Previous: The Dynamic Mode of
Next: Weather Modification Funding

Hygroscopic Seeding

As noted in Cotton and Pielke (1995) the dominant process for precipitation formation in warm clouds is collision and coalescence. We have seen that this process is very effective in clouds which are warm-based and maritime, or have substantial liquid water contents. The collision and coalescence process among liquid drops is also an important contributor to rain formation in many mixed-phase clouds, and the presence of supercooled drizzle-drops and raindrops enhances the rate of formation of precipitation in supercooled portions of clouds as well.

One method of seeding clouds to enhance precipitation is to introduce hygroscopic particles (salts) which readily take on water by vapor deposition in a supersaturated cloudy environment. The conventional approach is to produce ground salt particles in the size-range of 5-100 , and release these particles into the base of clouds. These particles grow by vapor deposition and readily reach sizes of 25 to 30 in diameter or greater. They are then large enough to serve as ``coalescence'' embryos and initiate or participate in rain formation by collision and coalescence.

Cotton and Pielke (1995) reviewed the various physical and statistical experiments that have been carried out over the years. The results of the statistical experiments were generally inconclusive though some suggested positive effects. Observational and modeling studies provide further support that at least in some clouds, the addition of hygroscopic seeding material can broaden drop-spectra and at least hasten the onset of precipitation formation. We concluded that `` there appears to be a real opportunity to enhance rainfall through hygroscopic seeding in some clouds. It has not been determined how open the `window of opportunity' actually is. In warm-based, maritime clouds the rate of natural production of rainfall may be so great that there is little opportunity to beat nature at its own game. On the other hand, some cold-based continental clouds may have so many small droplets that seeding-produced big drops cannot collect them owing to very small collection efficiencies. Thus there probably exists a spectrum of clouds between these two extreme types that have enough liquid water to support a warm cloud precipitation process that can be accelerated by hygroscopic seeding. The problem is ``to identify those clouds, and deliver the right amount of seeding material to them at the right time.''

As optimism for significant precipitation enhancement by static seeding of supercooled clouds has waned, enthusiasm for the potential of hygroscopic seeding has grown. Two ongoing research programs, one in Thailand, the other in South Africa, have contributed to that enthusiasm.

The South African experiment was motivated by a report by Mather (1991) which suggested that large liquid raindrops at -10C found in a cumulonimbus were the result of active coalescence processes caused by the effluent from a Kraft paper mill. Earlier, Hobbs et al. (1970) found that the effluent from paper mills can be rich in cloud condensation nuclei (CCN). Moreover, Hindman et al. (1977a,b) found paper pulp mill effluent to have high concentrations of large and ultra-giant hygroscopic particles, which is consistent with the idea that the paper pulp mill effectively ``seeded'' the storm.

Another reason for optimism is that Mather et al. (1996b) applied a pyrotechnic method of delivering salt, based on a fog dispersal method developed by Hindman (1978). This reduced a number of technical difficulties associated with preparing, handling, and delivery of very corrosive salt particles. Seeding with this system is no more difficult than silver iodide flare seeding. Compared to conventional methods of salt delivery, the flares produce smaller-sized particles in the size range of 0.5 to 10 . Thus, not as much mass must be carried to obtain a substantial yield of seeding material. The question of effectiveness of this size range will be discussed below. Seeding trials with this system suggested that the pyrotechniques produced a cloud droplet spectrum that was broader and with fewer numbers, which would be expected to increase the chance for initiation of collision and coalescence processes.

Mather et al. (1996b) analyzed radar-defined cells over a period of about an hour to identify the seeding signatures for 48 seeded storms compared to 49 unseeded storms. They showed that after 20 to 30 minutes, the seeded storms developed higher rain masses and maintained those higher rain masses for another 25 to 30 minutes. Bigg (1997) performed an independent evaluation of the South African exploratory hygroscopic seeding experiments and also found that the seeded storms clearly lasted longer than the unseeded storms. Bigg also suggested that there was a clear dynamic signature of seeding. He argued that hygroscopic seeding initiated precipitation lower in the clouds, which, in turn, was not dispersed horizontally as much as the unseeded clouds by vertical wind shears. As a result, Bigg speculated that low-level downdrafts became more intense, which yielded stronger storm regeneration by the downdraft outflows, and longer-lived precipitation cells.

Biggs hypothesis is a plausible scenario that should be examined thoroughly with numerical models and coordinated, high resolution Doppler radars.

Cooper et al. (1997) performed simulations of the low-level evolution of droplet spectra in seeded and unseeded plumes. Following a parcel ascending in the cloud updrafts they calculated the evolution of droplet spectra by vapor deposition and collection. The calculations were designed to emulate the effects of hygroscopic seeding with the South African flares. The calculations showed that introduction of particles in the size-range characteristic of the flares resulted in an acceleration of the collision and coalescence process. If the hygroscopic particles were approximately 10 in size, precipitation was initiated faster. But, when more numerous 1 hygroscopic particles were inserted, high concentrations of drizzle formed. For a given amount of condensate mass, if the mass is on more numerous drizzle drops than on fewer but larger raindrops, then evaporation rates are greater in the subcloud layer. This could lead to more intense dynamic responses as proposed by Bigg, suggesting that seeding with smaller hygroscopic particles may have some advantages. Keep in mind, however, that this is a very simple model. More comprehensive model calculations should also be performed.

In summary, there are some exciting new results of hygroscopic seeding with flares. This work is still very exploratory and is a long way from proving that such techniques can make significant increases in rainfall on the ground for a variety of weather and climate regimes. It is refreshing for a change to end an overview of the science of weather modification by cloud seeding on a rather upbeat note!

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