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Atmospheric Histories (1765-2015) for CFC-11, CFC-12, CFC-113, CCl_4, SF_6 and N_2O

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ABSTRACT

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The data file **CFC_atmospheric_histories_revised_2015_Table1.csv** and Table 1 contain a listing of mean northern (NH) and southern (SH) hemisphere tropospheric CFC-11, CFC-12, CFC-113, carbon tetrachloride (CCl_4), sulfur hexafluoride (SF_6) and nitrous oxide (N_2O) concentrations for the period 1765.5 to 2015.5. The concentrations are given for the mid-point of each year (e.g. 2013.5) and expressed as the mixing ratio (mole fraction) of the trace gas in dry air. Concentration values are reported in parts-per-trillion (ppt) for CFC-11, CFC-12, CFC-113, CCl_4 and SF_6 and parts-per-billion (ppb) for N_2O. Figs. 1-9 show plots of these data for the NH and the SH during the periods of 1765-2015 and 1920-2015. Figs. 10-11 show fits of ice-core N_2O data from 1502-1996 and atmospheric N_2O measurement data from 1977-2015, used to generate the N_2O concentration values shown in Table 1.

1. Details for CFC-11, CFC-12, CFC-113 and CCl_4

The initiation of global atmospheric monitoring programs for CFC-11, CFC-12, CFC-113 and CCl_4 began in the late 1970's and early 1980's. Atmospheric concentrations of these compounds prior to this period are derived from estimates of annual industrial production and release of these compounds, with corrections applied based on the atmospheric lifetimes of each compound. Details on the procedures for deriving annual mean CFC-11, CFC-12, CFC-113 and CCl_4 concentration values (and estimates of errors) for the period 1910-1998 are provided in Walker et al (2000).

Concentration values for CFC-11, CFC-12, CFC-113 and CCl_4 listed in Table 1 from 1910.5 to 2008.5 are based on a 2009 update (**bluemoon.ucsd.edu/pub/cfchist**) of the Walker et al. (2000) results. Information on the calibration scales used at the Scripps Institution of Oceanography (SIO) is also provided at this website. The most recent (2009.5 to 2015.5) concentration values reported in Table 1 are derived from CMDL atmospheric measurements tabulated at the website: ftp://ftp.cmdl.noaa.gov/hats/ in 2015. Because of small (typically < 1%) differences in the CMDL and SIO calibration scales for these compounds, the CMDL concentration values reported from 2009.5 to 2015.5 are not directly used in Table 1. Instead, the yearly changes (in ppt) reported by CMDL for each compound during the period 2008.5 to 2014.5 are added to the SIO concentration values for 2008.5 in Table 1 to derive the yearly concentration values for 2009.5 to 2014.5. The CMDL tabulations available (as of April 2015) at the website ftp://ftp.cmdl.noaa.gov/hats/ only go to January 2015. The 2015.5 concentration values for these compounds in Table 1 are extrapolated from the corresponding 2014.5 values, assuming the same changes (in ppt per year) between 2014.5 and 2015.5 as those observed between 2013.5 and 2014.5

There have been several revisions of the calibration scales used at SIO (e.g. SIO93, SIO98, SIO05) for reporting CFC-11, CFC-12, CFC-113 and CCl_4 concentrations (https://bluemoon.ucsd.edu/pub/cfchist//). The most recent SIO calibration scale for reporting CFC-11, CFC-12, CFC-113 and CCl_4 concentrations is the SIO05 scale, which differs slightly from earlier SIO calibration scales. Since most of the measurements of dissolved CFCs in seawater made as part of the World Ocean Circulation Experiment (WOCE) and other major studies have been reported on the earlier SIO98 scale, it has been recommended (Bullister and Tanhua, 2010) for consistency that all future measurements of the concentrations of CFCs in seawater continue to be reported (and stored in data centers) on the SIO98 scale. If desired, seawater CFC concentrations on the SIO98 scale can be converted by users to any other SIO scale using simple multiplicative factors (see https://bluemoon.ucsd.edu/pub/cfchist//.

All of the atmospheric CFC-11, CFC-12, CFC-113 and CCl_4 concentration values in Table 1 are reported on the SIO98 calibration scale.

2. Details for SF_6

A discussion of the atmospheric history of SF_6 is provided in Bullister et al. (2006). The initiation of global atmospheric monitoring programs for SF_6 began in the 1990's. In Table 1, annual atmospheric concentrations of SF_6 for the period 1953.5-1994.5 are based on the industrial production and release estimates in Maiss and Brenninkmeijer (1998) (MB1988) for this period. To convert these annual release estimates to atmospheric concentrations, the MB1988 cumulative release value for SF_6 in 1995.5 is compared to the measured CMDL (ftp://ftp.cmdl.noaa.gov/hats/sf6/combined/HATS_global_SF6.txt) NH and SH SF_6 atmospheric concentrations in 1995.5. The ratio of the observed CMDL SF_6 atmospheric concentration in 1995.5 to the MB1988 cumulative SF_6 release for 1995.5 is then used to convert the MB1998 derived cumulative release values for each year (from 1953.5 to 1994.5) to atmospheric concentrations.

Note: In Table 1, atmospheric SF_6 concentrations prior to 1953.5 are assumed to be 0. Based on the solubility of SF_6 in seawater (Bullister et al., 2002), the 1953.5 atmospheric concentration of SF_6 (~0.04 ppt) corresponds to a dissolved SF_6 equilibrium concentration of about 0.02×10^{-15} mol/kg seawater. This concentration is at or below the current detection limit for dissolved SF_6 in seawater using current measurement techniques (Bullister and Wisegarver, 2008).

In Table 1, SF_6 values for the period 1995.5 to 2014.5 are based on mid-year measurements of SF_6 for the NH and SH reported by CMDL (ftp://ftp.cmdl.noaa.gov/hats/sf6/combined/HATS_global_SF6.txt). The 2015.5 SF_6 concentration values in Table 1 are extrapolated from the corresponding 2014.5 values, assuming the same changes (in ppt per year) between 2014.5 and 2015.5 as those observed between 2013.5 and 2014.5

Because of small differences in the CMDL2006 and SIO2005 SF_6 calibration scales (Miller at al., (2008); Rigby et al (2010)), all SF_6 concentrations reported in Table 1 have been are converted to the SIO2005 SF_6 calibration scale.

It has been recommended (Bullister and Tanhua, 2010) that all measurements of the concentrations of SF_6 in seawater be reported (and stored in data centers) on the SIO2005 scale

3. Details for N_2O

The initiation of global atmospheric monitoring programs for N_2O began in the 1970's. Prior to that period, data from firn and ice core records (eg. Machida et al., 1995; Battle et al., 1996, Freing et al . 2009; MacFarling-Meure et al. 2006) can be used to estimate the atmospheric N_2O concentrations as a function of time.

For the period 1978 to 2015, monthly mean NH and SH atmospheric measurements (and estimates of errors are available from CMDL:
ftp://ftp.cmdl.noaa.gov/hats/n2o/combined/HATS_global_N2O.txt

Individual monthly mean CMDL N_2O data values for the period prior to about 1987 are relatively noisy. Rather than reporting single, mid-year CMDL values in Table 1, all monthly CMDL data from 1978-2015 have been combined with MacFarling Meure et al. (2006) ice core data from 1502-1996 and fitted with a linear nonpolynomial expressions shown below to derive atmospheric N_2O values for the period 1500 to 2015 separately for the NH and SH (see Figs. 10 and 11).

The fits used are:

$$\mathbf{N_2O_{nh}(t) = (a_0) + (a_1 * exp(T)) + (a_2 * T * exp(T))}$$

where:
t=time (in decimal years)
$N_2O_{nh}(t)$= NH concentration of N_2O as function of t
$T=(t- \mu_1)/\mu_2$
μ_1=1977.21
μ_2=67.48
a_0=269.6871
a_1=30.9728
a_2=4.3598

$$\mathbf{N_2O_{sh}(t) = (a_0) + (a_1 * exp(T)) + (a_2 * T * exp(T))}$$

where:
t=time (in decimal years)
$N_2O_{sh}(t)$= SH concentration of N_2O as function of t
$T=(t- \mu_1)/\mu_2$
μ_1=1977.21
μ_2=67.48
a_0=269.8026
a_1=30.2498
a_2=4.3381

Mid-year values of N_2O from 1855.5 to 2015.5 are calculated from these fits and reported in Table 1. Because of the sparseness and large uncertainties in the ice core data, both NH and SH N_2O concentrations reported in Table 1 for the years prior to 1855.5 (1765.5-1854.5) are the mean of the values from the fits to the NH and SH for those years.

The N_2O concentrations are reported on the NOAA 2006A calibration scale: http://www.esrl.noaa.gov/gmd/ccl/index.html

4. Additional Notes

There may be very slight differences (<1%) in some of the atmospheric concentrations of CFC-11, CFC-12, CFC-113, CCl_4 and SF_6 reported in this version of Table 1 vs. previous versions, due to small revisions and re-calibration of earlier measurements by the CMDL and SIO groups.

5. Acknowledgements

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APPENDIX 1

Table 1. Mean mid-year tropospheric CFC-11, CFC-12, CFC-113, carbon tetrachloride (CCl_4), sulfur hexafluoride (SF_6) and nitrous oxide (N_2O) concentrations in the northern (NH) and southern (SH) hemispheres for the period 1765.5 to 2015.5 The concentrations are expressed as the mixing ratio (mole fraction) of the trace gas in dry air and are reported in parts-per-trillion (ppt) for CFC-11, CFC-12, CFC-113, CCl_4 and SF_6 and as parts-per-billion (ppb) for N_2O. CFC-11, CFC-12, CFC-113, and CCl_4 concentrations are reported on the SIO98 calibration scale; SF_6 concentrations are reported on the SIO2005 calibration scale and N_2O concentrations on the CMDL2006A scale.

YEAR	CFC11 NH ppt	CFC11 SH ppt	CFC12 NH ppt	CFC12 SH ppt	CFC113 NH ppt	CFC113 SH ppt	CCl4 NH ppt	CCl4 SH ppt	SF6 NH ppt	SF6 SH ppt	N2O NH ppt	N2O SH ppt
1765.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.47	270.47
1766.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.49	270.49
1767.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.50	270.50
1768.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.52	270.52
1769.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.53	270.53
1770.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.55	270.55
1771.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.56	270.56
1772.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.58	270.58
1773.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.59	270.59
1774.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.61	270.61
1775.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.62	270.62
1776.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.64	270.64
1777.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.66	270.66
1778.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.67	270.67
1779.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.69	270.69
1780.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.71	270.71
1781.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.73	270.73
1782.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.74	270.74
1783.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.76	270.76
1784.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.78	270.78
1785.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.80	270.80
1786.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.82	270.82
1787.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.84	270.84
1788.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.86	270.86
1789.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.88	270.88
1790.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.90	270.90
1791.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.92	270.92

1792.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.95	270.95
1793.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.97	270.97
1794.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270.99	270.99
1795.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.02	271.02
1796.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.04	271.04
1797.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.06	271.06
1798.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.09	271.09
1799.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.11	271.11
1800.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.14	271.14
1801.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.16	271.16
1802.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.19	271.19
1803.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.21	271.21
1804.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.24	271.24
1805.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.27	271.27
1806.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.30	271.30
1807.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.33	271.33
1808.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.36	271.36
1809.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.39	271.39
1810.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.42	271.42
1811.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.45	271.45
1812.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.48	271.48
1813.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.51	271.51
1814.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.54	271.54
1815.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.57	271.57
1816.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.61	271.61
1817.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.64	271.64
1818.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.67	271.67
1819.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.71	271.71
1820.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.75	271.75
1821.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.78	271.78
1822.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.82	271.82
1823.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.86	271.86
1824.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.89	271.89
1825.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.93	271.93
1826.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271.97	271.97
1827.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.01	272.01
1828.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.05	272.05
1829.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.10	272.10
1830.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.14	272.14
1831.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.18	272.18
1832.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.23	272.23
1833.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.27	272.27
1834.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.32	272.32
1835.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.36	272.36

1836.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.41	272.41
1837.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.46	272.46
1838.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.51	272.51
1839.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.56	272.56
1840.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.61	272.61
1841.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.66	272.66
1842.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.71	272.71
1843.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.77	272.77
1844.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.82	272.82
1845.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.88	272.88
1846.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.93	272.93
1847.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	272.99	272.99
1848.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	273.05	273.05
1849.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	273.11	273.11
1850.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	273.17	273.17
1851.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	273.23	273.23
1852.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	273.29	273.29
1853.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	273.35	273.35
1854.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	273.42	273.42
1855.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	273.48	273.48
1856.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	273.55	273.55
1857.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	273.62	273.61
1858.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	273.69	273.68
1859.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	273.76	273.75
1860.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	273.83	273.82
1861.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	273.91	273.89
1862.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	273.98	273.97
1863.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	274.06	274.04
1864.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	274.14	274.12
1865.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	274.22	274.19
1866.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	274.30	274.27
1867.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	274.38	274.35
1868.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	274.46	274.43
1869.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	274.55	274.51
1870.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	274.63	274.60
1871.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	274.72	274.68
1872.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	274.81	274.77
1873.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	274.90	274.86
1874.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	274.99	274.95
1875.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	275.08	275.04
1876.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	275.18	275.13
1877.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	275.27	275.23
1878.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	275.37	275.32
1879.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	275.47	275.42

1880.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	275.58	275.52
1881.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	275.68	275.62
1882.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	275.79	275.72
1883.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	275.89	275.83
1884.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	276.00	275.93
1885.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	276.11	276.04
1886.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	276.23	276.15
1887.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	276.34	276.26
1888.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	276.46	276.38
1889.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	276.58	276.49
1890.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	276.70	276.61
1891.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	276.82	276.73
1892.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	276.95	276.85
1893.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	277.07	276.98
1894.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	277.20	277.10
1895.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	277.33	277.23
1896.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	277.47	277.36
1897.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	277.60	277.49
1898.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	277.74	277.63
1899.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	277.88	277.77
1900.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	278.03	277.91
1901.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	278.17	278.05
1902.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	278.32	278.20
1903.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	278.47	278.34
1904.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	278.62	278.49
1905.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	278.78	278.64
1906.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	278.94	278.80
1907.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	279.10	278.96
1908.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	279.26	279.12
1909.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	279.43	279.28
1910.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	279.60	279.44
1911.5	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	279.77	279.61
1912.5	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.00	0.00	279.95	279.78
1913.5	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.00	0.00	280.13	279.96
1914.5	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.10	0.00	0.00	280.31	280.14
1915.5	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.20	0.00	0.00	280.49	280.32
1916.5	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.30	0.00	0.00	280.68	280.50
1917.5	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.50	0.00	0.00	280.87	280.69
1918.5	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.70	0.00	0.00	281.07	280.88
1919.5	0.00	0.00	0.00	0.00	0.00	0.00	1.10	0.90	0.00	0.00	281.26	281.07
1920.5	0.00	0.00	0.00	0.00	0.00	0.00	1.20	1.10	0.00	0.00	281.46	281.27
1921.5	0.00	0.00	0.00	0.00	0.00	0.00	1.30	1.20	0.00	0.00	281.67	281.46
1922.5	0.00	0.00	0.00	0.00	0.00	0.00	1.40	1.20	0.00	0.00	281.88	281.67
1923.5	0.00	0.00	0.00	0.00	0.00	0.00	1.70	1.40	0.00	0.00	282.09	281.87

1924.5	0.00	0.00	0.00	0.00	0.00	0.00	1.90	1.60	0.00	0.00	282.30	282.08
1925.5	0.00	0.00	0.00	0.00	0.00	0.00	2.20	1.80	0.00	0.00	282.52	282.30
1926.5	0.00	0.00	0.00	0.00	0.00	0.00	2.50	2.10	0.00	0.00	282.74	282.52
1927.5	0.00	0.00	0.00	0.00	0.00	0.00	2.80	2.40	0.00	0.00	282.97	282.74
1928.5	0.00	0.00	0.00	0.00	0.00	0.00	3.10	2.70	0.00	0.00	283.20	282.96
1929.5	0.00	0.00	0.00	0.00	0.00	0.00	3.60	3.00	0.00	0.00	283.43	283.19
1930.5	0.00	0.00	0.00	0.00	0.00	0.00	4.20	3.50	0.00	0.00	283.67	283.42
1931.5	0.00	0.00	0.00	0.00	0.00	0.00	4.80	4.10	0.00	0.00	283.91	283.66
1932.5	0.00	0.00	0.00	0.00	0.00	0.00	5.40	4.60	0.00	0.00	284.16	283.90
1933.5	0.00	0.00	0.00	0.00	0.00	0.00	6.00	5.20	0.00	0.00	284.41	284.14
1934.5	0.00	0.00	0.00	0.00	0.00	0.00	6.80	5.80	0.00	0.00	284.66	284.39
1935.5	0.00	0.00	0.00	0.00	0.00	0.00	7.80	6.60	0.00	0.00	284.92	284.64
1936.5	0.00	0.00	0.10	0.00	0.00	0.00	8.90	7.50	0.00	0.00	285.18	284.90
1937.5	0.00	0.00	0.10	0.10	0.00	0.00	10.30	8.60	0.00	0.00	285.45	285.16
1938.5	0.00	0.00	0.20	0.10	0.00	0.00	11.60	9.90	0.00	0.00	285.72	285.43
1939.5	0.00	0.00	0.30	0.20	0.00	0.00	12.90	11.10	0.00	0.00	286.00	285.70
1940.5	0.00	0.00	0.40	0.30	0.00	0.00	14.40	12.40	0.00	0.00	286.28	285.97
1941.5	0.00	0.00	0.50	0.40	0.00	0.00	16.20	14.00	0.00	0.00	286.56	286.25
1942.5	0.00	0.00	0.70	0.50	0.00	0.00	18.50	15.80	0.00	0.00	286.86	286.54
1943.5	0.00	0.00	0.90	0.70	0.00	0.00	21.20	18.00	0.00	0.00	287.15	286.83
1944.5	0.00	0.00	1.20	0.90	0.00	0.00	24.20	20.50	0.00	0.00	287.45	287.12
1945.5	0.10	0.00	1.70	1.20	0.00	0.00	26.70	23.20	0.00	0.00	287.76	287.42
1946.5	0.10	0.10	2.30	1.70	0.00	0.00	28.20	25.30	0.00	0.00	288.07	287.73
1947.5	0.10	0.10	3.40	2.40	0.00	0.00	30.10	27.10	0.00	0.00	288.38	288.04
1948.5	0.20	0.10	4.80	3.40	0.00	0.00	32.50	29.20	0.00	0.00	288.71	288.35
1949.5	0.40	0.20	6.10	4.70	0.00	0.00	34.20	31.20	0.00	0.00	289.03	288.67
1950.5	0.70	0.40	7.60	6.00	0.00	0.00	35.60	32.90	0.00	0.00	289.36	288.99
1951.5	1.01	0.70	9.20	7.40	0.00	0.00	37.30	34.40	0.00	0.00	289.70	289.33
1952.5	1.51	1.01	11.00	9.00	0.00	0.00	38.40	35.90	0.00	0.00	290.05	289.66
1953.5	2.21	1.51	12.80	10.70	0.00	0.00	39.30	37.00	0.04	0.04	290.40	290.01
1954.5	3.02	2.21	15.00	12.60	0.00	0.00	39.70	37.80	0.04	0.04	290.75	290.35
1955.5	4.12	3.02	17.40	14.70	0.00	0.00	40.10	38.30	0.04	0.04	291.11	290.71
1956.5	5.33	4.02	20.20	17.10	0.00	0.00	40.40	38.70	0.04	0.04	291.48	291.07
1957.5	6.83	5.23	23.40	19.90	0.00	0.00	40.60	39.00	0.05	0.04	291.86	291.43
1958.5	8.14	6.53	26.80	23.00	0.00	0.00	41.50	39.50	0.05	0.04	292.23	291.80
1959.5	9.45	7.84	30.50	26.30	0.00	0.00	42.60	40.30	0.05	0.05	292.62	292.18
1960.5	11.06	9.15	35.00	30.10	0.00	0.00	43.70	41.20	0.05	0.05	293.01	292.57
1961.5	13.27	10.85	40.00	34.40	0.10	0.10	44.70	42.20	0.06	0.06	293.41	292.96
1962.5	16.18	13.07	45.80	39.40	0.30	0.10	45.90	43.30	0.07	0.06	293.82	293.36
1963.5	19.60	15.78	52.50	45.10	0.50	0.30	47.60	44.50	0.08	0.07	294.23	293.76
1964.5	23.72	19.20	60.40	51.80	0.80	0.50	49.40	46.10	0.09	0.08	294.65	294.17
1965.5	28.44	23.12	69.30	59.50	1.10	0.80	50.90	47.70	0.11	0.10	295.08	294.59
1966.5	33.67	27.64	79.20	68.20	1.49	1.10	53.00	49.30	0.13	0.12	295.52	295.02
1967.5	39.40	32.66	90.30	77.90	1.99	1.49	55.80	51.40	0.15	0.14	295.96	295.45

1968.5	46.03	38.29	102.80	88.80	2.69	1.99	59.10	54.10	0.18	0.17	296.41	295.89
1969.5	53.77	44.82	116.80	101.10	3.39	2.59	63.40	57.40	0.21	0.19	296.86	296.34
1970.5	62.41	52.26	132.00	114.70	4.18	3.29	69.30	61.70	0.23	0.22	297.33	296.79
1971.5	72.06	60.70	148.40	129.60	5.18	4.08	74.90	67.00	0.26	0.24	297.80	297.26
1972.5	82.71	69.95	166.10	145.70	6.27	5.08	77.60	71.40	0.30	0.28	298.28	297.73
1973.5	94.87	80.40	185.80	163.30	7.47	6.18	79.70	74.30	0.34	0.31	298.77	298.21
1974.5	108.34	92.16	207.10	182.50	8.96	7.37	83.20	77.20	0.38	0.35	299.26	298.69
1975.5	121.41	104.72	228.20	202.90	10.66	8.76	85.20	80.00	0.44	0.40	299.77	299.19
1976.5	133.97	117.09	248.10	223.20	12.45	10.36	87.00	82.10	0.50	0.46	300.28	299.69
1977.5	145.93	129.35	266.90	242.70	14.64	12.25	89.80	84.40	0.58	0.53	300.80	300.20
1978.5	156.58	140.80	284.30	261.20	16.93	14.34	91.90	86.70	0.66	0.61	301.33	300.72
1979.5	168.34	148.74	306.10	273.50	19.62	16.63	93.30	88.60	0.76	0.70	301.87	301.25
1980.5	176.68	159.30	323.20	292.30	22.61	19.32	94.90	89.60	0.88	0.81	302.42	301.79
1981.5	184.32	167.84	339.60	308.80	25.90	22.21	96.40	90.80	1.00	0.93	302.98	302.33
1982.5	191.46	176.08	353.40	325.50	29.18	25.30	97.50	92.30	1.13	1.04	303.55	302.89
1983.5	199.30	184.52	369.00	342.60	32.97	28.09	98.50	93.50	1.27	1.17	304.12	303.46
1984.5	208.04	192.46	385.70	359.40	37.85	31.37	99.80	95.10	1.40	1.29	304.71	304.03
1985.5	217.99	202.01	403.40	378.20	43.92	35.96	100.50	96.60	1.55	1.43	305.30	304.62
1986.5	229.35	211.36	424.30	396.50	48.31	40.94	101.90	98.20	1.71	1.58	305.91	305.21
1987.5	241.61	222.21	444.00	416.30	55.68	47.01	102.50	100.00	1.88	1.73	306.53	305.82
1988.5	252.86	233.27	465.40	435.80	63.55	53.29	103.50	100.60	2.05	1.89	307.15	306.43
1989.5	259.30	242.11	483.60	454.40	69.72	59.66	104.40	101.10	2.22	2.05	307.79	307.05
1990.5	265.83	251.06	497.70	472.70	75.60	66.14	104.90	102.30	2.41	2.22	308.44	307.69
1991.5	268.24	256.68	506.00	487.30	80.98	71.31	105.50	102.50	2.62	2.42	309.10	308.34
1992.5	268.14	260.80	516.30	498.30	83.96	77.19	104.90	101.90	2.85	2.63	309.77	308.99
1993.5	269.55	262.51	523.20	507.00	84.36	79.58	104.00	101.10	3.09	2.84	310.45	309.66
1994.5	269.65	263.72	528.50	514.80	84.46	81.27	103.00	100.30	3.33	3.07	311.14	310.34
1995.5	268.34	263.22	533.40	521.00	84.36	82.17	102.10	99.60	3.58	3.30	311.84	311.03
1996.5	266.93	262.91	537.30	526.50	84.06	82.67	101.10	98.60	3.86	3.55	312.56	311.73
1997.5	265.73	262.01	540.10	530.80	83.57	82.67	100.20	98.00	4.07	3.81	313.29	312.45
1998.5	264.52	261.01	542.90	534.30	83.17	82.47	99.20	97.00	4.25	4.01	314.03	313.17
1999.5	263.12	259.90	544.40	537.20	82.47	81.97	98.20	96.20	4.48	4.25	314.78	313.91
2000.5	261.71	258.29	545.90	539.00	81.87	81.37	97.30	95.40	4.68	4.46	315.54	314.66
2001.5	260.00	256.98	546.50	540.60	81.18	80.78	96.30	94.40	4.90	4.65	316.32	315.42
2002.5	258.19	255.08	546.70	541.30	80.48	79.98	95.30	93.60	5.14	4.88	317.11	316.20
2003.5	256.18	253.27	546.70	541.60	79.88	79.38	94.30	92.50	5.37	5.07	317.91	316.99
2004.5	253.97	251.36	545.70	541.50	79.08	78.78	93.30	91.70	5.58	5.30	318.73	317.79
2005.5	251.96	249.15	544.90	540.70	78.49	78.09	92.40	90.80	5.80	5.51	319.56	318.60
2006.5	249.55	247.34	543.10	539.80	77.69	77.59	91.30	89.70	6.04	5.75	320.41	319.43
2007.5	247.54	245.03	541.10	538.10	76.99	76.79	90.40	88.90	6.33	6.03	321.26	320.28
2008.5	245.63	243.12	538.60	536.20	76.29	76.20	89.30	87.70	6.62	6.29	322.14	321.13
2009.5	243.61	241.05	536.12	533.47	75.82	75.47	87.61	85.95	6.89	6.58	323.02	322.00
2010.5	241.31	239.15	533.26	531.03	75.01	74.79	86.57	85.14	7.21	6.87	323.93	322.89
2011.5	239.40	236.84	530.60	528.53	74.35	74.05	85.43	83.78	7.46	7.17	324.84	323.79

2012.5	236.89	234.77	527.20	526.00	73.66	73.39	84.34	82.82	7.73	7.43	325.78	324.71
2013.5	235.57	232.88	525.22	523.25	72.94	72.81	83.27	81.60	8.09	7.73	326.73	325.64
2014.5	234.97	231.49	522.97	521.00	72.17	71.98	82.51	80.79	8.40	8.11	327.69	326.58
2015.5	234.36	230.09	520.71	518.74	71.41	71.15	81.76	79.99	8.72	8.50	328.67	327.55

APPENDIX 2

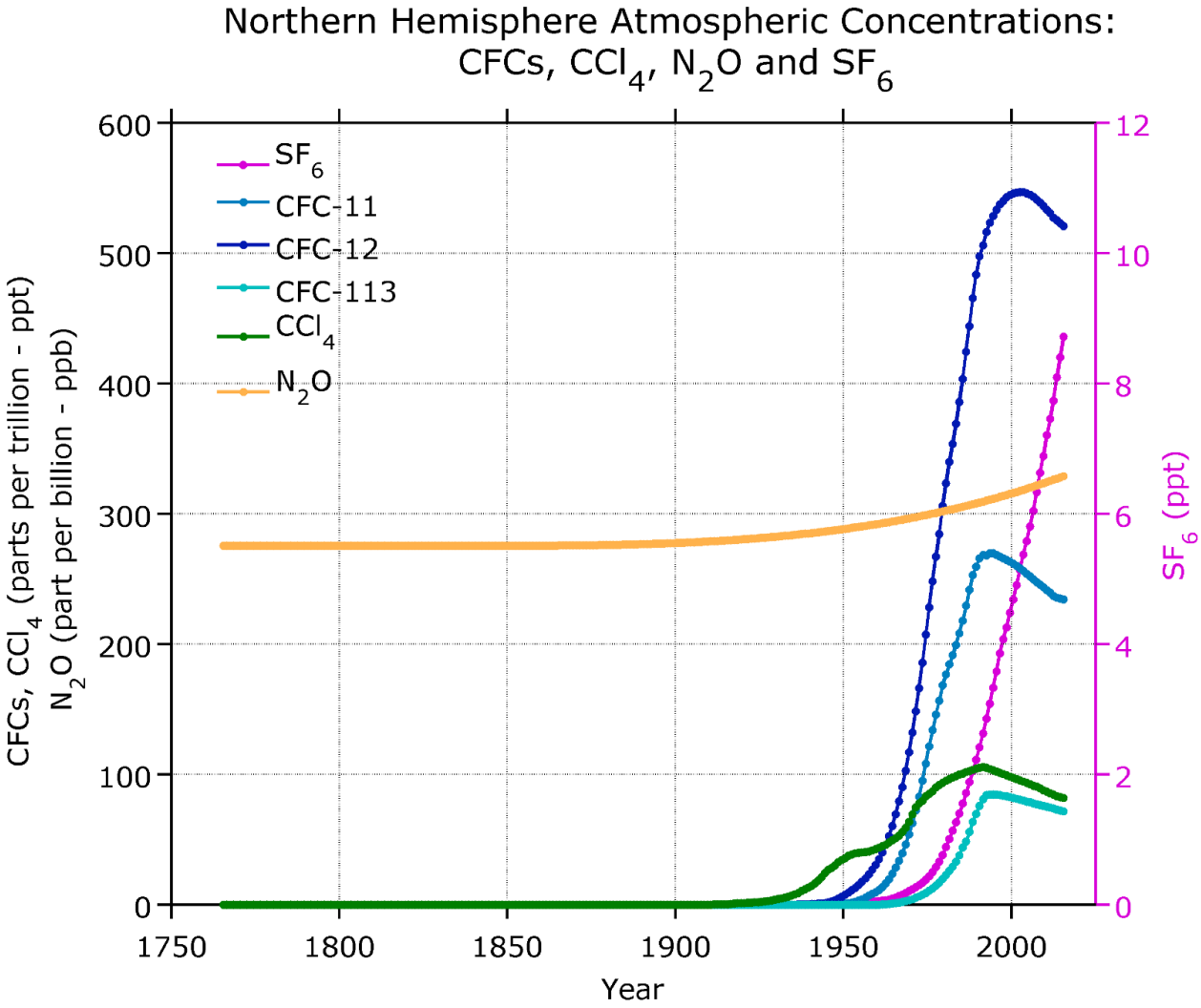

Fig.1. Mean mid-year tropospheric CFC-11, CFC-12, CFC-113, carbon tetrachloride (CCl_4), sulfur hexafluoride (SF_6) and nitrous oxide (N_2O) concentrations in the northern (NH) hemisphere for the period 1765.5 to 2015.5. The concentrations are expressed as the mixing ratio (mole fraction) of the trace gas in dry air and are reported in parts-per-trillion (ppt) for CFC-11, CFC-12, CFC-113, CCl_4, SF_6 and as parts-per-billion (ppb) for N_2O.

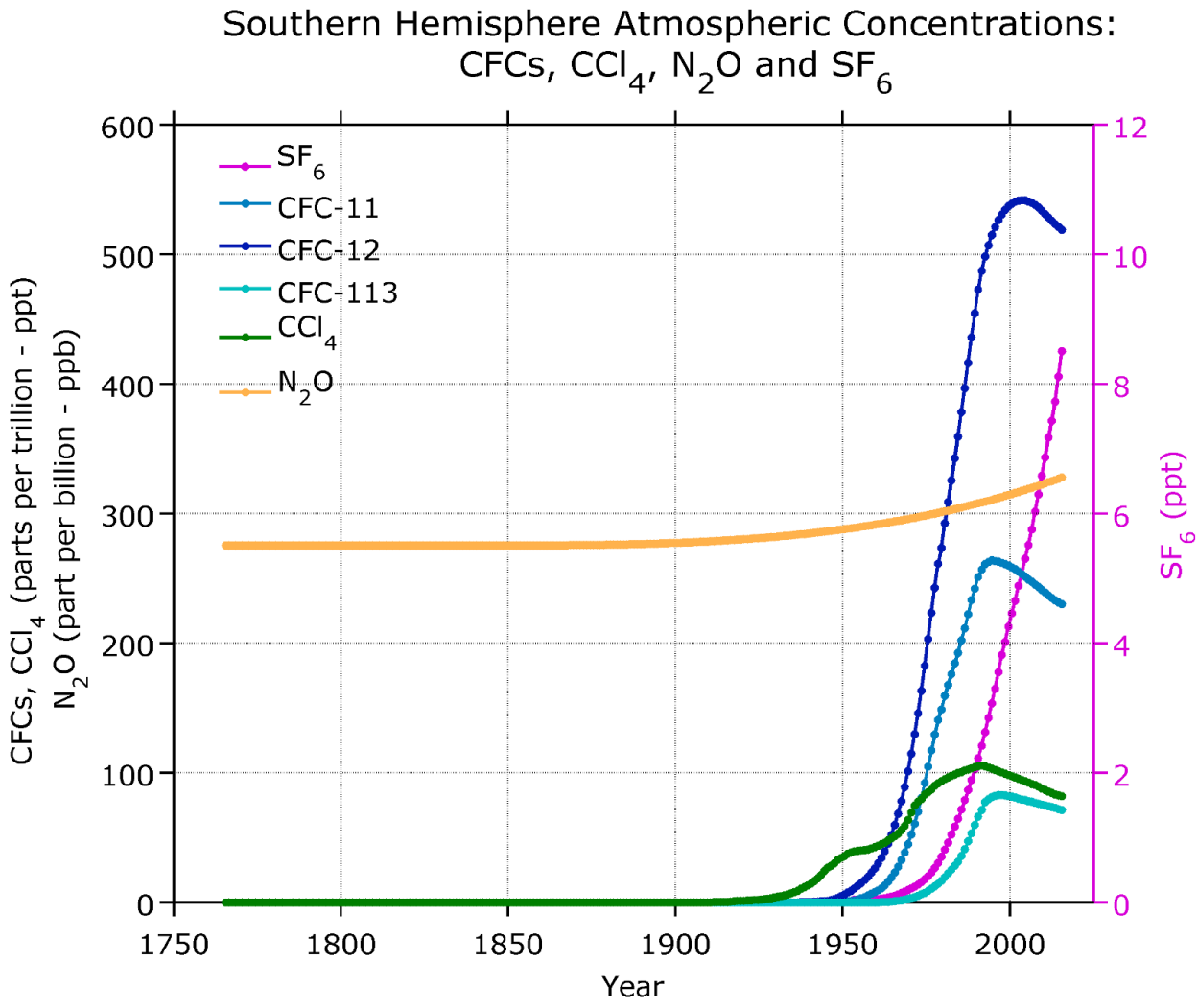

Fig.2. Mean mid-year tropospheric CFC-11, CFC-12, CFC-113, carbon tetrachloride (CCl_4), sulfur hexafluoride (SF_6) and nitrous oxide (N_2O) concentrations in the southern (SH) hemisphere for the period 1765.5 to 2015.5. The concentrations are expressed as the mixing ratio (mole fraction) of the trace gas in dry air and are reported in parts-per-trillion (ppt) for CFC-11, CFC-12, CFC-113, CCl_4, SF_6 and as parts-per-billion (ppb) for N_2O.

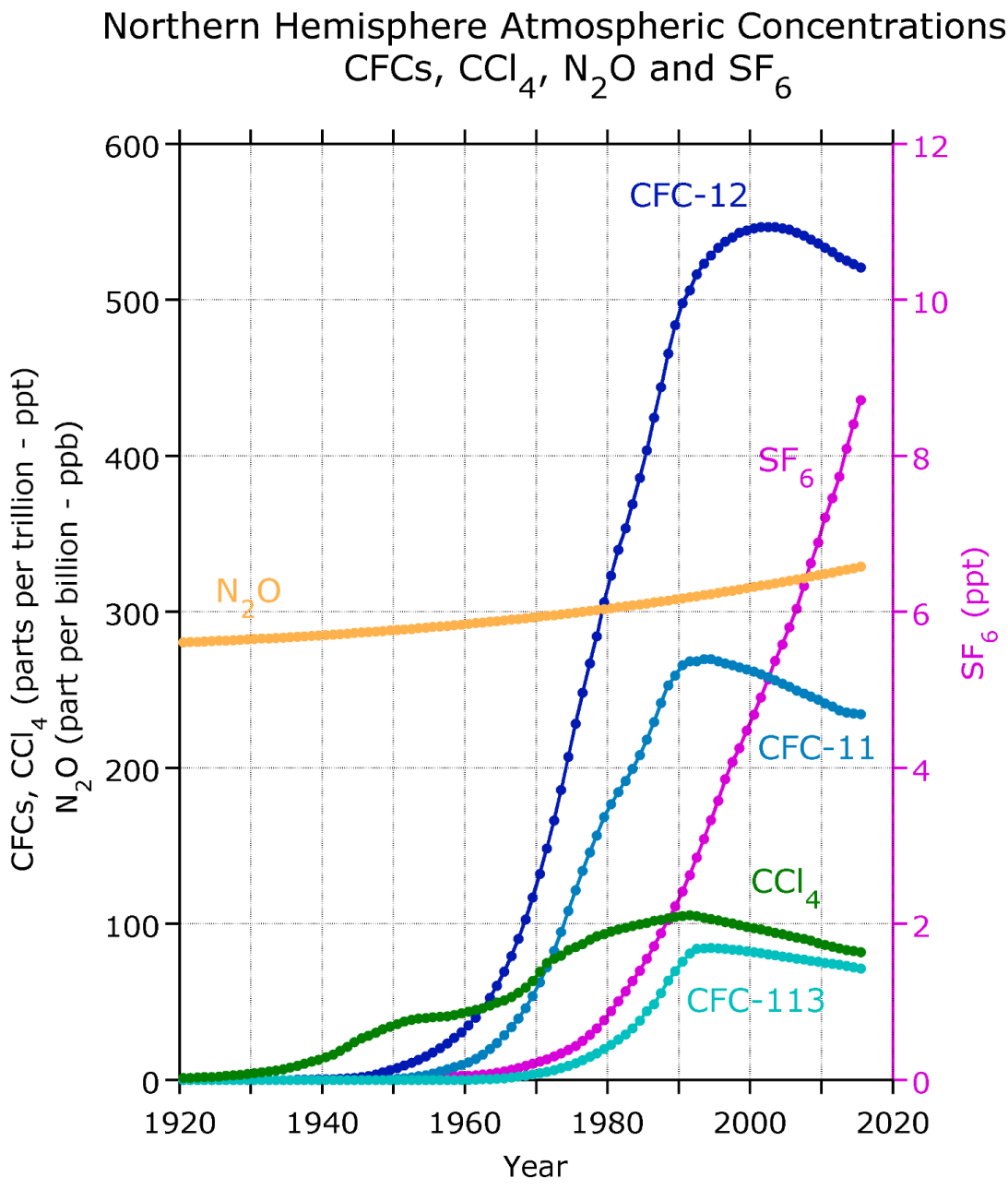

Fig. 3. Mean mid-year tropospheric CFC-11, CFC-12, CFC-113, carbon tetrachloride (CCl_4), sulfur hexafluoride (SF_6) and nitrous oxide (N_2O) concentrations in the northern (NH) hemisphere for the period 1920.5 to 2015.5. The concentrations are expressed as the mixing ratio (mole fraction) of the trace gas in dry air and are reported in parts-per-trillion (ppt) for CFC-11, CFC-12, CFC-113, CCl_4, SF_6 and as parts-per-billion (ppb) for N_2O.

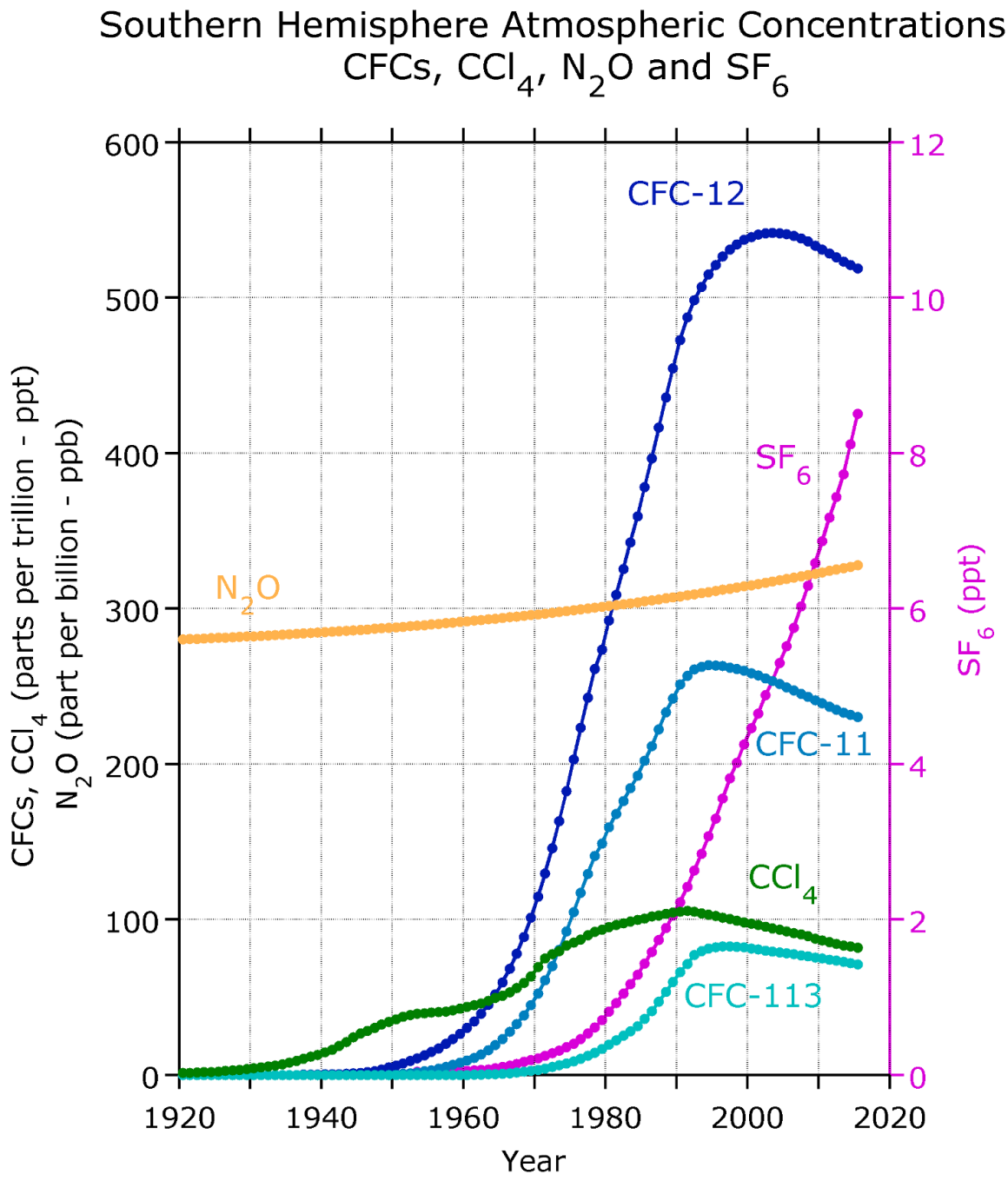

Fig. 4. Mean mid-year tropospheric CFC-11, CFC-12, CFC-113, carbon tetrachloride (CCl_4), sulfur hexafluoride (SF_6) and nitrous oxide (N_2O) concentrations in the southern (SH) hemisphere for the period 1920.5 to 2015.5. The concentrations are expressed as the mixing ratio (mole fraction) of the trace gas in dry air and are reported in parts-per-trillion (ppt) for CFC-11, CFC-12, CFC-113, CCl4, SF_6 and as parts-per-billion (ppb) for N_2O.

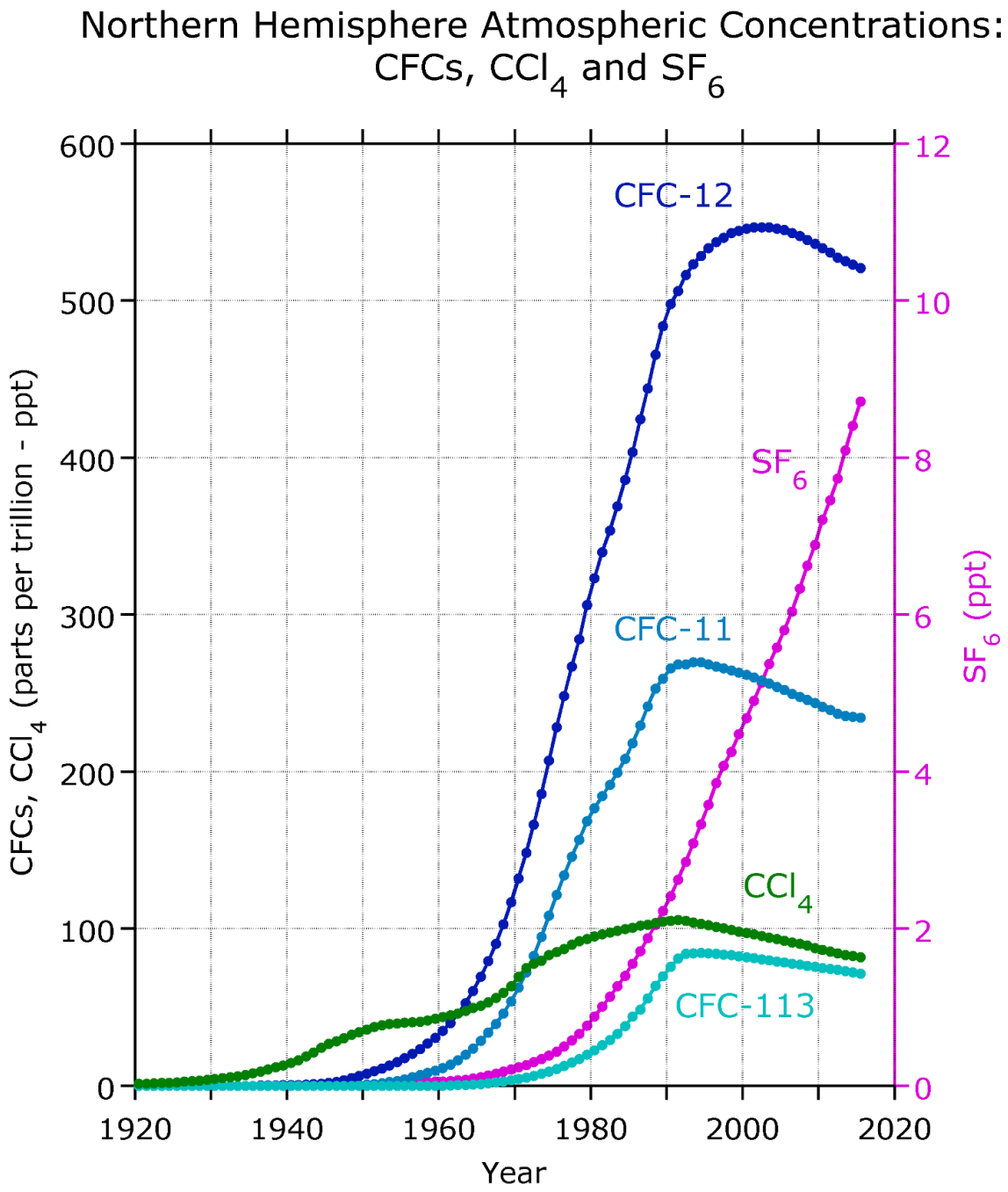

Fig. 5. Mean mid-year tropospheric CFC-11, CFC-12, CFC-113, carbon tetrachloride (CCl_4) and sulfur hexafluoride (SF_6) concentrations in the northern (NH) hemisphere for the period 1920.5 to 2015.5. The concentrations are expressed as the mixing ratio (mole fraction) of the trace gas in dry air and are reported in parts-per-trillion (ppt).

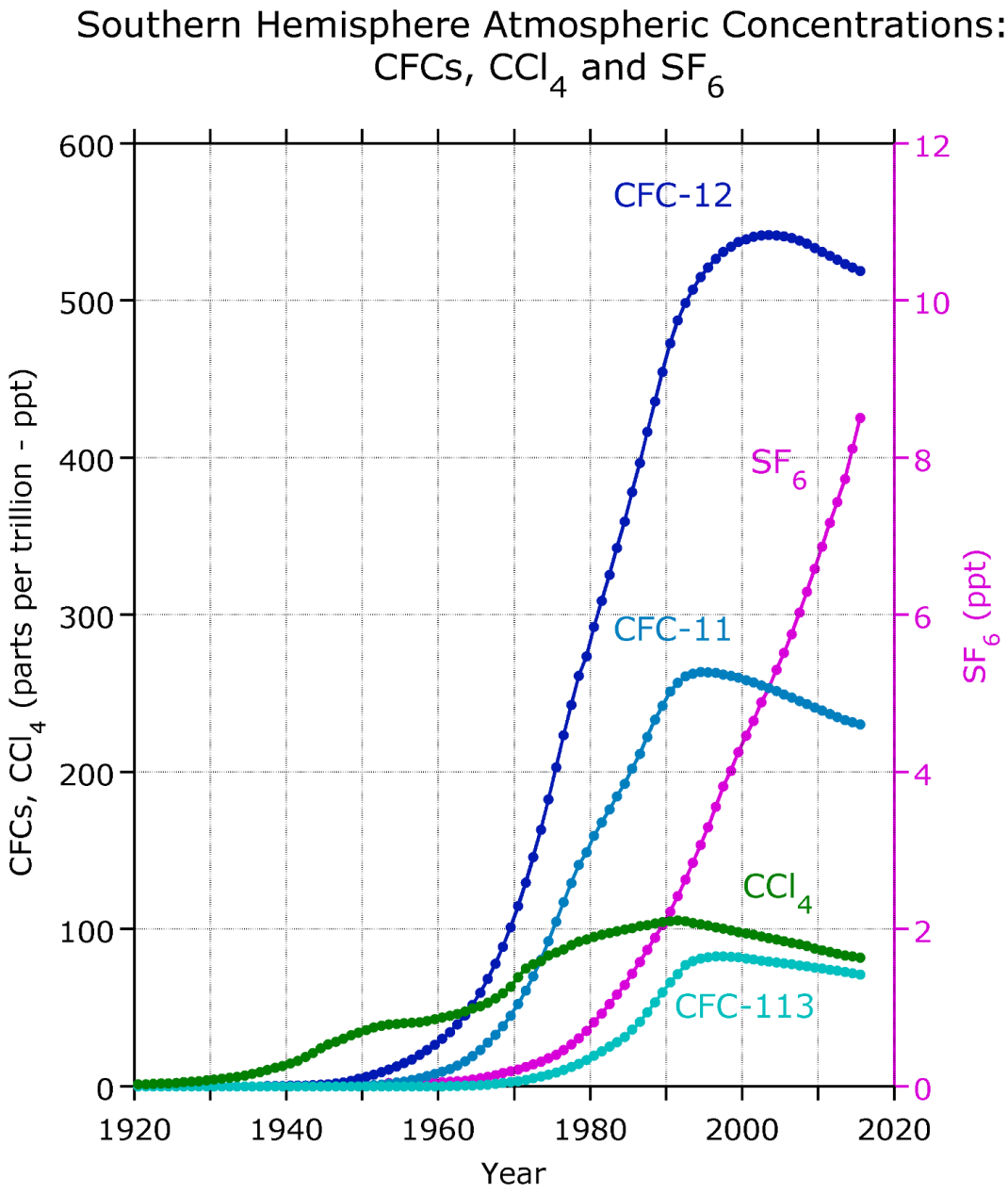

Fig. 6. Mean mid-year tropospheric CFC-11, CFC-12, CFC-113, carbon tetrachloride (CCl_4) and sulfur hexafluoride (SF_6) concentrations in the southern (SH) hemisphere for the period 1920.5 to 2015.5. The concentrations are expressed as the mixing ratio (mole fraction) of the trace gas in dry air and are reported in parts-per-trillion (ppt).

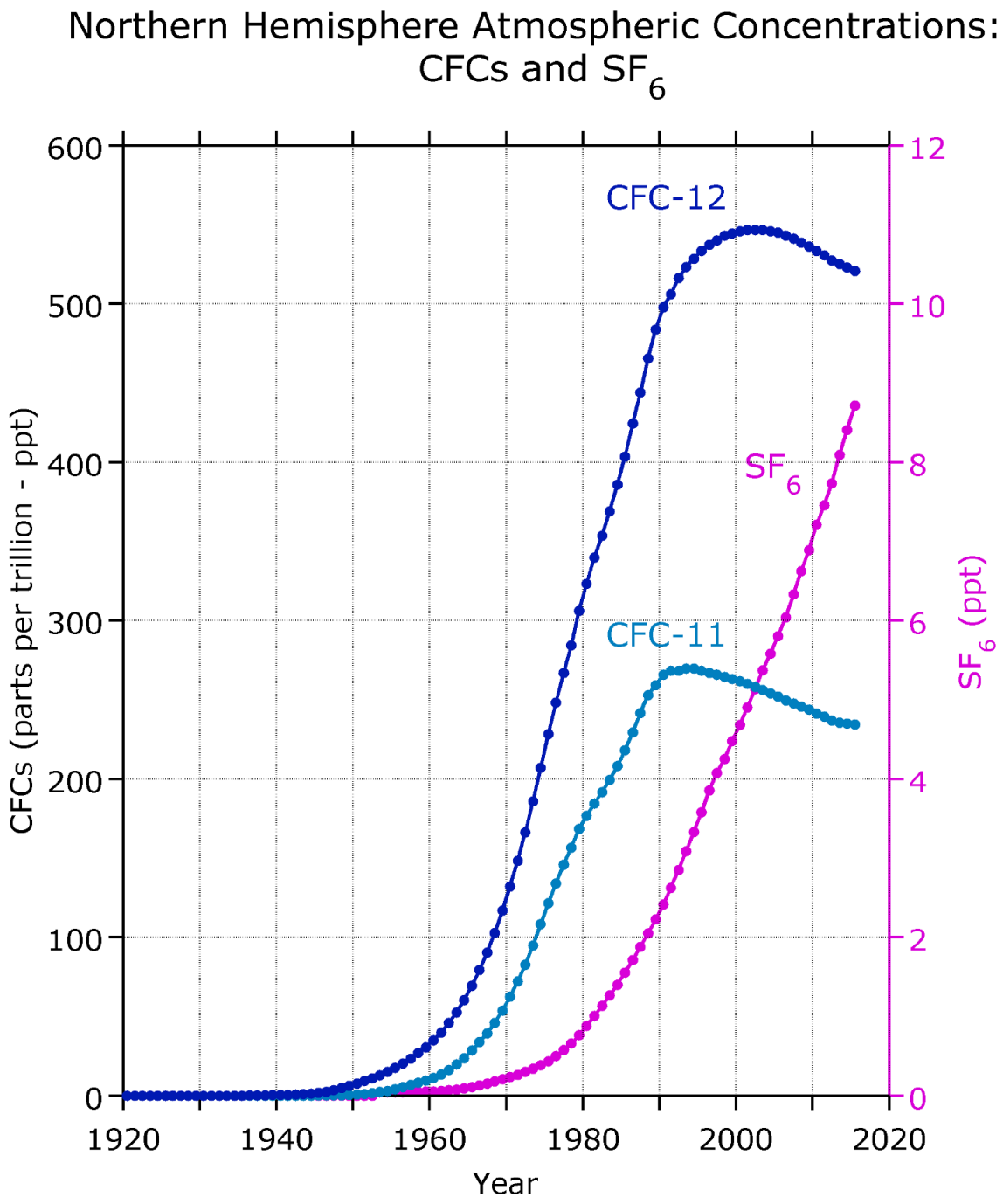

Fig. 7. Mean mid-year tropospheric CFC-11, CFC-12 and sulfur hexafluoride (SF_6) concentrations in the northern (NH) hemisphere for the period 1920.5 to 2015.5. The concentrations are expressed as the mixing ratio (mole fraction) of the trace gas in dry air and are reported in parts-per-trillion (ppt).

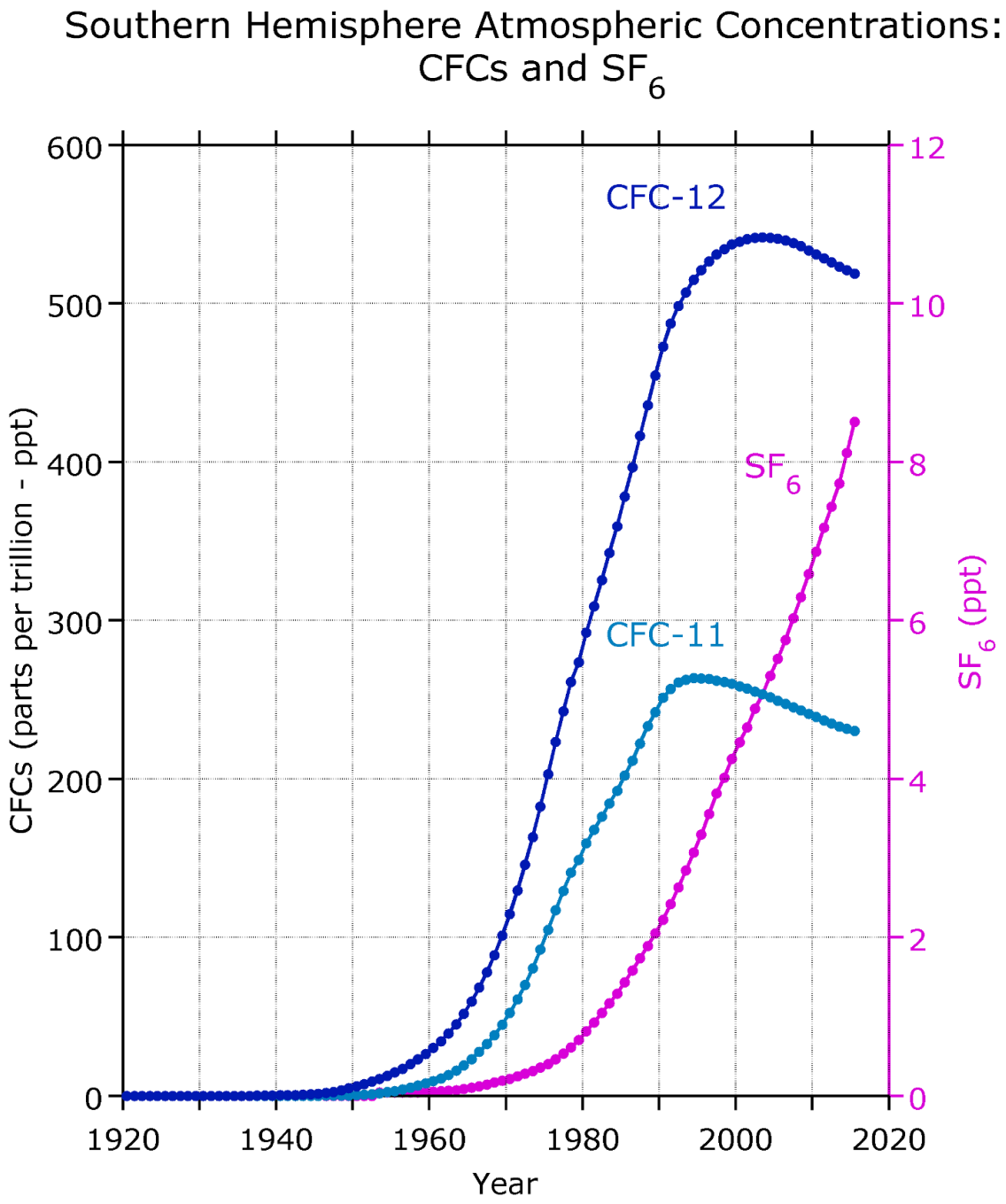

Fig. 8. Mean mid-year tropospheric CFC-11, CFC-12 and sulfur hexafluoride (SF_6) concentrations in the southern (SH) hemisphere for the period 1920.5 to 2015.5. The concentrations are expressed as the mixing ratio (mole fraction) of the trace gas in dry air and are reported in parts-per-trillion (ppt).

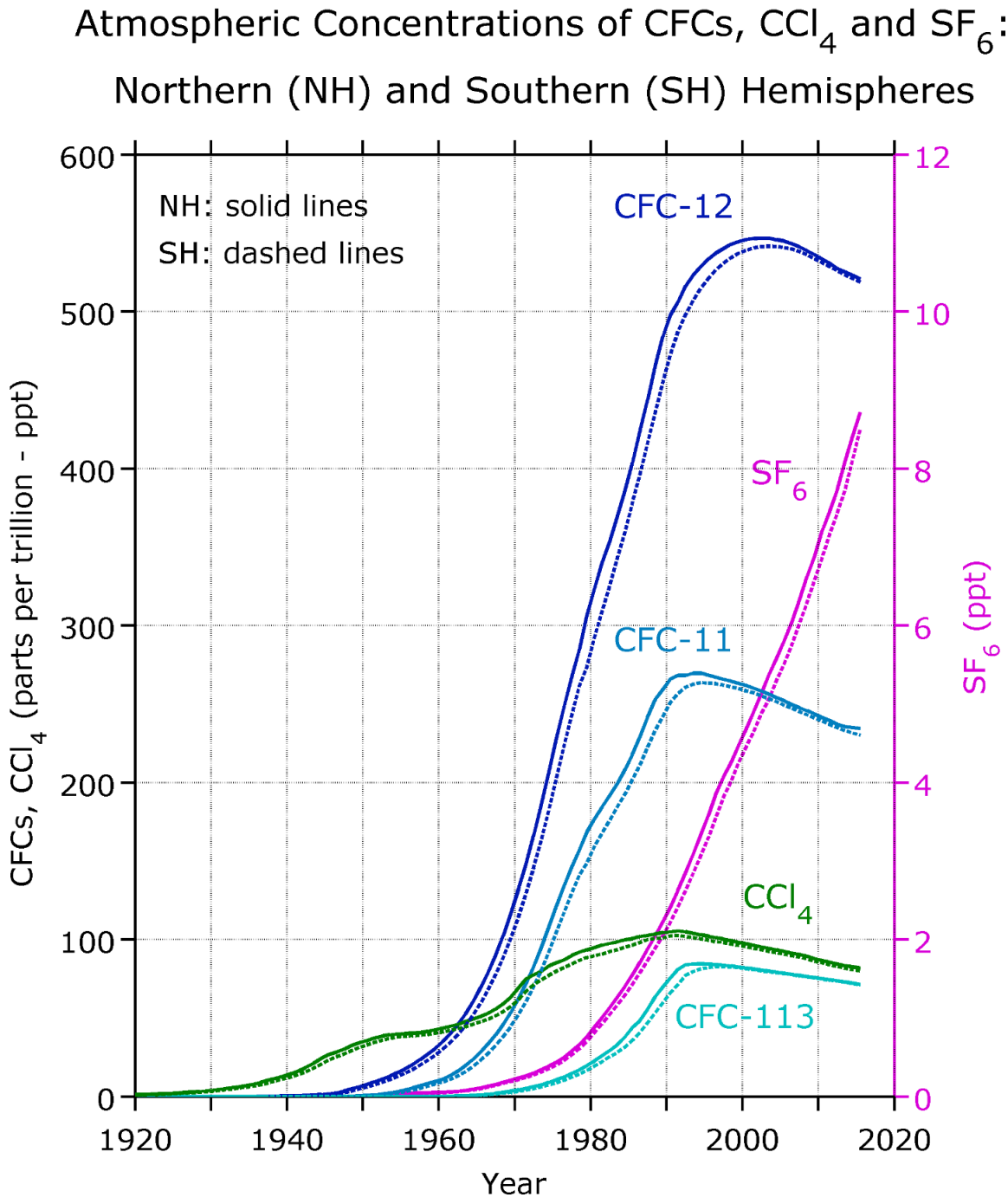

Fig. 9. Mean mid-year tropospheric CFC-11, CFC-12, CFC-113, carbon tetrachloride (CCl_4), sulfur hexafluoride (SF_6) concentrations in the northern (NH) and southern (SH) hemispheres for the period 1920.5 to 2015.5. The concentrations are expressed as the mixing ratio (mole fraction) of the trace gas in dry air and are reported in parts-per-trillion (ppt).

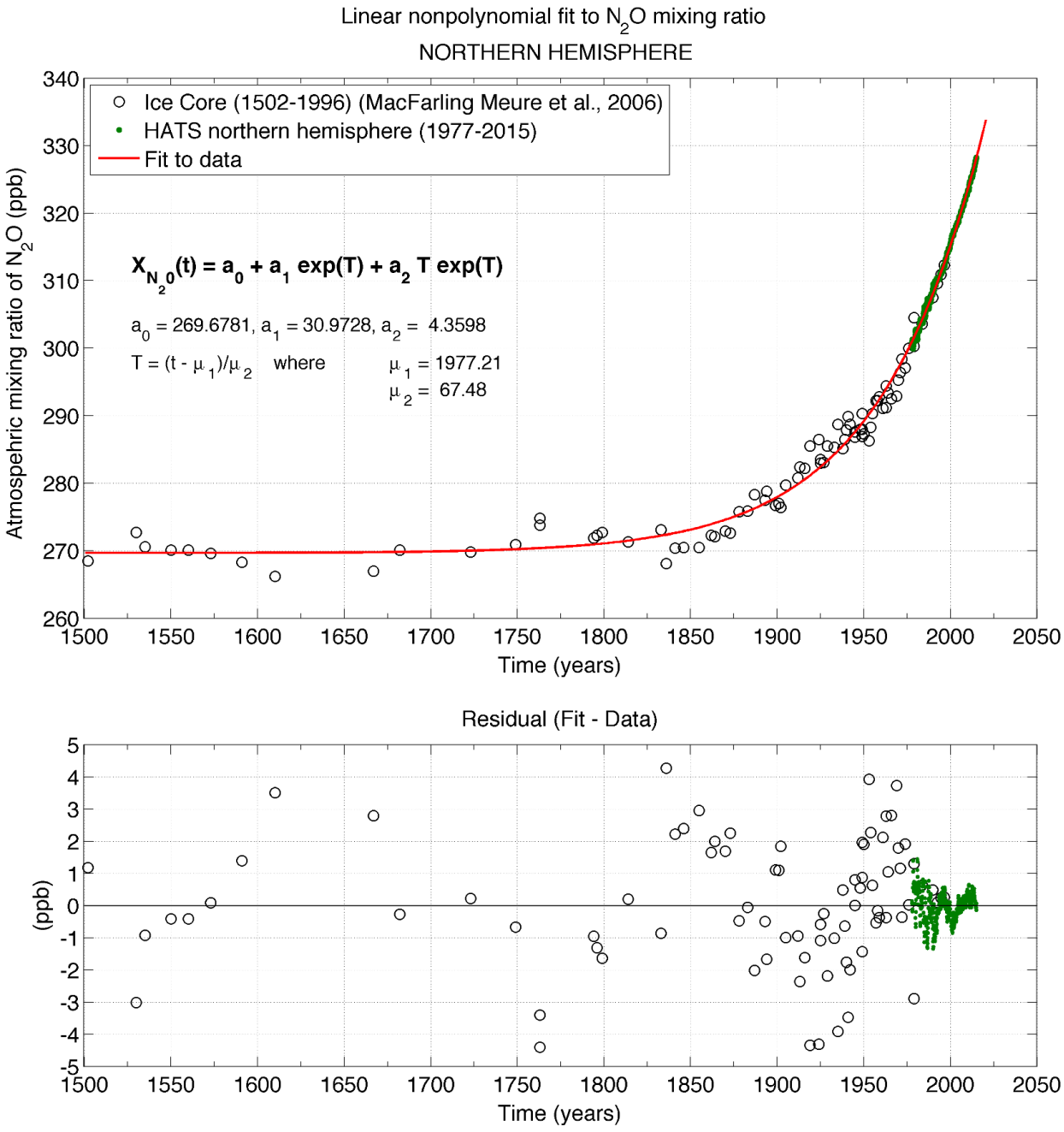

Fig. 10. Fit of Macfarling Muere et al. (2006) ice core data (1502-1996) and CMDL (ftp://ftp.cmdl.noaa.gov/hats/n2o/combined/HATS_global_N2O.txt) monthly mean northern hemisphere (NH) air measurements (1977-2015) for N_2O. Mid-year mean NH N_2O concentrations for the period 1855-2015 are calculated directly from this fit and reported in Table 1. Mid-year NH N_2O concentrations in Table 1 prior to 1855 are reported as the mean of the NH and SH fitted concentration values for those years.

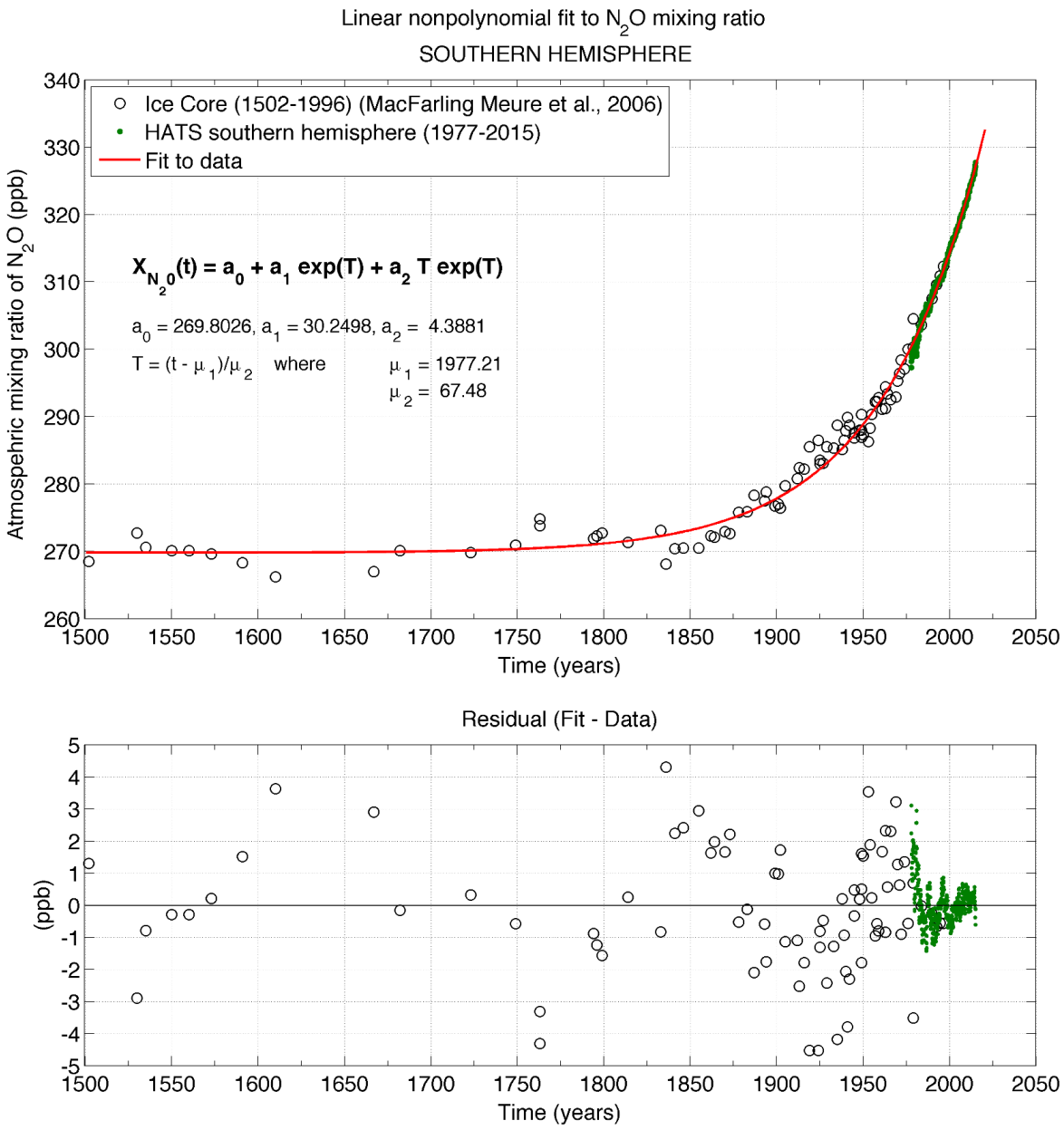

Fig. 11. Fit of MacFarling Muere et al. (2006) ice core data (1502-1996) and CMDL (ftp://ftp.cmdl.noaa.gov/hats/n2o/combined/HATS_global_N2O.txt) monthly mean southern hemisphere (SH) air measurements (1977-2015) for N_2O. Mid-year mean SH N_2O concentrations for the period 1855-2015 are calculated directly from this fit and reported in Table 1. Mid-year SH N_2O concentrations in Table 1 prior to 1855 are reported as the mean of the NH and SH fitted concentration values for those years.