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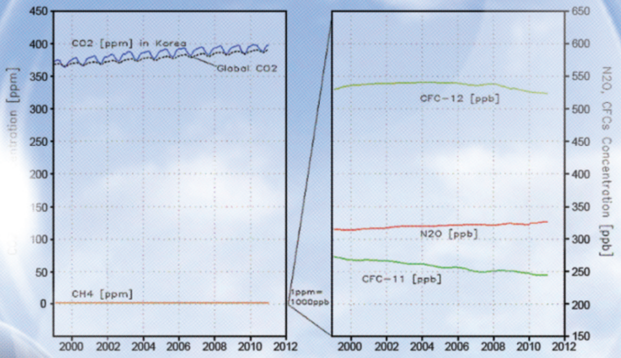

Summary of Korea Global Atmosphere Watch 2010 Report

KMA Korea Meteorological Administration

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GAW Global Atmosphere Watch

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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, 37 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

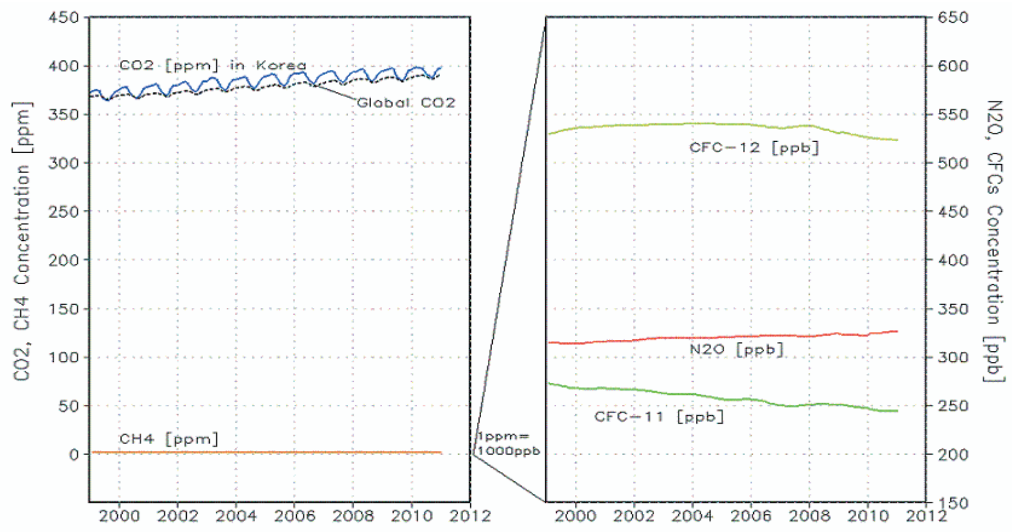

Fig. 2. Annual averages of GHGs (CO_2, CH_4, N_2O, CFCs) concentrations for 1999-2010.

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 2010, 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.

The average CO_2 concentration for the year 2010 recorded 394.5 ppm, an increase of 23.8 ppm (6.4%) relative to the annual average of 370.7 ppm for 1999, and 5.9 ppm higher than the global average of 388.6 ppm for the same year as documented by NOAA/GMD. The annual growth rate of CO_2 for the 12-year period from 1999 through 2010 was 2.12 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 1999-2010.

Year		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
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	394.5
	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	+2.0
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	388.6
	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	+2.4

The methane (CH_4) concentration in 2010 was 1.914 ppm, an increase of 0.031 ppm (1.6%) over 1999 (1.883 ppm), resulting in an annual mean growth rate of 0.00320 ppm/year. The N_2O concentration for 2010 was 325.2 ppb, an increase of 11.2 ppb (3.6%) over the value recorded in 1999 (314.0 ppb); the annual mean growth rate is 0.96 ppb/year, and a persistently increasing trend is evident. All three species of CFCs (CFC-11, CFC-12, CFC-113) are on the decline. There was a dramatic decrease of 25.7 ppt (-2.30 ppt/year) over 12 years in CFC-11, which fell from 270.4 ppt in 1999 to 244.7 ppt in 2010. CFC-12 also decreased by 8.3 ppt, from 532.5 ppt in 1999 to 524.2 ppt in 2010, which is a rather small annual mean decrease of -0.84 ppt/year (Table 2). Concentrations of CFC-113 recorded 77.4 ppt in 2009 and 76.8 ppt in 2010, a decrease of 0.6 ppt over one year, while the annual mean concentration of SF_6 for 2010 was 7.8 ppt, 0.6 ppt more than the 2009 average (7.2 ppt), suggesting a slight increase with every year.

Table 2. Average concentrations for 2010 and annual mean growth rates for the 12-year period from 1999 through 2010 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 2010	394.5 (ppm)	1.914 (ppm)	325.2 (ppb)	244.7 (ppt)	524.2 (ppt)
12-year avg. growth rates	+2.12 (ppm/year)	+0.00320 (ppm/year)	+0.96 (ppb/year)	-2.30 (ppt/year)	-0.84 (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 244.2 ppb in 2009 and 253.4 ppb in 2010, an increase of 9.2 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,

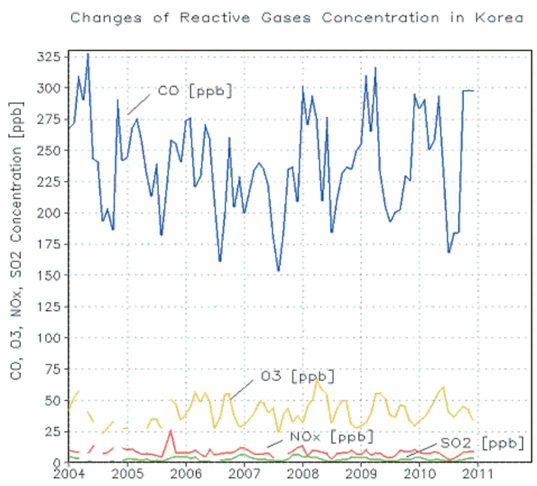

Fig. 3. Monthly variations in reactive gases (CO, O_3, NO_x, SO_2) concentrations (2004-2010).

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 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 2010 was 43.3 ppb, 2.3 ppb higher than the 2009 average (41.0 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 2010 was 6.8 ppb, 0.7 ppb lower than the 2009 average (7.5 ppb). SO_2 concentrations averaged 2.4 ppb in 2010, 0.2 ppb lower than the previous year (2.6 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 2010, the monthly maximum direct solar radiation was recorded in July (525.7 Wm^{-2}), and the minimum in December (276.5 Wm^{-2}); the annual average was 435.3 Wm^{-2}, 2.8 Wm^{-2} lower than the annual means (438.1 Wm^{-2}) for the last 12 years. With scattering of solar radiation, the monthly maximum for 2010 was recorded in June (158.0 Wm^{-2}), the minimum in August (89.8 Wm^{-2}); the annual average was 118.3 Wm^{-2}, 9.1 Wm^{-2} lower than the means of the last 12 years.

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 July and June 2010, recording 493.3 Wm^{-2} and 89.6 Wm^{-2} respectively, and lowest in December, recording 256.9 Wm^{-2} and 56.3 Wm^{-2} respectively. Downward solar radiation averaged 395.5 Wm^{-2}, and upward solar radiation 76.9 Wm^{-2} in 2010, 3.4 $Wm^{-2}$and 6.5 Wm^{-2} higher than the mean value of the last 12 years (1999-2010).

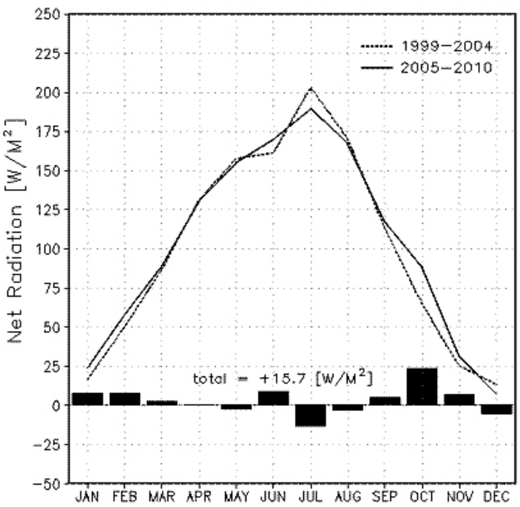

Fig. 4. Monthly averages of net radiation for 1999-2004 (dotted line) and 2005-2010 (solid line); difference between the two periods (bars).

In 2010, terrestrial radiation peaked in August, with downward radiation recording 392.9 Wm^{-2} and upward radiation, 477.2 Wm^{-2}. Downward terrestrial radiation was lowest in February (235.9 Wm^{-2}), while upward radiation was lowest in January (311.3 Wm^{-2}). The downward and upward terrestrial averages for 2010 were 16.1 Wm^{-2} and 10.1 Wm^{-2}, lower than the mean value of the last 12 years.

Net radiation, the sum of up/downward solar and up/downward terrestrial radiations, averaged 102.3 W m^{-2} in 2010, 6.1 W m^{-2} higher than the mean value of the last 12 years (96.2 Wm^{-2}). Figure 4 shows the net radiation monthly averages for two periods, 1999-2004 and 2005-2010, and differences between monthly means of net radiation for two periods (bars). Except for the summer months of July and August, April, and November, the monthly net radiation was higher in the later years (2005-2010). That the annual mean of net radiation differences is a positive value (+35.2 Wm^{-2}) and it 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 75.33 Mm^{-1} in 2010, with the highest and the lowest values recorded in November (112.4 Mm^{-1}) and July (54.88 Mm^{-1}) respectively.

The average of athelometer-measured absorption coefficients was 10.02 Mm^{-1}, with the highest and the lowest values recorded in October (14.05 Mm^{-1}) and July (7.17 Mm^{-1}) respectively.

The annual average of the Angstrom exponent, computed using the total scattering coefficients from the nephelometer was 1.35, with the highest and the lowest values recorded in June (1.71) and December (1.23) respectively. Single scattering albedos, calculated using the aerosol scattering and absorption coefficients, averaged 0.87 (for 2010), with the highest and lowest values recorded in March and December (0.89) and September (0.83) 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 2010 was 19.2 $㎛^3$ $㎝^{-3}$, which is roughly equivalent to the 5-year (2006-2010) average of 26.0 $㎛^3$ $㎝^{-3}$; the highest value of 24.3 $㎛^3$ $㎝^{-3}$ was recorded in March. The average number concentration of particles 0.01~0.5 ㎛ in diameter measured using the SMPS for the same year was 3,501.4 particles $㎝^{-3}$, a slight decrease compared with the 6-year average (3,837.2 particles $㎝^{-3}$). The number concentration of nucleation mode particles (0.01-0.1 ㎛) was the highest in February, probably due to the more frequent particle formation.

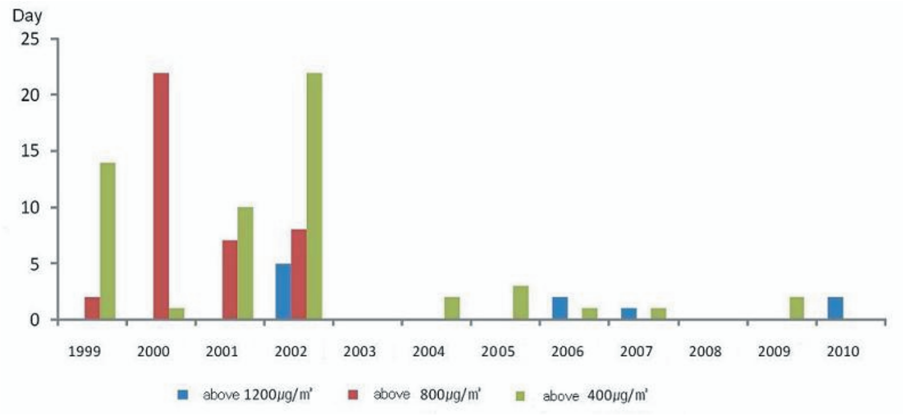

Fig. 5. Occurrence day with a maximum aerosol concentration recorded over 1200, 800, and 400 μg m^{-3} for 1999-2010.

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 2010 average mass concentration for PM_{10}, based on beta-ray attenuation, was 34.8 μg m^{-3}, lower than the 12-year (1999-2010) average of 54.9 μg m^{-3}. Figure 5 shows the occurrence of extreme aerosol concentration (1200, 800, and 400 μg m^{-3}) in Anmyeon-do for 1999~2010. The yellow sand phenomena for 2000~2002 were very severe. The most severe yellow sand over 1200 μg m^{-3} occurred for 5days in 2002, and 2 days in 2006 and 2010. The monthly ratio of $PM_{2.5}$ relative to PM_{10}, averaged for 2008~2010, is highest (82.1%) in July, and the ratio of $PM_{1.0}$ relative to PM_{10}, is 66.3% at the same time.

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 spectrophotometer in Seoul from 1985 to 2010 was 518 DU (11 May, 2010) and the daily minimum, 225 DU (29 July, 2004). The average annual variation of total ozone for 1985-2010 recorded the highest value in March (360 DU), and the lowest in October (291 DU), an annual range of 69 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 (1994-2010), the average for the entire period (1994-2010) was 313.4 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 August and the lowest in December. The total UV radiation is relatively small in June, which, under the influence of the summer rainy season which is dominated by cloudy days. Figure 6 compares the monthly average UV radiation index for Anmyeon-do from 1999 to 2010 and the UV index for 2010. This index records its highest annual value in August. Overall, the UV index for 2010 was lower than average. Table 3 illustrates dermatological response patterns at each UV index level.

The erythemal UV radiation has a strong seasonal variation, and the annual change of erythemal UV radiation averaged at the Anmyeon-do for 1999-2010 reveals a peak in August. Generally, the maximum UV radiation index decreases in higher latitudes.

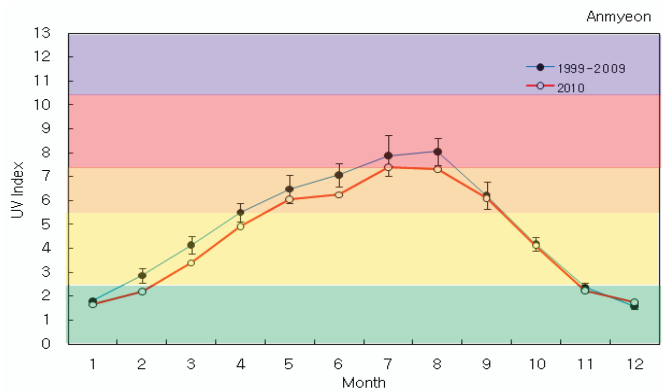

Fig. 6. Monthly averages of UV indices at the Anmyeon-do GAW Center for 1999-2010 and for 2010.

Table 3. Dermatological response according to UV index

UV Index	Description		Media Graphic color
0-2	Low	No danger to the average person	Green
3-5	Moderate	Little risk of harm from unprotected sun exposure	Yellow
6-7	High	High risk of harm from unprotected sun exposure	Orange
8-10	Very High	Very high risk of harm from unprotected sun exposure	Red
≥11	Extreme	Extreme risk of harm from unprotected sun exposure	Violet

Precipitation chemistry

At the Anmyeon-do GAW Center, precipitation acidity is calculated based on precipitation-weighted means. The pH value at Anmyeon-do for 2010 was 4.75, and this value is higher (less acidic) than the 12-year (1997-2010) average of 4.69. The precipitation pH (acidity) for Anmyeon-do most frequently lies within the range of 4.5-5.0. However, the frequence of pH between 4.5-5.0 and pH between 3.5-4.0 decreased, instead, pH between 5.0-5.5 and pH between 5.5-6.0 increased in 2010 (Fig. 7).

Ion analyses in accordance with WMO GAW guidelines reveal the amount of acidity-determining NO_3^-, SO_4^{2-}, and NH_4 including Na^+, Cl^-, Ca^{2+}, Mg^{2+}. Specially, proportion of Na^+, Cl^-, components of sea salt, is larger than other ions because Anmyeon-do station closely-located in the coast of the West Sea. The 2010 ion values tended to be lower than mean values for 1997-2009. 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.

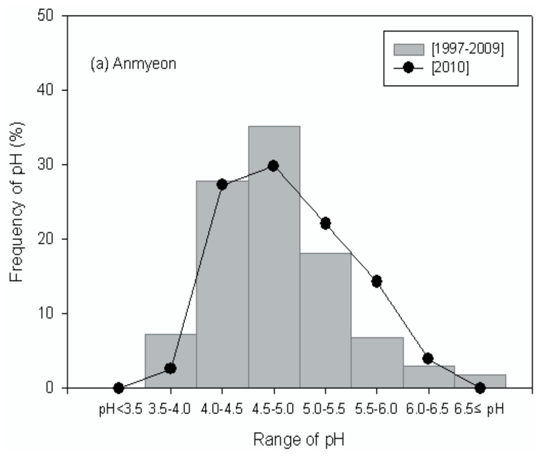

Fig. 7. Comparison of precipitation pH range frequencies as measured at the Anmyeon-do GAW Center for 1997-2009 and 2010.

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.

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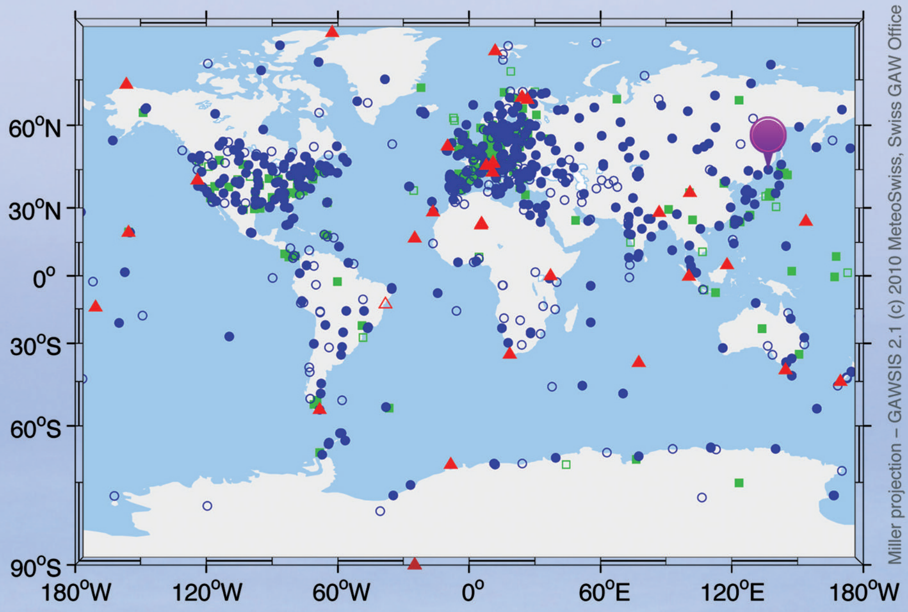

▲GAW Global Station ●GAW Regional Station ■Contributing Station
Open symbols denote closed or inactive stations.

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