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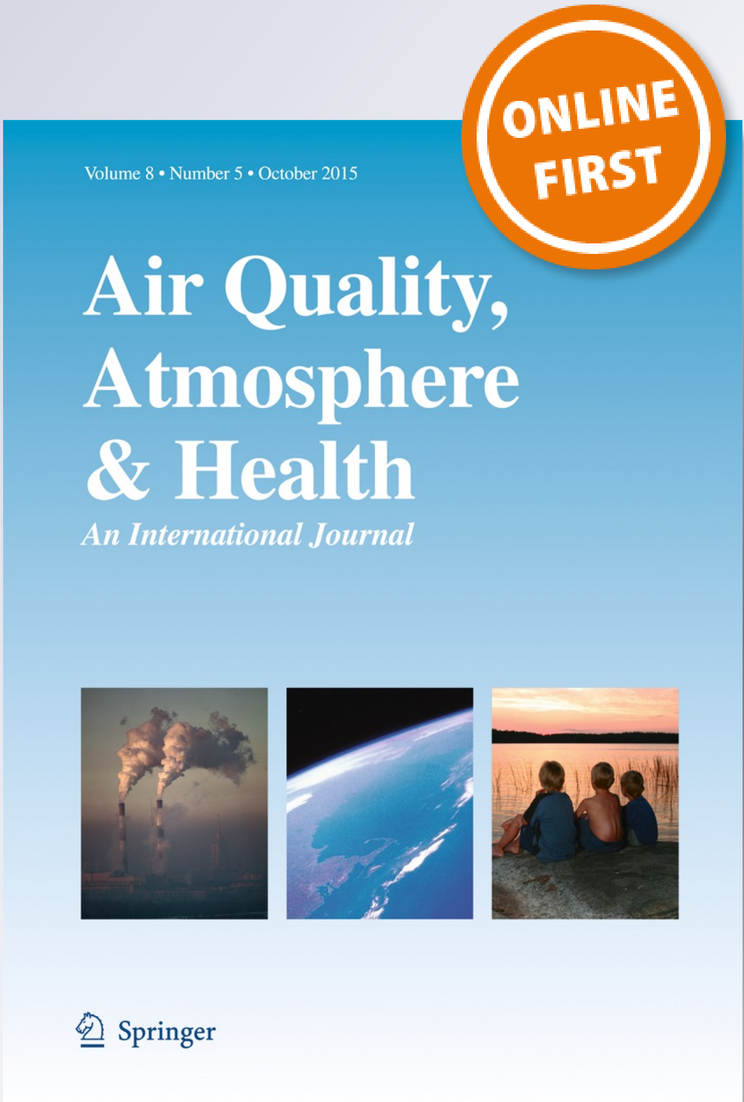

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On the August 12, 2015 occurrence of explosions and fires in Tianjin, China, and the atmospheric impact observed in central Korea

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Abstract Just before midnight on August 12, 2015, violent explosions and massive fires occurred in the Tianjin Harbor, China, releasing extensive amounts of toxic gas and smoke, debris, and mineral dust into the atmosphere. Atmospheric damage resulted from the long-range transport of air pollutants (LRTAP) in neighboring areas and countries. It has been found that the smoke plumes circled around the Huabei Plain in the lee of the Taihang Mountains, the Shandong Peninsula, and the Bohai Sea before reaching the Yellow Sea and the Korean Peninsula. The transport of widespread smoke plumes in the Yellow Sea region was evidenced from detailed analyses of images from various satellites including NOAA, MODIS, Himawari, and MTSAT. Satellite images clearly showed the generation of smoke emissions from Tianjin, the entire covering of smoke plumes over the Yellow Sea and nearby shore areas, and the LRTAP to the Korean Peninsula. The deposit of soil dust after the trace of rainfall confirmed LRTAP from the explosions and large fires in Tianjin. Also, air quality measurements of particulate matter (PM) 10, PM2.5, O_3, CO, and visibility showed the atmospheric impact of widespread smoke plumes from Tianjin.

Keywords Tianjin explosion · 2015 extensive fires of Tianjin · Widespread smoke plumes · Satellite detection of smoke plumes · Impact study of Tianjin explosion and fires

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Introduction

The source of the chemical pollutants from the violent explosions can be traced to several toxic chemicals stored in warehouses at the Tang-gu Harbor of Tianjin. A topographic map in Fig. 1 outlines the air pollution transport that occurred in the regions of Tianjin, the Huabei Plain and the Taihang Mountains, and the Shandong Peninsula. From the explosions, large fireballs and smoke plumes occurred over a vast area and the massive transport of smoke plumes was observed in the adjacent region.

Satellite data have proven effective in detecting smoke plumes and emissions originating from a large point source such as volcano and forest fire for nearly 30 years (Prata, 2009). Smoke plumes from the eruption of Mount St. Helens in Washington State were successfully tracked as far as Saskatchewan and New York State (Chung et al., 1981). Also, satellite measurements have been useful in the analysis of large-scale air pollution generated from massive forest fires and from large urban and industrial areas (Chung and Le, 1984; Chung and Kim, 2008; Engel-Cox et al, 2004).

Since 1993, the monitoring of the atmospheric environment using satellites and air quality measurements has been routinely carried out at the Korea Centre for Atmospheric Environment Research (KCAER) in west Cheong-ju in central Korea. This study deals with the large-scale transport of air pollutants (LSTAP) from the Tianjin explosions, and the observed air quality in central Korea is investigated and described here. Satellite data along with meteorological analyses are presented. Real-time measurements and the routine monitoring of air quality data, including particulate matter (PM) 10, PM2.5, O_3, CO, SO_2, and visibility, at 980-km downstream from the explosions are used for impact assessments. Additionally, trajectory analyses are discussed to support the observed air quality measurements.

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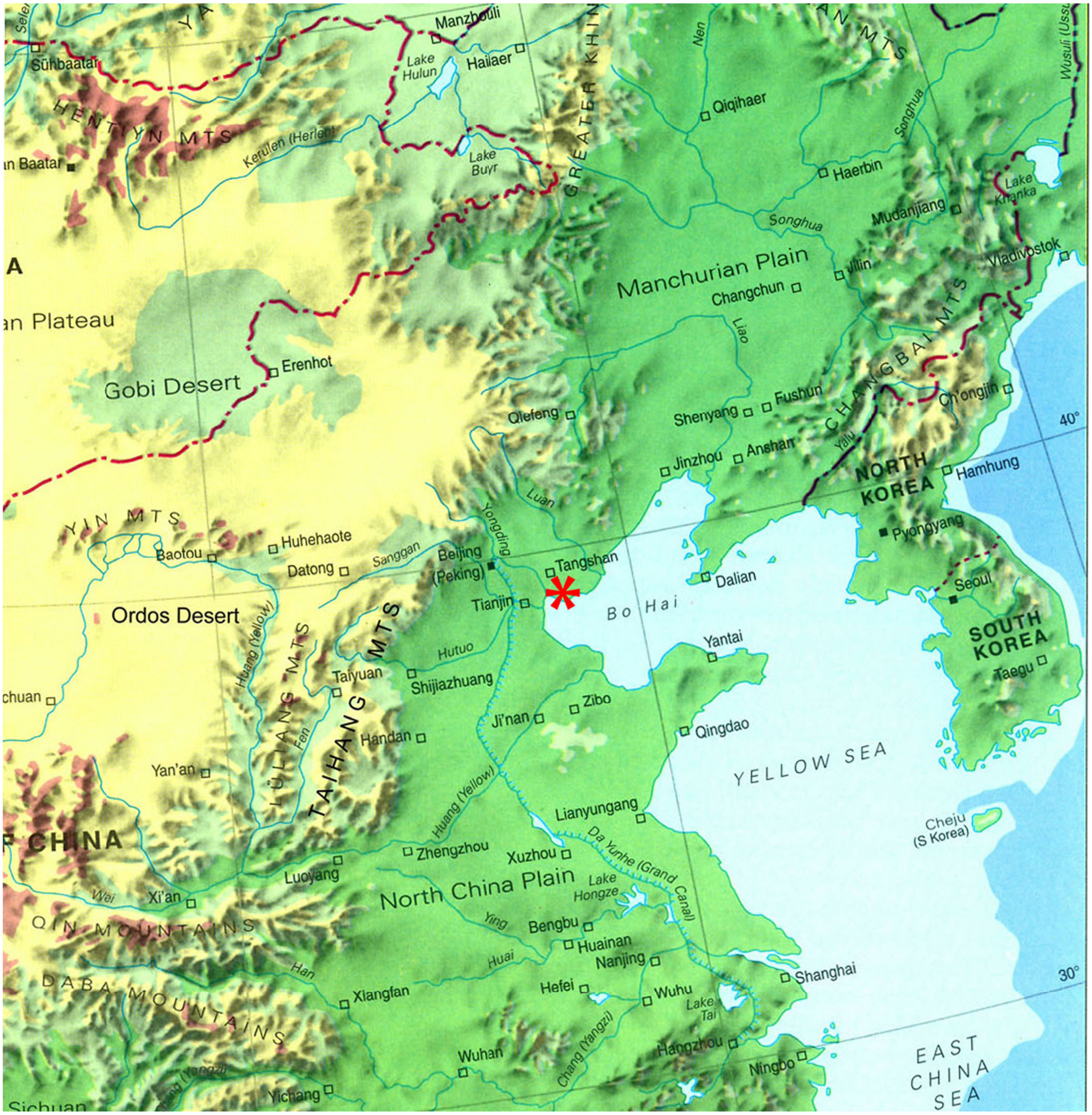


Fig. 1 A topographic map showing China, the Taihang Mountains, the North China Plain, the Yellow Sea, and Korea. *Asterisk* refers to the Tianjin Harbor

The explosions, extensive fires, and smoke plume occurrences

The initial explosions were reported to have occurred at 15:34 UT (23:34 Beijing time), August 12, 2015 with the strength of 3 t of TNT. Successive spectacular explosions and fireballs occurred with the strength of 24 t TNT, as shown in Fig. 2a. Blasts continued five to six times until 17:40 UT. A large crater, 100 m in diameter and 6 m deep, was created by the second explosion (Fig. 2b). The entire area damaged by the explosions and massive fires is about 2 km in diameter. In comparison, the diameter of the damaged area in the Hiroshima atomic explosion of World War II was about 3.4 km.

The strength of the massive explosions and blasts measured 2.3~3.5 on the Richter scale. Jolts from the explosions were felt as far as 20 km away. These indicate the strength of the massive explosions and the extent of the ensuing fires. Casualties from the disaster numbered in the hundreds.

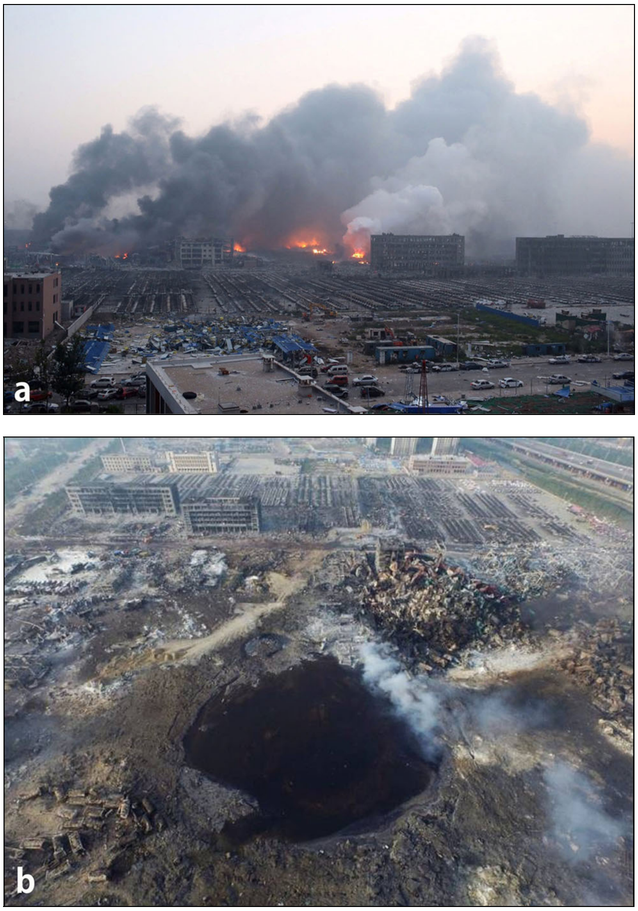


Fig. 2 **a** A massive fire occurring at the Tianjin Harbor from 23:34 Beijing time, August 12, 2015. **b** A big 6-m crater of 100 m in diameter is generated after spectacular explosions

Over 40 toxic chemicals such as NaCN and KCN were stored in factories and warehouses at the Tianjin Harbor; these chemicals exceeded 700 t. The number of new automobiles burnt and destroyed exceeded 20,000 units. The explosions and extensive fires generated large fireballs and smoke plumes, with the resulting toxic air plumes being transported to unknown destinations. The trajectory analyses of the smoke plumes include this detailed study.

Meteorological analyses and trajectory calculations

During mid-August 2015, tropical air was dominant in Tianjin and the Bohai Sea areas. Figure 3 indicates the synoptic weather system over the region. At that time, a weak airflow prevailed under a "col" sector between two high- and two low-pressure centers. In this situation, the wind and airflow at the low-level atmosphere were variable and there were no steady wind directions. The weak pressure gradient in the tropical atmosphere usually produces weak airflow with variable directions, and an airflow in the tropics does not necessarily follow the direction of a geostrophic wind field.

Initially, air-parcel trajectory analysis (Draxler and Rolph, 2003) was carried out to determine potential pathways of the massive smoke plumes from the Tang-gu Harbor in Tianjin. The calculated air-parcel pathways in Fig. 4a show the initial movement in the east-northeast direction and moving southeastward. From this calculation, many believed in the ENE transport of entire smoke plumes from Tianjin to NE China, i.e., Manchuria.

After the explosions and fires, however, widespread smoke plumes were generally drifting to WSW~SW directions. Our satellite detection in the following section shows that extensive plumes were already moving to and reaching the Shijiazhuang area. This suggests that the application of trajectory calculation is not quite useful in this case of a col situation and in the tropical atmosphere. A topographical map shown in Fig. 1 explains the southward turning of smoke plumes near the mountains. This is the lee side region (i.e., western foothills of the Huabei Plain) of the Taihang Mountains after the Tibetan Plateau. The large mountain barrier generates vertical stretching layers in the lee side (Queney, 1948), and significant horizontal convergence occurs at the low-level atmosphere. The lee side area conditions are favorable for trapping air pollutants and for mixing convergent airflows from neighboring regions. Six to twelve hours after the explosions at the Tianjin Harbor, extensive smoke plumes arrived and prevailed in the lee side of the Taihang Mountains.

Figure 5 shows the vertical stretching of air columns and the mixing of air currents in the lee side of a large mountain barrier. The lee side of the Taihang Mountain is a favorable area of cyclogenesis in East Asia (Chung et al., 1976), and it also produces buildup of air pollutants vertically in the stretching layers, such as those that occur in the Rocky Mountains, CO, USA (Brodin et al, 2010). The Taihang Mountains are 1500~3000 m high, and smoke plumes cannot cross over the barrier. It was observed that the plumes were turning around the massif to the south and southeast directions to the areas of Shijiazhuang, Jinan, and of the Shandong Peninsula.

Meanwhile, the anemometer level is 10 m above ground to measure winds. However, air pollutants at this height would soon fall to the ground level. The altitudes of trajectory calculations were chosen at 100, 300, and 1000 m. At the lowest level, smoke plumes from a fire flame have been recorded to rise as high as 100 m. The middle level is set at half the average height of the planetary boundary layer (PBL), and the highest level is set to the base height of cumulus clouds. The buildup of air pollutants often occurs from the ground to the cumulus level.

Based on the smoke plume moving in the southwest direction from Tianjin to the Huabei Plain (North China Plain), the trajectory starting point was moved to Shijiazhuang in Fig. 4b. A forward trajectory analysis starting at 00:00 UT on August 13 indicates that air pollutants were moving to the Yellow Sea and to the Korean Peninsula. At the 100-m level however, the air parcel

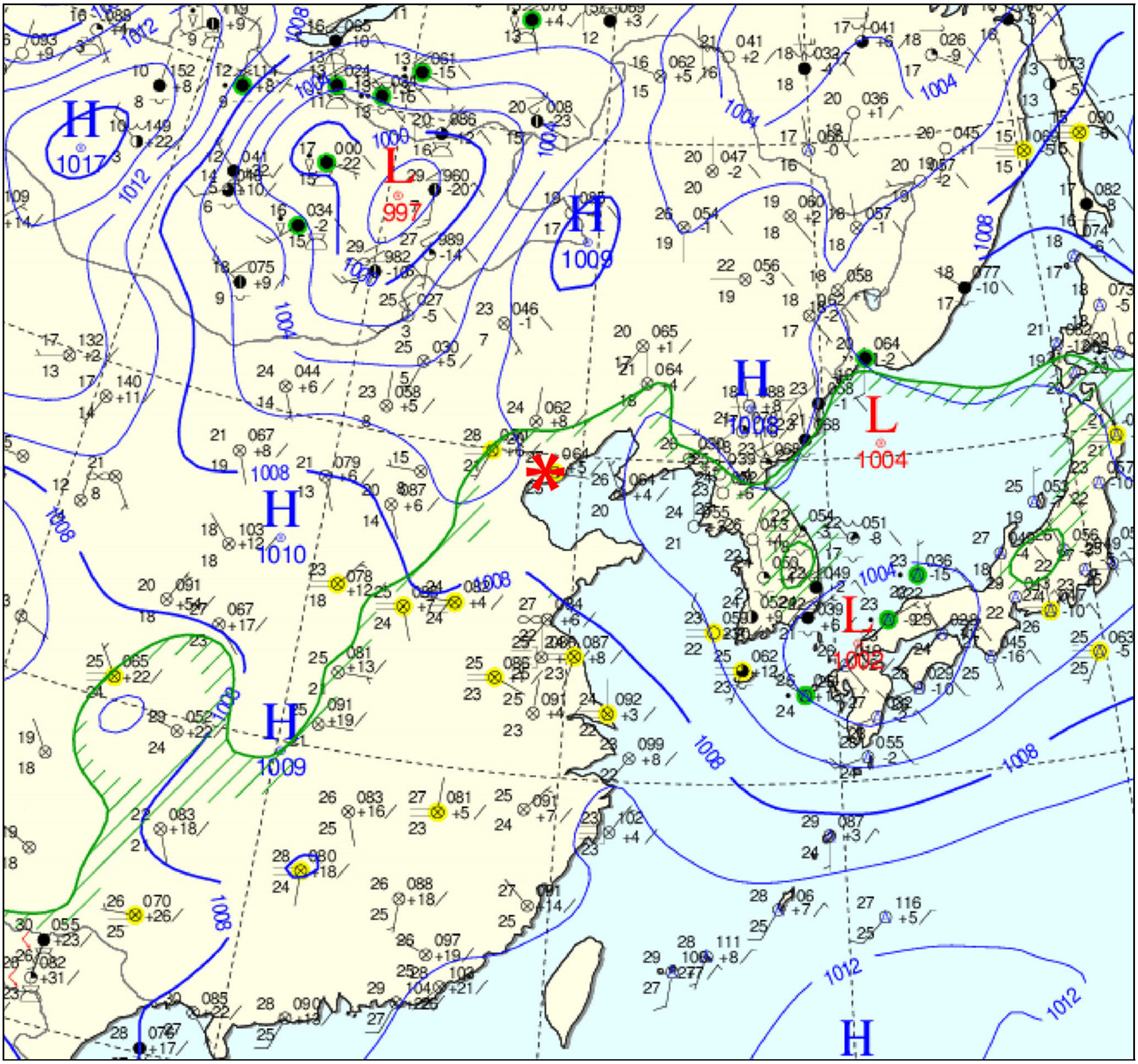


Fig. 3 A meteorological map showing a "col" condition in the Tianjin and Bohai Sea regions (15:00 UT, August 12, 2015). *Asterisk* refers to the Tianjin Harbor

would have moved to NE China. In addition, Fig. 6a shows another forward trajectory that the starting point was at the eastern tip of the Shandong Peninsula. Trajectory analysis, using the starting point of the Shandong Peninsula, also shows that smoke plumes at both 100- and 300-m levels were landing on the Korean Peninsula, while smoke plumes at the 1000-m level were circling south and southwest over the Yellow Sea. This indicates a widespread dispersion of smoke plumes in the neutral atmosphere with the maritime tropical (mT) air during the current episode period in summer.

On the other hand, backward trajectories shown in Fig. 6b also suggested qualitatively that at 15:00 UT, August 15 air pollutants from Tianjin were clearly arriving in Korea via the Yellow Sea and Shandong Peninsula regions. By this time, the massive smoke plumes from the Tianjin event had persisted for ~3 days. Both forward and backward air-parcel trajectory analyses confirm that widespread smoke plumes clearly reached the Korean Peninsula on August 15 and 16.

Starting at 06:00 UT, August 13, the synoptic pressure field had gained strength and an elongated cloud system from the NW region was steadily moving to the Tianjin area. Trajectory calculations were carried out, and the Shijiazhuang area rather than the Tianjin Harbor was determined to be the source point. In turn, the "moving" trajectory analysis was done using a starting point on the lee side of the massif and the resulting forward trajectories clearly show the plume transport in eastward directions to Korea.

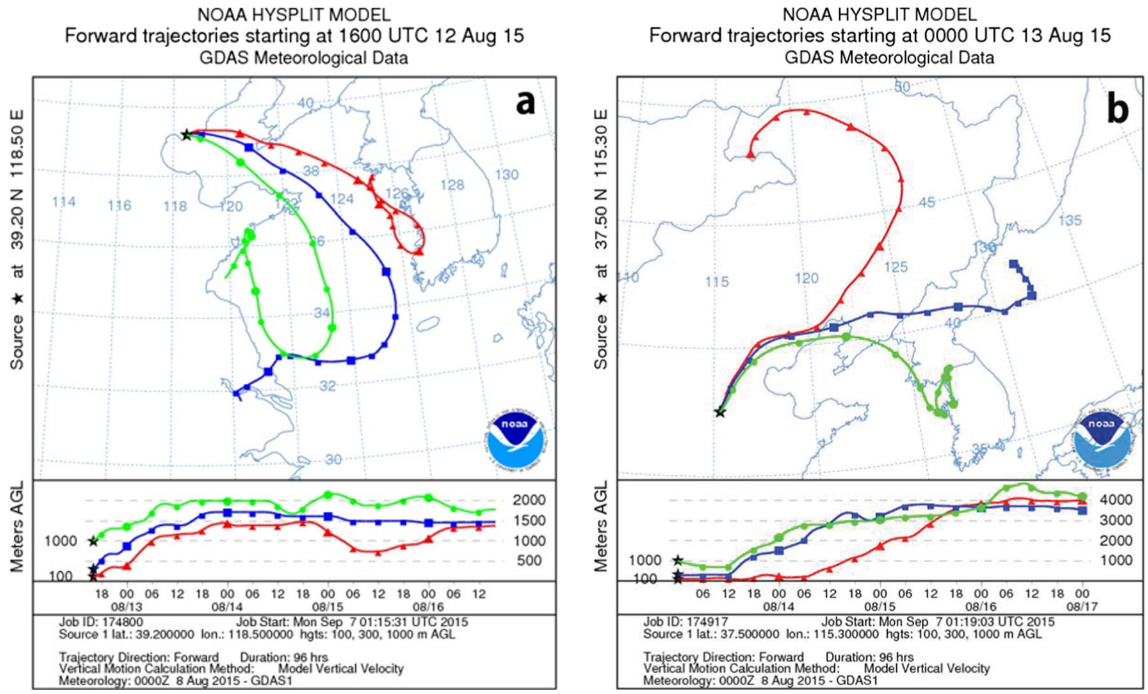
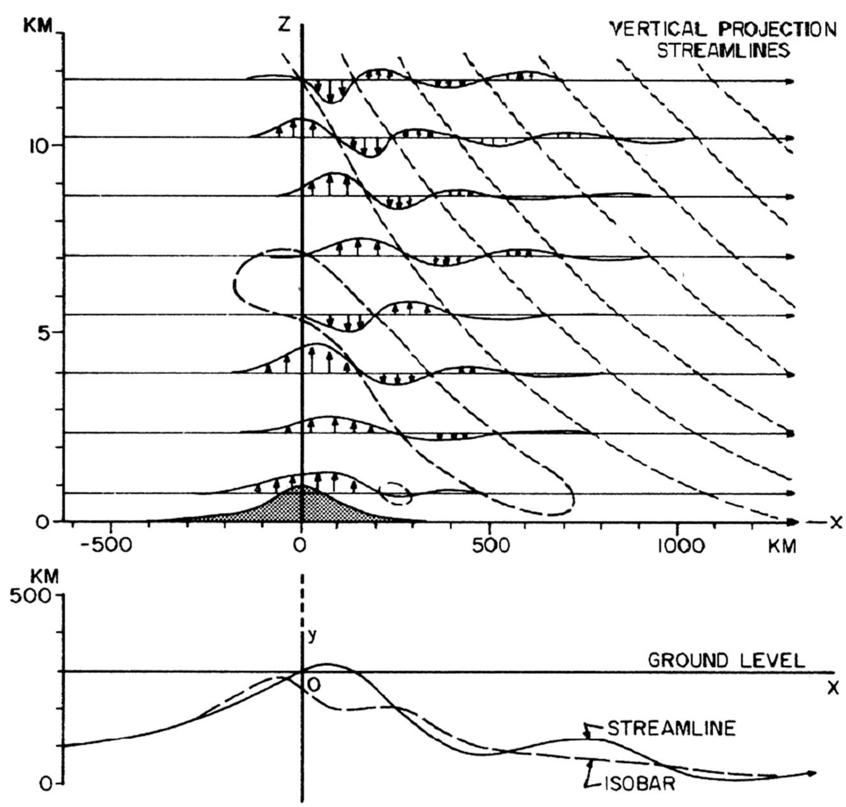


Fig. 4 Forward trajectory analyses **a** starting from Tianjin at 16:00 UT, August 12, and **b** starting from near Shijiazhuang at 00:00 UT, August 13

Satellite observations of massive smoke plumes

According to routine satellite monitoring on large-scale air pollutants, the massive smoke plume at 17:43 UT, August 12, moved to the western edge of the Bohai Sea, about 100 km SW of the Tianjin Harbor. Moreover, at 21:46 UT of the same day, the long but curled (plume c in Fig. 8a) white plumes transported 250 km SW from the Tianjin Harbor, as shown also

Fig. 5 Disturbed airflows are generated after crossing a mountain: vertical stretching and shrinking and horizontal pressure variation at the ground are illustrated (Queney, 1948)



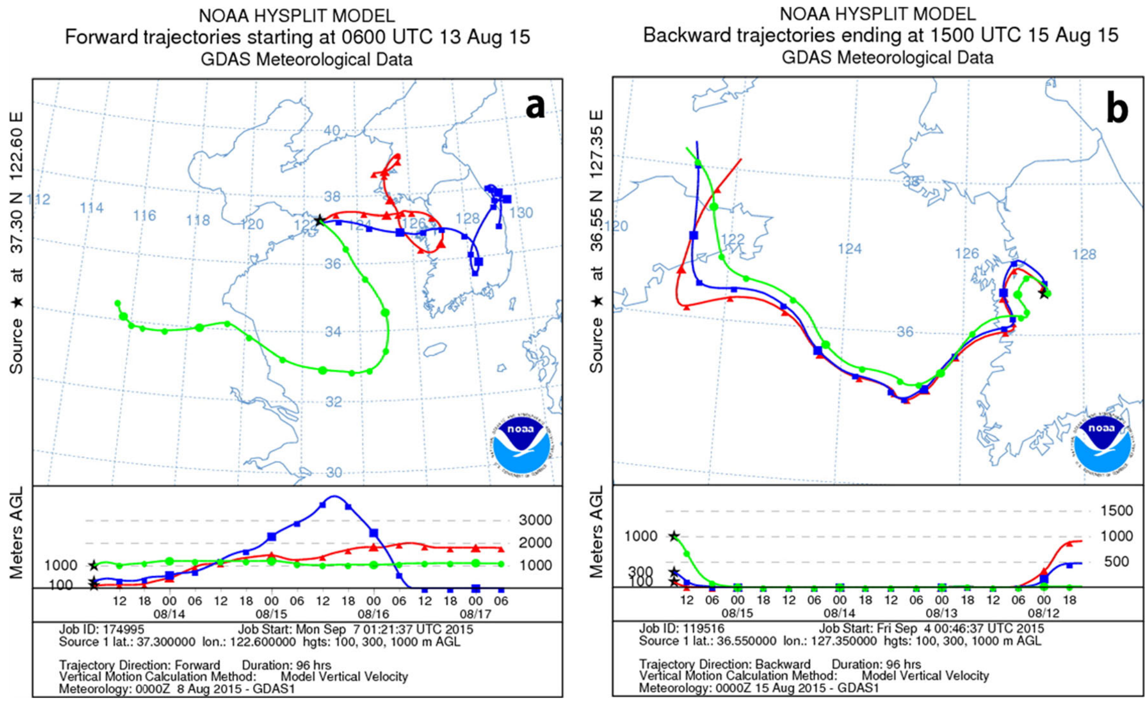


Fig. 6 **a** Forward trajectories starting at the tip of the Shandong Peninsula and **b** backward trajectories starting from west Cheong-ju in central Korea at 15:00 UT, August 15

in Fig. 7a. Interestingly, with the early morning sunlight, this long plume made a visibly dark shadow (plume s in Fig. 8) as far as 60 km to the west from the plume. This clearly shows the density and the thickness of the toxic air plumes.

Hima(wari)-8 satellite images in Fig. 8a show the wide spreading of giant smoke plumes on the morning of August 13. The smoke plumes were already extended to the southwest over Anyang and to the south over the entire Shandong Peninsula. The dark portion to the left of the center is the shadow of a cloud and smoke plume, while the curled (plume c) white thick plume seen in the NOAA image is also present on the left side of the dark portion. According to animation of Hima-8 satellite images, a small grey spot in the 2 o'clock direction from plume c is new black (plume b) smoke spewing up from the Tianjin Harbor. In the afternoon hours, Fig. 8b shows massive smoke plumes spreading widely to cover the entire Bohai Sea, the Shandong Peninsula, Anyang, and the surrounding area of the vast Huabei Plain.

Figure 9a–d shows four Moderate Resolution Imaging Spectroradiometer (MODIS) images taken in each day of the Tianjin event. The first MODIS image in Fig. 9a was obtained at 02:23 UT, August 13. Approximately 11 h after the initial explosion and fires, the extensive smoke plumes clearly moved near the Beijing-Baoding-Shijiazhuang-Anyang-Jinan areas and to the tip of the Shandong Peninsula. The thick mass of a plume shown in the NOAA satellite image is also presented in this MODIS image. At its climax, the length of the widespread plume from the Beijing area to the south of Anyang exceeded 500 km and the width was 320 km from west to east. Noteworthy is a distinctive cloud band visible in the upper left side of the image. This long cloud was moving steadily to the Korean Peninsula to produce rainfall on August 16, according to our animation of a 30-min series of Multifunctional Transport Satellite (MTSAT) images.

At 03:06 UT, August 14, the widespread smoke plumes from Tianjin were already approaching the west coast of the Korean Peninsula, while its southern edge was over Shanghai. The distance from Tianjin to Shanghai is ca. 430 km. Moreover, the elongated cloud band from the previous day was nearing the Beijing area, as shown in Fig. 9b. At 05:27 UT, August 15 (Fig. 9c), the extensive smoke plumes had already reached the Korean Peninsula. The elongated cloud streak was passing over the Shandong Peninsula, China. It is also indicated that the Bohai Bay area and the west of the Shandong Peninsula were still under the influence of extensive smoke plumes from Tianjin. In turn, the extensive smoke plumes over the Shandong Peninsula were under the elongated cloud band.

Widespread smoke plumes were successively moving to the east. By 04:32 UT, August 16, plumes were already over the Korean Peninsula as shown in Fig. 9d. In addition, it should be noted that the residual plumes were still floating around in the rear of the large cloud band. These smoke plumes are visible in the NE Shandong Peninsula and from Liaodong Peninsula to the east of the Bohai Sea and its SW direction.

At 06:00 UT, August 16, the measured base of scattered low clouds at the Cheong-ju Airport was at 1000 m above ground, the broken middle clouds were at 3300 m, and the overcast high clouds were at 6000 m above ground. In

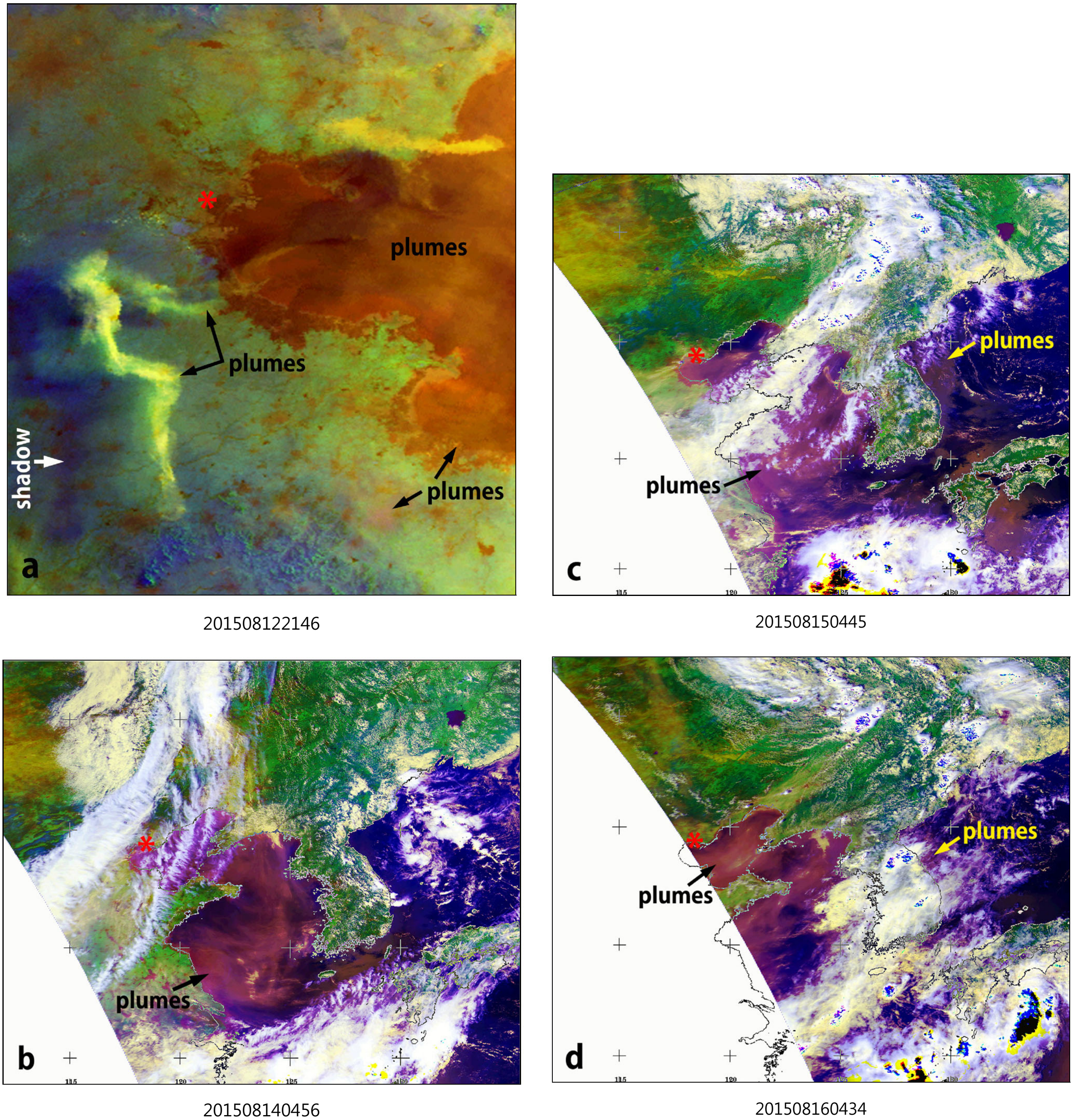
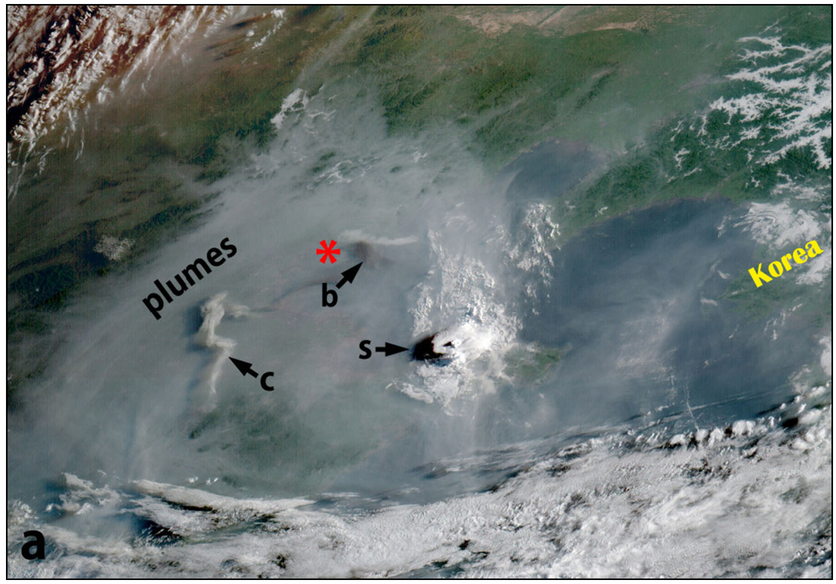


Fig. 7 NOAA satellite images showing widespread smoke plumes from Tianjin explosions and massive fires over the Bohai Sea, the Yellow Sea, and over Korea: a *curled white thick smoke* plume with its shadow is also visible at **a** 21:46 UT, August 12; **b** 04:56 UT, August 14; **c** 04:45 UT, August 15; and **d** 04:34 UT, August 16. *Asterisk* refers to the Tianjin Harbor

addition, upper-air soundings made at Osan Station in central Korea at 06:00 UT indicated the base of the low clouds at about 950 m (gpm), the middle clouds at 4760 m, and the high clouds at about 6620 m. These upper-air conditions suggested that the neutral boundary layer existed for the long-distance transport of smoke plumes to Korea. Furthermore, the dry deposition of air pollutants occurred below 900 m during the long-range transport of massive smoke plumes. Presumably, toxic air pollutants from the Tianjin Harbor were falling with the rainfall over the Korean Peninsula.

Figure 7b, c also reveals that at 04:56 UT, August 14, the extensive large-scale transport of smoke plumes from the Tianjin Harbor was evident over the Yellow Sea and the plumes were already reaching western Korea. The widespread smoke



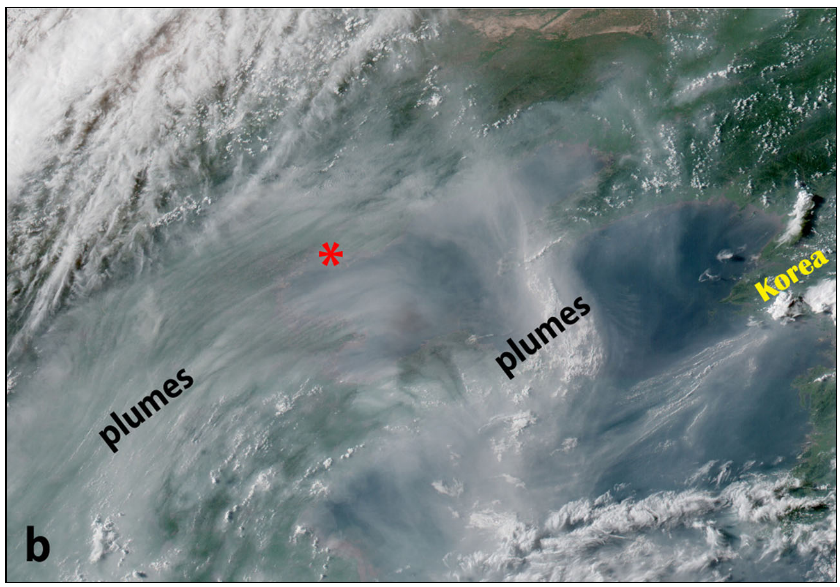


Fig. 8 Two satellite images of Himawari on August 13 showing widespread smoke plumes over Tianjin and the Bohai Sea regions. *Asterisk* refers to the Tianjin Harbor

plumes detected with the NOAA satellites in Fig. 7b are consistent with the MODIS image at 04:44 UT of August 14, as shown in Fig. 9b. The magenta plume in Fig. 7 is a typical air pollution mass as detected in Canada and the USA (Chung and Le, 1984; Chung, 1986).

In Fig. 7c, the widespread smoke plumes over the Yellow Sea had just landed over the west coast of central Korea. This plume image is also consistent with the MODIS image at 05:27 UT of August 15 in Fig. 9c. Likewise, the Korean Peninsula and the Yellow Sea were under the influence of smoke plumes and a polluted cloud band from China (Figs. 7d and 9d).

It is clear that smoke plumes from Tianjin spread widely over the entire Yellow Sea and its adjacent regions in 2 days. The Yellow Sea is ca. 600 km wide and 800 km long, and it was completely covered by emissions from the explosions and fires from the sectional source in Tianjin.

Observed air quality associated with smoke plumes

Routine monitoring of air quality and greenhouse gases with satellite measurements has been carried out at the KCAER, a rural site in Cheong-ju, central Korea. Figure 10a shows variations of real-time air quality data including concentrations of PM10 and PM2.5 with horizontal visibility measurements. Observed ground-level ozone and carbon monoxide values are also shown in Fig. 10b.

At Cheong-ju, with the mT air in summer, the observed dust values of PM10 stayed relatively low below 40 μg m^{-3} during both August 13 and 14. However, these PM10 concentrations rose to 66 μg m^{-3} from 00:00 UT, August 15, as shown in Fig. 10a. Similarly, PM2.5 concentrations were below 30 μg m^{-3}. However, from 00:00 UT, August 15, they increased to 55 μg m^{-3} with the influence of smoke plumes from Tianjin.

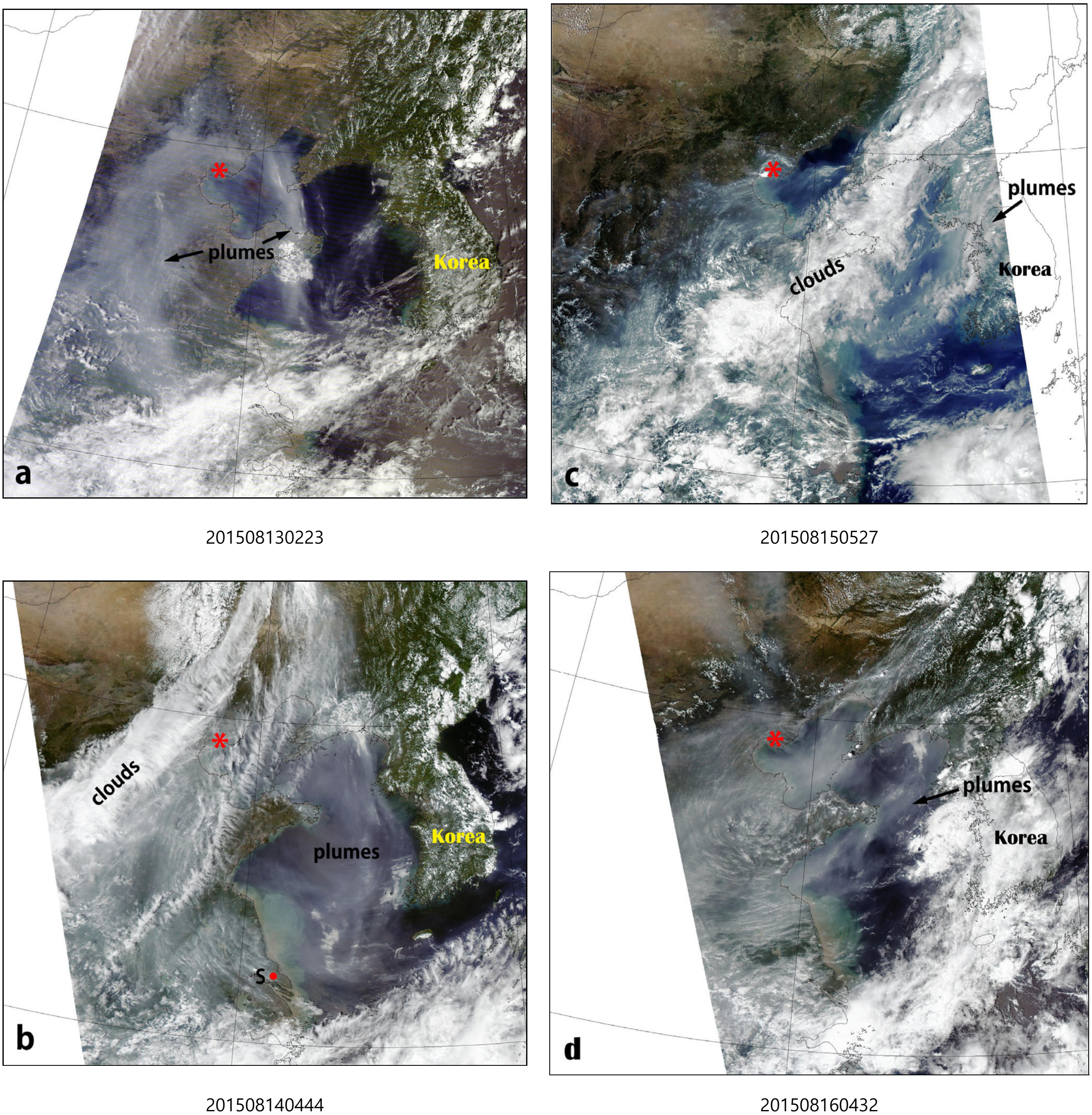


Fig. 9 A series of satellite images of MODIS showing the widespread smoke plumes generated from Tianjin and the successive moving smokes to the Yellow Sea and Korea: **a** 02:23 UT, August 13; **b** 04:44 UT, August 14, *S* refers to Shanghai; **c** 05:27 UT, August 15; and **d** 04:32 UT, August 16. *Asterisk* refers to the Tianjin Harbor

On August 15 at 17:00 UT, PM10 reached a maximum at 71 μg m^{-3} and remained above 40 μg m^{-3} on August 16 until 07:00 UT with rainfall occurring in central Korea. The maximum value of PM2.5 at 54 μg m^{-3} was recorded at 17:00 UT, August 15, and maintained above 30 μg m^{-3} until 06:00 UT, August 16. Hereafter, PM2.5 concentrations also decreased to below 30 μg m^{-3} with rainfall.

In general, fine particles impair horizontal visibility. With the increase in PM2.5 concentrations, the observed visibility decreased to a minimum 0.14 km at 23:00 UT, August 14 (Fig. 10a). The measured visibility also decreased steadily in the morning and reached 1.35 km at 22:00 UT, August 15. The visibility measurements also support the increase of fine particles from the Tianjin event.

Fig. 10 Variations of air quality data observed at KCAER in west Cheong-ju during the period of August 13~17: **a** PM10 and PM2.5 with visibility and **b** ozone and CO

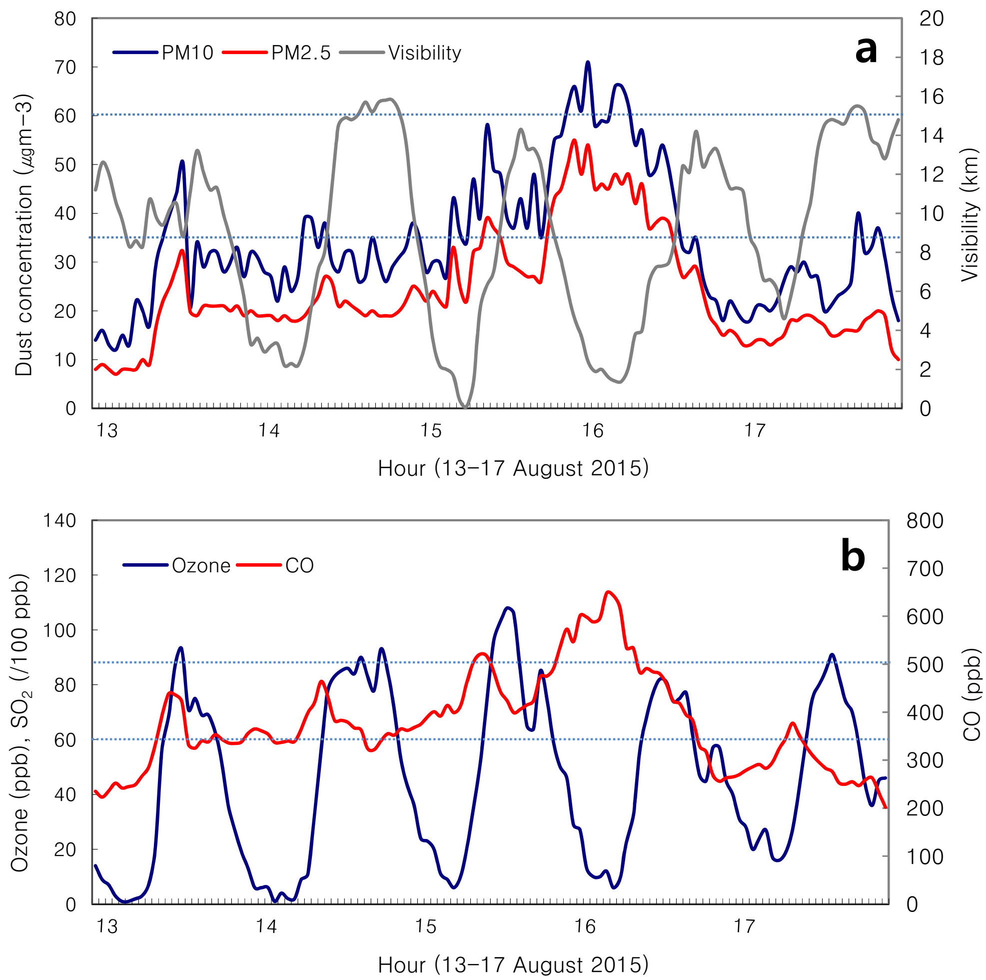


Figure 10b demonstrates the variations of ground-level ozone and carbon monoxide measured at KCAER in west Cheong-ju. With the availability of nitrogen oxides and hydrocarbons, high ozone concentrations usually occur in a warm sunny air environment. In the morning, the observed background ozone level was as low as 6 ppb. However, this reached 108 ppb at 06:00 UT with the hot air. The following morning, the lowest value at 6 ppb was recorded again, while the maximum ozone concentration was 82 ppb at 05:00 UT, August 16. With clouds prevailing, the ozone values were less than the value of the previous day.

Carbon monoxide is a toxic air pollutant, and measured CO variations are shown in Fig. 10b. Background CO values are around 200 ppb, particularly with maritime warm air from the NW Pacific in summer (Kim et al., 2010). As shown in Fig. 10b, the measured level of CO was below 400 ppb during August 13 and 14. However, these concentrations increased above 400 to 521 ppb at 02:00 UT on August 15 and as high as 643 ppb at 22:00 UT on August 16. Significantly, after the rainfall occurrence, this toxic gas decreased rapidly to below 300 ppb from 13:00 UT, August 16.

Sulfur dioxide (SO_2) measured on August 14 was generally below 1.0 ppb. However, it rose to a peak 2.0 ppb at 03:00 UT, August 15, and thereafter, it gradually decreased. At 15:00 UT, August 15, SO_2 concentrations increased again to the 1.2 ppb level. The SO_2 variations also indicate the influence and the impact of smoke plume transport from the Tianjin fires and explosions.

From the elongated cloud passing over Korea, significant rainfall occurred on August 16. Radar echoes in Fig. 11 measured by the Korea Meteorological Administration show heavy rainfall in central Korea and SE Korea. Observed rainfall was 29.0 mm at Seoul, 27.5 mm at Yang-peong, 21.0 mm at Kang-reung, 15.5 mm at Jaechon, and 26.0 mm at Ei-seong, and many other stations recorded 2.0~10.0 mm. Measured rainfall at the KCAER in west Cheong-ju was a mere trace.

Interestingly, soil dust on the windows and fenders of automobiles was conspicuous in the morning of August 17. Residue of soil dust after rainfall does not normally occur in August and summer but in the dust-storm seasons of spring and early winter. The observed soil deposit after

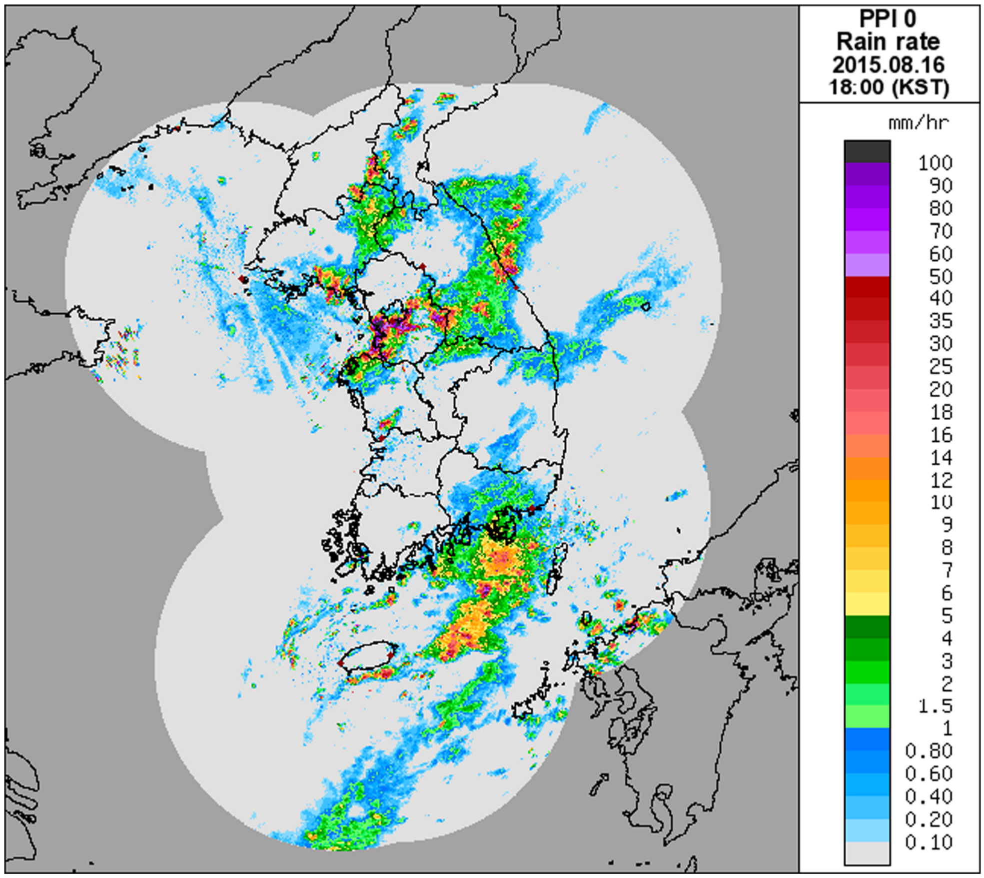


Fig. 11 A radar echo, observed by the Korea Meteorological Administration, showing intense rain-shower sectors in Korea

the trace of rainfall confirmed LSTAP resulted from the explosions and large fires in Tianjin on August 12. Smoke plumes also moved in on August 19, and the rainfall observed on August 19 and 20 was 0.5 mm. Measured pH value of this rainfall was 6.12, and this might represent the chemical contents of dust and minerals in the rain water.

Discussions

The massive explosions and extensive fires caused large-scale damage to both humans and the natural environment in Tianjin, China, and the resulting large-scale transport of smoke plumes also affected neighboring areas. Seoul, Korea, is about 820 km downwind from the source area of emitted smoke and air pollutants in the Tianjin Harbor, while the KCAER in Cheong-ju is about 980 km in the ESE downstream. These are distances achievable by LSTAP in 2~3 days even with moderate winds and airflow in the low-level atmosphere.

Many studies on satellite observations, air-quality-measured data, and on long-range transport of air pollutant (LRTAP) in East Asia and North America have been carried out (Chung, 1986; Chung and Kim, 2008; Martin, 2008). Results of the present study generally agree with the results of former studies done elsewhere (Kim and Chung, 2008).

Initial trajectory analyses show that the smoke plumes moved from the emitted area to the direction of ENE and NE regions in NE China. Owing to the variable airflow in a synoptic “col” pressure field, calculated trajectories show the movement of pollutants to the ENE direction to NE China (i.e., Manchuria). In Korea, many scientists argue that the transport of all pollutants moved from Tianjin to NE China. However, our satellite study shows that air pollutants from the explosions and fires initially drifted over the Bohai Sea and over the SW regions of the Tianjin accident.

The air environment during the period of August 13~16 in central Korea was in the range of 20.1~31.5 °C with warm mT air mass. The mT air situated over the Yellow Sea region included Tianjin in the high summer. According to upper-air soundings, the observed atmospheric stability was generally “neutral” for making the large-scale transport of smoke plumes. According to the present study, trajectory analyses suggest that the direction of airflow in the mixed layer at 100, 300, and 1000 m shows a large angle between different altitudes. In turn, the neutral stability in the weak airflow in the mixed layer of the mT air mass in the lee of the high mountains and over the sea was a factor in producing the widespread dispersion of smoke plumes in the Yellow Sea region during the present air-pollution episode period.

More importantly, before moving to the easterly direction, these giant smoke plumes moved initially to the west and southwest regions from Tianjin according to our detailed satellite investigation. However, the moving of the starting point of smoke plumes for forward trajectory analysis also supports the transport to the E and ESE toward the Korean Peninsula. Backward trajectory analyses starting from central Korea support the fact of an eastward transport of smoke plumes moving from the Shandong Peninsula and the Bohai Sea.

Satellite pollution images studied here support the air quality measurements. Before the arrival of extensive smoke plumes from the Tianjin area, the near-background air quality level was observed in central Korea with the mT air arriving. However, high-pollutant values at Cheong-ju in central Korea were measured when the extensive smoke plumes were landing in central Korea. Satellite images of NOAA, MODIS, Himawari, and MTSAT provide evidence on the impact of massive smoke plume transport from Tianjin to the Korea Peninsula and the resulting high-air-quality values.

Summary and conclusions

The violent explosions and extensive fires that occurred in the Tianjin Harbor, China, at 23:34 UT, August 12, 2015, are discussed in relation to the present atmospheric impact study. The Tianjin disaster produced incredible damage in an area of over 2 km in diameter and created a crater 100 m wide and 6 m deep. Stored toxic chemicals including NaCN, weighing over 700 t, exacerbated the degree of the disaster. The explosions and fires generated and spewed upward an insurmountable amount of smoke, debris, and mineral soil dust to the atmosphere.

The smoke plumes are a clear subject of the long-range transport to neighboring areas and countries as well. One day after the disaster, these toxic smoke plumes were transported to the Yellow Sea, and by August 15, they reached the Korean Peninsula. The widespread smoke plumes took about 2 days to cross the Yellow Sea. It is clear that the major portion of extensive smoke plumes moved to Korea via the Yellow Sea on both August 15 and 16. Qualitative evidence was obtained from various satellite images including those of NOAA, MODIS, MTSAT, and Himawari.

Before the arrival of the smoke plumes, people were enjoying the background clean air from the NW Pacific. On both August 15 and 16, however, measured values of atmospheric dust and gaseous pollution increased significantly with the invasion of widespread smoke plumes to Korea. The measured air quality data were also compared with data obtained at other sites in Cheong-ju and Seoul, etc. The air pollutant concentrations were high enough to cause respiratory disease in some people in receptor regions.

The present study provides a discussion of the impact of chemical explosions and massive fires on atmospheric quality. It also shows that the routine monitoring of atmospheric phenomena with satellites images, trajectory calculations, and air quality measurements is an important public service and crucial for future atmospheric impact analysis of chemical accidents.

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