.03	3.17
07/15	1825.78	17.48	1839.87	16.10	1828.70	2.10
08/15	1839.99	29.41	1825.02	1.97	1854.80	8.71
09/15	1859.26	45.43	1863.35	34.34	1872.40	10.05
10/15	1897.43	20.83	1864.17	12.12	1848.84	7.63
11/15	1886.31	21.92	1875.91	–	1871.02	1.77
12/15	1905.29	18.68	1858.57	2.39	1859.53	2.92
01/16	1909.91	35.70	1845.29	0.79	1903.75	4.70
02/16	1912.64	19.72	1855.57	13.03	1858.44	3.03
03/16	1920.40	11.06	1817.12	70.45	1881.64	7.64
04/16	1890.51	27.84	1859.17	25.93	1866.14	4.65
05/16	1911.81	14.92	1851.77	3.45	1924.06	15.16
06/16	1872.66	38.77	1891.73	4.94	1841.45	9.60
07/16	1831.59	5.24	1906.03	39.52	1902.86	34.28
08/16	1881.88	25.39	1862.25	2.94	1918.48	30.62
09/16	1872.13	5.52	1884.13	–	1888.00	13.69
10/16	1875.73	11.36	1893.50	35.31	1875.85	6.63

11/16	1901.35	23.17	1861.86	12.61	1899.60	7.96
12/16	1928.66	25.82	1887.30	36.95	1872.43	5.68
01/17	1935.61	12.85	1871.77	3.59	1907.70	6.39
02/17	1930.53	7.92	1848.15	5.00	1859.64	1.79
03/17	1934.90	15.90	1844.78	3.54	1859.85	9.17
04/17	1936.98	18.94	–	–	1870.40	9.28
05/17	1926.92	15.28	1851.62	–	1866.12	3.67
06/17	1943.77	29.21	–	–	1869.80	19.98
07/17	1843.25	7.14	1928.17	–	1863.17	7.83
08/17	–	–	–	–	1886.68	21.00
09/17	1877.55	35.54	–	–	1914.95	28.17
10/17	1874.77	4.67	–	–	1897.23	11.20
11/17	1922.47	17.92	–	–	1878.26	1.21
12/17	1924.05	24.69	1899.06	23.25	–	–

Table S3. The monthly averaged (Avg.) values and the standard deviation (SD.) of the satellite XCH₄ retrievals of GOSAT NIES, RemoTeC SRON (SRFP), RemoTeC HD (HD), and OCFP for the latitude range 30–40° N, 2014–2018

Date (MM/YY)	Avg. NIES (ppb)	SD.	Avg. SRFP (ppb)	SD.	Avg. HD (ppb)	SD	Avg. OCFP (ppb)	SD
01/14	–	–	–	–	–	–	–	–
02/14	–	–	–	–	–	–	–	–
03/14	–	–	–	–	–	–	–	–
04/14	1795.67	12.05	–	–	1816.75	7.47	–	–
05/14	1828.14	16.82	1826.08	4.74	1818.21	11.39	–	–
06/14	1827.69	14.33	1815.37	–	–	–	–	–
07/14	1837.09	12.24	1825.65	17.27	1822.62	24.54	–	–
08/14	1824.85	14.77	1801.77	6.52	1802.99	8.38	1794.47	10.18
09/14	1841.54	9.99	–	–	1861.18	–	–	–
10/14	1876.86	–	–	–	–	–	–	–
11/14	–	–	–	–	–	–	–	–
12/14	–	–	–	–	–	–	–	–
01/15	–	–	–	–	–	–	–	–
02/15	–	–	–	–	–	–	–	–
03/15	1820.27	14.38	–	–	–	–	–	–
04/15	1832.10	8.81	1819.89	5.45	1827.53	22.67	–	–
05/15	1823.59	9.02	1812.95	8.98	1810.39	9.28	1822.15	4.19
06/15	1838.49	10.18	1824.62	12.11	1828.58	10.93	1834.49	0.44
07/15	1820.12	14.86	1806.64	14.36	1811.41	14.47	1796.04	3.17
08/15	1845.27	20.53	1820.65	13.31	1824.36	12.64	1832.99	17.30
09/15	1848.69	18.64	–	–	–	–	–	–
10/15	1847.47	26.79	–	–	–	–	–	–
11/15	–	–	–	–	–	–	–	–
12/15	–	–	–	–	–	–	–	–
01/16	–	–	–	–	–	–	–	–
02/16	–	–	–	–	–	–	–	–
03/16	1835.86	18.81	–	–	–	–	–	–
04/16	1832.70	14.74	1827.79	8.63	1829.49	–	1833.08	–
05/16	1844.98	9.24	1819.92	–	1830.21	12.12	1835.85	–
06/16	1855.21	14.87	1841.44	13.74	1841.91	13.57	1835.67	11.55
07/16	1838.98	16.93	1830.20	19.00	1831.86	18.40	1828.61	13.96
08/16	1865.19	16.45	1821.14	12.06	1813.28	13.29	1862.16	29.80
09/16	1856.41	19.35	–	–	–	–	1842.02	13.52
10/16	1812.75	12.67	–	–	–	–	–	–

11/16	-	-	-	-	-	-	-	-
12/16	-	-	-	-	-	-	-	-
01/17	-	-	-	-	-	-	-	-
02/17	-	-	-	-	-	-	-	-
03/17	1855.55	16.09	-	-	-	-	-	-
04/17	1834.37	15.15	-	-	-	-	-	-
05/17	1852.79	12.30	1841.53	14.42	1839.96	13.84	-	-
06/17	1857.65	9.79	1850.53	11.41	1843.83	9.23	1846.35	-
07/17	1858.32	10.34	1838.98	19.06	1844.67	15.79	1835.52	16.86
08/17	1870.59	18.03	1843.67	10.89	1851.83	28.80	-	-
09/17	1872.87	12.55	-	-	-	-	-	-
10/17	1850.52	-	-	-	-	-	-	-
11/17	-	-	-	-	-	-	-	-
12/17	-	-	-	-	-	-	-	-

Table S4. The monthly averaged (Avg.) values and the standard deviation (SD.) of the satellite XCH₄ retrievals of GOSAT NIES, RemoTeC SRON (SRFP), RemoTeC HD (HD), and OCFP for the latitude range 20–30° N, 2014–2018.

Date (MM/YY)	Avg. NIES (ppb)	SD. –	Avg. SRFP (ppb)	SD. –	Avg. HD (ppb)	SD –	Avg. OCFP (ppb)	SD –
01/14	–	–	–	–	–	–	–	–
02/14	–	–	–	–	–	–	–	–
03/14	1817.46	7.80	1809.18	8.33	1809.19	7.97	1809.15	8.89
04/14	1829.92	11.14	1817.08	10.04	1817.08	15.59	1817.86	18.19
05/14	1825.44	19.38	1812.61	13.35	1814.16	13.08	1810.60	9.89
06/14	1835.82	10.03	1812.58	18.09	1806.02	10.32	1811.59	6.80
07/14	1818.37	5.78	1804.32	11.28	1808.71	11.82	1803.86	9.16
08/14	1841.25	19.60	1804.49	13.24	1805.52	14.27	1813.58	14.08
09/14	1842.17	16.73	1820.74	7.03	1820.56	7.36	1831.55	14.23
10/14	1850.94	16.37	–	–	–	–	–	–
11/14	–	–	–	–	–	–	–	–
12/14	–	–	–	–	–	–	–	–
01/15	–	–	–	–	–	–	–	–
02/15	1831.48	9.23	–	–	–	–	–	–
03/15	1826.02	8.84	1826.81	–	1839.22	–	1831.57	5.23
04/15	1827.31	9.79	1815.39	11.64	1818.62	10.85	1818.99	11.36
05/15	1834.13	11.24	1819.57	8.89	1824.01	8.58	1827.60	6.03
06/15	1826.88	7.63	1818.66	10.76	1820.27	10.22	1822.98	10.21
07/15	1822.39	12.19	1810.29	12.85	1812.64	11.31	1809.26	7.97
08/15	1835.73	12.71	1821.64	13.86	1823.25	13.76	1827.95	12.88
09/15	1863.28	18.27	1830.51	10.87	1830.34	11.89	1826.68	11.81
10/15	1846.77	12.87	–	–	–	–	–	–
11/15	1834.50	1.34	–	–	–	–	–	–
12/15	–	–	–	–	–	–	–	–
01/16	1823.47	4.54	–	–	–	–	–	–
02/16	1832.47	11.03	–	–	–	–	–	–
03/16	1843.07	11.37	1843.36	2.57	1847.07	5.92	1830.91	21.66
04/16	1837.44	8.84	1825.51	7.54	1830.38	9.45	1826.52	9.00
05/16	1845.65	9.10	1832.41	10.45	1835.04	9.45	1834.00	11.31
06/16	1837.26	17.88	1825.15	13.53	1825.05	13.15	1828.31	14.58
07/16	1846.93	19.23	1826.44	15.92	1824.13	18.28	1823.57	13.45
08/16	1856.33	3.74	1836.82	17.57	1841.47	13.59	1836.79	15.61
09/16	1864.27	19.19	1845.49	21.50	1843.82	20.95	1840.95	16.65
10/16	1848.80	11.24	–	–	–	–	1841.91	6.29

11/16	-	-	-	-	-	-	-	-
12/16	-	-	-	-	-	-	-	-
01/17	-	-	-	-	-	-	-	-
02/17	1837.78	11.31	-	-	-	-	1825.19	8.86
03/17	1844.20	8.21	1840.70	4.96	1841.53	-	1836.38	9.22
04/17	1845.21	12.40	1830.99	10.56	1837.81	12.67	1827.20	12.22
05/17	1852.53	9.94	1839.13	7.57	1842.91	9.76	1843.44	11.44
06/17	1863.15	9.42	1834.59	11.76	1834.32	12.02	1843.99	9.32
07/17	1853.46	14.59	1829.48	12.88	1833.03	14.12	1835.08	7.87
08/17	1838.11	9.46	1841.46	13.29	1841.75	14.19	1841.14	10.32
09/17	1892.64	9.71	1848.14	18.14	1847.74	13.37	1855.02	8.78
10/17	1863.58	16.76	-	-	-	-	1845.42	13.35
11/17	1860.87	-	-	-	-	-	-	-
12/17	-	-	-	-	-	-	-	-

Table S5. Monthly simple obs. XCH₄, obs. XCH₄, and blended obs. XCH₄ values and its uncertainty interval (UC) derived from uncertainties in the CH₄ profile construction (see text) for the latitude range 30–40° N, 2014–2018.

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Date (MM/YY)	simple obs. XCH₄ (ppb)	± UC.	obs. XCH₄ (ppb)	± UC.	blended obs. XCH₄ (ppb)	± UC.
01/14	–	–	–	–	–	–
02/14	–	–	–	–	–	–
03/14	–	–	–	–	–	–
04/14	–	–	–	–	–	–
05/14	1825.15	22	1826.07	17	1826.50	17
06/14	1806.93	22	1824.49	17	1826.78	17
07/14	1814.80	22	1815.78	17	1818.12	17
08/14	–	–	–	–	–	–
09/14	1848.76	22	1856.94	17	1854.83	17
10/14	–	–	–	–	–	–
11/14	–	–	–	–	–	–
12/14	–	–	–	–	–	–
01/15	–	–	–	–	–	–
02/15	–	–	–	–	–	–
03/15	1808.91	22	1831.08	17	1834.11	17
04/15	1838.95	22	1835.04	17	1834.69	17
05/15	1814.14	22	1822.93	17	1825.52	17
06/15	1837.56	22	1842.19	17	1844.20	17
07/15	1846.93	22	1829.02	17	1834.30	17
08/15	1885.51	22	1863.95	17	1862.25	17
09/15	1852.71	22	1861.14	17	1861.47	17
10/15	1874.26	22	1861.84	17	1859.33	17
11/15	–	–	–	–	–	–
12/15	–	–	–	–	–	–
01/16	–	–	–	–	–	–
02/16	–	–	–	–	–	–
03/16	–	–	–	–	–	–
04/16	1845.42	22	1841.91	17	1842.11	17
05/16	1834.21	22	1835.98	17	1841.43	17
06/16	1845.55	22	1845.35	17	1845.73	17
07/16	1820.04	22	1816.50	17	1823.08	17
08/16	1837.15	22	1846.36	17	1841.52	17
09/16	–	–	–	–	–	–
10/16	1873.40	22	1866.35	17	1862.97	17

11/16	-	-	-	-	-	-
12/16	-	-	-	-	-	-
01/17	-	-	-	-	-	-
02/17	-	-	-	-	-	-
03/17	-	-	-	-	-	-
04/17	-	-	-	-	-	-
05/17	1847.96	22	1848.65	17	1853.89	17
06/17	-	-	-	-	-	-
07/17	1841.61	22	1843.23	17	1841.29	17
08/17	-	-	-	-	-	-
09/17	-	-	-	-	-	-
10/17	-	-	-	-	-	-
11/17	-	-	-	-	-	-
12/17	-	-	-	-	-	-

Table S6. Monthly simple obs. XCH₄, obs. XCH₄, and blended obs. XCH₄ values and its uncertainty interval (UC) derived from uncertainties in the CH₄ profile construction (see text) for the latitude range 20–30° N, 2014–2018.

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Date	simple obs.	± UC.	obs. XCH₄	± UC.	blended	± UC.
(MM/YY)	XCH₄		(ppb)		obs.	
	(ppb)				XCH₄	
					(ppb)	
01/14	–	–	–	–	–	–
02/14	–	–	–	–	–	–
03/14	1829.98	22	1830.01	17	1829.39	17
04/14	1816.47	22	1828.14	17	1828.98	17
05/14	1827.43	22	1821.09	17	1826.34	17
06/14	1808.59	22	1815.33	17	1817.90	17
07/14	1824.85	22	1836.38	17	1832.13	17
08/14	1811.48	22	1803.85	17	1806.89	17
09/14	1825.34	22	1844.00	17	1843.74	17
10/14	–	–	–	–	–	–
11/14	–	–	–	–	–	–
12/14	–	–	–	–	–	–
01/15	–	–	–	–	–	–
02/15	1831.17	22	1847.24	17	1845.52	17
03/15	1823.17	22	1826.51	17	1828.45	17
04/15	1823.60	22	1826.49	17	1828.17	17
05/15	1817.34	22	1816.46	17	1820.77	17
06/15	1829.40	22	1818.95	17	1823.88	17
07/15	1807.91	22	1804.58	17	1814.63	17
08/15	1809.27	22	1817.79	17	1822.31	17
09/15	1837.51	22	1840.38	17	1840.41	17
10/15	1850.51	22	1846.02	17	1849.15	17
11/15	1849.03	22	1847.28	17	1847.32	17
12/15	–	–	–	–	–	–
01/16	1842.59	22	1858.72	17	1856.56	17
02/16	1841.86	22	1842.40	17	1843.67	17
03/16	1826.58	22	1844.37	17	1848.92	17
04/16	1838.26	22	1840.34	17	1840.99	17
05/16	1840.80	22	1860.36	17	1859.03	17
06/16	1848.15	22	1833.62	17	1836.25	17
07/16	1840.88	22	1843.38	17	1838.97	17
08/16	1842.80	22	1859.37	17	1858.98	17
09/16	1854.35	22	1855.83	17	1854.11	17
10/16	1861.93	22	1856.48	17	1854.36	17

11/16	-	-	-	-	-	-
12/16	-	-	-	-	-	-
01/17	-	-	-	-	-	-
02/17	1837.04	22	1838.05	17	1840.96	17
03/17	1846.02	22	1853.25	17	1854.66	17
04/17	-	-	-	-	-	-
05/17	1850.93	22	1851.81	17	1857.28	17
06/17	-	-	-	-	-	-
07/17	1857.04	22	1840.32	17	1837.86	17
08/17	-	-	-	-	-	-
09/17	-	-	-	-	-	-
10/17	-	-	-	-	-	-
11/17	-	-	-	-	-	-
12/17	-	-	-	-	-	-

Table S7. The monthly averaged (Avg.) values and the standard deviation (SD.) of the TCCON XCH₄ retrievals at Tsukuba and Saga for 2014–2018.

Date (MM/YY)	Tsukuba (ppb)	SD	Saga (ppb)	SD
01/14	–	–	1824.86	5.75
02/14	–	–	1816.11	4.26
03/14	1824.15	2.21	1822.38	7.43
04/14	1819.55	6.31	1827.52	8.18
05/14	1824.08	11.13	1828.19	7.87
06/14	1829.55	8.64	1824.12	8.76
07/14	1837.03	11.83	1836.38	13.72
08/14	1814.43	12.74	1854.64	2.57
09/14	1853.40	16.29	1858.81	15.83
10/14	1842.46	13.94	1839.39	6.24
11/14	1836.07	5.69	1838.19	4.19
12/14	1829.57	7.16	1836.17	2.58
01/15	1826.45	8.06	1836.71	6.54
02/15	1820.07	12.45	1830.81	7.62
03/15	1820.61	9.17	–	–
04/15	1831.67	7.60	–	–
05/15	1824.81	11.01	1836.68	5.28
06/15	1829.95	8.61	1841.32	8.86
07/15	1823.38	20.59	1819.40	5.52
08/15	1836.00	15.25	1832.05	23.41
09/15	1840.77	6.29	1858.52	8.19
10/15	1843.76	10.63	1850.49	8.65
11/15	1843.44	7.27	1846.77	3.13
12/15	1842.35	7.35	1848.10	4.97
01/16	1840.86	7.03	1849.40	5.86
02/16	1832.64	8.43	1838.30	6.71
03/16	1829.60	8.23	1839.86	9.93
04/16	1833.25	6.83	1842.61	5.70
05/16	1832.81	5.54	1840.62	6.94
06/16	1837.37	12.72	1851.85	4.19
07/16	1849.53	16.17	–	–
08/16	1854.21	10.61	1855.97	20.68
09/16	1874.13	14.61	1871.28	12.72
10/16	1853.78	8.59	1872.63	16.64
11/16	1853.15	5.14	1857.59	6.08

12/16	1850.72	5.18	1857.51	6.05
01/17	1844.24	6.71	1848.66	6.72
02/17	1840.49	4.52	1847.39	6.30
03/17	–	–	1845.50	7.41
04/17	–	–	1847.49	10.74
05/17	–	–	1851.50	8.95
06/17	–	–	1857.40	9.81
07/17	1847.97	10.73	1852.60	28.26
08/17	1869.46	12.11	1873.05	16.45
09/17	1862.91	5.32	1882.44	10.03
10/17	1858.60	4.09	1867.94	6.98
11/17	1857.70	8.62	1867.25	6.02
12/17	1856.46	7.06	1866.53	5.39