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Summary of Korea Global Atmosphere Watch 2009 Report

KMA Korea Meteorological Administration

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Korea Global Atmosphere Watch Center

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The Korea Meteorological Administration began global atmosphere watch at Sobaek Mt. meteorological Observatory, Danyang-gun, Chungcheongbuk-do, in 1995 to ensure a timely national-scale response to the pressing issue of climate change. That is the first site on the Peninsula for continuously monitoring background atmosphere.

Observation technology of climate change-inducing materials in the background atmosphere has been rapidly developed since the relocation of the site to the island of Anmyeon-do in Taean-gun, Chungcheongnam-do (36°32′N, 126°19′E; 45.7 m above sea level) in 1996. The site has been renamed the "Korea Global Atmosphere Watch Center (KGAWC)" in 2008. At present, 36 parameters, including greenhouse gases, aerosols, ultraviolet radiation, ozone, and precipitation chemistry, are being measured at the Center.

The KGAWC belongs to the regional station (registration number: 47132) since 1998, and the Center has been actively engaged in international activities, participating in intercomparison events, organizing international workshops, and sharing data from WDCGG (World Data Centre for Greenhouse Gases). Due to its relatively pollution free environment, KGAWC provides an ideal site for observations that are geographically representative of the background atmosphere of Northeast Asia including the Korean Peninsula.

Fig. 1. The Korea Global Atmosphere Watch Center is located at the relatively uncontaminated western coastal area.

Greenhouse gases (GHGs)

Since 1999, the Center has been monitoring major greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFC-11, CFC-12). In 2007, the number of GHGs monitored at the Center was increased to seven, with the addition of chlorofluorocarbon (CFC-113) and sulfur hexafluoride (SF_6). Figure 2 shows the concentration levels for the five GHG species observed at Anmyeon-do from 1999 to 2009, along with the NOAA/GMD global CO_2 concentration trends. The CO_2 concentrations at Anmyeon-do are substantially higher than the global average and the N_2O concentrations are steadily increasing, while CFCs exhibit a continuously declining trend.

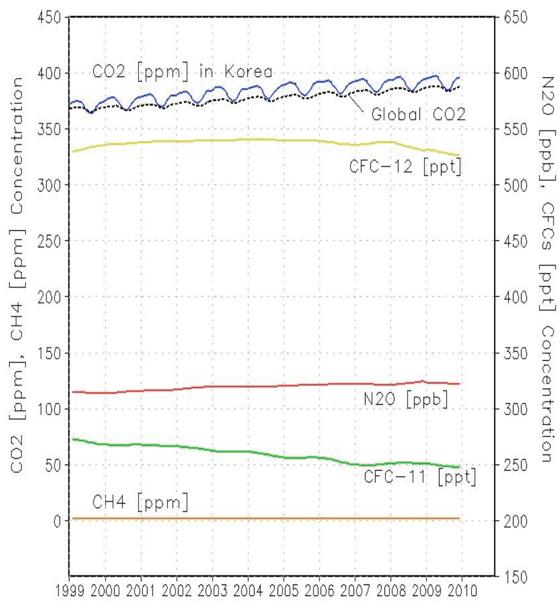

Fig. 2. Annual averages of GHGs (CO_2, CH_4, N_2O, CFCs) concentrations for 1999-2009.

The average CO_2 concentration for the year 2009 recorded 392.5 ppm, an increase of 21.8 ppm (5.9%) relative to the annual average of 370.7 ppm for 1999, and 6.2 ppm higher than the global average of 386.3 ppm for the same year as documented by NOAA/GMD. The annual growth rate of CO_2 for the 11-year period from 1999 through 2009 was 2.2 ppm/year, higher than the global average of 1.9 ppm/year, but has slowed in recent years. Table 1 summarizes the annual growth rates of CO_2 concentrations for Anmyeon-do and the NOAA/GMD global averages.

Table 1. Anmyeon-do and global CO_2 concentrations (ppm) and annual mean CO_2 growth rates for 1999-2009.

Year		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Anmyeon-do	Concentration (ppm)	370.7	373.8	376.9	379.7	382.6	384.3	387.2	388.7	389.9	391.4	392.5
	Growth rate (ppm/year)	+2.9	+3.4	+2.8	+3.2	+2.1	+2.4	+2.1	+1.5	+1.6	+1.2	+0.9
Global mean	Concentration (ppm)	367.6	368.8	370.3	372.4	374.9	376.7	378.8	380.9	382.7	384.8	386.3
	Growth rate (ppm/year)	+1.4	+1.2	+1.9	+2.4	+2.2	+1.6	+2.4	+1.8	+2.1	+1.8	+1.8

The methane (CH_4) concentration in 2009 was 1.906 ppm, an increase of 0.023 ppm (1.2%)

over 1999 (1.883 ppm), resulting in an annual mean growth rate of 0.00246 ppm/year. The N_2O concentration for 2009 was 322.6 ppb, an increase of 8.6 ppb (2.7%) over the value recorded in 1999 (314.0 ppb); the annual mean growth rate is far from large, at 0.97 ppb/year, but a persistently increasing trend is nonetheless evident. All three species of CFCs (CFC-11, CFC-12, CFC-113) are on the decline. There was a dramatic decrease of 21.1 ppt (-2.26 ppt/year) over 11 years in CFC-11, which fell from 270.4 ppt in 1999 to 249.3 ppt in 2009. CFC-12 also decreased by 3.6 ppt, from 532.5 ppt in 1999 to 528.9 ppt in 2009, which is a rather small annual mean decrease of -0.43 ppt/year (Table 2). Concentrations of CFC-113 recorded 78.0 ppt in 2008 and 77.4 ppt in 2009, a decrease of 0.6 ppt over one year, while the annual mean concentration of SF_6 for 2009 was 7.2 ppt, 0.5 ppt more than the 2008 average (6.7 ppt), suggesting a slight increase with every year.

Table 2. Average concentrations for 2009 and annual mean growth rates for the 11-year period from 1999 through 2009 of major GHGs in the background atmosphere of the Korean Peninsula.

GHGs	CO_2	CH_4	N_2O	CFC-11	CFC-12
Average concentrations in 2009	392.5 (ppm)	1.906 (ppm)	323.9 (ppb)	249.3 (ppt)	528.9 (ppt)
11-year avg. growth rates	+2.15 (ppm/year)	+0.00246 (ppm/year)	+0.97 (ppb/year)	-2.26 (ppt/year)	-0.43 (ppt/year)

Reactive gases

The Center also monitors four species of reactive gases—CO, SO_2, NO_x, and O_3. Figure 3 shows monthly trends of concentrations for the above four reactive gases. Carbon monoxide (CO)—a by-product of fossil fuel or biomass burning—and OH radicals, affect methane concentrations. Average CO concentrations were 247.8 ppb in 2008 and 244.2 ppb in 2009, a decrease of 3.6 ppb. The lowest values are most common in the summer month of July, while values are higher in the winter and spring, and geographically, in the northern hemisphere, where many of the emission sources are located. Atmospheric ozone (O_3) near the Earth's surface absorbs energy in the infrared spectrum in the troposphere, and exhibits

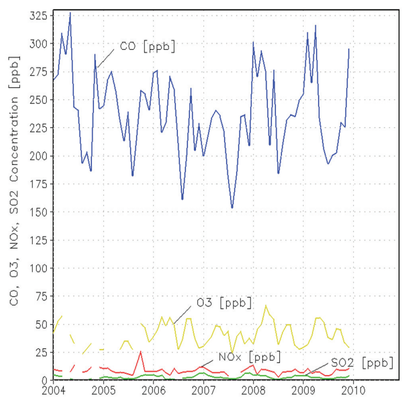

Fig. 3. Monthly variations in reactive gases (CO, O_3, NO_x, SO_2) concentrations (2004-2009).

a relatively high concentration in mid- and high-latitude urban areas. O_3 concentrations tend to be higher in the spring and fall, and lower in the summer and winter. The annual average O_3 concentration for 2009 was 41 ppb, 4 ppb lower than the 2008 average (45 ppb). Concentrations of nitrogen oxides (NO_x), which are emitted from combustion engines, also tend to be highest in the winter and lower in the summer. The annual mean concentration of NO_x in 2009 was 7.5 ppb, 0.6 ppb lower than the 2008 average (8.1 ppb). SO_2 concentrations averaged 2.6 ppb in 2009, 0.6 ppb lower than the previous year (3.2 ppb).

Atmospheric radiation

The Center continually monitors four atmospheric radiation parameters (direct solar radiation, global solar radiation, long-wave radiation, and net radiation) on clear days when cloudiness is less than 0.2 among 1.0. The monitored results have been publicly available since 2004.

In 2009, the monthly maximum direct solar radiation was recorded in August (544.3 Wm^{-2}), and the minimum in November (235.2 Wm^{-2}); the annual average was 399.8 Wm^{-2}, 39.9 Wm^{-2} lower than the annual means for the last 11 years. With diffuse solar radiation, the monthly maximum for 2009 was recorded in May (173.5 Wm^{-2}), the minimum in January (20.4 Wm^{-2}); the annual average was 190.5 Wm^{-2}, 18.3 Wm^{-2} lower than the means of the last 11 years.

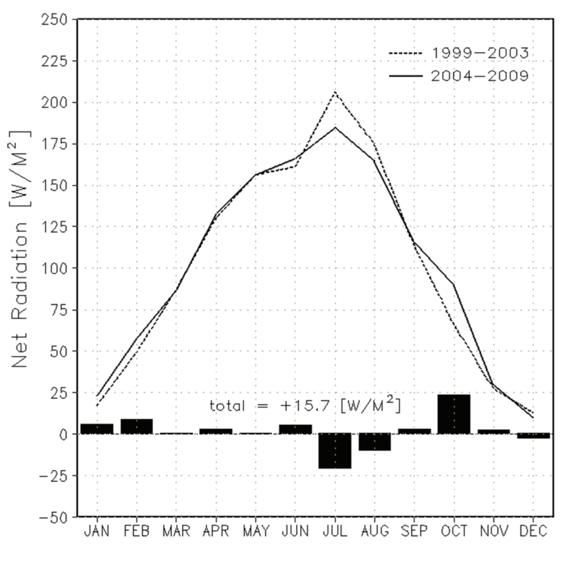

Fig. 4. Monthly averages of net radiation for 1999-2003 (dotted line) and 2004-2009 (solid line); difference between the two periods (bars).

Overall, downward and upward solar radiations yield the highest values in the summer, although they may be comparatively lower during the rainy season or in the event of localized downpours. These downward and upward solar radiations were highest in June 2009, recording 520.6 Wm^{-2} and 96.1 Wm^{-2} respectively, and lowest in November, recording 197.5 Wm^{-2} and 41.4 Wm^{-2} respectively. Downward solar radiation averaged 369.3 Wm^{-2}, and upward solar radiation 72.6 Wm^{-2} in 2009, 26.5 $Wm^{-2}$and 4.4 Wm^{-2} lower than the mean value of the last 11 years (1999-2009).

In 2009, terrestrial radiation peaked in August, with downward radiation recording 277.8 Wm^{-2} and upward radiation, 478.1 Wm^{-2}. Downward terrestrial radiation was lowest in February (225.3 Wm^{-2}), while upward radiation was lowest in December (314.4 Wm^{-2}). The downward and upward terrestrial averages for 2009 were 22.6 Wm^{-2} and 13.3 Wm^{-2}, lower than the mean value of the last 11 years.

Net radiation, the sum of up/downward solar and up/downward terrestrial radiation, averaged 94.6 W m^{-2} in 2009, 16.1 W m^{-2} lower than the mean value of the last 11 years. Figure 4 shows the net radiation averages for 1999-2003 and 2004-2010; also represented is the difference between the two graphs. Except for the summer months of July and August and the winter month of December, the monthly net radiation was higher in the later years (2004-2010). That the annual mean net radiation is a positive value (+15.7 Wm^{-2}) indicates that incoming radiation near the surface has increased in recent years.

Aerosol

A total of fourteen aerosol parameters, classified into optical, physical and chemical characteristics, are measured at the Center. Among optical characteristics, scattering coefficients, absorption coefficients, Angstrom exponent, and single scattering albedos are monitored using a nephelometer (Model TSI 3563) and an athelometer (Model AE16). Among the nephelometer-measured scattering coefficients, the coefficients measured at 550 nm averaged 87.20 Mm^{-1} in 2009, with the highest and the lowest values recorded in April (142.27 Mm^{-1}) and August (63.98 Mm^{-1}) respectively.

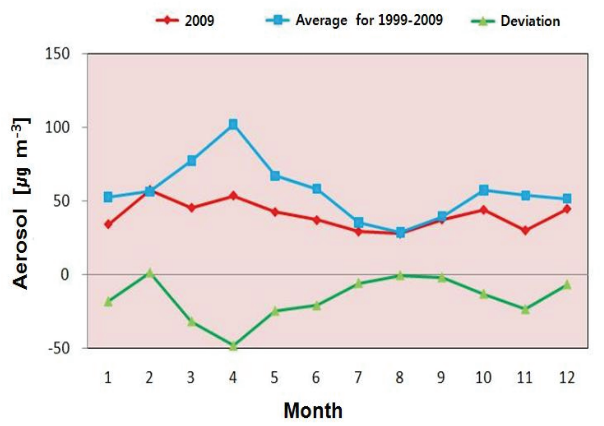

Fig. 5. Monthly averages of PM10 mass concentrations for 1999-2009 and for 2009; Deviation denotes for the differences between the two.

The average of athelometer-measured absorption coefficients was 9.47 Mm^{-1}, with the highest and the lowest values recorded in September (43.10 Mm^{-1}) and February (0.60 Mm^{-1}) respectively.

The annual average of the Angstrom exponent, computed using the total scattering coefficients from the nephelometer was 1.54, with the highest and the lowest values recorded in May (1.76) and December (1.30) respectively. Single scattering albedos, calculated using the aerosol scattering and absorption coefficients, averaged 0.87 (for 2009), with the highest and lowest values recorded in April (0.90) and September (0.82) respectively.

For monitoring physical properties of aerosols, the Center relies on the Aerodynamic Particle Sizer (APS) and the Scanning Mobility Particle Sizer (SMPS) to capture the size distribution of aerosols between 0.01 and 20 ㎛. The daily average volume concentration of particles 0.5-20.0 ㎛ in diameter measured using the APS for 2009 was 23.7 $㎛^3$ $㎝^{-3}$, which is roughly equivalent to the 4-year (2006-2009) average of 24.5 $㎛^3$ $㎝^{-3}$; the highest value of 47.2 $㎛^3$ $㎝^{-3}$ was recorded in February. The average number concentration of particles 0.01~0.5 ㎛ in diameter measured using the SMPS for the same year was 3,209.8 particles $㎝^{-3}$, a slight decrease compared with the 5-year average (3,918.1 particles $㎝^{-3}$). The number concentration of nucleation mode particles (0.01-0.1 ㎛) was the lowest in July and June, probably due to the more frequent particle formation.

Aerosol mass concentrations provide information on Asian Dust, a sand and duststorm phenomenon common in Northeast Asia, and are used as an air quality standards at many governmental agencies. To determine aerosol mass concentrations, the Center employs beta-ray attenuation (PM_{10}) and optical instruments (PM_{10}, $PM_{2.5}$, and $PM_{1.0}$). The 2009 average mass concentration for PM_{10}, based on beta-ray attenuation, was 40.2 ㎍ m^{-3}, lower than the 11-year (1999-2009) average of 56.8 ㎍ m^{-3}. PM_{10} mass concentration was not especially high in the spring of 2009 (Fig. 5). The ratio of $PM_{2.5}$ relative to PM_{10}, calculated using optical properties, averaged 76.1% in 2009, and the ratio of $PM_{1.0}$ relative to PM_{10}, is 62.7%. These two ratios were especially high in April, and lowest in December.

Ozone and ultraviolet radiation

According to satellite observations (1979-2009) on the global distribution of total ozone, the lowest concentrations of 244 DU (Dobson unit) appear at the equatorial Pacific region and the highest concentrations (391 DU) in the Sea of Okhotsk and Eastern Canada. The annual mean times series indicate a gradual decline from 1979 to the early 1990's, which then turned into a gradual increase after 1993. On the Korean peninsula, where the distribution of total ozone is monitored at Anmyeon-do, Pohang, and Seoul, there is a pronounced northward increasing trend.

The daily maximum value of total ozone measured using a Dobson spetrophotometer in Seoul from 1985 to 2009 was 499 DU (6 March, 2004) and the daily minimum, 225 DU (29 July, 2004). The average annual variation of total ozone for 1985-2009 recorded the highest value in March (358 DU), and the lowest in October (291 DU), an annual range of 67 DU. Interannual change in total ozone average was the highest in 2005 (331 DU) and the lowest in 1988 (313 DU).

As for the total ozone amount measured in Pohang using a Brewer spectrophotometer (1994-2009), the average for the entire period (1994-2009) was 313.8 DU. Interannual change increased after 1994, peaking at 336.3 DU in 2001, after which it shows a sharp drop, recording the lowest value (302.7 DU) in 2003, and subsequently alternating between rises and falls. The intra-annual change of monthly total ozone averages was the highest in April with 348.0 DU, and the lowest in October with 283.9 DU; seasonal changes were pronounced, with the peaks concentrated in the spring and the lowest values, in the fall.

At Anmyeon-do, vertical profiles of stratospheric ozone concentrations have been documented using an ozone lidar (model: StraZon 3079) since 2002. The annual average is highest in March and April at 21-23 km above ground, and relatively low in September at 25 km above ground.

UV-Biometers (Solar Light Co. Model #501) are in place at 5 sites—Pohang, Mokpo, Anmyeon-do, Gosan (Jeju Island), and Gangneung—as part of a multi-year programme initiated in 1994. This network serves to monitor harmful surface ultraviolet radiation over the Korean Peninsula. Annual trends of monthly average total UV radiation at Anmyeon-do is characterized by seasonal variations, with the highest value recorded in June and the lowest in December. The total UV radiation is relatively small in July, which, under the influence of the summer rainy season which is dominated by cloudy days.

The interannual variation of erythemal UV radiation reveals a relative lowering of the August maximum values for 2003, 2004, and 2005. The intra-annual variation of erythemal UV radiation at the Anmyeon-do GAW Center reveals a double-peak pattern (in May-June and in August), and a relatively lower value in July. The erythemal UV radiation observed at Anmyeon-do peaks in August, with the 2009 peak reaching 3.55 kJ m^{-2}.

Generally, the maximum UV radiation index decreases in higher latitudes. Figure 6 compares the monthly average UV radiation index for Anmyeon-do from 1999 to 2009 and the UV index for 2009. This index records its highest annual value (8.05) in August. Overall, the UV index for 2009 was lower than average. Table 3 illustrates dermatological response patterns at each UV index level.

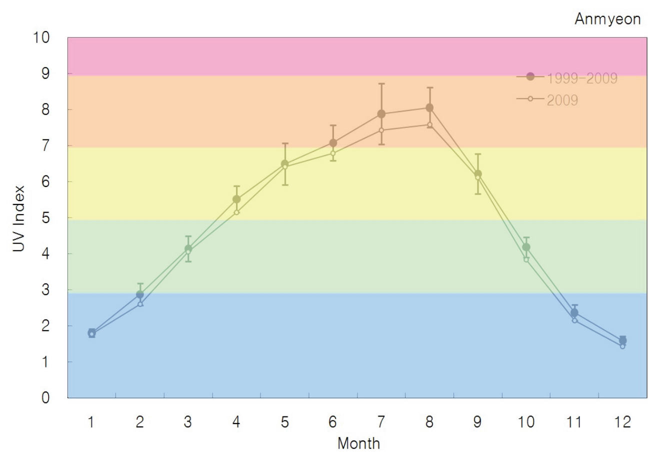

Fig. 6. Monthly averages of UV indices at the Anmyeon-do GAW Center for 1999-2009 and for 2009.

Table 3. Dermatological response according to UV index

UV intensity	Index range	Erythemal reaction time
Very high	≥9.0	Within 20 minutes
High	7.0 ~ 8.9	Within 30 minutes
Moderate	5.0 ~ 6.9	Within 1 hour
Low	3.0 ~ 4.9	Within 100 minutes
Very low	0.0 ~ 2.9	Within 2-3 hours

Precipitation chemistry

At the Anmyeon-do GAW Center, precipitation acidity is calculated based on precipitation-weighted means. The pH value at Anmyeon-do for 2009 was 4.66, and this value is lower (more acidic) than the 12-year (1997-2008) average of 4.8 for the Korean peninsula. The precipitation pH (acidity) for the entire peninsula most frequently lies within the range of 4.5-5.0. However, the frequence of pH between 4.5-5.0 decreased, instead, pH between 3.5-4.0 and 5.0-5.5 increased in 2009(Fig. 7).

Ion analyses in accordance with WMO GAW guidelines reveal that the amount of acidity-determining NO_3^-, SO_4^{2-}, and NH_4 has been declining for the last 3 years, while the 2009 values for Cl^-, K^+, Mg^{2+}, and Ca^{2+} tended to be slightly higher than in 2008 and the last 12 years (1997-2008). High concentrations of acids such as NO_3^- and SO_4^{2-} occur during the rainy summer season suggesting a greater effect of wet deposition than the dry deposition.

NH_4, a common neutralizing agent, yielded large amounts of wet deposition in the summer, while Ca^{2+} had a higher dry deposition rate compared with other substances.

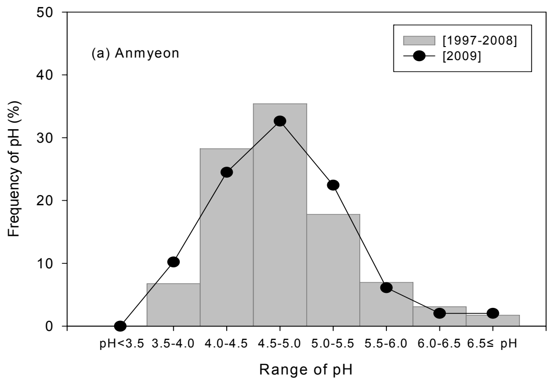

Fig. 7. Comparison of precipitation pH range frequencies as measured at the Anmyeon-do GAW Center for 1997-2008 and 2009.

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