A LABORATORY INVESTIGATION OF THE EFFECT OF HYGROSCOPIC AEROSOLS OF VARIOUS ORIGINS ON CONTROLLED CLOUDY ENVIRONMENTS

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ABSTRACT

The article is an examination of an experimental study of the interaction of hygroscopic aerosol particles of various origins, particularly thermocondensation variant and mechanically destroyed (pre-prepared powders), with a warm cloudy environment ($T \geq 273$ K). Depending on the concentration, properties, and spectrum of the aerosol used, as well as the structure of the colloidal cloud medium, the result of the interaction can be a stabilized and/or destabilized form of the latter. Our experimental results have shown no consensus on whether the variant from exposing standard pyrotechnic flares equipped with a composition that generates a hygroscopic-variant aerosol to destabilize the colloidal stability of the cloud media, and, accordingly, can lead to an increase in precipitation. The authors believe this is due to the significant uncertainty in the processes of aerosol formation, both in the process of laboratory experiments and directly during cloud seeding operations.

1.0 EXPERIMENTAL SETUP

The experiments were conducted using equipment that simulated actual environmental conditions to the maximum extent possible. The equipment consisted of a cylindrical cloud chamber with a height of 18 m, and a radius of 7.5 m to constitute a volume of 3200 m^3. The chamber is capable of an atmospheric pressure range from 1 – 2.5 atm and is designed to simulate and observe cloud physics in a controlled environment. The operation of the generator in the natural environment is simulated in a horizontal wind tunnel with air blowing at a speed representative of real environmental conditions of a generator in operation. Next, a representative sample of aerosol from the wind tunnel path is introduced into the cloudy environment formed in the climatic chamber.

The cloud in this study was simulated by adiabatically cooling the enclosed chamber air with a known initial humidity and aerosol background to simulate the formation of a natural cloud in an ascending air flow[1]. To simulate a convective cloud, a uniform pressure release was maintained to simulate the rise of an air mass at a speed of 2 m/s. For stratus clouds, a pulse of pressure reduction was used, and the appropriate pressure maintained to achieve the formation of the desired concentration of drops. During the experiments, the main environmental physical state, meteorological parameters including updraft velocity, cloud drop concentration and size spectra, were monitored using standard commercial sensing devices inside of the chamber as described in Section 2.2. The amount of water deposited on the test sites was measured continuously by a scale to monitor the weight of water precipitating onto a 1 m^2 collection membrane placed in the chamber in a location representative of the natural ground.

2.0 METHODOLOGY

2.1 Physical basis of seeding clouds with hygroscopic aerosols.

The main application of hygroscopic aerosols is to affect warm clouds ($T \geq 273$ K). There are two variants of functional manifestations of hygroscopic

[1] The terminology 'air flow' and 'air speed' are used in this text in place of 'wind speed' because the experiments take place within a controlled chamber environment.

aerosol, implemented separately or jointly.

1. **Thermodynamic effect**. Since the process of water adsorption by aerosol particles is associated with some heat release, the introduction of a hygroscopic aerosol could enhance the buoyancy of the cloud system sufficiently. The consequence of this phenomenon is that the cloud will develop to reach a level above the freezing point. An increase in the optical density of the system and, accordingly, radiation heating also contributes to this process. In this case, we can state the further formation of sediments by the glaciogenic mechanism.
2. **Change in the colloidal stability of the system.** The second option is directly related to changes in the particle size of a hygroscopic substance due to water adsorption, and changes in the dynamics of processes taking place in a colloidal medium which mainly affects the various mechanisms of coagulation (gravitational, turbulent, Brownian, electrostatic). Unlike the previous version, this process can lead to a change in the state and stability of the colloidal system, which can be identified by both an increase and a decrease in precipitation.

Reagents used in this research:

Multiple substances, including NaCl and $CaCl_2$ are considered. When water is absorbed by a hygroscopic substance - cloud condensation nuclei (CCN) - we consider the following stages:

1. Rapid water absorption. In terms of energy and bond strength, this stage is comparable to a chemical reaction – for example in practice, compounds like $CaCl_2$, $CaCl_2 * 4H_2O$, $CaCl_2 * 6H_2O$ should be considered different substances.

2. Fast transition from a solid to a state of concentrated solution. The state of the process at this moment is determined by the Van't Hoff factor associated with the number of initial molecules and degree of dissociation of the substance and therefore associated with the chemical nature of a particular substance.

3. The area of dilute solutions, for which Raoult's law is valid, according to which the partial vapor pressure over the solution is also proportional to the molar fraction and degree of dissociation of the given substance. Accordingly, at this stage of dilution, the physical and chemical features of specific substances do not affect the vapor pressure of water over the solution.

4. With further dilution, the concentration of the solute becomes too low, and the drop of solution does not differ in properties from the rest of the droplets of the cloud medium.

In traditional warm cloud seeding operations applied to convective clouds, hygroscopic aerosols ascend within an air flow until the air reaches the condensation zone, typically at or just below cloud base. In this situation it should be noted that the stages of chemical bonding of water vapor molecules with a hygroscopic substance through its transformation into a solution drop happens very quickly when humidity is close to 100%. The growth rate from a drop of concentrated solution to a significantly more diluted, typical sized cloud drop is also rapid, rendering the chemical composition physically insignificant. While environmental considerations are beyond the scope of this research, logic suggests using the most environmentally sound, worker and economically friendly hygroscopic agents.

2.2 <u>Change in the colloidal stability of a cloud system upon introduction of a hygroscopic aerosol.</u>

Depending on the size and concentrations of the aerosols generated, the change can occur in two directions - an increase in the stability of the system or its destruction. In the actual environmental situation a wide range of aerosol sizes must be considered, this leads to the simultaneous implementation of two opposite mechanisms.

Accordingly, the outcome will depend on which mechanism is predominant. This situation, from the point of view of the authors, takes place in all cases - both for the aerosol produced during the combustion of pyrotechnic compositions, and in the case of the dispersal of pre-prepared powders.

The following options for introducing aerosol were used: pneumatic spraying of pre-prepared powders into the volume of the chamber, burning small amounts of pyrotechnic compositions under conditions simulating a real airflow, as well as burning full-size pyrotechnic generators (Burn-In-Place Flares) in a horizontal wind tunnel with the introduction of a representative aerosol sample into the chamber. The spectra of aerosols of various origins were recorded by an electrostatic aerosol classifier of the TSI 3080 system and Laser Aerosol Spectrometer TSI 3340 manufactured in the USA are shown in Figure 1.

Considering the impact of a hygroscopic aerosol with a cloudy environment, two groups of effects are distinguishable:

1. The rain embryo effect: CCN with a diameter of more than 1 μm are introduced, respectively, when water vapor is absorbed, droplets are formed that are an order of magnitude, or more, larger than the size of the original aerosol. In this situation, the effect of various mechanisms of coagulation presides. (Rosenfeld 2010)

2. The competition effect: In the case of greater hygroscopicity compared to nature, the process of water adsorption prevails on the injected aerosol. In this case, under certain conditions, colloidal structures with different stability can occur. The development of this effect can both reduce the formation of precipitation in the case of a submicron aerosol and increase it in the case of a micron aerosol.

Our scientists believe that these effects are the interaction of the aerosol formed under the conditions of a specific air speed, and a specific spectrum with a two-phase medium.

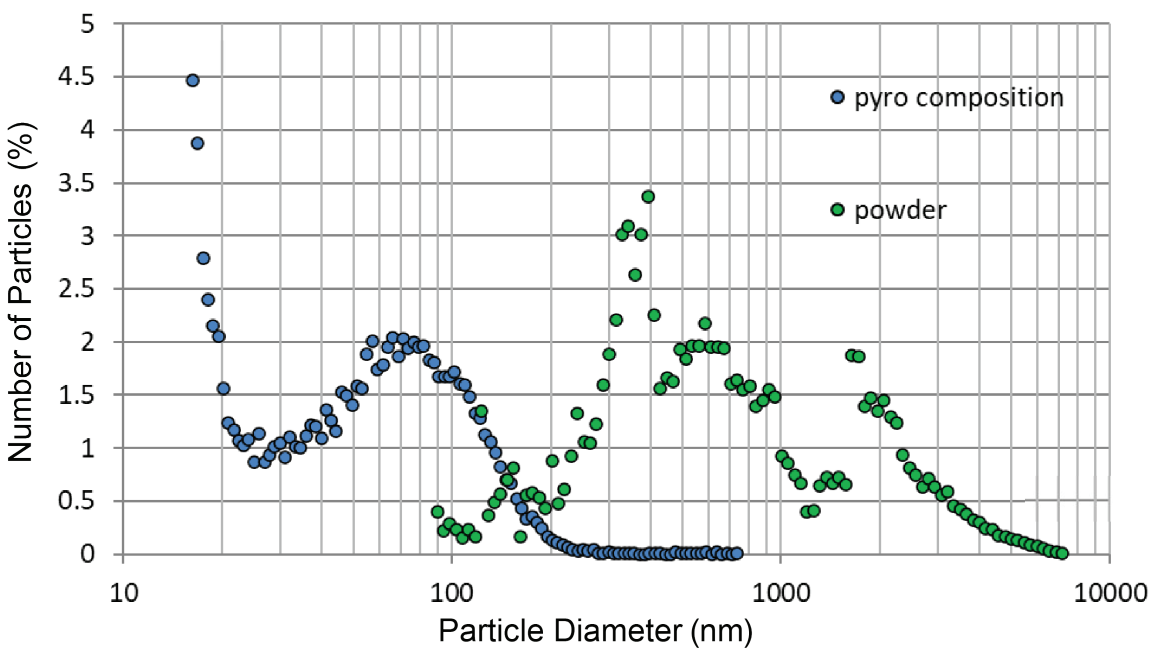

Fig. 1. Aerosol Spectra used in the experiment. Aerosol of pyrotechnic composition (composition described in the article ICE flares, blue dots) and aerosol obtained by pneumatic spraying of pre-prepared powder (NaCl with anti-caking additives). In both cases, the generator was in an air stream at a speed of 80 meters per second. From the point of view of the authors, in the second spectrum, the submicron size range is represented mostly by particles of an anti-caking additive that does not exhibit hygroscopic properties.

Since the formation of precipitation in a cloud occurs with the appearance of droplets larger than 30 µm in diameter, an increase in the amount of precipitation can be achieved by introducing particles larger than 1 µm into the cloud (e.g., DeFelice and Axisa 2017; DeFelice et al. 2023). Only such particles (or larger ones) can form the nuclei droplets which become raindrops. Nuclei with a diameter of less than 1 µm more likely perform the opposite function based on this and other hygroscopic seeding experiments like those conducted by Murakami et al. 2011.

Considering the effect of the real interaction of an aerosol with a cloudy environment, it should be considered that we are dealing with a spectrum formed as a result of a combination of the following processes:

1. Pyrotechnic aerosol - processes of condensation, coagulation, as well as changes in the chemical and physical properties of the formed aerosol.
2. Aerosol obtained by atomization of powders - physical destruction processes and powder dispersion under specific conditions of use.

2.3 Insertion of hygroscopic pyrotechnic aerosols to the cloud environment.

It should be noted that in the first case, the case of pyrotechnic flares, there are fewer opportunities for obtaining adequate information about the real environmental conditions while using generators. As a result, the information obtained by different researchers about similar compositions of Hygroscopic Burn-In-Place Flares differs significantly, but in almost all cases the percentage of droplet-forming particles larger than 0.9 – 1.0 microns is insignificant (Table 1).

It should be noted that in all observed studies, flares of approximately the same configurations were investigated – a charge diameter of 60 ± 10 mm, with a length of 120 – 300 mm, and in all the noted cases, similar compositions with minor deviations were examined: Potassium perchlorate ($KClO_4$) 65%, Hydrocarbon binder 18%, Sodium chloride (NaCl) 10%, Magnesium powder (Mg) 5%, [2]Lithium carbonate (Li_2CO_3) 2%; this conventional composition will be referred to as simply the Basic Reagent Composition or 'BRC'.

The numerous studies that have been conducted previously were done under different air speeds and other environmental variables making it impossible

Table 1. Comparison of aerosol spectra obtained by different research groups.

Information Source	Flare Composition	Air speed	Result
Zhengjun Su	n/a	n/a	70% < 0.5 µm
Rosenfeld D	South African Flare	Variable flight speed	99.5% < 1 µm
A. C. William, T.B. Roelof	South African Flare	90 m/s	mean diameter of particles 0.3 µm
R. T. Bruintjes and all	South African Flare, French Flare	30 to 40 m/s	Average diameter of 0.3 to 0.8 µm
M. Murakami	$CaCl_2$, $NaCl_2$ flares	n/a	Average diameter of 0.5 to 0.8 µm
WF-1 Airborne Pyrotechnic Flare Seeding System	Mg, KCl, $CaCl_2$, $KClO_4$ and Li_2CO_3	100 m/s	0.14% of particles with a diameter greater than 0.9 µm
Adapted from Haryanto, U., R. D. Goenawan, and D. Harsanti	South African Flare	n/a	1.1 – 2.1 µm

to draw conclusions from the multitude of studies on hygroscopic BIP flares.

The factors affecting the size spectrum are studied in detail in the next section.

Factors Determining the Spectrum of the Pyrotechnic Aerosol.

The authors studied the following factors, the influence of which to some extent determines the spectrum of the resulting aerosol:

- The composition of the pyrotechnic mixture.
- Flare design, including the effect of the generator wall on the spectrum of the resulting aerosol.
- The speed and direction of the airflow at the combustion front.

2.3.1 The composition of the pyrotechnic mixture.

We have studied four compositions that are very different from each other both in terms of combustion temperature and in terms of boiling points of high-boiling components:

1. The pyrotechnic composition of the US aircraft hygroscopic generator (BRC - #1).
2. Composition developed by the authors for the processes of stabilization of warm cloudy environments: based on a hydrocarbon binder and $KClO_4$ composition.
3. Classical pyrotechnic ice-forming composition (~12% AgI Composition).
4. Pyrotechnic composition of white smoke (KNO_3 70% Lactose 30% also known as "Rocket Candy").

The results of studying the aerosol spectra of the listed compositions are given in Table 2.

Despite the enormous difference of more than 1000 K in the combustion temperatures of the composition, and the difference of more than 2000 K of the boiling points of high-boiling components, the difference in the modal dimensions of the aerosol, and in the spectrum as a whole is quite small.

2.3.2 Flare design:

The spectrum of the formed aerosol depends both on the diameter of the flare and on the design features of the flare - primarily the presence of a wall and wall material. If in the case of diameter there is an almost linear dependence of the modal size on the diameter of the flare (Figure 2), then the effect of the wall is more complex.

Generally during combustion of a flare, the spectrum and amount of the resulting aerosol change as the combustion front moves deeper into the flare body,

Table 2. Investigation of the aerosol spectra of smoke compositions. Diameter of pyrotechnic material: 18mm, air speed: 8 m/s. Calculation of the content of the condensed phase in burning products and burning temperature under normal conditions and burning temperature performed using the "Astra-4" program.

# Composition	% Solid phase	Main condensed products	Estimated combustion temperature, K	Boiling point of high-boiling components, K	Modal aerosol size, nm
1	54	KCl, KOH, KO, $MgCl_2$, MgO, MgOH, NaCl, LiCl	2932	3873	124
2	41	KCl, KOH, KO	2801	1693	106
3	53	AgI	1860	2162	117
4	74	KO, K_2O, KOH	2968	1047	135

[1] Lithium chloride is the main product of the decomposition of lithium carbonate during combustion in the presence of a large amount of potassium perchlorate. For many reasons the authors have abandoned the use of lithium salts in formulations for environmental application.

while the process of aerosol deposition on the walls develops, the greater the deposition area and the greater the wall cooling rate by the oncoming air flow. In certain cases (non-combustible wall, relatively low burning rate and temperature of the pyrotechnic composition, high speed of blowing the flare with incoming cold air), more than half of the condensed phase may remain on the wall of the torch in the form of ash residue or condensed slag.

It should be noted that in the case of a non-combustible wall it is extremely difficult to model the processes occurring in real conditions during cloud seeding. The authors once witnessed a situation in which a hygroscopic composition with a very high content of ballast substances (more than 15%) and, accordingly, low energy characteristics, forming on the ground under experimental conditions a condensed phase that completely turns into an aerosol, caused a significant deposition of the condensed phase on the walls of the generator, up to complete overlapping of the generator tube in real flight conditions. This may have happened due to a combination of a significant cooling of the flame wall by a cold oncoming air flow and a slight decrease in the combustion temperature of the pyrotechnic mixture under conditions of lower atmospheric pressure. In this case, more stable results are obtained when burning flares with a completely combustible body, when there are no reasons for the deposition of the condensed phase on the walls, due to the absence of the latter (Figure 3).

2.3.3 The speed and direction of the airflow around the flare.

According to our studies, the speed of the air around the combustion front of the flare has the greatest influence on the aerosol spectrum. We have studied the aerosol formed during the combustion of a model generator equipped with the composition Hygroscopic Burn-In-Place Flares are used in the USA, Indonesia, Bulgaria, United Arab Emirates, etc. (Haryanto et al. 2011).

The diameter of the studied generator was 63.5 mm; combustion was carried out in a wind tunnel; the air speed was controlled from 5 to 80 m/s with an accuracy of 1 m/s. To eliminate the influence of near-wall flare effects, the sampling and analysis of an aerosol sample takes place during the first 20 seconds from the beginning of the flare burning. The results aerosol spectra and the dependence of the modal diameter on the velocity of the blowing flow are shown in Figures 4 and 5.

Summarizing the information obtained, it should be noted that the change in the modal size and spectrum of the hygroscopic aerosol depends on variations in the composition and design of the flare to a much lesser extent than on air speed relative to the combustion zone. According to our studies, the change in the modal size depending on the composition used does not exceed 30 nm, the influence of the flare diameter in the entire reasonable range of

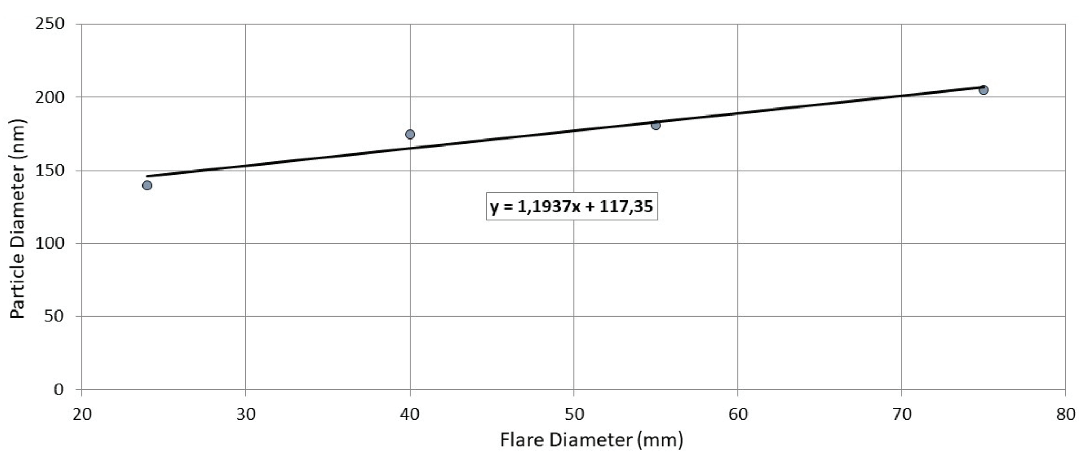

Fig. 2. Variation of the modal size of the aerosol depending on the diameter of the pyrotechnic charge (flare). Airflow speed 30 m/s, composition #1. The combustion of the composition without a shell.

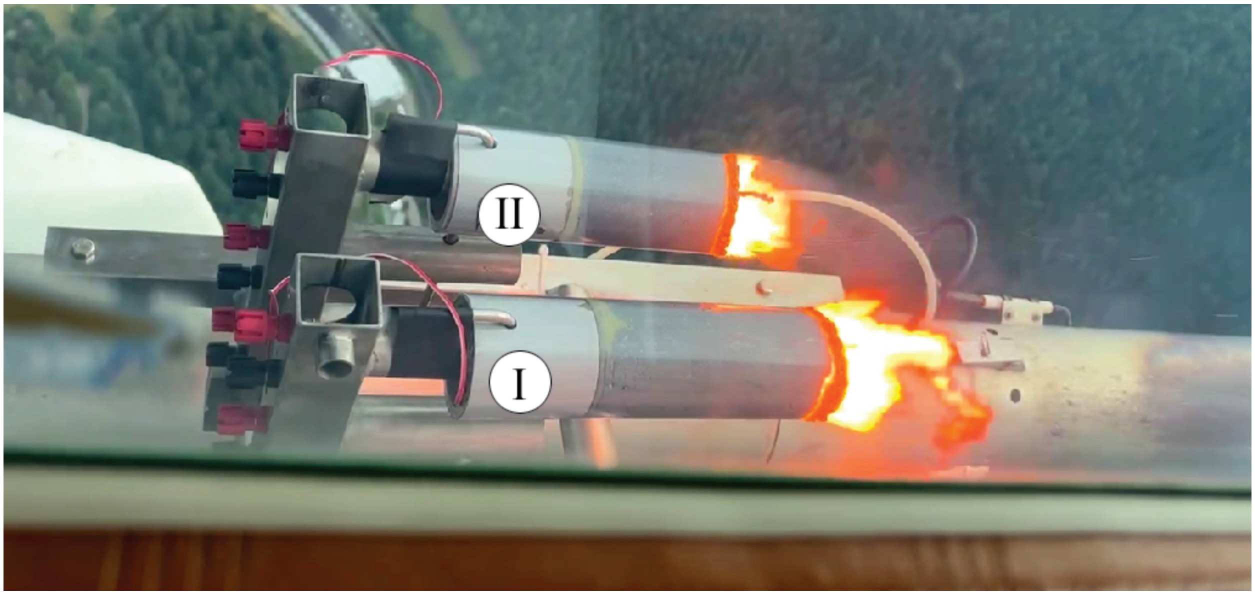

Fig. 3. Burning flares with an abnormally high content of calcium chloride in an easily combustible hull during flight.

sizes does not exceed 50 nm, while the change in air velocity in the speed range of 5-150 m/s leads to a change in the modal diameter by 200 nm.

Although the studied processes make it possible to change the spectrum of the formed aerosol, it is not large enough to reach the sizes of the micrometer range – required for the destruction of the cloud system and the formation of precipitation. Therefore, from our point of view, it is optimal to inject pre-prepared powders when the goal is to increase precipitation.

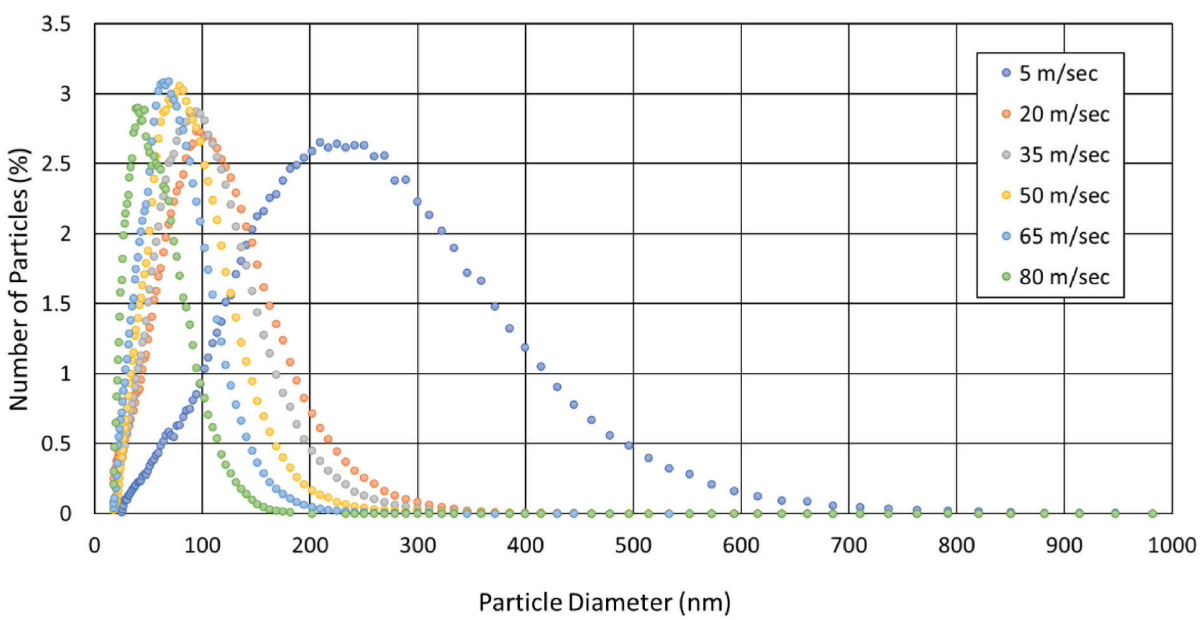

Fig. 4. Change in the spectrum of hygroscopic aerosol formed during the combustion of a torch with the composition 1 at air speeds from 5 to 80 m/s.

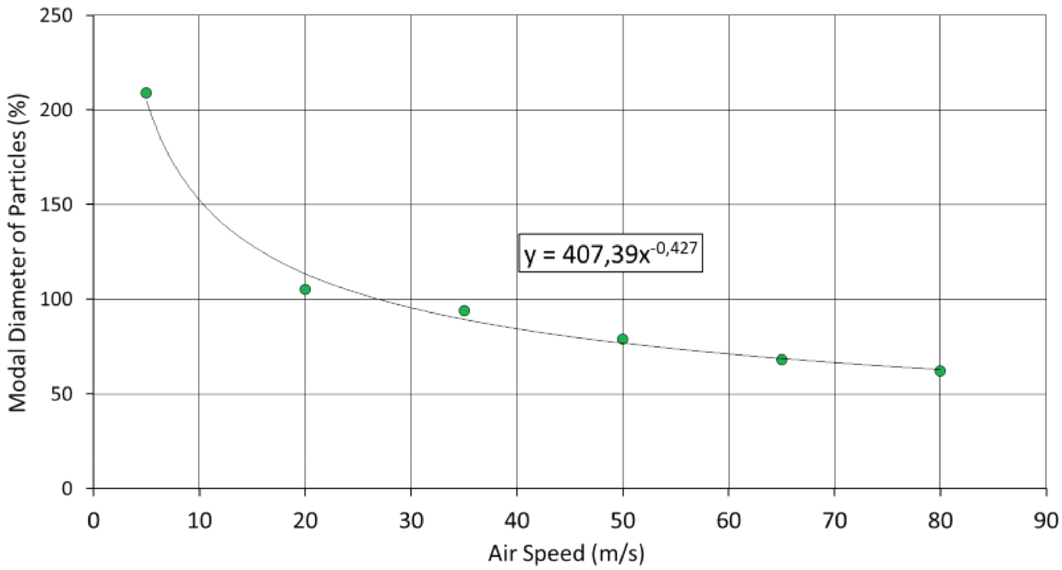

Fig. 5. Change in the modal diameter of the hygroscopic aerosol composition 1 as a function of air speeds from 5 to 80 m/s.

2.4 Insertion of hygroscopic powder-like aerosols to the cloud environment.

An alternative to the use of hygroscopic aerosols generated by pyrotechnic compositions is the use of pre-prepared powders. The advantage of this method is the constancy of the composition of the powder, as well as the spectrum of the aerosol when using specific dispersion systems, regardless of the speed and flight altitude of the aircraft.

It should also be noted the problems that arise when using this technology:

1. Since micrometer-sized particles have a high tendency to adhere, anti-caking agents must be added to the powder. Since this additive is characterized by nanometer size ranges, the manifestation of hygroscopic properties by the particles of the additive can lead to a tendency to stabilize the colloidal medium.

2. When studying the spectrum of an aerosol of a pre-prepared powder, it is very problematic to justify which particles are present in the nanometer part of the spectrum - whether they have hygroscopic properties or not. The only practical way to obtain such information is to directly conduct an experiment in a cloud chamber with a study of the dynamics of the spectrum of droplets of a colloidal system.

3.0 RESULTS AND DISCUSSION

3.1 Comparative impact of hygroscopic aerosol of various origins on the cloud environment.

Cumulus Cloud Modeling Environment.

The cloudy environment formed due to adiabatic cooling, with initial relative humidity of 90%, the temperature at 295 K, the rate of adiabatic cooling is equivalent to the rate of rise of the air mass at a speed of 2 m/s. The experiment is described in more detail by A. S. Drofa, V. N. Ivanov, D. Rosenfeld, and A. G. Shilin in Studying an effect of salt powder seeding used for precipitation enhancement from convective clouds, 2010.

The dynamics of changes in the cloudy environment in the climatic chamber under background conditions and in the case of the introduction of aerosols with the spectra presented above is shown in Figure 6.

If in the background experiment when simulating the implementation of a convective cloud process under conditions of experience, the number of initially formed droplets slightly exceeds 1000 drops per cubic centimeter, under the same conditions for the formation of a cloud medium, in the case of the presence of an aerosol formed during the combustion of a pyrotechnic composition, the number of drops exceeds ten thousand, and in the case of pre-introduced aerosol of micrometer size is at the level of several hundred. In the case of an aerosol in the nanometer range, the situation is even more pronounced than what is shown in the chart, since both the number of particles and the amount of mist droplets will peak at the lower detection limit of the instruments used.

This is reflected both in the amount of precipitated water (Figure 7), and in the lifetime of the colloidal system.

If the lifetime of the latter in a cloud chamber under background conditions is in the range of 30-40 minutes, in the case of the presence of a nano dispersed hygroscopic aerosol, the cloud system exists up to several hours, and in the case of the aerosol of micrometer sizes, the lifetime is reduced to 15-20 minutes.

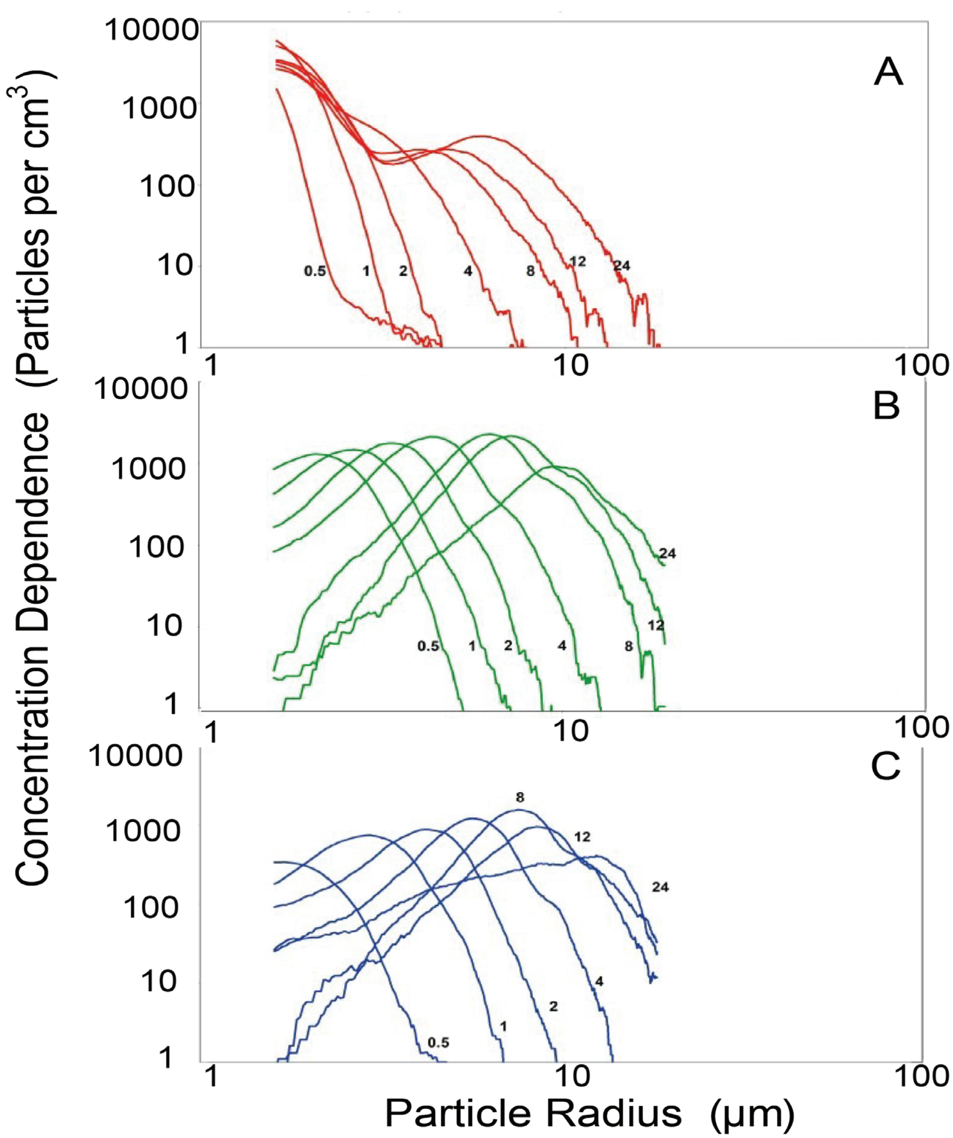

Fig. 6. The observed evolution of cloud drop spectrum in the cloud chamber measured at times noted from 0.5 to 24 minutes from the moment of formation of the cloudy environment.–Chart A is the Pyrotechnic composition - B is the background experiment, and Chart C shows the results in the presence of pre-prepared powder.

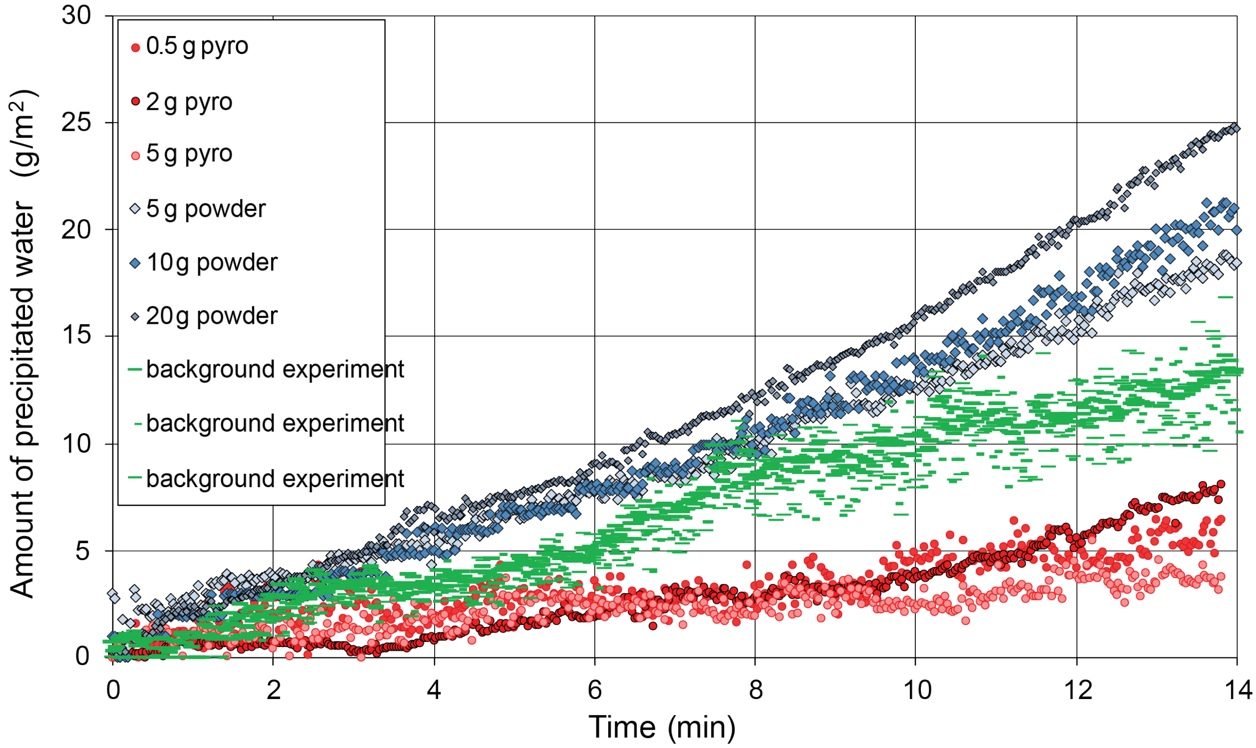

Fig. 7. The amount of water deposited over time on a test site. Accordingly, 5, 10, 20 g of powder was introduced into the chamber and burned 0.5, 2 and 5 grams of pyrotechnics, (a higher position of the dependence corresponds to a larger amount of powder introduced).

Our research suggests that artificial aerosol particles in the first case (Figure 6, A), with more pronounced hygroscopic properties in the process of adiabatic cooling and the associated increase in relative humidity turn out to be in more favorable conditions. Under these conditions, natural CCN either does not appear or their participation in the process is negligible and the process is driven by the presence of a large amount of aerosol of pyrotechnic origin.

In the third case (Figure 6, C), the main amount of water vapor is intercepted by artificial nuclei and natural nuclei do not participate in the process of water vapor absorption or their contribution to this process is very small.

We emphasize that in the first case the colloidal system is more stable. Aerosol nanoparticles, due to their chemical properties (meaning the formation of compounds of the $xMeCl_y{}^* \ zH_2O$ type) and hygroscopicity, inevitably absorb water vapor, increasing in size. But a result of the development of the condensation process creates a more dilute solution (decreasing effect of Raoult's law in combination with an increase in vapor pressure caused by a significant curvature of the droplet surface) further preferential droplet growth becomes impossible. The reverse process - the drying of drops - is also impossible because this increases the concentration of the solute. The result is a colloidal system capable of long-term existence.

3.2 Impacts on the nimbostratus cloud modeling environment.

Simulation Conditions: The predominant droplet size is from 7 to 8 microns with fluctuations from 2 to 72 microns, Droplet concentration from 100 to 1000 cm^3.

The impact of hygroscopic aerosols of various size ranges is qualitatively similar to the cumulus cloud simulation process; however, due to the small size of the droplets, the dynamics of the experiment are somewhat different (Figure 8).

3.3 Impacts on the environment simulating stratus clouds.

Simulation parameters: dominant droplet size from 4 to 7 µm, Droplet concentration from 100 to 1000 cm^3.

Due to the small diameter of cloud droplets and low water content in the case of stratus clouds, it is difficult to increase the amount of precipitation when exposed to powders, however, the effect of an aerosol of a nanometer size range stabilizes the cloud to a large extent (Figure 9). This is reflected not so much in the decrease in the amount of water deposited from the layered cloud system, an amount that is already miniscule, but in the duration of its existence in the chamber. While under background conditions, the existence of a stratus cloud in the chamber can be maintained for no more than 40 minutes, if enough hygroscopic aerosol of pyrotechnic origin is introduced, the cloud can exist for several hours or more.

The information obtained allows us to formulate the following provisions:

1. Exposure to an aerosol of nanometer size range (of pyrotechnical origin) stabilizes the cloud to some extent in the case of any model media.

2. The stabilization process is the more pronounced, the more pyrotechnic aerosol is introduced into the cloudy environment and the more the aerosol spectrum is shifted towards smaller sizes.

3. Aerosol exposure to pre-formed powder either results in increased precipitation in cumulus and nimbostratus cloud, or in the case of stratus cloud simulation exposure causes no significant change, but in no case results in stabilization of the cloud environment.

4. In all cases of exposure to aerosol in the micrometer size range, the statement “a larger amount of aerosol leads to an increase in precipitation” is true to one degree or another.

5. In all cases of exposure to aerosol in the sub micrometer size range, the statement “a larger amount of aerosol leads to a decrease in precipitation” is true to one degree or another.

3.4 Ways to increase the efficiency of hygroscopic aerosol generators.

It is possible to vary the distribution of particles formed in the process of thermal condensation either by changing the composition of the pyrotechnic mixture or the design of the generator, or by changing the speed of air in the condensation zone. In this case, the following regularities should be noted:

1. The change in air speed makes the biggest contribution to the change in the aerosol spectrum. The greater the air speed, the more the spectrum of the formed aerosol shifts towards smaller particle sizes.

2. Generator design: the larger the area of the burning surface and speed of production of the aerosol-forming material, the more the aerosol spectrum shifts towards larger sizes.

3. The composition of the pyrotechnic mixture: In general, there is a very small relationship between the parameters of the pyrotechnic mixture (combustion temperature, condensation temperatures of high-boiling components, the volume of gases released during combustion) and the spectrum of the formed aerosol, however, the presence of high-boiling components in the combustion products most likely contributes to the enlargement of the spectrum of the formed aerosol.

Hence, to increase precipitation, since the implementation of the colloidal instability of a cloudy medium is possible only when particles or drops appear that are significantly larger than the average size of the ensemble, it is preferable to use pre-prepared powders. The use of pyrotechnic generators

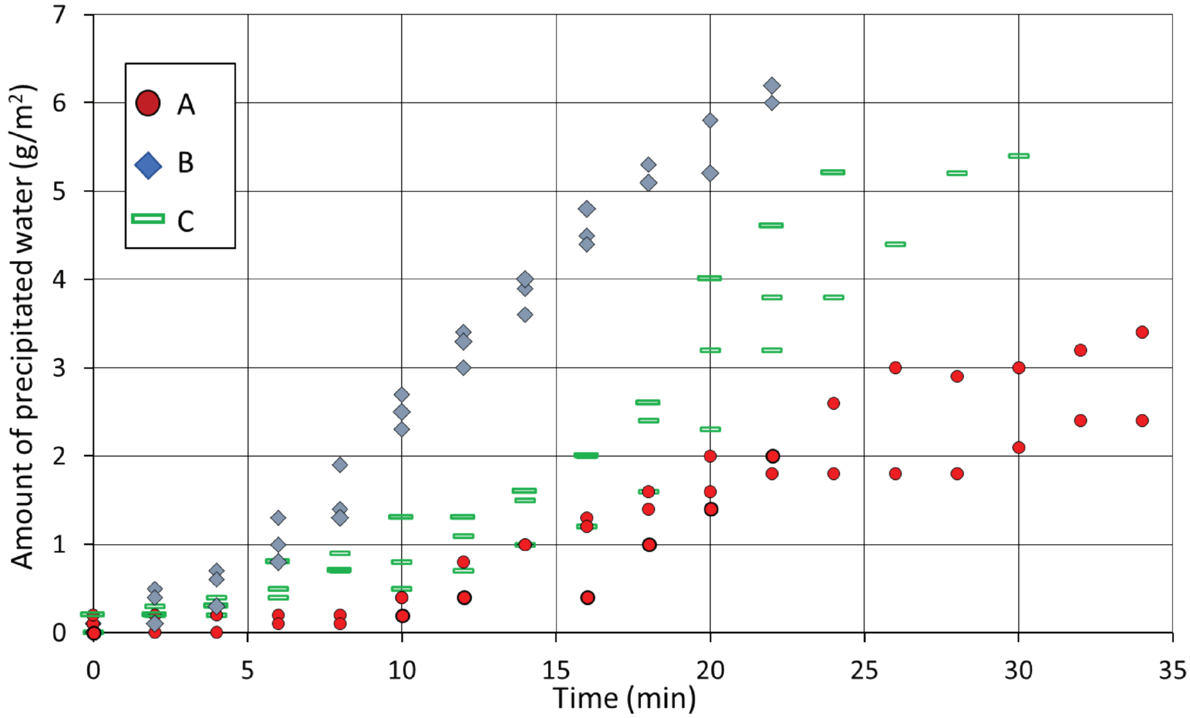

Fig. 8. The amount of water deposited over time on a test site. Marker A - background experiments. Marker B - exposure to various concentrations of hygroscopic aerosol from a pyrotechnic generator (higher aerosol concentrations correspond to a lower location of points). Marker C - exposure to an aerosol of pre-prepared powder. Accordingly, 5, 10 g of powder was introduced into the chamber, a higher position of the dependence corresponds to a larger amount of powder introduced.

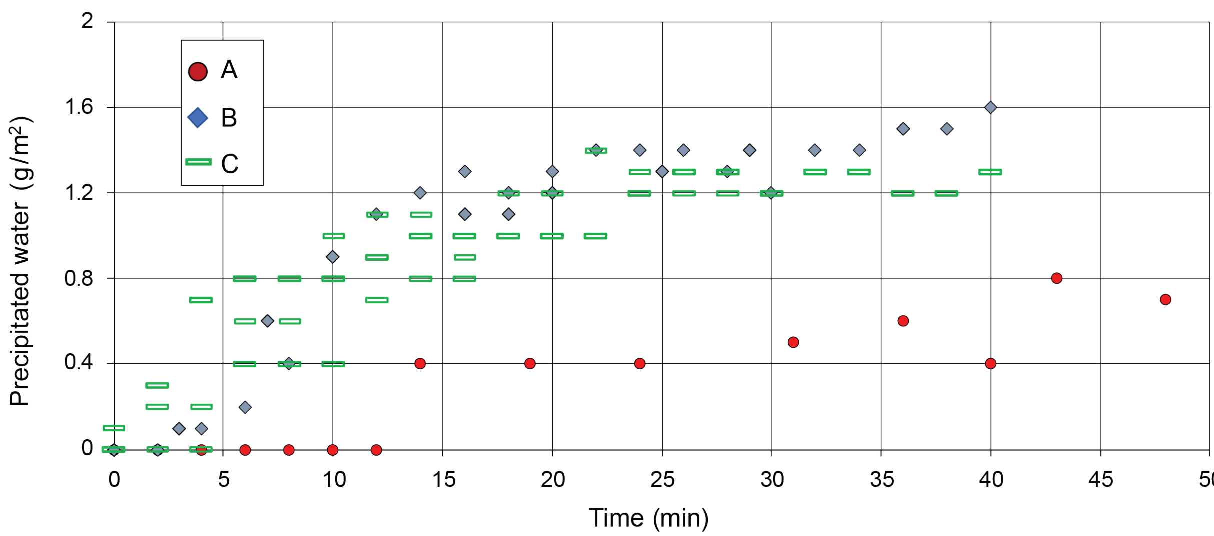

Fig. 9. The amount of water deposited over time on a test site. Marker A - background experiments. Marker B - exposure to hygroscopic aerosol of a pyrotechnic generator. Marker C - exposure to an aerosol of pre-prepared powder. Accordingly, 5, 10, 20 g of powder were introduced into the chamber.

makes sense only in situations where there is little or no air movement at the generator (wind speeds less than 5 m/s). As in the previous case, when studying the effect of powders, we did not find the effects of reseeding - that is, in general application, an overdose of the powder has no adverse effects.

4.0 CONCLUSIONS

It has been confirmed experimentally that it is impossible to obtain an aerosol in the micrometer size range by thermal condensation methods in the conditions associated with the actual use of the generator from the aircraft. This makes it possible to critically evaluate the results of work on increasing precipitation using hygroscopic pyrotechnic torches (Hygroscopic Burn-In-Place Flares). Experts within the World Meteorological Organization (WMO) are now beginning to come to the same conclusion (WMO 2018).

The factors that determine the spectrum of aerosols obtained by thermal condensation have been studied. It is shown that the compositions of the same class with respect to the content of the condensed phase in the combustion products form aerosols of approximately the same spectrum, which changes very slightly depending on the combustion temperature. The area of the burning composition has a greater influence on the aerosol spectrum, but the air speed around generator has the greatest influence.

The insertion of hygroscopic aerosols in the 1-10 micrometer size ranges can yield an increase in precipitation efficiency in modeled clouds - cumulus, stratocumulus, and stratus. Depending on the type of cloud environment, the efficiency can be significant (maximum for cumulus clouds and minimum for stratus clouds) but in no case was there a change in trend (decrease in the amount of deposited water compared to the natural process).

Future work is recommended to further understand the processes underlying the laboratory-based results pertaining to using powder reagent-coated aerosols as warm cloud seeding agents.

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