УДК 551.555.8:519.6(510)

MESOSCALE NUMERICAL EXPERIMENTS OF DEVELOPING MECHANISM FOR THE "93.5" BLACK STORM AND PARAMETERIZATION OF SAND-DUST TRANSPORT

LINSHENG CHENG AND CHUNTAO LIU

Результаты моделирования, основанные на мезомасштабной численной модели ММ 4, показали, что образование и развитие черной бури "93,5" прямо связано с генезисом циклонического вихря в нижней тропосфере. Модель включает параметризированную схему выноса,переноса и осаждения песчано-пылевой массы.

The black storms are a mesoscale system with severe destructibility in the Northwest Region of China, the people's subsistence environment is directly threatened by them. Synoptic analysis indicatted the "93.5" black storm not only related a specific large scale circulation and intensive front zone in the mid- and lower-levels as well as desert underlying surface, but also was in close relationship with intense allobar and developing mesoscale high and low at surface; the intensive cold front associated with the black storm to prossess the property of squall line. The results of the control simulation, which based on mesoscale numerical model MM4 with high resolution PBL parameterization and 40km fine-mesh, found that the formation and development of the "93.5" black storm was directly related to the genesis and intense development of a mesoscale cyclonic vortex in lower troposphere, a favorable allocation of the vertical vorticity column of the vortex was an important dynamic mechanism of intense development of driving black storm, while the extraordinary strong baroclinity in the mid- and lower-layers of troposphere and warm-cored structure in the PBL were thermal and convective instability condition of intensive development of the

Публикуется по Соглашению о научно-техническом сотрудничестве между Главным управлением по гидрометеорологии Республики Казахстан и Метеорологическим управлением Китайской Народной Республики.

black storm. In order to study a mechanism for driving and elevating as well as transporting and deposition of the sand-dust for the black storm, a parameterized scheme of source and sink terms for sand-dust and an equation of transporting sand-dust were achieved and posed, while both the scheme and the equation were introduced to the mesoscale model and simulation system for MM4 as mentioned above. Applying the improvedand developed model and simulation system to achieve successfully simulations for driving and elevating as well as transporting and deposition of the sand - dust for the "93. 5" black storm. The analyses of simulated results indicated that even if using the conventional observation data, the genesis and devel opment as well as structural evolution of the black storm mesoscale system could be also simulated when the mesoscale numerical model with basically perfect physical processes and with higher spatial resolution as well as a larger simulative domain. The results also revealed that adopting mesoscale numerical model included the parameterized scheme of source and sink terms for sand - dust and the equation of transporting sand - dust is a quite well method with applying prospects to study the black storm.

1. Introduction

The black storm is a suddenly outbreak and extraordinary severe storm with huge sand-dust while the instantaneous wind speed is greater that $25ms^{-1}$ and the visibility is less that 50m or near zero. This black storm is a mesoscale weather system with severe destructibility in the Northwest region of China and were frequent occurence in the Spring since 1952. A typical case of the extraordinary severe sand-dust storm was the ""93.5" (4-6 May 1993) black storm and it swept four Provinces and Autonomy Regions from west to east in China, which included the Gobi of east Xinjiang Autonomy Region, Nexi Corrido of Gansu Province, Badan Jaran Desert and Tengger Desert in Nei Monggol Autonomy Region. The people were hurted 264 and died 85 as well as missed 31; 5.55 million mu (15mu = 1hectare) farming fields and crops were destroied; 0.12 million livestock were died. The property damage incurred was close to 7.25 billion RBM (Yang et al., 1993).

Because of this severe disaster of the sand-dust storm, particularly the black storm, the many countries pay great attention to this kind of mesoscale weather system. As early as 1925 the black wind in Sudan of Northeast Africa was reported by Sutton, and then Idso (1972) reported a sand-dust storm in Arizona of the USA. However, the meteorologists paid more attention to study the Saharan dust storm. The general characteristics of synoptic-scale outbreak of Saharan dust over the tropical Atlantic Ocean have been studied from satellite imagery, two field programs (BOMEX and GATE) and diagnostic analysis (Carlon and Prospero, 1972; Carlson and Caverly, 1977; Carlson, 1979; Ott, et al. 1991); Carlson and Benjamin (1980) used a combined longwave and shortwave radiative transfer model to study the effects of Saharan dust on the radiative fluxes and heating/cooling rates in atmosphere; The analysis and large-scale numerical simulation for the Saharan Air Layer (SAL) and the mobilization and transportion of Saharan dust have been investigated by Karyampudi and Carlson (1988) and Westphal et al. (1988). In our contry, Xu et al. (1979) analysed an extraordinary heavy sand-dust storm in Gansu. In after years, there were a few synoptic analyses for severe sand-dust storms and black storms in Northwest and North Region of China; In recent years, the investigation of the black storms in Northwest Region of China was paid more attention, particularly the "93.5" black storm. The synoptic cause of this black storm have been analysed (Chen et al., 1993; Wang, et al., Jiang, 1995); Chen et al., (1995) used a two-dimensional model and idealized simulation to examine the effect of dust radiative heating on surface frontgenesis. Cheng et al., (1995, 1996) used the improved MM4 with high resolution PBL and fine - mesh to study the influence of mesoscale model resolution on the evolutive simulation of the "93. 5" black storm. Hower, up to date, there are very sew the study of numerical simulation concerning the developing mechanism of the black storm and the formation and transportion for sand-dust of the black storm in Northwest Region of China. For this purpose, we use the improved MM4 while with parameterized scheme of driving and elevating surface sand-dust and with an equation of transporting sand-dust to study the developing mechanism and the transportion of sand-dust for the "93.5" black storm.

2. Synoptic analysis briefly

2.1. Intensive frontal zone and severe cold front

Large-scale synoptic analyses on 500 hPa, 700hPa and 850 hPa during this period indicated that a rigde over Ural Mountains was rapidly developed while a developing cold trough over Xinjiang region moved eastwards and extended southwards, meanwhile, the frontal zones over lower levels were particular intensity, the temperature difference on 850hPa and 700hPa at 0000 UTC 5 May reached 12 °C/3Lat. and 20 °C/5Lat. (Fig 1a, b), respectively. The intensive frontal zones over lower levels were in company with a severe cold front at surface (Fig.2.).

2.2. Jump of meteorological elements and ""black wind squall line"

Based on the surface observed data at stations in Hexi Corridor of Gansu Province, obvious jump of meteorological elements in both sides of cold front can be seen when the severe cold front passed the stations Hexi of Gansu. Such as the time-varying curves of the meteorological elements at Jinchang station is shown Fig.3. We can see from Fig.3 this severe cold front companied by this black storm was possessed a character of squall line, it is also called "black wind squall line".

2.3. Intensive allobar and mesohigh with mesolow at surface

We can see from Fig. 4a, positive allobar for 3 hours ($+\Delta P_3$) behind cold front reached +4. 3hPa at Dingxin station, while $-\Delta P_3$ ahead cold front

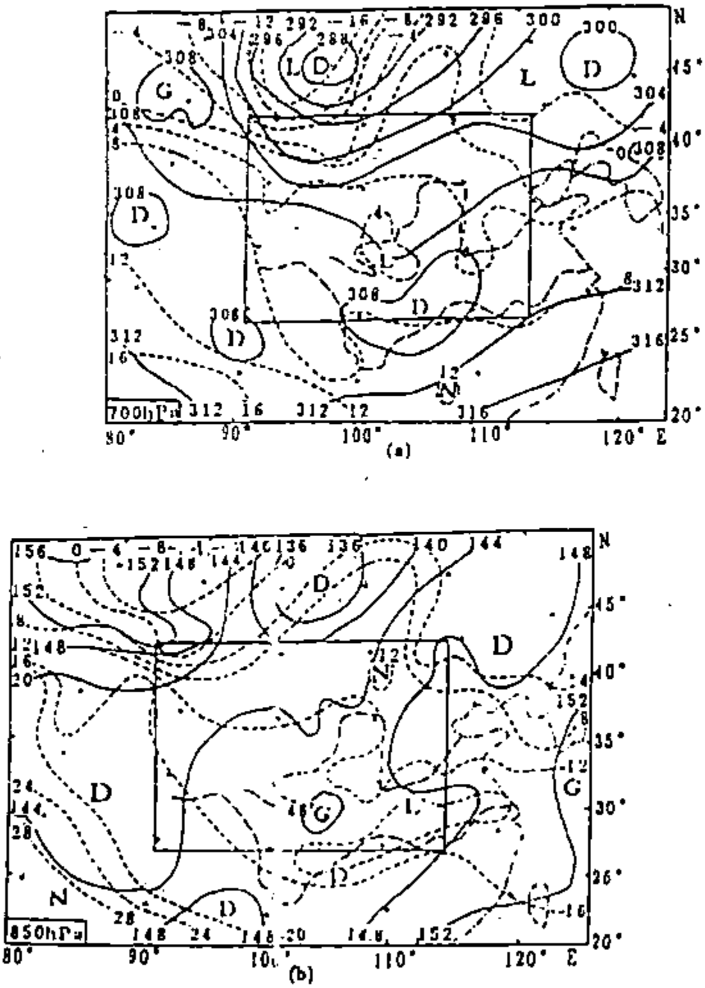


Figure 1. (a) 700hPa and (b) 850hPa analysis at 0000 UTC 5 May 1993. Solid lines are isohypses; dashed lines are isotherms °C

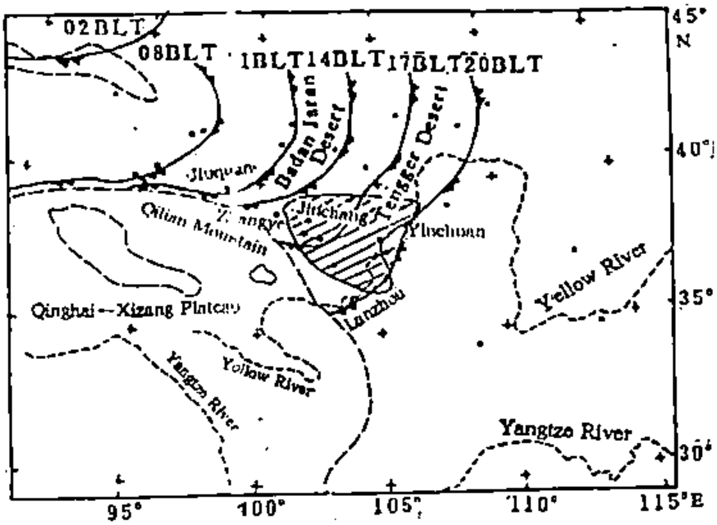


Figure 2. The consecutive movement of the cold front and the underlying surface condition as well as the black storm area

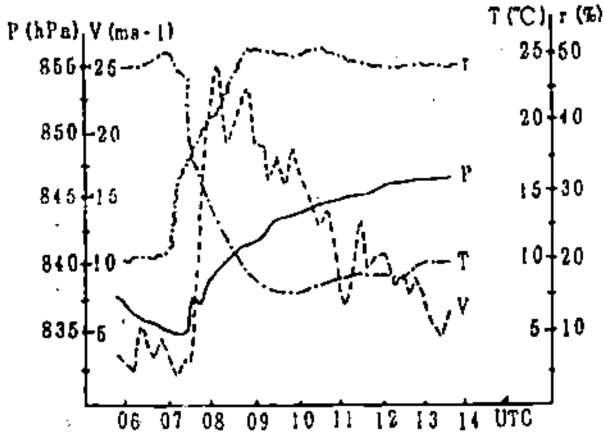


Figure 3. The time-varying curves of the pressure (P), temperature (T), relative humidity ® and wind speed (v) after 0500 UTC 5 May 1993 at Jinchang station

reached -4. 7hPa at Qilian station; The quite intensive allobaric gradient in both sides of the surface front was an obvious feature for the "93.5" black storm. So that the instantaneous wind speed reached 34ms^{-1} at 0754 UTC (1554 BLT) 5 May at Jinchang station: And then a mesohigh behind the cold front and a mesolow ahead the cold front were generated and developed (Fig. 4a, b).

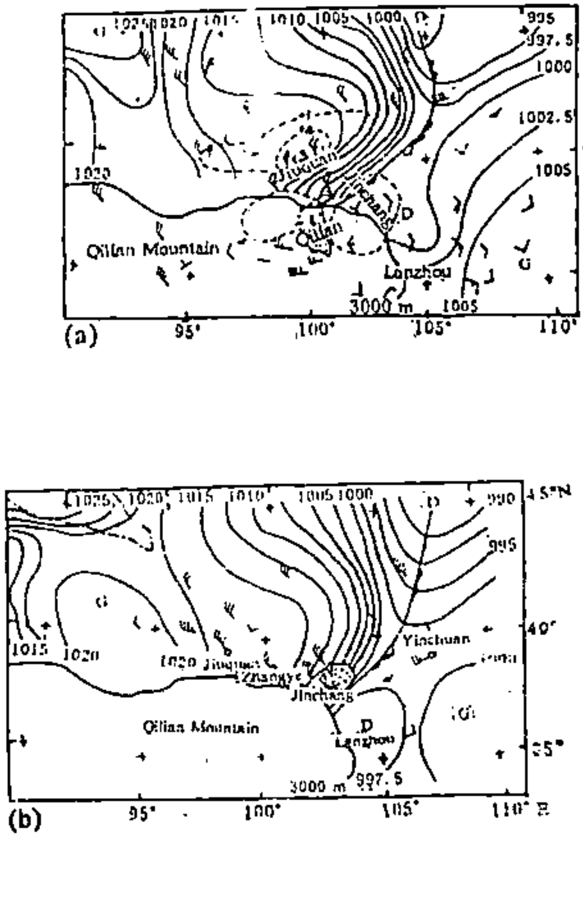


Figure 4. Regional surface synoptic analysis at (a) 0600 UTC (1400 BLT) and (b) 0900 UTC (1700 BLT) 5 May 1993. Solid lines are isopiestic, dashed lines are isophasm; reprints the black storm area

Based on the analysis as mentioned above, the genesis and development of the "93.5" black storm were not only related to the interaction between the large-scale circulation and mesoscale systems, but also related to a worse environment and a bare underlying surface with a vast desert and loose loess. Therefore, a key scientific problem of forecasting this kind of disastrous mesoscale weather systems is further to study their genetic and developing physical mechanism using mesoscale numerical simulative method.

3. Mesoscale simulation of the development of the "93.5" black storm

The observation based on the stations of Hexi, the outbreak of the "93.5" black storm occurred about 0740 UTC (1540 BLT) 5 May between Shandan and Jinchang stations and then moved eastward. The black storm area can be seen from Fig. 4b. So, one question must answer, namely, why does the black storm occur this area and such a period of time? For this purpose, we hope to answer through mesoscale numerical simulation.

3.1 Control simulation

The mesoscale model used in this study is MM4 of PSU / NCAR, which described by Anthes et al. (1987) and further discussed by Cheng (1994), some improvements and modified have been done. The main points of this version for control simulation are as follows:

Definable model parameters and radices: the vertical coordinate, $\sigma = (p - p_t) / (p_s - p_t)$; the constant pressure of the top of the model, p_t = 100hPa; the number of a levels, $k_\sigma = 16$; grid length, d = 40km; the computational domain contains an array of grid points, N = 46 x 61; the center of computational domain, C = 38°N / 103°E; the simulative domain is inner rectangular region in Figure 1.

Initial condition: Chinese NMC (T_{42}) global analysis + sounding data.

Lateral boundary condition: the time - dependent sponge boundary, the large - scale tendency is obtained by interpolating the 12h analysis linearly in time.

Planetary boundary layer (PBL) physical process: Blackadar's high resolution PBL parameterization.

Surface physical process: including surface heat, moisture and momentum fluxes is inhomogeneous surface; some unreasonable enough parameters in parameterized formulas have been revised based on HEIFE data.

Ground temperature: it is predicted from a surface energy budget and a slab model, in which the radiative fluxes depend on the model predicted.

Cumulus convection parameterization: using Anthes - Kuo's scheme.

Nonconvective parameterization: the excess condensation over saturation is removed as precipitation and latent heat is added to the thermodynamic equation. No evaporation is allowed in unsaturated layers.

Model topography: it is obtained by analyzing the NCAR 30 - minute terrain data using mesoscale objective analysis scheme.

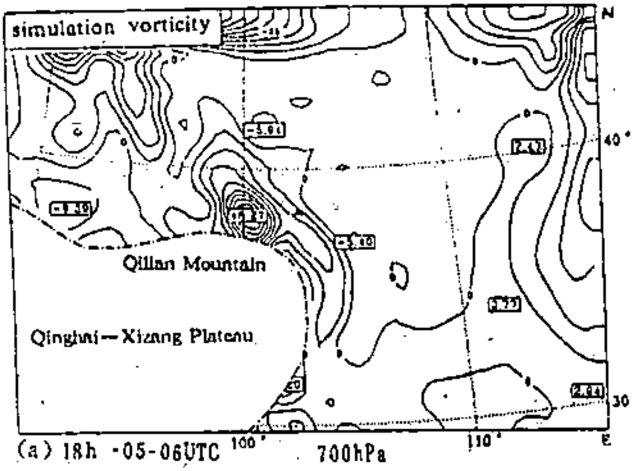
Pressure gradient force (PGF) caeculation in steep terrain: aborting a separated method of variables through defining horizontally invariant reference state from model's initial condition and time - dependent perturbation state, so that the PGF only needs to evaluate from perturbation state.

Simulative period of time: 24 hours, namely, from 1200UTC (2000BLT) 4 May to 1200UTC (2000BLT) 5 May 1993.

3.2. Results of control simulation and developing mechanism of "93.5" black storm

We found based on analysis of control simulated results for 24 hours that from 0600UTC (1400BLT) 5 May (simulated 18 hours), a mesoscale cyclonic vortex suddenly generated and developed over lower levels nearby the west of Jinchang (Fig. 5a), the location of the vortex was basically in a strong convergence area between the positive and negative allobar centers (Fig. 4a), the intensity of the vorticity center reachead 48,27 x 10^{-5} s^{-1} on 700hPa (Fig. 5a); after 3 hours, namely 0900 UTC (1700 BLT), this vortex moved to east and persistent intense developed (Fig. 5b), the intensity of the vorticity center reached 62,20 x 10^{-5} s^{-1}. The simulated results were consistent and synchronous with genesis and intensive development of the black storm, moreover, this intense developing vortex area (Fig. 4b). was basically consistent with the observed black storm area (Fig. 5a), Besides, the mesolow (mesohigh) ahead (behind) the black storm was also obviously developed from 0600 UTC to 0900 UTC 5 May on simulated vorticity fields (Fig. 5). UP to 1200 UTC (2000 BLT) 5 May (simulated 24 hours), the intensity of this mesoscale vortex was also maintained during the period of moving to east, there was only a little weakening in the surface layer, this result was also consistent with the evolution of the black storm. We can see from the discussion as mentioned above that the genesis and development of the "93.5" black storm was in close relationship with the intense development of the mesoscale cyclonic vortex in the lower levels.

We also found from the vertical structure of the mesoscale cyclonic vortex in Fig. 6 that an intense developing cyclonic vorticity column stretched from the surface to 400hPa while an anticyclonic vorticity column just superposd over it. The physical essentiality of the vorticity column structure for the black storm is the following. There was intense convergence inflow in lower levels and associated with intensive ascending motion while there was intense divergence outflow and associated with asymetric descending motion, as a consequence, the intense ascending motion in the vorticity column of the black storm was driven and persistent developed, the horizontal wind speed over the surface and lower levels was continuously intensified; in the meantime, the descending flow in the periphery of the black storm, particularly the descending flow behind the black storm was able to induce the genesis and development of the surface mesohigh. The observed result was indeed so (Fig. 5b).



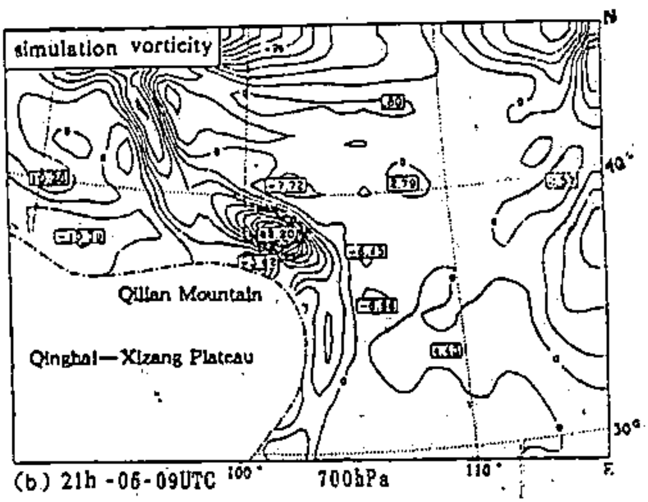
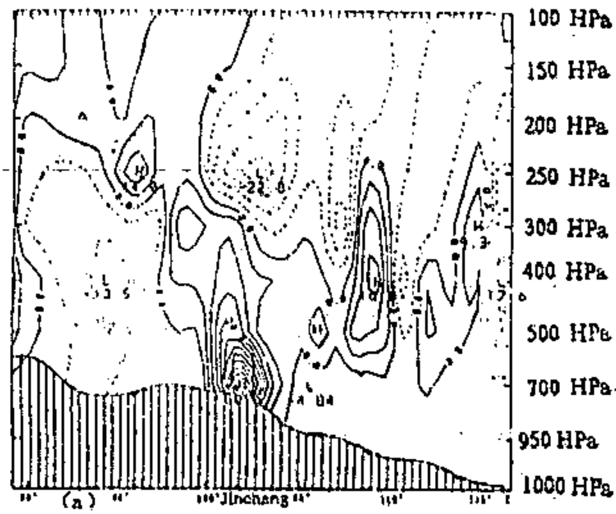


Figure 5. The 700hPa vorticity fields for (a) 18h and (b) 21h for control simulation verifying at (a) 0600UTC (1400BLT) and (b) 0900UTC (1700BLT) 5 May 1993. Contour interval for vorticity is $5 \times 10^{-5} s^{-1}$. The heavy dot - dashed line indicated the 3000m terrain contour. represents Jinchang



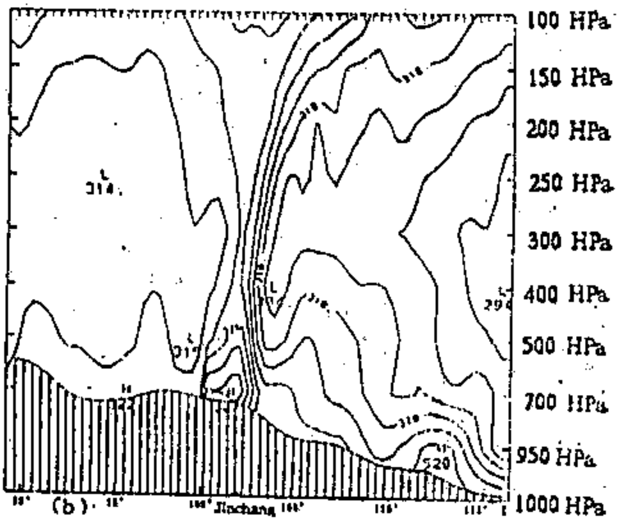


Figure 6. The West - East vertical cross section of (a) vorticity ($5 \times 10^{5} s^{-1}$) and (b) equivalent potential temperature (K) through the vorticity center (Fig. 5b) nearby Jinchang

Thus it can be seen that the development of the black storm was in directly relationship with the vertical and dynamic mechanism of the companied mesoscale vortex. Besides, we also can see from Fig. 6b that the black storm was generated and developed under extraordinary intense thermal contrast condition in the lower levels, even in whole air column; moreover. the warm-cored structure of the black storm in the PBL made this mesoscale system possessing obvious convective instabilit. This was an important thermodynamic condition for developing of the black storm.

4. Transport equation of sand-dust and parameterization for the source and sink terms of sand-dust

4.1. Transport equation of sand-dust

The dust or sand-dust can be considered an aerosol material in the atmosphere, thus it is similar to the conservation relation for aerosol contaminants, the conservation relation for the sand-dust material can be expressed mathematically as

$$\frac{dC}{dt} = S_c - D_c \quad \text{or} \quad \frac{\partial C}{\partial t} = -\vec{V} \bullet \nabla C + S_c - D_c, \tag{1}$$

where C is the mass for the sand-dust material in unit volume, namely, the sand-dust concentration; S_c and D_c are the source and sink term for the sand-dust, respectively; V is the wind vector, ∇ is the gradient operator. The eqution (1) can be transformed into a flux form in the modified terrain-following sigma (σ) coordinates system with the map scale factor; i.e.

$$\underset{1}{\frac{\partial p^*C}{\partial t}} = \underset{2}{- m^2 \left(\frac{\partial p^* uC/m}{\partial x} + \frac{\partial p^* vC/m}{\partial y}\right)} - \underset{3}{\frac{\partial p^* \delta C}{\partial \sigma}} + \underset{4}{S_c} - \underset{5}{D_c}, \tag{2}$$

where $\sigma = (p - p_t) / (p_s - p_t)$, p is pressure, p_s is surface pressure, p_t is the pressure at the top of the model atmosphere, m is the map scale factor for Lambert Conformal projection, $p^* = p_s - p_t$; term 1 is the tendency of sand-dust concentration with weight p*, terms 2 and 3 are the horizontal and vertical flux transport of sand-dust with werght p*, respectively; terms 4 and 5 are the source and sink of sand-dust in σ coordinates system.

4.2. Parameterized scheme for the source and sink terms of sand-dust

Based on the synoptic analysis of the formation for the black storm as mentioned above, we suggest the following parameterized scheme for source and sink of sand-dust:

The eqution (1) can be transformed into a flux form in the modified terrain-following sigma (σ) coordinates system with the map scale factor, i.e.

$$\underset{1}{\frac{\partial p^*C}{\partial t}} = - m^2 \underset{2}{\left(\frac{\partial p^* uC/m}{\partial x} + \frac{\partial p^* vC/m}{\partial y}\right)} - \underset{3}{\frac{\partial p^* \delta C}{\partial \sigma}} + \underset{4}{S_c} - \underset{5}{D_c}, \qquad (2)$$

where $\sigma = (p - p_t) / (p_s - p_t)$, p is pressure, p_s is surface pressure, p_t is the pressure at the top of the model atmosphere, m is the map scale factor for Lambert Conformal projection, $p^* = p_s - p_t$; term 1 is the tendency of sand-dust concentration with weight p^*, terms 2 and 3 are the horizontal and vertical flux transport of sand-dust with werght p^*, respectively; terms 4 and 5 are the source and sink of sand-dust in σ coordinates system.

4.2. Parameterized scheme for the source and sink terms of sand-dust

Based on the synoptic analysis of the formation for the black storm as mentioned above, we suggest the following parameterized scheme for source and sink of sand-dust:

$$S_\sigma(\sigma) = \begin{cases} 0 & u_* < u_{*c} \text{ or } q_{vs}(T_g) > q_c, \text{ or } L_d \neq L_d(9) \qquad (3) \\ F_0 u^4_* L_d & u_* \geq u_{*c} \text{ are } q_{vs}(T_g) > q_c, K_\sigma = 1, \; L_d = L_d(9) \end{cases}$$

$$D_\sigma = C'\left(\frac{m_c g}{s_D}\right)(\sigma_D + \sigma'_D) \qquad (4)$$

$$F_0 = a_0 \left(\frac{\Delta t}{\Delta s}\right)(\rho_s \rho_d), \; a_0 = A_0^2, \; A_0 = \frac{1}{k}\left[\ln\left(\frac{z_s}{z_0}\right) - \varphi_m\left(\frac{z_s}{L}\right)\right] \qquad (5)$$

where Δt is time step, Δs is mesh area of model; L_d is the parameter of the sand-dust underlying surface; ρ_d and ρ_s are densities of the sand and air at surface, respectively; $q_{vs}(T_g)$ is the saturation specific humidity at surface, q_c = 0,005Kg/Kg which is the critical value of $q_{vs}(T_g)$; u_* is the friction velocity at surface; u_{*c} is the critical value of u_*, here adopted u_{*c} = 0,6 ms^{-1}; k is Karman constant, z_0 is surface roughness length, z_s is the height observed surface wind speed; Ψ_m is nondimensional stability parameter for momentum; L is M - O length; g is acceleration of gravity; m_c is sand - dust mass in air column in unit area and m_c is related to spatial distribution of sand - dust particle size distribution; s_D is unit area; σ_D and σ'_D are air descending velocity and sand - dust dry deposition velocity in sigma (σ) coordinates, respectively.

$$S_\sigma(\sigma) = \begin{cases} 0 & u_* < u_{*c} \text{ or } q_{vs}(T_g) > q_c, \text{ or } L_d \neq L_d(9), \\ F_0 u_*^4 L_d & u_* \geq u_{*c} \text{ and } q_{vs}(T_g) > q_c, K_\sigma = 1, \; L_d = L_d(9), \end{cases} \quad (3)$$

$$D_\sigma = C\left(\frac{m_c g}{s_D}\right)(\sigma_D + \sigma'_D), \quad (4)$$

$$F_0 = a_0\left(\frac{\Delta t}{\Delta s}\right)(\rho_s \rho_d), \; a_0 = A_0^2, \quad A_0 = \frac{1}{k}\left[\ln\left(\frac{z_s}{z_0}\right) - \psi_m\left(\frac{z_s}{L}\right)\right], \quad (5)$$

where Δt is time step, Δs is mesh area of model; L_d is the parameter of the sand-dust underlying surface; ρ_d and ρ_s are densities of the sand and air at surface, respectively; $q_{vs}(T_g)$ is the saturation specific humidity at surface, $q_c = 0{,}005$Kg/Kg which is the critical value of $q_{vs}(T_g)$; u_* is the friction velocity at surface; u_{*c} is the critical value of u_*, here adopted $u_{*c} = 0{,}6\ ms^{-1}$; k is Karman constant, z_0 is surface roughness length, z_s is the height observed surface wind speed; Ψ_m is nondimensional stability parameter for momentum; L is M - O length; g is acceleration of gravity; m_c is sand - dust mass in air column in unit area and m_c is related to spatial distribution of sand - dust particle size distribution; s_D is unit area; σ_D and σ'_D are air descending velocity and sand - dust dry deposition velocity in sigma (σ) coordinates, respectively.

5. Development of mesoscale model and control simulation included equation for transporting sand-dust

When we consider parameterization of the source and sink terms for sand-dust and horizontal as well as vertical diffusions for sand-dust, the equation (2) can be expressed as follows:

$$\frac{\partial p^*C}{\partial t} = -m^2\left(\frac{\partial p^*uC/m}{\partial x} + \frac{\partial p^*vC/m}{\partial y}\right) - \frac{\partial p^*\sigma C}{\partial \sigma} + F_H(C) + F_V(C) + S_\sigma - D_\sigma, \quad (6)$$

where the horizontal diffusion $F_H(C)$ is used two types: one is a second-order diffusion, which is used the row and column of grid points next to the lateral boundaries; the other is a more scale-selective fourth-order diffusion, which is used on the interior of the grid. The vertical diffusion $F_V(C)$ is used a second-order form, the vertical eddy diffusivity is a function of the local Richardson number.

When the equation (6) is introduced to the PSU/NCAR Mesoscale Model Version 4 (MM4) (Anthes, et al., 1987), we obtained a developed mesoscale model, which included the equation (6) for transporting sand-dust with parameterized scheme for source and sink terms of sand-dust.

The control simulation here is the same as that of description in the subsection 3.1 except for initial sand-dust concentrational field needs to specify in the developed model and simulative system, which is an idealized field of horizontal uniform with very rare sand-dust.

6. Simulated results and discussion

Figure 7 (a), (b) is the horizontal distribution of sand-dust concentration near the surface for control simulated 18 hours and 21 hours, which are corresponding with Fig. 5 (a), (b), respectively, verifying at (a) 0600 UTC (1400 BLT) and (b) 0900 UTC (1700 BLT) 5 May 1993. Fig. 7 (a) shown the central value of the sand-dust concentration had reached 944, 1mg/m^3, in the mean time, the black storm had been generated and developing in the Badan Jaran Desert, while a small closed center occurred behind the main center. When the simulation was reached 21 hours, the central value of the sand-dust concentration had been increased to 1179, 0mg/m^3 near Jinchang (Fig. 7b), which was basically close to the observed value 1016mg/m^3 at Jinchang at 0830 UTC (1630 BLT) 5 May, in the meanwhile, the central value behind the main center was weakened. During this period, the black storm had been persistently developed and reached its mature stage, and moreover, its intensity was also enhanced the most intensive (Fig. 5b). UP to the simulated 24 hours, namely 1200 UTC (2000 BLT) 5 May, the central value of sand-dust concentration had been greatly decreased, but the sand-dust area was still larger; in the meantime, the black storm tended to decay (not shown).

Figure 8 is the West - East vertical cross section of the sand - dust concentration through the intense center of concentration in Fig.7b. We can see from this Figure, the sand - dust had gone up to 700hPa in the black storm area, Figure 9 is the accumulated sand - dust deposition amount at surface for control simulated 21 hours, we can obviously see a main deposition was located behind the sand - dust concentration center at surface while the deposition region was very large.

7. Conclusions

Based on the analysis and discussion concerning the results for mesoscale numerical simulation, we can obtained the following conclusions.

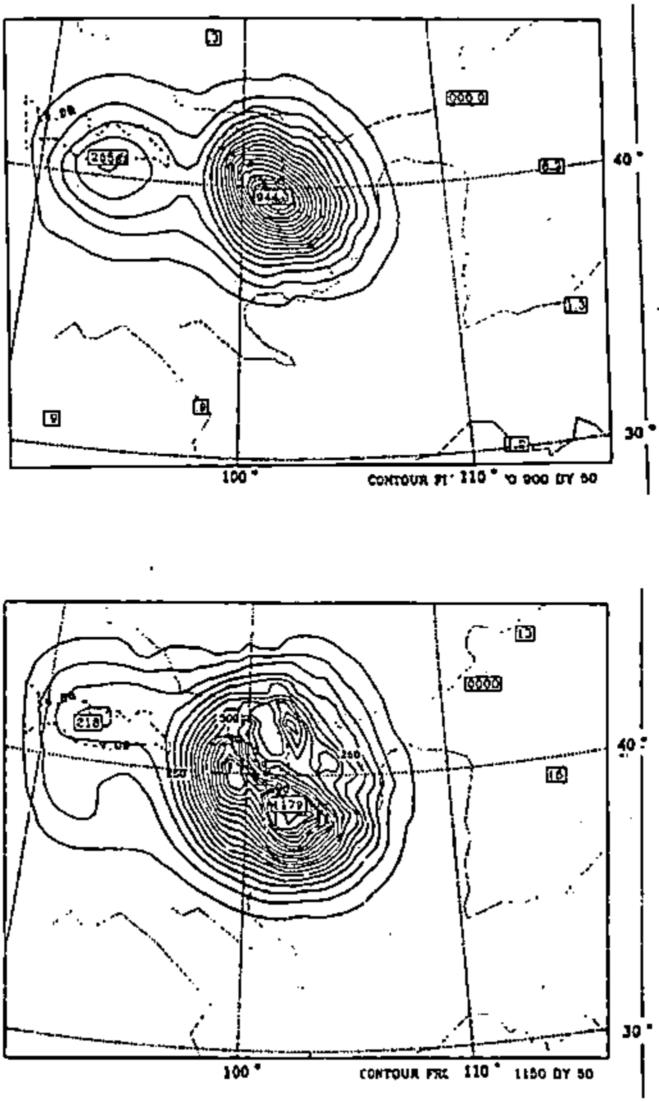


Figure 7. The sand - dust concentration fields near the surface for (a) 18h and (b) 21h for control simulation verifying at (a) 0600UTC (1400BLT) and (b) 0900UTC (1700BLT) 5 May 1993. Contour interval for concentration is 50mg/m³. represents Jinchng

The synoptic analysis indicated the genesis and development of the "93. 5" black storm not only related to the interaction between the large - scale circulation and mesoscale system as well as the desert underlying surface. The intense cold front associated with the black storm to possess the property of squall line.

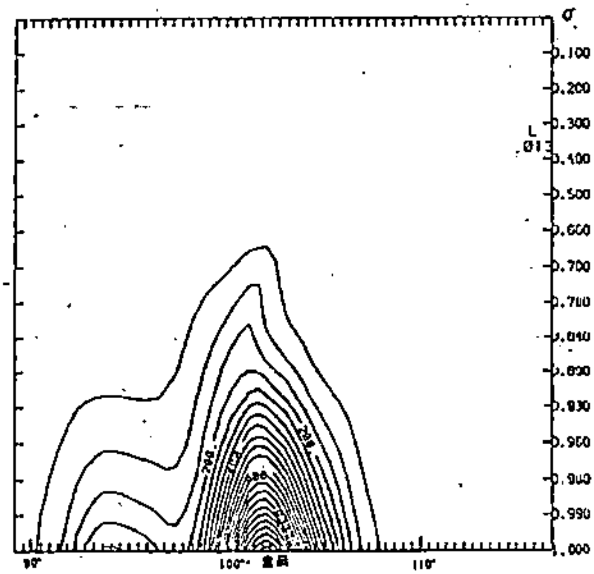


Figure 8. The West - East vertical cross section of the sand - dust concentration through the intense contur of concentration in Fig. 7b

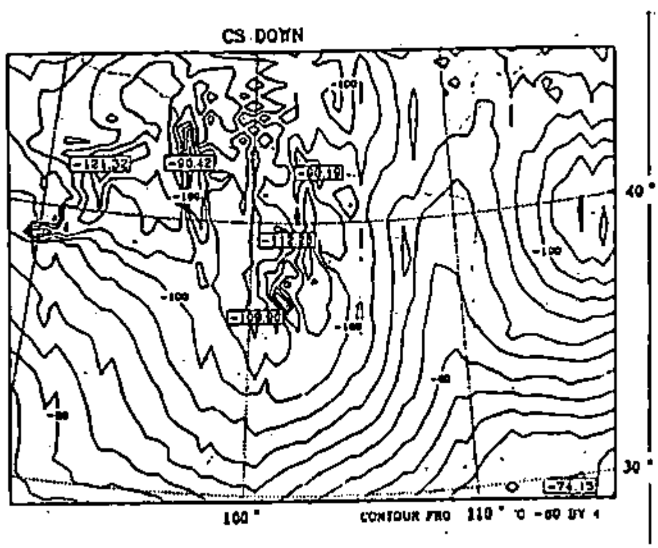


Figure 9. Accumulated sand - dust deposition amount at surface for 21h for control simulation. Contour interval for the amount is 4 kg

The results of control simulation based on mesoscale numerical model found the genesis and development of the "93. 5" black storm was directly related to the formation and development of a mesoscale cyclonic vortex in lower troposphere, a favorable allocation of the vertical vorticity column of the vortex was an important dynamic mechanism of intense development of driving black storm, while the very strong baroclinity in the mid - and lower-layers of troposphere and warm-cored structure in the PBL were thermal and connective instability condition of intensive development of the black storm.

A parameterized scheme of source and sink terms for sand-dust and an equation of transporting sand-dust were achieved and posed, while both this scheme and this equation were introduced to the mesoscale model and simulation system for MM4. Applying the improved and developed model and simulation system to achieve successfully simulations for the driving and elevating as well as transporting deposition of sand-dust for the "93. 5" black storm. The result revealed adopting mesoscale numerical model included the parameterized scheme of the source and sink terms for sand-dust and the equation of transporting sand-dust is a quite well method with applying prospects to study the black storms.

This study is supported by the National Natural Science Foundation of China under grant 49475268

References

1. Anthes R.A., Hsie E.Y. and Kuo Y.H. Description of the Penn State // NCAR Mesoscale Model Version 4 (MM4). NCAR Technical Note NCAR/TN - 282, STR. - 1987. - 66 p.
2. Carlson T.N., Prospero J.M. The large-scale movement at Saharan air outbreaks over the northern equatorial Atlantic // J. *Appl.Met.* - 1972. - Vol. 11. - P. 283-297.
3. Carlson T.N., Caverly R. Radiative chracteristics of Saharan dust at solar wavelengths // J. *Geophys.*, Res. 1977. - № 82. - P. 3141-3152.
4. Carlson, T.N., Benjamin S. G. Radiative heating rates for Saharan dust // J. *Atmos.* Sci., 1980. - Vol. 37. - P. 193-213.
5. Chen S. J., Kuo H.J. The effect of dust radiative heating on low - level frontogenesis // J. *Atmos. Sci.* - 1995. - P. 1414-1420.
6. Cheng L. *Mesoscale Atmospheric Numerical Model and Simulation (in Chinese).* China Meteorological Press, 1994. - 530 p.
7. Cheng L., Ma Y., Liu C. Influence of mesoscale model resolution on the evolutive simulation of the "93. 5" black storm. WMO/TD - №. 699. - 1995. - P. 323-328.

8. Cheng L., Ma Y. Development structure of the "93. 5" black storm and numerical experiment of different model resolution (in Chinese) // J. Appl. Meteo., 1996. - Vol. 7, № 4. - P. 193-198.
9. Jiang J. A study of formation for "black storm" using GMS - 4 imagery (in Chisese) // J.*Appl. Met.,* 1995. - Vol. 6. - P. 177-184.
10. Karayampudi V.M., Carlson T.N. Analysis and numerical simulation of the Saharan air layer and its effect on easterly wave disturbances // J. *Atmos.* Sci., 1988. - Vol. 45. - P. 3102-3136.
11. Westphal D., Toon O.B., Carlson T.N. A case study of mobilization and transport of Saharan dust // J. *Atmos.* Sci., 1988. - Vol. 45. - P. 2145-2175.
12. Xu G. C., Chen M. L., Wu G. X. An extraordinary heavy sandstorm on 22 April 1977 in Gansu (in Chinese) // *Acta Meteo.* Sin., 1979. - Vol. 37. - P. 26-35.
13. Yang G., Wang Y., Zhao Y. The endangering and countermeaures of "5.5" severe sandstorm in Northwest of China (in Chinese) // *Gansu Meteo.*, 1993. - Vol. 11. - P. 43-48.

Department of Atmospheric Science, Lanzhou University, Lanzhou 730000, China

MESOSCALE NUMERICAL EXPERIMENTS OF DEVELOPING MECHANISM FOR THE "93,5" BLACK STORM AND PARAMETERIZATION OF SAND-DUST TRANSPORT

LINSHENG CHENG AND CHUNTAO LIU

Мезомасштабты ММ4 санды үлгіге негізделген моделдің нәтижесі бойынша "93,5" қара шаң боранының пайда болуы және дамуы төменгі тропосферадағы циклонды құйынның генезисімен байланысты екендігі көрсетілді. Модель құм-шаң массасының шығу және көшу параметрлері үлгісін есепке алады.