Journal of Environmental Sciences Vol. 6, No. 2, pp. 189–199, 1994 ISSN 1001-0742

A numerical experiment for the simulating effects of Kuwait oil fire and volcanoes in Philippines and Japan on the general circulation and climate

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Abstract— With an AGCM/ mixed-layer ocean model, a numerical experiment to investigate the effects of Kuwait oil fire and volcanoes in Philippines and Japan on atmospheric general circulation and climate is carried out. It is shown from the simulation that the effect of smoke on climate is significant near the smoke sources, and quite weak-and-indirect in the distant areas. In the experiment, it is not found that the smoke had a significant effect on SST anomaly along the tropical oceans and flood in Yangtze-Huaihe river's basin of China in the spring and summer of 1991.
Keywords: prediction; smoke sensitive experiment (SE); control experiment (CE).

1 Introduction

In the spring and summer of 1991, there were many climate anomalies in Asia, such as strong tropical storms in Bangladesh, hot wave in Pakistan and flood in China. At that time or earlier, more than 700 oil wells were on fire during the Gulf War, which produced heavy smokes shutting out most of sunlight and had not gone out until August. In June, volcanoes of Mount Pinatubo and Unzendake Kazan in Philippines and Japan erupted respectively. The former was the strongest up to 1991 in this century, and the later was quite weak. Since these disasters were almost simultaneous with those climate accidents, it has been the subject of considerable scientific debate and widespread public concern whether there was any relation between two of them, so we carried out a numerical experiment to investigate the effects of smokes on the general circulation and climate.

It has been shown in Nuclear Winter studies that the main effect arising from the atom bomb's detonation on climate is its smoke's influence on the earth's radiation budget. Smoke absorbs and scatters the insolation light and has a negligible effect on the long-wave radiation. Although the oil fire and volcanoes heated the regional air around them, with a view to investigating their impact on large scale atmospheric circulation and climate, they may be looked upon as a nuclear winter, main effect arising from the smoke's influence on earth's radiation budget. With a similar supposement, Browning and Bakan (Browning, 1991) carried out the numerical experiments investigating Kuwait oil fire's effects respectively. After estimating the emission quantity and quality of smoke aerosol, the smoke plume's height and shape were calculated with simple models, the experimental scenarioes were set up, and the climatic effects were investigated by using general circulation model (GCMs). From the results, it was found that the plume remained in the lowest few kilometers of the troposphere, and most of smoke was in the source region with the smoke being rather rare for up to a few thousands kilometers downward. It was also found that the smoke had significant environmental effects in the source region with the daytime maximum temperature having dropped 10 ℃, acid rain and "black" snow occurred out to distance of one thousand kilometers, and the change of Asian summer Monsoon was unlikely to exceed the natural interannual variability. During one year's integration time, the state of deep sea was hardly influenced. In addition, the effects of oil fire on climate seemed to be less than that of the anomalous SST.

In present study, after introducing our numerical model and the experimental scenario, we will give the model's prediction of the general circulation and weather conditions, as well as experimental results of how Kuwait oil fire and the volcanoes influencing the Asian general circulation and climate.

2 The model

From fluid-dynamics, a set of equations is built up to describe the state of global atmosphere, sea, and sea ice. This is so-called general circulation model (GCM). Because of its nonline-arity, the equations have to be solved by numerical method. Up to date, many GCMs have been developed in the world, which are widely applied in the studies of climate predictability, greenhouse effects and so on. In this study, the model set-up is an extention of OSU atmospheric general circulation model coupled to a mixed-layer ocean model (OSU AMOGCM), which is basically the same as the model described by Schlessinger (Schlessinger, 1989) and Zhao (Zhao, 1991). This is a two-layer prolimitive equation AGCM formulated using normalized pressure as the vertical coordinate with the top at 200 hPa, and surface orography as resolved by a 4－5℃ latitude-longitude grid. The atmospheric model predicts the atmospheric velocity, temperature, surface pressure and water vapor, and the surface temperature, snow

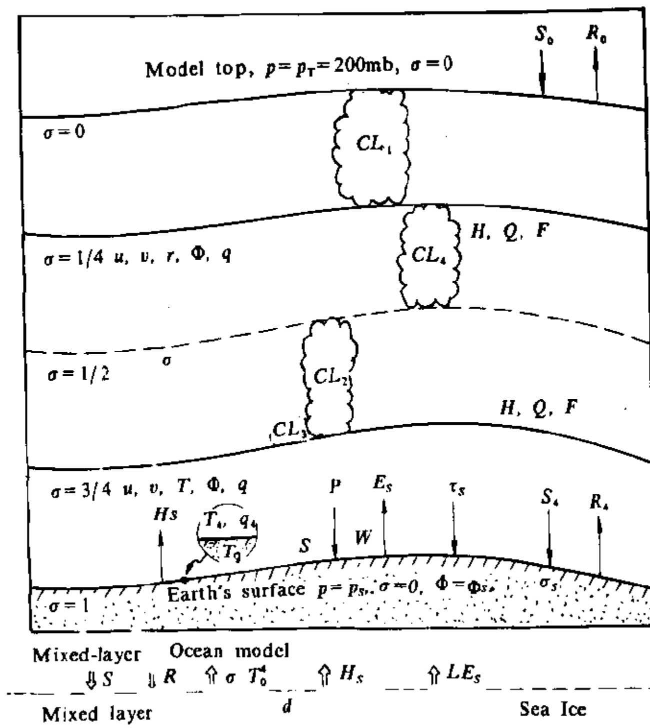

Fig. 1 The vertical structure and principle variables of the OSU AMOGCM

mass, soil water and clouds. The depth of the mixed-layer ocean model is 60m, with a pure thermodynamical sea ice calculation, which predicts the oceanic mixed layer temperature and sea ice thickness. Fig. 1 is the vertical structure and principle variable of the model. This model has been investigated the global annual-and-seasonal simulations to compare with the observed data. The results have presented the nice simulation (Schlessinger, 1989). This model has also been used to do the greenhouse effects simulations (Schlessinger, 1989). Both the model and these results have been included in the Scientific Assessment of the Intergovernmental Panel on Climate Change (IPCC) in 1990.

In Fig. 1, $\sigma = (P - P_T)/(P_S - P_T)$, where P is pressure, P_T the constant pressure at the model top and P_S the variable pressure at the earth's surface, u and v are the eastward and northward velocity components, T the temperature, Φ the geopotential, q the water vapor mixing ratio, S and R the net downward solar and net upward terrestrial radiation at the top of the model atmosphere (subscript 0) or at the earth's surface (subscript 4), αs the surface albedo, H, Q and F the diabatic heating, moisture source and friction. Hs the surface sensible heat flux, p the precipitation rate, Es the surface moisture flux, the surface momentum flux, S the snow mass, and w the ground wetness. CL1-CL4 denote the model's cloud types. In the mixed-layer ocean, S and R are the downward solar radiation and the atmospheric long-wave radiation respectively, $\sigma\ T_C^4$ the net upward surface flux of longwave radiation, Hs and LEs the net upward surface flux of sensible heat and latent heat.

Having modified some physical parameters and high latitude's calculation, we get this AMOGCM. Schlessinger (Schlessinger, 1989) and Zhao (Zhao, 1990) have applied the OSU AMOGCM in studying the greenhouse effects, and valued its modelling ability quite well. Since the height of oil smog being quite low and the model having considered the interaction between the atmosphere and the mixed-layer ocean, the model might be suitable for our study.

3 Initial field and experimental scenario

The scenario of smoke experiment is designed according to the surface and satellite observations, and the simulations obtained from Browning (Browning, 1991), Bakan (Bakan, 1991), Aldhous (Aldhous, 1991) and Small (Small, 1991). The observed and simulated data have shown that the soot injection normally did not exceed a height of $1-2$ km, the highest height was lower than $3-4$ km. The smoke of the burning oil wells centralized within the source of Kuwait and nearby. The smoke intensity with the distance of the source decreased obviously. Due to decreasing the injection of solar radiation on the surface, the observed maximum temperature in Kuwait decreased by about -10 ℃ . Therefore, according to the results from the observations and other simulations, the scenario in our smoke experiment considers influence in the radiative budget.

With the real data of February 28, 1991, when Iraq withdrew from Kuwait, as the initial field, we have integrated smoke sensitive experiment (SE) and control experiment (SE) and control experiment (CE) for six months to August 31, 1991, respectively. In the initial field, the atmospheric components and SST are the observed data released by NMC of China, while other variables such as ground temperature, wetness and snow mass are substituted by our former simulation, except the ice mass which is replaced by October's climatological data.

Since having paid attention on the effects of oil fire and volcanoes' eruption on large scale circulation and climate, we design the experimental scenario which focuses on the role of their smoke in the earth's radiation budget. Considering the satellite's and conventional observed data and using the experimental results of other model groups, we set up a smoke intensity parameter alpha which is within the scope of 0 to 1. Under the influence of smoke, the insolation radiative flux on the ground reduced 100% while there was a corresponding rise of absorbed solar radiative flux at lower part of troposphere by air. The alpha's distribution is shown in Fig. 2.

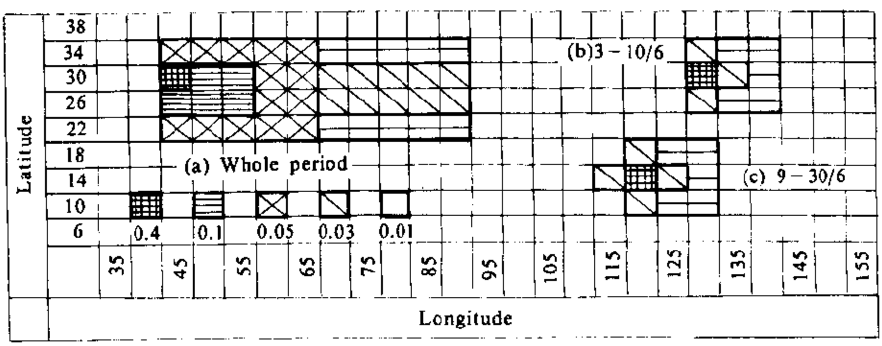

Fig. 2 The distribution of smoke intensity parameter alpha

a. Kuwait oil fire; b. Unzendake Kazan; c. Mount Pinatubo

Volcano's smoke affects radiation budget both in stratosphere and in troposphere. As soon as a volcano erupts, the aerosol may tower to stratosphere quickly, a great deal of aerosol suspending and spreading there, which may lead to the long-range climate change. In troposphere the volcano's aerosol could suspend only in a short bout, and most of them deposit to ground in a few days, therefore the smoke's radiative effect takes place during the eruption generally. In this study, because of the model being integrated not more than three months after the volcanoe's eruption (from June to August), and the model atmosphere's top being at 200 hPa, we assume the volcanoes' radiative effects only in troposphere, which similar to that of the oil fire. SE contains effects of Unzendake Kazan from 3 to 10 and Mount Pinatubo from 9 to 30 in June, respectively. Since the experimental scenario being roughly treated in some aspect and excluding the effects of SST and ice cover of 1991, this work might be looked upon as an explorative work to some extend.

4 Forecasting results

Because the initial field of the integration is mostly observative, *CE* could be considered as a prediction of the general circulation and weather conditions in that period (Wang, 1992).

The 500 hPa height field and some important synoptic components in the Asia-Pacific region from March to August, 1991 were analyzed. From the monthly areal index of ural high and North Pacific subtropical high from March to August (Table 1), it is noticed that just similar to the observation, the both highs were getting stronger and stronger with the peaks in May – June – July. This does be the important feature of the circulation in the Asia-Pacific region which caused the China's flood in 1991. By comparing the predicted rainfall with the observed, it is found that, in six months predictions, four month's are rather well and two fail. In Yangtze-Huaihe river's basin, the forecasted rainfall was quite heavy in May and July, especially in July, during that month the heavy rainfall in Yangtze-Huaihe river's basin and drought in south China are forecasted quite well. With some transformation, the model's prediction of tropical SST anomaly is analyzed (Table 2), which was positive and getting larger and larger along the eastern tropical Pacific region from March to August, rather like the observation for the period. All these forecasting results lay a foundation for our further investigation of the smoke's influence on climate.

Table 1 Monthly areal index of ural high (IU) and northwest Pacific subtropical high (IP) from March to August, 1991

	Month	3	4	5	6	7	8
IP	Forecast	18	11	19	34	48	47
	Observed	6	14	50	72	49	23
IU	Forecast	0	3	15	35	35	34
	Observed	0	15	19	30	25	16

Table 2 Predicted SST anomalies

(Unit: ℃)

Month	3	4	5	6	7	8
Region						
NINO3	0.63	0.93	1.76	2.58	3.31	4.16
NINO4	1.28	1.02	−0.07	−0.03	−0.16	−0.43
W. Indial	2.12	−1.92	−1.20	−0.06	−0.28	0.69

Notes: each region is defined on < < Climate monitoring bulletin> >

5 Climate and weather changes due to smoke's effects

The climate and weather changes due to the smoke effects are computed by means of *SE* minus *CE* for the general circulation and climate.

5.1 General circulation change in Eurasia

As discussed above, unusual intensity of both ural high and northwestern Pacific high were the major Eurasian circulation characteristic features in the spring and summer, 1991, which were the important causes of China's flood for the period. To know whether there was any connection between these circulation anomalies and the smoke, the areal index of these two highs were analysed and shown in Table 3. It is found that due to the influence of smokes, the highs were weakened, i. e., the smoke caused a negative impact on their growth.

Table 3 The change of areal index by *SE* minus *CE*

Month	3	4	5	6	7	8
IP	−4	8	−3	−7	−7	−13
IU	0	−6	−9	−5	0	0

5.2 Weather changes in Asia

It is noticed from the experimental results of the monthly surface air temperature (*Ts*) and precipitation rate (*Pr*) that the oil fire smoke had significant effects in the Gulf region, *Ts* having dropped considerably in almost every month while there being hardly any consistent tendency in Pr's monthly changes. There was little influent outside the Gulf region, such as in east Asia, where the changes of *Ts* were within the range of $-1-+1$ ℃, and $-1-+1$ mm/d for *Pr* from March to August, generally, Fig. 3 shows the distribution of the changes of *Ts* and *Pr* in April. It is found that due to the influence of smoke, the simulated *Ts* dropped by $2-4$ ℃ with the maximum cooling of about 7 ℃ in the Gulf region, while dropped by about 1 ℃ in Pakistan and some part of former Soviet as well as varied within the extent of -1 to $+1$ ℃ in China. *Pr* in the south of Pakistan Gulf had dropped, with the maximum of -3mm/d in north Arabian Sea, quite little in other regions.

Since the volcanoes erupted in June, their influences were introduced to *SE* on the background of the oil fire. In the distribution of varied *Ts* (*SE*$-$*CE*), it is found that the smoke might lower *Ts* in June near the smoke's sources, such as in Philippines and Japan.

In the spring and summer, 1991, there were many climate anomalies in Asia, such as the flood in south Iran and Saudi Arabian midland in March, the April's heavy drought in Sindh, Pakistan, Bangladeshe's severe landing strong tropical storms from

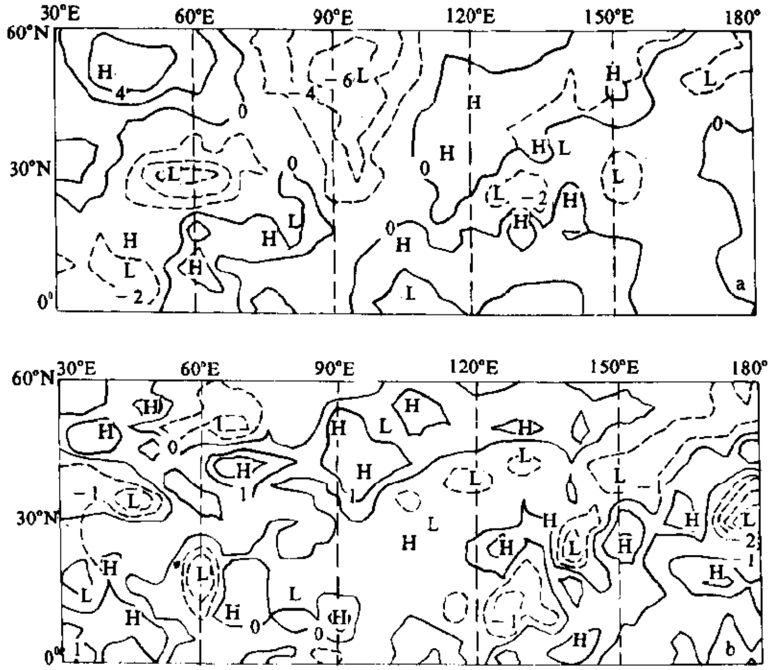

Fig. 3 The distribution of anomalous surface air temperature (top, unit: ℃) and precipitation rate (bottom, unit: mm/d) by *SE* minus *CE*

April to June, the maximum rainfall for the last 30 years in south and west India in June as well as the exceptionally torrential rain and flood in Yangtze-Huaihe rivers' basin along with the quite heavy rainfall in north and northeast China and drought-and-hot weather in south China from May to July (Climate monitoring bulletin, climate data office/NMC, China). By chance, Kuwait oil fire and the volcanoes' eruption appeared during that period. In order to evaluate the influence of smoke on the regional rainfall and model's regional climate predictability, a set of evolving perspectives on the rainfall variations over Asia is presented in Fig. 3 by accumulating *SE* and *CE* rainfall (Ra) from March 1st to the end of August, for selected model grid-points which represent some sites of Asia.

It is shown that the rainfall in Ar-Riyad increased due to the smoke (Fig. 4a). Ra (*SE*) in Zahedan was a bit less than Ra (*CE*) before May and quite more than Ra

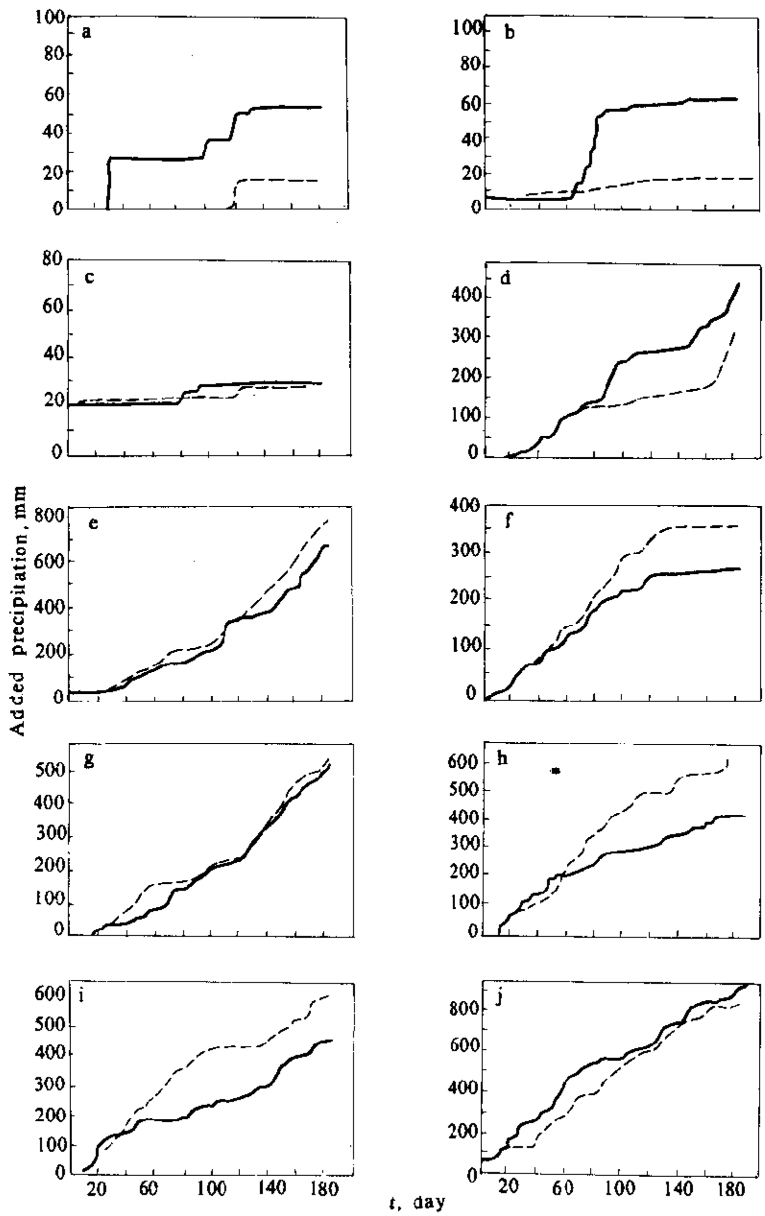

Fig. 4 Accumulated rainfall amounts from March 1st until the end of August for the *SE* (solid) and the *CE* (dotted), each panel is for one of the sites illustrated as below:
a. Ar-Riyad, Saudi Arabic; b. Zahedan, Iran; c. Sindh, Pakistan; d. Dhdaka, Bangladesh;
e. Hyderabad, India; f. New Delhi, India; g. Harbin, China; h. Beijing, China;
i. Bengbu, China; j. Guangzhou, China.

(*CE*) afterwards (Fig. 4b). Both Ra (*SE*) and Ra (*CE*) were almost identical in Sindh during the period and did not rise from mid-March to mid-May (Fig. 4c). In Dhdaka, Ra (*SE*) was near Ra (*CE*) before mid-May, then rose quickly and was much higher than Ra (*CE*) with the biggest increament appearing at the beginning of June (Fig. 4d). The plot of New Delhi (Fig. 4f) indicates that Ra (*SE*) was almost equal to Ra (*CE*) before July, and less than Ra (*CE*) afterwards, with the total decreament of about 100mm in the whole period, while Hyderabad's Ra (*SE*) being similar to its Ra (*CE*, Fig. 4e). In China, Ra (*SE*)s were quite identical to Ra (*CE*)s in Harbin and Guangzhou, but Beijing's Ra (*SE*) was lower than its Ra (*CE*) evidentily after May, and so was the Bengbu's which represented Yangtze-Huaihe river's basin (Fig. 4g−j). In conclusion, the effects of smoke on regional climate increased the rainfall in West Asia and dropped the precipitation of India weakly, but decreased the rainfall in north China and Yangtze-Huaihe river's basins and had hardly any influence in northeast and south China. One could not concluded that the smoke led to China's flood in 1991.

5.3 SST

For the period, the significant characteristics of global SST were the warming along the tropical Pacific region and cooling in the west India Ocean, with the maximum of about +2 ℃ and − 3 ℃, respectively. Is there any relation between the smoke and SST anomalies? The SST index (*SE* minus *CE*) of both regions are shown in Table 4. It is found that the variance of SST due to the smoke was

Table 4 Regional average SST (*SE*−*CE*)

(Unit: °C)

Month	3	4	5	6	7	8
Region						
NINO3	−0.01	−0.11	−0.28	−0.25	−0.25	−0.16
NINO4	−0.02	−0.02	−0.07	−0.18	−0.18	−0.16
W. Indian	0.00	−0.04	−0.06	0.04	−0.07	−0.11

Notes: each region is defined as Table 2.

considerably little, with the maximum of 0.28 ℃. As the direct impact of smoke, SST dropped slightly along the east part of the tropical Pacific region and hardly varied in the western Indian Ocean, i. e., smoke had scarcely any influence to SST.

6 Conclusions and discussions

The results as simulated by our AMOGCM have shown that the effects of the smoke on climate were obvious in the sources of smoke and were not significant on other regions (such as China) in the spring and summer, 1991.

The further investigation will focus on the other factors caused the floods along Yangtze-Huaihe river's basin during that period.

Acknowledgements— We would like to thank Ying Hong and Zhang Yuling of Beijing University for their constructive suggestions to this research. We also wish to express our gratitude to Ding Yihui for his help.

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(Received November 4, 1992)