5.4 TRANSPORT OF AEROSOL PARTICLES BY DEEP CONVECTIVE PROCESS AND ITS CONTRIBUTION TO THE FORMATION OF JUNGE LAYER

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1. INTRODUCTION

It is known for sometime that there exists a relative concentration maximum of “large” aerosol particles (radius between 0.1 and 1 m) in the stratosphere between 15 and 25 km. This aerosol layer was first observed by Junge et al. (1961a,b), Changnon and Junge (1961), and Junge and Manson (1961), and has subsequently established as a global phenomenon. This layer is sometimes called the Junge aerosol layer, or simply Junge layer. The dominant chemical species of the aerosols in the Junge layer appears to be sulfates (SO_4^{2-}) whereas H^+ and NH_4^+ are the major cations.

The origin of the aerosol particles in the Junge layer has been subject to a number of investigations. Current theories of Junge layer formation include the injection of sulfate particles by volcanic eruptions, turbulent diffusion of tropospheric sulfates, natural (biogenic) emissions of carbonyl sulfide, and other processes. It appears that there is not yet a definite conclusion. For a review of these theories, see Pruppacher and Klett (1997).

In this paper, I would like to propose a new mechanism that may have contributed to the aerosol particle source in the Junge layer. This is the transport of particles from the troposphere to the stratosphere by deep convective systems. These particles may have been pre-existent in the troposphere at the time of the development of deep convection, or may have formed via heterogeneous chemical reactions between trace gases and cloud/precipitation particles and are subsequently transported by the deep convection to the stratosphere.

The methodology used in this study is that of cloud model study. Two scenarios are studied: the first one involves the transport of inert tracers and the second involves the formation and transport of sulfate particles in deep convective clouds. Both results indicate that it is possible to transport tracers/particles from the troposphere to the stratosphere by such deep convective system. A brief sketch of this study is given in the following sections.

2. THE CLOUD MODEL WISCDYMM AND THE CCOPE SUPERCELL

2.1. The Cloud Model WISACDYMM

The cloud model used for performing the simulation is the Wisconsin Dynamical-Microphysical Model (WISCDYMM). This is a 3-dimensional nonhydrostatic primitive equation model cast in quasi-compressible form. Turbulent fluxes are approximated by the one-and-a-half order closure theory of Klemp and Wilhelmson (1978a). The thermodynamic equation with potential temperature as the dependent variable follows the approximation given by Das (1969). Radiation boundary conditions of Klemp and Wilhelmson (1978a) are applied to the lateral boundaries to allow horizontally propagation gravity waves to pass out of the domain with a minimal amount of reflection. Near the top of the domain, A Raleigh friction zone is applied to absorb vertically propagating gravity waves (Clark 1977). The cloud microphysical processes include the conversion and interactions among water vapor and five classes of hydrometeors (cloud water, cloud ice, rain, snow, and graupel/hail). In the present study, bulk parameterizations of microphysical processes are used. The expressions of the parameterizations are taken from Lin et al. (1983), Farley et al. (1986), and Farley (1987a, b). More details of the model and its parameterizations are given in Straka (1989).

2.2 THE 2 AUGUST 1981 CCOPE SUPERCELL

The 2 August 1981 supercell, which passed through the Cooperative Convective Precipitation Experiment (CCOPE) in southern Montana (Knight 1982; Miller et al. 1988), is used as an example to demonstrate the transport process. The sounding used in the initialization was taken 90 km ahead of the storm at Knowlton, Montana and was the most representative of the pre-storm environment (Johnson et al. 1993, 1994). The sounding shows a very unstable air mass (lifted index of -10^{o}C) and large vertical wind shear of 0.0093 s^{-1} in the lowest 4 km (Musil et al. 1991). Musil et al. also determined the convective available potential energy (CAPE) for the pre-storm environment at 3286 m^2s^{-2}. A calculation of the bulk Richardson number as defined by Weisman and Klemp (1982) gives a value of about 25, which is in the expected range for supercell storms. Strong veering of the environmental winds over the lowest 2 km (120^{o}) also indicates that there should be favored development of the rightward-moving storm (Klemp and Wilhelmson 1978b), as was the case of this supercell.It is noted here that there is no dew point sounding for levels above 300 mb. In this study, the typical midlatitude August 1999 water vapor profile taken from HALOE data was used to represent the moisture condition at high levels.

Johnson et al. (1993, 1994) had performed cloud model simulations of this supercell previously using a resolution of 1 km x1 km x 0.5 km over a domain of 55 km x 55 km x 19 km. This grid spacing was found to be adequate to resolve the physics and dynamics of the storm. This resolution is also the one adopted in the present study. Johnson et al. (1993, 1994) have shown that their results compare favorably with observations. In the present paper I will focus on the

3. RESULTS AND DISCUSSIONS

3.1. The inert tracer case

The initial concentration of the inert tracer is assumed to be 10% and is uniformly distributed in the lowest km. The tracers are then transported and dispersed by the storm like water vapor except that they don’t condense or freeze. Fig. 1 shows a snapshot of the tracer concentration profile at t = 90 min. It shows clearly the “tracer plume” above the overshooting top of the central cross-section of the storm, indicating the potential contribution of this transport mechanism to the aerosol particles in the Junge layer.

Recently, Kittaka and Wang (1998) and Kittaka (2001) have reported the formation and re-distribution of sulfate particles in clouds using the same cloud model study of the same CCOPE case but with the inclusion of chemical reactions with which sulfur dioxide gas react with water substance in clouds and are transformed to sulfate particles. Both the regions above the overshooting top and above a downstream anvil show local maximum concentrations of sulfates. The details of this latter study will be discussed in the conference.

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References

Chagnon, C. W., and C. Junge, 1961: *J. Meteor*., **18**. 746.

Clark, T. L., 1977: A small-scale dynamic model using a terrain-following coordinate transformation. *J. Compu. Phys*., **24**, 185-215.

Das, P., 1969: The thermodynamic equation in cumulus dynamics. *J. Atmos. Sci*., **26**, 399-407.

Farley, R. D., 1987a: Numerical modeling of hailstorms and hailstone growth. Part II:The role of low-density riming growth in hail production. *J. Climate Appl. Meteor*., **26**, 234-254.

Farley, R. D., 1987b: Numerical modeling of hailstorms and hailstone growth. Part III: Simulation of an Alberta hailstorm-Natural and seeded cases. *J. Climate Appl. Meteor*., **26**, 789-812.

Farley, R. D., and H. D. Orville, 1986: Numerical modeling of hailstorms and hailstone growth. Part I: Preliminary model verification and sensitivity test. *J. Climate Appl. Meteor.*, **25**, 2014-2036.

Goody, R. M., and Y. L. Yung, 1989: *Atmospheric Radiation: Theoretical Basis*. 2nd ed., Oxford University Press, New York, 519pp.

Heymsfield, G. M., and R. H. Blackmer, Jr., 1988: Satellite-observed characteristics of Midwest severe thunderstorm anvils. *Mon. Wea. Rev*., **116**, 2200-2224.

Holton, J. R., P. H. Haynes, M. E. McIntyre, A. R. Douglass, R. B. Rood, and L. Pfister, 1995: Stratospheric-tropospheric exchange. *Rev. Geophys*., **33**, 403-439.

Johnson, D. E., P. K. Wang, and J. M. Straka, 1993: Numerical simulation of the 2 August 1981 CCOPE supercell storm with and without ice microphysics. *J. Appl. Meteor.,* **32**, 745-759.

Johnson, D. E., and P. K. Wang, and J. M. Straka, 1995: A study of microphysical processes in the 2 August 1981 CCOPE supercell storm. *Atmos. Res.* **33**, 93-123.

Junge, C, C. W. Chagnon, and J. E. Manson, 1961a: *J. Meteor*., **18**, 81.

Junge, C, C. W. Chagnon, and J. E. Manson, 1961b: *Science*., **133**, 1478..

Junge, C., and J. E. Manson, 1961: J. Geophys. Res., 66, 2163.

Kittaka, C., and Pao K. Wang , 2000: A model study on the sulfate aerosol distribution in a deep convective cloud". Preprint Symp. Atmospheric Chemistry, January, 2000. AMS Annual Meeting, Long Beach, California, 14-15.

Klemp, J. B., and R. B. Wilhelmson, 1978a: The simulation of three-dimensional convective storm dynamics. *J. Atmos. Sci*., **35**, 1070-1096.

Klemp, J. B., and R. B. Wilhelmson,1978b: Simulations of right- and left-moving storms produced through storm-splitting. *J. Atmos. Sci*., **35**, 1087-1110.

Knight, C. A., Ed., 1982; Ther Cooperative Convective Precipitation Experiment (CCOPE), 18 May-7 August 1981. *Bull. Amer. Meteor. Soc*., **63**, 386-398.

LevizzaniV., and M. Setvak, 1996: Multispectral, high resolution satellite observations of plumes on top of convective storms*. J. Atmos. Sci*., **53**, 361-369.

Lin, Y. L., R. D. Farley, and H. D. Orville, 1983: Bulk parameterization of the snow field in a cloud model. *J. Climate Appl. Meteor*., **22**, 1065-1092.

Miller, L. J., D. Tuttle, and C. A. Knight, 1988: Airflow and hail growth in a severe northern High Palins supercell. *J. Atmos. Sci*., **45**, 736-762.

Pruppacher, H. R., and J. D. Klett, 1997: *Microphysics of Clouds and Precipitation*. 2nd Ed., Kluwer Academic Publishers, 954pp

Setvak, M. and C. A. Doswell III, 1991: The AVHRR channel 3 cloud top reflectivity of convective storms. *Mon. Wea. Rev*., **119**, 841-847.

Sharman, R. D., and M. G. Wurtele, 1983: Ship waves and lee waves. *J. Atmos. Sci*., **40**, 396-427.

Straka, J. M., 1989: *Hail growth in a highly glaciated central high plains multi-cellular hailstorm*. Ph.D thesis, University of Wisocnsin-Madison, 413pp.

Weisman, M. L., and J. B. Klemp, 1982: The dependence of numerically simulated convective storms on the vertical wind shear and buoyancy. *Mon. Wea. Rev*., **110**, 504-520.

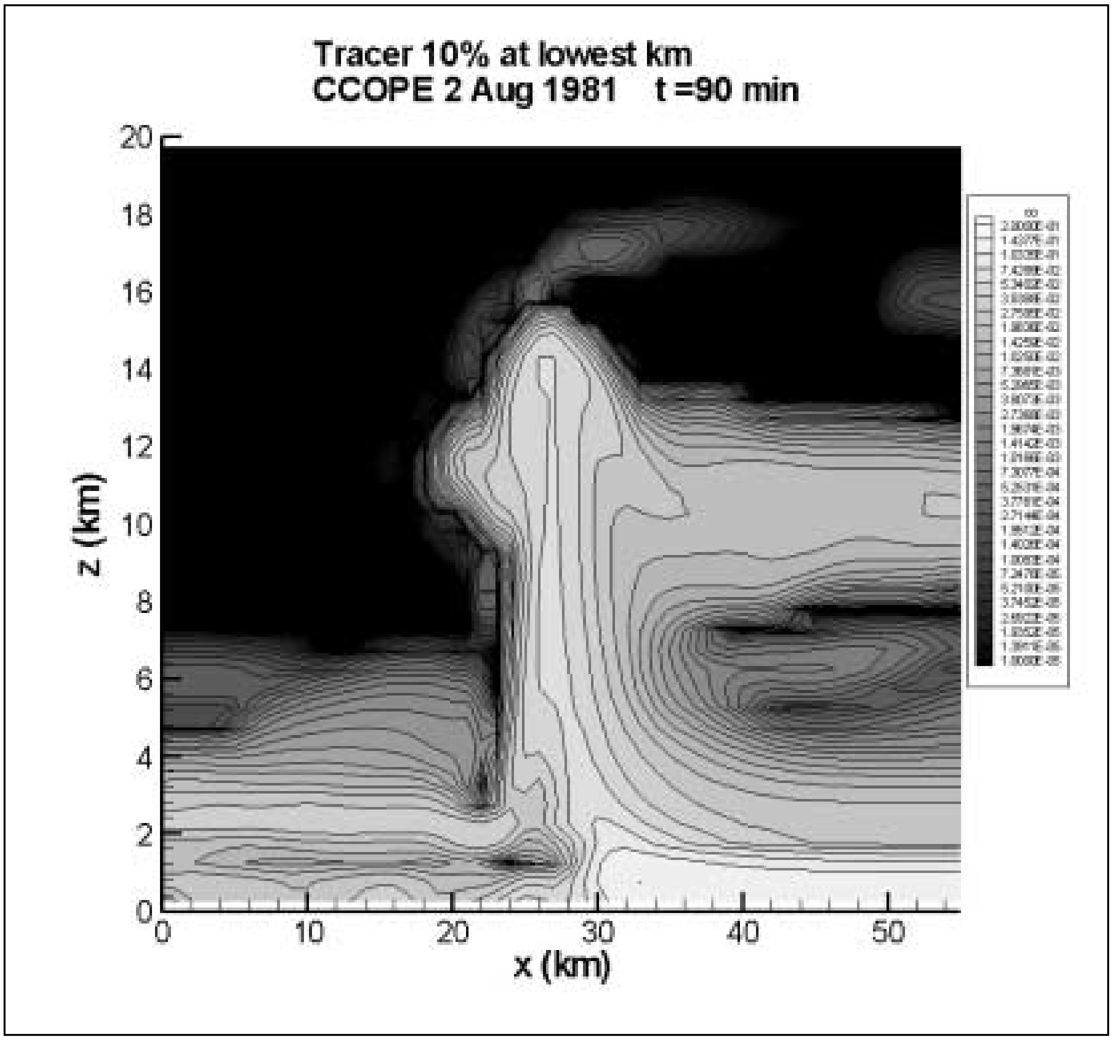
Tracer 10% at lowest km
CCOPE 2 Aug 1981 t =90 min
z (km)
0
2
4
6
8
10
12
14
16
18
20
x (km)
0
10
20
30
40
50

Fig. 1