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On large-scale Air Pollution in the Yellow Sea Region: Satellite and Ground Measurements

Y.S. Chung*, H.S. Kim and Y.S. Kim[1)]
Korea-China Centre for Atmospheric Research, Chongwon, Choongbook 363-891
[1)]Korea Aerospace Research Institute, Daejon 305-600

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Abstract

The present study details air pollution measurements in the Yellow Sea of East Asia. Large-scale air pollution was observed through satellite images and ground monitors in Chongju-Chongwon of central Korea. Evidence of a duststorm transport and resulting dustfall from the Gobi Desert in north China and Mongolia is shown. Also, transport of anthropogenic air pollutants from China to the Yellow Sea, Korea, and Japan was detected and discussed. It was found that the level of air pollution concentrations at a regional back-ground site increased 2 ~ 4 times than the values observed with the relatively clean air, when massive air pollution from China moved to the Korean Peninsula. Satellite measurements will be useful for monitoring regional- and global-scale air pollution in the future.

Key words : Satellite measurements, Large-scale air pollution transport, Duststorms, Yellow Sea air pollution, Korean Peninsula

1. INTRODUCTION

Air pollution is harmful to eco-systems and brings about environmental damage including human health. Air pollutants, on the Earth, are occurring on local, regional and global scales. Scientists carry out monitoring air pollution occurring in all scales. Satellite data are useful for detecting forest fires and resulting smoke plumes (Chung and Le, 1984; Fraser *et al.*, 1984), and in the past sand and duststorms and associated dustfall phenomena were detected by satellite analysis (Duce *et al.*, 1980; Chung *et al.*, 2003). Also, satellite data of air-pollution transport of anthropogenic origins have been investigated in earlier studies (Lyons and Husar, 1976; Chung, 1986). More recently, the detection of Arctic ice-melt due to global warming was discussed through animation data from satellite images (Chung and Le, 2003).

Concentrations of air pollutants and greenhouse gases in regional sites in Korea have been measured. This, also, includes monitoring of air pollutants and smoke plumes using various satellites. The purpose of this paper is to present study results obtained from satellite monitoring of atmospheric constituents in the Yellow Sea region. Data obtained from satellites of National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA) and Geo-stationary Meteorological Satellite (GMS) are included and discussed. In addition, air

* Corresponding author.
Tel : +82-(0)43-233-0002, E-mail : kccarl@kornet.net

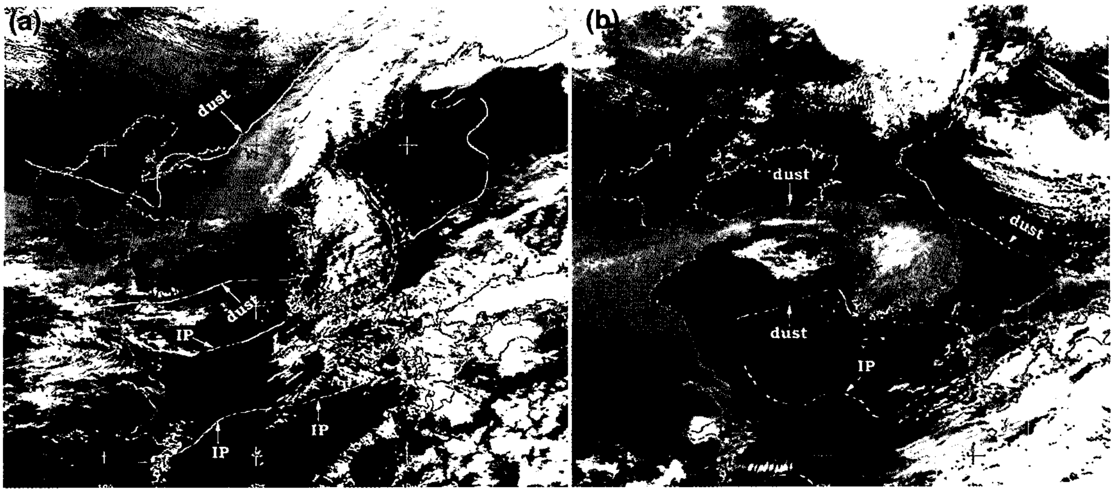

Fig. 1. (a) Satellite (NOAA-16; 1429 LST, 11 Nov. 2002) image showing an elongated duststorm from the west of Beijing via the Bohai Bay, Shantung Peninsula and the Yellow Sea to north Korea and the Korea East Sea. Also, a continental plume of anthropogenic origin is visible near Shanghai via Cheju Island of Korea to southwest Japan. (b). Same as Fig. 1a, but also illustrating two giant plumes being transported further south (NOAA-17; 1120 LST, 12 Nov. 2002).

pollution data obtained at a ground station in central Korea is used to substantiate satellite observations.

2. SATELLITE DATA

Since 1996, satellite monitoring of air pollutants has been carried out at the present research Centre. For this purpose, daily images from NOAA-N satellites and hourly images from GMS-5 are received and archived. Figure 1a shows satellite detection of NOAA-16 on large-scale air pollutants over the Yellow Sea region at 1429 LST, November 11^{th}, 2002. Figure 1b shows a satellite image of NOAA-17 taken at 1120 LST on November 12^{th}, which also clearly demonstrates the detection of air pollution masses over East Asia. The large scale plume from the south of Beijing in north China via the south of Shantung Peninsula to north Korea is an elongated dust cloud generated and transported from the Gobi Desert area situated in China and Mongolia. The continental-scale plume, covering the west of Shanghai in China via the Korea South Sea to southwest Japan, is the result of anthropogenic emission from China. These two giant plumes were steered by associated prevalent winds and weather systems at that time.

Table 1. Wavelengths (wl) and channels of satellites used.

NOAA	wl	GMS	wl	MODIS	wl
Channel 1	0.55~ 0.68 μm	VIS	0.55~ 0.75 μm	Band 1	0.62~ 0.67 μm
Channel 2	0.73~ 1.10 μm	IR1	10.5~ 11.5 μm	Band 3	0.459~ 0.479 μm
Channel 4	10.5~ 11.5 μm	IR3	6.5~ 7.0 μm	Band 4	0.545~ 0.565 μm

Figure 2a is an image of the Moderate-resolution Imaging Spectro-radiometer (MODIS of NASA) on November 12^{th}, which includes a comparison to the NOAA image. It shows two gigantic plumes covering the same regions. The length of the Korean Peninsula is approximately 1,000 km long, but the plume length is over 2,500 km. Although the existence of plumes can be clearly seen over the sea, it is rather hazy-looking over the land. Figure 2b shows a GMS image on the same day. This image also reveals the detection of massive air pollutants over the land and sea.

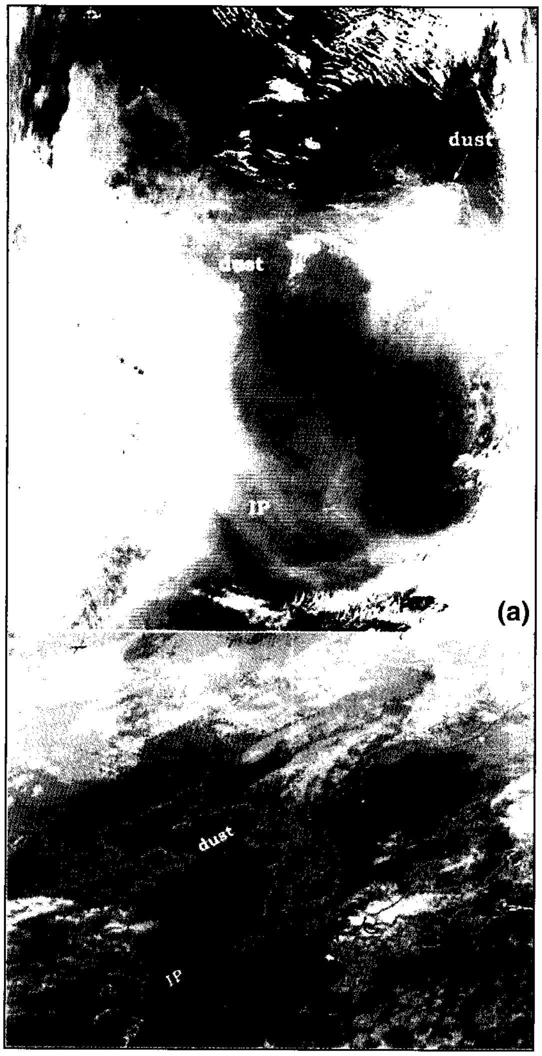

Fig. 2. (a) Same as Fig. 1b, but for a MODIS image (12 Nov. 2002). (b) Same as Fig. 1a, but for a GMS image (1325 LST, 11 Nov. 2002).

For satellite composite analysis (Chung and Le, 1984), the wavelengths and channels in Table 1 were used:

Figure 1 shows many lakes and river systems tinted in a magenta and purplish colour. This indicates the existence of large-scale pollutants over lakes and adjacent land. In contrast to the availability (magenta) of air pollutants over south China, there were no such

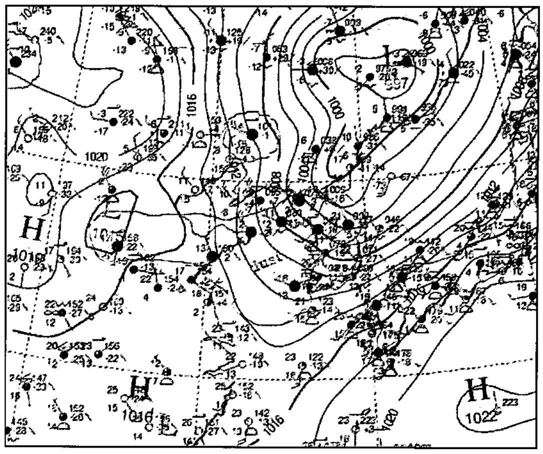

Fig. 3. A meteorological map (of Korea Meteor. Admin.) showing observations of duststorm phenomenon over Korea and the Shantung Peninsula in China.

pollutants found over far eastern Siberia, Manchuria, with a bluish colour appearing over lakes and land. Comparatively, this distinction of air-pollution existence over land and lakes is not clear in the MODIS image of Figure 2a. A meteorological map is shown in Figure 3. It illustrates that cold northwest winds brought in the dustfall phenomenon in Korea, Shantung and S Manchuria in China.

A satellite image (1155 LST, November 6^{th}, 2002) in Figure 4a shows a massive air-pollution plume extended from N China and the Bohai Bay to the Korean Peninsula. Figure 4b is a NOAA-17 satellite image (1133 LST, November 7^{th}) that demonstrates the transport of continental scale pollutants. The plume resided over central China, the Yellow Sea, central Korea and the Korea East Sea. The reddish-brown clouds over the sea of northwest Japan are the result of contaminated air from the land; the plume was over Korea on the 6^{th} of November, while it was above the Bohai Bay on the 5^{th} of November. The yellowish clouds are at a low altitude and contaminated with air pollution. Low clouds in the boundary atmosphere, downwind of an industrial region, often contain acidic water droplets and air pollution. A GMS image at 1431 LST on November 7^{th}, 2002, in Figure 4c shows a hazy plume

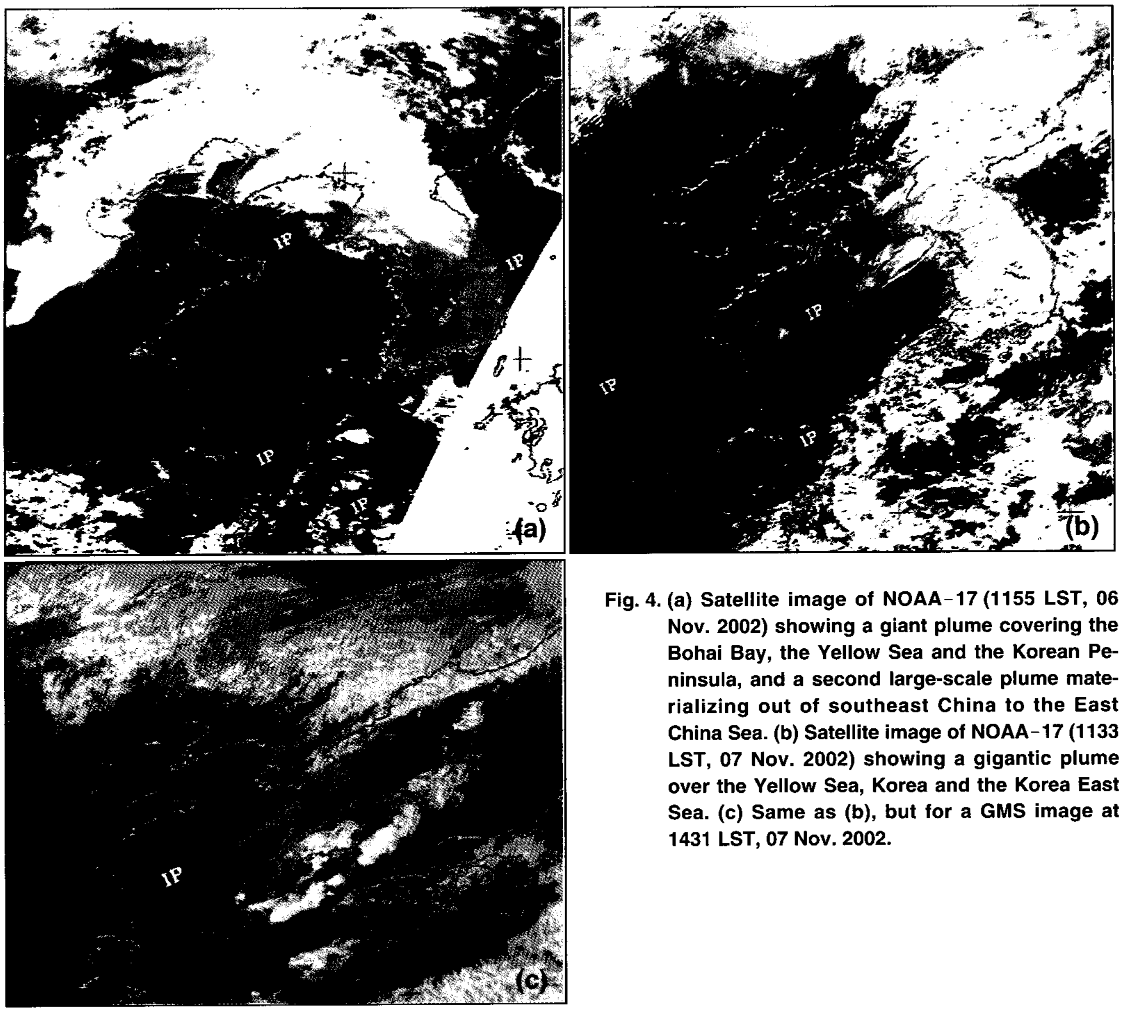

Fig. 4. (a) Satellite image of NOAA-17 (1155 LST, 06 Nov. 2002) showing a giant plume covering the Bohai Bay, the Yellow Sea and the Korean Peninsula, and a second large-scale plume materializing out of southeast China to the East China Sea. (b) Satellite image of NOAA-17 (1133 LST, 07 Nov. 2002) showing a gigantic plume over the Yellow Sea, Korea and the Korea East Sea. (c) Same as (b), but for a GMS image at 1431 LST, 07 Nov. 2002.

from the Yellow Sea to the Korean Peninsula, howbeit, the plume is not as clear as on the NOAA image.

3. AIR QUALITY DATA

Figure 5 shows the dust concentrations of PM-10 and PM-2.5 measured at the Chongwon-Chongju site in central Korea. There were 6 hours for PM-10 values above 500 $\mu g\ m^{-3}$, and the maximum PM-10 value occurred at 2200 LST on November 11th, 2002. The maximum value of PM-2.5, 181 $\mu g\ m^{-3}$, occurred at 2100 LST. The duststorm contained at least 6 times more coarse particles than fine dust, which reflects a typical proportion of dust profiles associated with sandstorms originated in the Gobi Desert area of China and Mongolia.

With a duststorm, variations of observed visibility and relative humidity (RH) are also of interest. The lowest visibility was between 3.1 ~ 3.2 km and occurred at the time of the maximum PM-2.5 value. The observed visibility and PM-2.5 values showed an antipode relation. According to data on a 5-minute average, there was a phase lag of 110 minutes between values of the maximum PM-10 and PM-2.5. Low values of RH, 57.1%, occurred at 0300 LST on November

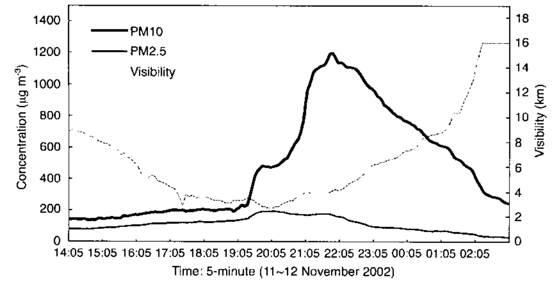

Fig. 5. Variations of 5-minute mean values of PM10 and PM2.5 (μg m^{-3}) with visibility (km) observed in Chongwon-Chongju, Korea during the event of a sandstorm and associated dustfall on 11 and 12 November 2002.

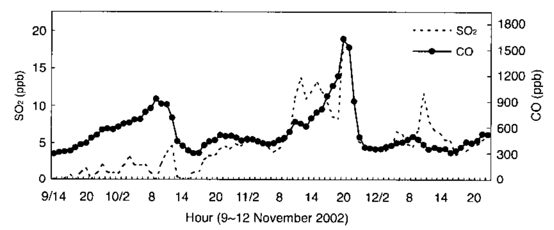

Fig. 6. Variations of hourly mean values of SO_2 and CO (ppb) observed in Chongwon-Chongju, Korea from 9 to 12 November 2002.

12th, after 5 hours of maximum PM-10 value.

Figure 6 shows two profiles of observed CO and SO_2 at the Chongwon-Chongju site. SO_2 and CO variations show that relatively higher values occurred until 2200 LST on November 11th, while lower values began after November 12th with the invasion of a sandstorm. The high concentrations of CO and SO_2 were associated with both air pollution transport from China and local sources in Korea. The CO profile exhibited a unique mode at maximum, while SO_2 presented a variable mode at maximum values.

Figure 7 shows temporal variations of photochemical oxidants. As CO and SO_2 values, maximum concentrations of ozone occurred in the afternoon of 10th and 11th November. Thereafter, ozone values decreased with the new air contaminated by a duststorm from the Gobi Desert. NO concentrations were mainly caused

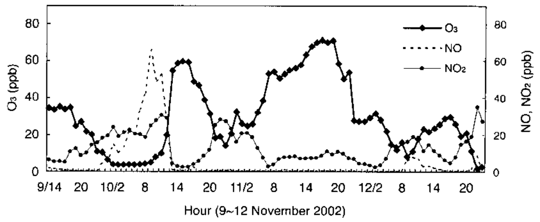

Fig. 7. Variations of hourly mean values of photochemical oxidants (O_3, NO and NO_2 in ppb) observed in Chongwon-Chongju, Korea from 9 to 12 November 2002.

by local sources and were generally conversely associated with ozone values. In contrast, NO_2 is a relatively long-lived species and plays for the generation of ozone in the boundary atmosphere (Chung, 1977). Also, values of NO_2 were moderately high in the rural atmosphere and were associated with ozone precursors coming from the Yellow Sea and China.

Table 2 shows daily maximum concentrations of air pollutants measured at Chongwon in central Korea. Real-time and continuous measurements were generated, and hourly mean values were included from the 4th to 9th of November 2002. During the six-day period the highest values of daily maximum concentrations recorded mainly on November 6th and 7th. During two days the giant plume from China produced the level of air quality in Korea (Figure 4).

4. DISCUSSION AND CONCLUDING REMARKS

In the air pollution analysis, satellite data obtained from NOAA, GMS and MODIS were utilized. These satellites were launched mainly for the use of weather service including cloud, air temperature, and so on. From these meteorological satellites, large-scale air pollutants were measured through computer composite analysis.

In particular, hourly data obtained by GMS-5 were utilized, and animation of hourly images was useful for

Table 2. Daily maximum values of air pollutants observed at Chongju-Chongwon in central Korea from the 4th to 9th of November 2002.

Date \ Pollutants	PM-10 (μg m^{-3})	PM-2.5 (μg m^{-3})	O_3 (ppb)	NO (ppb)	NO_2 (ppb)	CO (ppb)	SO_2 (ppb)
Nov. 4	32	12	34	6	13	290	5
Nov. 5	56	31	30	19	24	520	**10**
Nov. 6	75	40	52	**104**	**39**	839	7
Nov. 7	**84**	**46**	**68**	39	37	**867**	7
Nov. 8	72	31	31	2	15	519	3
Nov. 9	39	18	45	5	18	592	2

the present study and forecasting duststorms and industrial air pollution on a regional scale. Presently, the NOAA-12, 14, 15, 16 and 17 are in service, and NOAA-N series are efficient in detecting large-scale air pollution, especially during daytime. Images of NOAA satellites are excellent for observing air pollution over lakes and sea. The MODIS has 36 Bands, and in this study Band 1, 3 and 4 were employed. The MODIS is excellent in identifying the coverage of regional-scale air pollution. However, the MODIS image is less accessible than the NOAA-N image. At night, a visible channel and band are unavailable and composite analysis is less useful.

Air quality data obtained from real-time measurements at the ground level substantiate the quantification of satellite detection on atmospheric loadings of trace gases and particles. According to measured concentrations of air pollutants, atmospheric loadings generally increased a few times higher than the low values occurring with the clean air, when massive anthropogenic air pollutants from China moved into the Korean Peninsula.

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