1. INTRODUCTION

Stratus Clouds System is a main precipitation system in spring and autumn in north China and a main object for artificial precipitation enhancement by the seeding. The potential of artificial precipitation enhancement is capacity of the cloud system to increase rainfall on ground by artificial influence and it must be considered in judging and directing seeding task. To understanding various factors of the potential have an important significance for opening up cloud water resource and building up effect of artificial precipitation enhancement.

At present, the potential of stratus cloud system is studied by several ways. Someone respectively taken precipitation efficiency\(^1\) of the cloud system as the potential factor, and someone taken water vapor content, super-cooling water content, and concentration of ice crystal as other potential factors. Hu Zhijing et al.\(^2\) think that the super-cooling water content is a favorable condition for the artificial seeding, but the clouds with little super-cooling water have still certain potential to precipitation enhancement, because water resource for artificial precipitation enhancement is not only from transform of liquid water to ice but also vapor to ice. Formation of natural precipitation is a complex processes, it is related to the structure of cloud, also the microphysical processes in cloud. Therefore, the judging potential is a complex and integrative processes, too, so that the potential should not be evaluated by one single parameter, for example, precipitation efficiency or super-cooling water content et al. In this paper, using data of a stratus cloud system simulated by the mesoscale numerical model MM5, which occurred on 19 Oct., 2002 in Henan province (Henan cloud system) and produced precipitation over a great area, we try to analyse the potential factors for artificial precipitation enhancement in cloud and precipitation physics, and taken super-cooling water content, ice crystal concentration, amount of super-saturated water vapor with respect to ice(SQV), precipitation efficiency, precipitation mechanism, cloud water content and thickness of the warm cloud region as the potential factors to advance integrative evaluation way of the potential.

2. NUMERICAL SIMULATION OF THE STRATUS CLOUD SYSTEM

Fig.1  GMS-5 infrared satellite cloud picture at 8:00, on 18-20 October 2002 and distribution of thickness (mm) of water content in the model cloud system superimposed the cloud picture.D2 domain is noted by the large rectangle and in which the small rectangle represents Henan province area.
In this paper, MM5 of PSU/NCAR was used with graupel scheme of Reisner to simulate the stratus cloud system occurred on 19 Oct., 2002 in Henan province. The simulation time is from 08:00, 18 Oct. to 02:00, 20 Oct. Two nested-level domain with center point of (34.5°N, 109.5°E) were set. The horizontal resolution in outer domain was 45km and inner fine-mesh was 10km. The model atmosphere was divided into 23 levels from the surface to 100pfa for all two domains. The model was initiated not only using the NCEP/NCAR re-analysis data but also the general ground and radio-sounding data.

Overall, simulated cloud field, temperature field, wind field, low level shear line and jet stream are all consistent with actual thing, accumulated rainfall region is consistent with observation. From fig.1, it can be seen that area of simulated cloud is same as the satellite cloud picture.

3. ANALYSIS OF POTENTIAL FACTORS FOR ARTIFICIAL PRECIPITATION ENHANCEMENT

3.1 The Potential and Cloud Structure

Condition of the cloud water conversion is related to its distribution. In the simple cooled cloud or warm cloud processes, the cloud water is transformed hardly to precipitation, distribution of cloud water and structure of cloud system have a close relation to mechanism of the precipitation formation, therefore, to precipitation enhancement, too. Study on the cloud system structure, especially the vertical structure has an important significance for ascertaining of the potential region. Relationship of the structure and the precipitation is analyzed according to time change of water content and rainfall intensity in simulated Hena cloud system. It can be seen from fig.2 that there is warm cloud at Nantyang station during 00:00 and 18:00 on18,Oct., rainfall intensity corresponding to water content region with 0.2 g/kg is lower; three maximum rainfall intensity are all corresponding to centers of the water content and they are all “seeding-feeding” clouds, in which seeding cloud joins feeding cloud. It indicates “seeding-feeding” cloud is propitious to precipitation, of course, propitious to artificial precipitation enhancement.

3.2 Precipitation Mechanism and Potential for Precipitation Enhancement

At present, artificial precipitation enhancement is operated by effecting cold cloud microphysical processes, so that only such cloud in which the cold cloud process play an important role in precipitation enhancement.
formation is seeded, precipitation is increased.

In the various stages of cloud system, the cold cloud process has different contribution for rainfall (fig.3), we should choose period of time in which cold cloud precipitation is in the ascendant for seeding, for example, from 07:00 to 09:00 on 19, oct., so that precipitation mechanism should be a potential factor for precipitation enhancement.

3.3 Cloud Resource and Potential for Precipitation Enhancement

Here, cloud water resource is defined as vertical integral amount (mm) of cloud water content or cloud water thickness and it has a close relationship to surface precipitation (fig.4). For example, in Nanyang area the time at which maximum rainfall intensity appear consistent with that of total cloud water, supper-cold cloud water and warm cloud water, respectively. It is shown that the cloud water, that including supper-cold cloud water and warm cloud water, is important for precipitation. From the same change trend, we think that rainfall intensity is related to thickness of supper-cold water and cloud water. The lager cloud thickness is in favor of precipitation formation, and seeding for precipitation enhancement, too. Therefore, cloud water thickness is also a potential factor for precipitation enhancement.

3.4 Water Vapor And Potential For Precipitation Enhancement

In ice particles which have melted into liquid rain water, has the deposition process by expending water vapor or the accretion process by expending super-cooling water larger contribution to formation of rain water? It can be seen from fig.4 that, after 08:00 on 19, contribution of deposition growth to precipitation is lager than the accretion growth. This indicates that contribution of water vapor sublimation process to rain water formed by melting of ice particles larger than the accretion process and shows essentiality of water vapor in precipitation particles. Therefore, water vapor is an important potential factor.

What is called SQV, i.e., the excessive water vapor amount relative to saturation with respect to ice. Ice particle is grown by deposition in condition of supper saturation with respect to ice. In this Henan cloud system, deposition growth of ice particle by expending water vapor has lager
contribution to the ice particles mass than accretion by expending supper-cold water. In some cloud system, the contribution of them are almost same, for example, in stratus cloud system [3] occurred in Henan province on 5, Apr. 2002, contributing rate of the deposition process to rain water produced by ice particles melt is 54%, and supper-cold water transformation 39% at 05:00; at 08:00, they are 46% and 49%, respectively. If only cold cloud process play an important role in precipitation, deposition growth of ice particles is also important, so that supper saturation water vapor amount with ice surface related to precipitation, of course to potential for precipitation enhancement.

For Henan cloud system, SQV has a positive correlative with surface precipitation (fig.6), namely the lager SQV, the higher surface rainfall intensity. In fact, if the cold cloud process is main in rain water formation and deposition is main growth process of ice particle, water vapor must play an important role in cold cloud precipitation. Therefore, SQV has a close relationship to precipitation. If cold cloud process is main and deposition is an important microphysical process in the cloud system, SQV is a important potential factor.

3.5 Precipitation Efficiency and Potential for Precipitation Enhancement

Artificial precipitation enhancement make supper-cold water surface precipitation, therefore, we need to know cloud water amount which is not transformed into rain water. The study indicate that in cloud system in which cold cloud precipitation is main, deposition of ice particle is an important microphysical process in precipitation formation, so that how much deposition-water which is not transformed precipitation should be also known. Namely, we need to work out at precipitation efficiency of condensation water and deposition water.

For Zhengzhou area, in Henan cloud system,, before 05:00 on 19 (fig.7), the warm cloud precipitation is in the highest flight, precipitation efficiency of condensation water much higher than deposition; during 05:00 and 10:00, precipitation efficiency of deposition water go up quickly and exceeds condensation water and reach maximum of 71.0% at 10:00; after that, it begin to descend and average values of it is as much as
precipitation efficiency of condensation water, they are 34.7% and 29.4%, respectively. Thus it can be seen that there are large numbers of condensation water and deposition water in the cloud, as a result, it has larger potential for precipitation enhancement.

4. SYNTHETICAL EVALUATION OF POTENTIAL FOR PRECIPITATION ENHANCEMENT

From above analysis on the potential factors, we should use these potential factors to evaluate the potential for artificial precipitation enhancement. If cloud system and precipitation is being in developing stage, technique of synthetical evaluation potential for precipitation enhancement is as follows:

First, analyzing macrostructure of cloud system. In general, there is potential for precipitation enhancement in the "seeding-feeding" cloud, especially the seeding layer and the feeding layer are connected, the potential is larger.

Second, for "seeding-feeding" cloud system, contribution of the cold cloud process for precipitation is needed to analyse, if the contribution is larger, the cloud system has larger potential for precipitation enhancement.

Third, analyzing precipitation efficiency of condensation water and deposition water, if they are low, the potential is larger.

Four, analyzing supper-cold water content, ice crystal concentration, cloud water content in the warm region. If the supper-cold water content is higher, ice concentration lower and water content in the warm region higher, then the potential is larger.

Fifth, analyzing water vapor condition, including vertical flux of water vapor and SQV, when updraft is larger in the cloud and SQV is larger, the potential is larger.

5. CONCLUSION AND DISCUSSION

The potential factors of striform cloud system for artificial precipitation enhancement are studied using the simulated cloud system and consideration of synthetical evaluation of potential for precipitation enhancement is brought up. Namely, the stratus cloud system, in which there is structure of "seeding-feeding" cloud, cold cloud precipitation mechanism to be in the ascendant, higher supper-cold water content and lower ice concentration, larger SQV and lower precipitation efficiency, can be provided larger potential for precipitation enhancement.

Firstly, evaluation method of the potential proposed in the paper use many potential factors and overcome localization of evaluation by one or two factors. Secondly, some new potential factors are studied and put forward. One is the cloud structure, only "seeding-feeding" cloud structure; the other new potential factor is precipitation mechanism and this potential factor catch hold of essential of seeding theory for artificial precipitation enhancement, namely objective of artificial precipitation enhancement is achieved by
effecting cold cloud microphysical process. So that only cold cloud process has an important role in precipitation formation in the statiform cloud system, there is the lager seeding potential in the cloud system. Three is SQV, which is put forward by study growth process of ice particles in the cloud system in which cold cloud process is in the ascendant. In such cloud system, deposition growth of ice particles by expend water vapor is very important for precipitation.

Thirdly, from theory of artificial precipitation enhancement, precipitation efficiency of condensation water and deposition water which can shown ability of condensation water and deposition water to be transformed into precipitation particles and rainfall on ground. It makes the precipitation efficiency more suitable to evaluation of the potential for precipitation enhancement. If precipitation efficiency is calculated using condensation amount or sum of condensation amount and deposition mount. The former overrates precipitation efficiency because rainfall on the ground contains contribution of deposition water the latter do not distinguish contribution of condensation water and deposition to rainfall, therefore the potential evaluated is out of pertinency.

The potential factors in the paper are obtained by the numerical simulation and theory analysis, and evaluation of the potential is only based on qualitative analysis. Every potential factor has not a quantitative criterion. In fact, the quantitative criterion is very important for the evaluation of the potential. Beside, if we applied these potential factors and the evaluation consider of the potential to the practice of artificial precipitation enhancement, we have a long way to go. For example, how do we confirm the structure of “seeding-feeding” cloud? And what is the method to make sure the precipitation mechanism?

References

