IMPACT OF EAST ASIAN SUMMER MONSOON ON THE FATE OF ORGANOCHLORINE PESTICIDES IN NORTHEAST AISA

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Abstract

Using a dynamic numerical atmospheric dispersion model for organochlorine pesticides (OCPs), the relationship between the East Asian summer monsoon and the fate of α-hexachlorocyclohexane (α-HCH), a banned OCP, in the atmosphere over Northeast Asia was assessed. The modeled temporal and spatial patterns and variability of α-HCH air concentrations during the summer months of 2005 revealed strong association between this chemical in the atmosphere over Northeast Asia and the summer monsoon. At lower atmospheric levels, easterly and southeasterly winds blowing from relatively cold ocean surface convey α-HCH air concentration from Southeast China to Northeast China, Korea, and Japan. The modeled wet deposition fluxes of α-HCH agreed well with the changes in the typical summer monsoon rain bands, designated as Meiyu in China, Changma in Korea, and Baiu in Japan. The major wet deposition flux paralleled with the monsoon front as well as the monsoon rain bands. The temporal change in the fluxes exhibit abrupt northward advances, which is associated with a stepwise northward and northeastward advance of the East Asian summer monsoon.

Introduction

Northeast Asia (China, Japan, Korea) and the adjacent oceanic region are affected substantially by the East Asian monsoon, one of the strongest monsoon systems in the world (1). Briefly, the East Asian monsoon is basically a response of the atmosphere to the differential heating between the land mass of East Asian continent and the adjacent Pacific Ocean. Its seasonal change dominates the climate over the continent and its surrounding areas. In the winter monsoon, westerly winds prevail from low to high level of the atmosphere over the continent. In the summer monsoon, low level winds reverse from winter westerlies to easterlies and southeasterlies. Previous studies on long-range transport of air pollutants in East Asia have suggested that the winter monsoon regime favors more pronounced long-range and trans-Pacific transport of air pollutants than the summer monsoon regime (2). Because the westerly flow dominates mid-latitudes of Northeast Asia (China, Japan and Korea), the continent exhibits an outflow pattern from land to ocean. However, it is important to note that during the wintertime we always observe low air concentration of OCPs due to their weak volatilization associated with low air temperature. This turns out that, though wind regimes associated with the East Asian winter monsoon favors long-range transport of OCPs, such transport is less significant because a low air concentration is more readily dispersed to an undetectable level in the atmosphere. The present study is aimed to explore and assess the connections between the East Asian monsoon and spatial/temporal patterns of OCPs in Northeast Asia. Although α-HCH has been extensively modeled, this study undertakes the first systematic investigation in the impact of the East Asian monsoon on the budget of OCPs on China, and hence shed light on the understanding of the fate of OCPs across other Northeast Asian countries and North Pacific Ocean.

α-HCH emissions in China and Numerical Aspects

A α-HCH soil residues inventory in China in 2005 on a 1/6°×1/4° latitude and longitude grid system was used. These gridded residues were then interpolated into the model grids. Overall, southeast China and Central China Plain were major sources of α-HCH. Canadian Model for Environmental Transport of Organochlorine Pesticides (CanMETOP) has been employed in the present study. CanMETOP is a three-dimensional regional scale dispersion model coupled with a dynamic, three soil layer, fugacity-based soil-air exchange model, and a two-film model to estimate water-air gas exchange. The horizontal resolution of the model is 24 km and the model domain covers entire China, Japan and Korea. The coupled model has 12 vertical levels from the surface to 7 km height. The model integration time step is 12 min. The model has been used extensively in numerical assessments of OCPs in North America (3, 4). The meteorological data (wind, air temperature, precipitatioon) in

2005 were obtained by interpolating the 6-hourly objectively analyzed data from the United States National Center for Environmental Prediction (NCEP) reanalysis (5). The model is solved numerically by a finite-difference approximation and operator-splitting scheme.

Results and Discussion

The East Asian summer monsoon is of tropical and subtropical nature. The most significant weather phenomenon during the summer monsoon is the quasi-stationary front extending from south China to southern Japan. This front is called Meiyu in China, Changma in Korea and Baiu in Japan. The front is located along the northern and northwest periphery of the subtropical anticyclone over the north Pacific, named as the north Pacific subtropical high (NPSH). The westward (eastward) extension of the NPSH enhances (suppresses) monsoon activity. The westward displacement of NPSH intensifies the low level jet (a strong wind belt) at the northwest edge of this anticyclone, resulting in transportation of large amount water vapor into East Asia, in particular over the Yangtze River Basin of China (6). The monsoon rain commences from early to mid-May over the Indo-China peninsular, and then it extends abruptly to the Yangtze River Basin and south Japan in early to mid-June and finally penetrates to North China, Korea, parts of Japan and adjoining ocean (1). The seasonal features of the East Asian summer monsoon display a distinct stepwise northward and northeastward advance. These stepwise shifts of the monsoon are characterized by the changes in wind and precipitation systems across Northeastern Asia. Typically, the onset of the Meiyu over the Yangtze River Basin and the Baiu in Japan in June, marking the arrival of the East Asia rainy season, is associated closely with the northward penetration of the East Asian summer monsoon. These precipitation patterns may have a pronounced impact on the wet deposition of OCPs over these regions.

Figure 2 displays CanMETOP modeled monthly averaged α-HCH air concentration and winds derived from the NCEP reanalysis from May to August 2005 at 1.5 m height, respectively. Northward penetration of the summer monsoon into northern China can be seen clearly from the figure. Accordingly, the modeled monthly mean air concentrations jumped from southeastern China (the Yangtze River Basin) to northeastern China from May to June. Rapid increasing of air concentrations in northeastern China was associated nicely with a strong wind convergence zone formed by northward penetration of the East Asian monsoon and westerly wind extended from Mongolia to northeastern China (Fig 2a and b). In July, northeastern China still situated in the center of wind convergence, illustrated by an anticlockwise wind field (Fig 2c) and a low pressure system (not shown). Higher air concentration of α-HCH remain in northeastern China throughout June and July, which was conveyed by prevailing southerly and southeasterly winds associated with the summer monsoon from its major source region in the Yangtze River Delta. During August, along with decay of the East Asian summer monsoon, as shown by disappearance of southerly winds in southeastern China, the spatial distribution of air concentration of α-HCH in China exhibit similar pattern as that before the summer monsoon, showing the higher air concentration over the principal source region (Fig 2d).

The configuration of α-HCH at the lower atmosphere across eastern China, as illustrated by Fig 2, highlights strong association of the atmospheric transport of the compound with the East Asian summer monsoon. To gain further insight into the effect of the East Asian monsoon circulation on the fate of α-HCH in the atmosphere, in figure 3 we illustrate CanMETOP model simulated monthly averaged α-HCH air concentration at 3000 m height (the 10th model level) from May to August, overlaid by the wind fields from the NCEP reanalysis. Compared with the spatial distribution of air concentration of α-HCH at the lower atmospheric level, the chemical at the higher atmospheric level exhibits clearly a pattern of eastward atmospheric transport. The mean wind fields at 3000 m (Fig 3) show that during the summertime westerly winds dominate northern China, whereas southerly winds as part of the East Asian monsoon are observed only over southeastern China. Higher air concentrations at this level are also seen clearly as compared to that at the lower atmospheric level (fig 2). An important feature of the wind fields at 3000 m is a strong wind convergence zone extending from eastern China to Japan. This wind convergence was formed typically in June and July by southerly and southeasterly winds from the Pacific Ocean and westerly winds from northern China (fig 3b and c). Dynamically, a high level atmospheric convergence and strong winds would lead to an ascending motion from the surface, so that the vertical upward transfer of α-HCH would take place along this wind convergent zone. The vertical profiles of air concentrations from the surface to 3000 m height showed the presence of high air concentrations of this pesticide at relatively high levels of the atmosphere throughout May to July. The monthly changes in the concentration profiles in the vertical further confirmed northward transport of α-HCH in air from its principal sources in southeastern China. Higher air concentration at higher atmospheric level is more pronounced for the period of June 2005, when the East Asian summer monsoon reached its mature stage.

The onset of the East Asian summer monsoon is a key indicator characterizing the abrupt transition from the dry season to the rainy season and subsequent seasonal march. Figure 4 illustrates the modeled 5-days total wet deposition flux (pg m^{-2}) of α-HCH during the first and second dekads of June (left panel) and July (right panel). During the first and second pentad of June, the total 5-days wet deposition was centered in the Yangtze River Delta of China (Fig 4a and b), characterizing typically the onset of “Meiyu”. From the third pentad of June (Fig 4c), the major wet deposition zone extends to Japan and the magnitude of wet deposition fluxes increased considerably in the following pentad (June 16-20, Fig 4d). The narrow band of the wet deposition flux extending from the Yangtze River Delta to Japan, as shown from figure 4d, corresponds nicely to the East Asian summer monsoon rain band. In the first and second dekad of July, the period that has been described as the 4th stage (final stage) of the East Asian summer monsoon (1), marked by the northward progress of the monsoon to North China, Japan, and Korean Peninsula, greater deposition fluxes are found from Northeast China to Korea and Japan (Fig 4e-g). For Korean Peninsula, the large amount of the wet deposition fluxes is associated with so-called “Changma” rainy season. On the other hand, the stepwise northward advances of the summer monsoon conveyed α-HCH in the atmosphere to these regions (countries) from its sources, primarily in the Yangtze River Delta of China, which contributed substantially to the contamination of these regions by α-HCH via wet deposition.

References

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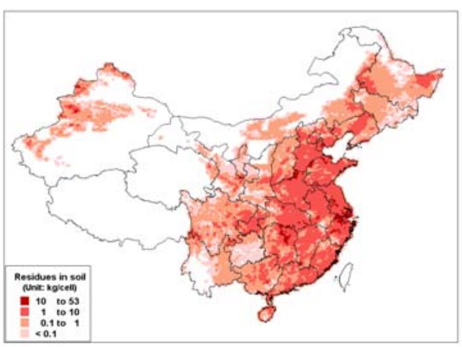

Figure 1. Soil residue concentration (kg $cell^{-1}$, 1 cell = 24 km × 24 km) of α-HCH in China in 2005.

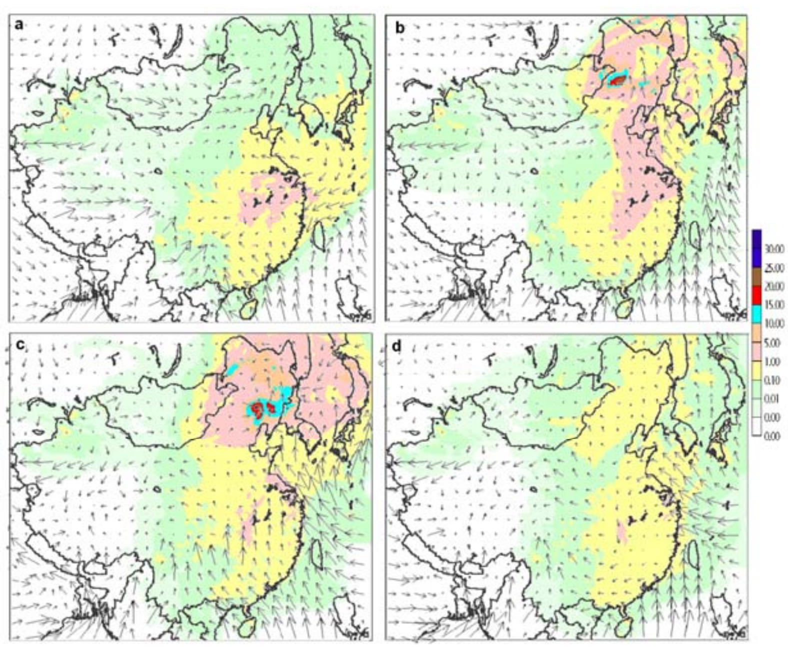

Figure 2. Modeled monthly mean air concentrations (pg m^{-3}) of α-HCH from May – August (a – d) 2005 at the first model level (1.5 m). Wind vectors averaged over each month from NCEP reanalysis are also overlaid with air concentrations.

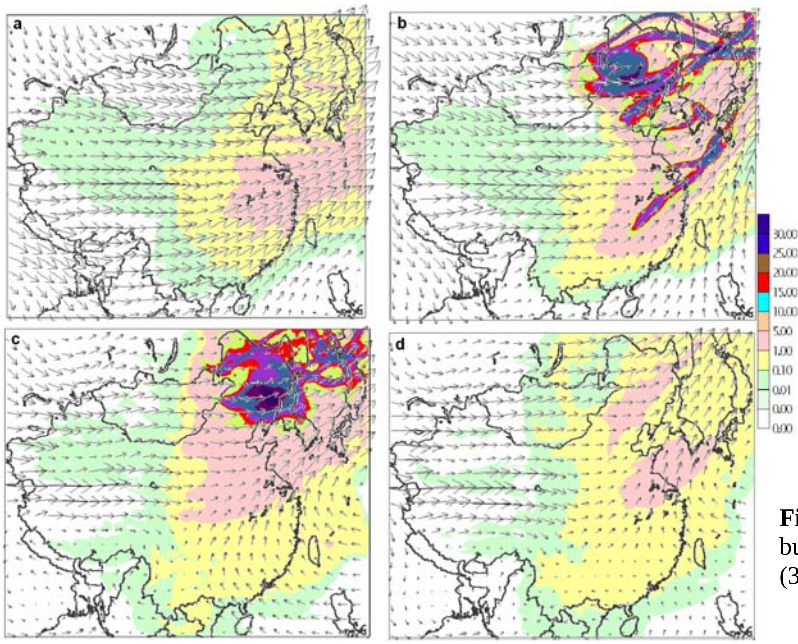

Figure 3. Same as Figure 2 but at the 10th model level (3000 m).

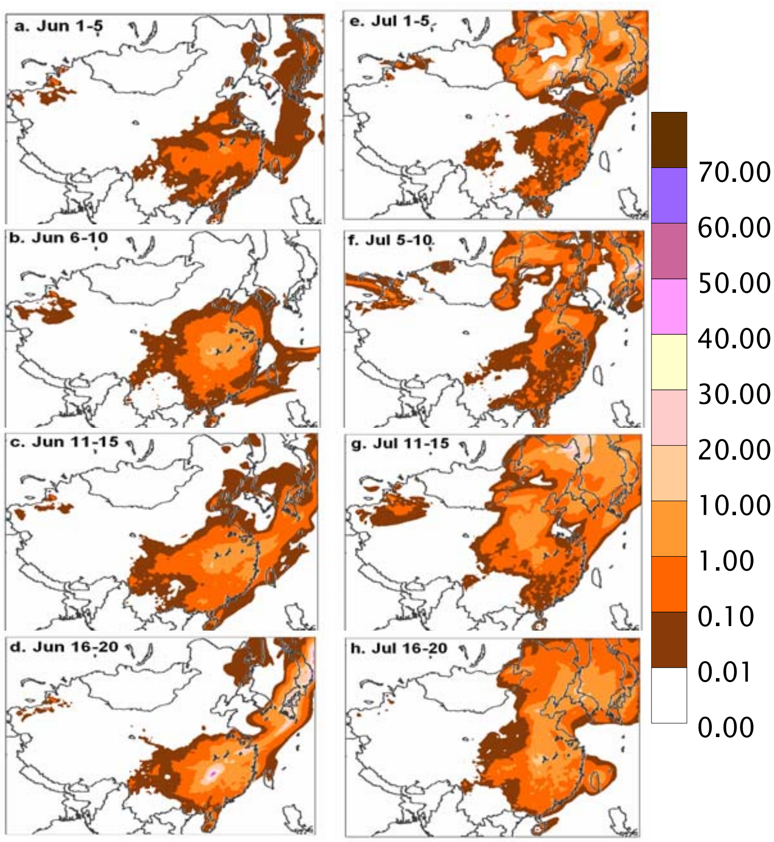

Figure 4. 5-days total wet deposition flux (pg m^{-2}) during the first and second dekads of June (left panel) and July (right panel.